Shipwrecking Probability in Mediterranean Territorial Waters

A Cultural Approach to Archaeological Predictive Modelling

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SUMMARY

This thesis presents a formal approach and a GIS-based methodology for the assessment of the shipwrecking probability in Mediterranean territorial waters, thus addressing the underdevelopment of archaeological predictive models in the maritime domain, particularly in the Mediterranean region. As archaeological predictive models are often criticized for oversimplifying complex historical phenomena to produce quantifiable outcomes, this study focuses on two different scales of analysis to meet the need for both a general tool applicable to spatial planning and a more detailed one providing insights for historical and archaeological research. First, a regional-scale model is developed, which focuses on navigation dynamics in the area between Cap Bon (present Tunisia) and Alexandria (present Egypt) in Roman times. Then, this model is extended to all Mediterranean territorial waters in a simplified version and without chronological limitations. At both scales, the criteria for selecting the input factors are formalized.

In order to identify areas with higher shipwrecking probability than others, two sub-questions are addressed that correspond to separate model components: 1. Where would ships be more likely to transit? 2. Where would ships have a higher risk of sinking? Grounding the theory-building on a systematic screening of accounts by primary sources, the first model component derives transit probabilities by considering multiple, oftentimes competing, criteria that trigger and affect mariners' movements, including in particular the effects of risk perception - thus rejecting the idea that sailors would necessarily choose the optimal or most efficient route. The second model component includes environmental hazards objectively increasing the risk of sinking.

Given the many elements of uncertainty and subjective reasoning behind the model building - a problem often unheeded in archaeological computational modelling - an entire chapter is devoted to a sensitivity analysis of the model and the exploration of diverse model scenarios. The overall methodology attempts to overcome some of the main pitfalls of current modelling approaches to seafaring and to shipwreck locations, namely, the inductive use of shipwreck data without a formal exploration of data biases, and the predominant reliance on environmental and economic input variables to the detriment of cultural and cognitive factors.

This study suggests that by explicitly differentiating between actual and perceived risks, and accounting for the effects this difference produces in terms of variations from the optimal navigation corridors, the predictive ability of the model increases. While constituting a valuable tool for optimizing maritime spatial planning and archaeological investigations, this model also offers insights into the biases in current shipwreck data. The model furthermore provides an adaptable toolkit applicable to other geographical contexts and chronological periods, and a suitable basis for expansion with a future component by modelling post-depositional dynamics that affect the preservation and detectability of wrecks at local scales.

SAMENVATTING

In dit proefschrift wordt een formele benaderingswijze en GIS-methodologie gepresenteerd waarmee de waarschijnlijkheid vastgesteld kan worden dat schepen schipbreuk lijden in territoriale wateren in de Middellandse zee. Hiermee wordt een lacune gedicht in de ontwikkeling van archeologische verwachtingsmodellen in maritieme context, specifiek voor het Mediterrane gebied. Omdat archeologische verwachtingsmodellen vaak worden bekritiseerd vanwege hun neiging om complexe historische fenomenen te over-vereenvoudigen om tot toetsbare resultaten te kunnen komen, wordt de analyse op twee schaalniveaus uitgevoerd. Daarmee wordt zowel voorzien in de behoefte aan een globaal en algemeen toepasbaar model voor ruimtelijke ordening, als in die aan een meer gedetailleerd model voor historisch en archeologisch onderzoek. Dit laatste wordt als eerste gepresenteerd aan de hand van een regionale *case study* die zich richt op de navigatiedynamiek in het gebied tussen Cap Bon (huidig Tunesië) en Alexandrië (huidig Egypte) in de Romeinse tijd. Vervolgens wordt dit model, in een vereenvoudigde vorm en zonder chronologische beperkingen, geëxtrapoleerd naar alle territoriale wateren in de Middellandse zee. Op beide schaalniveaus zijn de criteria voor het selecteren van de inputfactoren geformaliseerd.

Om te kunnen vaststellen welke gebieden een hogere kans op schipbreuk hebben in vergelijking met andere zijn twee deelvragen gesteld die overeenkomen met de twee hoofdcomponenten van ieder model: waar is het het meest waarschijnlijk dat de schepen gevaren hebben? En: waar hadden schepen een grotere kans om schipbreuk te lijden? Het hier ontwikkelde eerste modelcomponent is gebaseerd op een systematische analyse van primaire bronnen die informatie bieden over de vele, vaak tegenstrijdige, criteria die aan de navigatiebeslissingen van zeelieden ten grondslag kunnen liggen. Hierbij is specifiek rekening gehouden met het effect van de perceptie van gevaar, waarmee het idee verworpen wordt dat zeelieden in het verleden één enkele optimale route kozen, uitsluitend gebaseerd op het minimaliseren van de objectieve risico's. De tweede component van het model draait om de vraag of en hoe gevaren als gevolg van omgevingsfactoren de kans op schipbreuk objectief gezien vergroten.

Omdat er noodzakelijkerwijs vele onzekerheden en subjectieve afwegingen aan de basis liggen van het model – een probleem dat vaak genegeerd wordt in archeologische voorspellingsmodellen – wordt een heel hoofdstuk gewijd aan *sensitivity analysis*: het toetsen van hoe het model reageert op veranderingen in de berekening en weging van de inputfactoren. Hiermee wordt geprobeerd te ontsnappen aan de twee grootste nadelen van de huidige wijze van modelleren van historische navigatieroutes en van archeologische risicoanalyse; namelijk dat gegevens over scheepswrakken inductief worden gebruikt zonder dat een formele verkenning heeft plaatsgevonden naar de mate van vertekening van deze gegevens, en het overheersende gebruik van omgevingsfactoren en economische factoren ten koste van culturele en cognitieve factoren.

Op basis van de uitkomsten van dit onderzoek blijkt dat het voorspellend vermogen van het model toeneemt wanneer er expliciet gedifferentieerd wordt tussen de werkelijke en de gepercipieerde risico's én als de gevolgen van dit onderscheid, namelijk keuzes die afwijken van de optimale navigatiecorridors, in acht worden genomen. Hiermee levert het model niet alleen een bruikbaar gereedschap voor de ruimtelijke ordening van de maritieme omgeving en voor maritiem archeologisch onderzoek, maar het verschaft ook inzicht in de bestaande vertekeningen in scheepswrakgegevens. Het model biedt bovendien een flexibele GIS-*toolkit* die toegepast kan worden op andere geografische contexten en periodes, en kan in de toekomst uitgebreid worden met een component die ook de post-depositionele processen modelleert die op lokale schaal de bewaringstoestand en detecteerbaarheid van scheepswrakken mede bepalen.

SOMMARIO

In questa tesi viene presentato un modello predittivo, sviluppato utilizzando sistemi informativi geografici (GIS), il cui scopo è di stimare la probabilità di naufragio nelle acque territoriali del Mediterraneo. L'obiettivo è quello di compensare lo scarso sviluppo ed utilizzo di modelli predittivi in ambito archeologico subacqueo -soprattutto nel bacino Mediterraneo- il cui uso ottimizzerebbe invece le indagini archeologiche marine. Dal momento che i modelli predittivi vengono spesso criticati poiché per produrre risultati quantificabili tendono a semplificare e generalizzare fenomeni storici complessi, questo studio si focalizza su due distinte scale di analisi. Una più generale per venire incontro alla necessità di fornire un modello complessivo, applicabile nelle pratiche di archeologia preventiva, e una di dettaglio per supportare studi e analisi storico-archeologiche. Un primo modello viene quindi sviluppato su scala regionale, focalizzandosi sulle dinamiche di navigazione in età romana nell'area compresa tra Cap Bon (attuale Tunisia) e Alessandria (attuale Egitto). Successivamente tale modello viene esteso alle acque territoriali del Mar Mediterraneo, in forma semplificata e senza limitazioni cronologiche. Propedeutica allo sviluppo di entrambi i modelli è la formalizzazione dei criteri seguiti per la selezione dei fattori di input.

Per poter stabilire quali aree presentino una maggiore probabilità di incidenza di naufragi, vengono poste e affrontate due domande di ricerca che sottendono lo sviluppo di due distinte componenti del modello: dove è maggiormente probabile che le imbarcazioni transitassero, e dove è più probabile che naufragassero. Per quanto attiene alle probabilità di transito, queste sono state desunte attraverso un sistematico scrutinio delle fonti storiche, considerando molteplici fattori che possono aver determinato la scelta di destinazioni e rotte, inclusa la percezione del rischio. In tal modo si è anche rifiutata l'ipotesi che le imbarcazioni seguissero necessariamente rotte ottimali, solitamente alla base delle simulazioni di navigazione antica. Per quanto attiene alle probabilità di naufragio, si sono considerati quei parametri, ambientali, oceanografici e meteorologici, che oggettivamente costituiscono un rischio per le imbarcazioni. Visti i molteplici fattori di incertezza nel modello -un problema spesso non formalmente affrontato negli approcci computazionali in ambito archeologico- un intero capitolo è dedicato all'analisi di sensitività e all'esplorazione dei diversi scenari prodotti alterando il modello. L'intero approccio metodologico mira a superare alcune delle maggiori limitazioni degli attuali modelli sviluppati per simulare le antiche rotte di navigazione o predire la localizzazione di relitti. Tali limiti riguardano da un lato l'inferenza induttiva basata sull'osservazione dei siti noti, effettuata senza una adeguata valutazione e compensazione delle distorsioni che pregiudicano l'attendibilità e rappresentatività del campione di dati usati; dall'altro l'utilizzo predominante di fattori ambientali e socio-economici a scapito di quelli culturali e cognitivi.

Le evidenze prodotte da questa ricerca suggeriscono invece che, distinguendo formalmente il rischio reale da quello percepito e identificando così rotte di navigazione non necessariamente ottimali, la prestazione del modello migliora. Le aree indicate come a maggiore probabilità di incidenza di naufragi corrispondono infatti a quelle dove si rileva effettivamente un maggior numero di siti noti. Tale modello, a oggi unico nel suo genere, oltre a fornire un valido strumento per ottimizzare la pianificazione delle indagini archeologiche in mare, costituisce un *toolkit* adattabile e applicabile su diverse scale spazio-temporali e può essere utilizzato come base di partenza per implementare e valutare l'impatto delle dinamiche post-deposizionali per la preservazione dei siti subacquei.

“No book can ever be finished. While working on it we learn just enough to find it immature the moment we turn away from it”

Karl Popper

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[1] As for the inconsistent use of surnames in these acknowledgements, I beg for the indulgence of the readers. Consistency is oftentimes misleading since -barring the need for clarity- it prevents accounting for cultural differences and approaches, which in no way reflect different degrees of familiarity, reverence, or esteem.

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Ancient sources

Key Abbreviations	Ancient Authors	Works
Acts	Luke the Evangelist	Acts of the Apostles
Aeschines. In Ctes	Aeschines	Against Ctesiphon
Aesch. Supp.	Aeschylus	Suppliant Maidens
Amm. Marc.	Ammianus Marcellinus	History
Anth. Gr.		Greek Anthology
App. Mith.	Appian	Mithridatic Wars
Ap. Rhod., Argon.	Apollonius	*Argonautica*
App. B Civ.	Appian	The Civil Wars
Apul. Met.	Apuleius	Metamorphoses
Ar., Nub.	Aristophanes	The Clouds
Arist., Mete.	Aristotle	Meteorology
Arist. Hist. an.	Aristotle	History of Animals
Aristot. Econ.	Aristotle	Economics
Arr., Anab.	Arrian	Anabasis of Alexander
Ath.	Athenaeus of Naucratis	*Deipnosophistae*
Av., Ora Mar.	Avienus	*Ora Maritima*
Bacchyl.	Bacchylides	Epinician Odes
Caes. BAfr.	Anonymous	Caesar's African War
Caes. Bciv.	Julius Caesar	Civil War
Caes. BGall.	Julius Caesar	Gallic War
Cic., Att.	Cicero	Letters to Atticus
Cic. Fam.	Cicero	Letters to his Friends
Cic. Fin.	Cicero	*De Finibis Bonorum*
Cic. Verr.	Cicero	Against Verres
Dem. 35	Demosthenes	Against Lacritus

Dict. Cret.	Dictys Cretensis	Trojan War Chronicle
Dig.		*Iustiniani Digesta, Corpus iuris civilis*
Dio Chrys. Or	Dio Chrysostom	*Orationes*
Diod. Sic.	Diodorus Siculus	Library of History
Dion. Byz.	Dionysius of Byzantium	Anaplous of the Bosporos
Dion. Hal. Ant. Rom.	Dionysius of Halicarnassus	*Antiquitates Romanae*
Dionys. Per.	Dionysius of Alexandria (Periegetes)	Guide to the Inhabited World
Erat., Geog. Fr	Eratosthenes	Geography (Fragments)
Eur. Heracl.	Euripides	*Heracleidae*
Euseb.Chron.	Eusebius	Chronography
Gell. N.A.	Aulus Gellius	Attic Nights
Hdt.	Herodotus	Histories
Hes., Op.	Hesiod	Works and Days
Hom. Il.	Homer	Iliad
Hom. Od.	Homer	Odyssey
Hor. Carm	Horace	Odes
Joseph. AJ	Flavius Josephus	Jewish Antiquities
Joseph. BJ	Flavius Josephus	Jewish War
Liv.	Livy	History of Rome
Luc. Ph.	Lucan	*Pharsalia, De Bello Civili*
Luc. Salt	Lucian	*De Saltatione*
Mela. Chor.	Pomponius Mela	Description of the World
Marc., Peripl. Mar. Ext.	Marcian of Heraclea	*Periplus Maris Externi*
Marc., Epit. Peripl. Men.	Marcian of Heraclea	Epitome of Menippus of Pergamum's Periplus of the Inner Sea
Nonnus, Dion.	Nonnus	*Dionysiaca*
Ov. Ars am.	Ovid	*Ars Amatoria*
Paus.	Pausanias	Description of Greece
Per. Mar. Eryth	Anonymous	Periplus of the Erythraean Sea

Philostr. Her	Philostratus	*Heroica*
Phot., Bibl.	Photius	*Bibliotheca*
Plin. HN	Pliny the Elder	*Naturalis Historia*
Plut.	Plutarch	Parallel Lives
Plut. Cic.	Plutarch	Life of Cicero
Polyb.	Polybius	Histories
Ps.-Skylax	Pseudo-Skylax	Periplus
Ps. Xen. Const. Ath.	Pseudo-Xenophon	Constitution of the Athenians
Ptol., *GH*	Claudius Ptolemy	*Geographike Hyphegesis* (Geography)
Sen. Ep.	Seneca	Epistles
Sil. Pun.	Silius Italicus	*Punica*
SMM	Anonymous	*Stadiasmus Maris Magni*
Solin.	Solinus	*Polyhistor*
Str., Geog.	Strabo	*Geographia*
Synesius	Synesius	Letters
Tac. Ann.	Tacitus	Annals
Tac. Hist.	Tacitus	Histories
Theophr. Signs	Theophrastus	On Weather Signs
Thgn.	Theognis	Elegies
Thuc.	Thucydides	Histories of the Peloponnesian War
Vell. Pat.	Velleius Paterculus	Roman History
Verg. Aen.	Virgil	Aeneid
Virgil. G.	Virgil	Georgics
Vitr. De arch.	Vitruvius	Architecture
Xen. Anab.	Xenophon	Anabasis
Xen. Hell.	Xenophon	*Hellenika*

Other abbreviations

AMAPs = Areas of Maritime Archaeological Potential

APM = Archaeological Predictive Modelling

APMs = Archaeological Predictive Models

AUV = Automated Underwater Vehicles

BAtlas: The Barrington Atlas of the Greek and Roman world

CHM = Cultural Heritage Management

CIG = *Corpus Inscriptionum Graecarum*

CIL = *Corpus Inscriptionum Latinarum*

DARMC = Digital Atlas of Roman and Medieval Civilizations

EMODnet - The European Marine Observation and Data Network

GIS = Geographic Information System

IG = *Inscriptiones Graecae*

MBES = Multibeam

MedAtlas = the Wind and Wave Atlas for the Mediterranean Sea

NH = Navigation Hazards

NOAA = National Oceanic and Atmospheric Administration of the United States

ORBIS =The Stanford Geospatial Network Model of the Roman World

OXREP = The Oxford Roman Economy Project

ROV = Remoted Operated Vehicles

SBP = Sub Bottom Profiler

RSP = Relative Shipwrecking Probability

SSS = side-scan sonar

TP = Transit Probability

1 INTRODUCTION

Past, present and future converge in the oxymoronic expression 'archaeological prediction' and its implications. Indeed, foreseeing where archaeological sites may be found through models that approximate past dynamics is a crucial step towards mitigating the present "archaeological risk" (Kohler & Parker, 1986; van Leusen & Kamermans, 2005; Kamermans, 2006; Verhagen & Whitley, 2012). As it has been noted, this risk ambiguously refers either to the possibility of an archaeological site being damaged or to the probability of finding archaeological remains in a given area, two sides of the same coin in the realm of spatial planning and cultural heritage management (van Leusen and Kamermans, 2005; Verhagen, 2018). The 1992 European Convention for the Protection of the Archaeological Heritage, which has replaced the London Convention of 1969, has acknowledged that more significant threats to the archaeological heritage nowadays arise from construction projects than from unauthorised excavations, as in the 1960s[2]. According to the Convention, developers are asked to exclude the presence of archaeological evidence and cover the costs of preventive archaeological investigations and those of the necessary mitigating measures. Therefore, mapping the known archaeological sites and predicting yet unknown locations would optimise developmental plans while enhancing cultural heritage preservation chances. Moreover, since the modelling process implies hypothesis testing, predictive models may also foster our understanding of historical phenomena by enabling the formalization and verification[3] of historical hypotheses, thus having both pragmatic and scientific implications.

While the commercial and scientific interests at stake have a similar overall goal - namely ascertaining which areas present a higher archaeological potential than others -the different underlying needs and objectives inevitably impact the prioritisation of distinct theoretical and methodological approaches (Verhagen & Whitley, 2020). The tendency to oversimplify complex historical phenomena to produce indicative and quantifiable outcomes is opposed to the possibility of employing predictive modelling to stimulate the understanding of historical processes where exceptions and episodic events do matter. This potential gap contributed to increasing the distrust toward predictive modelling techniques among historians and archaeologists, emphasising the complexity of past behavioural dynamics. While it is generally acknowledged that a model is not meant to be a replication of reality, scholars have debated alternative modelling strategies: some modellers privilege highly abstract stance and simple model architectures with few variables; on the contrary, others approach the modelling process in a detailed and more descriptive manner, thus including many variables and rules (Rubio-Campillo, 2015; Saqalli & Vander Linden, 2019, p. 12). However, between simplicity and specificity, there is room for discussing whether the simplification should be interpreted quantitatively or qualitatively. Philosopher Karl Popper wrote that "science may be described as the art of systematic oversimplification — the art of discerning what we may with advantage omit" (Popper, 1992, p. 44); following his statement, it is crucial to debate not only 'how many' but rather 'what'

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[2] https://www.coe.int/en/web/culture-and-heritage/valletta-convention

[3] Here with the meaning of substantiate or prove the truth of something. A debate on the different and sometimes ambiguous use of the terms 'validation', 'verification' and 'test' in predictive modelling is in Chapter 7.

things we may omit and to which purpose, for different purposes might change the set of things to be omitted. For example, among the main criticism addressed to overly simplistic archaeological predictive models is the predominance of environmental factors over cognitive and cultural ones. Whilst the predictive modelling literature has addressed the debate around the accuse of environmental determinism (Brandon & Wescott, 2000; Dalla Bona, 2000; Deeben, et al., 2007; Ebert & Kohler,1988; Gaffney & van Leusen, 1995; Gaffney, et al., 1996; Wheatley, 1993; Wheatley, 1995; van Leusen, 1996;) and some scholars have criticised it by highlighting that 'Models based on landscape variables are meaningless' (Kvamme, 2006, p. 6), there have been few attempts to develop culturally-based predictive models (Harris & Lock, 2006; Verhagen, et al., 2007). How cultural variables should be interpreted and implemented and whether their inclusion actually improves the predictive capabilities of a model is still open to debate and challenging to test.

1.1 ARCHAEOLOGICAL PREDICTION IN MARITIME CONTEXTS: CHALLENGES AND OPPORTUNITIES

Whereas archaeological predictive models are increasingly employed in terrestrial contexts (Verhagen & Whitley, 2020, pp. 231-246), they are still underexploited in the underwater archaeological domain, particularly within the Mediterranean basin; this may sound like a paradox because the underwater and maritime contexts would enormously benefit from tools supporting the prioritisation of areas to investigate, as underwater operations are costly and logistically challenging to organise and sustain. Such underdevelopment highlights specific data quality problems and the difficulty of finding an effective compromise between complexity and simplicity for describing the multiple processes impacting the underwater archaeological record distribution (Gibbs, 2006; Gould, 2011; Martin, 2013; Martin, 2014; Muckelroy, 1975; Muckelroy, 1978; O'Shea, 2002). On the one hand, the few maps of maritime archaeological potential developed so far, mainly outside the Mediterranean context (Deeben, et al., 2002; Manders & Maarleveld, 2006; Manders, 2017; Merritt, et al., 2007; Merritt, 2008), have focused on post-depositional dynamics and preservation conditions without or barely addressing navigation strategies and mariners preferences. On the other hand, current modelling approaches to seaborne movement tend to overemphasise the role of environmental, technologic and economic input variables as archaeological site predictors scarcely accounting for cultural and cognitive factors (Indruszewski & Barton, 2007; Leidwanger 2013; Newhard et al., 2014; Potts, 2019; Slayton, 2018; Warnking, 2016;). Despite their acknowledged historical relevance, the latter are regarded as too abstract and intangible to model (Deeben, et al., 2007; Gaffney and van Leusen 1995; Joolen, 2003; Judge & Sebastian, 1988; Kvamme, 1988; Kvamme, 2006; Rocks-Macqueen, 2014; Stancic & Kvamme, 1999; Wheatley, 1996). However, religious considerations, superstitions and a different perception of space, distance, orientation and risks, profoundly influenced the way people sailed in antiquity (Arnaud, 2014; Arnaud, 2016b; Brody, 2008; Gambin, 2014; Kowalzig, 2018; Le Carrer, 2013; Westerdahl, 2011; Westerdahl, 2012; Talbert & Brodersen, 2004).

Whether and how the inclusion of cultural and cognitive factors improve current environmental-deterministic predictive models is a question requiring the availability of reliable data to test the model outcomes or the availability of multiple models to compare for ascertaining which one fits the evidence best. Hence, the field of maritime archaeological prediction risks being caught in a loop: on the one hand, the many biases affecting the underwater archaeological records constitutes an objective obstacle to the development of predictive models in maritime contexts; on the other hand, the lack of such models prevents the comparison of different independent outcomes, thus limiting the identification of the most suitable approaches and best practices.

1.2 OBJECTIVES AND RESEARCH QUESTIONS

This study aims to overcome the underdevelopment of maps of archaeological potential in the Mediterranean sea and provide, on the one hand, a tool applicable in cultural heritage management and maritime spatial planning and, on the other hand, an instrument for gaining insights on navigation dynamics and mariners strategies. The goal is to build both a suitable theory and a methodology for assessing the relative shipwrecking probability in the Mediterranean territorial waters (i.e. within the 12 NM zone as defined by the 1982 United Nations Convention on the Law of the Sea). The shipwrecking probability refers to the possibility that, within the selected area, the ships would be more likely to sink in one location than in another; however, in this research a pivotal distinction is made between shipwrecking probability and sinking probability. The latter refers to the presence of nautical hazards that *may* cause a ship's loss, although not necessarily, for seafarers may be able to prevent it or avoid the risky areas. Conversely, the shipwrecking probability implies both a nautical activity (i.e. the ship's passage) and the ship's loss. The term shipwrecking is preferred to shipwreck to highlight that the focus is on the shipwreck-*event* rather than the shipwreck-*remains*. To be more specific, the model aims to predict the occurrence, action or behaviour bounded in space, which may have had physical consequences (conditions) that are at least partially observable today (Verhagen & Whitley, 2012, p. 72). However, the model does not address the post-depositional dynamics, which contribute to preserving or dispersing the physical remains, for the reasons discussed in section 1.3.2.

Two different scales of analysis are considered: a global one covering the Mediterranean to meet the need for a general tool applicable in spatial planning and a more detailed one providing insights for historical and archaeological research. Specifically, following an upscaling approach (i.e., from regional to global), the model focuses first on Roman time navigation processes in the area comprised between Cap Bon (current Tunisia) and Alexandria (current Egypt). Then in a simplified version, it is extended to the Mediterranean waters[4] without chronological limitations. The Roman chronological framework is only indicative: the goal of the study is not to provide a treatise on navigation practices in Roman time, but rather to explore and define suitable strategies for modelling the shipwrecking probability by taking into account besides the environmental and economic factors also the cultural and cognitive dimension in ancient seafaring. The Roman time is chosen as a proof of concept to this end, given the broad and complementary disposal of textual and archaeological evidence and the increasing availability of computational models focused on Classical time navigation and connectivity. Developing the model at global scale does not imply assuming mariners practices in Roman times as universal; instead, the aim is to ground and test the identified general categories within a specific case study, which allows to discuss and clarify their potential for generalisation, and their temporal and geographical dependency. The

[4] The Black Sea and some islands are out of the scope of the present research due to limitations in the input-data coverage (see Chapter 6).

theoretical model can be thus assumed to be generally applicable, whereas the information and values assigned to the selected input-factors are subject to change. In this regard, it must be noted that although the global scale does not focus on a specific time frame, the chronological extent of the source data employed tend to more accurately address a period ranging from Classical to Medieval time than later or earlier periods.

The overall research question for both scales can be formulated as follows:

> "How to predict which are the locations that have a higher probability of shipwrecking incidence within the territorial waters?"

This question, which is purposely methodological oriented rather than result-oriented, entails wondering which factors contribute to increasing or decreasing the shipwrecking within the 12 nautical miles zone. For ascertaining this, two main sub-questions are addressed:

> a) Where would the ships be more likely to transit? This entails assessing what elements enable and trigger mariners movement. What elements would mariners conveniently seek, and what elements they would try to avoid because they have assumed, or *perceived*, to be risky
>
> b) Where would the ships be more likely to sink? This entails assessing the factors actually threatening the ship's safety

A distinction must here be made between the practical outcome and the theoretical goal of this investigation; the former is the assessment of likely shipwrecking locations; the latter is to design a customizable formal model for shipwrecking probability and propose alternatives to the current, mainly environmental deterministic approaches by considering the potential impact of cultural and cognitive variables.

The shipwrecking prediction serves to reinforce the expert knowledge about where to expect shipwreck remains. Indeed, although the preservation conditions and the post-depositional dynamics are out of the scope of the model, the overall probability of finding shipwreck remains increases with the shipwrecking incidence and post-depositional processes may be better addressed with tailored strategies after identifying areas with high shipwrecking potential. As a side benefit, by providing a first formal procedure to assess shipwrecking probabilities in Mediterranean territorial waters, the present research also offers a starting ground to debate alternative approaches, methods and results, thus contributing to the further development of archaeological risk maps worldwide.

1.3 RATIONALE AND SCOPE

1.3.1 Challenges and pitfalls of a global theory: tuning temporal and geographical scales

Building a predictive model for shipwrecking locations in the Mediterranean sea does not and cannot correspond to providing a diachronic essay on Mediterranean navigation history and its broad dynamics. As Predrag Matvejević wrote, the Mediterranean sea is "a passionate collector"[5] (Matvejević, 2008, p. 43), "a vast archive, and enormous grave" (Matvejević, 2008, p. 39), which has witnessed millions of successful and unsuccessful journeys across the millennia, whose dramatic remains the geophysical marine surveys and remote sensing have contributed to documenting on the seafloor (UNESCO 2001). The history and epistemology of navigation represent a tale of man-nature interactions combining histories of technology, commerce, exploitation, wars, discoveries, conquests, escapes, pilgrimages, and travels, but also and foremost histories of human perception, hopes and fears (Abulafia, 2019; Arnaud 2005; Arnaud, 2020 Horden & Purcell, 2000). Shipwrecks reflect these navigation epistemologies (Gould, 2011) and contribute to unravel the sea crossroad-function in terms of human-pathway. Quoting Horden and Purcell developing such an «*histoire totale* [...] explicitly embracing more than twenty centuries rather than Braudel's two or three, would be unfeasible, unrewarding and unpublishable» (Horden & Purcell, 2000, p. 44).

If the idea to build a single heritage management map of the archaeological potential of the Mediterranean sea seems unfeasible given the large scale and long chronological framework, in terms of heritage management, we cannot simply skip the issue, for in order to evaluate the archaeological potential of a certain area, one should address the time-span that the 'archaeological interest' entails[6]. The choice to analyse somewhat smaller areas (e.g. regional or national) and therefore gather information selectively from a limited range of periods and places is only an apparent solution. Indeed, particularly in the Mediterranean context, identifying factors determining the shipwrecks' presence in a specific portion of the seabed cannot be limited to that specific microregion, but rather it requires a global understanding and approach given the far-flung connectivity -in terms of both individuals and goods- characterising the history of this 'boundless sea of unlikeliness' (Abulafia 2019; Purcell, 2003) and its microregions (Horden & Purcell, 2000). An alternative option would be to analyse only a certain chronological range, thus assessing the probability to find, for instance, Greek, Roman, Medieval (and so forth) shipwrecks within a particular region. If the historical interest would be in this way fulfilled, the need of both developers and heritage managers would not, because such a thematic map would inform about the presence of specific classes of objects but would not exclude the possible presence of other archaeological remains.

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[5] The English translations from the Italian 2008 edition of *Breviario Mediterraneo* are mine

[6] According to the 2001 UNESCO Convention for the protection of the Underwater Cultural Heritage, article 1: "Underwater cultural heritage" means all traces of human existence having a cultural, historical or archaeological character which have been partially or totally under water, periodically or continuously, for at least 100 years". However in some countries, a 50 years rule is applied (cf a discussion in Yoder, 2014).

The above considerations, together with data limitations, impacted the temporal and geographical scope of this study and the methodology pursued. The two scales of analysis enable one to use and compare different modelling strategies. The regional model focuses on Roman sailing and uses this specific historical context as a proof of concept to enrich the theory development by enquiring the textual evidence (Chapter 4), while a simplified approach is employed to build the global model, which aims to provide a general and customizable base-map. The latter may be easily adapted and modified by adding increasing complexity depending on the research question one poses. Hence, the theoretical global model described in Chapter 5 includes a limited number of categories supposed to be valid no matter the period considered. However, the outcomes of the global model reflect conditions and processes valid for the period ca. 2000 BC and ca. 1500 AD conform to the archaeological data used to implement and test the model (Chapters 6 and 7).

1.3.2 Why focus on shipwrecking probability

This study focuses on the shipwrecking probability because even though the underwater archaeological potential is not limited to shipwrecks' remains, these do constitute most of what may lie on the seabed if one excludes partially or wholly submerged structures, which are less likely to be pillaged and are - from a logistical perspective - easier to investigate than deep-water sites. Following a consolidated definition (Muckelroy, 1978; Pomey, 2013), a ship can be defined in a threefold manner: as a complex machine designed to float and move; as a functional system responding to precise needs (e.g. political, economic, military); as a living and working environment of a micro-society presenting its own system of rules, beliefs, practices; as such, addressing a ship's loss, namely a shipwreck-event implies considering the multiple set of factors and considerations impacting both navigation decisions and sinking occurrence (Gould, 2011, pp.15-16). With "shipwreck remains", one refers to any material originally belonging to the vessel architecture or carried onboard a ship. The only remains that are not necessarily related to potential shipwrecking locations are isolated objects (e.g., isolated amphoras or anchors, *ex-voto*), which may have been on the one hand, intentionally thrown overboard or unintentionally lost from a ship in transit; on the other hand, moved intentionally (e.g., by pillagers) or unintentionally (e.g., by fishing-nets) from the original archaeological context.

The model addresses the shipwrecking incidence without explicitly accounting for the probability of remains-survival on the seafloor because post-depositional processes and preservation conditions vary depending on the nature and size of the materials considered; hence, their analysis requires the adoption of coarser scales than those applicable to investigate navigation dynamics. However, as noted above in section 1.1, modelling shipwrecking probabilities constitutes the essential first step for addressing the survival rate probability of the remains. Indeed, detected high-shipwrecking probability areas present a relatively higher archaeological potential and may be investigated through targeted remote sensing surveys; moreover, post-depositional factors may be modelled in these areas to address local conditions.

1.3.3 Why focus on territorial waters

Multiple considerations and constraints have dictated the decision to focus on territorial waters. First, the great majority of the recorded shipwrecks lies within 12 NM of the coastline (see Chapter 3); although this already hints at likely data biases - another topic this research will address in detail - and shipwrecks may lie farther out than 12 NM, all models require sufficient data to be tested, as the lack of testing makes any model useless (chapter 7). Second, territorial waters are the most accessible and exploited; the shallower the depths, the higher the risk of pillaging and damage to the archaeological remains; hence it is urgent to design strategies for identifying and protecting what is still in situ. Third, from a theoretical and historical perspective, limiting the study to this spatial extent allows one to better inquire into navigation strategies in proximity to the coast. The concept of 'coastal navigation' has been often used in literature (Chapter 4) to refer to somewhat different navigational strategies, which formal modelling tends to oversimplify. With limited exceptions focusing on the different degree of attractiveness of ports (cf. Potts, 2019), the tendency is to model navigation in binary terms (e.g. ORBIS) by distinguishing between direct routes in open waters and coastal trajectories without exploring, on the one hand, the coastal extent, i.e. the factors contributing to defining a certain water-space as coastal; on the other hand, the implications in terms of navigation preferences and risks. The latter issue is particularly relevant when addressing coastal navigation strategies as land proximity entails both advantages and threats (Arnaud, 2005).

Because of the above consideration, this model is built by taking into account attractive and repulsive factors, assuming that mariners would try to avoid the latter while approaching the former. A distinction is made between actual threats and perceived ones, thus challenging the nautical uniformitarianism principle, which has been considered the most suitable theoretical underpinning in current modelling approaches (Deeben et al., 2002, p. 28; Maarleveld, 2004, p. 142). According to this principle, the mariners' interaction with the environment may vary depending on experience and technology but will essentially be the same, regardless of time or culture; according to Maarleveld, "risk management and curative behaviour are unifying trends in all traditions of seamanship and the risks themselves have always been the same" (Maarleveld 2004, p. 142). However, many scholars, including anthropologists and philosophers, contribute warning on presentism-bias (Gould 2011, pp. 17-20; Janni 1996, p. 473-474; Talbert, 2010, p. 3) since past situations do not necessarily have modern-day counterparts and "present can never be safely used as a direct guide to the human past" (Gould 2011, p.18). Wondering whether past societies may have perceived and approached the world differently than we do in the present day (Arnaud, 2014; Obied, 2016; Talbert & Brodersen, 2004; Talbert, 2010) and more specifically addressing the difference between perceived and actual navigation risks, is far from wishful thinking or a historical exercise. Indeed, whereas actual hazards increase the chance to shipwreck, and the environmental ones may be considered -as categories-overall the same regardless of periods and cultures, the perceived threats may vary and, no matter whether real or not may result in different curative behaviours, hence, in changes to the otherwise expected most efficient seaborne patterns. This research does not claim to systematically enquire the spatial and coastal perception in Roman time (e.g. Obied, 2016) but rather to design a theoretical model capable of accounting for the potential difference between actual and perceived threats to navigation and analysing the consequences this difference may have on model outcomes.

1.4 OUTPUTS AND METHODOLOGY

A data integration and simulation system referred to in these pages as the 'Relative Shipwrecking Probability' (RSP) model is developed to answer the questions set out in section 1.1. The term relative entails that the model indicates which areas have higher shipwrecking probability than others; it does not provide an absolute probability. The RSP theoretical model is developed using a deductive, i.e. theory-driven approach (Chapter 2), multi-criteria cost-surface analysis and Geographic Information System technology (Chapter 6). The RSP theoretical model is divided into two components (Figure 1.1), namely the Transit Probability (TP) and the Navigation Hazards (NH), each one including multiple factors. Two outcomes are produced: a 'BASE' model, in which all factors have equal weight; and a 'PREFERRED' model, produced by assigning the input factors different weights based on their alleged relevance following the Analytical Hierarchy Process (Saaty, 1980). Moreover, several scenarios are produced by altering or removing model factors and parameters (chapter 7). The model is developed following an upscaling approach (i.e. from regional to global). In fact, to base the theory-development and the model building on careful screening of primary sources, a particular geographical and historical context is selected; namely, the sea region comprised between Cap Bon (Tunisia) and Alexandria (current Egypt) during the Roman Empire. Subsequently, the model is applied at the Mediterranean scale -keeping in mind some simplification steps- for providing indicative trends over the long period. Therefore, the methodology followed for building the regional and the global (i.e. the Mediterranean) case studies has been slightly different (section 5.6 and Chapter 6). Both models, and the Mediterranean one in particular, should be considered as a framework, open to further improvements.

The model has been built by taking into account the following sources of evidence and information:

- Primary sources and ancient literature from the classical and medieval periods describing the advantages and disadvantages of coastal navigation or benefits and hazards associated with coastal proximity. Meaningful passages have been identified through keywords searches on digital Libraries and Datasets
- Modern studies, namely secondary sources on ancient seafaring and related topics such as studies on the ancient Mediterranean natural environment, Mediterranean climate-change, the seamanship and seaworthiness, the maritime cultural landscape, Mediterranean oceanography and topography
- Modern studies on predictive modelling and computational techniques applied to archaeological and historical contexts with particular attention to GIS technology, which has been employed to develop the predictive model in the present research
- Modern studies on shipwreck formation processes. Even though a systematic study of post-depositional processes is out of the scope of the present study and is not systematically included in the implemented predictive model, the preservation dynamics and discovery issues are theoretically considered in the present research (Chapter 3) to shed light on the many causes affecting the low representativeness of the recorded shipwreck locations and discuss limitations of current modelling approaches

- Modern studies and simulations of Mediterranean environmental processes (i.e. bathymetry, geology, erosion, oceanography, meteorology)

This research provides, among the attachments to the present manuscript, the GIS model implementation and a selection of the most meaningful textual evidence excerpts discussed in chapter 4, providing insights on coastal navigation strategies and risk perception.

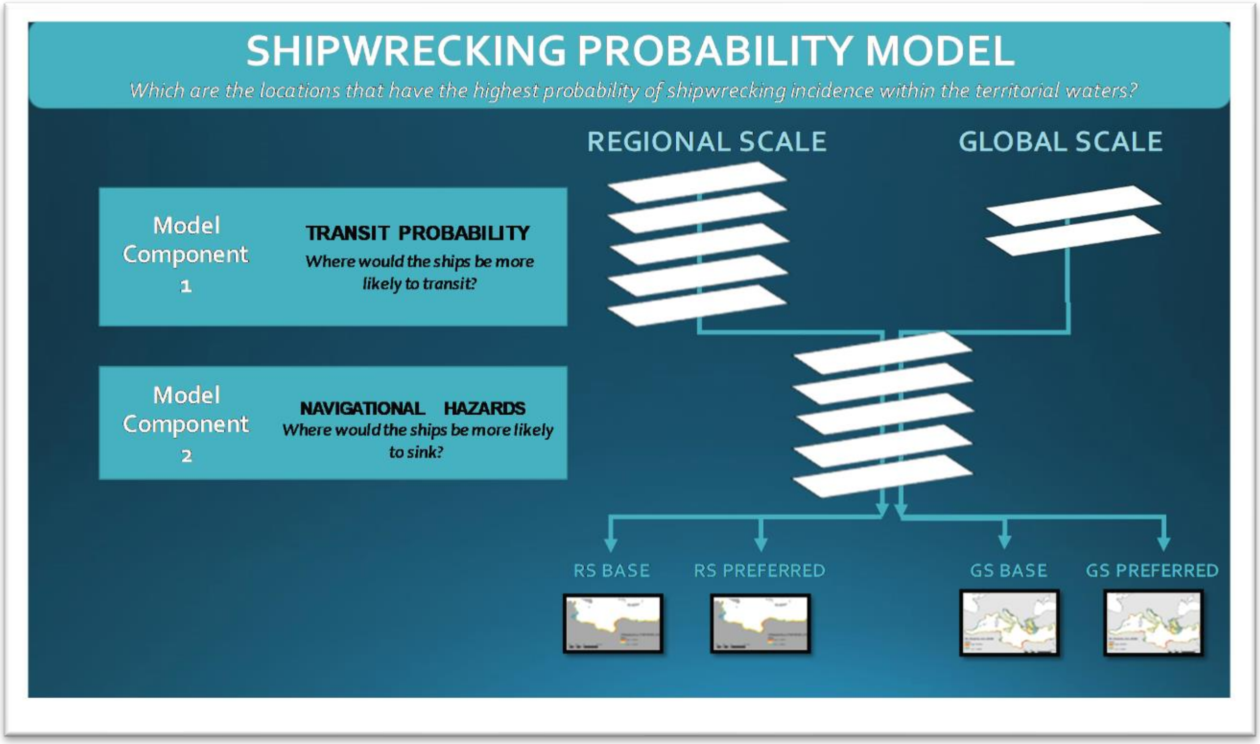

Figure 1.1: Relative Shipwrecking Probability (RSP) models' structure

1.5 THESIS OUTLINE

After discussing the state-of-the-art in maritime archaeological predictive modelling, the first part of this thesis aims at analysing biases in existing shipwreck data to justify the deductive approach followed to build the model. Afterwards, the primary and secondary sources are analysed to identify the factors implemented in each model component and suitable approaches (i.e. techniques) for the spatial modelling of these factors. Finally, the model is developed and tested at two different temporal and geographical scales. A full chapter is dedicated to the quality assessment of the model design and performance and the identification of sources of uncertainty that impact the model results, which are issues rarely addressed in archaeological computational modelling (Brouwer Burg, Peeters & Lovis, 2016; Kanters, Brughmans, & Romanowska, 2021). Specifically:

Chapter 2: reviews current approaches to archaeological predictive modelling in general and to computational modelling of past seaborne movements specifically, highlighting limitations in current practices, which the present study aims to overcome

Chapter 3: analyses the currently available shipwreck datasets and highlights significant data biases, thus explaining why these compromise the use of shipwreck data to make inferences about unknown site locations. Afterwards, it is discussed whether and how these data may be used for testing the model instead

Chapter 4: provides the theoretical underpinnings for addressing navigation dynamics and shipwrecking probability in territorial waters, focusing on shortcomings and ambiguities in the way coastal navigation has been theorised and modelled. The advantages and disadvantages of coastal proximity are assessed on the basis of both secondary sources and primary textual evidence

Chapter 5: contains the description of the theoretical Relative Shipwrecking Probability (RSP) Model and its two model components. The different input factors are presented after discussing the criteria employed for selecting them. Then, the North-African case study is introduced. Lastly, it is discussed how the RSP model developed at the Regional scale can be extended at the Global - Mediterranean- scale

Chapter 6: describes the procedures for building the model in ArcGIS at both regional and global Mediterranean scales. The Regional case study implementation is discussed first, followed by the Global Mediterranean one, highlighting the simplifications required. For each scale, the procedures for implementing each factor are discussed separately, then the methods for combining them to produce two different shipwrecking probability maps: the base map, which results from assigning all factors an equal weight; the preferred map, which results from assigning the factors a different weight calculated by following the analytic hierarchy process by Saaty (1980).

Chapter 7: addresses the model quality and sensitivity to variations in the inputs. After identifying all potential sources of uncertainty in the model, multiple scenarios are run for identifying which model variation has the greatest impact on the model results. Afterwards, the model results are compared against observed data for evaluating the produced scenarios through Kvamme's gain statistic, and the Chi-squared test, which are the most commonly used methods for measuring the quality of models (Ducke, et al., 2009; Verhagen, 2007).

Chapter 8: contains a general discussion of the research achievements, limitations, and possible future developments.

> "Whenever a theory appears to you as the only possible one, take this as a sign that you have neither understood the theory nor the problem which it was intended to solve"
>
> Karl Popper

2 STATE OF THE ART IN ARCHAEOLOGICAL PREDICTIVE MODELLING

In the introduction to this research, it was noted how, despite their potential utility, there had been minimal projects within the Mediterranean domain attempting to develop predictive maps for shipwreck locations. Such underdevelopment sounds like a paradox if one considers that underwater surveys are affected by many logistic and economic limitations, and predictive models may help to prioritise areas to investigate. Although increasingly used on land, predictive modelling does not constitute a standard practice in the desktop studies carried out in advance of underwater surveys; this highlights specific data quality problems (chapter 3) and a more general distrust toward an approach accused of oversimplifying complex phenomena to produce quantifiable outcomes. This distrust reflects a mistaken notion of what formal modelling in general and predictive modelling in particular are and what they should achieve.

Extending on the above issues, section 2.1 addresses definition(s), scope, and current methodological and theoretical approaches in Archaeological Predictive Modelling (APM). Section 2.2 focuses on the maritime, underwater domain by enquiring possible reasons behind the APMs underdevelopment (section 2.2.1), the theoretical foundations (section 2.2.2), the most frequent approaches adopted until now to predict shipwreck locations (sections 2.2.3 and 2.2.4) and past seaborne routes (section 5). Since the review focuses on archaeological prediction, it will not include GIS-based inventories and national registers aimed at mapping the underwater archaeological heritage when not employing predictive modelling as part of the desktop study. In section 2.2.6, the main challenges and shortcomings of current archaeological predictive models in the maritime context are discussed for highlighting the limitations that the present research aims to overcome. Section 2.3 sets the course of the study by introducing the methodological approach followed for building the predictive model.

2.1 REVIEW OF THEORIES AND METHODS OF ARCHAEOLOGICAL PREDICTIVE MODELLING

2.1.1 History and theoretical background

According to one of the most commonly employed definitions of archaeological predictive modelling, the latter may be described as a technique enabling one to "predict, at a minimum, the location of archaeological sites or materials in a region, based either on the observed pattern in a sample or on assumptions about human behaviour" (Kohler & Parker, 1986, p. 400). The definition has been reported in several related works afterwards (Balla, et al., 2014, p. 144; Kamermans, 2006, p. 35; van Leusen & Kamermans, 2005, p. 9; van Leusen, 2002, p. 5.1; Verhagen & Whitley, 2012, p. 52; Verhagen, 2018, p. 1; Verhagen & Whitley, 2020, just to name a few). The quote contains one of the most distinctive but also controversial characteristics of archaeological predictive models (APM), as it emphasizes the locational and spatial components. Indeed, the latter constitutes at the same time: a) the aspect that enabled the implementation of APM, b) the main reason for and trigger of APM initial development, but also c) the seed of one of the main criticisms levelled at APM in the following decades.

The possibility to predict where archaeological remains may be found is connected to the idea that the motivations - or preferences - driving human actions leave traces in the physical environment, hence they are patterned and can therefore be modelled (Brandt, et al.,1992, p. 269; van Leusen, 2002, ch. 1.3). This theoretical underpinning may be traced back to the New or Processual Archaeology movement, developed from the 1960s in the USA, (e.g., Binford, 1989; Kamermans, 2006, p. 35; Kvamme, 2006, p. 6; Trigger, 1989, pp. 310-312; Verhagen, 2007, p. 14). The latter - in opposition to the old archaeological school that was mostly culture-historical, descriptive and focused on chronological typology- aimed to overcome the mere observation of the archaeological record and to focus the attention on past social dynamics -or processes- in search for general laws of human behaviour (Binford, 1977; Shanks & Hodder, 1995).

According to processual archaeologists, an anthropological approach and the rigorous use of the scientific method and statistics (Kvamme, 2006, p. 6) may disclose the cultural developments of past societies, which reflects the adaptation to their specific environmental conditions. The development of computational techniques and the spread of Geographical Information Systems (GIS) fostered the development of spatial analysis approaches, enabling the formal investigation of the relationship between human actions and the physical environment; also, they created the pre-condition for predictive applications (Hodder & Orton, 1976, p. 244; Verhagen 2018; Kamermans 2006, p. 35). Nonetheless, as Verhagen and Whitley highlighted (Verhagen & Whitley, 2012, p. 51), it would be inaccurate to state that GIS has been the main factor influencing the initial development of predictive modelling, for the earliest models did not necessarily employ it (see for instance Kvamme, 1983).

Legislative and practical reasons contributed to the development of predictive models, first in the United States, following the introduction of a federal law called 'Historic Preservation Act' in 1966 that uttered the need "to identify historic properties [...] and to record such properties when they must be destroyed" (King, 1984 as cited in Verhagen, 2007, p. 14). A couple of decades later, in 1992, the ratification of the European Convention on the Protection of the Archaeological Heritage (the so-called 'Valletta Convention', or 'Malta Convention'), has introduced the obligation to assess the archaeological heritage in spatial planning processes and assigned to the developers the costs of archaeological investigations and possible mitigating measures. The United Nations Convention on the Law of the Sea of 1982 ('UNCLOS') already stated in its preamble that issues relating to the use of ocean space need to be considered as a whole. Moreover, the directive 2014/89/eu of the European Parliament[7] established a framework for maritime spatial planning that further stressed the need to consider relevant interactions of marine activities and developmental works (e.g., installations for the production of energy, oil and gas exploration and

[7] Available at: https://www.eea.europa.eu/policy-documents/directive-2014-89-eu-maritime. (Accessed: 18 November 2021)

exploitation, maritime shipping and fishing activities, ecosystem and biodiversity conservation, the extraction of raw materials, tourism, aquaculture installations). These interactions include the potential interference with the underwater cultural heritage. Following the above convention, the possibility to predict yet unknown archaeological sites' location became crucial, as it entails for the developers the possibility to reduce the risk of additional expenses and for the heritage manager the possibility to better plan their preservation efforts.

Despite their potential advantages, only a few European States have decided to invest in developing predictive models since the convention enables the signatory countries to choose their implementing strategies (van Leusen & Kamermans, 2005, p. 9). Notably, the Netherlands has been the first European country that systematically invested in APMs (Brandt, et al., 1992, p. 22; Deeben, et al., 1997; Maarleveld, 2003; van Leusen & Kamermans, 2005; Verhagen, 1995), which became an integral part in the phase of desk-top studies assessment, whereas elsewhere their development still struggles to take off, due to the substantial criticism and scepticism predictive modelling has encountered; the reasons for such criticisms and scepticism are further discussed below in section 2.1.3.

Here it is worth highlighting that these criticisms reflect the opposite theoretical and methodological approaches interpreted by the processual and post-processual schools (e.g., Wheatley 1993; Wheatley, 2004; Whitley, 2005; Witcher, 1999), which a limited number of scholars have tried to overcome by proposing alternative new practices (Kamermans, et al., 2009; van Leusen & Kamermans, 2005; Verhagen & Whitley, 2012, p. 50; Whitley, 2005). Within the variety of viewpoints embraced by the post-processual movement, which has contributed to decreasing the overall interest in quantitative approaches to archaeological questions, the claim that has most heavily influenced the second generation of predictive modelling techniques relates to the importance of taking into account human agency. According to post-processualists, the latter is the real driving force of all archaeological patterning, far more than both the natural environment and cultural "systems" of social organisation (Verhagen & Whitley, 2012, p. 60); this is the reason why a purely ecological or environmental deterministic approach fails to produce historically reliable outcomes. More generally, the post-processual movement rejects the positivistic and empiricist idea, according to which the application of the scientific method would make it possible to draw objective conclusions on the archaeological record. Instead, post-processualists emphasise the inherent subjectivity of any archaeological interpretation (for a broad discussion on the role of post-processual approaches, particularly concerning predictive modelling, see Verhagen & Whitley, 2012, pp. 60-63). Whereas the first generation of APMs, particularly in the United States, was firmly rooted in the processual tradition, the second generation is rather "located in the field of tension between processual and post-processual paradigms" (van Leusen & Kamermans, 2005, p. 19; see also Maarleveld, 2003; Wansleeben & Verhart, 1997).

The need to establish new strategies for taking into account the human agency has led to elaborate a new generation of predictive models able to explore different archaeological and non-archaeological theories (Whitley 2005; Whitley, et al., 2010), such as the Middle Range Theory, which was first introduced within sociology in the 1950s by Robert K. Merton (Merton, 1968) as a way to integrate theory and empirical data. Afterwards, the Middle Range Theory has been applied to the archaeological domain in an attempt to objectively interpret the meaning of the archaeological record besides its purely material consistency (cf. Bettinger, 1987; Binford, 1989; Binford, 1983; Verhagen & Whitley, 2012, pp. 63-70). Its first application within the archaeological domain dealt with site formation processes and the so-called behavioural archaeology, which was introduced in the mid of 1970s by Michael Schiffer (cf. Binford, 1981, pp. 21-30; Schiffer, 1976; Verhagen & Whitley, 2012; as for the maritime context, Muckelroy, 1976). Middle Range theory has been recently considered the best methodological tool for archaeological prediction based on behavioural inference since it enables "satisfying current theoretical concerns without becoming too complex to handle in practice" (Verhagen & Whitley, 2012, pp. 63-64). Attempts to combine processual and post-processual approaches may be ascribed to 'cognitive archaeology' (Renfrew & Zubrow, 1994). The latter, also referred to as 'archaeology of mind' (Renfrew, 1982) can be defined, among the wide divergence of positions (see Renfrew, et al., 1993) that reflect rather different views (e.g. cf Chippindale & Bell in Renfrew, et al., 1993, p. 254), as "the study of the ways of thought of past societies (and sometimes of individuals in those societies) based upon the surviving material remains (Renfrew, et al., 1993, p. 248). Bender highlights the interrelation between observer and observed by suggesting that while cognitive archaeology focuses on how people perceive and understand themselves, their relationships, and the world (real or imagined) around them", it is "only by understanding our own perceptions" that we can recognize the particular way in which we engage with the past and thereby accept that the way in which we listen to them is subjective" (Bender, 1993).

Influenced by the cognitive revolution in psychology that was linked to the development of computers (Hodder, 1993, p. 253; Sperber, 1992), cognitive anthropology and archaeology are based on the assumption that mental phenomena can be analysed by formal methods similar to those of mathematics and logic' (Tyler, 1987, p.14, in Renfrew, et al., 1993, p. 254). Renfrew foresaw the beneficial "convergence between such fields as cognitive psychology, studies in artificial intelligence, computer simulation and cognitive archaeology", but he thought this junction could happen only at the condition that "those archaeologists interested in the symbolic and cognitive dimensions devote more attention to the formation of a coherent, explicit and in that sense scientific methodology by which that dimension can systematically be explored through the examination and analysis of the archaeological record (Renfrew, 1993, p.250). Complexity science, which may be defined as the theoretical research perspectives and the formal modelling tools designed to study complex systems, constitutes in this sense a suitable and promising strategy to study historical and archaeological past (Bentley & Maschner, 2003; Brughmans, et al., 2019).

Given the above, cognitive archaeology represents a bridge between positivists and post-processualists, as it merges the scientific method and the formal approaches to testing hypotheses, with the focus on human agency. Nevertheless, as stressed by Peebles (Peebles, 1993, p. 257), all attempts to infer past cognition, however 'scientific' and objectivist their overt rhetoric, must involve hermeneutic procedures in which cognition is allied to local social meanings [...] "cognitive archaeology must be embedded within a non-positivist framework in which methods are described for the hermeneutic understanding of other particularities".

2.1.2 Definitions: main distinctions in methodological approaches

Archaeological predictive models are usually divided into two main groups depending on the methodological approach or strategies adopted to build them (Kamermans & Wansleeben, 1999; Sebastian & Judge, 1988; Verhagen & Whitley, 2020, pp. 232-233; Wheatley & Gillings, 2002). Inductive, or data-driven, models, which are also referred to as 'correlative' or 'inferential', predict the location of unobservable sites by correlating the observable sites to a set of variables considered to affect their distribution (e.g., the presence of a slope or water). If a significant relationship between the observed sites and the selected environmental variable is detected, the correlation is extrapolated on non-surveyed areas through statistical tools such as logistic regression (Conolly & Lake, 2006, chapter 8.8.) to predict the location of yet unknown sites (Verhagen, 2007, p. 14). To be more explanatory, in this kind of model, the prediction is derived from -and based upon- the observation of known archaeological sites. Besides the regression algorithms, which have been one of the most popular methods employed for creating predictive models (cf. Cole, Gould et al. 2006; Gillings & Wheatley, 2002 pp. 154–156), other options are increasingly employed, including Bayesian statistics (Finke, et al., 2008; van Leusen, et al., 2009), Monte Carlo simulations (cf. Vanacker, et al., 2001), ecological niche modelling (cf. Banks, 2017). Verhagen and Whitley highlight that "despite the current state of sophistication of statistical modelling, it is still very difficult to determine which statistical technique performs best since there are hardly any case studies available where methods are compared" (Verhagen & Whitley, 2020, p. 232; an attempt to discuss and address the performance of archaeological predictive models is in Rocks-Macqueen, 2014).

In deductive or theory-driven models, the prediction is based upon assumptions and hypotheses derived from expert judgement and prior knowledge derived from the combination of different researches and fields (e.g. historical, ethnographic, philological, epigraphical, anthropological, archaeological); the observed archaeological sites are used to test and validate the prediction rather than as input-data (Deeben, Hallewas, Kolen, & Wiemer, 1997; Deeben, et al., 2002; van Leusen & Kamermans, 2005, p. 16; Verhagen & Whitley, 2012, p. 52; Verhagen, 2018). These models are also referred to as 'explanatory 'or 'behavioural', but these names are deceptive since data-driven models may be 'explanatory' as well, depending on their aim (see the end of the section below).

Both approaches present advantages and disadvantages (see van Leusen, 2002, p. 99; Verhagen, 2007). The correlative (i.e., inductive) approach has been predominant in the United States and the first generation of predictive models in Europe. However, there are already published examples of theory-driven (i.e., deductive) predictive models in the second half of the 1970s (e.g., Chadwick, 1978). Inductive methods have been accused of overemphasising the importance of the physical environment (e.g., Gaffney & van Leusen, 1995; van Leusen et al., 2002; Wheatley, 1993; 1996a; 2003) and of underestimating the importance of socio-cultural factors (van Leusen, 2002, p. 99; Verhagen, et al., 2013). Moreover, they would be excessively dependent upon the available data. Indeed, given that uncertainty and partiality are ubiquitous in the archaeological record, one cannot be sure that the lack of recorded sites or materials in a region corresponds to a lack of potential yet unknown sites (Chapters 3 and 7); this means that the biases affecting the available dataset may potentially affect the prediction by generating biased models (Wheatley, 2004).

On the other hand, the deductive approach is considered easier to develop since it does not entail complex statistical analysis and is more suitable for including cultural and cognitive factors. However, it is also considered excessively subjective and dependent upon expert judgment (Dalla Bona, 1994; Dalla Bona, 2000; Verhagen, 2007, p. 79). Different scholars have highlighted that in the end, the difference between the two approaches, although "useful for describing the different approaches to predictive modelling at a methodological level", is not that distinct, and "elements of both approaches can, therefore, be found in many predictive modelling studies (Verhagen, 2007, p. 14). Particularly, according to van Leusen (2002, p. 100):

> On the one hand, supposedly 'inductive' models incorporate many assumptions about past human behaviour – why else would one attempt to correlate the location of sites with, say, terrain slope? Critique by many post-processualists and some processualists that induction lacks a theoretical basis is therefore misguided (cf. Kvamme, 1999, p. 173). On the other hand, at least part of the archaeological 'expertise' that goes into deductive models is based on informal induction.

From this, one could set forth that the purposeful combination of both inductive and deductive reasoning lines would improve predictive models for archaeological resource management (Verhagen, 2007, p. 14).

Since the distinction based on methodological differences is deceptive and does not contribute to shed light on the inner logic of archaeological predictive modelling, some scholars have proposed alternative classifications that are based on the model aims (e.g., Judge & Sebastian, 1988, p. 4; van Leusen, 2002, pp. 100-101). Particularly van Leusen, recalling the distinction made by Judge & Sebastian (1988, p. 4) that has since been forgotten, distinguishes between correlative and explanatory classes:

> If the ultimate aim of a model is to understand aspects of past settlement and land use behaviour, then prediction is only the means by which that understanding can be tested, and the model may be termed explanatory. If, on the other hand, the ultimate aim is to conserve the archaeological heritage, then the task of prediction is to estimate, as accurately as possible, the probability of the presence of archaeological remains in all parts of the study region, and the model may be called correlative.

He also proposes a second alternative distinction between "two fundamentally different approaches to prediction: possibilism and probabilism". According to him, archaeological predictive models have been mostly possibilistic since they only indicate how suitable an area is for a specific activity. On the contrary, probabilistic approaches express how likely an area is to have been used for a specific activity.

2.1.3 Main criticisms

In this section, a difference shall be made between those who have highlighted the limitations of the correlative approach characterising most of the first generation of PMs both in America and in Europe (Kamermans & Rensink, 1998; Kamermans & Wansleeben, 1999; van Leusen, 1996, 1995; Whitley, 2003, 2005, 2010), and those who maintain the full uselessness – if not the potential damage - of archaeological prediction (discussions in Ebert, 2000; Gaffney & van Leusen, 1995; Harris & Lock, 1995; Kamermans, 2007; Kamermans et al., 2009; Verhagen, 2007; Wheatley 2004).

Criticism of the first generation of predictive models has triggered improvements and alternative approaches (Kamermans, 2000; Verhagen & Berger, 2001; Wansleeben & Verhart, 1997; Whitley, 2010, 2005, 2003). Particularly, six major problem-areas were identified (van Leusen & Kamermans, 2005, p. 17):

- Quality and quantity of archaeological input data: namely the risk of generating biased prediction due to biased input-data: this refers to the need for the definition of strategies enabling one to assess and mitigate the input-data biases
- Relevance of the environmental input data: this relates to the need to evaluate the pertinence of contemporary environmental and meteorological data, namely in assessing whether they may be used to study and predict past phenomena
- Need to incorporate social and cultural input data (cf. papers in Lock, 2000; Stančič & Kvamme, 1999; Wheatley, 1996): this relates to the need to overcome the environmental-deterministic approach (Brandon & Wescott, 2000; Lock & Stančič, 1995) by taking into account human agency (Whitley, 2005, 2004). Also, the definition of strategies for their inclusion and for testing their real impact on the outcome (i.e., does their implementation really make a difference? How may we evaluate this impact?) (Verhagen et al, 2013).
- Lack of temporal or spatial resolution: this refers to the problematic aggregation -and consequent distorted prediction- of input data having a different spatial and temporal resolution
- Use of spatial statistics; this relates to the importance of improving the standards of statistical approaches in predictive modelling. Kamermans, Deeben, Hallewas, Zoetbrood, van Leusen and Verhagen (van Leusen & Kamermans, 2005, p. 20) highlight three main issues: the problem of autocorrelation in landscape variables, the provision of error estimates when giving predictions, and the correct application of Bayesian inference techniques
- Testing of predictive models. This issue relates to the need to define strategies enabling one to ascertain whether a model is working well. What 'working well' does mean is precisely the problem (chapter 7). Indeed, following inductive methods, good models are usually the robust ones, and the 'good outcomes are considered to be those closer to the observed input. Nonetheless, this approach risks generating a self-fulfilling prophecy that cannot detect significant anomalies and may reflect the biases affecting the input-data.

Some of the above relate more specifically to the correlative or inductive approach (e.g., the quality and quantity of input data or the use of spatial statistics). In contrast, the necessity to overcome the environmental determinism and the need to incorporate social and cultural input data relates both to inductive and deductive methods. Further limitations, shared by the two approaches, include the PMs' inability to predict anomalies or unique occurrences (Verhagen & Whitley, 2012, p. 89) either because of limited capabilities or -according to the New Archaeology School- because the research of universal laws is assumed to be scientifically preferable (e.g., Shanks & Tilley, 1987, p. 38).

The issue of scale is connected to the generalisation and specificity of the problem. Particularly, the danger connected to the erroneous extrapolation from one scale level to another: this issue relates to archaeology as well as other disciplines (e.g., geography, geology) and it occurs when one derives emergent processes and patterns at a scale that is greater than the one of the observed input-data that have been used to obtain them. This critical extrapolation may cause the appearance or disappearance of phenomena when switching from one scale to another (Verhagen & Whitley, 2012, p. 90; as for the risks connected to erroneous extrapolation, they mention Harris T., 2006).

Lastly, as for those opposing the employment of predictive techniques for selecting/prioritising the areas to survey (e.g., Wheatley, 2004), the main criticism that is usually raised relates to the supposed inability of any model to predict all archaeological remains accurately. Sites that fail to be predicted, which are usually referred to as idiosyncratic or 'red flag' sites (Altschul, 1990, p. 288; Kvamme, 2006, p. 6) risk to be destroyed by developments; hence, some scholars argue, erroneous predictive models' employment may compromise the archaeological investigations instead of optimising them (Ebert, 2000; Gaffney & van Leusen, 1995; Harris & Lock, 1995; Kamermans, 2007; Kamermans et al., 2009; Verhagen, 2007; Wheatley 2004).

Nonetheless, this objection is driven by two deceptive assumptions. The first is that a model should perfectly replicate reality, which is impossible and beyond the scope of any 'good' formal model (Epstein, 2008; Rubio-Campillo, 2015; Wurzer et al., 2015). Models are, by definition, a simplification of reality that enables one to specify theories about past phenomena formally and to test aspects of these theories as hypotheses using formal modelling approaches that are transparent and reproducible (Brughmans et al., 2019). As Epstein contributed to highlighting, formal models help us better understand reality while not being a perfect replication of it (Epstein, 2008).

The advantages of formal modelling are that they bring to the fore the need to make explicit and eventually formalise even implicit assumptions and biases, thus enabling to measure the results, test their validity, and enable others to replicate and improve the process. Predictive models are a particular kind of formal models whose aim should not be limited to the verification of scientific hypotheses but rather to provide a reliable estimate of the probability of encountering archaeological remains to support decision-making processes (Brughmans et al., 2019; Verhagen, 2007, p. 14). Even so, expecting that a model predicts the entire archaeological potential would be unrealistic. We are sure that something will be missing, and it would be both untruthful and counterproductive to claim the contrary. The construction of Predictive Models is, after all, a research activity, and, as every research, its results are always provisional.

As Kvamme and others observed, ‘the most interesting sites are the (idiosyncratic) ones that do not fit the pattern’ (Kvamme, 2006, p. 6) because

> ‘Once anomalies, or red flags, are identified, they become the subject of additional research. As patterns are found, many anomalies become predictable. Those sites whose locations remain anomalous grow in importance. Archaeologists want to know about these sites to further our insight into the past. Managers want to know the locations of these sites so that they can be included early in project plans.’ (Altschul, 1990, p. 288)

In other terms, ‘wrong results’ may actually trigger the improvement of predictive models (see also Maarleveld, 2004, p. 139). In this perspective, going back to the issue of testing PMs discussed above, no result can be considered wrong or exact; this brings us to the second consideration: discarding predictive techniques in light of their assumed inadequacy is just an illusionary solution; indeed, even when one pretends not to employ models, one actually does, i.e., in an implicit manner instead of a formal one. The explicit formalisation of imperfect models should be preferred to the unformalized assumptions (Epstein 2008; Verhagen & Whitley 2012, p. 55).

What is said above does not entail that there is no room for improvements for reducing the margin of unexpected outcomes, as Verhagen highlighted: “The models are only as good as the data and theories that have been used to create them since we can only extrapolate from the existing state of archaeological knowledge” (Verhagen, 2018). Hence, one should wonder what the ‘state of archaeological knowledge’ includes and entails. The systematic account of different kinds of independent data besides the purely archaeological ones (e.g., historical sources), may enhance the model’s robustness despite the archaeological data-biases. Unfortunately, this is not current practice in archaeological predictive models (Verhagen et al., 2019).

2.2 REVIEW OF PREDICTIVE MODELS FOR SHIPWRECK LOCATIONS

2.2.1 Paucity of predictive models in the maritime context: whys and wherefores

The archaeological predictive modelling technique -particularly the locational prediction- has received much less attention within the maritime domain than inland. It is still underdeveloped if one compares the number of projects carried out in terrestrial contexts with the maritime ones. This paucity of archaeological predictive models in the maritime domain is particularly evident in the Mediterranean region, whereas relatively more numerous projects are attested in the US and Northern Europe (Table 2.1). The predictive models aimed at assessing the probability of finding archaeological remains underwater have mainly been developed by individual researchers instead of public authorities commissioned. Indeed, most public authorities have invested in archaeological registers based on desk-top studies and geophysical surveys carried out with remote sensing techniques, rather than in formal predictive models (e.g., see the Italian Archeomar Project [8] or the European projects MoSS (i.e., Monitoring, Safeguarding and. Visualizing North-European Shipwreck sites), BACPOLES, MACHU, WreckProtect (Björdal, et al., 2012) and SASMAP that were undertaken in cooperation by several European countries). At the moment, only in one European country, the public authorities have financed a predictive map for underwater archaeological risk assessment at a national level, i.e., *the Indicatieve Kaart Archeologische Waarden* developed in the Netherlands, which includes both land and underwater terrain (Deeben et al. 2002; Manders & Maarleveld 2006; Manders, 2017). One other country has promoted the development of predictive maps of maritime archaeological potential as a pilot project on a limited area (i.e. the Eastern English Channel), namely the 'Refining Areas of Maritime Archaeological Potential (AMAPs) for Shipwrecks' project (Merritt, 2008), which was commissioned by the English Heritage in 2007 and was undertaken by the Bournemouth University. Other countries have expressed a general interest in their future development (e.g. France, *Le Département des recherches archéologiques subaquatiques et sous-marines. Brochures de présentation des missions du DRASSM 2018*).[9]

If one considers the two main reasons for developing predictive models discussed in the introduction, namely the pragmatic need for locating potential sites to optimise the selection of areas to investigate, and the scientific interest in further understanding past phenomena through computational techniques, the latter has received more attention than the former in the underwater domains. The scarce use of PM for cultural heritage management in the maritime context does not seem to be due to a lack of potential utility, but rather to mistrust in the technique and to the fear that something important may be lost due to incorrect prediction (Maarleveld 2003; 2004). Conversely, there has been an increased amount of studies employing computational techniques for gaining insights into the dynamics affecting past movement potential, hence past maritime routes (e.g. Gustas & Supernant, 2017; Indruszewski & Barton, 2007; Leidwanger, 2013a; Newhard, Levine, & Phebus, 2014; Potts, 2019; Slayton, 2018). Several considerations may contribute to shed light on the reasons behind PMs' underdevelopment in the maritime contexts; these are not entirely straightforward and may even look paradoxical if one considers the potential

[8] Available at: http://www.archeomar.it. Accessed: 23 June 2015

[9] Available at: http://www.culture.gouv.fr/Thematiques/Archeologie/Archeologie-sous-les-eaux

benefits PMs may bring for compensating the logistic and economic limitations of underwater surveys.

The first consideration relates to the fact that underwater archaeology is a relatively young discipline; indeed in 1972, the United Nations Educational, Scientific and Cultural Organization (UNESCO) was considering it a 'nascent' field (Maarleveld, 2008, p. 309). Hence, when the predictive modelling technique started to be increasingly applied to terrestrial contexts, underwater archaeology was still busy trying to define itself, its scopes, priorities and goals. This search for a self-definition, which characterised the nascent maritime archaeology field, is well proven by the above mentioned UNESCO 1972 book "Underwater Archaeology: A Nascent Discipline" whose articles document the little coherence and the lack of shared vision or approaches at that time (Maarleveld, 2008, p. 310). Although "the demand for predictive pre-assessments specifically addressing maritime environments has been felt since the early nineteen-eighties" (Maarleveld, 2004, p. 140) at least in northern Europe (e.g. Maarleveld, 1996; Maarleveld, 1998), it has been only after the 2001 UNESCO Convention on the protection of the Underwater Cultural Heritage that predictive models started to be increasingly developed within the maritime and underwater contexts, although not in the Mediterranean sea. This timing reflects the more conscious and structured idea of the challenges and risks the discipline -now more mature- is facing (see, e.g. Manders & Maarleveld, 2006; Manders, 2017; Maarleveld, Guérin, & Egger, 2013). Earlier modelling attempts - carried out in the South-Pacific and the Caribbean - were only limited to the assessment of movement potential and not to proper archaeological site-location probability assessment (Callaghan, 1999; Irwin et al., 1990; Levison et al., 1972. Cf. for a detailed review Slayton, 2018).

The second observation, connected to the former, relates the fact that the countries first investing in maritime predictive modelling are those where such a technique has been initially developed, namely the United States and the Netherlands. In contrast, this technique is almost entirely unexplored among the Mediterranean countries. Indeed, as previously said, in Europe the first indicative map of archaeological values encompassing maritime zones besides land surfaces was developed in the Netherlands at the beginning of 2000s by the *Rijksdienst voor Archeologie, Cultuurlandschap en Monumenten* (i.e. the Cultural Heritage Agency of the Netherlands). Particularly, whereas the first generation of the *De Indicatieve Kaart van Archeologische Waarden* (IKAW) only included terrestrial sites and settlement archaeology (Deeben et al., 1997), the second (Deeben et al., 2002; Manders & Maarleveld, 2006) and third-generation (Deeben, 2008) included underwater sites as well.

The third consideration around the whys and wherefores the predictive modelling technique did not find great estimators among underwater and maritime archaeologists is connected to the methodological and theoretical approach that has characterised the first generation of predictive modelling techniques, namely the data-driven one as discussed in chapter 2.1. Indeed, due to the many biases affecting the underwater archaeological records (Chapter 3), this approach may be considered less suitable in underwater contexts than inland. Our knowledge of the underwater cultural heritage is limited to patches of explored areas or random discoveries, and most of the recorded sites, besides a few fully excavated ones, are those visibly lying on the seabed. Therefore, the distrust toward a technique that claims to predict yet unknown sites-location based on the observed ones is not surprising.

Table 2.1: A selection of existing modelling approaches and simulations to seafaring and shipwreck locations based on GIS and/or least-cost path analysis. The review highlights the significant underdevelopment of predictive models for shipwreck locations in the Mediterranean context: regarding this, it is worth noticing that the only exception is represented by a Master thesis carried out at the University of Southern Denmark, whose Supervisor is a pioneer of Northern Europe maritime archaeological predictive modelling (i.e. Maarleveld; Perissiou 2014).

Year	Authors	Region	Scope	Time-Period
1973	Levison et al.	Pacific (South)	Movement potential	Middle to Late Pleistocene
1985	Wild	Sunda-Sahul	Movement potential	Prehistoric
1989	Garrison et al.,	Gulf of Mexico	Shipwreck locations	16th to the 20th centuries
1990	Irwin et al.,	Pacific	Movement potential	Pleistocene
1999	Callaghan	Caribbean	Movement potential	Prehistory
2001	Callaghan	Caribbean	Movement potential	Ceramic period (from 1 BCE)
2002	Deeben et al.,	Netherlands	Shipwreck locations	From Paleolithic to Late Middle Ages (ca. 1500)
2003	Pearson et al.,	Gulf of Mexico	Shipwreck locations	16th to the 20th centuries
2003a	Callaghan	Canadian Pacific Coast	Shipwrecks location	Japanese EDO period (CE 1603-1867)
2003b	Callaghan	South American West Coast	Movement potential	Prehistoric
2005	Rahn	Orkney Islands	Movement potential	Iron Age
2006	Montenegro et al.,	Atlantic and Pacific	Movement potential	Prehistoric
2007	Avis et al.,	Pacific Ocean	Movement potential	Prehistoric
2007	Callaghan & Bray	Caribbean coastal area	Movement potential	Prehistoric
2007	Di Piazza et al.,	Pacific	Movement potential	Prehistoric
2007	Merritt et al.,	United Kingdom - Eastern English Channel	Shipwreck locations	Prehistoric to post-medieval
2007	Indruszewski & Barton	Baltic Sea	Movement potential	Viking Age
2008	Fitzpatrick & Callaghan	Indian Ocean	Movement potential	Prehistoric

Year	Authors	Region	Scope	Time-Period
2008	Evans	Pacifc	Movement potential	Prehistoric
2008	Montenegro et al.,	Pacifc	Movement potential	Prehistoric
2010	Cooper	Caribbean	Movement potential	Pre-Columbian
2011	Callaghan	Caribbean	Movement potential	300 BCE – CE 1500
2012	Meeks & Grossner	Mediterranean	Movement potential	Roman Empire
2012	Scheidel	Mediterranean	Movement potential	Roman Empire
2013	Leidwanger	Mediterranean	Movement potential	Greek Archaic Period
2013	Fitzpatrick & Callaghan	Pacific (Western)	Movement potential	Prehistoric
2014	Bar-Yosef Mayer et al.,	Mediterranean	Movement potential	Neolithic
2014	Leidwanger	Mediterranean	Movement potential	Roman time
2014	Perissiou	Mediterranean (Greece)	Shipwreck locations	5000 BCE - 1830CE
2014	Scheidel	Mediterranean	Movement potential	Roman Empire
2015	Callaghan	Mid-Atlantic	Movement potential	Pre-Columbian
2015	Davies & Bickler	Global	Movement potential	Prehistoric
2016	Montenegro et al.,	Pacific	Movement potential	Prehistoric
2017	Rooney	Atlantic	Shipwreck locations	16th-19th century
2017	Gustas & Supernant	Pacific Northwest Coast	Movement potential	Late Pleistocene and Holocene
2018	Slayton	Caribbean	Movement potential	pre-Columbian
2019	Potts	Mediterranean	Movement potential	Roman empire

2.2.2 Theoretical underpinnings

The goal of this section is to highlight the primary theoretical basis and assumptions behind the development of predictive models for shipwreck locations in general terms, noting that it is beyond the scope of the present section –and research- to discuss in detail navigation and wreck-formation theories in a diachronically manner. In Chapters 4 and 5, a more detailed overview of navigation theories in Classical and Roman times supports the development description of the model and highlights the contribution new to this research better.

The fact that predictive models started to be developed mainly in and for terrestrial contexts has had important theoretical and methodological implications, which are still affecting PMs' development in the maritime domain. Among these are the lack of a comprehensive and tailored theory on predictive modelling approaches for the underwater archaeological domain and the lack of alternative strategies to be compared in this respect. In other terms, there is no community standard for using computational methods in general and GIS-based techniques in particular to model shipwreck locations in maritime contexts. Similarly, there is no community standard for modelling past maritime movement potential (Slayton, 2018). Indeed, whilst current computer-based models refer to specific aspects of navigation theory or wreck-formation processes, a more comprehensive theoretical debate on how to approach the building of predictive maps for underwater remains is currently missing. While different strategies have been employed, the factors selection and prioritisation strategies have not been formalised, nor have the results evaluated.

Thijs J. Maarleveld, who has been among the few addressing the theory and knowhow of predictive modelling for shipwreck locations (Maarleveld, 1998; 2003; 2004; 2008; see also Deeben et al. 2002), stated that to approximate where shipwrecks may be found, we need models and theories at three levels that may address the following questions: 'what happened originally, what happened in the meantime, what happens upon discovery' (Maarleveld, 2004, p. 14). The first question refers to the time of the ship and addresses navigational dynamics and maritime behaviour. The second question refers to post-depositional processes, whilst the latter refers to the time the surveys are carried out, namely to the factors enabling the discovery.

It follows that the theoretical background for developing a predictive model for shipwreck locations include but cannot be limited to 'formation theory' in general and 'wreck-formation theory' in particular (Gibbs, 2006; Martin, 2013 and 2014; Muckelroy, 1978; O'Shea, 2002; for differences with terrestrial sites see also Renfrew & Bahn, 1991; Schiffer, 1987). Indeed, the formation theory does not systematically consider the movement potential and only accounts for navigation dynamics when these potentially increase a vessel's probability of sinking. Particularly, the wreck-formation theory includes:

- The 'depositional theory', namely the processes that move a vessel from being a systemic context participating in behavioural dynamics to an archaeological one (Schiffer, 1987). O'Shea (2002, p. 212) calls it a 'static' archaeological context, although for the reasons explained below, it is better to avoid misleading adjectives
- The 'post-depositional theory', which encompasses both the processes occurring after the wreckage and contributing to the modification of the site till the moment of the discovery (i.e. post-depositional processes) and the actions and the operations altering the site at discovery

(i.e. recovery processes. Muckelroy, 1978; O'Shea, 2002); as noted by Gibbs, the processes affecting the disintegration of the remains have received more attention than the cultural transformation (Gibbs, 2006, p. 4)

The three groups of aspects Maarleveld is referring to encompass pre-depositional and post-depositional processes. Although caution must be paid when using the term 'pre-depositional' as slightly different concepts may be encompassed. Indeed, under a strictly chronological point of view, pre-depositional processes may include all the phenomena happening before ships' remains pass from a systemic condition, to be an archaeological site on the seabed, hence:

1) The movement potential, namely the navigational patterns and corridor-routes: this implies considering the reasons triggering the movement, the actors involved, the technical and environmental constraints, as well as the seamanship and the cognitive processes conditioning the perception of time, space and risk (Verhagen & Joyce, 2019)
2) Hazards to navigation, namely the factors that increase the probability of wrecking, which include adverse meteorological and environmental conditions, but also circumstantial reasons such as an attack, damage to the vessel or human error

Whereas post-depositional processes include:

3) Preservation potential, namely the post-depositional processes occurring after the wreckage and determining the alteration, survival or dispersal of the ship-remains on the seabed (Gibbs, 2006; Martin, 2013 and 2014; Muckelroy 1978)
4) Discovery potential, namely the processes and factors enhancing or reducing the chances to detect the archaeological remains possibly lying on the seabed (e.g. visibility, accessibility, technology)

Nonetheless, in wreck-formation theory (e.g. O'Shea, 2002), pre-depositional processes have been included either among the wrecking process, thus referring to the actions and the efforts undertaken immediately before wrecking for mitigating the risk (Souza, 1998), or to factors that, although not chronologically close to the wreck-moment may have contributed to it (e.g. techniques and style of construction, repairs, alterations; Conlin, 1998; O'Shea, 2002; Souza, 1998). In such scholarship, the 'pre-depositional processes' do not include navigational dynamics, strategies and behaviours if not connected to unsuccessful voyages and consequent wreckages.

One may argue that a predictive model for shipwreck locations looks -by definition- after wrecks, hence to unsuccessful journeys; therefore, it may be useless to address the movement potential in general. Nonetheless, a higher wreck probability is connected to the higher transit probability since unexpected accidents may have occurred. Furthermore, focusing on navigational dynamics is crucial for addressing real hazards and perceived ones, as both these aspects impact the navigational dynamics and cannot be considered necessarily coincident. The former increase the chance of wrecking, the latter increase the ships' transit probability. Indeed, if one assumes that a given area is known to be extremely dangerous from an environmental point of view, one may expect a higher wreck probability here. However, *if the danger is acknowledged*, ships may have well-tried to avoid the area. Hence one may find a lower number of sites than otherwise expected. This difference has never been tackled in current predictive models; indeed, the issue of perceived hazards and, more, in general, the impact of cultural and cognitive factors on past movement potential is currently underexplored in predictive modelling for both shipwreck locations and movement potential.

Connected to the under-exploration of cultural and cognitive factors is also the principle of 'nautical uniformitarianism', which has been the main theoretical underpinning -either explicitly or inexplicitly- for approaching the modelling of past seamanlike behaviour and movement (Deeben et al. 2002, p. 28; Maarleveld 2004, p. 142). Thijs Maarleveld describes it as follows:

> It is the proposition that a mariner's interaction with environmental factors like tides and winds may be variable according to his experience and according to the size and propulsion of his craft, but will essentially be the same, regardless of his position in time or culture. Of course, there is bound to have been cultural preferences and differences. Nevertheless, 'Nautical Uniformitarianism' is probably the best approach to predictive assessment at this level. Risk management and curative behaviour are unifying trends in all traditions of seamanship, and the risks themselves have always been the same (cf. Irwin, 1992; McGrail, 1993).

The main limitation in using such a principle in predictive modelling relates to the "cultural preferences and differences" that have never been formally addressed so far. Indeed, current computer-based approaches have tended to under explore and simplify the many cultural and cognitive factors shaping the ancient mariner's experience and their ways of perceiving distances and directions, which scholars studying ancient navigation have contributed to disclose. General uniformitarianism in navigational dynamics and behaviour has been assumed without exploring, for instance, the impact of cults, superstitions or taboos in shaping seaborne patterns (e.g. Brody, 2008; Gambin, 2014; Kowalzig, 2018; Le Carrer, 2013; Westerdhal, 2011, 2012).

Actually, a careful screening of primary sources highlights how the risks have not always been perceived in the same manner, and the risk-management would entail different curative behaviours in case, for instance, of multiple risks occurrence (e.g. the attack of enemies, superstitions, dangerous coastlines). Quoting Janni (1996, 473-474):

> I believe it is methodically important not to fall into a dangerous 'egocentrism' when making history of technology. The error has already been denounced and consists in believing that the needs felt by men, and also the type of response to those needs, must be identical or almost identical in different cultures. The ancient world, was not a bad attempt to produce something similar to our world. The historian of economics and technology Carlo M. Cipolla wrote instead, at the end of his small and interesting book on watches, that a specific culture conditions both the perception of a need and the response that is given to it[10] (Janni 1996, p. 473-474).

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[10] My translation from the following original excerpt in Italian: "io credo sia metodicamente importante non cadere in un pericoloso 'egocentrismo', quando si fa storia della tecnica. L'errore è stato giá denunciato e consiste nel credere che le esigenze avvertite dagli uomini, e anche il tipo di risposta a quelle esigenze, debbano essere identici o quasi in diverse culture. Il mondo antico, diciamo cosí, non fu un tentativo mal riuscito di produrre qualcosa di simile al nostro mondo. Lo storico dell'economia e della tecnica Carlo M. Cipolla ha scritto invece, a conclusione di un suo piccolo e interessante libro sugli orologi, che una specifica cultura condiziona in una data maniera sia la percezione di un'esigenza sia la risposta che le si dá"

What above entails a possible misalignment between real risks and the perceived ones, which may have practical consequences in navigation modelling and cannot be assumed to be equal to the perception of risk that mariners have in present days. Maarleveld admits that:

> "The cultural dimension of the location of sites resulting from accidents may not immediately be evident, but can neither be repudiated. In fact, it is rather influential both in preferred trade routes and in curative behaviour: in order to avoid shipwreck, to reduce risk and to reduce loss in cases where disaster is unavoidable a sailor will take deliberate action. As a consequence, he chooses or influences an eventual place of loss." (Maarleveld 2003, p. 123)

According to him, 'nautical uniformitarianism' may be advocated to deal with these circumstantial factors, and it is "the best approach to predictive assessment at this level". Unfortunately, besides the theoretical debates, it is not possible to formally ascertain whether the account of cultural preferences and risk perceptions would have a significant impact on navigation prediction given the underdevelopment of maritime predictive models so far. Probably, as noted by Leidwanger and Knappett (Leidwanger & Knappett, 2018, pp. 5-7), the predominant focus on environmental factors and the adoption of the nautical uniformitarianism, are the product of an epistemological split: models addressing the prehistoric seafaring, rather than historical dynamics, are inevitably more tied to the physical geography, given the paucity of sources on the socio-cultural factors impacting the maritime connectivity.

In general terms, scholarship has acknowledged that in order to model past-movement potential, one should take into account the goals triggering the movement (e.g. socio-cultural, economic, religious), the agents involved in it (e.g. traders, soldiers, pilgrims, simple passengers), the movement capability (e.g. techniques available, knowledge/know-how) as well as the meteorological and environmental conditions in which it occurred (Arnaud, 2018, 2005, 2020; Verhagen & Joyce, 2019). These aspects have never been taken into account altogether, and current approaches to modelling sea-based movement potential tends to overemphasise the role of environmental and economic input variables as site predictors (see further in Chapter 4- Theory Development). The relevant interplay between the physical environment and the individuals moving and interacting within it has led to the frequent adoption of the concept of 'affordances' for approaching the modelling of movement within maritime contexts or inland. The term was introduced by the American psychologist James J. Gibson (Gibson, 1950, 1966, 1979; Ingold, 1986; Llobera, 1996; Llobera, 2001; Safadi, 2016; Verhagen et al., 2019; Webster, 1999). According to the definition Gibson provided in his 1979 book, The Ecological Approach to Visual Perception:

> The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment. — Gibson (1979, p. 127)

According to Gibson, humans and animals can perceive the environment thanks to its affordances, representing the opportunities for action provided by the environment or by an object. In other terms, one does not perceive the quality of a particular space but only the qualities implying an opportunity for action. Current approaches to the modelling of movement-potential have referred to Gibson theory while also mentioning the distinction he made between actions that the environment both affords and suggests (i.e. 'perceptible'), those that are afforded but not suggested (i.e. 'hidden'), and those that are suggested but are not really afforded (i.e. 'false').

On the contrary, current approaches to the modelling of movement potential have not formally addressed the concept of 'convenience' of an action. To be more explanatory: assuming the environment affording a particular opportunity for action and assuming the living entities within the environment can perceive this opportunity, are we sure they would have profited off them? The above question is a rhetorical one since socio-cultural and cognitive processes play a crucial role in decision-making; hence they are essential for better approximating past likely movements and pathways. Harbours and ports constitute a possible example: generally interpreted as nodes within a network of potential routes (e.g. ORBIS), hence as hubs of regional redistribution and local stopping points for cabotage (Nieto, 1997), as such with higher ships-transit probability (e.g. Garrison, Giammona, Kelly, Tripp, & Wolff, 1989; Merritt, 2008, p. 21; Pearson, James, Krivor, El Darragi, & Cunningham, 2003; Perissiou, 2014) current models tend to take into account mostly the geomorphological conditions, the technological requirements and the economic considerations resulting in preferences for accessing one port instead of another (e.g. Arnaud, 2010; Arnaud & Keay, 2020; Preiser-Kapeller, 2015; Salomon, Keay, Carayon, & Goiran, 2016; Schörle, 2011; Wilson et al., 2012). Conversely, the socio-cultural component is often unheeded or limited to the analysis of the population size (e.g. Potts, 2019; Preiser-Kapeller & Daim, 2015; Tartaron, 2013) without considering "the interplay between actors and decision-makers for the selection, organisation, utilisation and maintenance of harbours" (Arnaud, 2015); probably – as suggested by Arnaud- due to the scarce and uneven amount of evidence on this matter (see Chapter 5). Similarly, whereas there is a vast scholarship on mariners' devotion, superstitions as well as on ritual voyages or pilgrimages by sea (e.g. Brody, 2008; Gambin, 2014; Kennerley, 2007; Semple 1927; Westerdahl, 2005) the religious and devotional component has been oversimplified in currently environmental and economic deterministic modelling. However, quoting Ezra B. W. Zubrow -though less resolute than posited by him- *it is possible* that "people had preferences independent of economic necessity. Furthermore, some decisions are independent of utility"(Zubrow, 1994, p. 108).

A formal approach to modelling movement potential that may take into account a 'Maritime Cultural Landscape perspective' would be suitable to overcome some of the above limitations in predictive modelling (e.g. Ford, 2011). The term, which first appeared as a caption in Swedish in the late 70s: *Det maritima kulturlandskapet* (Westerdahl, 1978) has been introduced by Westerdahl for referring to "the network of sea routes and harbours, indicated both above and under water". Later, the concept was further elaborated by Westerdahl (cf. literature cited in Westerdahl, 2012) and other scholars after him (e.g. Aberg & Lewis, 2000; Flatman, 2011; Ford, 2011; O'Sullivan & Breen, 2007; Parker, 2001; Reinders, 2001) by referring in a more explicit manner to the maritime culture and to 'any hermeneutic kind of human relationship to the sea' and between sea and land (Westerdahl, 2012, p. 745). The 'Maritime Cultural Landscape' concept is particularly suitable for addressing the relationship between the maritime and the terrestrial component, which is strictly intertwined and better exploits the mariners' relation with the coastline and the cognitive approaches to navigation. Both the contribution of the Maritime Cultural Landscape to modelling the past movement potential, and the contribution that other theories outside the archaeological or historical domain may also bring (e.g. ecology, environmental psychology) are further discussed in Chapter 4- 'Theory Development', as their theoretical and methodological application for modelling movement potential and shipwrecking probability are new to this research.

2.2.3 Predictive models for shipwreck locations in the Mediterranean basin

Predictive models holistically addressing all the four groups of aspects listed in the previous section, namely movement potential, hazards to navigation, preservation dynamics and discovery conditions, have not been developed for the Mediterranean Sea. The only -partial- exception is a Master thesis defended by Dimitri Perissiou at the University of Southern Denmark in 2014. Nonetheless, its scope was limited to the prediction of the wooden remains of shipwrecks and the sole Greek Region (Perissiou, 2014). The overview that follows highlights how the current modelling approaches have addressed each of them independently: particularly a relatively abundant amount of works have attempted the prediction of past seaborne routes and past movement potential by taking into account different strategies and approaches (Gustas & Supernant, 2017; Indruszewski & Barton, 2007; Leidwanger, 2013a; Newhard et al., 2014; Slayton, 2018). Relatively fewer studies have focused on the wreck-formation processes, either from a general point of view (e.g. Ward et al., 1999) or by looking at specific factors affecting the preservation (e.g. Fernández-Montblanc et al., 2018; Quinn, 2006; Quinn & Boland, 2010). The hazards to navigation are treated in combination with the navigation models or for assessing the wreck probability in combination with the preservation dynamics. The discovery dynamics are almost completely underexplored with the previously mentioned exception indeed Perissiou takes into account the range of activity within which divers and trawlers are active, namely the depths that are more or less accessible (Perissiou, 2014, pp. 71-73 and p. 86). No contribution takes into account the impact that different remote sensing strategies may have on discovery (e.g. the relation between Side Scan Sonar frequency and survey width). This overview focuses mainly on the few projects that have attempted to predict shipwrecks' remains by considering both the pre-depositional processes and the post-depositional ones. Moreover, included in the overview are also the models addressing movement potential and hazards to navigation, which are the aspects included within the present research scope.

The work by Perissiou is unique from many points of view. Besides methodological and theoretical limitations, it is up to this moment the first –and sole- predictive model developed within the Mediterranean area, taking into account navigational dynamics, preservation processes and discovery constraints. The latter, particularly, have never been included in other predictive models up to the present day. The factors Perissiou's model includes are visibility, currents, winds, ports, and road connection to estimate the routes; capes, reefs and lighthouses as navigational hazards; salvage probability (i.e., depth, proximity to the shore), physical and biological factors (i.e., salinity, dissolved oxygen,) as for the preservation conditions; lastly, the legislative buffer zone of trawlers as for the discovery potential. Perissiou adopted a deductive and statistical approach, consisting of weighted binary addition, to develop the model. Particularly, he turned the maps produced for each of the thirteen variables he considered into "thematic maps", each one divided into a grid of cells expressing the presence or absence of positive attributes, i.e. variable, in each cell (i.e. having value 1, or 0). Each variable – map (thematic map) was multiplied by an assigned weight depending on the subjective consideration of their relative importance, and then maps were added to each other to produce the final model. In contrast to models based on pure environmental determinism, he proposed the implementation of Marxist theory as a theoretical basis for site location, thus assuming that "economic factors affect all the aspects of society and by extension, this could include site location" (Perissiou 2014, 27).

Although Perissiou's work should be applauded for its innovative and far underexplored topic, there are several limitations, some of which the author himself was aware of (Perissiou, 2014, p. 93). Among them are issues of scale, data resolution (e.g. lack of uniformity in the resolution of the available input data derived from the diverse and sparse dataset), absence of data and a biased control group; all of these are common problems in predictive models in general and in water-based predictive models particularly.

As for the statistical approach he chose, namely weighted binary addition, this enabled him, on the one hand, to classify the different variables based on their importance, although the binary transformation of each cell of the grid into presence-absence (1-0) options "fails to take into account the cases where a variable is present multiple times in a grid-cell" (Perissiou 2014, p. 94). Besides quantitative limitations, the binary classification fails to consider the higher or lower degree of importance or impact each factor may have. The harbours constitute a clear example: not only does the binary classification prevent one from considering multiple landing sites within the same cell, but it also fails to take into account the different degree of potential 'attractiveness' each site may have.

Besides the above technical limitations discussed by the author at the end of his work, several theoretical assumptions in the thesis are worth discussing. The main one relates the choice of focusing only on wooden remains, without considering other classes of materials, such as pottery, marble, metals. Indeed, the above classes constitute both the most likely materials to be preserved and detected in the Mediterranean waters and the majority of records documented in the control group that Perissiou uses for his model, namely Parker[11] (1992; as for the classes of materials onboard shipwrecks, see section 3.2). It is evident that to account for different classes of materials, far broader preservation variables and deterioration dynamics should be considered, which would be beyond the scope of a Master thesis.

The second significant limitation relates to the theoretical basis Perissiou chose to estimate navigational behaviour, namely the so-called 'coastal navigation theory' according to which for mariners 'the basic navigational aid is visual contact with land, while celestial or magnetic navigational aids are secondary' (Perissiou 2014, p. 39). While acknowledging that navigation out of the sight of land has been documented both by primary sources and archaeological evidence even before the introduction of the magnetic compass and other navigational instruments (Perissiou 2014, pp. 41-45), Perissiou lists two reasons for choosing the coastal navigation theory:

1) The first relates to the geomorphology of his research area (i.e. Aegean sea), for in light of the ca. 6000 islands present in ca. 24,000 km2, the land is considered to be almost always visible 'under optimal weather conditions' (Broodbank, 2006, p. 205; Perissiou, 2014; Schüle, 1970, p. 450). Nonetheless, such a range of visibility is quite optimistic, since

[11] According to the catalogue done by Parker in 1992, which Perissiou uses as a control group, only 355 shipwrecks out of 1259 have reported wooden remains (28%)

weather conditions deeply affect the visibility range even -or mainly- in summer due to, e.g., heat and humidity (cf. below in Chapter 4, Figure 4.1) (Davis, 2001, pp. 29–31; Davis, 2009, pp. 46-50). Perissiou acknowledges what Davis has highlighted by looking at real meteorological data (Davis, 2001, pp. 29–31), and he admits that "ancient mariners apart from the landmarks, were also relying on navigational aids such as knowledge of the winds and currents, solar and celestial orientation, use of land birds etc.' (Perissiou, 2014, p. 43). Nonetheless, he decides to "address this issue, by attempting to estimate possible routes where visibility would be assured even in hazy weather" (Perissiou, 2014, p. 56), namely by limiting even more the maximum visibility range and the supposed 'coastal navigation', up to 5 NM. However, the potential navigational hazards connected to such a limited buffer, particularly in a region with high density in low visible rocks and islands, are underestimated. To be more explanatory, assuming that the visibility of the land would be beneficial to mariners, Perissiou has shortened the buffer of the potential navigational corridor to maintain such an eye-contact, without questioning whether this proximity would be hazardous and whether mariners would take the risk of being so close despite this acknowledged risk.

2) Since the compass was introduced to Europe from China, soon after 1185 CE (Needham & Ronan, 1986, p.161), coastal and celestial navigation was the predominant orientation technique for its project's biggest part time-frame. Even after the magnetic compass introduction, Perissiou assumes that the navigation in sight of the shore would have been preferred:

> "If you can see where you are going, why would you use a compass"? And the answer is obvious, "you would use a compass, in the cases that you cannot see where you are going" (Perissiou, 2014, p. 44).

This approach that may sound logical implies the rather slippery assumption already mentioned above, namely that it would be safer to navigate close to the coastline and in sight of the shore, without even questioning such a supposed safety. A further drawback also relates to the assumption that the only criterion defining the navigation as 'coastal' is the visibility range, which is not necessarily the case.

On the contrary, as it will be debated later in this Chapter and further in Chapter 4, being in sight of the shore would have many disadvantages, and being close to the shore, particularly in case of adverse weather conditions, is something that expert mariners would fear more than the open sea (i.e., Synesius, Epistle 4; see further Chapter 4.2; Arnaud, 2005, p. 28)

A third limitation is connected to the main economic-environmental deterministic approach followed by Perissiou, who does not extensively take into account the cultural and cognitive variables, assuming them extremely difficult to model (Perissiou 2014, p. 20). Nonetheless, the inclusion of the lighthouses among the other factors, as human-made alerts for navigational hazards can be considered an attempt to consider the human agency, although the way the presence of the lighthouses is interpreted is problematic. As noted by Perissiou (2014, p. 31) , an attempt for considering lighthouses as human-made aids to mariners can be ascribed to Kimura (2006). The latter study cannot be fully considered a 'predictive model' since it does not provide a predictive map; nonetheless, it is worth mentioning because the author analyses diachronically the distribution of shipwrecks in relation not only to environmental hazards but also to navigational aids (Kimura 2006). Notably, the author assumes that a decrease in shipwrecks should be expected around lighthouses. The observation carried out by Kimura turned out to give opposite outcomes to the expected ones: a greater majority of wrecks lies around lighthouses; indeed, lighthouses are placed where waters are known to be extremely dangerous, which is the reason why Perissiou includes the lighthouse proximity among the wreckage probability variables. Kimura had the merit to attempt the combination of environmental and cultural correlation by considering one human product developed to mitigate a supposed maritime risk. Under this point of view, lighthouses may be considered both a cultural and a cognitive factor.

The striking paucity of archaeological predictive models for shipwrecking probability in the Mediterranean basin is counterbalanced by the relative abundance of computational approaches addressing Mediterranean mobility and connectivity across the centuries. Before discussing these studies in section 2.2.5, a short review of maritime archaeological predictive models outside of the Mediterranean context is given.

2.2.4 Predictive models for shipwreck locations outside the Mediterranean

By extending the review outside the Mediterranean context, one finds the following three models that predict the location or the preservation conditions of underwater sites. Unlike Perissiou, these projects do not address holistically all the four groups of aspects that are supposed to enhance the probability of finding shipwrecks (i.e. movement potential, hazards to navigation, preservation potential and discovery dynamics):

- The Indicative Map of Archaeological Values of the Netherlands (IKAW), which was produced primarily for archaeological heritage managers. In its second generation, IKAW was extended to include also underwater contexts, particularly drowned landscapes and shipwrecks (Deeben et al., 2002; Deeben, 2008). The project was aimed at assessing the 'relative archaeological wealth' (Deeben et al., 2002, p. 26) of Dutch heritage; in fact, it addresses mostly environmental preservation conditions. While emphasising the potential caveats of a prediction exclusively derived from the observation of the finds distribution, the latter was combined with palaeomorphological interpretation and landscape reconstruction to corroborate the environmental model and identify seven zones of maritime archaeological potential ranging from very low to very high. The IKAW considers only preservation conditions; however, it does not include the possible anthropogenic interference, which may have altered the remains in the past or modern times. The nautical uniformitarianism is adopted and considered the most suitable approach to predict shipwrecks probabilities:

> The cultural dimension of the location of sites resulting from accidents is not immediately evident. In fact, it is rather manifest: in order to avoid shipwreck, to reduce risk and to reduce loss in cases where disaster is unavoidable, a sailor will take deliberate action. In dealing with these factors in predictive assessment, however, one could advocate a nautical uniformitarianism: the proposition that a mariner's interaction with environmental factors like tides and winds may be variable according to his experience and according to the size and propulsion of his craft, but will essentially be the same, regardless of his position in time or culture.

> Adopting this uniformitarian approach has the consequence (and the practical advantage) of giving even more weight to (palaeo-) geography. For the rocky coasts of the Mediterranean, the concentration of wreckage and dumped material at the cliff-foots of shipping hazards - reefs, isolated islets, projecting headlands - has long determined the search agenda and continues to do so (Deeben et al., 2002, p. 28)

- The_Mapping Navigational Hazards as Areas of Maritime Archaeological Potential (AMAP) and the 'Refining Areas of Maritime Archaeological Potential for Shipwrecks Project' (Gregory, 2006; Merritt et al., 2007) are two related projects that were carried out respectively in 2007 and 2008 by the Bournemouth University, in association with the Southampton University, Seazone Solutions Ltd. and the National Museum of Denmark, on behalf of the English Heritage Archaeological Commissions Program. The aim of the two works was "to undertake quantitative spatial analysis of shipwreck data using GIS to compare tautologized wreck scatters to environmental, historical and hydrographic datasets to identify biases in the data and refine areas of maritime archaeological potential". During the *Navigational Hazards* projects, hazardous areas for navigation have been derived from historical maps, and historical charts and a related dataset has been established. Afterwards, the above data were combined with a model of the marine sediments aimed at "identifying areas where a high potential for ship losses coincides with a high potential for preservation of archaeological materials"; furthermore, a quantitative analysis of the potential significance of shipwrecks scatters was performed. The project integrates shipwreck data, environmental data and historical data, i.e. documentary evidence of historical port and harbour activities. The choice to consider the presence of ports and harbours as main historical evidence for potential past seaborne activities is based upon the assumption that the potential for shipping in an area is primarily dependent on their proximity (Merritt, 2008, p. 21), "although there are inevitably isolated occurrences of vessels making unscheduled stops in ports and harbours due to human error or for emergency purposes" (Merritt et al., 2007, p. 6). This aspect is connected to this work's main shortcoming, namely the lack of a formal exploration of historical and social dynamics behind navigation, which prevents from accounting further potential causes of hazard to navigation. Conversely, the main asset is represented by the in-depth analysis of the relationship between sediment-type, granulometry and material-survival potential. The projects reveal a somewhat different focus compared to Perissiou's work. Whereas the latter addresses the past human behaviour besides post-depositional processes by wondering which were the variables affecting seaborne routes, the AMAP project is mainly aimed at determining the sinking probability, and the preservation potential without formally addressing the mobility (i.e., the movement potential). A pragmatic-managerial perspective seems to prevail over research, which is explicitly declared: AMAP looks at the "characterization of the potential for the presence of archaeological materials in different marine environments, in order to assist industry, regulators and curators in giving guidance on the possible impact of different types of aggregate extraction on the historic marine environment".
- The Gulf of Mexico High-Probability Model for Historic Shipwrecks (GuMS), which was developed for cultural resource management purposes and started in 1989 when the first version of the model was developed (Pearson et al., 2003; Garrison et al., 1989). It included the isolation of wreck-probability zones by looking at magnetic anomalies and side-scan sonar

contacts, and it was aimed at assessing the high-preservation potential zones by also taking into account preservation conditions. Notably, as stated at the beginning of the Report: "the study evaluates in a diachronic manner the relationships between the observed distribution of historic shipwrecks and the historical and natural factors supposed to influence it; the chronological period considered spans between the 16th to the 20th centuries" (Garrison et al., 1989, p. 24). In 2003 the model was improved by adding a cluster analysis of shipwrecks distribution, which slightly changed the high probability zones previously assessed. Particularly, areas containing densities of 25 or more reported shipwrecks per 0.5-degree unit-area have been classified as high probability areas (Pearson et al., 2003, p. 9). The model is inductive and presents an explicit environmental and economic determinism. Worth highlighting is the attempt to take into account the relative importance of hurricanes paths on historic ship losses together with other four factors affecting shipwreck locations, namely (1) historical shipping routes; (2) port location ; (3) shoals, reefs, sandbars, and barrier islands; (4) ocean currents and winds (Garrison et al., 1989, p.19). As for the state of preservation, the study has taken into account five out of the eleven factors that Muckelroy (1978) following Hiscock (1974) and King C. (1972) considers as affecting shipwreck preservation: "three relate to sediments: (a) topography; (b) the coarsest material in deposits; and (c) the finest material in deposits, the others the water movement (e.g. energy zones) wave and current energy zones. Particularly, they assumed, as did Muckelroy, that the main determining factor in archaeological remains' survival is sediment type and distribution, especially if the sediments are low in oxygen (Garrison et al., 1989, p. 81).

2.2.5 Models predicting past seaborne movement

The following review focuses on studies addressing maritime mobility and maritime connectivity. Borrowing the definition introduced by Horden and Purcell (2000) and consolidated afterwards by others (e.g. Leidwanger & Knappett, 2018, p. 4; Woolf, 2016), connectivity reflects a potential or precondition that mobility instantiates and realizes. The literature review does not encompass studies addressing mobility and connectivity outside the archaeological and historical context. A summary of the most recent interdisciplinary contributions on shipping-data analysis and modelling worldwide spanning from antiquity to present-day are in Ducruet, 2018, which includes the study by Arnaud focused on reconstructing Mediterranean and Atlantic routes during the Roman Empire (Arnaud, 2018).

As for the mobility, migrations and movement inland have been modelled with different computational techniques -including but not limited to GIS- since the 70s (a review of modelling approaches to ancient movement is in Verhagen & Joyce, 2019, pp. 217- 249; see also Judge and Sebastian, 1988; Llobera, 2001; Verhagen, 2007; Wheatley and Gillings, 2012). Instead, studies aimed at modelling water-based movement in the archaeological and historical context are more recent (Gustas & Supernant, 2017; Indruszewski & Barton, 2007; Leidwanger J., 2013a; Newhard et al., 2014; Potts, 2019; Slayton, 2018, 54-62; Scheidel, 2014; Warnking, 2016). By extending the review to the modelling of maritime connectivity, the contributions are more numerous, primarily relying on network approaches (Fournier, 2016; Preiser-Kapeller, 2015; Rivers et al., 2009; Rivers, 2015; Rivers et al., 2016; Rivers et al., 2018;). Potts has provided an extensive debate on both advantages and limitations of such approaches (Potts, 2019).

The first pioneering attempt to model sailing routes using computer processing and GIS-referenced data sets date back to 1973 (Levison et al., 1972). Most of the works that followed have been carried out starting from the 90s and have focused mainly on the Pacific (e.g., Avis et al., 2007; Callaghan, 2003; Davies & Bickler, 2015; Di Piazza et al., 2007; Evans B., 2008; Fitzpatrick & Callaghan, 2013; Irwin et al., 1990; Montenegro et al., 2006). Works focused on the Mediterranean region are much more recent (Arcenas, 2015; Leidwanger, 2013; Leidwanger, 2014; Potts, 2019; Scheidel, 2012, 2014; Slayton, 2018; Warnking, 2016).

The modelling of past movement potential has been often approached by means of cost-surface and least-cost paths (LCPs) analysis (Herzog, 2014; Slayton, 2018; White & Surface-Evans, 2012). This modelling method became popular in the archaeological domain starting from the mid-1990s onwards (van Leusen, 1998, 2002). It enables the identification of an optimal route based on user-defined criteria. Particularly, it is based upon the creation of a cost-surface indicating the relative 'cost' needed for crossing each of the grid-cells constituting the space of reference. Once the cost is established, it is possible to compute the cumulative cost for passing from one cell to another, hence identifying the optimal, most efficient path.

The cost can be expressed in a variety of different manners: in units of energy, time, speed, most of which are medium-based, namely connected to the property of the transport mode and the environmental setting. In land-based models, the terrain-based properties are the most frequent, e.g. the slope (Herzog, 2013; Verhagen & Joyce, 2019). Among the most frequent non-terrain-based cost factor for modelling movement potential is also the visibility because of its pivotal importance in cognitive processes and navigation, but also because it is relatively easy to implement based on digital elevation models (Llobera, 2003; Verhagen & Joyce, 2019, p. 228; for alternative proxies for visibility besides total viewshed, see Verhagen & Jeneson, 2012 and Yokoyama et al., 2002). Further studies focused on the impact of visibility in sailing and sea-routes in general, are, e.g. Brughmans et al., 2017; Friedman et al., 2010; Gustas & Supernant, 2017).

Following the criticism of 'predominant visualism' moved in the past few years to GIS-based visibility analysis (Conolly & Lake, 2006, p. 233; Wheatley & Gillings, 2000; Witcher, 1999), increasing efforts have been spent on finding strategies for implementing other senses in GIS (e.g. smell, sound; van Leusen, 2002, ch. 6). The implementation of a hypothetical 'perception shed' has been attempted for instance by Tschan, Raczkowski, & Latalowa (Tschan et al., 2000), which have suggested that hearing and smell, 'could be modelled by adapting existing visibility analysis tools' since they are 'subject to distance as a process' (Tschan et al., 2000, p. 45; also Renfrew & Zubrow, 1994); nonetheless, they were not capable of providing worked examples. Among the seaborne models, the routes generated in time-cost are usually more frequent than those in energy-cost (e.g., Arcenas, 2015; Callaghan, 2003; Cooper, 2010; Irwin et al., 1990; Leidwanger J., 2013a; an exception is, e.g. Slayton, 2018).

In principle, costs may also be expressed by means of socio-cultural expenditures. Since these are not expressed in numerical or computational units (Herzog, 2013), one needs to employ tailored strategies and techniques for dealing with the problematic combination of factors that are not intrinsically comparable, as well with the issue of subjectivity in the weighting process (e.g. multi-criteria analysis; Dalla Bona, 1994; Saaty, 1980; Verhagen J., 2006).

In the last decade, many projects have been carried out, attempting to model water-based movement by adopting computer-based approaches that rely mostly but not exclusively on GIS-based data and techniques, including least cost-path (LCP) analysis as defined above. Among these, Potts (2019), who employs different GIS technologies for modelling movement and interconnectivity between areas of the Roman Empire mainly by taking into account environmental factors, port locations and spheres of contact; Slayton (2018), who models potential canoe routes connecting Amerindian communities in three different Caribbean areas by mean of computer modelling and least-cost path analysis; Gustas & Supernant (2017), who employ LCP analysis for modelling past maritime movement on the Pacific Northwest Coast by using a multivariate weighted methodology and combining environmental, physiological and cultural parameters[12]; Newhard, Levine, & Phebus (Newhard et al., 2014) employ LCP analysis for modelling pathways across the Argo-Saronic gulf in Greece, by taking into account both marine and terrestrial contexts; Leidwanger (2013), who models the sailing time-distance in the Eastern Mediterranean in Classical times by taking into account vessel travel speed, wind direction, and sailing conditions. Indruszewski & Barton (2006) study the Viking northern European seafaring by employing cost surface analysis, historical sources and experimental archaeology.

If the above contributions are mainly focused on limited geographical areas, and chronological periods, at least two studies are worth mentioning for their attempt to develop a more extensive framework to predict the Roman maritime trade system.

1. The first in order of development is The Stanford Geospatial Network Model of the Roman World 'ORBIS', which has been designed by Walter Scheidel and Elijah Meeks in cooperation with IT experts and students at the University of Stanford (Scheidel et al., 2012; Scheidel, 2014). As stated in the introductory description of the projects, ORBIS aims at reconstructing the time cost (i.e., sailing time) and financial expense associated with different types of travel in antiquity, including but not limited to the marine ones. The network system includes cities, roads, rivers and sea lanes that mainly reflect the conditions around 200 CE; nonetheless, few of the sites and roads included were created in late antiquity.

   As for the part of interest for the present research, namely the simulation of sea travels, this is based on a cost surface and takes into account monthly wind conditions, currents and wave-height (average). The routes include both open-sea connections and 'coastal' (also called short-haul) ones between 513 pairs of nodes linked in both directions. Nonetheless, the definition of these two categories of routes, i.e. coastal and overseas, is not based upon any relations with the coastline, such as buffer or a viewshed. The distinction only refers to whether a route connects nearby sites that share the same coastline or not. As a consequence, 'some coastal routes will follow least-cost paths beyond the visible range of coastlines and some overseas routes may hug coastlines for much of their path' (Scheidel et al., 2012, p. 35). The variety of possible coastal approaches, which the scholarship has contributed to discussing (Chapter 4), and the consequent possible variations in seafaring patterns are not considered. This

[12] Worth noticing is the categorisation of some environmental factors, such as the visibility, the protected waters and inland waters, as 'cultural factors', given the supposed -cultural- preference attributed to them (Gustas & Supernant, 2017, p. 43. Tab. 3).

limitation is common in current approaches to modelling past-movement potential, and reflects both a theoretical and methodological limitation, as it is further explained at the end of this Chapter and in the next one.

The model takes into account 'two sailing speeds that reflect the likely range of navigational capabilities in the Roman period' (ORBIS Introduction); it is based upon earlier works by Pascal Arnaud (2005; 2011). Besides the possibility to choose between coastal and open sea 'network modes', the model enables the generation of different outcomes for each selected route, depending on the departing period (months or seasons) and priority (i.e. fastest, cheapest or shortest path). ORBIS prioritizes averages over particular outcomes, large-scale connectivity over local conditions and logical implications of choices over actual preferences. ORBIS constrains the system by considering areas having 3m+ waves for more than 10% frequency during a certain time as impossible to cross; hence the model is forced to avoid these restricted zones during months having those conditions. According to ORBIS, wave height-based restrictions affect the Atlantic primarily but also create a shifting barrier between Sardinia/Corsica and the coast of France from November to March. As it will be further discussed at the end of this chapter and in the following one, slightly different conclusions and a more accurate reflection on the navigational constraints may be gathered by including further available datasets, i.e. the incidence of storms on Mediterranean shores, which may better reflect the actual local constraints and hazards, mainly connected to coastal navigation.

2. While highlighting ORBIS' main limitations, Pascal Warnking has proposed in his 2015 doctoral dissertation[13] an alternative method for computing time and cost of maritime travel in Roman time. Particularly, he adapted a modern commercial regatta software to model sailing conditions in antiquity and determine the most important shipping routes and sailing times during the Roman Era (Warnking, 2015; Warnking, 2016, p. 46). Particularly, Warnking (2016, pp. 46-50) has attempted to overcome some of the main limitations of ORBIS, which, according to him, include:

   - A too-large grid for wind data with fewer than 20 data points used for the entire Mediterranean basin, which does not take advantage of the increased amount of more detailed data available nowadays
   - The use of monthly averages as wind data points that do not take into account local wind variations and 'quickly changing weather' (Sen. *QN*. 15.7; Warnking, 2016, p. 49)
   - Limitation connected to data points static links instead of dynamic ones, which has already been discussed by Englert (Englert, 2012, pp. 273-27). This approach tends to underestimate that the time required to travel a certain distance varies drastically depending on wind conditions. Furthermore, according to Warnking, the routes cannot simply be considered as the sum of short segments in a grid with integrated average wind conditions since each segment cannot be considered independently. Indeed, 'with ancient

[13] Pascal WARNKING, *Der römische Seehandel in seiner Blütezeit. Rahmenbedingungen, Seerouten, Wirtschaftlichkeit*. Pharos, Studien zur griechisch-römischen Antike Bd. 36. Rahden/Westfahlen: Verlag Marie Leidorf GmbH 2015

navigation technology, a ship could not simply wait on the open sea until more optimal circumstances arose'

- Unrealistic assumptions about the tacking capabilities of ancient vessels against the wind (Arcenas 2015, p. 35)

To challenge the above limitations, Warnking has employed a modern navigation regatta software program, *Expedition*, which provides dynamic calculations of routes and enables to consider the technical capabilities of the vessel (Warnking 2016, p. 51); the use of modern regatta software enabled to adopt the following enhancements:

- The use of weather data from satellite records from The United States National Oceanic and Atmospheric Administration (NOAA) for the year 2008, which has been collected every six hours at intervals of 0.25 degrees
- A higher resolution grid for wind data thanks to the employment of satellite data: particularly 239 data points (instead of ORBIS 20) with a resolution of 1 degree (instead of Orbis 5)
- The assumed sailing capabilities of ancient ships have been verified by taking into account the available data from replicas (e.g. Oberstimm, the Kieler Kogge and the Gorch Fock) and by calibrating the navigation software using data from ancient sources

Warnking's work has many merits: 'in contrast to programs that make estimates based on wind probabilities, *Expedition* calculates the route under real conditions. Unfavourable wind conditions along the course do not cause the program to simply stop but instead allow it to continue to process the new conditions, simulating the different routes a ship can take, resulting in virtual voyages'(Warnking 2016, p. 54). Furthermore, the program enables one to take into account sailing capabilities (not oaring).

Nonetheless, this approach seems to be more suitable for testing specific research questions (e.g. 'was it possible to reach Narbo from the east under the Mistral', Warnking, 2016, p. 58) rather than for providing general trends; this also in light of the following considerations:

First, the decision to adopt NOAA data for a specific year to work with factual weather data collected instead on average values, which results in a static system such as the MedAtlas one has a twofold implication: although extraordinarily accurate and 'twice as detailed as the data in MedAtlas' the data from NOAA still refer only to one specific year. This means that, although the meteorological conditions in antiquity are considered to be more or less equal to those of nowadays (e.g. Murray, 1987, p. 156; more cautious Bresson, 2014; Harris W., 2013, p. 7; McCormick et al., 2012) this approach risks to give misleading results as it generalizes conditions that may represent just one of the many anomalies and periodical variations occurred in the past. Indeed, as for the last 2000 years, it has been already possible to highlight a sequence of humid/ dry and warm/cold periods that have produced effects on environmental conditions in the Mediterranean (Lionello, 2012; McCormick et al., 2012; the issue is discussed more in detail in Chapter 4).

From this point of view, it may be better to adopt average values computed over a longer period (e.g. thirty, forty years at least), rather than factual data of a specific year. Warnking seems to be aware of this, although he considers the inclusion of weather averages over many years a refinement rather than a limitation (Warnking, 2016, pp. 55-59).

Second, the navigation modelling is particularly biased in coastal areas because of two reasons:

- Modern regatta software is unable to model oared-propulsion and is unable to account the limited manoeuvrability of square-rig in narrow bodies of water, such as the straits, or specific regions e.g. the Aegean and the Adriatic Sea due to numerous islands; Warnking, 2016, p. 56).
- NOAA data fails to include complete data for coastal wind conditions; this 'may lead to inaccuracies in calculating some stretches of the route' (Warnking, 2016, p.55). Particularly, the software does not take into account diurnal winds despite the importance they had for coastal navigation. Indeed, thermal winds may be advantageously used in case of opposite dominant winds close to the coast.

Several further considerations should be mentioned. First, Warnking recognizes that there is no *one* specific route and no *one* exact trip length; instead, the many possibilities depend on the wind. More specifically, experienced captains made decisions about which route to take based on wind conditions; to incorporate the above uncertainty, "a statistical model has been developed to accommodate a range of travel time" (Warnking, 2016, p. 57). However, such uncertainty cannot be linked to weather conditions exclusively, for additional factors played a role in shaping mariners behaviour and decisions. These include economic, political, but also cultural and psychological considerations. In Chapter 4, primary sources are discussed for documenting the many decisions taken against apparent logic.

2.2.6 Main limitations of current models

Extending from the issues that relate to the predictive modelling technique in general, which have been discussed in the first part of the present chapter, here is a summary of the main shortcomings specific to the maritime context, which the present study aims to overcome:

1) The quality and quantity of archaeological input data: this relates to the risk of generating biased predictions due to biased input data. The issue is even more striking in underwater contexts, as extensively debated in chapter 3.

2) The relevance of the environmental input data: this relates to the need to evaluate the pertinence of current environmental and meteorological data and debate whether long-term hindcasts may be more suitable than factual weather data collected in a specific short range of time. In approximating the past maritime movement potential over centuries or millennia, one may argue whether it is useful or somewhat deceptive to accurately model dynamic travelling in real-time conditions, for the resulting route cannot be anything other than an illusionary one. On the one hand, given the Mediterranean past climate variations (Lionello, 2012; see Chapter 4, 5). On the other hand, because the multiple factors and circumstances impacting navigation contribute to making the past ships' exact course assessment unlikely to determine. At maximum, one may approximate the most likely route-corridors (Arnaud, 2005; Davis, 2009).

3) Connected to the previous point is the need to overcome the deterministic environmental approach. In this regard, it is worth highlighting that whereas the need to incorporate the cultural and cognitive dimension has been so far theoretically acknowledged and discussed,

the emotional component has not been specifically addressed since psychological approaches to the study of the past are still –unfortunately- mostly underexplored. As for the seafaring aspects, scholars have wondered whether in specific periods or among specific cultures the sea would be feared or not (e.g. in the Islamic tradition, Conrad, 2002; in Roman and Classical time, Arnaud, 2005, 2020; Beresford, 2013; Davis, 2009, pp. 3-5; Horden & Purcell, 2000; Warnking, 2016, p. 57); however less attention has been paid to the circumstances enhancing or reducing the fear: '*when'* and '*what*' would mariners fear? Which behaviour would they take on those occasions? These considerations clearly may impact the resulting seaborne patterns. Unfortunately, whereas the field of psychology has often turned to the past for finding inspirations for the development of new theories, the historical field has been less keen to adopt psychological theories into its hermeneutic apparatus (Lauwers et al., 2018), with few noteworthy and somehow recent exceptions (chapter 4). From a technical and methodological point of view, simulation techniques, such as Agent-Based modelling (ABM) are particularly suitable to integrate cultural and cognitive factors in archaeological modelling, hence also the behavioural component (Saqalli et al., 2019; Wurzer, Kowarik, & Reschre, 2015). Indeed, in ABM, individual agents governed by pre-defined behavioural rules interact with each other and with their environment. Agents follow a set of deterministic rules but are autonomous adaptive and can sense, learn, communicate and change their behaviour (Romanowska et al., 2021). Nonetheless, although broadly applied in the archaeological domain (a comprehensive list of literature and resources on ABMs in Archaeology is maintained and created by Iza Romanowska and Lennart Linde[14]), ABMs have been relatively underexplored as predictive tools, particularly in combination with GIS (recent exceptions are Davies et al., 2019; Rocks-Macqueen, 2014; Verhagen & Joyce, 2019). No agent-based *archaeological* predictive model has been developed so far in the maritime context, although some scholars have started showing an interest in elaborating more complex trading models, also taking into consideration the maritime dimension (e.g. Chliaoutakis & Chalkiadakis, 2020). Although limited to seafaring and not to the underwater archaeological prediction, a partial exception is constituted by a so-called 'serious game', which has been developed within the i-MareCulture Horizon 2020 project. The latter aims to 'bringing inherently unreachable underwater cultural heritage within digital reach of the wide public by implementing virtual visits, serious games with immersive technologies and underwater augmented reality'. Notably, the development of two serious games based on archaeological and historical data are among the 10 Objectives of the H2020 iMareCulture[15]. The first game is a seafaring game called 'The Seafarers' where 'the player will choose a ship loaded with merchandise and will navigate it over the recovered routes' (Philbin-Briscoe et al., 2017; Poullis et al., 2019); the second game, is a 'U-excavation game', where 'the player will have to surface finds excavating a realistic but randomly re-generated underwater archaeological site'. 'Serious games' may be considered simulations, having assumptions, rules, and consequences to 'what if' events. Hence, they may be used to

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[14] Linde, Lennart, and Iza Romanowska, 2018, The-ABM-in-Archaeology-Bibliography. bit.ly/ABMBiblio. DOI: 10.5281/zenodo.1343332. Available on Github: https://github.com/ArchoLen/The-ABM-in-Archaeology-Bibliography

[15] https://imareculture.weebly.com/project.html

simulate scientific and historical events if the assumptions and rules are scientifically and historically correct. The i-MareCulture Horizon 2020 Project, represents, at the moment, the only example with such characteristics. The inclusion of 'cultural variables' is not problematic per se, since they may still have a spatial component and thus being implemented in GIS (e.g. temples and sanctuaries; taboo-zones; the lighthouses included as CF by Kimura 2006 first, and Perissiou 2014 after him) in combination or not with simulation techniques (Rocks-Macqueen, 2014; Saqalli, M. & Vander Linden 2019). The real issue is the definition of formal strategies and interpreting criteria for implementing the cultural logic and testing the real impact on the final outcome (Verhagen 2007, p. 204). Indeed, even when the cultural factors and the cultural logic are claimed to be taken into account (Gustas & Supernant, 2017; Kimura, 2006) the assumptions behind such inclusion are highly subjective (e.g. the supposed preference for navigation in sight of the shore in unknown territories) and not supported, for instance, by a systematic screening of different independent sources of data (e.g. textual or iconographical evidence; Verhagen & Joyce 2019, p. 221).

4) Uneven temporal or spatial resolution and the difficult choice of a suitable chronological and geographical scale: the issue is twofold. On the one hand, is the problematic aggregation -and consequent distorted prediction- of input data having a different spatial and temporal resolution. On the other hand, as also noted in the introduction of this study, is a theoretical and methodological paradox: to build a map of the Mediterranean sea's archaeological potential, one should consider several centuries of history and a very large geographical scale; however, «such an *histoire totale* on a Braudellian scale, explicitly embracing more than twenty centuries [..] would be unfeasible, unrewarding and unpublishable» (Horden & Purcell 2000, p. 44). Nonetheless, from a cultural heritage management perspective, one cannot entirely skip this issue. To evaluate the archaeological potential of a particular area, we must consider the chronological span of the concept 'archaeological' as defined by National and International laws and Conventions. According to the 2001 UNESCO Convention for the protection of the Underwater Cultural Heritage, article 1:

> "Underwater cultural heritage" means all traces of human existence having a cultural, historical or archaeological character that have been partially or totally under water, periodically or continuously, for at least 100 years.

In some countries, a 50 years rule is applied (a discussion in Yoder, 2014). Different solutions have been adopted to overcome the chronological scale problem in predictive modelling: for instance, limiting the prediction to a specific geographical scale (Garrison et al., 1989; Pearson et al., 2003; Perissiou, 2014). However, the factors determining the presence of shipwrecks in a particular portion of the seabed are, in most cases, the result of broader dynamics and exchanges. Hence their analysis cannot be limited to that specific region, but they rather require a global understanding and approach. A second common approach has been addressing only a certain chronological range or specific classes of materials, e.g. assessing the probability to find Greek, Roman, Medieval (and so forth) shipwrecks within a specific region. Suppose the scientific aim is fulfilled, the need of both developers and heritage managers would not because such a thematic map would inform us about the presence of specific classes of objects but would not exclude the possible presence of other archaeological remains (Perissiou, 2014).

5) Connected to the above is the issue of 'prediction scope', which affects the design and the development of current predictive models. Indeed, it has been noted that none of the models considered in the previous review manages to take into account all the groups of aspects considered to affect shipwreck's discovery, at least without limiting the prediction to specific classes of materials (Perissiou, 2014). This limitation reflects the potential conflict of interests between the two domains where PMs find application, namely research and management. Even though the two domains are not necessarily opposed to each other, their interests and aims may be sometimes misaligned. Indeed, the main reason behind the development of a predictive model for heritage managers and developers is optimization: developers are mainly interested in reducing times and costs of archaeological and non-archaeological operations hence they want an effective tool enabling them to quantify the archaeological potential in terms of finding-probability and to suggest the areas to avoid in order to decrease additional costs for archaeological investigations and mitigating measures. Hence, heritage managers need a tool suggesting areas worth investigating in light of economic and logistic constraints. Furthermore, they may be interested in knowing which technique is more suitable to find what is expected. Such a pragmatic and results-oriented approach may disregard historical 'details' that are supposed to be redundant and unable to change the final prediction consistently. Examples of managerial-oriented models (or models developed mainly for management reasons) are the Indicative Map of Archaeological potential of the Netherlands (IKAW), The Gulf of Mexico High-Probability Model for Historic Shipwrecks (GuMS) (Garrison et al., 1989; Pearson et al. 2003) and the Mapping Navigational Hazards as Areas of Maritime Archaeological Potential (AMAP): in all the three cases the archaeological high-probability zones have been assessed by looking at navigational hazards and/or preservation conditions exclusively, without considering factors determining changes or preferences in navigational patterns. On the other extreme of the scale, are historically oriented models, which include different variables connected to navigational dynamics but that are not aimed at locating potential shipwrecks; hence their applicability in spatial planning is reduced.
6) Nautical uniformitarianism. Such a theoretical assumption is not a limitation per se, although the strict and uncritically adoption of this principle risks to under explore the specificity of cultural and cognitive attitudes and their related effects in maritime patterns and navigation behaviour. Scholars have contributed to highlighting that, religious considerations, superstitions (Arnaud, 2016; Brody, 2008; Gambin, 2014; Kowalzig, 2018; Le Carrer, 2013; Westerdhal, 2011), as well as a different rational perception of space, distance and orientation (Arnaud, 2014; Talbert & Brodersen, 2004) deeply influenced the way people sailed in antiquity; the navigation strategies of ancient mariners, which have been compared to the traditional natural navigation in the Micronesian culture (Arnaud, 2014; Finney, 2011; Hutchins, 1983, 1996; for natural navigation approaches more generally Gooley, 2011, 2017) may result in specific navigational behaviours and navigational patterns that need to be specifically addressed.
7) Problematic modelling of coastal navigation; this relates both technical and theoretical issues. Indeed, on the one hand, there is the need to access and use a further set of meteorological and environmental data (different from currently employed wind and currents averages), which may account for the specificity of the littoral areas. On the other hand, under a more theoretical point of view, coastal navigation has been approached simplistically, without wondering what

the adjective 'coastal' really entails (e.g. being in sight of the shore, being in sight of landmarks, perceiving the land nearby). The scholarship has contributed to discuss the variety of possible definitions, as well as the inaccurate contraposition between two modes of navigation, i.e. in open waters or along the shore, that does not really reflect the whole range of possible variations in navigational attitudes, hence patterns (Arnaud, 2011, 2020). Nonetheless, current modelling approaches have not addressed the above issue (e.g. ORBIS).

8) Subjectivity in variable selection and weight assignment; with 'criteria for variable-selection', one refers to the criteria adopted to decide which variables to consider and which variables to exclude: e.g. why would one take into account winds, currents, wave-high, and not the storms-incidence or the attack of pirates as navigational hazards. The variables-weight refers to the possibility to assign the selected variables an equal or a different 'weight' depending on their assumed relative importance or impact on the phenomenon (Verhagen et al., 2019). In deductive models, both these two operations are usually based upon the expert judgement; hence they are highly subjective. In inductive models, the two issues are faced through statistical correlation, which enables researchers to highlight the meaningful relationship between the site-density and specific (usually environmental) variables. This enables them to select the variables that have a higher impact on site density (Goodchild, 1986; Verhagen, 2007, pp. 74-75). One of the most common approaches to weight selected variables in deductive models is the Analytical Hierarchy Process (Saaty, 1980; e.g. in Perissiou), although it is still bounded to the expert judgement (Dalla Bona, 1994, 2000; Verhagen, 2007, p. 79). Bayesian statistics, which is one of the options available to compromise between purely objective and purely subjective weighting of the variables (Verhagen, 2007, p. 77), has not been used in Predictive models for shipwreck locations yet. As for the variables selection, none of the models described above specifies the selection criteria adopted systematically, namely how the variables to implement have been chosen. Indeed, the justification for their inclusion is too often limited to vague and generic 'importance to' navigation; in the meanwhile, the exclusion of others, eventually considered equally 'historically important' is often connected to the 'impossibility to model', which is, for instance, the case for cultural and cognitive factors.

9) Testing of predictive models (Verhagen, 2008; Verhagen et al., 2019). This issue relates to the need for the definition of strategies enabling one to ascertain whether a model is working well, hence to discuss what 'working well' really entails (Chapter 7). Indeed, whilst in inductive methods, the 'good outcomes' are considered to be those closer to the observed input, this approach risks generating a self-fulfilling prophecy that is unable to detect significant anomalies and may reflect the biases affecting the input-data

2.3 From limitations to suitable modelling trajectories

The literature review provides the starting ground for setting goals and strategies to develop the model described in the following chapters; indeed, the aim is to address and overcome the limitations listed in the previous section. In order to improve current approaches for modelling past seaborne movements, and by extension, predictive models for shipwreck locations, the 'coastal navigation' represents a pivotal issue that this research addresses (Chapter 4). From a theoretical point of view, one needs to wonder what makes a navigation 'coastal', and which are the considerations leading a mariner to approach the coastline or rather to stay far from it. In order to overcome the simplistic binary distinction between *capotage* and offshore navigation, and economic and environmental deterministic approaches, primary sources are accessed for investigating perceived hazards to navigation and mariners strategies for facing them. This in order not to assume perceived risks equal to factual environmental ones.

From a methodological point of view, the specificity of the littoral areas imposes the adoption of specific strategies and data: this research takes into account, among other environmental factors, the storminess effects along the coast of the Mediterranean sea, in terms of increasing mean sea level and storm return value (Lionello et al., 2017). The storm effects on the coast have never been included so far in archaeological predictive models and are new to this research. As for the meteorological and oceanographic factors, long-term hindcasts are deemed preferable to factual real-time weather data collected in a specific short time range. The above decision was made in light of the Mediterranean past climate variations (Lionello, 2012; Chapters 4 and 5) and the model scope, which encompasses the modelling of maritime movement over millennia rather than the simulation of specific routes -assuming the latter even historically realistic to achieve.

The scale problem is addressed by developing two different models, i.e. Regional and Global, this to meet the need for a general tool applicable in spatial planning and a more detailed one, providing insights for archaeological research. In fact, to base the theory development and the model building on careful screening of primary sources, a particular geographical and historical context is first addressed. Afterwards, the model is applied at the Mediterranean scale following several simplification steps for providing indicative trends over the long period. Therefore, the methodology followed for building the regional and the global models have been slightly different, as further explained in section 5.6 and Chapter 6. The Mediterranean model should be considered as a framework, open to further improvements. Neither of the two model scales includes the preservation and discovery potential. This research focuses on transit probability and hazards to navigation (i.e., shipwrecking probability) without addressing post-depositional dynamics because the latter are deemed necessary to implement at a far finer scale targeting specific classes of materials. Indeed, the biological, physical and chemical factors impacting the preservation conditions of underwater remains are dependent on the materials' nature and size. By targeting the shipwrecking probability, the model enables to identify the areas where the chance of finding shipwreck remains is higher than others, for one may assume it is most likely to find archaeological remains along highly transited routes and/or highly dangerous maritime zones. Since the model is designed and described to be customizable, it will be possible to add post-depositional factors in the future to better refine the probability of identifying preserved shipwreck remains.

2.4 SUMMARY

This chapter has explored definitions and approaches in archaeological predictive models (APMs) by highlighting limitations and unheeded issues. APM aims to identify archaeological-risk areas and would be particularly useful in maritime contexts given the constraints characterizing underwater surveys and excavations. Particularly, APMs have a practical application in cultural heritage management (CHM), as they support the prioritization of areas to investigate, and they have a scientific utility, for they allow the formalization and verification of historical and archaeological hypotheses. The standard distinction between inductive (or data-driven) and deductive (or theory-driven) methods is based on the way the prediction is inferred. Inductive methods rely on statistical inference and are susceptible to tautological argumentation: as they employ the archaeological evidence as input parameters and the latter is often biased, particularly in underwater contexts, it risks generating a biased prediction. Deductive models are built based on expert judgement; since the prediction is independent from the archaeological record, the latter can be used to validate the results; they are impacted by subjective reasoning while being relatively simpler than data-driven models to implement.

APM are underdeveloped in maritime contexts, and with a single exception, are not yet applied in the Mediterranean basin. After discussing the theoretical underpinnings of shipwrecks location assessment, and the dynamics that should be considered for predicting the location of shipwrecks' vestiges, the scope and goals of current studies were analysed. Two groups of works were identified. First, models that simulate mobility and connectivity through different computational approaches without providing any archaeological prediction; as such, they cannot be utilised in CHM. Second, models with pragmatic and managerial oriented focus, which address wreck-formation processes without exploring the variety of dynamics impacting ancient seafaring. An in-depth account of navigation preferences and dynamics may improve the model's prediction, as it could identify factors affecting the shipwreck probability, which are currently deemed not relevant and hence neglected. The literature review also brought to light some limitations of current computational approaches that the present research aims to overcome. Among these are the problematic incorporation of cognitive and cultural factors with the predominant use of environmental input variables as archaeological site predictors and the simplistic modelling tendency to distinguish among two modes of navigation, which does not consider the scholarship contribution discussing what the adjective 'coastal' entails.

“Archaeology is like a jigsaw puzzle, except that you can't cheat and look at the box, and not all the pieces are there.”

Stephen Dean[16]

«It is probable that a greater number of monuments of the skill and industry of man will in the course of ages be collected together in the bed of the oceans, than will exist at any one time on the surface of the continents.»

Charles Lyell[17]

3 A DIVE INTO SHIPWRECK DATA BIASES: EXPLORATORY ANALYSIS

After presenting in chapter 2 the main methodological approaches to predictive modelling, this chapter has a twofold aim. First, summarising why the recorded archaeological evidence is unreliable to infer the location of yet unknown sites and a theory-driven (deductive) approach is deemed more suitable for developing the predictive model introduced in chapter 1. Second, discussing whether and how the archaeological evidence may be employed for model testing, which implies discussing data biases and possible measures to mitigate them. Particularly, the following questions are addressed:

- Can the shipwrecks distribution reveal patterns and properties that might be inductively used for the model building, or rather is it biased by factors preventing a complete understanding of the potential archaeological patterns?
- Is there room for mitigations of the detected biases? How can we use the available data?

Section 3.1 presents the shipwreck data sources employed in the present study and describes the criteria employed for combining and organising them into a new database for supporting the exploratory data analysis (EDA). The problems occurring in the cleaning phase and the consequent methodological choices are highlighted. The following two sections address the two issues set above. Particularly, section 3.2 aims at discussing the shipwrecks data biases, which prevent the employment of a data-driven approach to building the model. Section 3.3. focuses more specifically on the analysis of the shipwreck data quality to discuss whether and how these data may be employed for testing the model outcomes. Concluding remarks resulting from the EDA are in section 3.4

[16] From the interview article by Sarah Marsh, “Being a Council Archaeologist is ‘Like Being a Detective”, *The Guardian* (6 Sep 2013). https://www.theguardian.com/local-government-network/2013/sep/06/being-a-council-archeologist-like-being-a-detective

[17] Principles of Geology, 1830

3.1 BUILDING AN INTEGRATED RELATIONAL SHIPWRECK DATABASE AND GEODATABASE TO SUPPORT EDA

The main sources informing the present analysis, which have been employed for building the integrated shipwreck database, are the Oxford Roman Economy Project (OXREP)[18] based in the Faculty of Classics at the University of Oxford, and the Digital Atlas of Roman and Medieval Civilizations (DARMC) set up by the University of Harvard[19]. Both databases include the catalogue set up in 1992 by Allan John Parker[20], Senior Lecturer in Roman Archaeology at the University of Bristol, titled 'Ancient Shipwrecks of the Mediterranean and the Roman Provinces' (Parker, 1992). This seminal work, which constituted the first attempt to build a comprehensive catalogue of shipwrecks from Mediterranean antiquity, included 1189 underwater Mediterranean shipwrecks dating from the Graeco-Roman period to AD 1500 and a further 71 'non-Mediterranean' entries from inland[21]. Despite its limitations, most of which Parker himself was aware of, as we shall see in section 3.2, it is still a milestone in the maritime archaeology and history of antiquity. DARMC and OXREP have updated Parker's catalogue with later discoveries and now constitute the most comprehensive collections of (published) shipwrecks in the Mediterranean basin available. The two datasets also complement each other, for they have a slightly different scope and focus (Leidwanger, 2020).

The Oxford Roman Economy Project (OXREP) spans from the earliest seafaring (i.e. 2500 BC) through 1800 AD; however, more than three-quarters of the OXREP dataset involves sites dating back to the Roman and Late-antique centuries (Figure 3.1). The first version published in 2013 was derived from Julia Strauss' PhD thesis entitled 'Roman Cargoes: Underwater Evidence from the East' (Strauss, 2007) and included shipwrecks documented by Parker and those reported in literature published since 1992.

The Harvard Digital Atlas of Roman and Medieval Civilizations (DARMC) targets the transformation of the Classical world into the Medieval and up to the Early Modern era, thus including sites dating between 500 BC and 1650 AD. The DARMC database was designed by Michael McCormick with the collaboration of J. Kirsten Ataoguz, Kelly L. Gibson, Leland Grigoli, Brendan Maione-Downing, Alexander F.M. More, Robin Reich, Ece Turnator, Julia Wang. The

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[18] As reported on the official website, the Oxford Roman Economy Project *"is a research project based in the Faculty of Classics, at the University of Oxford. The project, led by Prof. Alan Bowman and Prof. Andrew Wilson […] addresses the fundamentals of the Roman imperial economy and analyses all major economic activities (including agriculture, trade, commerce, and extraction), utilizing quantifiable bodies of archaeological and documentary evidence".* The above mentioned materials have been collected and organized in six different databases accessible online, of which the Shipwrecks Database was compiled by Julia Strauss (Strauss, 2007). Originally funded by the Art and Humanities Research Council for the period between October 2005 and September 2010, the OXREP received additional private funds by the Baron Lorne Thyssen to continue. (Source http://www.romaneconomy.ox.ac.uk/)

[19] The Digital Atlas of Roman and Medieval Civilizations (DARMC) offers a series of maps and geodatabases bearing on multiple aspects of Roman and medieval civilization for the mapping and spatial analysis of the Roman and medieval worlds. Directed by Michael McCormick, Professor of Medieval History at Harvard University, DARMC includes among its geodatabases: Roman Economic Data, Geodatabase of Ancient Ports and Harbours (version 1.1), Summary Geodatabase of Shipwrecks. Source: https://darmc.harvard.edu/.

[20] Allan John (better known as 'Toby') Parker retired as Senior Lecturer in Roman Archaeology at the University of Bristol in 2002. He was Advisory Editor of the International Journal of Nautical Archaeology (IJNA) till 2015.

[21] The attribute 'non-Mediterranean' refers to the shipwreck locations

first version was published in April 2008 when M. McCormick's "Movements and markets in the first millennium: information, containers and shipwrecks" was sent to press (McCormick, 2012), and it has received an update in June 2013.[22]

In the past decade, these datasets have enormously supported the increasing development of computational approaches to model maritime connectivity and quantitative analysis of shipwrecks data; in this context, shipwrecks have been mostly used as a proxy for studying distribution economies or technologies (Bowman & Wilson, 2009; de Callataÿ, 2014; Leidwanger, 2014; Leidwanger & Knappett, 2018; Leidwanger, 2020, pp. 13-35 and pp. 110-153). Conversely, the socio-cultural and ethnographic dimension that they could also document has been somewhat underexplored, with a few notable exceptions (e.g. Greene, 2018; Kowalzig, 2018). Even though considerable efforts have been put to extend the catalogues, these two datasets reflect the many biases affecting the shipwrecks record. Particularly, they present considerable variations in the level of detail provided and more generally, they do not reflect the true number of shipwrecks lying underwater or that of shipwrecks discovered up to now which might be known to local authorities only.

The relational shipwrecks database (DB)[23] that has been employed for the exploratory analysis discussed in this chapter is mainly based upon these sources, i.e., DARMC, OXREP, (Appendix 3), whereas to support the model testing, a targeted literature review has been carried out on the local case-study area to complement the OXREP and DARMC database with further sites. The results of this literature review are presented in more detail in section 7.3.3 and are used to test the model output. As for the OXREP database, it has been used the 2013 version available for download on the OXREP website; as for the DARMC database, it has been accessed the second version of the DARMC Geodatabase, i.e. 'The DARMC Scholarly Data Series 2017-1', last updated in 2013. The relational database, which was built to support EDA, includes most of the attributes present in OXREP and DARMC, although the fields with uneven or mainly unavailable data and/or qualitative or descriptive specifications have been excluded; however, the IDs enable to join the original sources and retrieve the removed information. The principles followed to organize the DB have been the following:

1. Find out information on data quality and survey coverage in the Mediterranean Sea

   In order to justify the methodological approach of this project and prove that a theory-driven model is more suitable for the Mediterranean Sea, it is particularly important to assess state of the art in maritime archaeological surveys in this area. That is why, far from claiming to collect all the available data to map all the known archaeological sites precisely, the aim is to assess which areas have been investigated and how, whether in a systematic way or as an accumulation of random discoveries.

2. Avoid misleading information

   One of the main challenges (and risks) of the application of computational analysis within historical and archaeological contexts is excessive determinism, which can lead to an

[22] Source: https://darmc.harvard.edu/data-availability [Accessed on 10.04.2017]
[23] Developed in Microsoft Access 2007-2010; plug-ins required to access the DB are: Adobe acrobat reader, Adobe Flash Player, Microsoft Excel, Microsoft Word

oversimplification of data. For example, when dealing with ancient routes and trade patterns, there is the tendency to attribute as a place of origin (and/or stopovers) of the ship, the place of production of the objects constituting the cargo. This approach can easily lead to misleading results since a ship could well have taken on board, in the same *emporium*, products coming from different places (Leidwanger, 2020). Therefore, the attributes 'place of origin' and 'place of destination' should be associated with the products rather than with the shipwrecks on which they were loaded. For this reason, in the merged DB combining DARMC and OXREP described below, the above mentioned two fields were not included, whereas the information on the cargo provided in the originals was maintained. It must also be noted that the origin of the product may differ from the origin of the container, and the latter may have been reused or transported empty, as the most recent scholarship highlighted (e.g., Duckworth & Wilson, 2020, particularly the contribution by Brughmans & Pecci evaluating the impact of amphora reuse through computational simulation modelling, Brughmans & Pecci, 2020, pp. 191-234).

3. Clarity and avoidance of redundancy

   The original wreck-IDs attributed by the sources have been maintained, but for clarity, the acronym of the source has been added (i.e. 'OXREP_wreck_ID', 'DARMC_wreck_ID', 'Parker_wreck_ID'). Any further internal sub-IDs (such as the Strauss_ID in OXREP) have been excluded except for Parker's original ID, which has been used as a control-ID to associate shipwrecks with slightly different names in OXREP and DARMC.

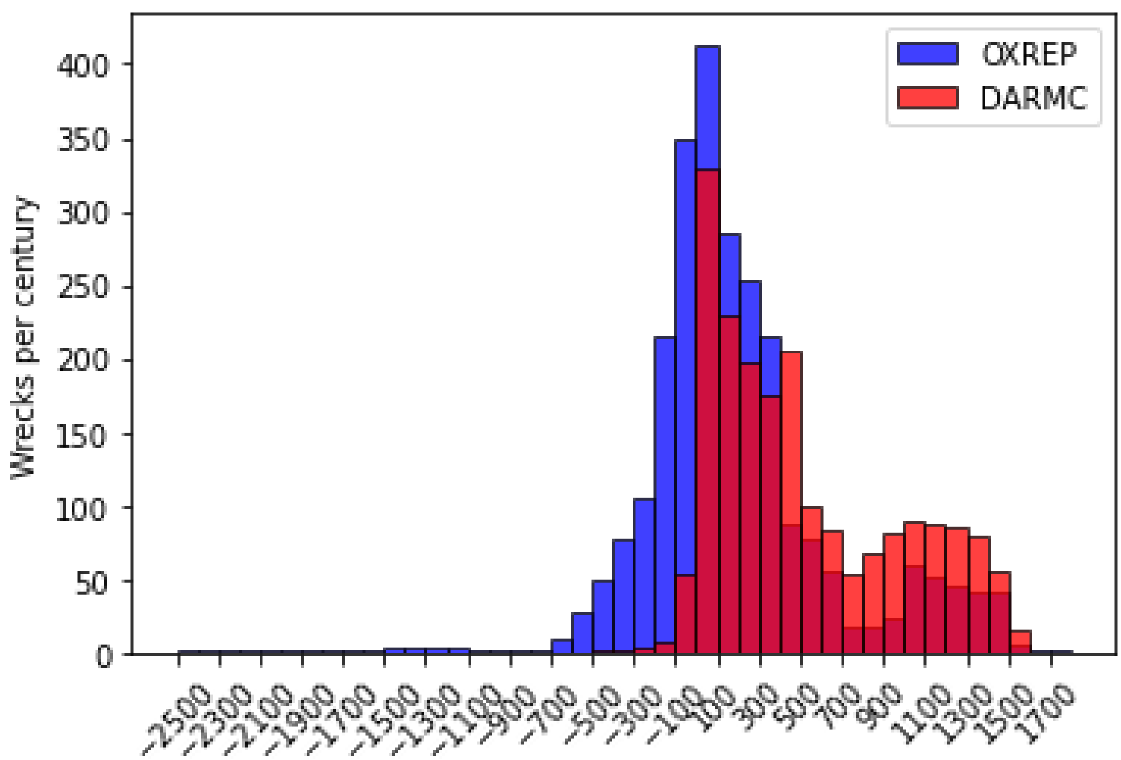

Figure 3.1: Graph of Mediterranean shipwrecks in OXREP and DARMC datable within 100-year ranges according to an equal probability of sinking in any year during the date range for each wreck. In dark red, the overlap of the two datasets (produced by the author based on DARMC and OXREP data).

Table 3.1: Comparison between the fields included in the OXREP and the DARMC geodatabases. The bold text highlights the fields used.

	DARMC	OXREP	NEW COMB
IDENTIFICATION	**Name 1**	**Wreck ID**	**OBJECTID**
	Name 2	Strauss ID	**Name 1**
	2008 Wreck ID	**Name**	**Name 2**
	2010 Wreck ID	**Parker Number**	**DARMC_2010_WreckID**
	Parker reference		**OXREP_2013_wreck_ID**
			Parker reference
LOCATION POSITION			**LAT**
			LONG
	Latitude	**Latitude**	**DARMC latitude**
	Longitude	**Longitude**	**DARMC longitude**
	Geo Q	Sea area	**OXREP latitude**
	Geo D	Country	**OXREP longitude**
	Depth	Region	
	Depth Q	**Min depth**	
		Max depth	
		Depth	
CHRONOLOGY	**Start Date**	**Period**	**DARMC Start Date**
	End Date	Dating	**DARMC End Date**
	Date Q	**Earliest date**	**Period**
	Date D	**Latest date**	
		Date range	
		Mid-point of date range	
DISCOVERY	**Year Found**	-	**Year found**
	Year Found Q	-	

INFO ON THE CARGO	Cargo 1	Amphorae	**Cargo**
	Type 1	Amphora type	
	Cargo 2	Columns etc	
	Type 2	Sarcophagi	
	Cargo 3	Blocks	
	Type 3	Marble type	
	Other Cargo	Marble	
		Other cargo	
SHIP AND GEAR	Gear	Hull remains	
	Capacity	Shipboard paraphernalia	
	Length	Ship equipment	
	Width	Estimated tonnage	
	Size D		
ROUTE	-	Place of origin	
	-	Place of destination	
OTHER INFO	Comments	Comments	
	Bibliography 2008	Reference	
	Bibliography 2013	Probability	

The new database resulting from the combination and reorganisation of OXREP and DARMC contains one entity-shipwreck per row and information on their identification and location organized in the following fields:

OBJECTID	The new identification number attributed to each shipwreck
Name 1 and Name 2	Names of the shipwreck
	The name of the wrecks is geographical (e.g., a headland) in the sources as well. Two different fields are present to keep track of possible slightly different or misspelt names; in case of multiple shipwrecks with the same name, both Parker and

	OXREP add letters, whereas DARMC uses numbers. Entries with different or slightly different names have been associated only when the Parker_ ID is the same. If so, the numbers in the main name have been preferred to letters (i. e., Dramont 1 instead of Dramont A).
DARMC_2010_wreck_ID	The identification number of the shipwrecks in the Harvard Database when present
OXREP_2013_wreck_ID	The identification number of the shipwrecks in the Oxford Database when present
Parker reference	The identification number of the shipwrecks in the Parker catalogue when present
Latitude and *Longitude*	Latitude and longitude of shipwreck locations in both sources are expressed with approximate decimal coordinates. The degree of the approximation is unknown (see below section 3.3). Shipwreck coordinates differ depending on the database they are included in. See further in section 3.3 for a qualitative assessment of the input data. The quality of the location data is not specified by the two sources, other than that the coordinates of the sites are 'approximate'. On the OXREP website, it is said: "Latitude and longitudes are NOT to be taken as accurate: precise locations are not revealed by excavators to prevent pillaging and it was the aim of this database simply to log them for general mapping purposes". As for Parker, the DMS coordinates included in his catalogue only indicate degrees and minutes, no seconds. An assessment of systematic errors as well as an evaluation of error range due to the lack of seconds is in the forthcoming paragraph 'database analysis'. The merged database includes the original coordinates provided by Oxford and Harvard (i.e., 'OXREP_latitude', 'OXREP_longitude', 'DARMC_latitude', 'DARMC_longitude') and the fields 'longitude' and 'latitude' including the coordinates employed for the use of this dissertation and model among those provided by the two sources.
Sea area	Information derived in ArcGIS*
Country	Information derived in ArcGIS*
Depth	Information derived in ArcGIS*
Period, Start Date & End Date	Earliest and latest estimated date of the shipwreck as presented in the sources. Both DARMC and OXREP provide the following fields: an end-date, a starting- date, a period.

	OXREP also includes the middle point of date-range, which usually is used for statistics purposes. Wilson has highlighted the biases derived by a chronological analysis based upon the middle range of date- range (Wilson, 2011, pp. 33-39) thus proposing an alternative since for shipwrecks attributed generally to "republican "or "imperial era" the mid-point is always the same hence this approach tends to overestimate certain centuries on others
Year Found	Information on the date of wreck discovery when available
Year_Found_Q	Quality of the wreck discovery year when provided
Bibliography	Bibliographical references provided by the two sources; for the readers' convenience, the full information was maintained in the merged DB: however, only the references actually consulted and cited in this manuscript are included in the thesis' bibliography
Cargo	Information on the cargo as provided in DARMC and OXREP can be retrieved in the original DBs through the original wreck ID

*Since the spatial information related to depth, sea area, country and region of discovery is not always noted precisely and is not available for all the sites in the sources, it was derived in ArcGIS.

3.2 SHIPWRECK RECORDS: THE MEANING OF ABSENCE

This section aims to answer the first question set in the opening of the chapter, namely, whether the shipwrecks' distribution reveals patterns and properties that might be inductively used for the model building, or instead, it is biased by factors preventing a complete understanding of the archaeological patterns. There is already a vast literature on the processes and the biases impacting the chronological and geographical distribution of the shipwrecks, including limitations in surveys and reporting and the different degrees of preservation and visibility of sites and materials. Among the most recent contributions summarising the issues at stake are the work by Leidwanger (2020, pp. 13-23 and pp. 35-40) and Wilson, who also proposed a different approach for the computation of shipwrecks' chronology (Wilson, 2011, pp. 33-60).

Because of these processes and biases, scholars have evidenced the caveats in using wrecks as evidence for mobility and trade while proposing solutions to exploit the enormous potential of information shipwrecks and their cargoes may provide (De Callataÿ, 2005; Gibbins, 2001, pp. 273–83; Hopkins, 1980, pp. 105–106; Horden & Purcell, 2000, pp. 368-375; Leidwanger, 2020, pp. 13-23 and pp. 35-40; Parker 1992, pp. 8–9; Parker 2008, p. 187 fig. 12; Rice, 2016, pp. 166-168; Whittaker, 1989; Wilson, 2009, pp. 219-229; Wilson 2011, pp. 34-36). The combination of the shipwreck evidence with other sources of evidence for maritime connections and economic activity (e.g., epigraphical, literary, topographical evidence) may optimize the utility of bulk shipwreck evidence, particularly when tackling specific and contextualised phenomena or economic sectors (e.g. Boetto 2012; Franconi, 2014; Heslin, 2011; Marzano, 2013; Rice, 2011; Russell, 2013a, pp. 114-118; Russell, 2013b, pp. 344– 349; Schörle, 2011; Wilson et al., 2012). However, employing these partial data to infer the location of yet unknown sites presents relevant downsides.

The lack of records in any part of the sea represents the main issue at stake since it reflects, for various reasons set out below, neither the real flow of connections and trades over the centuries nor the archaeological potential of both shallow and deep waters. In purely quantitative terms, it is evident that the available sample is far from being representative of the huge maritime archaeological potential; indeed, quoting George Bass:

> "if only one vessel sank in every year of every decade of every century of every millennium since the first seafarers sailed out from their cave dwellings in Greece 11,000 years ago, we would have 11,000 wrecks in the Aegean alone. But hundreds of ships have sunk in Aegean storms in a single day. We cannot calculate the number of wrecks in that one sea. The number of wrecks beneath the Seven Seas is truly unimaginable"[24].

Clearly, not all the ships which have sunk have the chance to become a wreck or to be found. In 1976 Keith Muckelroy developed a model (Muckelroy, 1978, p. 158) to describe the many processes involved in a wrecking event, which contribute to the degradation and preservation of ship remains. His influential work has been elaborated by several scholars afterwards (e.g., Gibbs, 2006; Gibbs & Duncan, 2016; Keith, 2016; Martin, 2013; Ward et al., 1999) and it represents the

[24] Bass G. F., Beneath the Seven Seas: Adventures with the Institute of Nautical Archaeology", Thames and Hudson, London, 2005, p. 27

first application of Shiffer's Site Formation Process (1972) to the maritime contexts. The processes contributing to altering the original deposition of the artefacts on the seafloor include both natural and cultural dynamics, namely "the complex mechanisms of destruction, dispersal, reordering, decay, and stabilization with which the relevant area of the seafloor has reacted to the intrusion of a wreck" (Martin, 2013).

In order to reply to the question above, it is necessary to wonder whether the lack of records reflects an effective absence of ships (i.e. no route and/or no wreck event) or rather processes occurring after the wreck event and preventing the preservation of the remains as described by Muckelroy's model and other scholars after him (a literature review in Keith, 2016), or their discovery; indeed the possibility to detect the preserved remains is also subject to potential limitations, and the sea-bed distribution does not necessarily correspond to the one observed through direct or remote surveys.

For the sake of clarity, two possible scenarios (A and B) and different situations can be distinguished while looking in a purely theoretical way, at the current absence of shipwrecks in any portion of the seabed, as highlighted in
Table 3.2:

Table 3.2: Possible scenarios behind the lack of recorded shipwrecks remains

A. **THE ABSENCE OF ARCHAEOLOGICAL REMAINS REFLECTS THE ABSENCE OF WRECKAGES**	1. The route was not used 2. The route was used, but ships did not sink
B. **THE ABSENCE OF ARCHAEOLOGICAL RECORDS DOES NOT REFLECT THE ABSENCE OF WRECKAGES**	3. The route was used, and the ships sank, but their remains were not recorded because of: • Conservation issues • Discovery issues

The B scenario implies a potential crucial difference between:

- lack of archaeological remains: the sites were originally on the spot, and now they are not there anymore because of natural processes impacting their degradation or because intentionally or unintentionally moved from their original site
- lack of discoveries: the remains may still be on the spot, but they have not been detected because that portion of the seabed has not been investigated or because remains were unnoticed

In the first case, the archaeological potential is at present low, and the understanding of processes that have compromised the original integrity can contribute to preserving other archaeological sites. In the second case, the archaeological potential may be high; this is one of the main issues at stake in any archaeological context, not only the maritime one[25]. Nonetheless, the apparent lack of records in the maritime domain turns out to be, at the same time, far more biased and potentially interesting than in terrestrial archaeology. Indeed inland, we would never pretend to assess or describe the archaeological potential of an area by looking at the visible, superficial remains exclusively, whereas this is what has happened underwater till recent days.

Besides the casual discoveries, since the 1960s, many underwater finds have been detected through remote sensing (Campbell, 2002, p. 4). It has been emphasized that various techniques are now available to conduct underwater investigations, and large-scale remote sensing surveys can make major contributions to site detection and management (Gambin et al., 2021, pp. 2732-2733). However, whilst the most employed acoustic instruments such as the side-scan sonar (SSS), the Multibeam (MBES) and the Sub Bottom Profiler (SBP) 'provide details on the composition and structure of the seafloor' (Gambin et al., 2021, p. 13), only limited anomalies are usually further investigated through remotely operated vehicles (ROV) or automated underwater vehicles (AUV); less frequently through archaeological excavations. Moreover, the 'ease' with which targets can be identified depends on the type of seabed, its geological composition, the distance from the transducers to the object, the height of the sonar off the seabed, and the general topography surrounding the anomalies, where geological formations can obscure potential cultural targets (Gambin et al., 2021, pp. 2734).

Therefore, conservation dynamics and discovery constraints are the most crucial factors when considering potential biases, a 'bias' being a systematic overestimate or underestimate of a parameter or measurement. As for the conservation of the ship's remains, scholars have strongly highlighted the controversial role of the cargo's presence. On the one hand, vast quantities of durable materials (e.g. heaps of amphorae, dolia, marble) protect the wooden part of the hull against the action of the waves, thus enhancing their chance of both detection and survival. On the other hand, this causes an over-representation of ships carrying those materials to the detriment of vessels carrying any cargo or a mix of perishable and hardly visible materials (e.g. military ships). The presence of durable materials in significant observable quantities (e.g. heaps of amphoras) contributes to preserving perishable objects that otherwise would disperse and help localise the site; this does not mean that perishable or small objects are necessarily absent elsewhere. However, in the absence of conspicuous and evident remains hinting at the presence of a shipwreck, finding those objects may turn out to be like finding a needle in the grass. It has been suggested that one of the reasons behind the drastic fall in the number of shipwrecks starting from the second century AD (Figure 3.1) could be the substitution of amphorae with wooden barrels as containers for transporting goods (Jacoby, 2010; McCormick, 2012, pp. 74-76; Whittaker, 1989, p. 537; Wilson, 2009, p. 221); although, this phenomenon in Late Antiquity seems to prevail regionally instead of investing the entire Mediterranean (Baratta, 2006; Leidwanger, 2020, p. 40; Marlière, 2002). Moreover, further historical explanations have certainly played a role, e.g. the defeat of piracy, advances in nautical engineering, safer transport conditions (e.g. Wilson, 2011). If perishable and organic materials are rarer to find than durable ones (Parker, 1992, p. 20), specific environmental conditions may contribute to preserving them (e.g. the presence of fine clay, low dissolved oxygen, low salinity that is unsuited for shipworm

[25] On the controversial meaning of 'low density zones' see Kamermans, et al., 2009; Verhagen, et al., 2010.

(Macheridis et al., 2020; Horden & Purcell, 2000, pp. 342-400). Moreover, targeted excavations may bring to light the durable elements of these perishable objects, such as the metal rings or steel bands of wooden barrels (Figure 3.2).

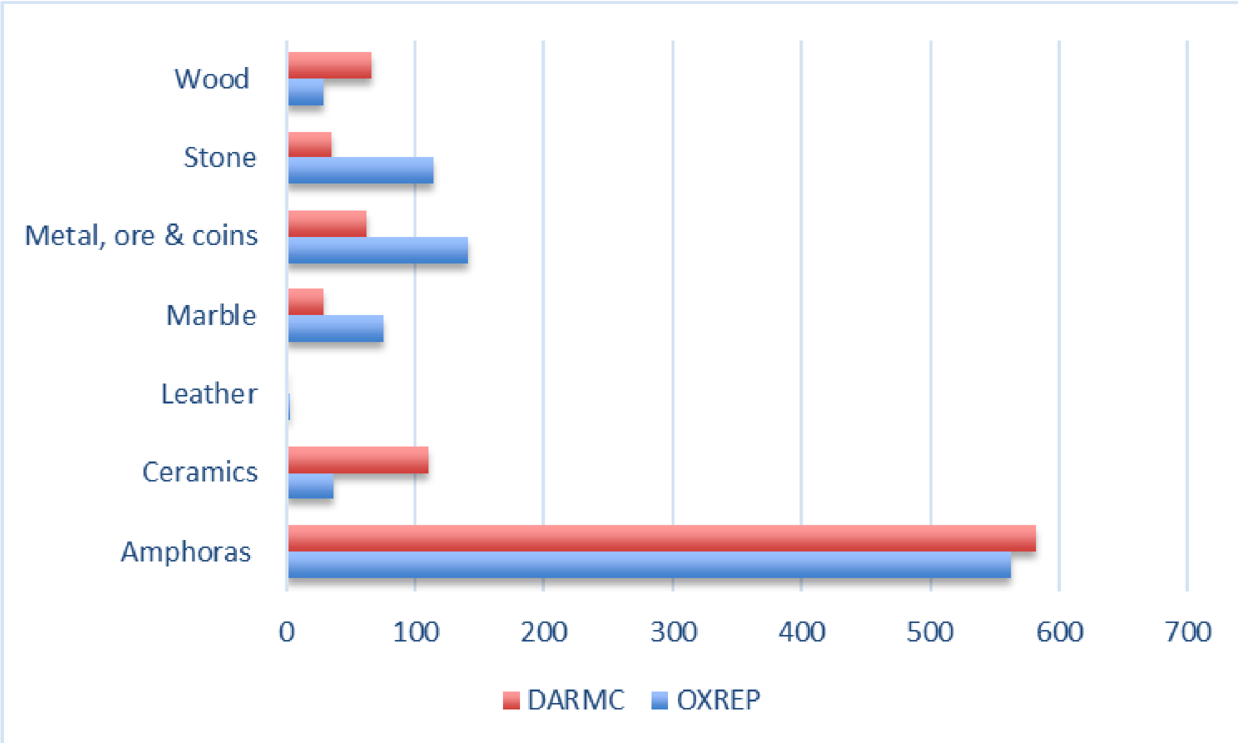

Figure 3.2: Classes of materials documented onboard shipwrecks (produced by the author based on DARMC and OXREP data)

Advances in remote sensing technologies enabled to survey large areas with high resolution, thus increasing the chance to detect categories of objects never or hardly detected before due to their small sizes. An example is the detection of eight helmets and twelve battering rams on the seabed of the Island of Levanzo, off the Sicilian coast (Italy), which turned out to be the location where on March 10th, 241 BC, the last clash of the First Punic War between the Carthaginian and Roman fleets happened. This astonishing discovery conceived and directed through the cooperative efforts of the *Soprintendenza Del Mare* led by Sebastiano Tusa, *Regione Siciliana*, and RPM Nautical Foundation, was possible thanks to the combination of preliminary desk-top studies examining historical sources and the environmental condition of the area, with high-resolution remote sensing technologies (Ricordi, 2005; Tusa, 2005, pp. 63-68; Tusa & Royal, 2012, pp. 7-48; Royal & Tusa, 2019). The latter enabled not only to increase the level of details in the surveys, but also to reach previously unreachable depths[26], as confirmed by the many astonishing discoveries made in deep waters and previously unexplored environments in the last 25 years, starting from the Skerki Bank exploration (Ballard et al., 2000; a literature review of deep water archaeological

[26] A literature review on the most recent advances in robotic technology and remote sensing techniques for mapping and monitoring the underwater cultural heritage is in Kapetanović, et al., 2020; Quinn, 2013

discoveries is in Wachsmann, 2013; cf. also Brennan et al., 2020; Drap et al., 2019; Søreide, 2011). Not by chance, considering the more favourable preservation conditions of timber in deep waters, the increasing depths of the discoveries has also led to the detection of exceptionally well preserved and rare cargoes. Besides, since the phenomenon of pillaging both in modern and contemporary times leads to a higher chance of survival for sites lying at depths not accessible by plunder, the possibility to explore through remote sensing previously unreachable depths has indeed enabled the discovery of several 'new' and well-preserved sites. The following two weighted maps by Parker show the distribution of the published Mediterranean shipwrecks; particularly, the most striking differences between the sites recorded in 1992 and 2008 are highlighted.

Parker noted that besides the increasing depths at which shipwrecks have been discovered 'recent additions have tended to fill out and reinforce the former pattern. Thus the general weighted distribution map of ancient shipwrecks has only a few newly populated squares, and the pattern is broadly the same as before' (Parker, 2008, p. 187). His statement seems to be also supported with discoveries made after 2008., such as the 58 shipwrecks found in the Fourni archipelago at ca 60 m depth between September 2015 and September 2018[27]. Indeed, the overall pattern looks broadly the same as before and reveals what follows:

1. A higher density of sites in the north-west Mediterranean, central Mediterranean and Aegean sea (Figure 3.3), with very few sites recorded in the southern coasts, particularly along the African coasts (Leidwanger 2020, p. 35; Morley, 2007a, pp. 572–573; Morley, 2007b, p. 98; see Chapter 6 for a debate on the archaeological potential of the northern-African waters). Considering the multinational dimension of the Mediterranean sea, and the number of Countries having a coastline on its basin[28], it is reasonable assuming that the amount of finds reflects legislative limitations in archaeological surveys, uneven national policies (particularly between European and non-European Countries), non-uniform acceptance of International Conventions or late ratification, and more in general, uneven archaeological initiatives (Khakzad, 2014)[29]. The above considerations may contribute to explain the very few records along the North African coastline and the disproportions within the European Countries as well (Figure 3.4). Among the many possible archaeological, historical and environmental reasons behind the high number of French records, the establishment in 1966 of the first specialized organization for underwater archaeology in Europe, namely the *Département des Recherches Archéologiques Subaquatiques et Sous-Marines* (DRASSM) certainly played a role, since

[27] https://www.southampton.ac.uk/news/2016/07/shipwrecks-discovery.page (Accessed 23/11/2017); https://rpmnautical.org/location/greece/ (Accessed 23/11/2017). I am grateful to Peter Campbell who kindly gave me information on the sites.

[28] In alphabetic order: Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, , Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, Syria, Turkey, Tunisia.

Other territories which border the Mediterranean Sea are: The British overseas territory of Gibraltar, the Spanish autonomous cities of Ceuta and Melilla and nearby islands, the Sovereign Base Areas on Cyprus, and the Gaza Strip.

[29] The updated status of the ratification process for the UNESCO 2001 Convention is at: https://treaties.un.org/pages/showdetails.aspx?objid=08000002802198d9. As for the European Convention on the Protection of the Archaeological Heritage, also known as Valletta treaty or Malta Convention, the Status of signatures and ratifications as of 27/10/2021 is available at: https://www.coe.int/en/web/conventions/full-list?module=signatures-by-treaty&treatynum=143

over the last 50 years, several wrecks were identified by the DRASSM through targeted underwater surveys and excavations (L'Hour, 2012).

Mediterranean Shipwrecks

Figure 3.3: The locations of underwater shipwrecks in the Mediterranean sea (author's interpretation of the DARMC and OXREP databases)

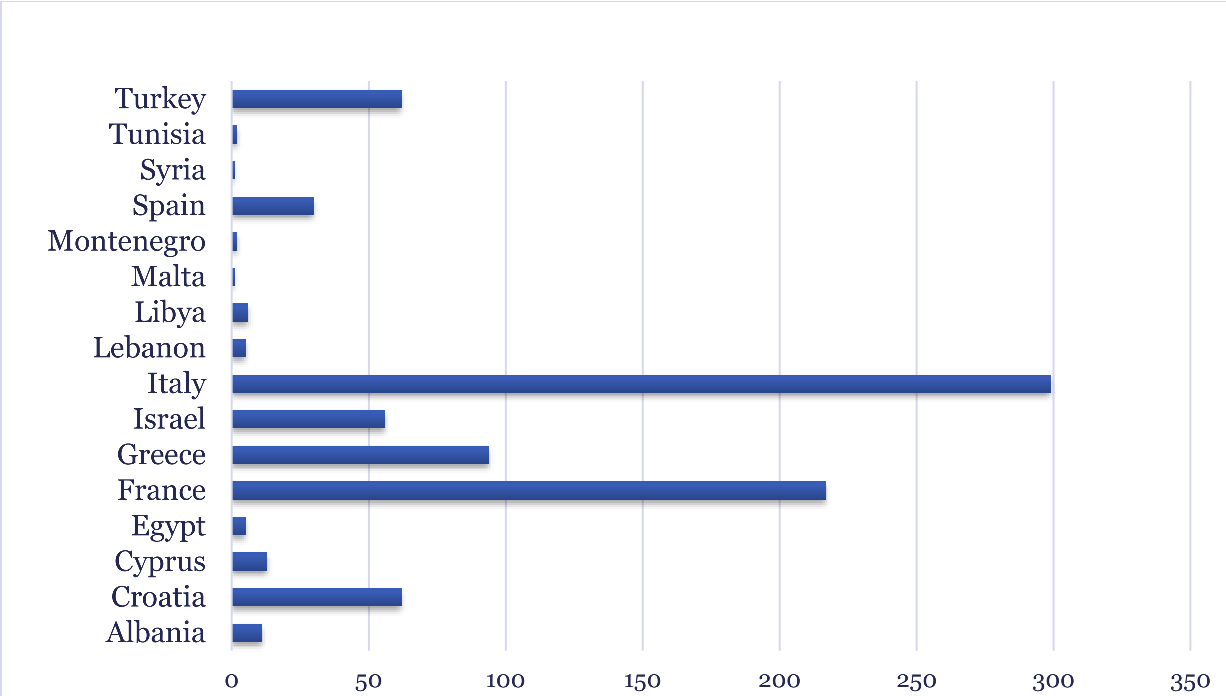

Figure 3.4: Graph showing the amount of (underwater) shipwrecks per Country (produced by the author based on OXREP data). The very few records in the S Mediterranean and non-European countries hint to an underrepresentation of the real archaeological potential, indicating lack of publications and/or archaeological surveys.

2. Presence of shipwrecks within the 12 NM from the coastline with a predominance within the 3NM (Figure 3.5). Compared to the past sixty years when underwater discoveries mainly were connected to the activity of scuba divers, sponge divers, trawlers and biased in terms of depth distribution by their range of action, the use of remote sensing technologies has contributed to moving a bit deeper the frontier of the underwater discoveries, by bringing to light several sites between 50 m and 150 m depth. However, whereas the definition of 'accessible waters' may change in time, deep-water sites are still underrepresented, and a bias toward accessible waters still exists, which affect the uneven geography of shipwreck records.

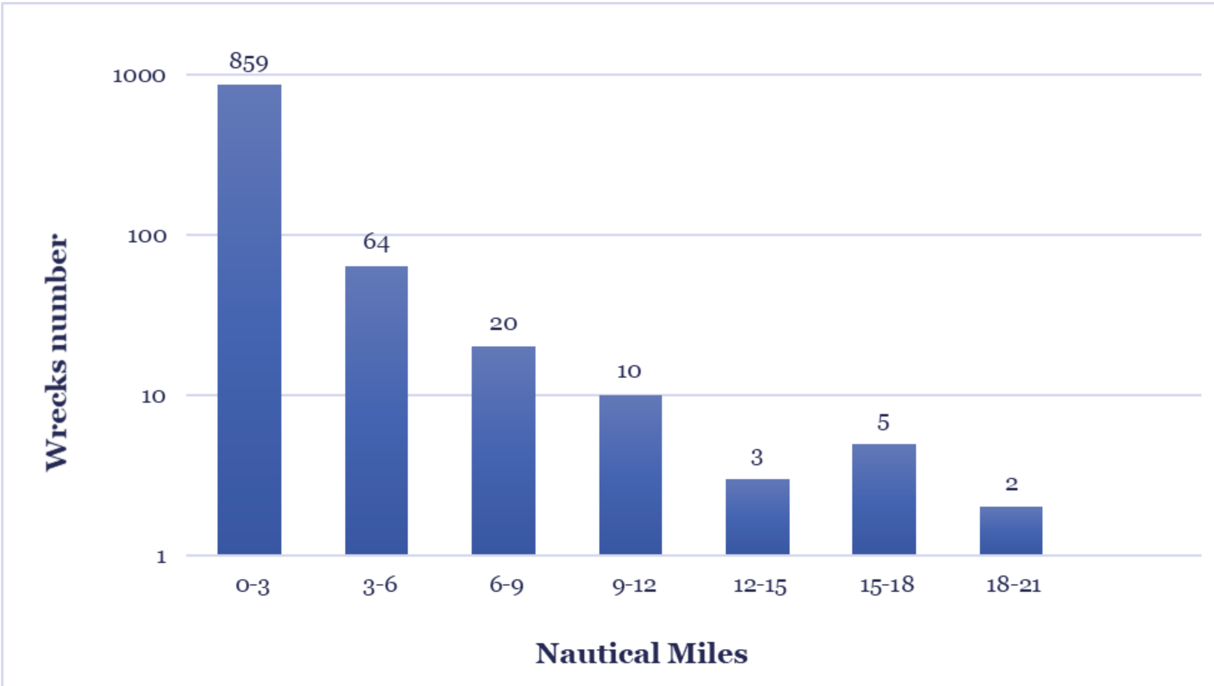

Figure 3.5: Average shipwrecks distance to the coast (produced by the author based on DARMC and OXREP data)

According to some scholars, such as Leidwanger, this bias

> "should not represent an insurmountable dilemma. The vast majority of ships— as much as 80% by certain estimates for the Early Modern era —probably sank within a short distance of land, and for obvious reasons: ships commonly founder when they strike promontories, cliffs, or shallow reefs. Some vessels sank even in port: the famous storm of ad 62 recorded by Tacitus (Ann. 15.18.3) claimed over 200 ships within Claudius's harbour at Portus" (Leidwanger, 2020, p. 35).

Although undeniable, this risks triggering circular reasoning in predictive modelling as new insights on accidental events or further threats (e.g. piracy routes) may emerge by looking where one has not looked yet; this connects to the original question set at the beginning of the section. It is clear that the archaeological aspects, preservation dynamics, and technological, logistic and legislative constraints have limited the possibility to explore the Mediterranean sea uniformly. Furthermore, pillaging has altered the distribution of the sites. Hence, by referring back to the questions set at the beginning of this chapter, we may conclude that the number and the location of shipwrecks are biased by factors preventing a complete understanding of the potential archaeological patterns.

Besides, a further aspect is worth considering: it would be excessively approximate to evaluate the archaeological potential of an area by looking at the visible remains exclusively. Nonetheless, a great part of what has been surveyed and mapped underwater is limited to the superficial records; exceptions are connected to further investigations of already detected areas, either through remote sensing, such as the sub-bottom profiler or excavations. Hence, archaeological remains might be where investigations have not been carried out yet and where the geomorphology may enable the preservation of archaeological remains. The preservation and the discovery constraints sometimes coexist. For instance, dense meadows of *Posidonia oceanica* contribute to conserving with their rhizomes and roots the heritage laying underwater. However, since this endemic species, present only in the Mediterranean Sea, is protected under the Habitats Directive of the European Union (92/43 EEC of 21/05/1992 and the adaptation with the Directive 97/62/EC of 27 October 1997)[30], destructive archaeological investigations are not possible.

Advances in technologies and remote sensing have definitely opened up the possibility of exploring previously unreachable depths, thus increasing the chance to detect well-preserved cargoes and classes of material that had a low chance of being found in the past. Hence the biases which affect the understanding and the knowledge of the underwater cultural heritage nowadays are slightly different from the past. Even considering the above technological advances, an extensive and uniform exploration of the underwater seabed, particularly of the Mediterranean Sea, is far from feasible. The great potential of predictive models lies exactly in the possibility to assess which materials might be found and where for choosing and employing the most suitable technologies to detect them.

The final issue, whether and how the available data may be used, is controversial. The discussion above has summarised the main caveats in the shipwreck records, among which the overrepresentation of particular historical periods and the geographical distribution that reflect a bias toward accessible depths or disbalance in National archaeological initiatives. These biases do not entirely prevent using shipwrecks 'assemblage' (a definition in Murphy, 1997) as a proxy to study maritime trades and connectivity as statistical approaches may identify the most significant patterns; an example in Parker comparing the distribution of all wrecks with the distribution of Dressel 1 and Dressel 6 amphoras (Parker, 2008, p. 191). A novel technique based on formal network randomisation for identifying statistically relevant amphoras associations onboard shipwrecks is in Ritondale & Prignano (in preparation).

However, in terms of predictive modelling approaches, the employment of shipwrecks data to infer the location of yet unknown sites presents a twofold set of limitations. First, as "the models and resulting predictions are only as good as the data and theories that are put into them" (Verhagen et al., 2010, p. 437; a similar statement in Verhagen & Whitley, 2020, p. 232), biased data will generate a biased prediction that will reinforce the current state of knowledge and discoveries, thus leading to a vicious circle of self-fulfilling prophecies preventing the identification of currently underexplored sites. The second interconnected issue relates to the need to test and validate the generated models. Indeed, using the shipwrecks data as input parameters prevents one from using the same data set to check the model outcomes. Although there is a tendency to take subsets of the same data in archaeological prediction and use these for both hypothesis inference and testing (e.g. Steele and Werndl 2013), this practice has been criticised (Verhagen 2007, pp. 287-290; Worrall, 2010). Given the lack of predictive models in the maritime Mediterranean context, the

[30] These Directives are included here as a reference, noting that it is behind the scope of this study to provide a comprehensive analysis of the reasons justifying this habitat's protection or an updated Legislation review

above issue deserves even greater attention and rigour in the model testing, in light of the impossibility to compare the performance and outcomes of different models and approaches.

Once decided to avoid using shipwrecks data to infer model hypotheses and instead employ them to test the model, the next step, addressed in section 3.3, is to debate how to mitigate the identified biases.

3.3 QUALITY ASSESSMENT: TESTING LOCATIONAL UNCERTAINTY AND DIFFERENCES BETWEEN SOURCES

To use the available archaeological evidence as a control group to test and validate the model, one needs to assess the available data's quality and quantity, hence possible strategies to mitigate the data biases. Three major problems need to be addressed with reference to the shipwrecks distribution: absence of data, incomplete data, approximate data.

The absence of data problem and the potential biases behind it have been addressed in the previous section; different scenarios may explain why shipwrecks are not recorded, preserved, or found as described in

Table 3.2. In order to mitigate the bias, the model scope is reduced to the area within which shipwrecks have been recorded, namely limited to the 12 NM zone, given the impossibility of testing without data. In chapter 7, it is further debated how to interpret the model outcomes in light of the possible reasons behind the lack of data. The problem of data incompleteness refers to the lack of information associated with a given entry in the database sources, particularly to the unknown or unreported locations. It is worth noticing that out of a total of 1947 entries, only 1133 have locations known and/or given. Among these, the underwater sites are 802. However, due to the third problem listed above, namely the data approximation, the number of sunken shipwrecks is higher, for many sites falling on land due to approximate locations are in reality in shallow waters, as further explained below in this section. The degree of this location approximation is not known or not specified. On the one hand, the approximation is the result of strategic and managerial policies aimed at mitigating the risk of pillaging; on the other hand, it is due to the accidental ways the sites have been detected and signalled to the public authorities during the time. Indeed, not all the sites have been discovered during archaeological surveys. Particularly before 1992, many have been found by chance, mostly by fishers. The spatial coordinates provided by DARMC and OXREP for the same site usually differ (Attachment 4c); to ascertain whether this difference is consistent, thus corresponding to a systematic error, or inconsistently vary, a group of sites was tested here. Five shipwrecks whose locations satisfy the following two conditions were selected:

- Sites whose coordinates are provided in both DBs
- Sites having at least one source in common to be used as control-ID to uniquely identify the shipwreck despite possible differences in the names (i.e. Parker).

Table 3.3: Distance in NM between shipwreck locations provided in OXREP and DARMC for the same site. The Shipwreck number supplied by Parker (1992) is used as a cross-reference

DARMC NAME	OXREP NAME	Parker ref	Country	Distance in NM
Cap Bénat 1	Cap Bénat A	172	France	0.52
Est Perduto 1	Est Perduto A	392	France	1,23
Lavezzi 1	Lavezzi A	584	France	0,18
Marsala 1	Marsala A	663	Italy	2,10
Port Vendres 2	Port Vendres B	875	France	0,66

The cases in Table 3.3. confirm that the difference between the locations provided by DARMC and OXREP is not consistent, and therefore it is not possible to identify a systematic error (i.e. a fixed offset between the two sources); this is not surprising given the way data have been gathered over time (e.g. incidental discoveries, multiple different sources). Limited parts of this vast dataset were checked with targeted surveys, but in light of national policy aimed at protecting underwater cultural heritage from pillaging, the exact locations have not been published.

The problem of data aggregation and data sharing does not affect the underwater context exclusively. In the past decades, several initiatives worldwide have attempted to make the published and unpublished archaeological information available online by pursuing the FAIR (Findable-Accessible-Interoperable-Reusable) data principle (Wilkinson et al., 2016; Wilkinson et al., 2019; a discussion around the challenges of data-centric methodology to address large-scale research in archaeology is also in Niccolucci, 2020). This is, for instance, the goal of the European Commission's 7th Framework Programme ARIADNE[31] (Archaeological Research Infrastructure for Archaeological Data Networking in Europe), which since 2013 aims to aggregate existing archaeological research data infrastructures and make available various distributed datasets (Aloia et al., 2017; Meghini et al., 2017; Niccolucci & Richards, 2013; Niccolucci, 2018):

> "There is now a large availability of archaeological digital datasets that, together, span different periods, domains and regions; more are continuously created as a result of the increasing use of IT. These are the accumulated outcome of the research of individuals, teams and institutions, but form a vast and fragmented corpus and their potential has been constrained by difficult access and non-homogenous perspectives"[32]

[31] http://www.ariadne-infrastructure.eu/ [Accessed 12-04-2017] ##Add Ariadne Plus##
[32] https://cordis.europa.eu/project/id/313193/it

The more recent ARIADNE extension, ARIADNEplus (Richards & Niccolucci, 2019), aims to expand the ARIADNE focus by employing digital technology to support searching and finding according to FAIR principles (Niccolucci , 2020, p. 39).

This section has highlighted the significant and unsystematic differences between placements provided by two sources; this issue constitutes an unresolved problem with many implications that are discussed in the below conclusions.

3.4 CONCLUSIONS

The many biases affecting the Mediterranean shipwrecks record suggest approaching the model building in a deductive (i.e. theory-driven) way (chapter 1). Indeed, the patterns disclosed by the available archaeological sites may lead to misleading hypotheses about maritime patterns and could reinforce the existing documented knowledge, thus preventing gaining insights on underexplored phenomena or undocumented areas. As shipwrecks data will not be employed inductively to infer probabilities, it is possible to use them as an independent dataset to test the model performance instead; this is crucial because due to the lack of other predictive models in the Mediterranean territorial waters to compare with, it would not be possible to assess the model performance otherwise.

The following precautions are taken to mitigate the shipwrecks data limitations and enable their use for model validation (Chapter 7). First, the research area has been limited to the territorial waters because further than the 12 NM zone, an exiguous number of sites is known, not statistically significant for testing the model. Second, given the approximate shipwreck locations provided in the dataset, a 1.5 NM buffer is generated around each site to compare the shipwrecks position against the final relative shipwrecking probability (RSP) value. The average RSP value within this buffer is calculated instead of taking into account the RSP value at the recorded ships' location. Third, a 2 NM buffer from the coastline landward has been generated to include in the analysis the underwater sites in shallow depths, which the approximate coordinates locate on land. In case of conflicting coordinates, the locations provided by Harvard have been employed.

At the local scale, the presence of other potential sites besides those mentioned in the OXREP and DARMC dataset has been ascertained through a targeted literature review (Chapter 7), however, despite the measures taken to limit the impact of data accuracy, it is licit wondering whether the biases affecting the shipwrecks dataset might compromise the model-testing as well. This issue is discussed in chapter 7.

3.5 Summary

An exploratory analysis of shipwrecks data recorded in the Mediterranean Sea was carried out in this chapter with the aim to establish whether an inductive or deductive methodological approach would be more suitable to develop a shipwrecking probability model. Two different open databases were used as sources, i.e., the one developed within the Oxford Roman Economy Project and the Digital Atlas of Roman and Medieval Civilizations set up by the University of Harvard. The analysis evidenced the many biases affecting the current underwater archaeological pattern and discussed the potential reasons behind them. The increasing employment of remote sensing technologies has significantly contributed to surveying previously unreachable depths, thus discovering new and well-preserved sites in deep waters. However, the shipwrecks distribution is still profoundly affected by uneven national archaeological initiatives and logistic constraints. The fragmented patchwork of discoveries made through targeted archaeological investigations and casual discovery mostly within the 12 NM zone suggests not to interpret the absence of recordings as a lack of archaeological evidence necessarily. Given the biases affecting the shipwrecks record, it was decided to approach the model building by following a theory-driven approach and use the archaeological record to test the model performance instead. A new database merging the Oxford and Harvard datasets was then set up by enquiring about data quality and differences between the two sources. The analysis contributed to establishing targeted strategies for handling the detected data limitations in the phase of model building and model validation, which are further discussed in Chapters 6 and 7.

«ὑμῖν δὲ πῶς ἄν τις καὶ χρήσαιτο, οἳ καὶ τὴν γῆν καὶ τὴν θάλατταν»

Synesius, Epistle 4[33]

"On ne répètera jamais assez que pour le marin, le danger est toujours la terre, plus que la mer"

Pascal Arnaud[34]

4 THEORY DEVELOPMENT: A NEW TAKE ON MARITIME PREDICTION

The content of the present chapter represents both an outcome and a premise. On the one hand, it discusses a particularly significant shortcoming that emerged from analysing the state of the art in current predictive approaches to movement potential and shipwreck locations (Chapter 2). On the other hand, the identification of this limitation has triggered the definition of a new and original theoretical strategy for building the proposed implementation while overcoming current deficiency in predictive modelling approaches. Addressing the advantages and disadvantages of coastal proximity, namely the reasons why mariners would choose to approach the land rather than staying far from it, is a particularly suitable starting point for modelling shipwrecking probability within the 12 NM zone (section 4.2). Current approaches to modelling past seaborne movements and shipwrecking probability have tended to assume that mariners in the past would consider benefits and risks of coastal proximity in the same way as present-day mariners would do. In other terms, in the name of the so-called 'nautical uniformitarianism' (sections 3.2.2 and 3.2.5.), it is common practice to consider threats affecting current navigation safety identical to the risks ancient mariners would try to circumvent. Nevertheless, there may be a difference between perceived and real hazards. To further ascertain this, Greek and Latin documentary sources are analysed in search for explicit mentions of shortcomings and advantages in relation to the coast, as well as of strategies adopted to avoid or mitigate hazards (section 4.3). The aim here is to challenge the uniformitarian hypothesis by exploring some cultural, perceptive and contextual variables as surfacing from primary (mainly textual) sources.

4.1 COASTAL NAVIGATION: SHORTCOMINGS AND AMBIGUITIES IN THEORIES AND PRACTICES

A number of open issues highlighted in previous chapters turn out to be connected to the 'coastal area', which is far from being a straightforward concept. These issues include biases in the discovery and management of underwater sites, oversimplified definitions of 'coastal navigation', and methodological limitations in current predictive approaches, such as the adoption of average data-values that do not reflect the specificity of littoral areas. As highlighted in chapter 3, the

[33] "So how can anyone help you, you who mistrust both land and sea?", Synesius, Epistle 4. Translation by Davis 2009

[34] Arnaud, 2005, p. 28

territorial waters and, more in general, the portion of the sea close to the shore is pivotal in terms of heritage management. Indeed, on the one hand, this area is easier to survey for coastal States; on the other, shallow waters are more accessible, hence more easily altered by pillagers and trawlers; this makes the spatial distribution of the known archaeological data highly biased.

In Chapter 2, a number of shortcomings in current predictive models were identified, several of which specifically relate to the concepts of 'coastal area' and 'coastal navigation':

- From a technical and methodological point of view, the statistically averaged wind-data that are usually employed for modelling maritime navigation cannot represent the specific conditions of the coastal area; indeed, the regime of winds and waves is here more unstable, being affected by land and sea breezes. Furthermore, 'an obvious source of error is the presence of the coast. Its description with a finite grid is always approximate. Except for the cases when the waves move perpendicularly towards the coast, its approximate geometry is likely to affect the local results' (Warnking, 2016, p. 53).
- From a more theoretical point of view, the way 'coastal navigation' has been theorised and modelled is simplistic and misleading; indeed, it encompasses several different navigational approaches, such as cabotage (or *capotage*, i.e. navigation from cape to cape), tramping (i.e. navigating from port to port), and navigation 'in sight of the shore' (Arnaud, 2011; Beresford, 2013; Braudel, 1949; Gould, 2011; Morton, 2001). Each of these navigation modalities may result in slightly different corridor-routes, although scholars sometimes still tend to blur them (e.g. *capotage* as equal to tramping in Medas, 2008, p. 197; for a debate on the "slippage" in English language publications between the use of cabotage to describe tramping, see Arnaud, 2011, p. 62; Wilson, 2011, p. 53). As noted by Arnaud, the fact that tramping and coasting cannot be necessarily connected is also proved by literary documents (Arnaud, 2011, p. 63); for instance in P. Bingen 77, a port registry dating the 2nd century AD that records the arrival and tonnage of eleven merchant vessels to an unspecified Roman port in the Egyptian Delta (Heilporn, 2000; Casson 1971, pp. 159, 338; Obied, 2016, p. 192) "the ships mentioned are coasters but none of them seems to be involved in tramping" (Arnaud, 2011, p. 63). Despite attempts to explore advantages and disadvantages of coastal navigation in opposition to open-sea routes (e.g., Aczel 2001, p. 11f; Arnaud, 2005; Beresford 2013; Davis, 2009; Gianfrotta, 2005, pp. 22-26; Medas 2008, p. 116-121; Morton 2001, pp. 143-172, 262, 279; Rougé, 1981; Taylor, 1971; Toghill, 1994, p. 101), the reasons triggering the different 'coastal strategies', and therefore the resulting potentially different 'coastal corridors', have not been adequately addressed in computer models. The ORBIS project[35], for instance, declares that the two navigation categories, namely coastal and open-water, are based solely on whether a route connects nearby sites that share the same coastline and does not operate with any relation to the coastlines (for instance, through a buffer or a viewshed). As such, ORBIS asserts that some coastal routes will follow least-cost paths beyond the visible range of coastlines, and some overseas routes may hug coastlines for much of their path.

[35] https://orbis.stanford.edu/

- Connected to the above issue is the tendency to consider 'coastal navigation' as opposed to overseas or open-sea routes. Computer approaches have followed a long tendency in scholarship on ancient seaborne patterns to distinguish two opposite models of sailing: the direct crossing on the open sea, which is usually associated with primary distribution network (i.e. direct) with trade operations at the final destination, and coastal approaches characterised by tramping and secondary distribution (Arnaud 2011; Casson, 1971; McCormick 2001; Rougé, 1966). In the past sixty years, the scholarship has mainly addressed aspects of permanency and changes in sailing approaches and trade systems across the centuries. Particularly, scholars have wondered whether the identification of binary models of seaborne patterns (i.e. open-water *versus* coasting; primary direct distribution network *versus* secondary cabotage redistribution network) may be appropriate for describing the entire pre-modern sailing system (Arnaud 2011, p. 61-80; Horden & Purcell, 2000, p. 137–52; Morton, 2001). Despite this theoretical sophistication highlighting how approximate and artificial the contrast between 'coastal' and 'open sea' routes is (Arnaud, 2005, 2011; Morton, 2001, p. 250), this 'Manichean vision of shipping lanes' - quoting Pascal Arnaud (2011, p. 61) - persists in current computer approaches to seaborne movement, which tends to ignore the variations in trade and sailing patterns resulting from economic and jurisdictional variables, as well as human and cultural ones (an overview of the impact of tax regulations and frontiers on trade mechanisms and patterns is offered by Arnaud, 2011)
- The imprecise definition of 'coastal navigation' also hides an absence or oversimplification of the criteria used to define the coastal area: what makes a particular water space 'coastal'? How far does the 'coastal area' extend? The single criterion usually adopted is that of shore-visibility, and it is a very approximate and misleading one since it only considers the optimal or theoretical visibility (i.e. in 'optimal weather conditions'), and it does not distinguish the visibility of landmarks from that of the shoreline or of the nearby heights (Davis, 2009; see further in section 4.2.3). Additional potential indicators of coastal proximity, such as swell and wave refraction, currents, biological indicators, shore-related clouds, smell and sound (Gooley, 2011, 2017) have not been included in formal approaches to past movement potential. However, the idea of a perception-shed in GIS resulting from the combination of different senses for perceiving the space (i.e. the cells in a raster map) instead of a merely vision-based shed has been mooted for two decades (Conolly & Lake, 2006, p. 233; Landeschi, 2019, pp. 17-32; Tschan, Raczkowski, & Latalowa, 2000).

4.2 Coastal proximity in scholarship

There is a further controversial theoretical aspect that has not yet been explicitly mentioned in the previous Chapters, and that regards the degree of risk or benefit attributed to the proximity to the shore and the sight of the land. These two aspects, although intertwined, need to be treated separately. Whereas the hazards associated to coastal proximity in general, and the landing moment related risks in particular, have been widely highlighted by the scholarship (see below), the possibility to spot the land –assuming it possible within a certain range- has been generally perceived by scholars as an advantage. This idea actually underestimates the human-risk factor that mutual visibility entails: being in sight of the land implies being seen and therefore potentially attacked from land.

The theoretical issues summarised in this section, namely the risks and benefits associated with coastal proximity, the shortcomings connected to the land-sight and the effective range of visibility in Mediterranean waters, have methodological implications as they provide a starting point for modelling the shipwrecking probability within the 12 NM zone. Particularly, as further explained in chapter 5, addressing the advantages and disadvantages of coastal proximity in a formal manner enables one to overcome current binary approaches to modelling past seaborne movements that do not take into account criteria for properly distinguishing the two navigation strategies and the variety of combined approaches behind them.

4.2.1 A land of opportunities or a mortal hug: dangers and benefits of coast approaching

Regarding the risks connected to coastal proximity, the most recent scholarship has challenged and overcome the long-lasting view of ancient mariners as supposed coast-huggers reluctant to venture into open waters. The issue has been discussed starting from the 60's with scholars increasingly highlighting that "*pour le marin, le danger est toujours la terre, plus que la mer*" (Arnaud 2005, p. 28) and 'the peril of rough weather is nothing to that of being driven on to a lee shore' (Taylor & Richey 1962, 1 quoted in Beresford 2013, p. 175). Similarly, Medas notices that the Italian expression '*girare al largo*', derived from the nautical domain, is used to suggest someone stay at a distance from a supposed risk or avoid a problem (Medas 2008, p. 116). Advantages and disadvantages of both coastal approaches and open-sea routes have been discussed by mainly addressing environmental aspects (e.g., Aczel, 2001, p. 11f; Arnaud, 2005, Beresford 2013, ch.4; Gianfrotta, 2005, pp. 22-26; Medas, 2008, pp. 116-121; Morton, 2001, pp. 143-172, 262, 279; Rougé, 1966, 1981; Toghill, 1994, p. 101), although some scholars have also mentioned the human risk, i.e. the assault-probability connected to either the presence of pirates along promontories, straits and islands (Beresford 2013; de Souza 1999; Gianfrotta 1981, pp. 227-242; Gianfrotta, 2001, pp. 209-214; Gianfrotta, 2013, pp. 51-66; Morton 2001, p. 156), or frontiers of inimical coastal states, for instance, due to *sylai* , i.e. the right of reprisal (Arnaud, 2011, p. 64). The assault probability, however, has never been tackled in navigation modelling.

It is now generally acknowledged that "Open water seafaring and coastwise pilotage […] presented very different navigational problems that required very distinct sets of skills if they were to be successfully overcome" (Beresford 2013, p. 175). Indeed, open water navigation, which has been defined as 'the true art of navigation' (de Souza, 2002, p. 30) implies mastering navigation knowledge and mental mapping abilities for setting a course, positioning the vessel in space also in the absence of landmarks, and bringing it from a place to another (Beresford 2013, p. 175; de Souza, 2002, p. 30; on mental mapping abilities of ancient mariners Arnaud, 2014, pp. 39-68). On the contrary, coastal or inshore navigation, which is also commonly referred to as the art of pilotage (Beresford, 2013, p. 183) deals mainly with environmental risk-management, i.e., with the coastal topography: shoals, shallows, outcrops and more in general with the challenging manoeuvrability in narrow waters at the entrance of harbours or adverse meteorological conditions (on the types of coasts more dangerous to navigation see Rougé, 1981, pp. 18-19 and Taylor, 1971; on perils of coasting in general Beresford 2013, p. 175, Cunliffe, 1987 and the bibliography the former mentions at this regard, i.e. Kemp 1992, p. 578; Seidman, 2001, p. 174). The vessel type and its propulsion affected navigation strategies (e.g. Harris & Iara, 2011; McGrail, 2015, pp. 60-89; Pryor, 1988; Whitewright, 2018). Moreover, even when the same vessel could deal with both navigation approaches during the same route, scholars have highlighted that the nature and disposition of the cargo –in the case of commercial boats- would be adapted to deal with the chosen predominant strategy (e.g. Harris & Iara, 2011; notably, Arnaud's contribution, pp. 147-160). As for the acknowledged advantages of coasting, these include the possibility to find shelter during a storm, the possibility to replenish water, repair damages, connect to different transport systems (land-networks, rivers), and trade at harbours or on beaches (McCormick, 2001, p. 84 and p. 422). A further advantage is represented by the presence of sea and land breezes enabling one to sail in directions other than the prevailing winds (section 4.3).

In the introduction of his *The Ancient Sailing Season,* Beresford notes that although scholars generally agree on the advantages and disadvantages of coastal approaches and open-sea routes, they can reach opposite conclusions about their implications or mariners preferred strategies (Beresford, 2013, p. 4). For instance, referring to the most likely navigational approach used by mariners in Early Antiquity during the winter season, Morton suggested these wintertime voyages took the form of short coastal 'hops' from one anchorage to another in order to easily reach a harbour in case of need (Morton 2001, p. 145). For others, such as Oded Tammuz (2005, p. 145), coastal navigation was brought to a standstill in winter because it would be more dangerous to stay close to the shore with unstable meteorological conditions, whereas open-water routes would remain open. These opposite conclusions underline that the nautical uniformitarianism concept alone cannot address the potential differences in perceived risks and that cultural preferences and discrepancies should be thoroughly investigated and formally taken into account in predictive modelling.

4.2.2 "You who mistrust both land and sea": subjective perceptions

The scholarly debate around risks and benefits of coasting and open-water navigation reflects the same controversy documented in primary sources. Indeed, context specific preferences for either coasting or open-water navigation under certain conditions are often attested in ancient sources, for instance, during a storm when a lee shore is feared more than anything else (Sen. Ep., 53.2). On the contrary, statements documenting an explicit and general preference, i.e. independent of specific conditions, for either coasting or open-water approaches are quite rare. Among these, for instance, is Strabo, who talking about trades between Baetica and Rome says:

> The navigation is excellent as far as the Pillars, (excepting perhaps some little difficulties at the Strait) and equally so on the Mediterranean, where the voyages are very calm, especially to those who keep the high seas. This is a great advantage to merchant-vessels. The winds on the high seas blow regularly; and peace reigns there now, the pirates having been put down so that in every respect, the voyage is facile. (Str. *Geog*, 3.2.5).

Even more explicit is Strabo account on the *Syrtis* and its shallows (Str. *Geog*, 17.3.20):

> Sailors, therefore, in coasting, keep at a distance (from the shore), and are on their guard, lest they should be caught by a wind unprepared, and driven into these gulfs. Yet the daring disposition of man induces him to attempt everything, and particularly the coasting along a shore.

The most meaningful and explicit account documenting divergent and opposite perceptions on coastal proximity is the letter that the bishop of Cyrene Synesius wrote in 404 AD[36], which describes his journey from Alexandria to Rome (for commentaries on seafaring aspects of Synesius' voyage between Alexandria and Azarium, see Casson 1994, pp. 159–62; Janni, 2003). Scholars have often mentioned the document as one of the few complete descriptions of a maritime journey from Antiquity, together with Lucian's narration of the trade vessel *Isis'* trip from Alexandria to the Piraeus in the *Navigium* (e.g., Casson, 1971, pp. 268-269; Davis, 2009; Houston, 1987, pp. 444-450; Janni 1996, pp. 453-474) and Saint Paul's account of his journey from Caesarea to Rome in the Acts of the Apostles.

The following extended excerpt of Synesius text is worth recalling here (Synesius, Epistle 4, 49-75, translation by Davis, 2009):

> "Upon reflecting on this we cried out before finding ourselves in danger. He [the captain Amarantus] had scarcely turned away from fighting a sea battle with the rocks when he turned the ship away as though an afterthought, then let us loose upon the open sea. For a time he threw us against the waves, but then a south wind freshened and bore us along; under its force we quickly lost sight of land and encountered those freighters which have no need of our Libya, but routinely sail another course. When we wailed of hardship and complained of our position so far from land, Amarantus, pretending to be Iapetus, stood on the stern and hurled the most murderous curses upon us. "We shall certainly not fly," he said, "so how can anyone help you, you who mistrust both land and sea?" And I replied to him, "Not quite, my good Amarantus, at least if someone steers us aright. For us, there's no need for Taphosiris, for we wished to live. And what need is there for the open sea? But let us voyage to Pentapolis, keeping the shore tolerably close by, in order that if there is some difficulty as is wont to occur at sea (doubtless unknown, as is said even among yourselves) we can reach a nearby harbour." My talk did not persuade him, but the outcast turned a deaf ear to it, that is until a great northerly wind struck up and piled up the waves before it. This wind struck hard and fast against the sail, pushed it back and reversed its billowing. The ship nearly capsized by the stern. So with difficulty we headed her in. With a thunderous growl Amarantus says, "This is what it is to voyage with skill, for I myself expected these high-seas winds some time ago, and I sailed out to sea on this

[36] Synesius, Epistle 4, 49-75, translation by Davis, 2009. An extended part of this Epistle will be discussed later in this section

account. We're going in at an angle now, since sea-room has been added to this leg. But such a manoeuvre as the one I have taken would not have been possible if were sailing along the coast, for we would have been cast up on land."

There are many different reasons why this account is fascinating: first, the amusing narrative style, second, the indirect accounts on cultural prejudices of the time, indeed Amarantus was not considered a trustworthy and experienced mariner since he was Jewish (Janni 1996, pp. 457-458); third, the possibility to detect indirect proofs of an early adoption of the lateen rig, which still leaves open a debate among scholars (Casson, 1971, pp. 268-269; Janni 1996: 453-474). Finally, the importance for mariners to 'constantly assess the state of the weather and of the sea' to adjust courses accordingly (Morton, 2001, 148).

Nonetheless, in this context, the opposite perception the passengers and mariners had of the high-seas, as well as the mention of a 'tolerable' distance to keep from the shore, deserves particular attention. One may assume that the *tolerable* distance is the one allowing to avoid the risks while benefiting of the advantages of coastal proximity. As Synesius excerpt shows, expert captains would know how to balance these advantages and disadvantages, although there is still a vibrant debate among scholars around the expertise or the inadequacy of captain Amarantus. Casson (Casson, 1971, pp. 268-269), while commenting A.H.M Jones' point of view full of sympathy for the unfortunate experience of Synesius (Jones A., 1964, pp. 842-843) says that "it is rather the skipper, an able man maligned for properly -and successfully- doing his duty, who deserves the sympathy". Synesius' excerpt may thus be considered both as a pinnacle and a mirror of present debates around coastal-proximity perception, for it reflects in this matter the opposite points of view.

4.2.3 Do I want to see what I see? Implications of mutual visibility

Whereas the advantages of coastal proximity do not meet universal agreement, the possibility of staying in sight of the land is usually considered an advantage for mariners and the modern scholarly debate revolves rather around the actual range of land-visibility in the Mediterranean Sea, which many scholars consider to be generally great. The following statement by Beresford is in this sense meaningful: "while we may question whether Graeco-Roman shipping on the Mediterranean was irrevocably tied to the coast, there is little doubting the importance of the visible shoreline to seafarers" (Beresford 2013, p. 183). The land-sight has long been considered 'the navigator's best aid and surest compass' (Braudel, 1972, p. 103), at least up to the diffusion of navigational instruments and of nautical charts[37] in the Mediterranean Region (a synthesis on cartography in prehistoric, ancient, and medieval Europe and the Mediterranean is in Harley &

[37] The systematic analysis of ancient cartography was behind the scope of the present research; for a discussion on the use -and the existence- of nautical charts in antiquity see Janni 1996, p. 468; also Janni, 1984. According to Casson there is no evidence for the use of charts in antiquity (1971, pp. 283), whilst Höckmann is more possibilist (Höckmann, 1985, p. 163). For the information provided by toponyms and the vocabulary employed in ancient charts see P. Janni (1984, pp. 108-114). On the relation between navigation, distances and representation of the space see Arnaud, 2014, Janni, 1984.

Woodward, 1987; particularly Dilke 1987, pp. 105-106 and pp. 212-257; on portolan charts Campbell 1987, pp. 371-463).

It has been highlighted that the tendency to keep visual-contact with land in favourable environments, such as the Greek one characterised by multiple nearby islands, would have been preferred anyway even after the introduction of the compass: “if you can see where you are going, why would you use a compass”? Perissiou wonders (Perissiou, 2014, p. 44), and further elaborates: “the answer is obvious; you would use a compass in the cases that you cannot see where you are going”. Therefore, in environments characterised by a great range of land-visibility such as in the Greek region, the transition from coastal hopping to compass and map navigation would have been slow and dictated by political and economic circumstances (e.g. Aubet, 1993, fig 23; Broodbank, 2000, fig. 4; Horden & Purcell, 2000, map 9; Nicholas, 1992; Schüle 1970, pp. 449-62).

Although focusing on a different geographical and chronological context, Gustas and Supernant have argued that ‘early travellers would most likely have tried to keep the shoreline in sight when entering a new environment as scouting for suitable landing stopping points” (Gustas & Supernant, 2017, p. 46). Nonetheless, one may even state the opposite, namely that it is risky to venture in unknown waters without keeping a safe distance from the coast, as primary sources document (section 4.3). The issue is two-fold: on the one hand, there are environmental threats connected to land-proximity; on the other, there are non-environmental threats associated with land proximity and land sight, namely the possibility of being spotted and assaulted. Hence, Beresford’s statement ‘there is little doubting the importance of the visible shoreline to seafarers’ should be questioned and articulated, at least in terms of trying to determine ‘up to which distance’ it would be safe to keep sight of the shore to benefit from the orientation aid without facing both the environmental and non-environmental risks connected to being close to the shoreline.

According to scholarly tradition, in the Mediterranean Sea, the land's sight does not necessarily imply the risk of being close to it. Indeed, in many areas “promontories and islands could be seen from ships fifty, or even one hundred miles away [hence] it is clear that merely remaining within sight of the coast does not necessarily imply a constant effort to stay near to the shore” (Morton 2001, p. 144). Scholars have debated for nearly a century how great the range of visibility in the Mediterranean sea actually is; whether the latter is characterised by vast ‘maritime Saharas’ of open sea (Braudel, 1972, pp. 103-109) or rather by a predominant ‘mutual visibility’ with very few “restricted zones where, in the clearest weather, sailors will find themselves out of sight of land” (Horden & Purcell, 2000, p. 126; see also Aubet 1993, pp. 142-4; Beresford 2013, p. 183; Boodbank 2000, p. 40; Cary 1949, p. 29; Davis 2009, 45-50). As noted by Davis (2009, p. 46), Braudel’s view has been labelled as ‘misleading’ by Horden and Purcell and later scholars, which have tended to emphasise the high degree of inter-visibility throughout the Mediterranean in optimal weather conditions (Broodbank, 2000, p. 40; Horden & Purcell, 2000, p. 126).

In 1949 Cary (1949, 29) wrote in his ‘The Geographic Background of Greek and Roman History’ that the “Mainland chains or island peaks will show up at ranges extending to 100 miles, thus enabling ships to hold an almost straight course over long routes without losing sight of land”. Similarly, in 1993 Aubet (pp. 142-144) stated: “it has been proven that in favourable weather conditions, with very few exceptions, the coast or the mainland is visible from any point in the Mediterranean”. According to Pascal Arnaud:

En été, la transparence de l'air garantit le plus souvent en Méditerranée une visibilité supérieure à 10 nautiques, sauf sous les grains d'orage, ou dans les cas de bancs de brouillard de rayonnement qui se forment parfois pendant la nuit le long des côtes, que les brises poussent vers le large parallèlement aux côtes, surtout en août, et que le soleil ne suffit pas toujours à dissiper. (Arnaud 2005, 29)

Scholars have spent much effort supporting their positions by discussing the supposed correctness or the inaccuracy of the visibility-range elaborated by scientific and computing means[38]. The map that is most commonly referred to in this matter is the one elaborated by Schüle (1967, p.79; cf. Schüle, 1970, pp. 449–62), which illustrates theoretical sighting distances at sea (Figure 4.1). This has been modified afterwards and referred to by many scholars (e.g. Aubet 1993, fig. 23; Arnaud 2005, pp. 30–31; Broodbank 2000, fig. 4; Chapman, 1990, fig. 59; Davis, 2009, fig. 2.16; Horden & Purcell 2000, Map 9; McGrail, 2014, p. 87, fig. 2.12).

The map seems to support the idea of a Mediterranean 'bound together by ties of mutual visibility' (Davis 2009, p. 45). Nonetheless, such an optimistic view that even Str. *Geog*. suspected to be an exaggeration (Str. *Geog*, 7, fragment 6) takes into account 'optimal weather conditions'. The actual range of land-visibility is much shorter since it is affected by multiple environmental and meteorological conditions such as humidity, heat and 'dusty' winds even during the 'good season' (Arnaud, 2005; Davis 2009, pp. 49-50; Leidwanger, 2020, pp. 28-30). Acknowledging this limitation, Arnaud suggests using Schüle's map to identify the areas where the land is never visible, not the contrary (Arnaud 2005, p. 30). He also highlights that:

Cette carte ne tient compte que des contraintes de géométrie de la sphère et en aucune façon des spécificités optiques propres à la transparence de l'air. La visibilité ordinaire dépasse rarement 20 milles nautiques (un peu moins de 40 km) en été. (Arnaud, 2005, p. 31)

Furthermore, the map does not highlight *what* may be spotted exactly, for seeing the top of a hill or rather a landmark or the shore may have different implications for a mariner (Medas, 2004, pp. 71-80). In fact, whereas hills and mountains may provide a 'safe' visual aid for they are visible at a great distance, it may be dangerous to get close enough to the land to spot the shoreline at the risk to encounter sandbanks and reefs:

Dans une atmosphère limpide, la distance à laquelle un objet est théoriquement visible est définie par son altitude: une côte de 2 m de hauteur n'est visible depuis le pont d'un bateau qu'à 2,9 milles. Un point situé à 500 m d'altitude est visible à 46,9 milles correspondant, pour un bateau évoluant à 3 nœuds, à un trajet de plus de quinze heures. Un sommet de 1 000 m est théoriquement visible d'une distance de 66,4 milles. (Arnaud 2005, p. 29 and figure in p. 33)

[38] The mathematics behind the calculation of the distance to the horizon based on the observer's height above mean sea level, as well as the differences between visible, sensible and geometric horizons due to the atmospheric refraction and the curvature of the earth's surface is explained in several nautical handbooks. See e.g., https://www.sailingissues.com/navcourse5.html. Accessed: 16 June 2020

Similarly, even when at a broad and safe distance from the shore, there might be low outcrops or flat islands threatening the safety of the boats, which the map does not take into account.

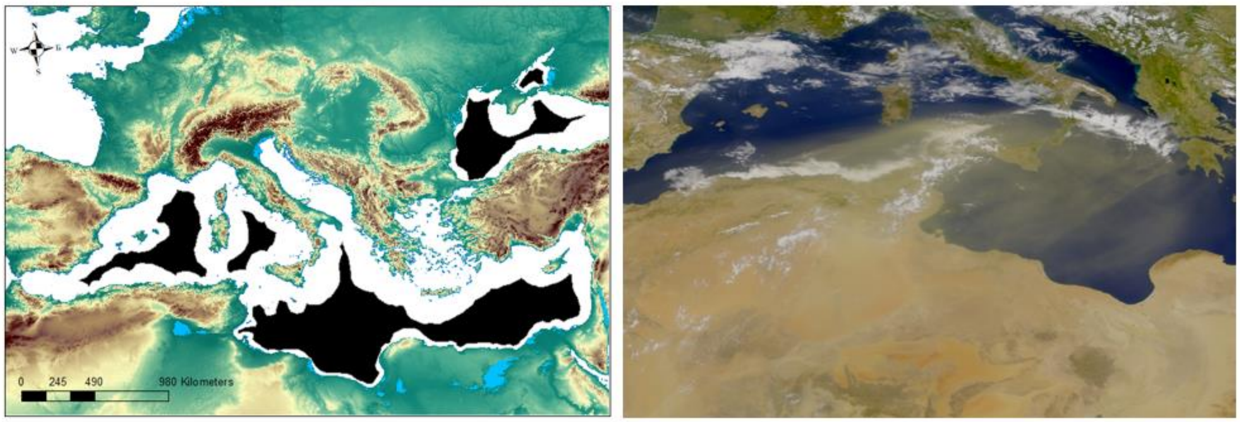

Figure 4.1: To the left: Geographic range of visibility. Black represents areas that are always out of sight of land (adapted after Chapman 1990, fig. 59 in Davis, 2009, fig. 2.16). To the right (A) Saharan dust storm over the Eastern Mediterranean in April 2000. (B) Saharan dust storm heads out of North Africa over the Mediterranean to Europe on July 18, 2000 (SeaWIFS, public domain, NASA/Goddard Space Flight Center, The SeaWiFS Project and GeoEye, Scientific Visualization Studio. Cf. also in Davis, 2009)

Besides, as previously said, the human hazards potentially connected to being in sight of the shore are usually underestimated or even neglected when only considering the suitable distance at which one should be in order to avoid the environmental threats of the shore. Albeit theoretically acknowledged, the assault probability has been only sporadically addressed by investigating suitable mitigating risk-measures or route preferences. However, there is not always agreement among scholars: according to Morton (2001, p. 156), the commercial vessels would have tried to avoid dangerous coastline whilst warships would not have been scared to face an attack. Conversely, according to Braudel (1975, p. 107), remaining in coastal waters would enable one to reach land and a nearby safe port in case of assault, whereas in open sea “there was nowhere to run to”. The impact of piracy on the sailing season is more broadly discussed by scholarship (Beresford 2013; de Souza, 2013; Dominiguez Monedero, 2013); for instance, it is a common opinion that

> the threat posed to shipping from human hazards— in the form of pirates, privateers, buccaneers, and other commerce raiders— would, for long periods of Graeco-Roman history, have provided a strong incentive for ship-owners and merchants to risk their vessels and cargoes on winter seas in an effort to avoid the dangers presented by these seaborne predators (Beresford, 2013, p. 237)

The above position is also supported by information in primary sources documenting the impact of technologies on pirates’ navigation strategies: pirates would prefer small and light crafts for gaining in speed and for being able to quickly hide their vessels inshore (Str. *Geog*, 11.495; Tac. *Hist*., 3.47 Thuc., 4.67.3); these kinds of vessels would not likely handle navigation in extreme winter conditions.

As stressed by Pascal Arnaud:

> *Autant et plus que les conditions naturelles, les conditions politiques sont susceptibles de modifier les routes de la navigation. Ce phénomène a été bien mis en évidence pour le Moyen Âge (Petti-Balbi 1996, pp. 272-273). La nécessité d'éviter des zones entières ou de faire relâche dans des ports spécifiques dans les conditions déterminées par les traités ont certainement eu leur rôle à jouer (Arnaud, 2005, p. 33)*

However, the political conditions and more generally, the assault-probability (or human hazard) have never been taken into account in current navigation-modelling approaches, which have emphasised the utility of land sight in terms of orientation, thus even constraining the range of likely corridor-routes to the range of visibility (e.g. Gustas & Supernant, 2017; Perissiou, 2014) without considering the risks connected to it. As further discussed below the risk perceived by ancient mariners does not necessarily entail an effective higher probability of sinking but may result in navigation preferences. This difference between potential navigation preferences reflecting how the hazards were *perceived*, and the threats actually enhancing the risk for the vessel, bring us back to the nautical uniformitarianism concept (section 2.2.2) and to the need to investigate past mariners' perception for better addressing navigation preferences and strategies. In contrast to studies assuming that past mariners would try to avoid the same risks as present-day mariners, other scholars pointed out that this may not always be the case (e.g. Janni, 1996, pp. 473-474), and the following overview aims at reinforcing this.

4.3 A REVIEW OF ACCOUNTS IN PRIMARY SOURCES

The present section does not claim to list the beneficial aspects or the threats affecting coastal strategies, nor to summarise the whole range of variables impacting direct routes and tramping, which the scholarship has already widely discussed (see, e.g., Arnaud, 2005; Arnaud, 2011; Beresford, 2013; Davis, 2009; Horden & Purcell, 2000; Morton, 2001; see chapter 5 for references on the selected model-factors). Rather, it aims to highlight a number of underestimated issues that impact the performance of current navigation-modelling approaches, which are derived from primary sources accounts. In particular, the systematic screening of historical accounts from the digital libraries ToposText and Perseus, aims at ascertaining whether risks and benefits of coastal-proximity (a summary is provided in Tab 2) may be clearly distinguished in ancient sources as opposing categories or rather their perception may be circumstantial, hence dependent upon economic and socio-cultural conditions.

The review has been carried out by querying digital libraries through keywords. First, excerpts containing the words ‘coast’, ‘coastline’, ‘shore’, ‘shoreline’ have been selected in order to identify potentially recurrent elements associated to the coast (e.g. ports, shelters, anchorages) and related to navigation strategies. Afterwards, the identified elements have been further searched independently since they may be mentioned alone by sources, namely without explicit reference to the shore or the land. The above procedure enabled to select more than 15000 excerpts, from which only those hinting at meaningful advantages or disadvantages of coastal proximity, as well as explicit accounts on navigation strategies in littoral areas, have been considered. The most meaningful of these accounts are listed in Appendix 1.

In this investigation and selection process, a number of potentially interesting accounts might have been omitted, for synonyms or related terms such as ‘land’ could not be inquired. Indeed, as ‘land’ does not refer exclusively to the coastal area, the research results would have been too numerous and impossible to process without having recourse to automatic systems or machine learning, the employment of which was beyond the scope of the present research. Another constraint relates to the fact that only the sources included in the Digital Libraries were queried. A schematisation of the advantages and disadvantages emerging from ancient sources in relation to coastal proximity is given in table 4.1 and will be discussed in the section below. The table does not include references from the *Stadiasmus*, which are recalled in sections 4.3.1, 4.3.2, 4.3.3, 4.3.4 and discussed more extensively in sections 5.3.2 and in Attachment 2 of this thesis as for the part of interest for the Regional model. The full list of selected excerpts is in Attachment 1.

Table 4.1: Selection of primary sources accounts describing advantages and risks associated to the coastal proximity

ADVANTAGES OF COASTAL PROXIMITY	
SHELTER IN CASE OF DETERIORATING WEATHER CONDITIONS	Caes. *BAfr.*, 62; Hom. *Od.*, 13.95; Liv., 37.16; Se. *QNat.*, 6.1; Str. *Geog*, 16.4.18; Vell. Pat., 2.72.3; Vitr. *De arch.*, 5.12.1;
HARBOURS, ANCHORAGES AND SHELTERS	Liv., 27.30; *Per. Mar. Eryth*, 12, 20, 24, 26; Str. *Geog*, 16.4.18; 17.3.20, 17.3.22
PRESENCE OF LAND AND SEA BREEZES NOCTURNAL DIURNAL WINDS	Amm. Marc., 20.1.3; Amm. Marc., 19.10.4; *Anth. Gr.*, 10.17, 10.24; Ap. Rhod. *Argon.*, 1.922; Arr. *Peripl.* 4; Hom. *Il* 1.482; Hom. *Od.* 2.388, 2.421–428, 4.786, 13.93–95; Luc. *Ph.* 9.140; Nonnus, *Dion.*, 3.1.16; Ov. *Met.*, 11.474
WATERING AND SUPPLIES	Diod. Sic., 3.44.6; Hom. *Od.*, 9.63, 10.56, 12.260; *Per. Mar. Eryth*, 26; Str. *Geog*, 17.3.22; Synesius, 51.1
LAND-NETWORK (E.G. NEARBY CITIES, ROADS)	Str. Geog, 17.3.22
ORIENTATION, LANDMARKS, LIGHTHOUSES, BEACONS	Nonnus, *Dion.* 3.1; Str. *Geog*, 17.1.6;
CULTURAL ATTRACTORS (I.E. SANCTUARIES FOR ASYLUM/PROTECTION)	Hdt., 2.113
RISKS OF COASTAL PROXIMITY	
HUMAN-HAZARD (I.E. ATTACK-PROBABILITY, HOSTILE SHORES)	Arr. Anab., 2.1.2; App. B Civ., 5.13.123; Dion. Byz., 77; Diod. Sic., 16.5.1; Diod. Sic., 1.67.8; Hdt., 4.156; Joseph. BJ , 3.419; Liv., 28.37, Liv., 31.17, 37.16; Polyb., 1.53.1; Str. Geog, 14.1.7; Tac. Ann., 4.67; Tac. Hist., 2.35; Thuc., 2.90, 4.8.7, 4.14; Xen. Hell., 5.1.9

VISIBILITY-RISK	Tac. *Ann*., 4.67; Thuc., 2.90; 3.81;
NO-HARBOUR	Aesch. *Supp*. 755; Caes. *BAfr*., 3.9; Dion. Byz., 77; Diod. Sic., 1.31.1, 20.74.1; Joseph. *AJ*, 15.9.6; Joseph. *BJ* , 1.408; Polyb., 1.39.1; 1.37.1; Str. Geog, 16.4.23, 17.1.6 Thuc., 4.8.7
UNSAFE ANCHORAGE	Diod. Sic., 14.49.1, 20.74.1; Dion. Hal. *Ant. Rom*., 1.56.1; Joseph. *AJ*, 15.9.6; Liv., 37.16; Polyb., 1.37.1, 1.39.1; Verg. Aen.2.1
MYTHOLOGICAL HAZARDS, SUPERSTITIONS, TABOO	Ap. Rhod. *Argon* 4.885; *Dict. Cret*., 6.5; Dio Chrys. Or., 33.41; 33.35; Hom. *Od*., 12.165, 12.31; Ov. *Ars am*., 3.310; Paus., 5.25.3; Plin. *HN,* 9.4.1, 10.70.1; Verg. *Aen*.5.835
SHALLOWS, SHOALS, SAND BARS	Arr. *Anab*., 1.3.1; Caes. *BAfr*.3.9; 3.13; Dion. Byz., 77; Diod. Sic., 1.31.1, 20.74.1; Hdt., 2.102, 4.179; Phot. *Bibl*., 224.36.1; Plin. *HN*, 5.4.1; Plut. *Pomp*., 78; Polyb., 1.39.1; Solin. 32.40; Str. *Geog*, 17.1.6, 17.1.18, 17.3.20; Tac. *Ann*., 14.29; Tac. *Hist*., 2.35, 4.27, 5.15; Thuc., 2.91
ROCKS UNDERWATER OR OUTCROPS	Diod. Sic., 1.31.1; Joseph. *BJ* , 3.419; Polyb., 1.37.1; Str. *Geog*, 16.4.18, 17.1, 16.4.23
VULCANISM	Str. Geog. *Geog*, 6.2
HAZARDOUS ENTRANCE IN HARBOURS	Arr. *Anab*., 1.3.1; Str. Geog., 17.1
STORMS CLOSE TO SHORE - DIFFICULT MANEUVERABILITY IN STORMY WEATHER; ADVERSE WINDS	App. *B Civ*., 2.9.59, 5.10.89; Caes. *BAfr*.5.10; Caes. *Bciv*.3.27; Diod. Sic., 14.68.1, 20.74.1; Hom. *Od*., 7.240; Hdt., 7.188; Joseph. *BJ* , 1.408; Joseph. *AJ*, 15.9.6; *NT Acts,* 27.13-17; Polyb., 1.37.1, 1.39.1; Phot. *Bibl*., 224.36.1*;* Sen. *Ep*., 53.2

4.3.1 Shelters providing conditional refuge

Strabo provides an explicit summary of the beneficial conditions of coasting (*Geog*., 17.3.22):

> The rest of the sea-coast of Cyrene from Apollonia to Catabathmus is 2200 stadia in length; it does not throughout afford facilities for coasting along it; for harbours, anchorage, habitations, and watering-places are few.

Among the main advantages most often associated to coastal proximity is the possibility to reach a nearby harbour or shelter in case one needs to face 'one of those uncertainties that are unfortunately frequent in the sea' (Synesius, 4.8). From a terminological point of view, there is a broad variety of terms used for distinguishing the broad variety of sites located at the interface between land and water that may be included under the term of landing sites (Ilves, 2012; Safadi, 2016, p. 349) in Greek (*λιμήν, ὅρμος, πάνορμος, ὕφορμος, σάλος, ἀγκυροβόλιον, αἰγιαλός, ἐμπόριον, ἐπίνειον*) and in Latin (e.g. *limen, hormos, salos, emporion, portus and statio*[39]; Arnaud & Keay, 2020, p. 6; Rougé, 1966, pp. 107–120). For a more detailed discussion on their differences and their problematic use for elaborating landing-sites hierarchy see Chapter 5.

The availability of shelters and ports is essential in case of storm (Caes. *BAfr*., 62; Hom. *Od*., 13.95; Liv., 37.16; Se. *QNat*., 6.1; Str. *Geog*, 16.4.18; Vell. Pat., 2.72.3; Vitr. *De arch*., 5.12.1) but also for re-filling water and for accessing extra facilities (Diod. Sic., 3.44.6; Hom. *Od*., 9.63, 10.56, 12.260; *Per*. *Mar*. *Eryth*, 26; Str. *Geog*, 17.3.22; Synesius, 51.1), or to enable the reparation of damaged vessels. Obviously, landing also makes it possible to trade and connect to land-based transport networks. Because of this, *importuosus* shores, in Greek *ἀλίμενος*, namely coastline without havens and shelters were considered inconvenient and risky to approach (Aesch. Supp. 755; App. *B Civ.,* 2.9.59; Caes. *BAfr*., 3.9; Dion. Byz., 77; Diod. Sic., 1.31.1, 20.74.1; Polyb., 1.37.1, 1.39.1; Str. Geog, 16.4.23; 17.1.6 Thuc., 4.8.7; Joseph. *AJ*, 15.9.6; Joseph. *BJ* , 1.408; Polyb., 1.54.1; Tac. Ann., 12.20).

Nonetheless, ports, anchorages and shelters are not all equally convenient indeed logistic, economic and political considerations would make it better to access one place rather than another, or even prevent the access to a certain type of vessel or mariner (the most recent contribution is Arnaud & Keay, 2020; see further in chapter 5).

As for the environmental aspects, harbours are often mentioned in ancient sources with additional qualitative adjectives such as 'good' (Pseudo Scylax, *Periplous*, 30; *Stadiasmus*, 104) or even 'the best of all in the Syrtis' (Str. *Geog*, 17.3.20, similarly also Str. *Geog*. 5.2.5). According to Vitruvius (Architecture, 5.12.1) the harbours providing greatest service are those that have natural advantages, such as projecting capes or promontories that curve inwards naturally; he advises to build around them colonnades, shipyards, passages from the colonnades to the business quarters, and towers on both sides, from which chains can be drawn across by machinery. Knowing the position and nature of the harbours available along a planned route is therefore fundamental for

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[39] It has been already noted that this assortment is greater in Greek than in Latin, the latter apparently translating the terminology of the former, which may be due to the greater mariner tradition of Greeks over the Latins (Rougé, 1966, p. 107). Although this interpretation is not broadly accepted by the scholarship (Medas, 2010, p.130; on the original Roman contribution to mariner terminology see Uggeri, 1968).

safe navigation; Julius Caesar, (Caes. *BGall.*, 3.9) lists them among the hazards an experienced mariner should be aware of:

> they felt that, even though everything should turn out contrary to expectation, they were predominant in sea-power, while the Romans had no supply of ships, no knowledge of the shoals, harbours, or islands in the region where they were about to wage war.

The 15th-century navigational handbook *De Navigatione* by Benedictus de Cotrullis, provides a formal assessment of the factors contributing to make a harbour safe and generally 'good', namely the size, capacity, exposure, nature of the seabed, water-access (Kotruljević , 2005, pp. 82-84). Similarly, medieval portolans and more in general, Greek and Latin sources provide information in these regards when mentioning the different havens, although in occasional and unsystematic manner.

Accounts regarding harbours' capacity are rarely precise, as for instance, in Str. *Geog*. "large enough for only fifty boats" (Str. *Geog*. 9.2.) or in Diodorus "The dockyards could accommodate sixty triremes and had an entrance that was closed off, through which only one ship could enter at a time". More often, sources state that ports may contain only small ships (*Stadiasmus* 86, 308). In the *Stadiasmus* at least in one occasion, there is a rough indication of the dimension of the vessels allowed to enter, which may have up to a certain units of cargo (*Stadiasmus*, 2). Moreover, the inscription known as the Law of the port of Thasos dating 250/200 BC, which was first published by Launey in 1933 (IG XII Suppl. 151, no. 348 = SEG XVII: 417) suggests that ships would be excluded from certain harbour basins depending on their tonnages (Arnaud 2011, p 63, particularly note 24 for the problematic interpretation and translation of the text; Casson 1971; Houston 1988, pp. 553-564; Launey 1933, pp. 394-415; Nantet 2020, pp. 79-80).

The most famous examples in literature of super freighters becoming unusable after a very short period of time because port facilities could not accommodate them are the ships *Isis* and *Syracusia*. The *Isis* is described by the satirist Lucian of Samosata (*Navigium*, 5) as a grain carrier that in the second century CE was following the route from Alexandria to Rome when it was blown off course to Athens. The *Syracusia* is known thanks to Athenaeus (Ath., 5.37–44; ibid. 6.20), who transcribed an account by the Hellenistic paradoxographer Moschion: Hiero of Syracuse (306–215 BCE) is said to have ordered the building of this three-masted grain carrier under the supervision of the scientist Archimedes. Although the scholarship still debates around the degree of trustworthiness of both the Syracusia and the Isis accounts (e.g. Houston 1987), their estimated tonnage is impressive: indeed, according to the dimensions given by Lucian, namely 120 cubits (55 m) long, and approximately 15 m in beam with a hold 29 cubits (14 m) deep, the Isis' burden ranged from 1,100 to 3,250 tons; whereas according to Moschion's data, the Syracusia's deadweight would have been between 1,700 and 4,200 tons (Carlson, 2013, pp. 392-393; Casson, 1971, pp. 183-200; Macintosh Turfa & Steinmayer Jr, 1999; Pomey & Tchernia 1978, pp. 233-251).

Depths and nature of the seabed are also often recorded, e.g. Str. *Geog* (17.1.6) specifies that the great harbour of Alexandria 'has sufficient depth near the shore to allow the largest vessel to anchor near the stairs' (Str. *Geog*., 17.1; see also Str. *Geog*. 5.2.5). In the Periplus of the Erythrean Sea there are several references to the kind of bottom enabling anchors to hold safely, and to the sea bottom causing anchors to be cut-off because rocky and rough (*Per. Mar. Eryth,* 24; 43).

Similarly, as for the exposure, some ports may protect from all winds (*Stadiasmus*, 16, 20, 29, 297, 304) or be exposed to specific wind-directions (Liv., 26.42; *Stadiasmus,* 308), while others may be suitable in certain seasons only (*Stadiasmus*, 322).

The access to certain ports might have been difficult and hazardous because of rocks at the entrance (e.g. *Stadiasmus*, 343), because of shoals nearby (e.g. in *Stadiasmus*, 114, the difficulty to access is explicit; more general warning on the presence of shoals also in *Stadiasmus* 5, 23, 57, 112) or because of narrow and tight passages: Diodorus specifies that in Ortygia (Syracuse) the small harbour known as *Laccium* had dockyards that could accommodate sixty triremes but ships could only pass one at a time through the entrance (Diod. Sic. 14.7).

Besides the environmental factors, jurisdictional and economic aspects played an important role in making certain sites potentially more attractive than others. From around the 5th century BC, most international trading operations in the Mediterranean were regulated by international agreements and conventions (*synthekai, spondai*) between states (e.g. the treaties between Romans and Carthaginians Polybius, Historia 3.22–5), which established the conditions for trading, the nationalities allowed to enter certain ports, the activities that were possible to be carried out (e.g. commercial operation, temporary shelter in case of storm, water refill). Violating any part of these commercial treaties could be a reason for starting a war, as happened at the beginning of the Peloponnesian war. Thucydides refers that the tension between the Athenians and the Spartans was increasing and many believed the war could start any time, but the event that sparked the conflict was the decision of the Athenians to ban the Megarian ships from the harbours of the Delian League:

> There were many who came forward and made their several accusations; among them, the Megarians, in a long list of grievances, called special attention to the fact of their exclusion from the ports of the Athenian empire and the market of Athens, in defiance of the treaty. (Thuc. 1.67.4; see also Thuc. 1.123)

A further aspect connected to the jurisdictional or political convenience of ports is represented by the risk of being attacked from land by inimical coastal states. The assault probability is further debated below among other disadvantages of coastal proximity (section 4.3.4), but here it is worth mentioning that ships in transit along the coast also had to face the risk of reprisal (*syle*). Indeed, cities or private citizens (e.g. Aristot., *Econ*., 2.1347b) had the right to assault a foreign ship passing by the shore or entering a harbour, for covering losses or injures previously received by citizens whose provenance was the same as the ship's (for a debate on the consequences of *sylai* on trade in classical time see Arnaud, 2011).

> The people of Chalcedon had a large number of mercenary troops in their city, to whom they could not pay the wages they owed. Accordingly they made proclamation that anyone, either citizen or alien, who had right of reprisal against any city or individual, and wished to exercise it, should have his name entered on a list. A large number of names was enrolled, and the people thus obtained a specious pretext for exercising reprisal upon ships that were passing on their way to the Pontus. They accordingly arrested the ships and fixed a period within which they would consider any claims that might be made in respect of them. Having now a large fund in hand, they paid off the mercenaries, and set up a tribunal

to decide the claims; and those whose goods had been unjustly seized were compensated out of the revenues of the state (Aristot., *Econ*., 2.1347b)

Sylai constituted a serious risk for vessels in transit along the coast, although the right of reprisal was not granted everywhere:

> And, if they do not enter Pontus, but remain in the Hellespont ten days after the rising of the dog star, and disembark their goods at a port where the Athenians have no right of reprisals, and from thence complete their voyage to Athens, let them pay the interest written into the contract the year before (Dem. 35. 13; see also Polyb. 4.53; Thuc., 1.142)

The risk associated to the assault probability was taken into account by mariners approaching harbours no less than other environmental considerations: by referring to the harbour of *Phoenicus* Livy says that it afforded a safe shelter from the violence of the waves, but it was surrounded by high cliffs, which the townsmen together with the king's troops who formed the garrison promptly occupied (Liv., 37.16). Similarly, although referring to a harbourless shore, Tacitus argues that "the isolation of the Island of Capri was its main attraction for him (Tiberius), since its coastline is without harbours and provides scant shelter for even small vessels, nor could anyone land without being seen by the sentries" (Tac. *Ann*., 4.67).

As for the economic considerations, these include taxes to pay, particularly the *portoria*, i.e. the custom duties (see Meijer & van Nijf, 1992, p. 78), and *vectigalia,* i.e. the so-called indirect taxes (Aeschin. *In Ctes,* 112 and 119; Cic. *Fam*., 60.29.2; Cic, *Att*.2.16*)*. The two terms are sometimes used as synonyms, such as in the definition contained in the Digests of Justinian, derived from the jurist Ulpian (Dig. 50.16.17.1)[40]:

> *"Publica vectigalia intellegere debemus, ex quibus vectigal fiscus capit: quale est vectigal portus vel venalium rerum, item salinarum et metallorum et picariarum"*
>
> We have to understand public taxes as those from which the Treasury captures revenue: for instance, the tax of the harbour or the tax on selling products, likewise on salt-pits and mines and bitumen fabrics (translation by Günther 2016).

The literary evidence on the Roman taxation systems is scarce, and needs to be addressed by combining different sources, e.g. epigraphic, numismatic, papyrological; such a reconstruction lies out of the scope of the present research. In order to take the taxation system-related variables into account in the present work, a number of secondary sources have been used, among which the seminal synthesis by De Laet published in 1949, which still constitutes one of the main references on *portorium* in the Roman Empire, and a few recent contributions (i.e. Jérôme, 1999; Kritzinger et al., 2015; Günther, 2016; Hopkins, 1980; Lo Cascio, 2000, particularly the contributions by Raymond Descat, and Yan Zelener).

The overall information from both historical and archaeological evidence is highly scattered, and the exact amount of the custom dues during the high Roman Empire are known only for very few *stationes* (Zarai CIL, VIII, 4508; and Lambése AE, 1914, n. 234). We do know that a fixed amount

[40] A discussion on the differences between the two taxes, on the situations in which the terms are used as synonyms and on direct and indirect taxes is in Günther, 2016, p. 3 and *Ibid*. 2008; cfr. also Kritzinger, et al., 2015, p.12

ad valorem was applied in all the Roman Empire districts to all commodities irrespective of their nature and that there was no unified tariff within the Roman Empire; indeed, custom dues differ according to the different Roman fiscal districts and depending on the declared goods; moreover, changes may have occurred across different periods of time. In light of the available evidence, values have been estimated to be 2 % in Spain, 2 ½ in Gaulle and Asia, and 5 % in Sicily (De Laet 1949: 242; Günter 2016: 11-12; see also Cod. Theod., t. II, ed Mommsen Meyer, p. 95, XIII, 12 as mentioned in De Laet 1949, p. 271); nonetheless, archaeological and epigraphic evidence document that variations occurred also within the same district: *portoria* were generally higher at the border of the fiscal districts than at the inner stations (examples are documented by the inscriptions of Zarai and Lambése in Africa and CIL, VIII, 4508; AE, 1914, n. 234 as reported in De Laet, 1949, p. 269). Also, variations are documented depending on the origins of the goods declared: those coming from other parts of the Roman Empire were taxed less than those coming from outside (e.g. the toll of the *Portorium Illirici* was 2% for Roman provenances, and 5 % for non-Roman origins; moreover, tolls could be higher at the border of the Roman Empire, as reported in De Laet , 1949, p. 245).

Sources document that new taxes may have been introduced temporarily, such as in the case of the 'tax on edibles' -probably a *portorium*- introduced by Caligula for the toll district of Rome (Suet. *Cal*. 40) and probably abolished by Claudius (Suet. *Claud*, 11.3). Information on local abolishment is also in Cicero, as for Italy (Cic. *Att*., 2.16). Temporary concessions granted to targeted groups with specific aims are also attested, although scholars debate around the historical veracity: Livy, for instance, documents how at the time of Porsenna, the senate accorded many concessions to the plebs, among which the abolition of harbour-dues and war-tax, in order to maintain the harmony in the country through the subsequent stress of siege and famine (Liv., 2.9); this is also the oldest attestation of *portorium* in the sources (De Laet 1949: 45). We also know that the custom-dues were leased out to contractors (Liv., 32.7), and forms of extorsion occurred, e.g. Cicero reports that ca. 60 BCE citizens would complain more for 'certain extortionate conduct on the part of the collectors' than for 'the dues themselves' (Cic. *Fam*., 60.29.2).

The area falling within the selected regional case-study (i.e., from Cap Bon, current Tunisia to Alexandria, current Egypt; section 1.2) included the following districts during the High Roman Empire: the *Quattuor publica Africae*, the *portorium* of Cyrenaica and the *portorium* of Egypt.

The *portorium* in the Africa province is the one for which less information are available, particularly if compared to the districts of the *Quadragesima Galliarum* and the *Publicum portorii Illyrici* (Dupuis 2000, p. 294; De Laet 1949, pp. 247-271); particularly, scholars have discussed whether to interpret the *Quattuor publica Africae* as a single tax, i.e. the *portorium* of the province of Africa, whose territory would have been divided into four customs districts, or rather as four different public revenues -including but not limited to the *portorium*-, the administration and collection of which were entrusted to the same hands. The former hypothesis is sustained among other by F. Kniep, M. Rostovtzeff, O. Hirshfeld; the latter by R. Cagnat, F. Thibault, M. Guérin, R.M Haywood and de Laet, although these scholars disagree as for the nature of the four different revenues. According to De Laet, the *Quattuor publica Africae* must have been organised before the separation of Numidia from Africa (in the reign of Caligula) and before the inclusion of Mauretania, hence likely under the reign of Tiberius. According to him, it included

(De Laet 1949, p. 253 and note 1 p. 255): *the portorium, the Vigesima libertatis, the Quinta et vicesimal venalium mancipiorum, the vigesima hereditatium.*

Sources mention fifteen custom offices, distributed along the whole territory of the province of Africa, Numidia and Mauretania, either at ports or at inland stations. De Laet notices that:

> *En essayant de localiser les bureaux douaniers de ce district, nous ne pouvons pas perdre de vue que les employés des* Quattuor Publica Africae *étaient chargés de la perception de quatre impôts différents. Une* statio *des* Quatturo Publica *n'était donc nécessairement un bureau douaniers. Toutefois, l'emplacement des bureaux connus nous autorise á supposer qu'il s'agit, dans tous ces cas, d'une* statio *du* portorium (De Laet 1949, p. 253).

As for the *Portorium*, offices present in ports that are of interest to the present research, sources refer to those of Leptis Magna (i.e. Lebda, CIL, VIII, 22670 a = ILS, 8918), Carthago (CIL, VIII, 1128, 12655, 12920, 12656, 24607); Utica (i.e. Hammam Ellif, CIL, VIII, 997), Rusicade (CIL, VIII, 10484, 2-6)[41] and Chullu (i.e. Collo, CIL, VIII, p. 700, p. 979) although one cannot exclude the existence of further offices besides those for which sources accounts are known (De Laet, 1949, pp. 258-271).

The exact amount of the custom dues during the high Roman Empire are known only for very few *stations*. Particularly in the *Africae* district there was a fixed amount *ad valorem* applied to all the commodities no matter their nature, like in the other Roman Empire districts, and these values were higher at the border of the fiscal districts while lower at the inner stations, as the inscriptions from the inner stations of Zarai (CIL, VIII, 4508) and Lambése (AE, 1914, n. 234) show. Particularly, here the toll paid for wine and garum was around 2 ½ % which is considerably lower than the 5 % attested, e.g. in Sicily or in the districts of the *Quadragesima Galliarum* and the *Publicum portorii Illyrici*.

As for the other districts: the *portorium* was charged in the main ports of Cyrenaica, but we do not know the amount (see a passage by Cervidius Scaevola in Dig. XIX, 2, *loc. cond.,* 61, I; De Laet 1949, p. 295). As for Egypt, under the Ptolemaic and during the high Roman Empire in general, custom offices are known around the border of the whole country to control the commerce with the outside; particularly, custom offices were in Alexandria and along the mouth of the Nile up to Péluse (De Laet 1949, p. 300). Strabo states that custom duties had to be paid on goods exported from Egypt to other parts of the Roman Empire and that the port of Alexandria was the most important *portorium* office for the Northern Egyptian border (Str. *Geog* 17.1.13; Str. *Geog* 17, 1, 16).

Without claiming to provide a comprehensive account of this still relatively underexplored field of studies, what discussed above aims at highlighting that besides purely environmental and meteorological considerations, landing sites and harbours would be chosen by also taking into account economic convenience and socio-political conditions. For instance, big and furnished harbours providing many extra facilities might have been less convenient to approach for a small private seller, who would rather attempt to avoid tolls.

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[41] De Laet mentions besides CIL, several seals/plombs de douane, that have been found on the beach, which report the inscription RVSICADE; see references in De Laet 1949, 257, note 4)

4.3.2 More or less secure anchorages

Anchorages share a few similarities with harbours. For example, they are also recorded together with qualitative adjectives such as "smooth" (Callimachus, Hymn to Delos, 153), "safe" (Liv., 27.30; Polyb., 1.37.1;), "unsafe" (Verg. *Aen.*2.1), "more or less secure" (Polyb. 1.53.10), or "bad" (*Per. Mar. Eryth*, 10). Sometimes the reasons why an anchorage is considered unsafe are made explicit:

> This city is situated in Phoenicia, in the passage by sea to Egypt, between Joppa and Dora which are lesser maritime cities, and not fit for havens, on account of the impetuous south winds that beat upon them, which rolling the sands that come from the sea against the shores, do not admit of ships lying in their station; but the merchants are generally there forced to ride at their anchors in the sea itself. (Joseph. *AJ*, 15.9.6)
>
> The anchorage is dangerous at times from the ground-swell because the place is exposed to the north (*Per. Mar. Eryth*, 12)
>
> Navigation is dangerous along this whole coast of Arabia, which is without harbours, with bad anchorages, foul, inaccessible because of breakers and rocks, and terrible in every way (*Per. Mar. Eryth*, 20)
>
> The market-town of Muza is without a harbour, but has a good roadstead and anchorage because of the sandy bottom thereabouts, where the anchors hold safely (*Per.Mar. Eryth,* 24)

Also, the utility and relative safety at the anchorages depended upon the meteorological conditions, hence it was crucial for mariners to be able to anticipate them (App. *B Civ.,* 5.10.89). Anchorages would also be, as is further discussed below, more or less hazardous depending on the hostility of the inhabitants (e.g. Liv., 31.17; 'anchorage for pirates' Str. *Geog*, 14.1.7).

4.3.3 Clear, sweet fresh waters[42]

The possibility to refill drinkable water is not necessarily connected to the presence of a harbour; besides registering the availability of watering places along the coast (e.g. Str. *Geog*. 1.2.30; 3.5; 16.2; Plin. *HN* 2.106; Xen. *Anab*. 6.4; Hom. *Od*. 9.2; *SMM*, 26, 29, 31, 32, 35, 36,42, 75, 77) sources also frequently inform on their relative quality:

> Beyond Ocelis, [..] after about twelve hundred stadia there is Eudaemon Arabia, a village by the shore, also of the Kingdom of Charibael, and having convenient anchorages, and watering-places, sweeter and better than those at Ocelis (*Per. Mar. Eryth*, 26; see also Diod. Sic. 3.44.6)
>
> From Syke to Panormos 30 stades. It is a deep hollow; under the fig trees there is very good water (*SMM,* 31).

Generally in the *Stadisamus,* the presence of water on the shore is often associated with adjectives providing additional information on its nature: rainwater (*SMM*, 29), freshwater (*SMM*, 32), spring water (*SMM*, 26, 75), flowing water (*SMM*, 77), brackish water (*SMM*, 35, 36, 42), or 'good' water (*SMM*, 322 and *SMM*, 348 respectively beside the above-mentioned excerpts).

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[42] An homage to Francesco Petrarca '*Canzoniere*'

4.3.4 Unfavourable landmarks

As mentioned before, the advantageous aid in terms of orientation offered by the land sight (or by the visual spot of elements that may be connected to the land, such as the smoke, e.g., Hom, *Od*, 1.5; Synesius, 51. 1) is counterbalanced by the risk to be spotted and attacked. Besides the numerous accounts mentioning the utility of landmarks, beacons, torches or lighthouses, e.g., for facilitating access to the harbour (e.g. Str. *Geog*, 17.1.6), the downside of the mutual visibility is currently underestimated in predictive modelling despite being documented in primary sources by multiple accounts (Diod. 16.5; Thuc. 2.90, 4.8; Xen. *Hell*. 5.1).

Xenophon, for instance, (Xen. *An*. 5.1.9) declares that "when the ships of Eunomus were close to the shore near Cape Zoster in Attica, Gorgopas gave the order by the trumpet to sail against them". In the Mithridatic Wars, Appian (11.77) says that "they did not venture out to sea, but hugged the shore because they were afraid of the army of Lucullus. Thus, they were exposed to missiles on both sides, landward and seaward, and received a great many wounds, and after heavy slaughter took to flight". Again Appian, in the Civil wars, states that "the ships of Octavius were anchored away from the shore, as it was said that Lepidus intended to set fire to them" (App. *B Civ*., 5.13.123; see also Hdt., 4.156); similarly Flavius Josephus in the Jewish War (Joseph. *BJ*, 3.419) says that "the shore was so rocky, and had so many of the enemy upon it, that they were afraid to come to land".

Thucydides documents both attempts to approach land by trying not to be seen by the enemies dwelling on the shores (Thuc. 3.80.2, 81.1), and war-strategies consisting in waiting for the enemies to come close enough to the land for attacking them (Thuc. 2.90; 4.8.7; 4.14)

The assault-probability is also documented in time of 'peace' (i.e. not during wars) for instance in Diod. Sic., 16.5.1:

> In Apulia he founded two cities because he wished to make safe for navigators the passage across the Ionian Sea; for the barbarians who dwelt along the coast were accustomed to put out in numerous pirate ships and render the whole shore along the Adriatic Sea unsafe for merchants.

Particularly meaningful is the excerpt by Dionysius of Byzantium referring that the barbarians dwelling on the coast of the Pontos trick the ships and enhance their risk of wrecking by putting deceitful torches onshore:

> At the summit of the hill after Chrysorroas stands the tower of Timaia, very high, visible from all sides, and conspicuous from far at sea, built for the safety of navigators. For both parts of *Pontos* lack ports that can take large ships. For the long shore of the restless and turbulent sea has inlets in neither continent. From this tower flaming torches used to be kept lit at night as a guide of the correct way to the mouth of the Pontos. But the barbarians stole away confidence in the true torches by putting fraudulent torches on the shore of Salmydessos to lead sailors astray and cause shipwrecks. For the shore there is harborless and the shallows, by reason of the excess of water, are not firm for anchors, so a shipwreck is prepared for those who stray from the right road and confuse the true signs with false indications. But now, all-consuming time has extinguished the lamp, and much of the tower has collapsed (Dion. Byz., 77).

The attack probability enhanced by environmental conditions is not only connected to the sight of the land but also to the presence of shallows. Indeed, enemies could profit of ships being stuck in them for climbing aboard or for dragging them: Tacitus reports many episodes of this kind (Tac. *Hist*., 2.35; 4.27; 5.15).

4.3.5 Scent of a shore: creatures of the sea and further indicators of coastal proximity

Given the upside represented by landmarks in terms of orientation but also the risks entailed in being close to the land, mariners would attempt to timely ascertain the vicinity of the land by means of additional strategies besides land visibility. At least two accounts document that the presence of nearby land was surmised in different ways, and not necessarily seen:

The first, is the letters 51.1 by Synesius, who refers that the mariners noticed the beacon fire lit upon a tower to warn ships running too close. The second is the famous account of Paul's stormy voyage and shipwreck in the autumn of AD 60 (*Acts* 27. 27):

> When the fourteenth night had come and we were being carried along in the Sea of Adria [Ionian Sea], the sailors *suspe*cted (ὑπενόουν) that they were nearing land, and casting the sounding-weight they found 20 fathoms.

As for the aspects and the strategies enabling mariners to suspect the presence of land, sources document the use of specific tools and technologies such as the employment of sounding weights mentioned by Paul (Oleson, 2008, pp. 117- 174; see also Oleson, 1988, 1994, 2000) but also the account of different natural clues besides the (land) sight. Among these are the swell direction, biological indicators such as insects and birds, smells (e.g. Hom. *Od*. 4.398) and sounds (e.g. App. *BC* 4 appendix)

The swell, similarly to ripples and waves, is a manifestation of the wind giving the water energy. The condition by which wave energy travels beyond the area where the waves are created by the wind is called swell. Natural navigators are mainly interested in swell, since it is more dependable than waves; indeed, unlike the waves, which travel in the same direction of wind, swell may continue across or even against it (Gooley, 2011, p. 112; see also Gooley 2017, pp. 167-195). This principle appears to be well known to Strabo who, referring to the continual movement on the sea-surface produced by its agitation, states:

> This effect is certainly most considerable when the wind is on the water, but it continues when all is hushed, and even when it blows from land the swell is still carried to the shore against the wind, as if by a peculiar motion of the sea itself (Str. *Geog*, 1.3.8 - ca. 24 CE).

If navigators are able to recognise the swell direction, this can be used as a compass given the overall seasonal regularity of prevailing winds in the Mediterranean (chapter 5.3, 5.4.2, 5.4.3). Dionysius of Alexandria says that "from the Iapygian land, the swell of the Adriatic grows wide and stretches towards the north, and again towards the western corner, and those dwelling nearby also call it the Ionian sea" (Dionys. *Per*., 90).

The swell may also provide clues to nearby lands by looking at the patterns generated by its encounter with the shore. Indeed, "when a reflected wave meets an incoming wave they interfere with each other and the pattern in the water, the height, shape and rhythm of the waves will change" (Gooley, 2011, p. 116). Explicit accounts on the observation of the swell geometry for getting clues on land-proximity are for the Classical period -to present knowledge- unrecorded, although there are abundant testimonies on the employment of such a technique among low-technology seafarers following natural navigation approaches (see Fenton 1993, pp. 46-47, Hutchins, 1983, Hutchins, 1996 for the seafarers in Micronesian islands; Morton 2001, pp. 207, 223, 268 discussing the issue in ancient Greek seafaring; Arnaud, 2014 on mariners in Classical time; Gooley, 2011 and Gooley, 2017 on natural navigation approaches more generally). Navigators in the Marshall Islands, a small Micronesian community, have created stick representations of swell patterns generated after the encounter of the swell and the shore (Figure 4.2, mentioned in Gooley, 2011, p. 115); although nothing similar is attested in Classical and Roman time yet, a targeted iconographical inquiry may be fruitful since such tools have not been even looked for so far.

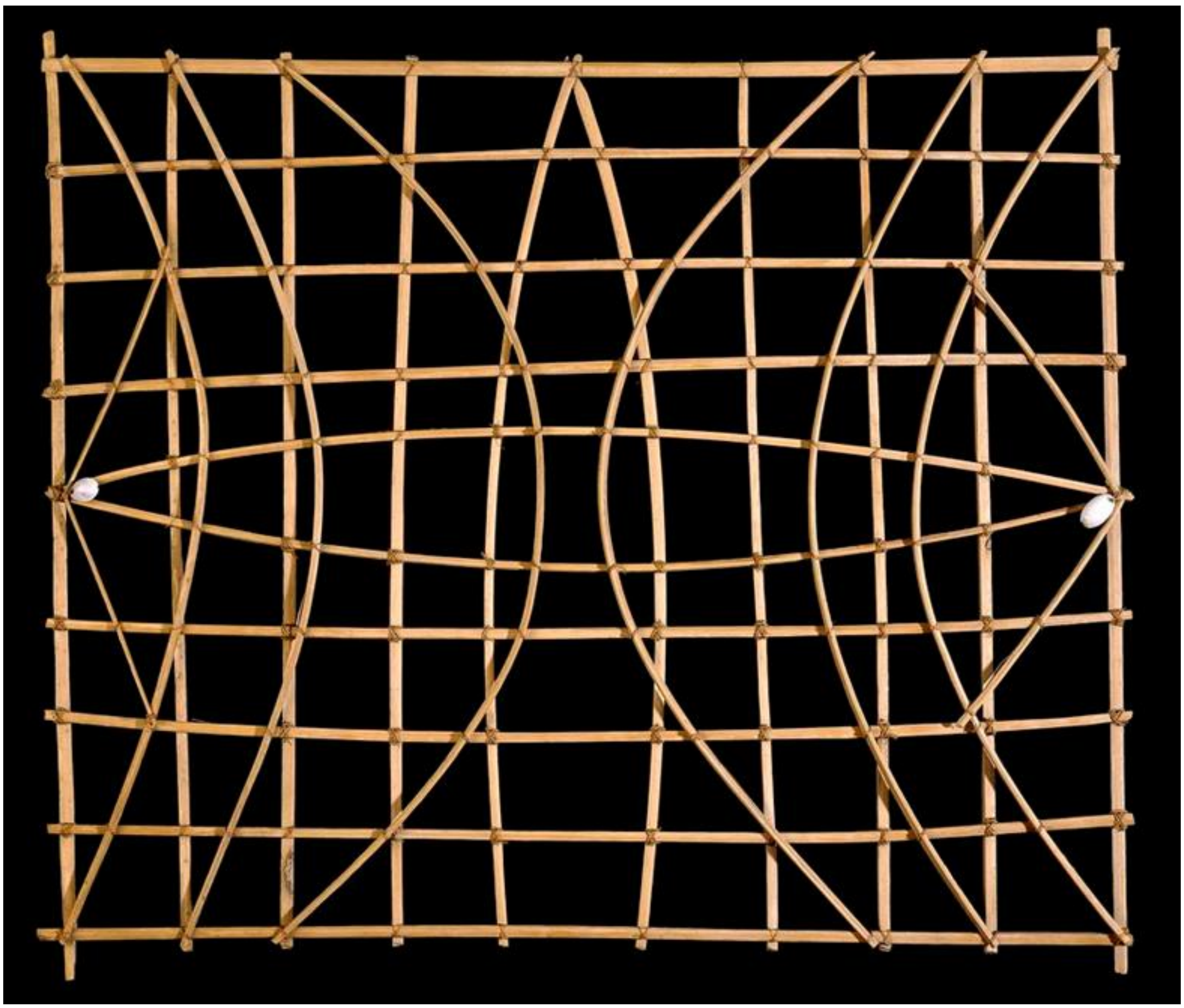

Figure 4.2: Stick chart from the Marshall Islands made out of straight and curved slivers of light wood tied in position by fibers, which represent the swell movement in relation to the land. The white shells represent islands. The British Museum, asset number 34111001 (© The Trustees of the British Museum, CC BY-NC-SA 4.0 license).

The practice of observing birds for gaining insights on the nearest landfall has been broadly discussed by the scholarship (Mynott, 2018; Morton 2001, p. 225 and ibid. note number 135 with bibliographical references; McGrail, 1983, p. 314; McGrail, 1991, p. 86; Hornell, 1946, pp. 142-148 Semple, 1932, p. 622). Birds provide two different kinds of spatial information, namely directions and land proximity clues. Both pelagic and coastal birds are able to provide directional clues. The former, like petrels and albatrosses, are able to cross the oceans and sustain themselves on the open sea for long periods. Although they do cross at specific times and moments of the year, and in principle, they may provide directional clues, it is actually difficult to use such information in the middle of the sea, particularly if mariners do not already know their exact position and orientation.

Besides direction, coastal birds provide more generally an indication of coastal proximity; indeed, given their limited autonomy from land, the presence of coastal species indicates that the land is within their range of flying from shore, which is a useful information in poor visibility conditions. Most coastal species set out in the morning and come back to land at night, hence a flock of such birds -rather than isolated animals- heading in a uniform direction at dusk are likely indicating the direction of land (on the greater reliability of observed flocks rather than single individuals, see Fenton 1993, 52; Gooley, 2011, p. 124). Arrian mentions a group of birds frequenting the temple of Achilles on the Island of Leuke, at the mouth of the River Danube, that every morning "fly out to sea and having moistened their wings, fly back again to the temple where they sprinkle the pavement with the moisture and clean it" (Arr. *Peripl.* 32). Certain species of birds were renowned for needing specific wind directions for their migrations across the Mediterranean (e.g. Aristotle mentions the quails in his *Historia Animalium* (Arist. *Hist. an.*, 8.12.7; Arnott 2007, p. 237).

Sources document that birds were often brought onboard ships and released to gain orientational clues from their flight. Velleius Paterculus reports that according to some accounts, the Chalcidians founded Cumae (Italy) by following the flight of a dove which flew before them (Vell. Pat., 1.4.1), whilst in the Argonautica, a dove was sent forth from the ship to test the passage through the perilous clashing rocks *Symplēgádes* (Greek: *Συμπληγάδες*) (Ap. Rhod. *Argon*, 2.328).

Further renowned literary episodes are the flood myth contained in Tablet XI of the Gilgamesh epic (Beckman , 2019, tablet XI, 80) and the story of Noah in the biblical flood (Genesis, 4-14, 20-21; see also Eusebius, Chronography, 7), both sharing a significant degree of literary similarities. In both stories, birds are used for assessing the level of water; indeed the animals come back onboard when they do not find a place to land. In the case of the biblical flood, a dove finally comes back to Noah holding an olive leaf in the mouth, thus suggesting that waters were abated from off the earth (Genesis, 11). In the epic of Gilgamesh, both a dove and a swallow are brought out in two different moments, and both came back after flying off without finding land where to rest; it is the raven that flew off and did not come back, as it saw the water subsiding and found food and cawed.

Certain birds were also used as weather forecast, particularly the raven, "the old prophet of rain" according to Horace (Odes, 3.17); indeed, either rain or fine weather could be expected depending on its behaviour and kind of cawing (as a clue of rain beside Horace also Theophrastus Weather Signs 16, 39, 40, Virgil Georgics 1.351; for expected fine weather Theophrastus Weather Signs 53).

Birds constitute an indicator of coastal proximity not just when spotted but also when heard (Mynott 2018, 43-67). In this regard, it is worth noticing that the sirens, the mythological creatures (Eur. Hec. 1265; Leidwanger, 2020, p. 29, note 16) supposed to lure the mariners with their enchanting voice and let them wreck on the rocks, originally had the body of birds with woman's head; only later on, started from the Middle Age, they assumed a mermaid-like shape, half human half fish (Moro, 2019, pp, 17-59).

Directional information and land-proximity clues are provided by insects as well. The trans-oceanic dispersal of some species has been proven to be in relation to wind currents (Bowden & Johnson 1976, p. 105); whilst other species can only fly off land up to a certain distance (Beavis 2002; Cheng 1976). Despite numerous ancient textual accounts on insects, including an entire chapter in Pliny's Naturalis Historia (book 11), explicit references to their use as indicators of coastal proximity or landfall direction could however, not be identified in the course of this research.

A further meaningful sense, which may have provided spatial clues to mariners in lack of sight, is constituted by the smell. The scholarship so far has mostly addressed the relationship between odour and worship (Clements, 2014, pp. 46-60, Green, 2014, pp. 146-157, Toner, 2014, pp. 158-170) as well as the ways people in antiquity responded to smells, for instance, whether these were considered pleasant or unpleasant (Bradley, 2014, particularly the contributions by Draycott, pp. 60-73, and Morley, pp. 110-119). Although the impact of smell on orientation is broadly acknowledged and the olfactory cues used for wayfinding discussed (e.g. Koutsoklenis & Papadopoulos, 2011, pp. 692-702) the implications this has on ancient navigation dynamics have not been formally explored, and related textual references have thus far not been inquired. An explicit reference to fragrances present on the coast, which may be perceived by ships approaching land is provided by Diod. Sic. (3.46.1.4-5) who, talking about Arabia, says that:

> even though those who sail along this coast may be far from the land, that does not deprive them of a portion of the enjoyment which this fragrance affords; for in the summer season when the wind is blowing offshore, one finds that the sweet odours exhaled by the myrrh-bearing and other aromatic trees penetrate to the near-by parts of the sea; and the reason is that the essence of the sweet-smelling herbs is not, as with us, kept laid away until it has become old and stale, but its potency is in the full bloom of its strength and fresh, and penetrates to the most delicate parts of the sense of smell. And since the breeze carries the emanation of the most fragrant plants, to the voyagers who approach the coast, there is wafted a blending of perfumes, delightful and potent, and healthful withal and exotic […]

Fragrances belonging to the vegetal domain are broadly documented, among others, by Theophrastus in *de odoribus* and the *Historia Plantarum*, by Pliny the Elder *Naturalis Historia* and by ancient Greek and Roman agricultural treatises such as Xenophon's *Oeconomicus*, Cato the Elder's, Varro's, Columella's and Palladius treatises on Agriculture.

Besides, in the ancient world places might have been recognized by further signature scents. Among possible examples is Martial's reference to a range of foul smells in the early Roman empire among which *amphora corrupto nec vitiata garo* (Mart. 6.93), thus one may assume that the areas were *garum* was produced on the coast may have propelled foul smells perceivable from the sea even far from land. Similarly, a foul and signature scent may come from volcanic and hydrothermal areas (Str. *Geog*. 6.2.11). Besides the many references to pleasant or unpleasant scents (e.g., Pausanias, Description of Greece, 5.5.8-10) that ancients may have recognized and identified with specific locations, one may wonder how far these fragrances may have been perceived depending on local meteorological conditions. A vague reference is in the Odyssey, although not connected to smell perception in the sea, as the passage refers to Ulysses' arrival at Calypso's house: "There was a large fire burning on the hearth, and one could smell from far the fragrant reek of burning cedar and sandal wood" (Hom. *Od*. 5.2). To present knowledge, the only explicit account to distances at which specific odours may be perceived is in Str. *Geog*, who - referring to the *Anigrus* river- says that 'since the region is muddy, it emits an offensive odour for a distance of twenty stadia, and makes the fish unfit to eat' (Str. *Geog*. 8.3.19).

4.3.6 Seamanship and risk management

The ability to make the right choices in case of competing risks depends upon the mariner's individual experience and seamanship. The latter entails a deep understanding of natural signs and the ability to take timely actions. Indeed, there is a general agreement among sources about the fact that in case of adverse meteorological conditions, it is preferable either to keep the land as far as possible (e.g. Sen. *Ep*., 53.2) or to anticipate the tempest and find a good and safe shelter before its arrival (e.g. Hdt., 7.188). Indeed, during a storm, the risk to be driven against the land by the winds, without having the possibility to manoeuvre the vessel is higher (e.g. App. *B Civ*. 2.9 and 5.10.89; Diod. Sic., 14.68; Synesius, 4, 49-75). Hence, the ability to forecast the arrival of a storm is crucial for taking decisions accordingly, as the following passage highlights:

> Presently, however, the weather became rough, and there was an appearance of an unusually dangerous disturbance setting in from the sea. The Carthaginian pilots, from their knowledge of the particular localities and of seamanship generally, foresaw what was coming; and persuaded Carthalo to avoid the storm and round the promontory of Pachynus. He had the good sense to take their advice: and accordingly, these men, with great exertions and extreme difficulty, did get round the promontory and anchored in safety; while the Romans, being exposed to the storm in places entirely destitute of harbours, suffered such complete destruction, that not one of the wrecks even was left in a state available for use. Both of their squadrons in fact, were completely disabled to a degree past belief (Polyb., 1.54.1)

Similarly, Appian (App. *B Civ*.,5.10.89) describes how Menodorus, apprehending that the rising storm would increase in violence, moved farther seaward and rode at anchor where, on account of the depth of water, the waves were less boisterous, while other ships were too close to the land and did not have the chance either to tarry nor to escape and were wrecked.

Seamanship and a deep knowledge of the territories traversed is crucial for avoiding environmental hazards. Polybius says that "from ignorance of the waters" the Consuls Gnaeus Servilius and Gaius Sempronius "ran upon some shallows" when they arrived at the island of the Lotophagi called Mēnix (Polyb., 1.39.1). Similarly, Diodorus Siculus (Diod. Sic., 1.31.1), while talking about the coasts of Egypt, refers that:

> the sea is full of rocks and sands, not discernible by mariners unacquainted with the places; so that when they look upon themselves as safe, and to have escaped the danger of the seas, and make with great joy to land (wanting skill to steer aright), they are on a sudden and unexpectedly shipwrecked.

Often mentioned with adjectives such as 'boiling' (e.g. Verg. *Aen*.3.548, and 7.1) or 'tricky' (Verg. *Aen*.3.692), shallows may be particularly insidious when approaching harbours (e.g. in Alexandria as documented by Solin. 32.40). The passage through the shallows would have been more difficult under certain conditions than others: the flowing of the tide (e.g. Str. *Geog*, 17.3.20), stormy weather conditions, or in general strong winds would complicate the passage and threaten the navigation. (e.g. under the force of the Etesians in Tacitus Annales 6.33; Phot. Bibl., 224.36.1). Also, the kind of vessel would make a difference: flat-bottomed boats or light vessels would be facilitated (e.g. Tac. *Ann*., 14.29).

Particularly infamous were the shallows of the two Syrtes, which rendered them perilous (Plin. *HN* 1-11, 5.4.1). Only expert sailors, acquainted with the traversed region would find a way to pass through the shallows (e.g. via channels cut in them according to Plin. *HN* 1-11, 6.26.2) and possibly use them to their own advantage for attacking enemies (Tac. *Hist*., 2.35; 4.27; 5.15; section 4.3.4). More in general, knowing the coast and the water space one travels well, is crucial for mitigating the risk of wrecking not just in Roman time (App. *B Civ.,* 5.10.89; this contradicts who sustains that mariners would prefer navigating close to the shore and in sight of land when scouting new territories like Gustas & Supernant, 2017.). Such a knowledge may also make the difference in battle: in this regard, the excerpt by Julius Caesar, (Caes. *BGall.,* 3.9) is particularly eloquent:

> Moreover, they felt that, even though everything should turn out contrary to expectation, they were predominant in sea-power, while the Romans had no supply of ships, no knowledge of the shoals, harbours, or islands in the region where they were about to wage war; and they could see that navigation on a land-locked sea was quite different from navigation on an Ocean very vast and open.

Similarly, when talking about the great disaster occurred to the Roman fleet off the territory of Camarina (225 BCE) during which two hundred eighty-four ships wrecked during a storm, Polybius severely blames the stubborn Roman commanders instead of the ill-fortune; indeed, "the captains had repeatedly urged them not to sail along the outer coast of Sicily, that turned towards the Libyan sea, as it was very rugged and had few safe anchorages", but the commander paid no attention to this advice, and Polybius remarks that the Romans "owe their success in many cases to this spirit, but sometimes they conspicuously fail by reason of it and especially at sea" (Polyb., 1.37.1).

Despite well-known and acknowledged environmental risks, expert mariners may have preferred to 'steer towards land, and anchor under a rocky and altogether dangerous part of the shore, for judging it better to run all risks rather than fall into the hands of the enemy' (Polyb., 1.54.1). Although a few passages cannot be generalized, the above excerpts provide multiple insights:

1) A rocky and altogether dangerous part of the shore would *normally* not be approached at all

2) The above statement is not always valid, for, in case of a *perceived* greater risk, the *importuosus* and rough shores might be considered preferable to the possibility of being overwhelmed by a more numerous inimical fleet
3) Which risk would be considered greater than others is clearly subjective and circumstantial

What above contributes to highlighting the need to overcome deterministic modelling approaches where factors are considered either as purely positive or purely negative in favour of strategies supporting historical multiperspectivity (Stradling, 2003, p. 14; Wansink et al., 2018, pp. 495-527). The latter refers to the epistemological idea that "history is interpretational and subjective, with multiple coexisting narratives about particular historical events" (Wansink et al., 2018, p. 496).

4.4 CONCLUSIONS: INSIGHTS GAINED AND IMPLICATIONS FOR MODELLING APPROACHES

This review of Greek and Latin accounts from the digital Libraries Perseus and ToposText enables one to draw at least two main interconnected considerations: first, despite the many excerpts documenting the risks and benefits associated with the shore, particularly under certain conditions, these do not lead to identify a declared preference for one of the two main navigation approaches. Second, benefits and risks associated with coastal proximity appear to be more or less risky or beneficial depending on circumstances and subjective considerations. Indeed the supposed advantages, such as the availability of havens and shelters, may also entail limitations or threats hence they are not all equally convenient to approach. Moreover, certain risks may be considered on occasion more preferable than others. The above two considerations are intertwined and highlight the limits of current modelling approaches that attempt to categorize factors either as purely advantageous or purely hazardous, which turns out to be both reductive and misleading.

Synesius' reference to a '*tolerable* distance one should keep from the shore' contributes to the definition of the main theoretical and methodological underpinning behind the model that is further described in the next chapter. Indeed, given that proximity to the land entails both advantages and potential risks to navigation, it is fair to assume that mariners would try to balance these by keeping a distance that enables one to limit the hazards while benefiting of the proximity to the coast. This implies considering how far the land may be sensed and which are the indicators of coastal proximity beside the land sight.

As the excerpts discussed in the previous section highlight, the advantages and risks of coastal proximity may be perceived differently depending on subjective considerations. On the one hand, not all the perceived risks are necessarily in fact hazardous; on the other, mariners may have consciously taken smaller risks in order to avoid perceived greater ones. Examples from primary sources have highlighted how even seemingly straightforward statements, such as 'shelters offer protection', 'harbours are safe-places', 'coastline without anchorages are insidious', may rather be disproved by apparently incongruent choices and preferences. Polybius statement is in this sense representative (Plb. 1.54): "He therefore steered towards land, and anchored under a rocky and altogether dangerous part of the shore; for he judged it better to run all risks rather than allow his squadron, with all its men, to fall into the hands of the enemy". The excerpt suggests that multiple criteria should be applied when assessing the degree of risks and benefits associated with the coastal proximity; moreover the attractiveness and the actual threats must be accounted separately. Three different examples can be conceived:

- An acknowledged *highly* dangerous coastline, without shelters and landing sites (i.e. *importuosus*, *ἀλίμενος*) presents a high-risk degree but also very low attractiveness in the sense that there would be no reason for approaching it at all beside circumstantial exceptional cases (such as escaping an otherwise unavoidable attack). Hence the shipwrecking probability may be lower than expected because the transit probability is low.
- Shelters placed along an acknowledged environmentally risky coast may have been approached due to competing considerations, such as the need for water, or in an attempt

to find a shelter in advance of a tempest. This highlights the need to formally address all the potential criteria driving mariners actions to infer possible routes

- Big and safe harbours may have had a lower than expected attractiveness for certain groups of sailors, e.g. for private traders, who may have rather preferred to approach smaller ports to avoid tolls. Modelling approaches should overcome the tendency to consider ports and harbours as simple hubs of the maritime network. Following the broad complexity of phenomena and dynamics that the scholarship has contributed to entangle, computational models should also address the hierarchical relationships between entrepôts, lesser ports and anchorages by accounting the port socio-cultural complexities instead of looking exclusively at the geomorphological aspects or the economic dynamics. "Thus knowledge of the roles played by the actors and social groups is key to understanding how ports worked, and connections were mediated" (Arnaud & Keay, 2020, p. 19)

The above considerations highlight the need to distinguish between *perceived* and *actual* advantages and disadvantages in formal navigation modelling, for the former may affect potential route preferences, no matter whether these notions are real or not, whilst the latter may actually increase the risk of wrecking. Myths and taboos should be formally inquired to better understand the cultural logic underlying their origin, development, and possible persistence and practical implications. The case of the Sirens is, in this sense, emblematic. It would be pointless wondering whether the places associated with them were 'cleverly eluded' (Dict. Cret., 6.5; similarly Dio Chrys. Or., 33.35) or rather their stories would be considered 'untrustworthy and fabricated' (Philostr. Her., 717). Be that as it may, several aspects connected to their myth offer precious insights, particularly in relation to the coastal-proximity matter which, precisely thanks to the analysis of the contexts of use of the Sirens' myths and iconography in Antiquity, can qualify, in general, as a liminal space (on the shore as a liminal area cf. Ford, 2011, 2013; Westerdahl, 2009). Sirens, with their enchanting and distinguishable sound - that given their original body shape may reflect the acoustic clues coming from coastal birds - are tied to a place, i.e. the rocky shore that lures mariners with the many opportunities and benefits it provides, yet at the same time attempts on their safety. Indeed, the landfall entails great risks for sailing and only experienced mariners may manage to keep their course and successfully face the threat they represent. To this end, mariners need navigation knowledge, expertise, and wisdom granted by the sirens to those brave enough to listen to them (Cic. *Fin*., 5.49). Circe does not suggest Ulysses to fill his ears with wax but rather to find alternative ways to protect himself while listening to what the creatures want to tell him.

The difference between perceived and actual threats or benefits has never been tackled before in predictive modelling, whilst in the present study, it constitutes the original, and main theoretical foundation behind the model described below in Chapters 5 and 6. The core contention here is that to predict the shipwrecking probability within the 12 NM zone, one needs to assess the coast's 'attractiveness' beside the actual threats to navigation it might present.

4.5 SUMMARY

This chapter focused on the controversial way coastal navigation is defined, modelled and evaluated in terms of maritime safety both in the scholarship tradition and in primary textual sources from Classical time. Through a targeted inquiry of meaningful excerpts retrieved from Digital libraries through keywords, the factors constituting an advantage or a threat to seafarers were detected, evidencing how the degree of risks and benefits may vary in different moments of time depending on multiple conditions and subjective considerations. Accounting separately for all the numerous criteria driving mariners' actions and navigation preferences instead of considering advantages and disadvantages in binary terms (i.e. purely beneficial and purely risky) is necessary for improving modelling outcomes.

"Essentially, all models are wrong, but some are useful" George Edward Pelham Box

"Experience without theory is blind, but theory without experience is mere intellectual play" Immanuel Kant

5 A FORMAL MODEL TO ASSESS SHIPWRECKING PROBABILITY IN TERRITORIAL WATERS

This chapter includes the description of a theoretical model aimed at identifying the areas within territorial waters (i.e. 12 NM from the baseline), presenting the highest relative historical shipwrecking occurrence. The term *relative* refers to the fact that the model does not determine an absolute probability rate. Instead, it allows ascertaining which areas present higher shipwrecking probability than others within the targeted study areas. As discussed in chapter 1, shipwrecking probability is referred to as the probability that ships may have sunk without considering whether the event entails the survival of any specific class of remains. Although this research does not explicitly address post-depositional processes, it nonetheless provides insights on the probability to find shipwreck *remains*. Indeed, the probability of having archaeological remains is higher in the areas with high shipwrecking potential than in those with low potential. Possible exceptions may be represented by isolated objects thrown overboard along the route due to circumstances such as devotional practices or jettisoning for lightening the boat in storms. Further exceptions are also represented by materials of the cargo accidentally moved from the wreckage site after the shipwreck event, for instance, by trawlers nets (Gianfrotta & Pomey, 1981; Martin, 2013; Martin, 2014; Muckelroy, 1975; Muckelroy, 1978). Whereas the first case is more difficult to address, the second may be potentially established: indeed, the use of modern Automated Identification Systems (AIS) on board of ships (Bole, Wall, & Norris, 2014, pp. 255-275), and the availability of AIS data, would allow tracking the movement of vessels around known underwater archaeological sites.

After summarising in section 5.1 the theoretical underpinnings and the overall model structure, in section 5.2 are discussed the criteria employed for selecting the factors, which are then systematically presented -divided into two model components - in section 5.3 and section 5.4 respectively by also clarifying what assumptions have been made for implementing them. In section 5.5, the regional case-study area is introduced by highlighting the historical and practical reasons why it was selected. In section 5.6, it is discussed whether and how the regional theoretical model may be upscaled to model the shipwrecking probability in Mediterranean territorial waters.

5.1 THEORETICAL MODEL UNDERPINNINGS: DEALING WITH A LOGIC CONUNDRUM

The literature review (Chapter 2) has identified two clusters on an imaginary scale of maritime archaeological modelling applications. The first group includes different computational approaches to model marine movement or connectivity, mostly by taking into account environmental and technological constraints and socio-economic factors. The second group includes archaeological predictive models that inductively aim to identify "areas where high potential for shipwreck losses coincides with areas of high preservation potential" (Merritt et al., 2006, page 3); these by taking into account navigation hazards, post-depositional processes and preservation conditions without or barely addressing the multiple dynamics impacting mariners' movement. If both the navigation and the shipwreck formation processes have been broadly debated and modelled in the past decades (Chapter 2), this research does not and cannot just bridge the two groups, as the relationship among navigation hazards and the potential shipping routes pattern is ambiguous in current scholarship and leads to a logic conundrum. On the one hand, the movement potential is usually derived by assuming that a vessel would avoid navigation hazards; hence, the routes are often constrained by preventing the passage in well-known hazardous waters either temporarily (e.g. in certain seasons) or permanently. On the other hand, shipwrecks probability models include navigation hazards to infer potential ships' losses locations, thus assuming the ships' passage in those areas. This logic conundrum is reflected in the equivocal ways the presence of a shipwreck may be interpreted. Indeed, as Potts (2019, p. 55) recalled, the position of wrecks could indicate a point of nautical activity or an area of risk to shipping. This ambiguity compromises the possibility to use shipwrecks inductively for inferring the location of yet unknown sites in predictive models as it would put on the same level the shipwrecking due to accidental problems that occurred along an otherwise relatively safe route, and the ship-loss associated with the presence of recurrent or constant hazards that a ship could not avoid, ignored or deliberately challenged for competing reasons.

This model challenges two predominant theoretical underpinnings behind this logic conundrum affecting the models' efficiency. The first relates to the assumed preference for the 'optimal route'. Current modelling strategies tend to approximate past seaborne movement by assuming that mariners would opt for the most efficient route, the one minimizing risks, costs, distances, thus taking that the route assumed to be optimal is indeed the optimal one. Connected to this is the second theoretical assumption that this thesis objects to, namely the nautical uniformitarianism principle (Irwin, 1992; McGrail, 1993; Deeben et al., 2002), which assumes that mariners at all times would try to avoid hazards in setting their course and that current environmental threats and the mitigating strategies for facing them are the same as past ones. The present research aims to problematise the pitfalls in such approaches and propose a new methodological approach to overcome the above-mentioned conundrum. Without neglecting the crucial importance of environmental, socio-economic and technologic factors, a distinction is made in the model below described between actual and perceived 'optimal routes'; the latter resulting from the consideration of cultural preferences and cognitive dynamics and the practical effects these have in terms of modelling approach and outcomes. By challenging the nautical uniformitarianism principle and making a difference between perceived and actual risks, it is possible to gain insights into the possible reasons behind a shipwreck presence while improving the model's predictive ability. In Chapter 2, it has been said that in order to assess the shipwrecking probability, one needs to take into account two different groups of aspects and dynamics:

1. The movement potential, or transit probability, namely the chance of having had ships navigating a certain water-space or corridor route, which is the result of environmental and technical constraints but also intentional navigation choices and fortuity
2. The hazards to navigation, namely factors that increase the probability of sinking, which include both environmental risks and human attacks or technical damages.

Therefore, to answer the main research question and identify which are the locations that have a higher probability of shipwrecking incidence within the territorial waters, one needs to answer the following sub-questions:

- *"Where is it more likely that ships would transit?"*
- *"Where is it more likely that ships would sink?"*

A targeted modelling strategy is designed to answer these questions while overcoming the two theoretical caveats mentioned above, namely the implications of nautical uniformitarianism and the concept of 'optimal route'. Particularly, two different model components are designed to address separately the actual threats to navigation that increase the sinking probability and the multiple factors potentially triggering mariners movement, which include socio-cultural, economic and logistic factors as well as the risk perception. The latter does not necessarily entail a real threat but may result in route-corridors that are different from the actually optimal ones:

1) The so-called Transit Probability (TP) model component aims at ascertaining where ships would have more likely transited by considering factors influencing mariners' movement
2) The hazards to navigation model (NH) aims at assessing the probability that ships would sink by addressing risk-factors that may actually affect the navigation safety

The main theoretical foundations of the model are derived from the analysis of primary sources as presented in section 4.3, particularly:

- The twofold implications of coastal proximity, i.e. the idea that being close to the shore implies both threats and benefits to navigation and that the degree of these disadvantages and advantages may change depending on circumstances and from both socio-cultural and environmental conditions
- The concept that mariners would try to avoid the hazards while profiting of the advantages associated with the coastal proximity
- The need to distinguish, hence model separately, the perceived and the actual hazards, for the former affect navigation preferences, while the latter increase the chance of sinking

More specifically, the so-called Transit Probability (TP) model is approached by considering pulling and pushing factors derived from primary sources, thus assuming mariners would approach the former and avoid the latter [43]. Pushing and pulling factors include both

[43] The idea that site selection is 'a cognitive process based on the application of both choice and risk' (Verhagen & Whitley 2020, p. 236) has been employed in other archaeological predictive models, for instance in the Georgia Coast Model, a

environmental and socio-cultural factors. These attractive and repulsive factors are implemented through cost-surface analysis to avoid simplistic binary categorizations. Moreover, each of them is assigned a different weight, i.e. a degree of convenience, by means of the Analytical Hierarchy Process (AHP) method of multi-criteria analysis (Saaty, 1977, pp. 234-281; Saaty, 1980). Since it is beyond the scope of this research to ascertain in which century or moment in time each criterion would be preferred or most impactful (assuming this possible), multiple possible scenarios are tested by weighting the criteria differently (Chapter 7).

The hazards to navigation (NH) model, differently from the TP model, does take into account actual environmental threats derived from present-day sailing directions and present-day meteorological and geomorphological data. Besides factors currently included in ancient navigation models, such as wind strength, waves height, bathymetry, coastal geomorphology, the models also includes the incidence and impact of storminess along the Mediterranean coastal waters (Lionello et al., 2017), which have thus far been excluded from current navigation modelling. The model has a number of collateral benefits aimed at overcoming some of the limitations discussed in Chapters 2 and 4.2, 4.3. Particularly:

- Addressing the specificity of the littoral area
- Defining strategies for taking into account cultural and cognitive factors, i.e. the, cultural logic, by distinguishing between perceived and actual hazards.
- Identifying formal criteria for defining the 'coastal area' and for modelling coastal-navigation approaches

After discussing state of the art in current modelling approaches (Chapter 2) and the theoretical foundations deduced from primary sources (Chapter 4), the theoretical model description presented below aims at:

- clarifying the selection criteria for the implemented factors
- systematically presenting the selected model components
- clarifying what assumptions have been made for implementing these components

The procedural details for implementing the model components are described in chapter 6.

5.2 CRITERIA FOR FACTOR SELECTION

The theoretical model arises from the enquiry into both scholarship contribution and primary textual evidence (chapter 4). Particularly, in this study, the factors deemed to impact the transit and sinking probability are illustrated in Figure 5.1 and Figure 5.2, respectively.

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theory-driven model developed by Whitley starting from 2009 (Whitley et al., 2010; Whitley, 2013). However, it must be stressed that differently from settlements, the shipwrecks occurrence is not just the result of a cognitive process, for a ship does not decide where to sink. Therefore, besides the choices driving mariners actions, which affect the route, the model must take into account the chance for the vessel to sink.

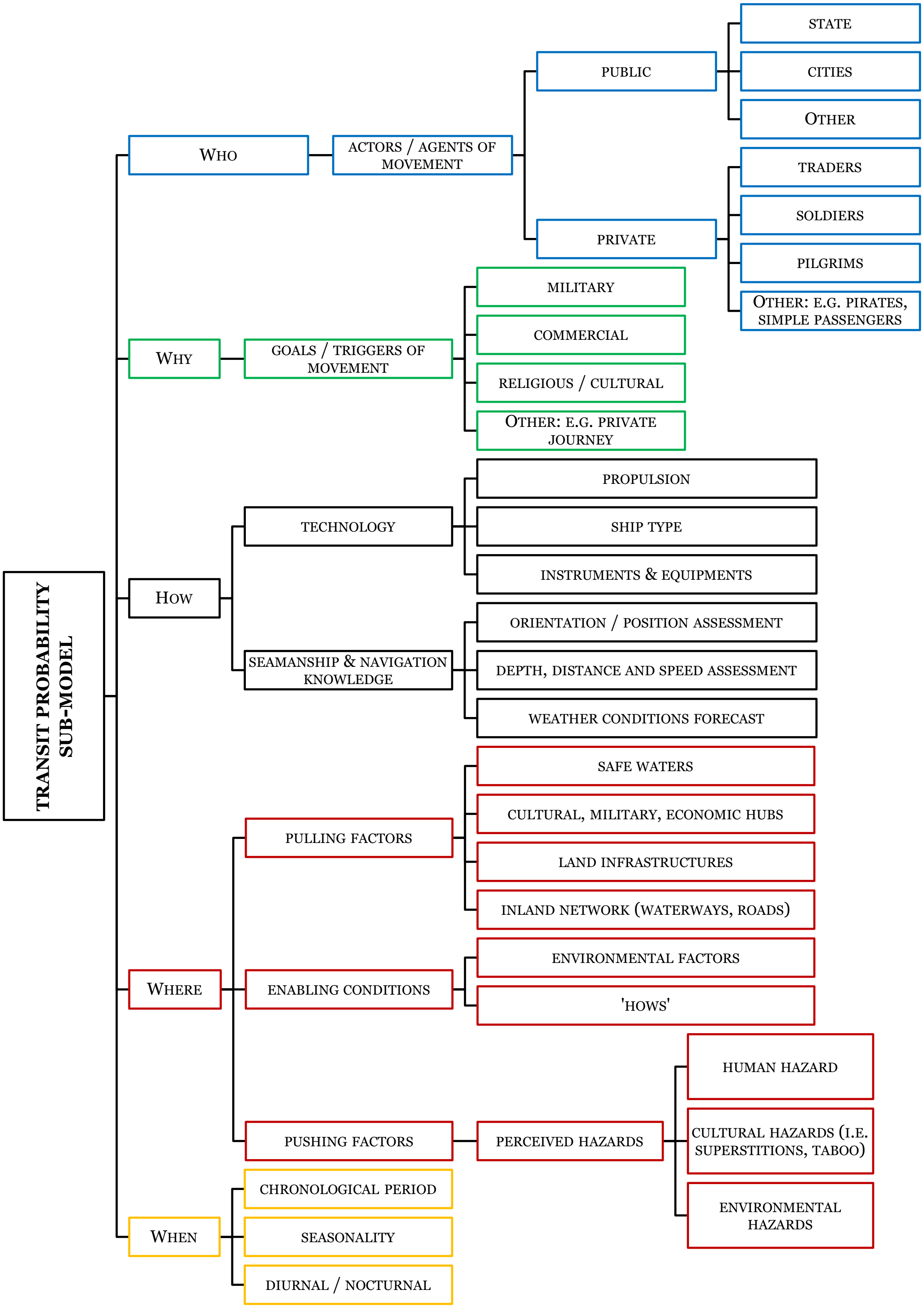

Figure 5.1: Factors impacting the transit probability

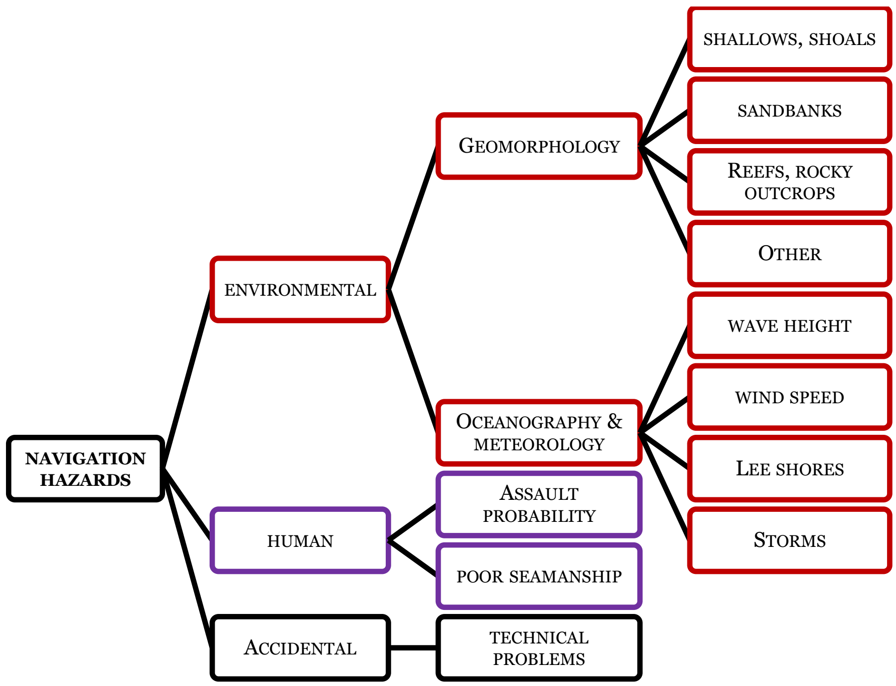

Figure 5.2: Factors increasing the risk of sinking

The two main criteria considered for selecting the model factors are the feasibility (f) and the estimated impact (i). With estimated impact, one refers to the influence and the effects each factor is deemed to have on navigation dynamics. With feasibility, one refers to the possibility to model a certain factor either because it has been already done before, or in light of current developments within or outside the archaeological and historical domain. Four different degrees are distinguished for each criterion (Table 5.1).

Table 5.1: Criteria for selecting the model factors

LEVELS OF FEASIBILITY (F)	
1	Never developed and really difficult to do so
2	Possible to develop but never done before in the historical/archaeological context
3	Possible to implement at certain geographical and/or chronological scales, or at specific conditions
4	Already been developed in the historical/archaeological context
LEVELS OF ESTIMATED IMPACT (I)	
1	Limited and controversial impact
2	Potentially high impact but with controversial effects
3	High impact at specific geographical/chronological scale or specific conditions
4	Unequivocal impact on navigation at broader chronological and/or geographical scale

Particularly, as for the feasibility, the first two levels refer to the impossibility to model a certain variable or to implementations made within different scientific domains. An example of extremely difficult factor to develop (f1) is represented by accidental hazards. Meteorological factors such as the intensity, duration and effects of storminess along the coast are factors addressed e.g. in civil engineering, spatial planning or meteorology, but their implementation in archaeological and historical contexts pose challenges (f2), for instance, in terms of data representativity (are we entitled to employ present-day data to infer past climate conditions?) The third level of feasibility (f3) includes factors that can be implemented under specific conditions exclusively, or at specific chronological or geographical scales. An example of f3 is represented by the assault probability: while the risk of being assaulted in motion, namely in the middle of a ship's journey, is difficult to translate into a traditional GIS environment[44], one can take into account the conditions for an attack to happen, which is, for instance, the fact of being visible to the potential offenders from a fixed location, as documented in primary sources (chapter 4). The decision to assign lower feasibility to factors already implemented but only outside the archaeological domain than to factors already implemented in archaeological models but only at specific conditions (feasibility level 2 and 3 respectively) is due to the fact that the transferability of methods and data to the historical and archaeological context may pose problems. The fourth level of feasibility (f4) includes factors that are currently considered in historical and archaeological models and do not pose technical or theoretical issues, such as the geomorphology.

As for the Impact, this depends upon two main aspects: its being limited depending on the scales one considers and its unequivocal interpretation. Within the scope of the present study, which does not aim at modelling specific routes trajectories but only isotropic transit probabilities, the wind direction is deemed relatively unimpactful (i1). Further justifications to this choice are below in chapter 5.3 (cf. Arnaud 2005, p. 21). Level two, 'Potentially high impact but with controversial effects'(i2) refers to factors that have an undoubted relevance to navigation dynamics, whose implications or effects -however- are not necessarily straightforward to grasp. Examples of controversial impact may be represented by superstitions. Indeed, although broadly documented in any time and place, superstitions may be specific to different cultural contexts, and they do not necessarily correspond to certain mitigating actions: indeed, a superstition around a supposed hazardous place may entail its avoidance or the enacting of rituals to mitigate the risk (Chapter 4.3.6). Level three (i3) corresponds to factors that have an unequivocal impact only under specific conditions or at specific geographical or chronological scales. An example is represented by technology and propulsion indeed different transport modes clearly entail diverse constraints and adaptation to environmental conditions (Rougé, 1981; Casson, 1971; Gianfrotta, Pomey, Nieto, & Tchernia, 1997; Arnaud, 2011b). As for the highest impact level, an example of factors having an "Unequivocal impact on navigation at broader chronological and/or geographical scale" is represented by the storm-incidence, for it always negatively affected the navigation safety, although the prediction results are subject to the uncertain representativity of present-data in historical projections.

[44] The possibility to employ alternative modelling approaches, such as agent-based modelling is discussed in the Conclusions of the present study.

In Figure 5.3, are prioritized the factors to model based on their impact and feasibility assessment. In Table 5.2 are discussed the feasibility and estimated impact of the factors that are assumed to be relevant for modelling the transit probability and navigation hazards as derived from primary textual evidence and secondary sources.

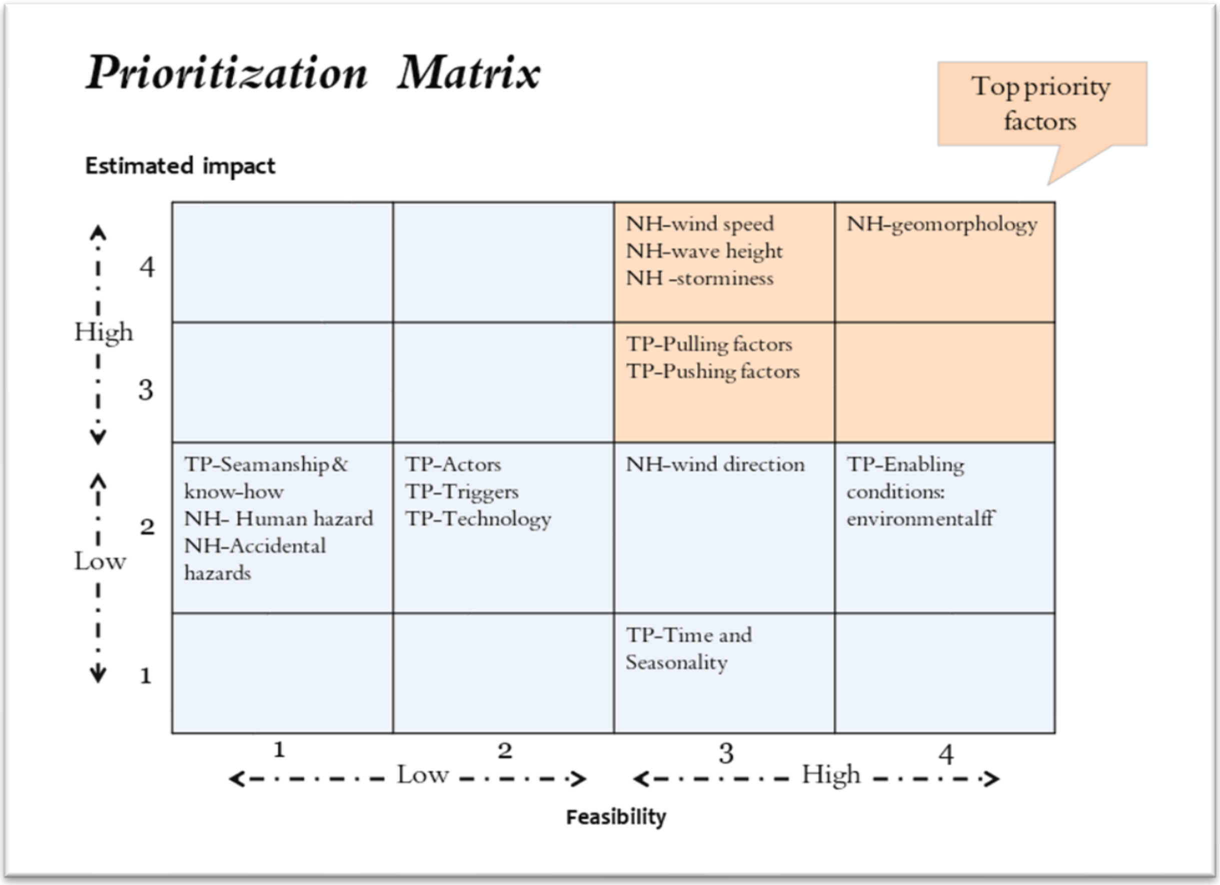

Figure 5.3: Selection of factors based on their estimated impact on navigation and feasibility of modelling. The prioritized factors, which will be included in the model, are evidenced in red

Table 5.2: Estimation of the impact and the implementation-feasibility of factors assumed to be relevant for modelling seafaring and navigation hazards

Transit Probability model-component

FACTORS	ESTIMATED IMPACT	ESTIMATED FEASIBILITY	RATIONALE	LEVEL OF PRIORITY
Who: ***Actors/agents***	2/4	2/4	Different categories of mariners may choose different paths, destinations and navigation strategies depending on the motivation triggering their movement (i.e. religious, military, commercial), their status or affiliation (e.g. working privately or on behalf of public authorities). The account of different agents' movement may vary the transit probability, although the impact would vary depending on the period considered. Traditional GIS-based models are not suitable for accounting for these differences. Conversely, agent-based modelling approaches (Davies, Romanowska, Harris, & Crabtree, 2019) would be more appropriate for simulating the movement of different agents within the same spatial environment and to understanding the resulting patterns of interacting behaviour better	medium
Why: ***Triggers***	2/4	2/4	Motivations and goals triggering mariners movement depend on the actors and agents involved in the movement. Therefore, modelling them as independent scenarios is constrained by the same considerations outlined in relation to the actors & agents. However, different potential movement-triggers (e.g. economic, religious) may be considered as pulling factors (e.g. sanctuaries, production centres, fiscal districts), which are time-dependent.	Medium
How: ***Technology***	2/4	3/4	In current predictive models the account of technological conditions enabling mariners to navigate are implemented in an indirect manner, namely by constraining the environmental parameters (e.g. wind directions) to the technology and navigation knowledge supposed to be available to mariners in a specific context or period of time. A clear example is constituted by the vessel-type and its propulsion. Up to the 'steam-era', rigs and oars were the main propulsion-tools (e.g. Casson, 1971; Whitewright, 2016; Whitewright, 2018) therefore, current models constrain the routes by considering, the winds-direction, the wind-strength and currents-direction supposed to be favourable to sailing and oaring for following a certain course. A similar association between environmental	Medium/high

			parameters and technological factors relates the supposed availability of navigational instruments, such as the compass and the consequent preference for a navigation strategy over one other (e.g. navigation in sight of the shore or in open waters). In terms of feasibility, the account of technological factors is constrained to specific scales (i.e. both chronological and geographical) and conditions. Their implementation is problematic in light of the scattered information available, which must rely on the information derived from both archaeological evidence and iconographic documents (e.g. Basch, 1987; Casson, 1971), the latter being often difficult to interpret (Whitewright, 2018, pp. 28-44). The kind of information available is also uneven, for archaeological evidence mostly document the hull structure (McGrail, 1998), whilst less is known about, e.g. the propulsion system due to its perishable nature. It follows, in terms of impact, that the effects of the adaptation of certain technology to the environmental conditions are significant but not always straightforward to understand. Ongoing debates relate, for instance, the implications of the sailing-rig development (Whitewright, 2018, p. 28) or the directions supposed to be completely prevented to vessels depending on the rig-type and the wind. (Whitewright 2016; Arnaud, 2011b, pp. 147-160).	
How: ***seamanship & navigation knowledge***	2/4 	1/4 	Although pivotal seamanship and navigation knowledge are extremely difficult to account for in GIS-based predictive modelling. The difficulty is not merely technical but also theoretical, for in lack of navigational handbooks from antiquity, any assumption about mariners' knowledge or nautical behaviours is both partial and circumstantial, being derived from fragmented archaeological, iconographical data or indirect accounts (see above in Chapter 3 the discussion around the 'nautical uniformitarianism' principle)	low-medium
Where ***Pulling factors***	3/4 	3/4 	Current models do take into account navigational hubs, namely probable origins and destination within past maritime networks, although these are implemented in binary terms, namely by only considering the presence or absence of, e.g. ports, without addressing their potentially different level of attractiveness (an attempt to model ports hierarchization in Potts, 2019). The account of environmental, economic and cultural pulling factors may constitute a significant improvement even though these elements are time and regional dependent; hence their implementation would be constrained to specific conditions.	medium-high

Enabling conditions: environmental factors	2/4	4/4	Environmental factors, such as winds, surface currents, bathymetry and geomorphology (e.g. nature of the seabed, presence of sandbanks and shoals, nature of the shoreline) are always included in models predicting past seaborne movements as factors constraining the route definition. Differences relate to the choice of the average-values one considers, hence the seasonality (e.g. as for wind and wave data, the monthly, annual or seasonal average data collected on a specific year or over decades). Although the impact of these factors is undeniable, this also deeply varies depending on specific conditions and circumstances (e.g. kind of propulsion, ship type and ship size). Moreover, also by the research scope: to answer specific historical questions, such as "which corridor-routes the Roman Annona-fleet would follow for transporting grain from Egypt to Rome" (Meijer & van Nijf, 1992, pp. 93-101), it may be useful to take into account, e.g. wind and surface-current directions. Given the goal of the study, which is to ascertain which maritime regions have higher transit probability without considering neither specific ship-provenance and destinations, nor the ship type, the impact of environmental factors in determining route preference is equivocal. Rather, it is deemed better modelling the environmental conditions (e.g. geomorphology, extreme meteorological and oceanographic conditions) as factors enhancing the risk of sinking (see below)	medium-high
Pushing factors	3/4	3/4	Pushing factors are the -perceived- risks or disadvantageous situations that mariners would likely try to avoid or circumvent. By following the nautical uniformitarianism principle, these pushing factors should be equal to the hazards affecting navigation safety. Nonetheless, this study distinguishes the perceived and the real risks, for the former do not necessarily increase the possibility of sinking, but they may impact route preferences, resulting in the avoidance of certain places. This distinction has never been made in current predictive models It is theoretically possible to implement perceived hazards in specific contexts and scales by looking, e.g. at historical or iconographic sources; the feasibility is dependent upon the availability of sources documenting or reflecting subjective perceptions, which are also bounded to specific cultural contexts. The impact is deemed high because perceived risks, taboos and superstitions have always existed, although the effects are controversial.	medium/high

Navigation-hazards model-component				
FACTORS	ESTIMATED IMPACT	FEASIBILITY	RATIONALE	LEVEL OF PRIORITY
Environmental Hazards				
Wind Speed	4/4	3/4	Among the factors currently considered are, on the one hand, meteorological-oceanographic aspects such as the average wind speed and the average wave height; on the other hand, aspects connected to the topography such as shoals and shallows, promontories supposed to be hazardous because of contrasting currents nearby and for the presence of outcrops. The wind direction is the only factor here considered to impact less than the others, given the research goal (i.e. assessing the movement potential, not route trayectories) and following Arnauds'consideration: "*Il nous semble donc essentiel d'admettre que, pour les Anciens, le vent défavorable n'était pas nécessairement un vent mal orienté, mais un vent soufflant avec une force telle que sa direction ne permettait plus de se rendre vers sa destination*" (Arnaud, 2005, p. 21)	high
Wind Direction	2/4	3/4		medium
Wave height	4/4	3/4		high
Storminess	4/4	3/4	At least one aspect has never been included in archaeological predictive models, namely the storminess. The latter, both in terms of occurrence rate and in terms of local effects on the shore, are factors currently modelled outside the archaeological domain. The current model takes into account two different parameters: the return rate, namely how often storms tend to occur in a certain locality within a certain period, the water level reached by sea during a storm event. Both these two aspects are new to this research.	high
Geomorphology	4/4	4/4		very high
Surface currents	2/4	1/4	Similarly to most other navigation models, the surface currents are not implemented among the oceanographic variables impacting seafaring; indeed, as noted in Orbis (Scheidel, 2014): "Although feasible in principle, the inclusion of currents raises modelling challenges because they act on seaborne vessels differently from wind and, more importantly, the force of surface currents themselves is to a significant extent determined by wind strength in ways that may also affect their direction".	medium-low

Human hazard	2/4	1/4	The possibility to be attacked in motion during the navigation cannot be implemented in a traditional GIS, and indeed it has never been included in predictive models (f1). Conversely, the combination of GIS with other simulation modelling approaches such as ABM (Romanowska, Wren, & Crabtree, 2021; Vanek, Jakob, Hrstka, & Pechoucek, 2013) may be suitable for including the human hazard and the interaction of different competing categories of mariners (e.g. traders and pirates). Nonetheless, even in a traditional GIS, the risk of being attacked from land by pirates or inimical coastal states may be theoretically possible to implement at definite geographical and chronological scales (F2); particularly, by considering specific phenomenon-implications having a geographical component: to be more explanatory, if the possibility of a ship being attacked in motion, namely in the middle of its journey, is difficult to translate into a GIS action, one can take into account the conditions for an attack to happen, which is, for instance, the fact of being visible to the potential offenders, as documented in primary sources (chapter 4.2.3; 4.3.4). This model takes into account the risk of being attacked from land among the perceived risks (i.e. perceived threats that may not necessarily occur but that may affect navigation choices).	Medium-low
Accidental hazard	2/4	1/4	Accidental hazards are by definition circumstantial and impossible to account for in a traditional GIS. Alternative modelling approaches, such as ABM, may enable to consider a greater or lower probability of accident occurrence depending on a number of additional related impacting factors, such as the ship type and its size and availability of technology. Given the specificity and relative circumstantiality of these categories of hazards, the impact on the model cannot be fully ascertained	Low

5.3 FIRST COMPONENT: TRANSIT PROBABILITY

The Transit probability model-component aims at ascertaining where ships would more likely transit within the 12 NM by considering advantages and disadvantages associated to coastal proximity, one can thus assume sailors would be interested in avoiding the hazards while profiting from the benefits. These pushing and pulling forces include environmental and socio-cultural factors derived -as categories- from primary sources accounts. As explained in the introduction of this research and in sections 4.3 and 5.1, the textual evidence is employed in two ways.

First, following the notion of multiperspectivity in history (Wansink et al., 2018, pp. 495-527; Stradling, 2003, p. 14), which refers to the existence of parallel or synchronic contemporaneous subjects' perspectives (section 4.3.6), the textual evidence was surveyed to explore the different ways risks and benefits of coastal proximity are referred depending from circumstances. Such a screening, which has been carried out on digital libraries based on keywords as described in chapter 4, is used for identifying categories of factors driving mariners action; indeed, the information derived suggests privileging a multi-criteria modelling approach for implementing the model factors instead of pursuing binary methods (i.e. factors purely advantageous or purely risky). This approach aims at overcoming current limitations in maritime predictive models, which tends to underestimate the cultural logic by assuming the current conditions actually enabling the movement and the navigational threats being equal to those past mariners would acknowledge and perceive. When implementing the model at the regional scale a second targeted analysis of textual evidence is carried out on a specific source, the *Anonymous Stadiasmus Maris Magni*, as a proof of concept for modelling the landing sites attractiveness and avoid modelling the actually optimal routes (section 5.4.2). It must be stressed that this approach does not claim to provide indications on risk-perception or coastal perception in Classical time but only aims at designing a methodological framework for taking it into account in predictive modelling. Once this framework is established, it will be possible to answer specific historical questions by complementing the textual evidence with further sources (e.g. epigraphical, iconographical, papyrological), hence collecting the most suitable data for answering them.

The TP model component does not predict past maritime routes; instead, it is designed for identifying sea areas having a higher potential of ships in transit, no matter their direction or their navigation approach (e.g. cabotage, or open-water routes). In other words, the model ascertains where - within the 12 NM zone- mariners would prefer to sail either while following a coastal navigation, or when approaching the shore after crossing the open sea. For this reason, the TP model also represents a useful complement to existing navigational models (e.g. Orbis), for it may be added to them to improve the prediction rate within the 12 NM. Since the regional case-study area encompasses the route that the Neo-platonic philosopher and Bishop of Ptolemais Synesius followed in his problematic voyage from Alexandria to Cyrene (section 4.2.2), the TP model also provides information on the 'tolerably' distance one should keep from the shore -when coasting- in order to balance advantages and risks of coastal proximity, thus addressing the issue derived from *Synesius* in his struggles with captain *Amarantus*[45] (Synesius*, Epistle 4, 49-75)*. However,

[45] "When we wailed of hardship and complained of our position so far from land, Amarantus, pretending to be Iapetus, stood on the stern and hurled the most murderous curses upon us. "We shall certainly not fly," he said, "so how can

the model intentionally provides transit probability areas rather than precise trajectories and the measurement of such an optimal distance to keep from the shore is purposely left unanswered in the present thesis. Indeed, it would be misleading and simplistic to take this tolerable distance as the path mariners would actually follow. The research questions underlying the TP model component can be formulated as follows:

Within the 12 NM where is it more likely that ships would have transited to balance risks and advantages of coastal proximity?

In order to model the transit probability within the territorial waters, a preliminary assumption is made, namely that the overall study area (i.e. within the 12 NM zone) may be entirely navigable. This is because of a number of considerations:

- Although the directions of predominant winds and surface currents in the Mediterranean sea prevents specific routes in certain seasons (Arnaud, 2005, pp. 14-27; Beresford, 2013, pp. 53-106; Casson, 1971, pp. 270-273; Davis, 2009, pp. 26-43; McCormick, 2001, pp. 450-468; Petti-Balbi, 1996, pp. 279-280; Rougé, 1952, pp. 316-325; Rougé, 1975, p. 24; Warnking 2016, 45-90), the TP model-component aims at identifying the probability of ships in transit no matter their specific direction.
- Along the shore, the effect of diurnal winds, also known as sea and land breezes, presents a remarkable regularity and may overwhelm the prevailing regional conditions, thus enabling sailors to follow courses against the prevailing winds (Arnaud 2005, p. 21). The effects of diurnal breezes may arrive up to a coastal range of 20 NM in the Mediterranean (Arnaud 2005, p. 23; Beresford 2012, p. 85), although the degree of this possibility varies depending on multiple factors, which include the hour, orography, topography, seasonality, and meteorological conditions (Arnaud 2005, 22-23; Beresford 2012, 85-86; Davis 2009, 42). Overall the effects are considered to be minimal over the 10 NM (Arnaud 2005, 23). Primary sources document the knowledge of breezes and their use to approach the shore or to navigate along the coast (*Anth. Gr.*, 10.17; *Anth. Gr.*, 10.24; Amm. Marc. 19.10.4; Niketas Choniates, *Annals*, 537; Luc. *Ph.* 9.140; Ap. Rhod. *Argon.*, 1.922). They also document the adaptation to their regime when planning the route (e.g. Heliod. *Aeth.* 5.17.5–18.1) and a sense of caution because of their instability (Ap. Rhod. *Argon.*, 1.922; Dion. Hal. *Ant. Rom.*, 20.9.1.; Plut. *Cic.* 32; Morton 2001, fig 52; McGrail, 2004, 95).
- The environmental conditions that enable or prevent the navigation are accounted in the hazards to navigation model-component as factors decreasing or enhancing the probability of wrecking.

The fact that the 12 NM zone are considered to be, as a starting point, generally navigable (without considering specific directions), does not mean that there is an equal probability of transit in this area. To calculate this probability degree, the model takes into account the categories of *perceived*

anyone help you, you who mistrust both land and sea?" And I replied to him, "[...] what need is there for the open sea? But let us voyage to Pentapolis, keeping the shore tolerably close by, in order that if there is some difficulty as is wont to occur at sea [...] we can reach a nearby harbour."

advantageous and threatening conditions associated to the coast proximity, as discussed in sections 4.2 and 4.3. (Table 5.3).

Table 5.3: Factors considered for modelling the transit probability within the 12 NM. In grey are those that were not possible to implement

TRANSIT PROBABILITY FACTORS			
COASTAL ATTRACTIVENESS	landing sites	natural harbours artificial harbours	beaches with slope < 2% , ports, channels, breakwaters, jetties, quays
	harbour convenience	Exposure	To specific wind or all wind-directions
		Capacity and size	limited to specific vessel types
		Accessibility	easy to access vs with hazards nearby
		Nature of the seabed	providing strong support for anchoring
		Extra facilities or attractors	Shipsheds, warehouse, slipways, water availability (at the port)
		economic convenience	fiscal districts / *portoria*
		jurisdiction & flag	agent-dependent
	in-land network	water sources	rivers and springs at a walkable distance from the landing
		navigable rivers roads socio-cultural & economic attractors	proximity to landing sites and ports
		port-network	n. of cities served by a port
	assault-probability (AP)	unfriendly shores	agent dependent
		mutual visibility	the AP is higher when in sight of land
	orientation	landmarks	prominent features – viewshed
		Other indicators	coastal birds fly-range

5.3.1 Landing places and anchorages

Landing sites and anchorages (McGrail, 1997, pp. 49-63; Rogers, 2013, pp. 181-196) can be considered by definition the most attractive places to mariners because of safety, logistic and socio-economic reasons (Arnaud & Keay, 2020, p. 1; Rougé, 1966; Tchernia & Viviers, 2000). Ships need to depart from and land somewhere; along the route, they may need to anchor temporarily nearby the shore. However, landing sites and anchorages are neither all equally attractive, i.e. equally convenient to approach nor necessarily safe. The motivation triggering ships movement and the reason for landing impact the probability of ships in transit at landing sites. Before considering their level of convenience and safety, potential places where ancient Roman sailors might have sought to land or to find a temporary shelter are mapped.

The targeted places include different categories of sites, both natural ones or with artificial structures, which are generally addressed with a variety of different terms: according to the Oxford English Dictionary (1989) the harbours represent natural or artificial places where vessels can seek shelter and be stored. Ports are artificial constructions where vessels are loaded and unloaded therefore they constitute important hubs of regional redistribution and local stopping points for cabotage (Leidwanger, 2013, pp. 221-243; Nieto, 1997; Rogers, 2013, pp. 181-196;). Besides ports and harbours are also wharfs, jetties and breakwaters, which were cheap and effective measures to provide protection without the need to build expansive excavated harbours (Arnaud 2014, p. 164). Anchorages are also mapped, together with beaches and natural landing places, which have been the earliest features associated with water travel (McGrail, 1997, pp. 49-63, in Rogers, 2013, p. 182).

In this stage, all sites are equally ranked and considered capable of localised trade without considering their nature or supposed level of increasing development and connectivity with the hinterland (cf. Potts, 2019; Ducruet et al., 2016; Rimmer, 1967).

The catalogue by Arthur De Graauw (de Graauw et al. 2014) has been employed as main data-source in this preliminary step, because it presents a number of upsides for the present model.

First, the catalogue includes three categories of sites:

- those that have been already identified by the scholarship as ancient harbours thanks to the archaeological evidence
- those that have been already identified by the scholarship as ancient harbours because mentioned in ancient texts dating between 1500 BC and 500 AD
- those that are acknowledged as excellent shelters by modern sailors and might thus be further investigated by historians and archaeologists to find out if they were indeed ancient settlements (de Graauw, 2017)

The inclusion of the above three groups of sites is important given the scope of the present model and the objective impossibility to enquire the archaeological evidence for getting insights on the diachronic evolution of all the sites and the material evidence of the structures in different periods of time.

Second, it considers as potential 'shelter' different types of sites, i.e. "anchorages, landing places on beaches, and ports including structures such as access channels, breakwaters, jetties, landing stages, quays, warehouses for storing of commodities and equipment, ship sheds and slipways".

Third, the catalogue has been developed by referring to the most authoritative studies on ancient harbours, including the most recent contributions (Arnaud, 2017, pp. 15-49; Marriner et al., 2017, pp. 382-403; Arnaud, 2016, pp. 224-242; Morhange et al., 2016, pp. 85-106; Morhange et al., 2015, pp. 117-139; Talbert, 2000; and the digital libraries Pleiades and Dare).

For all the above reasons, this catalogue represents an optimal starting point for mapping all potential shelters and landing sites in Roman time before addressing their relative attractiveness in section 5.3.2. The catalogue includes a total of 5093 ancient ports, of which 375 reside in the selected study-area; in addition, there are also 238 'potential ancient harbour' deduced from 'excellent shelters in modern pilots, among which none in the selected study area, probably because -as suggested by de Graauw- here the ancient sources and the *Anonymus Stadismus Maris Magni* were more accurate in mapping sites than elsewhere. This represents an advantage to the present research.

5.3.2 Port attractiveness

The port attractiveness refers to the variety of aspects contributing to make a certain place more attractive to approach than others. Scholarship have employed different criteria for addressing the "*Systèmes et hiérarchies portuaires*" (Arnaud, 2010, pp. 107-114; port hierarchies discussed also in Arnaud & Keay, 2020; Blackman, 1982; Nieto, 1997; Potts, 2019; Ducruet et al., 2016; Rimmer, 1967; Keay, 2012; Rickman, 1988; Rickman, 1985; Schörle, 2011; Wilson, Schörle, & Rice, 2012, pp. 379-385;) for instance by looking at their enclosed harbour area, size and capacity, (Wilson, Schörle, & Rice, 2012, pp. 367-391; Schörle, 2011; Boetto, 2010, pp. 112-128; Keay, 2012, pp. 33-67), the increasing level of connectivity with the hinterland (Rimmer, 1967; Potts, 2019), the relationship between ports and cities development (Blackman, 1982; Potts, 2019) or at the industrial activities such as ceramic quantification and assemblage in the port surrounding area or on shipwrecks (Boetto, 2012; Rice, 2011, pp. 81-92; Bonifay, 2004; Nieto 1997; Fulford, 1989, pp. 169–191; Fulford, 1987, pp. 58-75), glass (Wilson, Schörle and Rice 2012; Degryse et al., 2014, pp. 97-112), and the production of fish sauce (Arévalo & Bernal, 2007; Botte, 2009).

Wilson notices that

> "One could also try to move beyond the simple quantification of harbour basin sizes to a more nuanced analysis of the relative importance of harbours in a region by considering other factors — the size of the associated port city, its legal status and range of public buildings — to come up with a kind of Central Place Theory ranking of functions and services, with larger centres providing a greater variety of goods and services over a larger geographical range" (Wilson, Schörle, & Rice, 2012, p. 380; for Central Place Theory see Christaller, 1933, cited in Beavon, 1977, p. 2; Evans & Gould, 1982).

Other approaches have focused on primary sources accounts or inscriptions for getting insights in the social dimension of ports and the communities around them (Arnaud & Keay, 2020; de Graauw, 2017; Terpstra, 2013). A way for evaluating the hierarchy between different types of landing sites, entrepôts, lesser ports and anchorages in the selected study area might have been by referring to the terms used for describing them (Arnaud & Keay, 2020, p. 6; Rougé 1966, pp. 107–120). For instance, in the *Stadiasmus Maris Magni* ('Periplus of the Great Sea'), a *periplus* dating c. AD 200-300, eight different words are used (Medas, 2008):

λιμήν, ὅρμος, πάνορμος, ὕφορμος, σάλος, ἀγκυροβόλιον, αἰγιαλός, ἐμπόριον, ἐπίνειον

In some passages this hierarchy seems explicit, such as in the cases of Utica, where it is said that there is no harbour but a roadstead (*Stadiasmus* 126; similarly in *Stadiasmus* 3, 9, 99). Nonetheless, as the scholarship has already contributed to highlight (Arnaud, 2017; Medas 2008; Rougé 1966) the adoption of the terms is misleading and often generic in the S*tadiasmus*, since a same word is used for describing rather different contexts (e.g. *λιμην* sometimes refers to structured harbours, elsewhere to a natural one; *όρμος* is used for natural harbours but also for simple anchorages; further examples in Medas 2008, 130-154). Archaeological investigations may certainly shed more light on the consistency of the archaeological remains, although the source may describe a different period from the one documented by the archaeological evidence (Medas, 2008, p. 131).

Even if it would be possible to establish a reliable hierarchy of places ranging from simple landing sites on beaches to artificial harbours, one cannot necessarily assume that those higher in the hierarchy scale would have a higher transit probability. In other terms, even assuming the terminology employed consistently and reflecting the real conditions of the sites, the preference specification based on the sole physical conditions reflected in the terminology would fail to account for potential variations in mariners' preference, which depend on the mariner status (Rougé 1966, pp. 239–55), and on economic, political, jurisdictional and technological conditions (the most recent debate in Arnaud & Keay, 2020). The ancient harbour was not just a mooring and trading place. Its traditional functions for shelter, as a technical base (shipyards, watering and victualling) and as a trading location were subject to different types of access and procedures of control. For example, a ship could enter the harbour of Rhodes for watering without waiting and be away after three hours, whereas the situation of ships entering the harbour for trade operations was very different (Arnaud 2011, p. 65).

It follows that it would be both simplistic and misleading basing a port hierarchization on a limited type of evidence: "Notwithstanding the importance of all these approaches, it is only by combining them with a consideration of the social dimension of ports, and the roles of the many different actors who made up their populations, that we can gain a more holistic understanding of port functions (Arnaud & Keay, 2020, p. 8). David Potts doctoral thesis, which was published in 2019, models maritime movements and the Mediterranean port system by taking multiple aspects into account to classify ports: port facilities, the urbanization pattern, hinterland connection and population size of ports' nearby cities (Rimmer, 1967; Russell, 1985; Ducruet et al., 2016). Particularly, a Class 1 Port is for Potts a major location, whose 'presence has a global effect on all possible movement patterns' (Potts, 2019, p. 148; he identifies two possible such locations, namely Constantinople and Portus). A Class 2 Port 'is a supplier port or location that has a large population as defined by Russell (1985)'(cited in Potts, 2019, p. 149 and section 4.1.9). A Class 3 Port is considered to be 'Any port location that has some type of infrastructure, a lighthouse, mole, ship shed etc is assumed to be an important place of travel, but not as important as a class 2 port' (Potts, 2019, p. 149). Potts then assigns additional properties to each port, based on their interrelationship and the spatial environment (e.g. lee shores, populated area, shipwrecks around the port location), although he could not model them all because of data coverage problems (some properties address very localised areas, others apply at a global scale). Besides the limitations that Potts acknowledged, it should also be stressed that some of his port properties may have ambiguous implications. For instance, according to Potts, the number of shipwrecks within 5 km of the port location suggests the presence of a navigation hazard; however, the same occurrence may also reflect the opposite condition, i.e. high transit of vessels at those locations that may over centuries produce numerous wrecks due to accidental causes.

For the above reasons, an alternative approach is employed for assessing the transit probability at different shelters, landing sites and anchorages. Particularly, the 'attractiveness index' (a-index) is introduced and used to express the probability for places to be reached, depending on their perceived convenience and risk. In Chapter 4, the conditions contributing to make landing sites, ports and anchorages more or less safe and attractive have been discussed in light of multiple primary sources accounts. Particularly, following ancient sources as well as medieval and modern portolans such as the navigational handbook *De Navigatione* by Benedictus de Cotrullis, dating back to the 15th century, ports and anchorages are considered more or less 'good' depending on the following aspects (Medas, 2008, p. 132; Kotruljević, 2005, pp. 82-84):

- Capacity and size: this refers to the number of vessels a harbour may contain as well as to the limitations in terms of tonnage and draft. A limited capacity (e.g. exclusion of commercial vessels) is assumed to have a lower transit probability.
- Exposure: this refers to the protection afforded from limited or all wind directions, or to the harbour- seasonality. A site providing protection from all winds is assumed to be preferred, namely to have a higher transit probability.
- Accessibility: whether easy to approach or not. When the SMM and other sources explicitly refer to the presence of hazards nearby (e.g. shoals in the vicinity; hazardous currents), the harbour is assigned a lower transit probability. Besides geomorphological hazards, also the presence of lee shore winds (i.e. winds blowing in the direction of the coastline) make sites particularly dangerous to access
- Nature of the seabed: i.e. providing a secure grip to anchors or not. When sources specify that a site provides strong anchor support, a higher preference is assigned
- Extra facilities: these may include artificial structures enhancing the harbour safety, the availability of water, warehouses or shipsheds for reparations. When available, the site is assigned a higher preference
- Socio-economic and cultural (SEC) attractors: these include cities, industrial, or worship centres mentioned in the textual evidence. The presence of roads, inland waterways, and sites having a socio-cultural and economic function as documented through further independent evidence are also modelled with a separate factor, i.e., the inland network (Chapter 5.4.3). The reason is twofold: on the one hand, the information provided by textual evidence is not necessarily reliable; the modelling of a factor based on textual evidence and a factor based on verified data enables to test them independently through sensitivity analysis. Moreover, as better explained in the following section, the inland

network does not necessarily affect all ships in transit, and different scenarios can thus be produced by accounting or not their presence

- Economic data and political conditions: these include information on administration, laws and taxes. Unfortunately, this group presents too many limitations for being implemented in the model. Indeed, the information on economic data is too scattered and fragmented. As for the political conditions, these include the jurisdictions and flags of the coastal states, namely the potential risks entailed in approaching ports out of agreement or conventions. These factors are not easy to be taken into account, for clearly, they vary depending on the 'flag' of the coastal state and the provenance of the ship one considers. The *Stadiasmus* mentions the presence of 'barbarian forts' (e.g. *SMM*, 86) in the vicinity of certain shelters, which may be risky to approach for Roman traders but not necessarily for others. Alternative approaches to traditional GIS, such as Agent-Based modelling (ABM), would be more suitable for accounting for different categories of travellers or agents interacting in the same geographical space (see section 8.4.3). Although the economic data and political conditions could not be implemented, the theoretical model includes them, for they may be significant when addressing specific historical contexts or research questions (e.g. for enquiring variations in Roman trade patterns before and after the Punic wars; or the effect of piracy in maritime connections).

Chapter 6 details how these aspects have been processed to be implemented into the model. Connected to the political conditions and the concept of unfriendly shores' is the assault probability (section 5.3.4). The model takes it into account, among other perceived hazards and repulsive factors, by assuming a lower navigation preference when in sight of the shore, the closer to the land. It is assumed that mariners would stay far enough for eluding attacks but still close enough for employing landmarks for wayfinding.

5.3.3 Inland network

The transit probability at harbours is assumed to increase in case of proximity to potential inland attractors, which include:

- roads
- sites having a socio-cultural, military or economic interest (i.e. cities, worship centres, forts, quarries, mines, kilns).
- navigable rivers
- water-sources (rivers and springs in the vicinity of the ports)

Nonetheless, the transit preference associated with the above factors is agent dependent. Indeed, whereas the environmental characteristics of a harbour have a broader impact on any category of agents or actors involved in the movement (i.e. sailors, travellers, traders, pilgrims), the economic or cultural ones may not. For instance, the proximity to road networks or production centres may impact trade operations, while the presence of nearby temples or sanctuaries may affect pilgrims only. Moreover, the transit preference may vary depending on the aim triggering the ships' movement, for even commercial vessels may not necessarily be interested in the inland network when seeking just a temporary shelter to wait for a storm to pass or needing water to refill. This is the reason why in chapter 6, different scenarios are tested by considering alternative settings (i.e. weights) for factors that are supposed to be agent dependent.

As a general rule, a location is assigned a higher transit preference the higher the number of attractors nearby a landing site or the number of cities served by a certain port. As for the river proximity, the model considers this in two ways: first, by assuming vessels may need to prosecute their maritime journey via inland waterways; second, by considering the rivers as fresh-water sources. This distinction entails a slightly different implementation procedure. Indeed, in the first case, ships need to be able to access the river directly from the sea, whilst in the second, it is fair assuming ships may temporarily land on beaches and reach the water source at a walkable distance.

Information on the road system and on the presence of cities and further potential socio-cultural attractors have been derived from the *Stadiasmus* and complemented with information derived from the Barrington Atlas of the Greek and Roman World (Talbert, 2000).

5.3.4 Implications of mutual visibility: assault probability and wayfinding

There are two opposite implications that follow from the mutual visibility issue discussed in Chapter 4.2, namely, the assault probability and the factors contributing to mariners' orientation. These two sides of the same coin (i.e. factor) are taken into account by assuming that mariners would try to keep landmarks in sight while trying to stay as far as possible from land so as either not to be seen, or to have the chance to escape in advance of an assault. In modelling terms, this implies assigning a higher transit preference at the seaward edge of the land range of visibility (i.e. the sea spaces placed as far as possible from the shore but from which the land is still visible), and an increasingly lower preference the shorter the distance from the shore. Since the assault probability does not necessarily correspond to an actual hazard, for it does not necessarily occur, it has been interpreted as a perceived risk and approached in terms of transit preference for supposed safe maritime zones. It is therefore included in the transit probability model component instead of in the navigational-hazard model component.

As for the modelling of visibility, the GIS environment provides several tools for performing different forms of visibility analysis such as line-of-sight analysis, viewsheds, skyline and sun shadow. (Gillings & Whitley, 2020; Cuckovic, 2016; Gillings, M., 2015; Llobera, 2007; Llobera, 2003; Wheatley, 1995; van Leusen, 2002, ch. 6). Line-of-sight analysis enables one to ascertain whether two points in space are intervisible (Figure 5.4). The viewshed for a specific point, is created over a digital terrain model (DTM), and it is the collection of areas visible from that point; it is based on cell-to-cell intervisibility.

"Views from any non-flat location are blocked by terrain. Elevation will hide points if the elevations are higher than the line of sight between the viewing point and target point [...]. If there is no intervening terrain, the cell is classified as visible. The classification identifies areas that are visible and areas that are hidden, and also the number of observer points from which the same cell is visible. Viewsheds for line or area features are the accumulated viewsheds from all the cells in those features" (Bolstad, 2012, pp. 458-459 and fig 11-20).

Nonetheless, it would be reductive to limit viewshed analysis to the simple binary in-view *versus* out-of-view assessment because, as the present research contributes to exemplify, the implications of the intervisibility are not necessarily straightforward (see Gillings, 2017 for a critique of the 'intellectual laziness' around visibility analysis studies and a discussion of its underexplored potential).

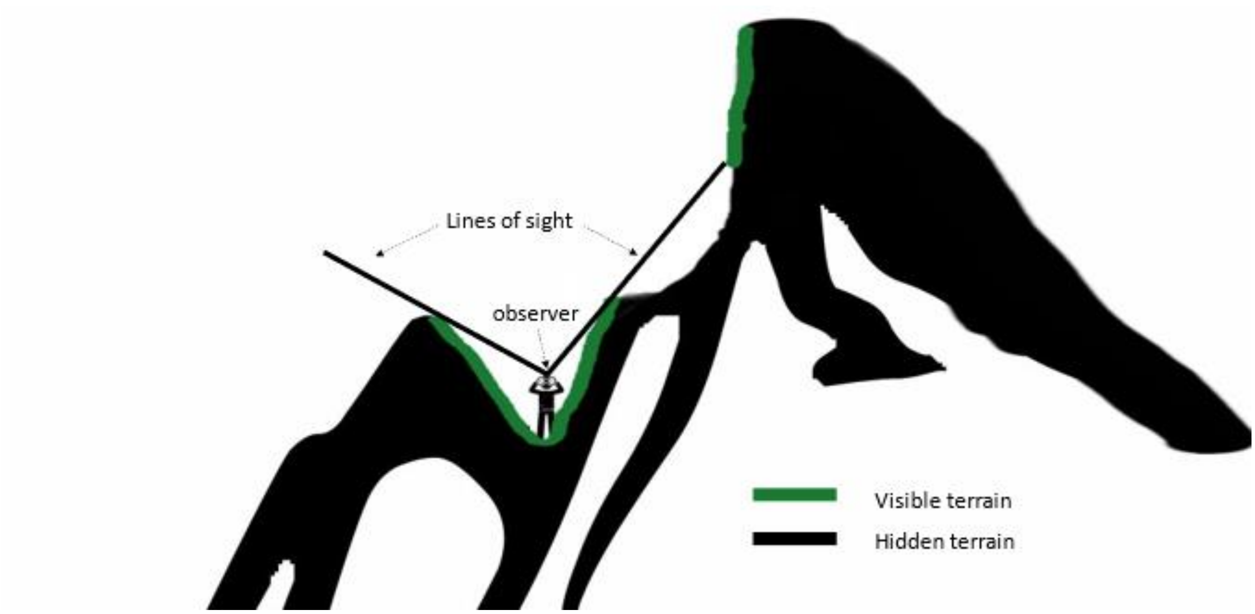

Figure 5.4: Lines of sight and the portion of the terrain visible (in green) from a given viewpoint

For assigning a higher transit preference to the seaward edge of the land viewshed, it is necessary to answer the question: "up to which distance can the land be seen", or "when offshore, up to what distance can one be seen from the land", which presents technical challenges. Indeed, whereas it is relatively simple to calculate viewsheds from a discrete number of points (i.e. observers), the present research does not address the visibility generated from specific points or landmarks. The great majority of current GIS-based visibility studies focus on the visual properties of specific locations, with a few notable exceptions (the Visual Neighbourhood Configurations (VNCs) elaborated by Brughmans et al., 2018, pp. 14-25; and the visual prominence in Llobera, 2003; cf. also the cumulative viewshed index (CVI) in van Leusen, 2002).

Addressing the above questions entails preliminary identifying optimal sites or prominent land features that may generate the broadest viewshed seaward; hence, total viewshed analysis is more suitable to this aim. Total viewsheds enable to generate viewsheds from all the cells of the digital elevation model (DEM) (Llobera, 2003; Llobera et al., 2010), but the procedure has significantly high computation time and cannot be easily run on extensive areas (Cuckovic, 2016; Cuckovic, 2018). Moreover, the resolution of the most precise DEMs is too fine to run these models regionally and DEMs, therefore, need to be aggregated to coarser resolutions through procedures that affect the representation of the land surface and the results (Coz et al., 2009). In section 6.2.4 is described the procedure, which has been designed to this end.

5.3.5 Other indicators of coastal proximity

Among the indicators of coastal proximity different from the sight that have been discussed in chapter 4.3.5, only the coastal bird fly-range has the potential to be implemented in the model, as modern technologies enable one to monitor the movements of birds by tracking them with geolocating techniques (Figure 5.5). Bird tracking systems provide two kinds of data potentially insightful in terms of coastal proximity indication: the maximum distance from the shore at which a certain species has been found and the density of birds of the same species at different distances from the coastline. The first information is less reliable than the second since individual birds may get lost (Fenton, 1993, p. 52; Gooley, 2011, p. 124), whereas the higher the density of flocks known to dwell in littoral areas, the closer the distance to the land (the greater reliability of observed flocks rather than single individuals has been discussed in section 4.3.5). Unfortunately, it has not been possible to gather such data for the selected case-study area; moreover, the use of present-day data for approximating past flocks movement is debatable and would require expert judgement and targeted studies.

As for the implementation of senses different from the sight, odour dispersion modelling (a review in Capelli, Sironi, Del Rosso, & Guillot, 2013) and noise dispersion modelling (Hadzi-Nikolova et al., 2012) may serve the purpose. According to Wheatley (2014), 'the sight and hearing are the only senses capable of reaching over a long distance, typically on a landscape scale, whereas smell, touch and taste are experienced on a more intimate scale' (cited in Landeschi, 2019, p. 9). In section 4.3.5, it was argued, based on textual evidence, that certain smells may spread over a relatively long distance as well, thus providing orientation clues. However, given the input data required (e.g. source characteristics and emission rates) it is difficult applying them in historical contexts, as the information on noise and smell sources in antiquity is too scattered and potentially different from present day time to enable any reliable -and historically valuable- model. A few experimental attempts to model 'smellscapes' and sensory maps in the domain of cultural geography -also in a historical perspective- are the works and projects by researcher Kate McLean, which combine cartography, art and digital design (McLean, 2019, 2017, 2017a; McLean, Lammes, & Perkins, 2018). Targeted case studies, which are worth exploring in future developments of the present research, may take into account natural odour sources, such as volcanic areas with effusive gaseous manifestations, which may present similarities between past and present and were both notorious and distinctive in textual evidences (chapter 4).

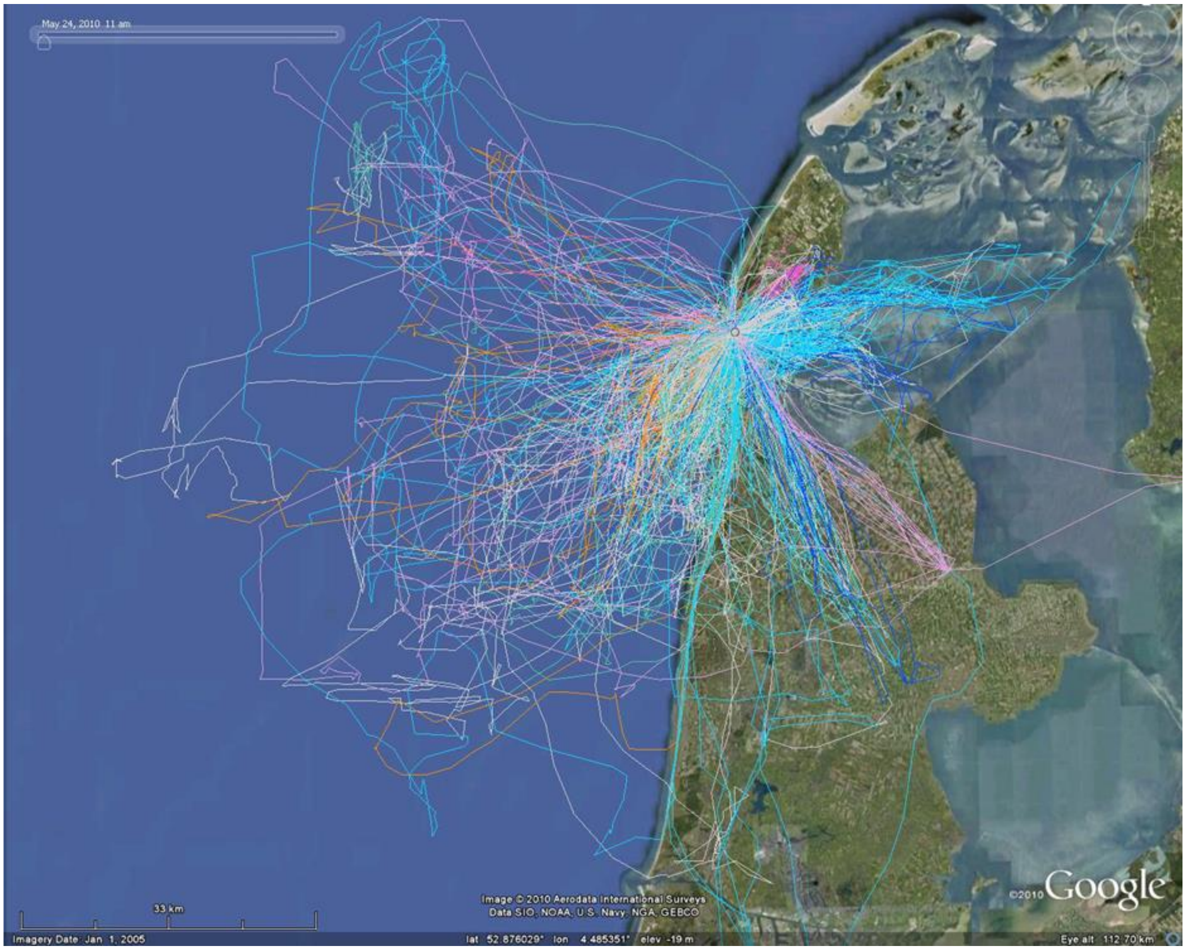

Figure 5.5: The foraging movement of 15 lesser black-backed gulls (Larus fuscus) during the month of June, 2010 tracked with GPS technology by the University of Amsterdam Bird Tracking System project (UvA-BiTS) (Shamoun-Baranes et al., 2017)[46]

[46] Available at : http://www.uva-bits.nl/project/multi-scale-movements-of-gulls-from-texel/. Accessed: 23 February 2021

5.4 SECOND COMPONENT: NAVIGATIONAL HAZARDS

The navigational hazards model component includes environmental threats to navigation, namely factors that may actually increase the probability of sinking. Therefore, the questions behind this model component can be formulated as:

where is it more likely that ships would sink? And *which are the factors that increase the chance for a vessel to sink?*

Given what emerged from the analysis of both primary and secondary sources, the model considers as hazards:

1. Geomorphological threats: topography and bathymetry
2. Severe meteorological and oceanographic conditions

5.4.1 Geomorphological hazards

The model includes topographical and bathymetrical data for identifying geomorphological threats to navigation; this includes shallows, reefs, shoals and offshore rocks and islands that may be hard for mariners to spot in harsh meteorological conditions. Particularly, the model assumes:

- An increasingly higher risk at depths less than 5 meters: the shallower the water, the higher the risk;
- A high risk for depths ranging between 5 and 10 meters only where the probability of storm occurrence and the average wave height exceed a certain threshold value;
- A high risk within the 1 NM zone from shallow offshore outcrops or islands generating a seaward visibility lower than 1NM, for they may be particularly hard to spot during storms.

Even though the scholarship also considers the surrounding of headlands and promontories as threatening for navigation (Casson, 1995, pp. 271-272; Medas, 2004, p. 145, Beresford, 2013, p. 244; Morton, 2001, p. 68), this model does not count them as input variables. Since the dangers are associated with their topography and the meteorological-oceanographic conditions around them (Beresford, 2013, p. 244; Morton, 2001, p. 68), the choice was made to derive the navigation risk-degree in their vicinity from the modelling of these other factors. The reasons are multiple: first, this approach would allow using the location of well-known hazardous promontories and headlands for testing (see further in Chapter 7); second, because, despite the difficulty in crossing them, headlands and capes may actually also provide safe anchorages and shelters on one side depending from the meteorological and oceanographic conditions (e.g. *Stadiasmus*, 95); third, because rounding promontories may be risky due to both environmental hazards and the greater attack probability. Indeed, enemies (Thuc. 8.35) or pirates profited from the difficulty of commercial vessels to round a promontory in the face of adverse winds by lurking in the vicinity to attack them (Beresford, 2013, p. 244). The correlation with either environmental risk or pirates' attack probability may generate rather different model outcomes.

5.4.2 Severe meteorological and oceanographic conditions

Severe meteorological and oceanographic conditions such as extreme wind speed values and wave height impact the navigation safety as well as the accessibility and the protection afforded by the harbours (see also above in the TP model chapter 5.3).

Waves are generated offshore by the friction of the wind on the sea surface (such waves are called 'wind waves'). Waves travel on the sea surface over hundreds (even thousands) of kilometres after they are generated (such waves are called 'swell'). When they reach the shallow coastal waters, they change in height and direction due to shoaling, refraction and diffraction effects. [...] Wave generation and propagation are complex processes, and statistics play an important role in the description of the wave climate in a given coastal location. As stated by De Graauw, "a simple way to define a sea state is to mention its 'significant wave height Hs', which is defined as the average of the one third highest waves of that sea state"[47]. The wave height varies in relation to the geomorphology of an area (i.e. bathymetry, nature of the sediments); since waves change in height and direction due to shoaling, refraction and diffraction effects when they reach the shallow coastal waters, so the wave climate differs depending from the coastal locations. Moreover, the same meteorological event is able to produce wave storms of different energy contents along different coasts (Mendoza et al., 2011). Ancient navigation models usually employ present-day datasets such as the average wind and wave values provided by the federal agency for the National Oceanic and Atmospheric Administration of the United States (NOAA), the Wind and Wave Atlas for the Mediterranean Sea (MedAtlas), the European Marine Observation and Data Network (EMODnet), and the European Earth Observation Programme Copernicus. The assumption behind their adoption is that present climate conditions do not significantly differ from the past ones (see below).

Among the meteorological and oceanographic threats to navigation, the present model takes into account the average significant wave height and the wind speed, but also the incidence and impact of storms in Mediterranean coastal areas, which are currently excluded in ancient navigation models. A storm is defined as a violent disturbance of the atmosphere with strong winds and usually rain, thunder, lightning, or snow (Oxford dictionary). When this happens in the sea, the most immediate effects are the increase in wave height and sometimes sea level (i.e. storm surge) for a certain period of time. (Mendoza et al., 2011, p. 2453). Usually, the so-called significant wave height (Hs) value taken as a threshold is 2m, whereas the period or time lapse depends on the intensity of the storm. The minimum period is usually set to 6 h for the first class (e.g. classes of storms in Mendoza et al., 2011). Overall, "though shallower, with a smaller extension and shorter lifetime than their counterparts in the north Atlantic storm track, the Mediterranean cyclones cause extreme precipitation, storm surges, and windstorms. The complex morphology of the Mediterranean region has an important role in the generation and evolution of Mediterranean cyclones" (Lionello, 2012, p. 64-65; see also Lionello et al., 2006). Some factors, such as the orography or sharp temperature-contrasts such as between the Mediterranean sea and the north African areas, may enhance the intensity and effects of cyclones, whose path (i.e. storm-track) may be predicted by means of algorithms accounting for different impacting factors (Lionello et al.,

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[47] https://www.ancientportsantiques.com/ancient-port-structures/design-waves/)

2016, Figure 5.6). The frequency with which storms tend to occur in a different region of the Mediterranean, and their intensity, particularly the maximum level the water can reach, during a storm along the coast, has not only essential consequences on coastal defences and coastal erosion (Lionello et al., 2017, p. 89) but also on ancient sailing, particularly in littoral areas (as for the seasonal variation in track density in different parts of the Mediterranean basin see Lionello, 2012, Fig. I.16, p. lxv).

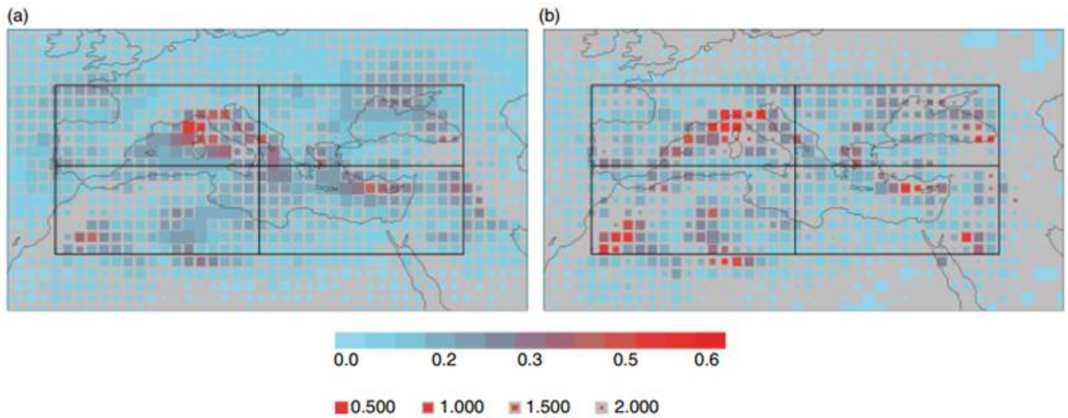

Fig. 1. Cyclone tracks and cyclogenesis in the Mediterranean region. (a) Track density according to the multi-methods mean. Colours represent the probability (%) that a cyclone track crosses each 1.5° × 1.5° cell of the domain in the 6-hourly field (values according to the label bar below the panels). (b) Probability (%) that cyclogenesis occurs in each cell in the 6-hourly field. In both panels, only cyclones whose track crosses the Mediterranean region are considered. The filled fraction of each cell corresponds to the level of agreement (given by the normalised standard deviation) among methods as annotated below the panels. The large rectangle denotes the Mediterranean region with its subdivision in four sectors.

Figure 5.6: Cyclone tracks and cyclogenesis in the Mediterranean region (after Lionello et al., 2016, Fig. 1, p. 3).

Therefore, the present model takes into account two additional factors specifically related to the cyclone genesis and the storminess effects along the coast of the Mediterranean sea:

- the maximum level that the water can reach -along the coastline- during a storm by simultaneously considering different combined factors (i.e. storm surges, ocean wind-generated waves, and steric effects on sea level. Lionello et al., 2017)
- the 5-year return value of the wave maximum amplitude, indicating how often the wave maximum amplitude tends to occur in five years.

This information has been derived from a study carried out at the University of Salento in cooperation with the Euro-Mediterranean Center on Climate Change in Lecce[48] (Lionello et al., 2017), whose base data consists of a set of 607 points located along the whole coast of the Mediterranean basin (islands and Black Sea are excluded) (Figure 5.7). The coastal grid points are associated with 5 different parameters: wave amplitude (wa); storm surge level (ss); and water level (wl), which is the sum of the previous two. The values refer to two 30 yearlong periods: 1971–2000, representing the past (reference), and 2021–2050 representing the future climate

[48] Prof. Piero Lionello kindly provided the original data. Any possible mistake in their analysis or elaboration in the present thesis is my own.

projections. These data have been fundamental to the present research for two interconnected reasons. On the one hand, because the incidence and impact of storminess have never been included so far in ancient navigation models, which only rely on predominant winds, waves and surface currents; on the other, because these storm data allowed to address the specificity of the littoral area, for they focus on the coastal zone "where effects of water level maxima are most important" (Lionello 2016).

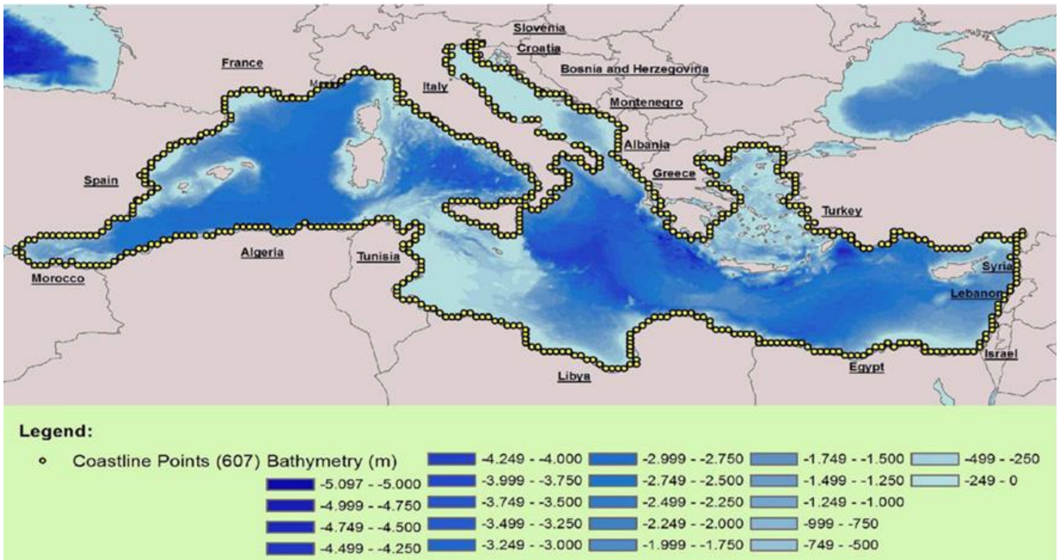

Figure 5.7: The Mediterranean Sea bathymetry with the coastal grid points (yellow dots) where the climate change analysis is performed in Lionello et al., study (Lionello et al., 2017, Fig. 1a) [49]

Overall, the present model takes into account the following meteorological-oceanographic factors:

- The annual mean significant wave height (Hs), by assuming an increasingly higher risk at higher values
- The annual mean wind speed (Uw), by assuming as dangerous for mariners both extremely high values and extremely low ones. Indeed, the complete lack of winds, or extremely weak ones, may leave the vessel at the mercy of the waves, which is particularly hazardous when close to the shore. The best wind conditions for ancient sailing are those corresponding to Beaufort 3-4 (Arnaud, 19), whereas the situation becomes increasingly insidious with values greater than 6.
- The average annual water level maximum (wlind1), which during a storm results from the superposition of wave amplitude and storm surge" (Lionello, 2017). The higher this value, the higher is the risk to navigation
- The 5-year return value of the wave maximum amplitude, indicating how often the wave maximum amplitude tends to occur in five years. The higher the value, the higher the risk is assumed to be.

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[49] Reprinted from Lionello et al., 2017, p. 82., Copyright (2017), with permission from Elsevier.

5.4.3 Past climatic variations

In the opinion of most scholars (Rouge 1966, p. 39; Semple, 1932, p.100; Meigs, 1961, p. 374; McCaslin, 1980, p. 88; Morton, 2001; Arnaud, 2005; Warnking, 2016, p. 51; Xoplaki, 2002, pp. 1-29) the more striking aspects of the physical environment referred to in ancient sources, particularly the climate and weather, have not changed significantly since ancient times, and the prominent features of today's physical environment are the same (a discussion in Morton 2001, pp. 5-11).

According to Murray (1987, p. 156), there has been no overall change in the meteorological conditions of the Mediterranean as a whole, and "we are fully justified, therefore, in applying modern wind data to the problems of classical antiquity. Bintliff, 1982, p. 152 states "careful study of literary sources gives strong evidence for a climate during this era [700-200 BC] comparable to that of the present-day". However, other authors are more cautious than Murray and Bintliff. For instance, Beresford, acknowledges the 'fluctuating nature of the climatic history of the Mediterranean" (Beresford, 2013, p. 62) while still adopting modern meteorological records for gaining general insights. Bresson is equally cautious and formulates doubts about the methods of previous research (Bresson, 2014). McCormick highlights the need for new data to "revise and deepen the knowledge on every aspect of ancient climate" (McCormick 2013, p. 63); a similar position in Harris (Harris, 2013, p. 7).

Nonetheless, considering the scope of the present research, namely the coastal area, it cannot be neglected that, as highlighted by Morton "the coastal topography seems to be the area of the physical environment most likely to have undergone notable changes since ancient times (Morton 2001, p. 7). If the average overall sea-level rise has been of one meter per millennium, which means that in 1 BC the sea level was two to three meters lower than now (Morton 2001, p. 7), at local level, particularly due to tectonic movements, the difference may be even greater (Morton 2001, p. 7). It is generally agreed that it is a matter of scale since, at global level, the overall situation is unchanged.

The scale of the model turns out to be crucial for reaching the acceptable (and possible) level of detail. If at large scale the adoption of modern data without any additional modifications may be sufficient to approximate past environmental and meteorological conditions, the development of models at a smaller and more specific chronological scale may benefit of more accurate and detailed datasets available. Indeed, as for the last 2000 years, it has been already possible to highlight a sequence of humid/ dry and warm/cold periods that have produced effects on environmental conditions in the Mediterranean (Lionello 2012, pp. xlv-xlvi), and further insights are expected from the ongoing SoHP Historical Ice Core Project[50], which is aimed at employing both ice core data and pre-industrial written and archaeological records to reconstruct/study climate change and human-climate interactions from the last ca. 2,000 years.

Despite the current struggle in carrying out complete and consistent regional scale reconstructions from local records and the lack of even amount of data for the past centuries, a number of significant paleoclimate and historical variations have been identified by analysing different kinds

[50] https://sohp.fas.harvard.edu/historical-ice-core-heart-europe

of independent proxies (e.g. tree-rings, biological indicators, ice core; Lionello 2012, xlv-xlvi; McCormick, 2012); but also by comparing modern and past agricultural practices and crops (Semple, 1932; Meigs 1961; Cary, 1949). Particularly, changes in precipitations and sea surge, as well as increases and decreases in temperatures, have been identified in Roman time and Late antiquity (cf. McCormick, 2012; Lionello 2012, xlv-xlvi), as well as in the Middle Age and Modern Age (e.g. the so-called Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA)[51].

The possibility in current predictive models to account for temporary extreme weather variations (e.g. in precipitation) may certainly be beneficial for in-depth analysis to provide further insights on the increased environmental hazards to navigation in specific periods. Nonetheless, the large variability at different timescales and the uneven amount of information available prevents including this data in large-scale models.

[51] Beside controversies around their exact extension and timing (Bradley, et al., 2003; Xoplaki, et al., 2011, and the references therein as cited in Lionello, 2012), the MCA is conventionally referred to a period of relative warmth extended from the tenth to the fourteenth century in Europe, Greenland, and Asia; the LIA as a cold period extending from ca. the sixteenth to the nineteenth centuries (Lionello 2012, xlv-xlvi; Mann, et al., 2009; Luterbacher, et al., 2012).

5.5 BRIEF HISTORICAL INTRODUCTION TO THE REGIONAL PERSPECTIVE

The area selected for the in-depth analysis of the model encompasses the territorial waters enclosed between Alexandria (current Egypt) and Cap Bon (current Tunisia) under Roman rule, during which the territory was organized in three provinces, namely the *Africa Proconsularis*, *Cyrenaica* and *Egyptus*. The beginning of the Roman rule and the foundation of these provinces occurred in different moments, and both the structure and the extension of the provinces underwent transformations across the centuries (for a more exhaustive summary of the historical debate around the origins of the province of *Africa*, which is beyond the scope of the present section and research to provide, see Romanelli, 1959; Fishwick, 1993; Fishwick, 1994; Bullo, 2002; Le Bohec, 2005).

The Province of *Africa* was established in 146 BC after the defeat of the Carthaginians in the Third Punic War. The province, called *Africa Vetus*, at first included only the territories originally subjected to Carthage, which correspond roughly to modern Tunisia. After the defeat of King Juba in 46 BC the territories of Numidia also fell under Roman rule with the name of *Africa Nova*. Under Augustus, in consequence of his provincial reform, the two territories became part of a unique senatorial province called *Africa Proconsularis*, after the name of the *proconsul* ruling this type of Roman territorial division, in contraposition to the imperial properties, e.g. *Egyptus*, ruled by a *legatus Augusti. The Africa Proconsularis* included the north-east of present-day Algeria, Tunisia and the coast of Libya up to *Arae Philaenorum* (Qararat Qasr at Turab), namely the rich territory of Tripolitania (in Greek Τριπολιτάνια, three cities), so-called after the three important cities there included: Sabratha, Oea (Tripoli) and Leptis Magna. In the second half of the 3rd century AD, Diocletian reorganized the division of the provinces, by dividing them in smaller units: particularly, *Africa Proconsularis* was divided into *Zeugitana*, *Byzacena* and *Tripolitania*. The Roman administrative presence ended by 429 with the Vandal invasions.

The Roman senatorial province of *Cyrenaica* was established in 67 BC, and it also included Crete up to the reorganization by Diocletian (298 AD), who divided them into two distinct provinces. Formerly, the territory had been occupied starting from 631 BC by Greek colonists who named it *Pentapolis* after the five major cities there present, namely Euhesperides (Banghāzī), Barce (al-Marj), Cyrene (Shaḥḥāt), Apollonia (Marsa Sūsah), and Tenchira (Tūkrah). Afterwards, the Ptolemais of Egypt ruled from 323 BC till the death of Ptolemy Apion (96 BC), the last king of the Hellenistic Kingdom of Cyrenaica. Having no son for succession, he left the territory to the Romans, who up to the Jewish settlers revolt in 70 BC, did not establish a direct control but rather let local rulers govern instead. In Roman times, besides the cities mentioned above, also *Ptolemais* (Ṭulmaythah) and *Daims-Zarine* (Darnah) became prominent. Barbarian raids affected Cyrenaica like other northern-African territories in Late Antiquity.

The Roman province of *Egyptus* was established in 30 BC after the victory of Octavian over Mark Antony and Cleopatra, the ruler of the Ptolemaic Kingdom. Differently from the provinces of Africa Proconsularis and Cyrenaica and Crete, the province of *Egyptus* was an Imperial one, ruled by a *Praefectus augustalis* with delegated authority appointed by the Emperor. The region had to face a period of religious conflicts toward the end of the first century, particularly in Alexandria, which became the most important Jewish centre after the destruction of Jerusalem in 70 CE.

Overall, the North-Eastern African regions and their coasts were among the richest and fertile areas of the Mediterranean and of the Roman Empire (Mattingly & Hitchner, 1995, pp. 165-213). Their wealth mainly came from agriculture but also from the abundance of medicinal plants (numerous mentions in Pliny Natural Histories), precious metals, slave trade, exotic products and animals, textiles. Besides grain, of which *Egyptus* was one of the main suppliers, thus being called the "granary of Rome", other crops included fruit, figs, grapes, and beans (Meijer & van Nijf, 1992).

5.5.1 Reasons for choosing the north-eastern African coast as a case-study

There are two main reasons for selecting this case study: first, from a cultural-heritage management perspective, the area is particularly interesting since, despite its historical significance, the shipwrecks along its coasts are particularly underrepresented in the published datasets. Particularly, the DARMC dataset reports nine shipwrecks in its waters, whilst OXREP reports eleven. Further published sites bring the total to nineteen (section 7.4, Table 7.5). This paucity of remains is unlikely to reflect infrequent crossing or successful journeys, given the historical significance and the acknowledged environmental hazards of the region (Dowler & Galvin, 2011). Rather it may reflect the research underdevelopment in the south and the east of the Mediterranean compared to the northern side of the western and central Mediterranean, which has been studied more intensively (Keay, 2012, p. 1), as well as a lack of archaeological initiatives or poor information sharing as it has been previously argued (see above in section 3.2). In this regard, it is significant and worth highlighting the fact that neither Egypt nor Libya have recognised the Valletta Convention[52]; whilst as for the UNESCO Convention on the Protection of the Underwater Cultural Heritage, which has been ratified by Libya, Tunisia, and Egypt "the law alone is not enough and risks remaining merely ink on paper without the sincere desire and commitment of people who want to protect cultural heritage", as Abdelssalam A. Elkawash, Advisor in the Department of Antiquities in Libya has stated in the National Report on the underwater cultural heritage made in the UNESCO Regional Meeting in Istanbul on 25 -27 October 2010. The above considerations reflect the particular need for the assessment of the archaeological potential of the area in question.

The second point relates to the historically renowned hazardous nature of this sea space, which in antiquity was considered to be among the riskiest regions to navigate in the Mediterranean Sea (e.g. Quinn, 2011). Particularly, the long-lasting and unfortunate fame of the Syrtis became a literary *topos*; indeed, it has been proposed (How & Wells, 1912, vol. 1 p. 359, in Morton, 2001, p. 134) that somewhere along the north African coast, most likely in the Syrtis Gulf, the Tritonian Lake was situated, where Jason and the Argonauts got stuck into the shallows and managed to find their way out thanks to the help of Triton (Hdt. 4.179; Ap.Rhod.*Arg*. 4.1240–78 and 4.1554-83). However, the identification of the Tritonian lake with actual features is still under debate (Morton 2001, 134 and p. 267f). The reasons why the area was known to be dangerous emerge from primary sources accounts: the already mentioned excerpt by Strabo (see above Chapter 0) highlights that "the sea-coast of Cyrene from Apollonia to Catabathmus [..] does not throughout afford facilities for coasting along it; for harbours, anchorage, habitations, and watering-places are few" (Strab, *Geog*., 17.3.22)

[52] https://www.coe.int/en/web/conventions/full-list/-/conventions/treaty/143/signatures?p_auth=MPQsTwIm

The rare watering places and the paucity of havens along the North African coast is remarked by several primary sources accounts, although the scholarship has recently reconsidered the issue by comparing the literary and archaeological evidence. For instance, according to Stone (2014), the picture drawn from textual documents has misled earlier scholars, and the extent of construction of artificial ports is a more reliable source of information. As for the literary evidence, besides the already mentioned excerpt by Strabo is also Flavius Josephus, who reports both in the Jewish Antiquities (Joseph. *AJ*, 15.9.6) and in the Jewish War (Joseph. *BJ* 1.408) the lack of havens and landing sites between Joppa and Dora. Furthermore, Flavius Josephus also mentions:

> the impetuous south winds that beat upon the maritime cities in Phoenicia, which rolling the sands that come from the sea against the shores, do not admit of ships lying in their station; but the merchants are generally there forced to ride at their anchors in the sea itself (Joseph. *AJ*, 15.9.6).

The south wind is particularly insidious, for “if it blew but a little fresh, such vast waves are raised, and dash upon the rocks, that upon their retreat the sea is in a great ferment for a long way” (Joseph. *BJ,* 1.408). Besides the paucity of ‘good’ harbours and landing sites, particularly between Parcetonium and Joppa, Diodorus Siculus also states (Diod. Sic, 1.31.1)

> [..] all along the coasts of Egypt, the sea is full of rocks and sands, not discernible by mariners unacquainted with the places; so that when they look upon themselves as safe, and to have escaped the danger of the seas, and make with great joy to land (wanting skill to steer aright), they are on a sudden and unexpectedly shipwrecked. Others inconsiderately, because they cannot see the land, in regard it lies so low, are carried either into the bogs, or to the deserts.

Last but not least are the notorious shallows and shoals, which threatened the navigation of mariners not acquainted enough with the area, particularly in light of the tides, which are relatively weaker elsewhere in the Mediterranean (Morton 2001, 45):

At length, they came to the island of the Lotophagi called Mēnix, which is not far from the Lesser Syrtis. There, from ignorance of the waters, they ran upon some shallows; the tide receded, their ships went aground, and they were in extreme peril. However, after a while, the tide unexpectedly flowed back again, and by dint of throwing overboard all their heavy goods, they just managed to float the ships. (Polyb., 1.39.1)

Along this coast, the two Syrtis – the *Major* or *Magna*, and the lesser or *Minor* Syrtis - had particularly ominous fame among ancient mariners who greatly feared to navigate there (see also Hor. *Carm*., 1, 22, 5; Ov., *Fast*. 4:499; Tib. 2, 4, 91). The hazardous nature of these two Gulfs, which correspond respectively to the Gulf of Sidra (i.e. the greater Sirtis) and the Gulf of Gabes, is reflected by the name: indeed, the greek *Σύρτις* comes from *σύρω*, which means to drag. Strabo says that the difficulty of navigating both the Great and the Lesser Syrtis arises from the circumstances of the soundings in many parts being soft mud and that the ebbing and flowing of the tide, enhances the chance for vessels to be carried upon the shallows. Therefore, in coasting, sailors keep at a distance from the shore, and are on their guard, lest they should be caught by a wind unprepared and driven into these gulfs (Strab. *Geog*., 17.3.20).

The above excerpts provide insights on the many environmental hazards connected to both the *Syrtis*, despite the great confusion around the geographical and geomorphological shape of *Syrtis* provided in documentary sources (for a discussion, see Janni, 1984, pp. 141-142). Indeed, Herodotus mentions only one big Syrtis (Hdt 4.169), whereas according to Pomponius Mela (Mela, *Chor.,* 1.35-36) Pliny (Plin. *HN*. 5. 4, 26-27), Strabo (Str. *Geog*. 17.3.20) there were two gulfs, one greater than the other, as it is in the Geography of Ptolemy and the Peutingerian Table (Figure 5.8). Here, the *Syrtis Maior* is interestingly depicted with a curled-appendix (i.e. a kind of cork-nail shape), which may be put in relation to the circular currents in this area (McGrail, 2015, p. 54; Davis, pp. 19-20 and pp. 29-30; Quinn, 2011, p. 12).

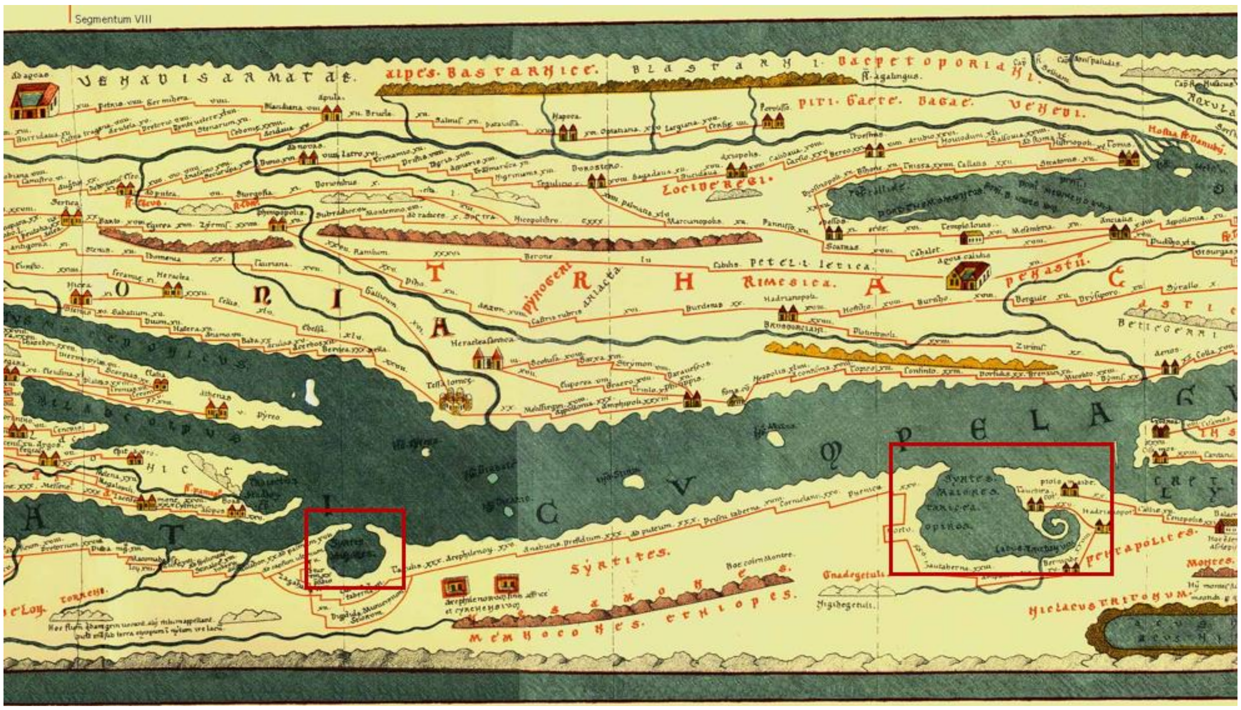

Figure 5.8: Case study area in the Peutingerian table From the left: Syrtis Minor (Gulf of Gabes), and Syrtis Maior (Gulf of Sidra) with the typical snail-shape; Alexandria's Pharos is to the right (Bibliotheca Augustana, Pars IX, segments VII, VIII)

5.5.2 The *Stadiasmus* as a source for implementing port attractiveness

Whereas a general survey of Classical textual evidence derived from digital libraries (ca. 800 BCE - 600 AD) was used to identify categories of advantages and disadvantages of coastal proximity, one specific text is employed to provide a proof of concept for implementing the shelters-attractiveness at regional scale, namely the *Stadiasmus Maris Magni (SMM)* ('Periplus of the Great Sea'). The latter is a Greek *periplous*, originally titled ΑΝΩΝΥΜΟΥ ΣΤΑΔΙΑΣΜΟΣ ΗΤΟΙ ΠΕΡΙΠΛΟΥΣ ΤΗΣ ΜΕΓΑΛΗΣ ΘΑΛΑΣΣΗΣ, written by an anonymous author whose exact date is still under debate although approximately thought to be ca. AD 250-300 (for a critical analysis of the *SMM*, its chronology, structure, nature and terminology, see Medas, 2009-2010 and Arnaud, 2016). The text is known from a 10th-century manuscript (Arnaud, 2017, p. 16), and it describes the coastline clockwise from Alexandria to the Pillar of Hercules, from Alexandria anti-clockwise to Hellespont, and then westward from Hellespont back to the Pillar of Hercules. While evidencing the many lacunas, duplications and confusion reflecting the complexity of the text's transmission and copy (Arnaud, 2009, p. 175), and the lack of awareness by the copyist of these omissions (Arnaud, 2017), some authors have suggested that the original manuscript may have provided a complete circumnavigation of the Mediterranean coast, similar in style to the medieval *portolans* (Marcotte, 2000, p. XLIX as referred to in Obied, 2016; Medas, 2009-10, pp. 351-352, Medas, 2008, Medas, 2011).

This document was chosen first because it provides nautical information, advice and warnings from a mariner perspective, as well as distances in stades between ports, thus specifying facilities and risks around them, which are relevant for implementing the attractiveness of shelters; and second, for its time-period and political context. Indeed, while being known from a 10th-century manuscript (Arnaud, 2017, p. 16), it is set in the Roman Imperial period, and it is deemed to be based on the compilation of several different sources (e.g. historians, geographers, mathematicians, astronomers, local travellers, merchants, and mariners, Obied, 2016, p. 46, Arnaud, 2017, pp. 16-17)[53]. Medas highlights the maritime nature of these sources, which may have included both oral reports and written nautical instructions (Medas 2009-10, pp. 339, 351; on the sources and influences in the SMM see also Uggeri 1998, pp. 38-46). Third, because the section of interest for the present research, namely the first one covering the North African coast from Alexandria to Utica (Stadiasmus 1-127), is the most detailed and complete compared to the rest of the text, providing much nautical information (Medas, 2004, p. 118).

However, it must be stressed that the text serves for providing a proof of concept to implement the shelters attractiveness and distinguish the actual environmental hazards from the risks documented in the textual evidence. It is beyond the scope of the present study to analyse the SMM's genesis and the different multifaceted reasons why the *SMM* was written and transmitted as such. Similarly, it is outside the realm of this research to address the text's fallacy and omissions or to debate the origin and the intention and nature of the author's work and its intended public, which are issues deserving targeted research (cf. Arnaud, 2017; Obied, 2016; Medas, 2008). Although the lack of information associated with relevant localities, such as Apollonia, may suggest that these were so well-known as not to require further indications, no external data were added to compensate the lacunas for consistency with the above-declared goals. From the above, it follows that the attractiveness associated with such localities at the Regional scale may be lower than expected, and different outcomes are obtained with the Global scale model, which is not based on textual evidence.

To conclude, it would be simplistic to use this text as evidence of historical geography or claim to analyse the Roman risk perception based on this sole document. The latter may be addressed more rigorously by accessing multiple sources of evidence (e.g. textual, iconographic, cartographic) in future developments of the present study.

Chapter 6 details the critical editions used and the procedures followed for modelling the 'ports attractiveness' factor based on the SMM.

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[53] Arnaud evidenced that "In entire areas, places renamed or founded after the Roman conquest are entirely missing. Here or there, one even finds traces of names that mirror earlier periods, sometimes as old as the late IVth century at the latest. We are therefore facing a jigsaw puzzle of elements from various periods, whose latest contents are not later than Augustus, inserted by Hippolytus in his Chronicon in the late Severian period"(Arnaud, 2017, p. 17)

5.6 A GLOBAL PERSPECTIVE: DESIGNING A SIMPLIFIED MEDITERRANEAN-SCALE MODEL

As specified in the Introduction, it is beyond the scope of the present research to address the Mediterranean navigation processes diachronically over the *longue-durée* (Braudel, 1949), assuming this task even feasible (Horden & Purcell 2000, 44), or to provide a systematic discussion on how to integrate the different archaeological theories for developing a general Mediterranean shipwrecking predictive model (see the useful discussion around the role and the implications of post-processual theories and Middle range theory in archaeological prediction in Verhagen & Whitley 2012). This section aims instead at debating whether and how the factors identified in chapter 5 can be used to model shipwrecking probabilities in different regions and time periods and which are the implications and limitations of such a bottom-up approach.

The Mediterranean global-scale model is developed by following a slightly different procedure, which reflects methodological and logistic limitations but also a rather different scope. Indeed the goal is to provide to heritage managers and developers an indicative map, more general and simplified than the local-scale model, suggesting the areas where the chance to encounter shipwrecks 'remains is higher without taking into account a specific time period. In this perspective, the model, which may be considered as a 'beta-version' open to further improvements, implements a small number of factors that may be considered valid in a long-term perspective. The rationale behind the implementation of the environmental factors included in the regional navigation hazards model component (Chapter 5.4) is valid at the global scale as well (a diachronic essay on shipping flows dynamics across space and time and their modelling is Ducruet, 2018). Both at the regional and the global scale, the environmental factors are implemented by considering the conditions increasing the navigation hazards rather than the enabling conditions for specific routes trajectories, which the model does not attempt to ascertain (e.g. the wind strength is deemed more impactful than wind directions, which are indeed excluded from the model). It is worth stressing that the implemented environmental hazards are considered overall risky at certain conditions; however, technological developments, shipbuilding innovations and or evolutions contribute to changing the impact the environmental factors have on navigation safety in different centuries. Moreover, while the global scale model does not address Roman time exclusively, it is still bound to the era of sail and oars and cannot be deemed applicable to model shipwrecking probabilities in the time of machine-powered vessels such as steamboats (i.e. early 19th century).

Contrary to the navigational hazards model component, the rationale behind the global scale transit probability model component presents major changes compared to the regional scale analysis, both in terms of estimated impact of each selected factor and in terms of feasibility to implement them at the global scale. As theoretical categories, the presence of landing sites and harbours, as well as the idea of a different degree of perceived convenience and ports hierarchization is valid in different centuries and regions, although the resulting patterns of mobility clearly vary across centuries depending on the motivation triggering vessels mobility, and the actors involved (besides considering technological developments). To be more explanatory, the factors presented as theoretical categories are valid at the global scale as well, although the variables (i.e. the data) needed to implement them change. At regional scale, the potential degree of ports, shelters and anchorages attractiveness was derived by looking at the information provided in textual evidence; particularly, the *Stadiasmus* was employed for gaining insights on landing sites, ports and anchorages attractiveness factors. At the global scale, such an approach would be unfeasible and deceptive. Therefore, a simplified factor is considered, which is implemented by taking into account the presence of all potential attractors in the neighbourhood of the landing site, thus including economic, religious, cultural attractors as well as natural ones (e.g. river proximity) without chronological distinction. At the global scale, the land sight is also not taken into account among the transit probability factors because it is deemed less impactful in periods during which navigational instruments and nautical charts were increasingly employed.

5.7 SUMMARY

This chapter includes the description of the regional and global scale models for predicting shipwrecking probabilities in Mediterranean territorial waters. First, the need to face a logic conundrum emerging from the literature review carried out in chapter 2 was discussed, as well as the necessity to develop a tailored new strategy instead of relying on the combination of existing shipping and preservation potential models. The conundrum relates to the discordant way the navigation hazards are handled in the above two groups of computational approaches. In current models of past seaborne movement, which aim to identify optimal route-corridors, the passage through risky areas is minimized or avoided. In models focusing on the shipwrecks' preservation potential and on post-depositional dynamics, the same hazardous zones are assigned an increased shipwrecking probability. Without neglecting the correctness of both interpretations, the relative shipwrecking probability model is designed to take into account the potential distinction between perceived and actual hazards, thus rejecting the assumption that the risks mariners would try to avoid are necessarily those that actually increase the chance of sinking. Hence, the transit probability and the navigation hazards model components were described after clarifying the criteria employed for selecting the input factors. The navigation hazards model component includes geomorphological, meteorological and oceanographic parameters, and it is developed following the same procedure both at the Regional and the Global scale. The Transit probability model component is implemented following a slightly different procedure at the two scales of analysis. At the regional scale, four factors were considered, i.e. the distance to ports and anchorages, the attractiveness degree of ports, the inland network including rivers and roads, the impact of land visibility in terms of orientation potential and assault probability. At the global scale, the model was simplified by reducing the number of input factors. The most notable difference relates to the 'attractiveness index' designed to reflect how convenient to approach a port would be for mariners. In the regional model, the information on the conditions potentially attracting or averting the seafarers' movement at ports and shelters was derived from a specific textual source, i.e. the *Stadiasmus Maris Magni*, used as a proof of concept. At the global scale, the port-attractiveness factor was simplified by only considering the density of potential attractors nearby a port. Moreover, the impact of the land sight was only considered at regional scale.

"All theories are legitimate, no matter. What matters is what you do with them"

Jorge Luis Borges

6 GIS IMPLEMENTATION OF THE FORMAL MODEL

This chapter describes the GIS implementation of the theoretical model for assessing the shipwrecking probability in Mediterranean territorial waters, as set out in Chapter 5. Two different spatial scales of analysis – local and global – are considered to meet the need for a general tool that is applicable in spatial planning and a more detailed one that provides insights for historical and archaeological research (Chapter 1). The procedures followed for modelling the Transit-Probability and the Navigational Hazards model components at the local level are described in sections 6.2 and 6.3, respectively. Section 6.4 sets out the procedure for producing a relative shipwrecking probability (RSP) map as discussed in section 1.4; particularly, two different RSP maps are generated by combining the cost surfaces produced for each input factor: a 'base' map resulting from the combination of all factors equally weighted, and a 'preferred' map produced by assigning different weights to the factors. The weights are calculated following the standard Analytical Hierarchy Process (Saaty 1980). The description of the simplified model at the global, i.e. Mediterranean, scale is in section 6.6. Chapter 7 is devoted to the enquiry into the model performance and the problematic issues connected to model validation.

6.1 METHODOLOGY

The theory-driven model developed in Chapter 5 is implemented in ArcGIS 10.6 in the form of a multi-criteria cost-surface based procedure. Cost surfaces are implemented as raster map layers in which the cell value expresses the cost that a particular activity would have in that cell (Bolstad 2012, pp. 434-437; Wheatley & Gillings 2002, p. 152). The present model employs grids with a cell size of 1 square kilometre; this resolution was influenced by the great degree of resolution variations in the input factors and by the sparseness of observed data employed for the model validation. These limitations would make setting finer resolutions both useless and misleading since certain parameters would show no variations at all. Although coarse at first glance, the adoption of 1 km^2 resolution still enables one to meet the research goals set in Chapter 1. Particularly, as for the necessity to provide heritage managers and developers with a tool applicable in spatial planning, an area of 1km * 1km may be covered relatively quickly with remote sensing surveys, considering that the ideal survey speed with traditional high-resolution side-scan sonar is about 3 to 4 knots (i.e. 5,6 to 7,4 km/h) for acquiring sufficiently high-resolution data for archaeological purposes; this may be increased up to 10-16 knots when more advanced multi-pulse side scan systems are employed (see, e.g. the 'Marine Geophysics Data Acquisition, Processing and

Interpretation' standards set by Historic England[54], pp. 17-18). A discussion around this resolution impact on the model utility is in section 7.2.

A cost surface is generated for each of the factors affecting the transit probability and the hazards to navigation, as determined in Chapter 5. The resulting 'factor maps' are in the end combined for producing the model output. The steps followed for developing the two models (i.e. the local and global scale models) are the standard ones for multi-criteria cost surface analysis (Howey, 2007):

- Creation of a raster surface for each of the pre-determined factors relevant to the probability of shipwrecking. Each factor-map cell is assigned a value reflecting the different cost of the corresponding activity or phenomenon in that cell.
- Normalization of the input values to a scale ranging from 0 to 10. This step enables the simplification of the calculations and is required for creating a weighted overlay of the different factor maps.
- Weighting the factor maps depending on the supposed relative importance that each factor has to the targeted phenomenon.
- Weighted sum addition of multiple factor maps into a total cost grid
- Model validation and model testing. This will be discussed in chapter 7.

In the models, costs can have different meanings (Figure 6.1):

1) The final cost, which results from the implementation of all the factors included in each model, measures the shipwrecking probability (RSP): the higher the value, the higher is the probability that a ship has sunk in a raster cell. This value reflects a relative probability, not an absolute one; in other terms, it only indicates whether in a cell the shipwrecking probability is higher than in another one.
2) In the transit-probability (TP) model component the cost expresses the relative probability of ships in transit: the higher the cost of a raster cell, the higher is the probability a ship would have sailed there.
3) In the navigational hazards (NH) model component the cost represents the relative probability of sinking: the higher the cost of a raster cell, the higher the degree of navigational hazard, and the probability of wrecking.

54 https://historicengland.org.uk/images-books/publications/marine-geophysics-data-acquisition-processing-interpretation/mgdapai-guidance-notes/; for survey speed see p. 17

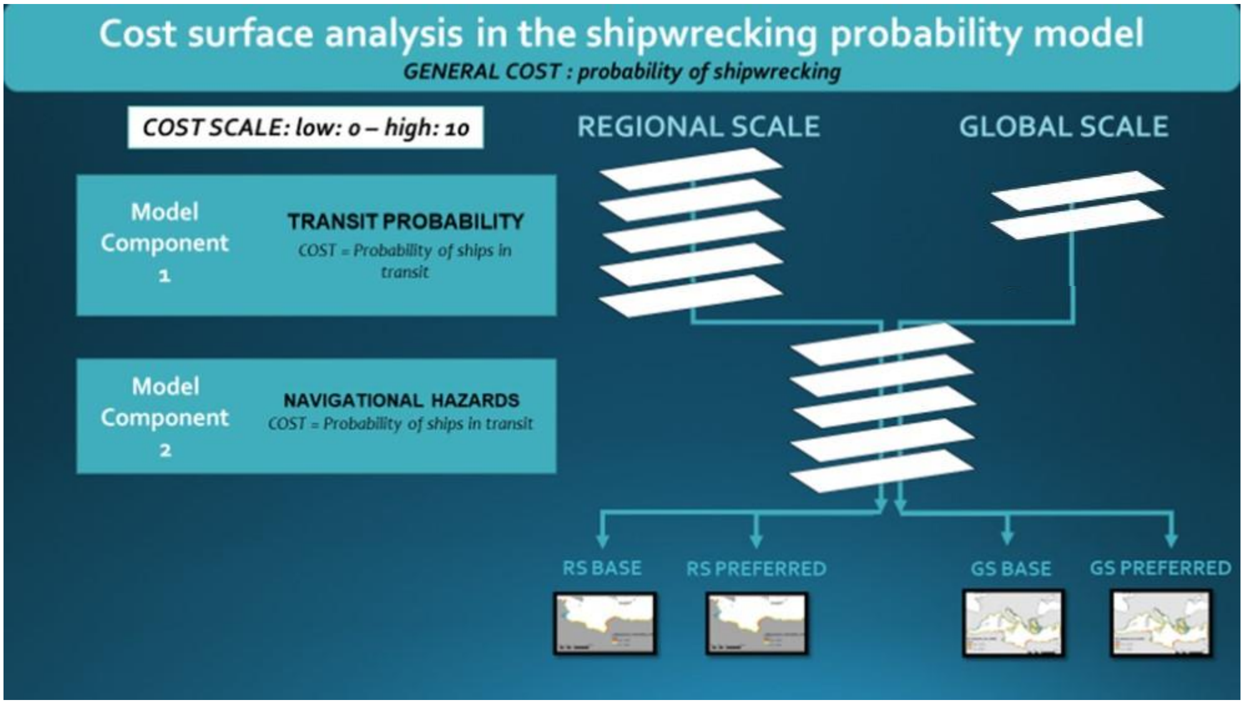

Figure 6.1: Overview of the Shipwrecking Probability model structure. The model, which is applied at two different scales (i.e. regional and global), is divided into two model components, which are implemented through cost-surface analysis. The overall cost resulting from the summation of all the input factors normalised to a scale from 0 to 10 represents the relative shipwrecking probability. In the TP model component, the cost represents the probability of transit, in the navigation hazards, the risk of sinking.

6.2 TRANSIT-PROBABILITY. REGIONAL SCALE

The spatial framework of the selected local case-study encompasses the territorial waters ranging in Latitude from 36°42'59.7N to 31°12′ N, and in Longitude from 10°23'05"E to 29°55′E (Figure 6.2)

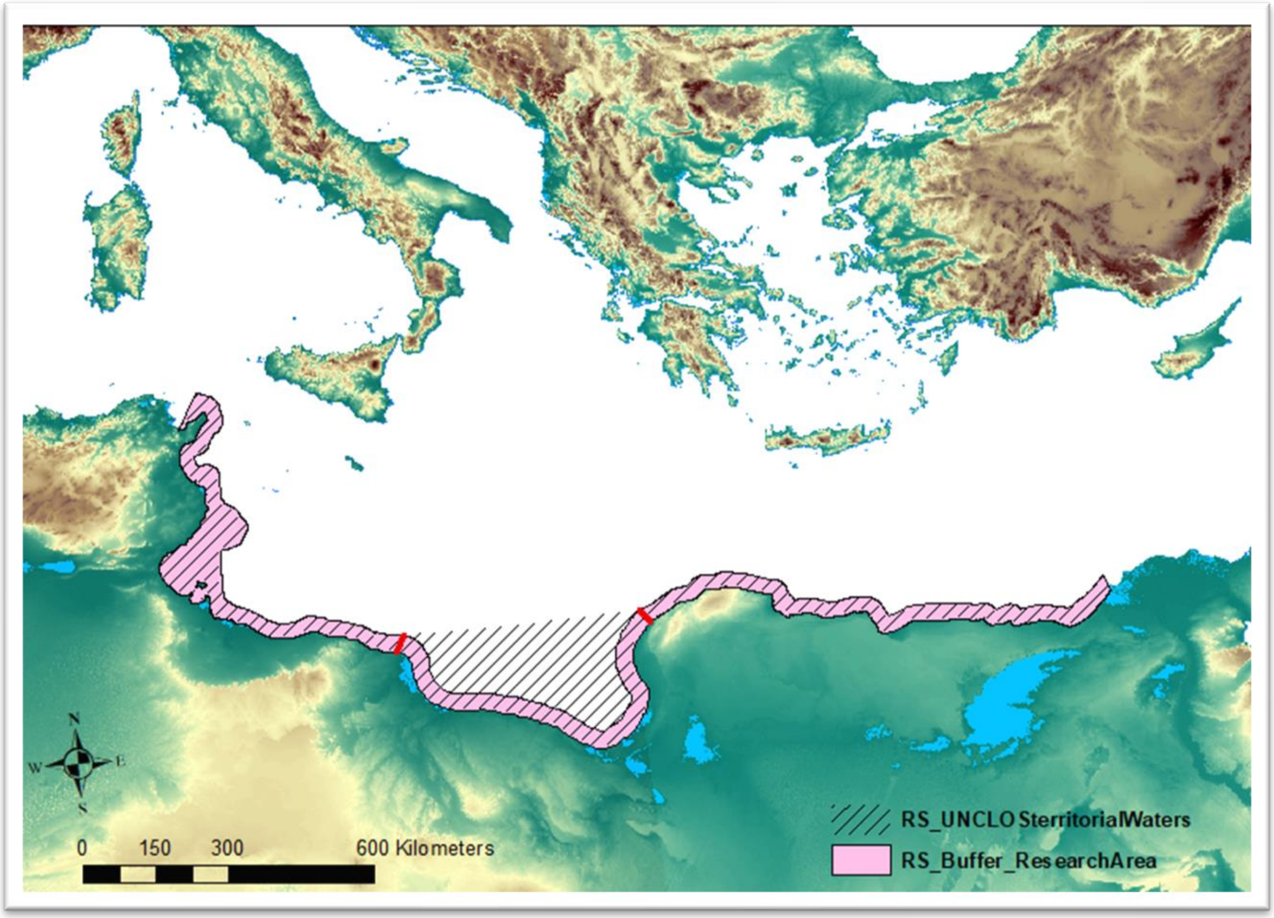

Figure 6.2: The purple area in the map represents the Regional scale model extent; this corresponds to the extension of the territorial waters defined by the 1982 UNCLOS convention except in the Gulf of Sidra, limited to 15 NM from the natural coastline. The two lines delimiting the Gulf of Sidra where the UNCLOS territorial sea polygon was cut and merged with the 15 NM buffer from the natural coastline are highlighted in red[55].

According to the 1982 United Nations Convention on the law of the Sea (UNCLOS), the territorial sea is described as the belt of the sea where the State extends its sovereignty beyond the adjacent land territory and internal waters and, in the case of an archipelagic State, its archipelagic waters (Article 1 and Article 3). Each state has the right to establish the breadth of its territorial sea up to a limit not exceeding 12 nautical miles measured from the baseline; since the latter does not correspond to the actual coastline and may be drawn far from it by connecting points along the coast through straight lines (see UNCLOS Article 5 and Article 7), the territorial waters extends

[55] Unless differently specified, all charts have been produced by the author

further than the 12 NM measured from the natural coastline. Both at the local and global scale, the UNCLOS territorial waters constitute the model extent, except for the Gulf of Sidra where a buffer of 15 NM from the coastline has been considered (Figure 6.2). Particularly, the territorial waters and internal waters shapefiles were imported from the Maritime boundaries geodatabase provided by the Flanders Marine Institute[56] and merged for creating a unique shapefile to use as the model extent and mask in raster analysis. The resulting merged polygon was cut in correspondence to the limit of the study area specified above and further edited as follows:

- The 1982 UNCLOS territorial-waters buffer was cut 10 km east from the present-day city of Zliten (Libya) and in correspondence to the boundary between the districts of al-Marj and Banghazi to limit the research area to 15 NM from the natural coastline only between these two locations. The resulting 15 NM buffer was merged with the previously cut UNCLOS territorial-waters shapefile (Figure 6.2)

This model employs the Roman era coastlines provided by the Barrington Atlas of the Greek and Roman World (Talbert, 2000)[57], which do not coincide everywhere with the present-day coastlines. The mismatch is evident at local scale (see, e.g., in Figure 6.3). In order to compensate for this mismatch and ensure that the missing sea areas are covered, the processing extent has been extended 2 NM inland. However, as discussed in the conclusions of this thesis (section 8.3) neither the Regional nor the Global model are suitable to address the local conditions specifically.

In chapters 4 and 5 the following composite factors have been determined to impact the probability of ships-transit:

- Landing sites and shelters, which include a broad range of places located at the interface between land and water where mariners might seek for various reasons to land or to find a temporary shelter (Safadi, 2016, p. 349; Ilves, 2012).
- Port convenience, which refers to the different degree of attractiveness landing sites and shelters present
- Inland network, which includes roads and navigable rivers
- Assault-probability, namely the risk of reprisal
- Orientation, which relates the visibility of landmarks as one among the many possible wayfinding strategies

The implementation of each of these as factor cost surfaces is described in the next sections.

[56] Flanders Marine Institute (2019). Maritime Boundaries Geodatabase: Territorial Seas (12NM), version 3. Available online at https://www.marineregions.org/ https://doi.org/10.14284/387. Internal Waters, version 3. Available online at https://www.marineregions.org/ https://doi.org/10.14284/385.

[57] Accessed and downloaded from the MERCURY-MINERVA-SIMREC Project website https://projectmercury.eu/datasets/ Credits: Ancient World Mapping Center, and Talbert et al. 2000.

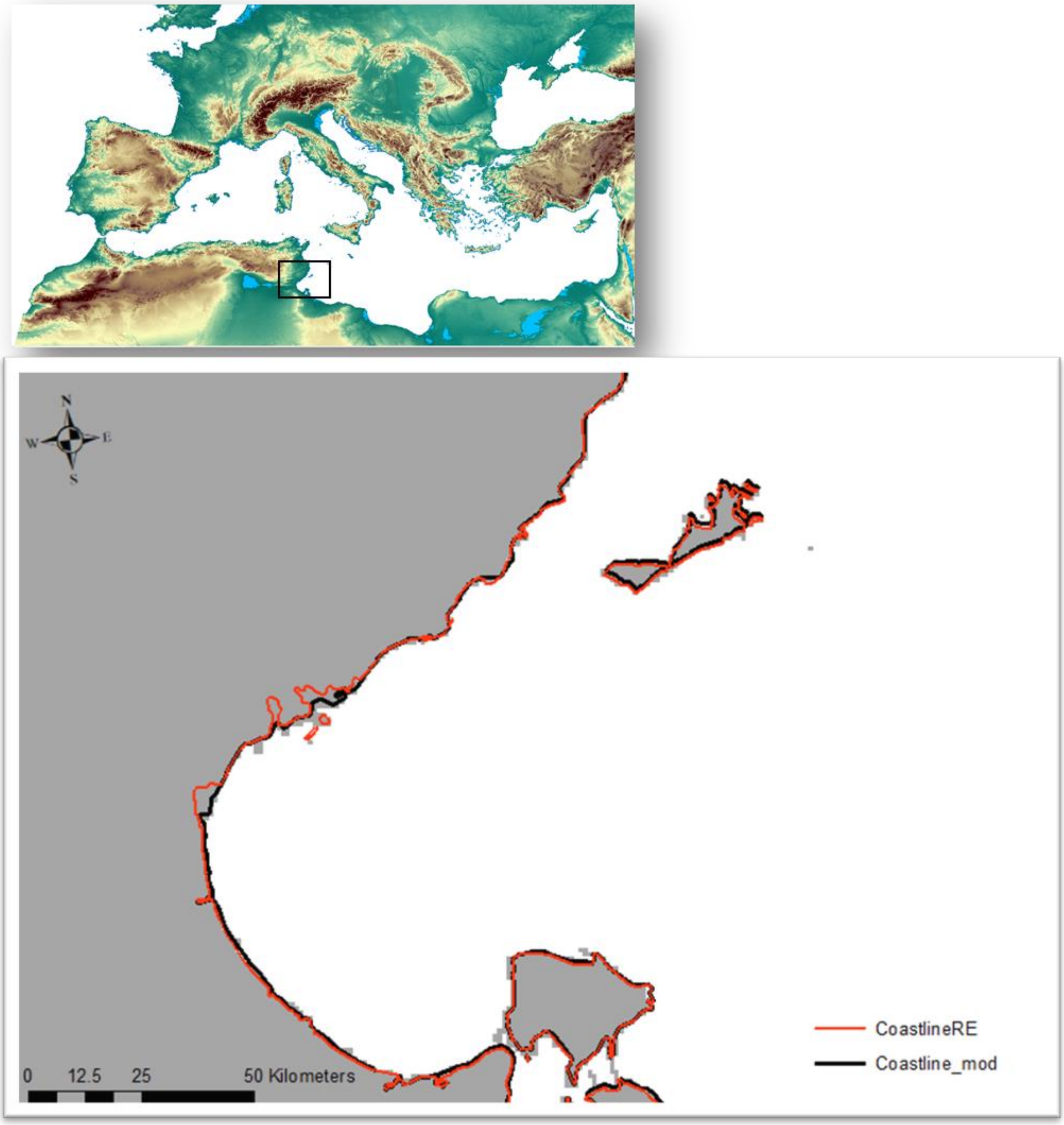

Figure 6.3: Local differences between Roman Era (RE) and present-day coastline

6.2.1 Landing sites

To generate a cost surface for this factor, it is necessary to have (1) a suitable source for harbour, shelter and landing site location data, (2) a rule to establish how cost should vary with distance to these locations, and (3) procedures to implement this in ArcGIS 10.6.

Data

The 7th edition of the DARMC scholarly data series (de Graauw et al. 2014, last updated 13-11-2020) present a dataset of 3175 ancient harbour sites, 375 of which are located in the studied area; this has been developed by referring to the most authoritative studies (e.g. the Barrington Atlas), and brought up-to-date using the most recent literature (e.g. Arnaud 2016; 2017; Marriner et al., 2017; Morhange 2015; 2016) and the digital libraries Pleiades and Dare.

Rule

The smaller the distance to the landing sites, the higher the probability (or 'preference') to have ships in transit. Costs should therefore decrease with increasing distance to landing sites.

Procedure

The De Graauw catalogue was imported in ArcGIS as a spreadsheet document and converted into a shapefile point feature class. The 375 points falling within the study area were selected and exported to create a separate shapefile to use at the local scale. Since it is assumed that shelters and landing sites are navigational hubs and the transit probability is higher closer to them, a two-step procedure is followed:

1) Measurement of the distance from each cell in the raster to the closest landing site through the ArcGIS Euclidean distance tool.
2) Attribution of a higher preference (i.e. cost) the smaller the distance to the landing sites through the ArcGIS Rescale by Function tool. This was employed to normalize the Euclidean distance output raster to range from 1 to 10; the 'Small' transformation function was employed, for it indicates that the smaller values from the input raster have higher transit probability, i.e. cost. ArcGIS includes different transformation functions, which similarly assign a preference to low values (e.g. the 'MSSmall', 'Near', 'Logistic decay' functions) and their employment may generate slightly different outcomes. The choice of the transformation function constitutes a factor of uncertainty in the model, as further discussed in Chapter 7. The midpoint value, which is the crossover below which the other values gradually increase, and above which the values gradually decreases with greater distances from the coast was set to 4 NM, instead of maintaining the ArcGIS default cross-over value at around 6NM. The value was changed because ships may well transit at 6NM from a shelter without being necessarily directed there, whereas in this procedural step we are assigning a higher transit probability connected to landing sites and shelters accessibility. Bearing in mind that the ship velocity in Roman time has been estimated to be around 1 to 2 knots in adverse wind conditions and 4 to 6 knots with favourable winds, 4 NM correspond to the average distance covered in around 1 hour of navigation (Whitewright 2011, 2–17).

The choice of different midpoint values may impact the final results and it represents, similarly to the transformation function choice, a factor of uncertainty in the model (see Chapter 7). Both for the Euclidean distance and the Rescale by Function tool, the study-area polygon was used as a mask and processing extent. The procedure is summarized graphically in Figure 6.4,[58] and its outcome is shown in Figure 6.5.

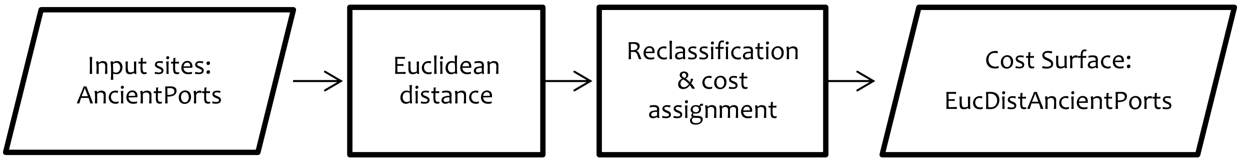

Figure 6.4: Main steps for implementing the higher probability of ships in transit the smaller the distance to the landing sites.

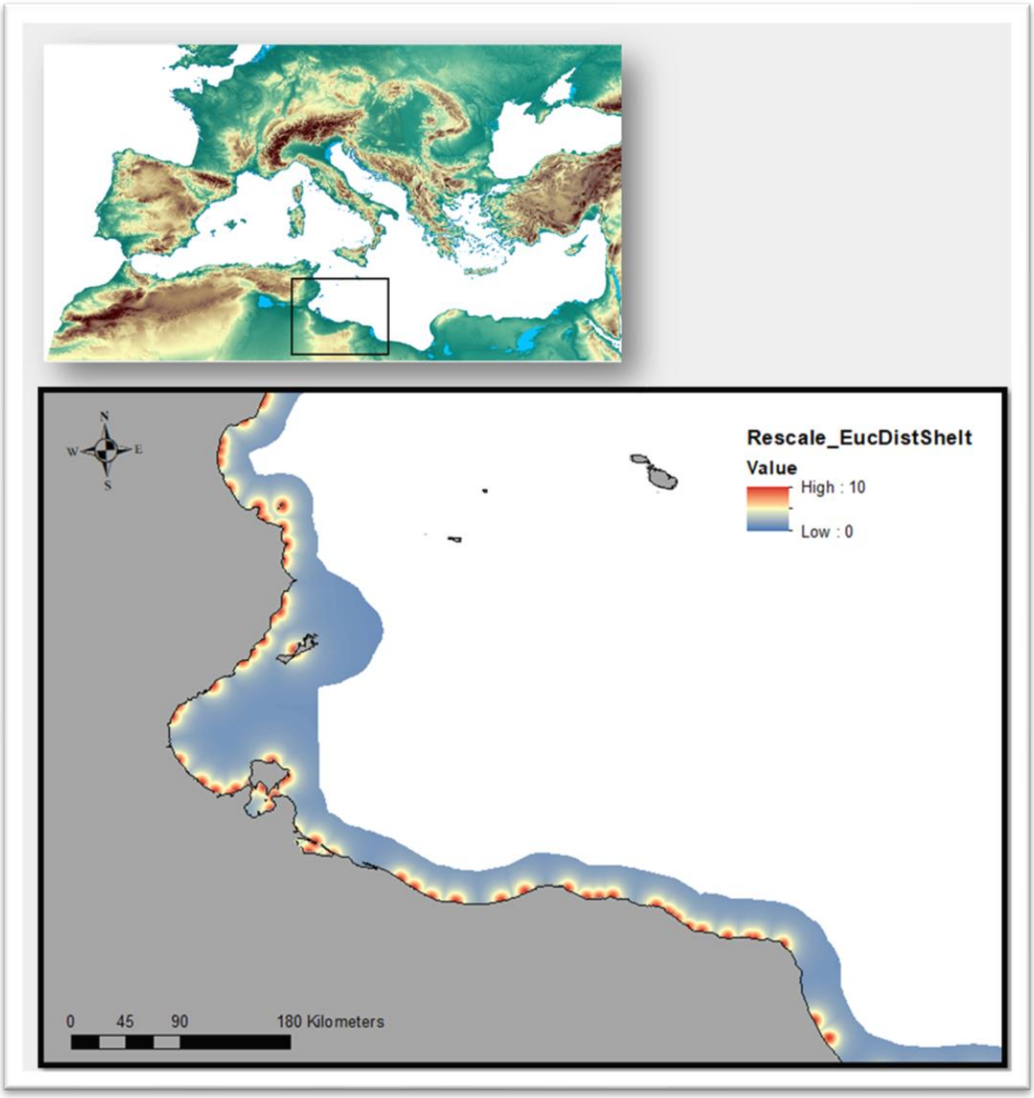

Figure 6.5: Detail of the Landing Sites factor map. The values indicate the relative transit probability at landing sites. At this stage, each site presents an equal weight.

58 Following standard flowchart conventions, the rectangles indicate the processes, the rhomboids the input and outputs.

6.2.2 Port attractiveness

In the previous chapter, the ports' attractiveness was introduced to express the degree of attractiveness of shelters and landing sites, which depends on the perceived risks and advantages of each site. The model does not simply take into account the *Stadiasmus* terminology for referring to different landing sites (*λιμήν, ὅρμος, πάνορμος, ὕφορμος, σάλος, ἀγκυροβόλιον, αἰγιαλός, ἐμπόριον, ἐπίνειον*) but rather distinguishes the following aspects (see definitions in chapter 5.3.2):

- Exposition/Seasonality
- Accessibility
- Character of the Seabed
- Extra Benefits
- Capacity
- Size

With respect to what is discussed in Chapter 5, the administrative and economic implications of the Roman fiscal system are excluded because of a lack of data, whereas the political sphere is not taken into account since the model does not target specific groups of mariners. This multicriteria approach for modelling the port attractiveness enables overcoming the inconsistent use of terms in the *Stadiasmus*, and handling conflicting attributes (e.g. a harbour may be advantageous for protecting from multiple winds, but it may present a disadvantage in terms of water accessibility or capacity).

To generate a cost surface for this factor, it is necessary to have (1) a suitable textual source for gathering information on the above criteria, (2) a rule to establish how the cost (i.e. the transit probability) should vary with the shelters' attractiveness, and (3) an ArcGIS 10.6 procedure for generating a shelters attractiveness index based on the above criteria.

Data

The anonymous *Stadiasmus Maris Magni* (SMM) or Periplus of the Great Sea, translated by Brady Kiesling with Leif Isaksen (2014) from the 1855 Muller edition (in *Geographi Graeci Minores*), which is freely available under an open license for scholarly purpose at ToposText indexed collection (the reasons for employing this textual source are explained in Chapter 5.5.2).

Rule

The shelter attractiveness depends upon the evaluation of six aspects, which result in the calculation of an attractiveness index (a-index). The higher the a-index, the higher the transit probability (i.e. the cost).

Procedure

Each of the six criteria is assigned a value ranging between 0 and 6 as specified below (Table 6.1).

Table 6.1: Evaluation criteria for the assessment of the landing-sites attractiveness (i.e. a-index). Ns stands for 'not specified'

CRITERIA	CARDINAL EVALUATION/RULE			MAXIMUM WEIGHT ASSIGNED
Exposition / Seasonality	Limited=0; not specified = 1; all winds= 2			2
Accessibility	Risky = 0; not specified = 1; not risky = 2			2
Seabed-Nature	Instable= 0; not specified= 1; stable = 2			2
Extra Benefits	Water availability: yes (2)/no (0)/ ns (1)	Nearby attractor (town/sanctuary/harbour): yes (2)/no(0)/ns (1)	Port extra facilities: yes (2)/no(0)/ns (1)	6
Capacity	Limited tonnage = 0; not specified= 1; merchant ships = 2			2
Size	Limited number/'small' = 0; not specified= 1; no limitation/'large -long'= 2			2

Based on the information provided in the *Stadiasmus*, each landing site is assigned an 'attractiveness' value ranging from 0 to 16 by the values assigned for each of these criteria. Sites for which the criteria are not specified (ns) are assigned a value equal to 1 for each criterion. The sites that are not mentioned in the *Stadiasmus* and for which it was not possible to establish a specific attractiveness value, were assigned a standard value equal to 2: as illustrated in Table 6.1, this value results from considering the site close to a city (Extra Benefits) and by assigning a zero value to exposition/seasonality, accessibility, seabed nature, capacity, size harbour extra facilities and water availability. Although the shelters' attractiveness calculation is not based on the *Stadiasmus* terminology alone, the different terms employed are assumed to have the following base-value computed by considering the criteria in Table 6.1 equal to 'not specified' unless further information are provided in the text (e.g. an anchorage with a nearby city is assigned 7; a harbour with a nearby city is assigned 10):

Harbour: without additional info, all the criteria are given a value equal to 1, hence the total is equal to 8

Harbours for merchant ships: these are assumed to have better seabed than simple harbours because the bottom must have been deep and stable enough for enabling commercial boats to enter (i.e. seabed value assigned is 2; see Medas 137); therefore, the total is equal to 9

Open roadstead, harbourless – assumed to be exposed (i.e. exposition value 0); extra facilities are assumed to be not present if not specified. The total is equal to 4

Roadstead – Since it is sometimes specified 'harbourless', one may assume that in lack of this specification, a roadstead would be close to a harbour (i.e. nearby attractors, equal to 2); without further indications, the facilities are still assumed to be missing, whereas all the other criteria are assumed to be unspecified (i.e. value 1). The total is equal to 7

Open roadstead – as a roadstead, but exposed. The total is equal to 6

Anchorage –without further notice, all criteria are equal to 1, without facilities. The total is equal to 5

Anchorage for cargo ships – same as anchorage but with capacity equal to 2 (see above 'harbour for merchant ships'). The total is equal to 6

Artificial anchorage – *χειροποίητος όρμος* whereas the simple *όρμος* usually refers to a natural harbour this is manmade, although not a proper *Λιμην*. One may assume that the term refers to anchorages that were reinforced with artificial structures (e.g. jetties). Therefore, it is assumed an enhanced protection (i.e. exposition equal to 2). The total is equal to 6

Deep hollow – *νάπη έστί βαθεια* in lack of further information, all criteria are assumed to be unspecified (i.e. equal to 1) and the facilities equal to 0. The total is equal to 5

Beach: without further info it is assumed to be exposed (i.e. exposition value equal to 0), whilst accessibility, seabed-nature, capacity, size are undefined (i.e. equal to 1). The total is equal to 4

To exemplify the procedure followed for evaluating the ports attractiveness, a few cases are included in Table 6.2, where 'ns' stands for not-specified; the full list is in the Appendix 2. The interpretation is subjective and subject to discussion (see chapter 7), nonetheless it has the advantage of presenting the analytical process in a transparent and formalised manner, thus enabling reviews and modifications.

Table 6.2: Extract of Appendix 2 with the calculation of the attractiveness index (a-index) for a selection of sites. The attractiveness index is calculated based on the information provided in the Stadiasmus by following the procedure described above.

SMM ref	NAME	DESCRIPTION	Comments & References	a-index
1	Chersoneso	a harbour	In SMM 1, it is said to be a harbour distant two stadia from Alexandria – In Pseudo Scylax, Periplous "After Cherronesos is the Plinthinic gulf"; therefore, it is unlikely to be associated with BAtlas 38 Cherronesos/Chersonesos Akra, and Pleiades: 373770 DARMC_DeGraauw 3941	**8**
2	Dysmay	a harbour for merchant ships not exceeding a thousand units of cargo	DARMC_DeGraauw 3942 On the cargo unit and equivalent tonnage of this 'merchant ships' see Medas 137, Muller GGM, 1: 429-430	**9**
3	Plinthinae	an open roadstead, harborless	(Egypt) Kom el-Nagous? – Πλινθίνη Date range: (330 BC - AD 640) https://pleiades.stoa.org/places/727205 BAtlas 74 B2 DARMC_DeGraauw 3944	**4**
4	Taposiris	harbourless city with a sanctuary of Osiris (just an anchorage, city and sanctuary nearby)	(Egypt) Abousir – Ταπόσειρις Date range: (30 BC - AD 640) https://pleiades.stoa.org/places/727241 BAtlas 74 B3 DARMC_DeGraauw 3945	**7**
5	Chimo	a town, with rocky shoals visible (i.e. risky access and unstable seabed)	(Egypt) 3 el-Bordan – Χειμώ Date range: (330 BC - AD 300) BAtlas 73 G3 Ch(e)imo https://pleiades.stoa.org/places/716544 DARMC_DeGraauw 3946	**5**

The *a-index* is added as a new attribute to the ports and landing sites shapefile that was already used in section 6.2.1. Then, the Kernel density tool is used to assign a proportionally higher transit probability the higher the shelters attractiveness index. Indeed, differently from other density tools, Kernel enables to weight some features more heavily than others through the 'population field': here, the *a-index* was used as population field (Table 6.2)[59]. The surface value is highest at the location of the landing-site points and diminishes with increasing distance from them, reaching zero at the Kernel 'search radius'. The latter was set to 10 NM (i.e. 18,520 m): indeed, bearing in mind that the ship velocity in Roman time has been estimated to be around 1 to 2 knots in adverse wind conditions and 4 to 6 knots with favourable winds, - for an average of 4 nautical miles per hour, i.e. 4 knots-, and that for sailors it is important to find a shelter in case a storm arrives, they may cover this distance in two and a half hours of navigation (Whitewright, 2011, pp. 2-17).

The cost surface generated by the Kernel density tool is normalised to a range from 0 to 10 by employing the 'Rescale by Function' tool. Since the kernel density is proportional to the attractiveness value, the 'large' transformation function was employed to assign a higher transit probability the higher the attractiveness values (i.e., the higher the value of the Kernel density tool). The spread factor and midpoint value were determined automatically by ArcGIS based on the input raster. The procedure is summarized graphically in Figure 6.6, and its outcome is shown in Figure 6.7.

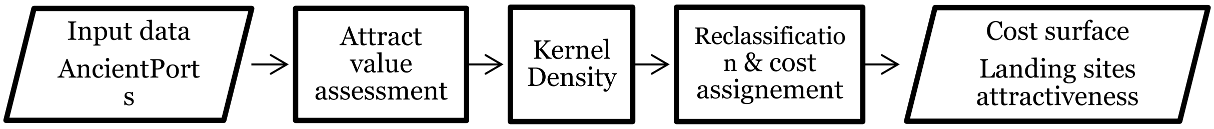

Figure 6.6: Summary procedure for implementing the higher probability of ships in transit, the higher the landing sites attractiveness.

[59] https://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/how-kernel-density-works.htm

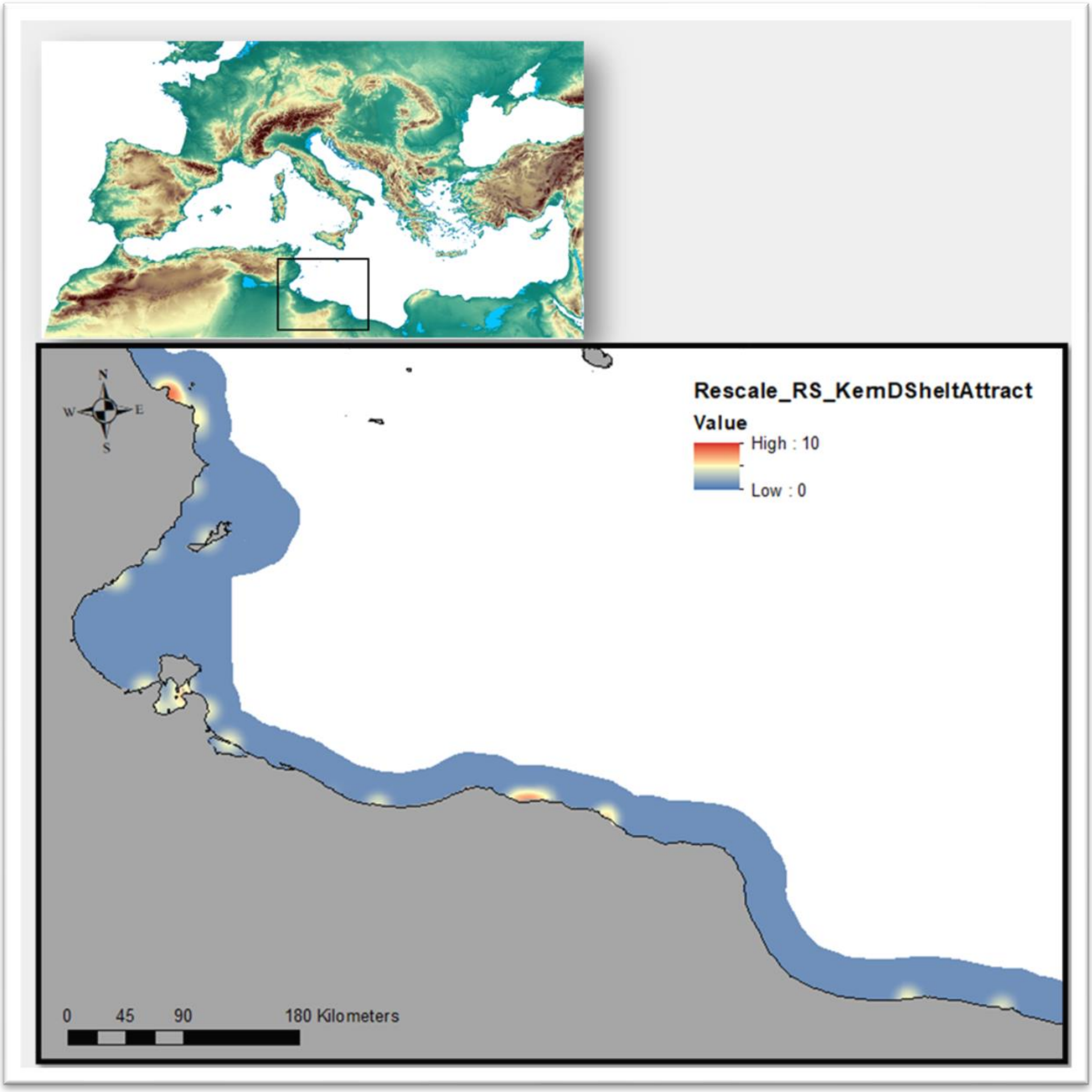

Figure 6.7: Normalized shelter attractiveness cost surface (detail) after the procedure outlined in this section

6.2.3 Inland network: proximity to roads and water sources

The composite Inland Network factor includes two different components, which in chapters 4 and 5 are said to impact the transit probability at ports and are modelled independently as factor maps, namely:

- Proximity to Roads (Factor 3)
- Proximity to rivers and other water sources (Factor 4)

Since the procedure for implementing them is the same, it is described only once (Figure 6.8) while indicating any minor procedural difference between the two. The outcomes are shown in Figure 6.9 and Figure 6.10.

Differently from other factors, the inland-network proximity factors will affect only certain categories of mariners or will be impactful on occasions, for one may well approach anchorages or landing sites just for temporary shelter. This has potential consequences for the weighing of the variable during summation, as shown in section 6.4 and further discussed in chapter 7, where different scenarios are tested by implementing this group of factors or not.

The river proximity is implemented by considering the rivers either as navigable waterways or as potential sources of drinkable water. Indeed, if one needs to use the river to navigate, there must be immediate access from the sea to the river, whereas in case of water supply, one may assume that mariners may cover a longer distance by walking toward the river or other fresh-water sources from their landing site. It follows that, when assessing the presence of navigable rivers and water sources in the neighbourhood of a landing site, different buffer distances must be considered.

To generate a cost surface for each of the two inland-network factors, it is necessary to determine (1) a suitable source for Roman roads and inland water data (2) rules to establish how the cost should vary in relation to the road proximity and water sources proximity, and (3) procedures to implement this in ArcGIS 10.6.

Data

Roads, rivers and inland waters data are derived from Talbert and Bagnall 2000, Barrington Atlas of the Greek and Roman World. Princeton, N.J.: Princeton University Press. The digital datasets were retrieved from the project MERCURY website.[60]

Rule

The smaller the distance between the landing sites and roads, rivers and inland waters, the higher the transit probability.

Procedure

The procedure for assessing the transit probability in relation to roads, rivers and water sources proximity to the landing sites is mostly the same and includes the following steps:

1. Base data import in ArcGIS as shapefiles feature classes
    - Assessment of the landing-sites distance to a) nearest roads, b) nearest rivers, c) nearest inland water sources by means of the ArcGIS 'Near' tool. The analysis only takes into account the Euclidean distances between landing sites and the three feature classes without considering possible barriers for reaching them. Given what is discussed above, in the case of navigable rivers, the near-distance analysis is constrained within a range of 1 km from the landing sites, whereas no constraint is set for ascertaining the proximity to roads and inland water sources, which include rivers and lakes. The 1 km buffer distance from landing sites to navigable rivers does not contradict what was previously stated about the need to have immediate access from the sea to the waterway rather, it aims at mitigating the inaccurate location of the shelters, whose position is neither accurately recorded nor always documented by archaeological remains. Within the local case-study area, only three rivers are within 1 km from the shelters and may actually be identified even without having recourse to GIS procedures: Kinyps, Berenice and Ausigidis (Nausis, Nausidos)
2. The distance values resulting from the Near Distance analysis were inversely normalised to a scale ranging between 1 and 10, where 1 is assigned to the highest

[60] https://projectmercury.eu/datasets

distance values (because less preferred) and 10 to the lowest distance values (because most preferred).

3. Similar to the procedure described for implementing the shelters attractiveness, a Kernel function was used to assign a proportionally higher transit probability the lowest the distance to roads and inland water sources. Particularly, the normalised distance values described in step 3 were used as 'population field' in the Kernel density tool. The search radius was set to 10 NM (i.e. 18.520) for the reason explained above in section 6.2.2.
4. The Rescale by Function tool is employed for bringing the step 3 resulting cost-surfaces into a scale ranging between 1 and 10. Since the distances were already assigned a normalised scale with higher values being equal to higher shelters preference (i.e. short distance to inland attractors), the 'large' option is chosen among the other options of the Rescale by Function tool, with midpoint set to default and spread at 5.

This procedure takes into account both the shelters density and their index of preference connected to the proximity to inland attractors; as a consequence, isolated shelters with shorter distance to attractors may end up having a lower transit probability score than a cluster of shelters positioned nearby each other, with farther individual distances with inland attractors. This represents a potential pitfall if one aims at calculating the shelters attractiveness at single places; conversely, the combination of shelters density and shelters index of preference is deemed effective to ascertain the ships transit probability in the area. The procedure is summarized graphically in Figure 6.8, and its outcome is shown in Figure 6.9 and Figure 6.10.

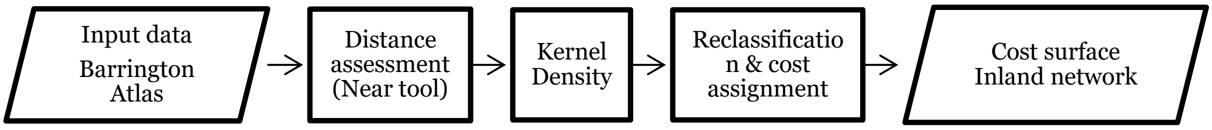

Figure 6.8: Summary procedure for obtaining the Inland Network factor maps (i.e. proximity to rivers and proximity to roads)

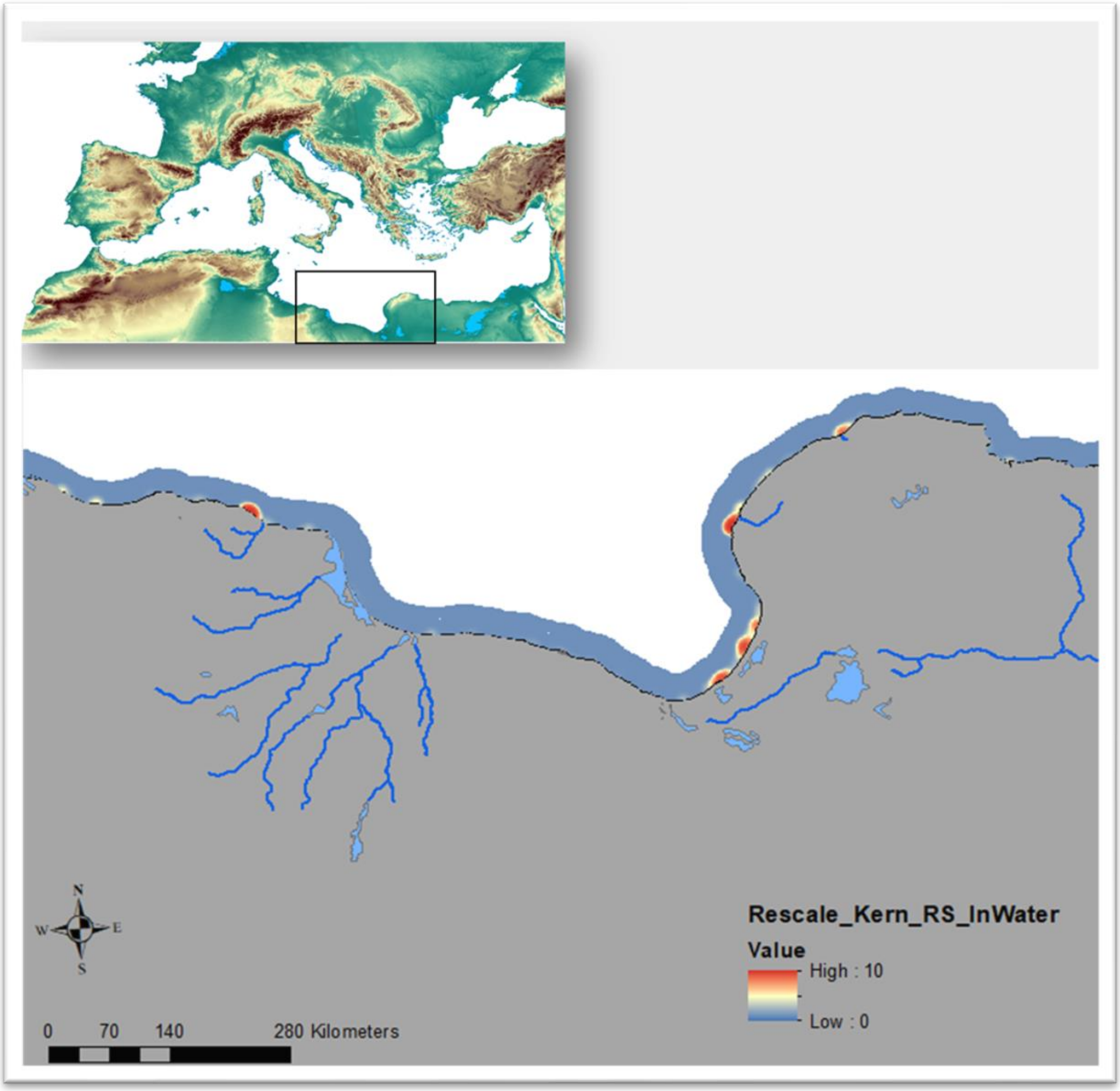

Figure 6.9: Proximity to rivers and water sources factor (detail). The cost-surface was generated through the Kernel density tool and normalised through the Rescale by Function tool by assigning a higher transit preference (red) the closer the water sources to the landing sites.

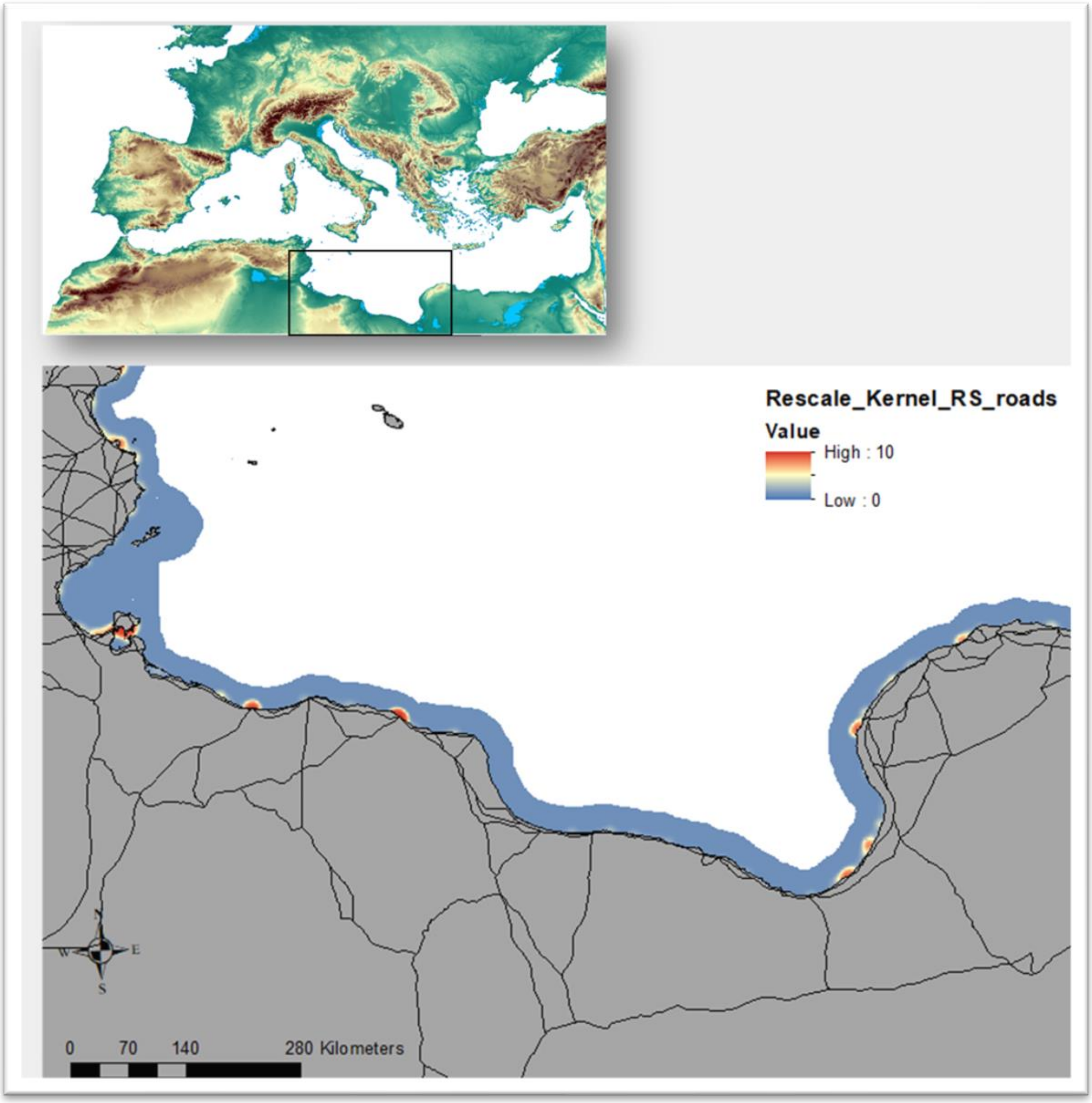

Figure 6.10: Proximity to roads factor (detail). The cost-surface was generated through the Kernel density tool and normalised through the Rescale by Function tool by assigning a higher transit preference (red) the closer the roads to the landing sites.

6.2.4 Assault probability and orientation potential

The assault probability and the orientation potential represent opposite sides of the same coin, which, as was explained in section 4.2.3 and section 5.4.4, lies in the presence of lines of sight between locations on land and on the sea. Therefore, a single procedure for implementing these factors has been developed. In section 4.2.3, it has been stressed that despite the tendency of current modelling approaches to assign a transit preference to the maritime spaces that are in sight of the land, the mutual visibility also entails underestimated potential threats for mariners. Particularly, the advantages represented by orientation and wayfinding are counterbalanced by the possibility of being spotted and attacked by pirates from the coast and by the risk of encountering geomorphological hazards when navigating too close to the shore.

The geomorphological threats are included in the navigational hazard model-component (section 6.3.1), whilst here a procedure is described for translating the following assumption into GIS: mariners will try to follow a route enabling them to stay *as far as possible* from land to minimize both environmental threats and the chance of being attacked while keeping visual contact with landmarks. This implies assigning a (slight) transit preference to the edge of the land-visibility range, hence answering the following question:

At which distance can the land still be spotted from sea?

GIS provide different tools that enable the assessment of the range of visibility and the lines of sight from a set of known locations (i.e. observer points). Particularly, with a Digital Elevation Model (DEM) and a number of observer points from which to compute viewsheds, the analysis is relatively simple. However, in this case, we cannot depart from known observer points; instead, we must identify which are the most prominent land features, which are visible from farthest in the sea and are therefore the most suitable observer points. ArcGIS has no tools that can do this directly. Therefore, a three-step procedure has been developed to meet the specific needs of the present study.[61]

To generate a cost surface describing the transit preference in relation to the land visibility range it is necessary to have (1) a suitable DEM for calculating cumulative viewsheds (2) a rule to establish how the cost should vary with the land visibility range, and (3) procedures to calculate the land visibility range in ArcGIS 10.6, which entails as a prerequisite the need to identify suitable observer points.

Data

The topographic data generated from NASA's Shuttle Radar Topographic Mission (SRTM) were used as a raster digital elevation model. The SRTM data were sampled for public release at 3 arc-seconds, which translates to a resolution of about 90 meters.

Rule

The cost, namely the transit probability, is highest close to the seaward limit of the range of visibility of the land. It decreases both with decreasing distance to the shore and when out of sight of land (although navigation is still assumed to be possible in these low-probability areas, as discussed in Chapter 4.2.3).

Procedure

The procedure, which is summarized graphically in Figure 6.11, includes the following stages:

1. Detection of prominent geomorphological features visible from the sea (up to a distance of 15 NM)
2. Selection of observer points within the geomorphological features identified in stage 1
3. Visibility analysis seaward from those points & transit preference specification

[61] The work has been carried out in cooperation with Frits Steenhuisen ##University of Groningen – Arctic Centre##, who wrote the python code for running the visibility analysis landward and seaward.

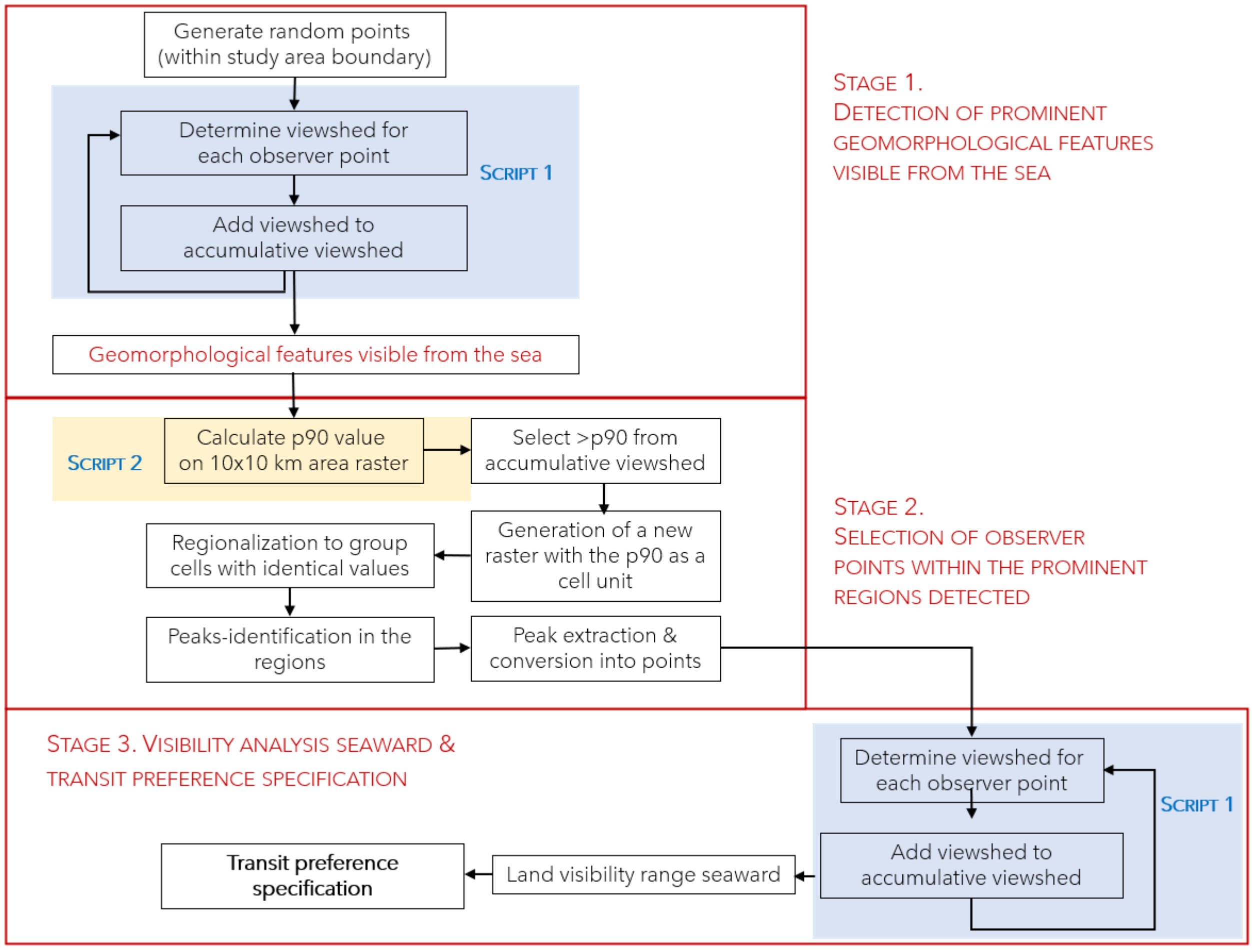

Figure 6.11: Steps followed for ascertaining up to which distance the prominent geomorphological features of the land can be seen from the sea

<u>Stage 1 - Detection of prominent geomorphological features visible from the sea</u>

As a preliminary step, the different SRTM tiles were aggregated to produce a single digital elevation raster. To this end, the 'Aggregate' ArcGIS tool was employed, where a cell factor of 3 and a 'maximum' aggregation type were chosen for retaining the highest values of the DEM (i.e. namely, the peaks). These highest values are fundamental to the purpose of this visibility analysis because they may generate the broadest viewshed.

Next, random points representing imaginary observers on boats were generated within the 15 NM buffer zone constituting the study area in the local case study. The number of points (6400) was computed to ensure an average nearest neighbour distance of 5 km in order not to produce observer points either too close or too far from each other. The average distance choice set at 5 km is arbitrary and represents a factor of uncertainty in the model (see Chapter 7); indeed, by altering this number, thus generating a different number of random points, the model outcomes may change.

From these points, the cumulative viewshed was constructed by running the python script purposedly written (Attachment 4). The script enables to determine whether each cell of the DEM (i.e. portion of land) is visible from each observer point, and it also provides -in the end- the total number of observer points from which the same portion of land (cell) can be seen. A minimum and maximum viewing range of 1500 and 200,000 m respectively, was set for running the viewsheds; furthermore, an observer-point offset of 8 m was introduced to represent the indicative height of Roman ships' main-mast. The resulting raster surface is displayed in Figure 6.12 (note that the 'zero values' representing out-of-sight areas and the portion of the viewshed falling in the sea were removed).

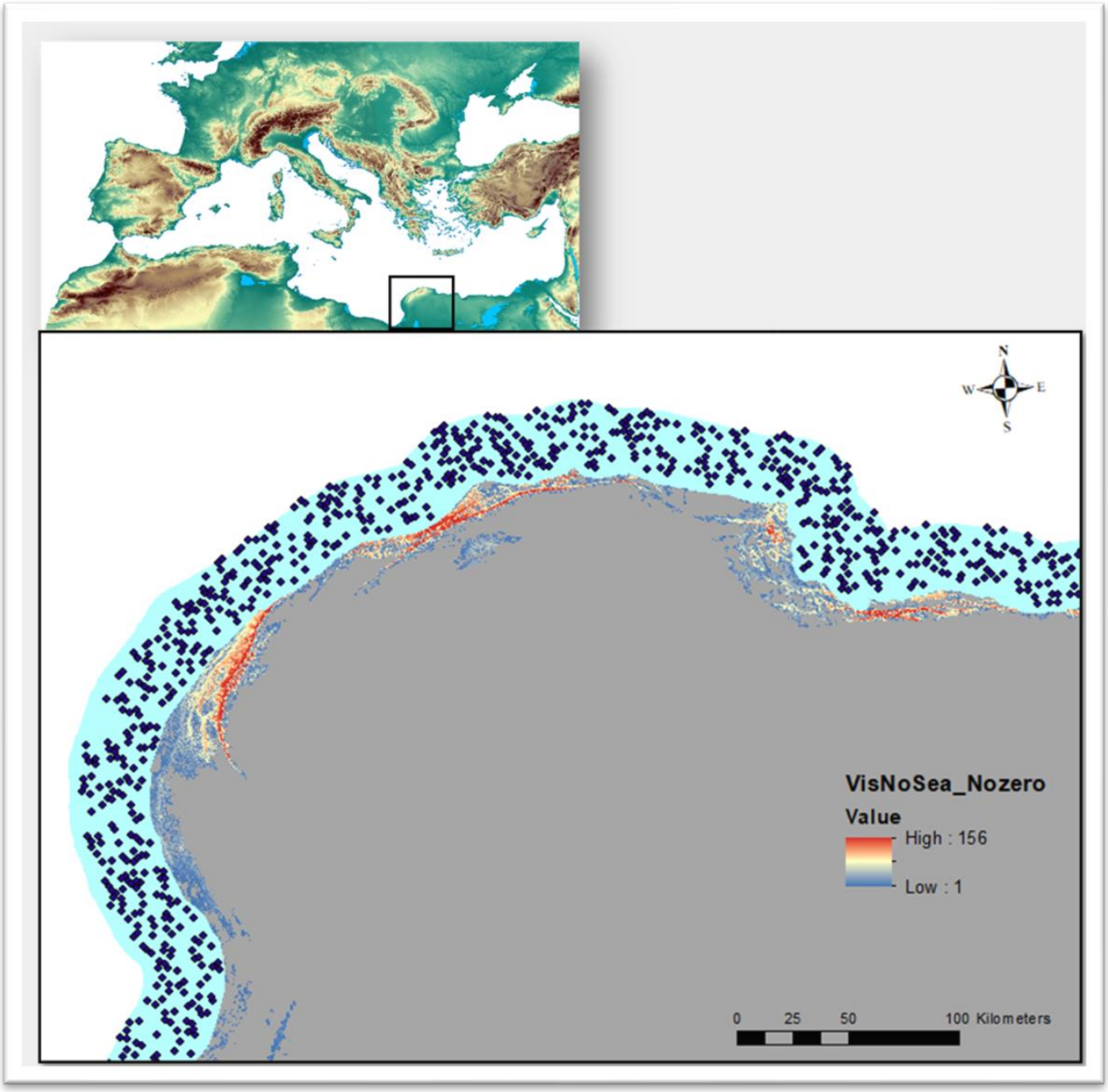

Figure 6.12: On-land cumulative viewshed, generated from 6400 random points within the 15 NM zone. High values identify prominent land features.

Stage 2 - Selection of observer points within the prominent regions detected

The aim of this stage is to identify the cumulative viewshed's highest values (i.e. the peaks`) among the geomorphological features visible from the sea identified in stage 1, and use these peaks as observer points to run the viewshed seaward. The following steps have been taken to gradually lower the resolution of the cumulative viewshed and identify the peaks:

The out-of-sight cells were removed from the cumulative viewshed generated in Stage 1; the remaining raster cells were divided in 10 x 10 km squares regions to select through a script purposedly written the 10 % highest values in each region. Particularly, the script (Attachment 4) allows identifying in each 10x10 km squares region the 90% lowest values of the cumulative viewshed -i.e. the p90 value- and to generate a new raster having the p90 value as a cell-unit. This enables to highlight in the new raster only the 10% highest values of the original viewshed. The resulting raster was then regionalized in ArcGIS, through the Spatial Analysis Region Group tool and Zonal geometry tool, to group together cells with the same values; zonal statistics was performed on these grouped regions to isolate the maximum elevations within them; particularly, the grouped regions were used as 'input raster or feature zone data', the DEM as input raster where to perform statistics, and the 'maximum' as statistics. Through raster calculator, the maximum elevations (i.e. the peaks) were isolated in the regions and afterwards converted into observer-points (Figure 6.13). In total, 8451 observer points were created.

This procedure for identifying observer points by isolating the highest peaks (i.e. viewshed values) presents disadvantages since the observers often end up being close to one another, thus generating nearly identical, overlapping viewsheds. Therefore, in the final cumulative viewshed seaward (Figure 6.14), certain cells may have high cumulative values, being visible from a great number of observer points (blue in the fig) only because these are close to each other. A way for removing such useless duplications might be by retaining only one point among clusters with the same or similar (to define) elevation and slope. Nonetheless, this limitation does not affect the final goal of the current analysis since our aim is only to ascertain up to which distance the land can be seen and not whether a same peak or area is visible from multiple and distant sea regions. Improved strategies for observer-point selection combined with automated morphometric techniques to determine the shape of the peaks might be a suitable strategy for identifying maritime landmarks and ancient transit lines (Gooley, 2011). The issue is worth further investigating, and it will be explored in future developments of the present research.

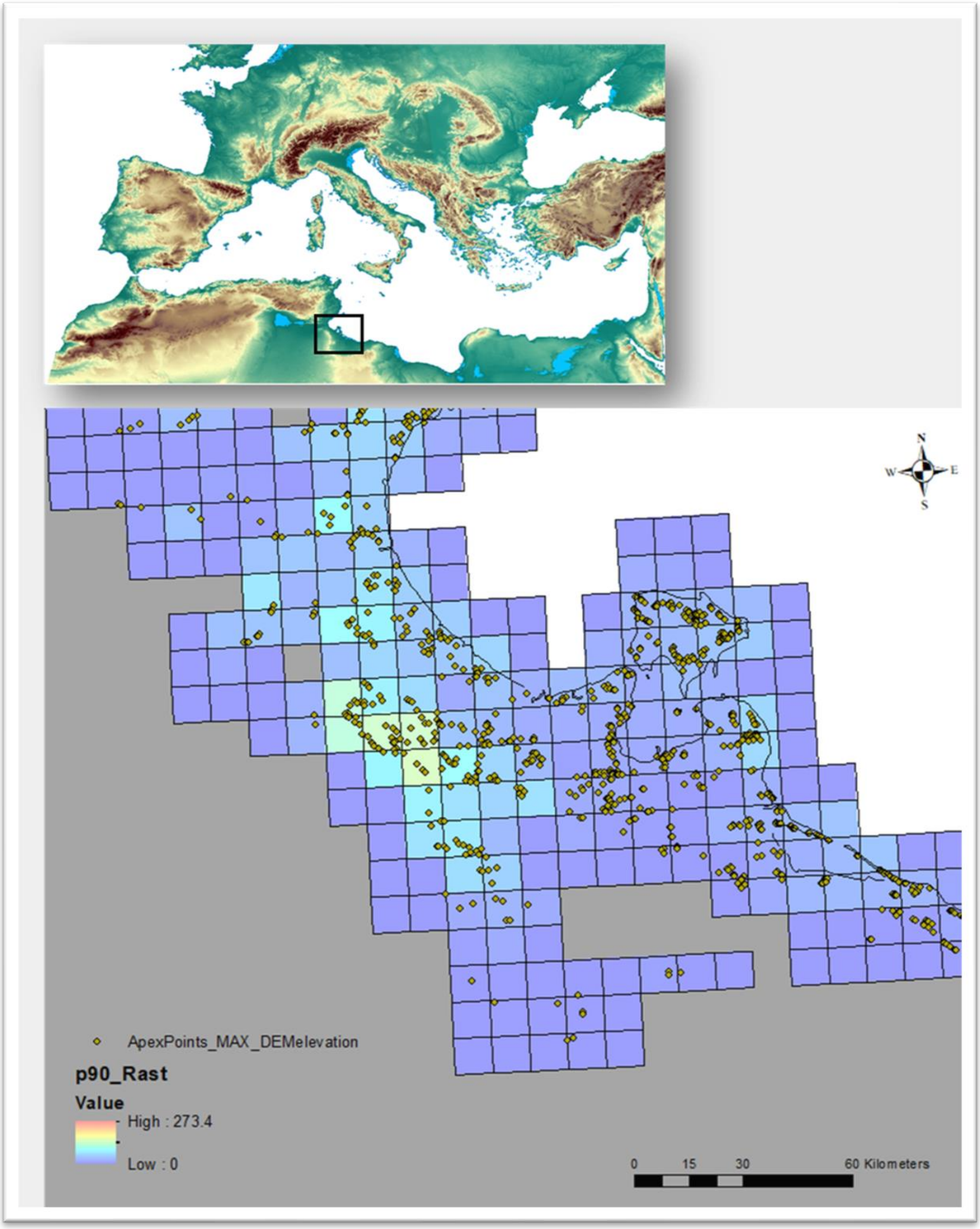

Figure 6.13: Observer points created for running the seaward cumulative viewshed on the basis of local peaks in the landward cumulative viewshed. The squares represent a 10 x 10 square km fishnet -having as extent the DEM-created to detect the 10% highest cumulative viewshed values and convert them into observer points. In total, 8451 observer points were created (here is a detail).

Stage 3 - Visibility analysis seaward from the detected optimized observers & transit preference specification

Once the most prominent observer points were identified, the viewshed analysis seaward was run by again employing the python script in Attachment 4. The results are shown in Figure 6.14.

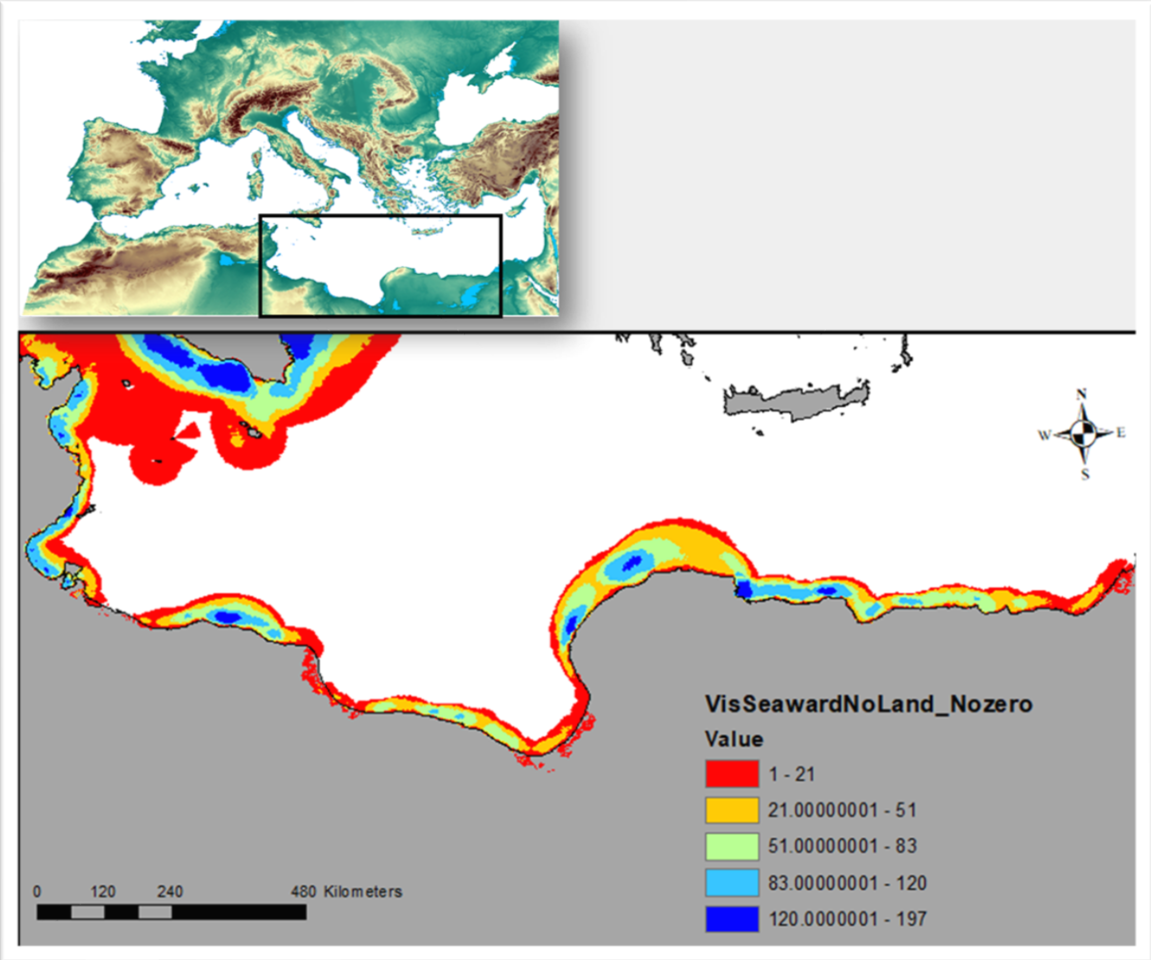

Figure 6.14: Cumulative seaward viewshed generated from the observer-points identified in stage 3. High values correspond to a large number of overlapping viewsheds, but that is not relevant for the current analysis.

A cost surface must now be created that assigns higher transit preference values closer to the seaward edge of the cumulative viewshed. To this end, the seaward viewshed-limit was manually digitized, and the Euclidean distance tool was then employed for calculating the distance in two directions: toward the coast and toward open water. Finally, the Rescale by Function tool was used to rescale these Euclidean distances to values ranging between 1 and 10, thus assigning higher transit preference (i.e. cost-value) the smaller the distance to the viewshed edge; the 'small' transformation function was used to this end. The results are in Figure 6.15 (a), whilst in Figure 6.15 (b), the cost-surface has been clipped to the study area.

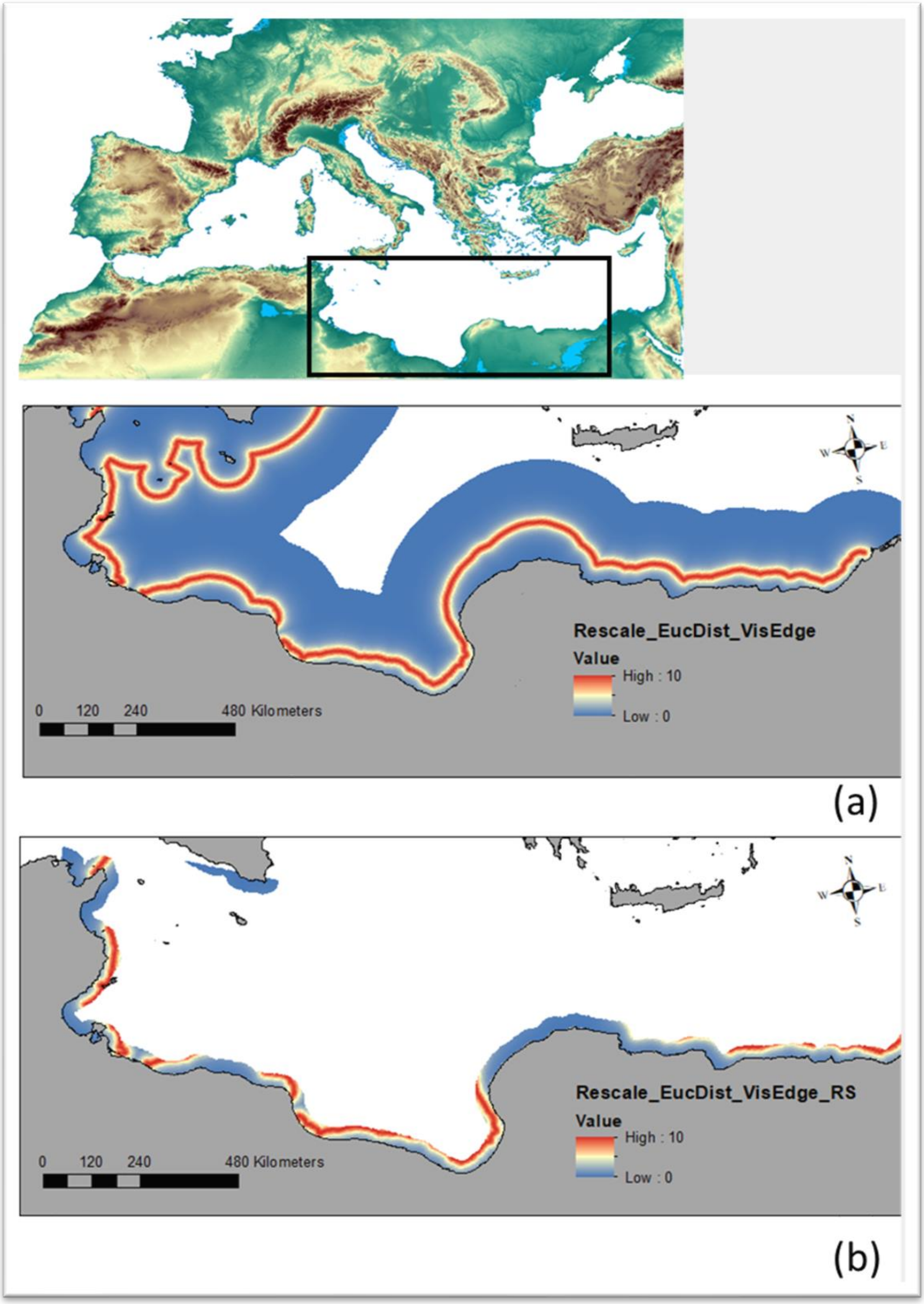

Figure 6.15: (a) Above, the normalised visibility cost-surface produced through the Rescale by Function tool, which was employed to assign a higher transit preference the closer the edge of the cumulative viewshed seaward. Below (b), the same cost surface is clipped to include the study area exclusively.

6.3 NAVIGATIONAL HAZARDS

The Navigational hazards model component aims to ascertain where ships have higher chances of sinking within the territorial waters. The procedure below describes the implementation as raster cost surfaces of the hazards to navigation that have been introduced and discussed in chapter 4. As explained in that chapter, the cost expresses the risk of sinking, for the greater the probability of sinking, the greater the overall shipwrecks occurrence probability. The two categories of factors (geomorphological threats and severe meteorological and oceanographic conditions) are treated in separate subsections.

6.3.1 Geomorphological hazards

The procedure aims at identifying geomorphological threats to navigation, which include shallows, reefs, shoals but also offshore rocks and islands that may be hard for mariners to spot in harsh meteorological conditions. Shallow waters are extremely hazardous to navigation, particularly at less than 5 m depth. To generate a cost surface for this factor, we need (1) a suitable source for bathymetrical data, (2) a rule to establish how cost should vary in relation to water depth, and (3) procedures to implement this in ArcGIS 10.6.

Data

The bathymetric survey data and Digital Terrain Model (DTM) developed in the framework of the European Marine Observation and Data Network (EMODnet) as initiated by the European Commission and collated from public and research organizations was employed. Particularly, the 2018 version with a resolution of 3.75 arcseconds was used (circa 115 * 115 meters).[62]

Rule

The smaller the deptHm0, the higher the risk (i.e. cost); navigation is assumed to be the riskiest at deptHm0 ranging between 0 and 5 m; moderate risk is assigned to deptHm0 ranging between 5 and 15 m. No risk is assigned at deeper waters.

Procedure

The EMODnet bathymetry was imported in 14 different tiles, which were converted to the chosen coordinate system and combined together for creating a single raster. The latter was reclassified with the ArcGIS reclassify tool by assigning a high cost (10) to depths below 5 m, a medium-low cost (i.e. 2) to ranges between -15 and -5, and no cost (0) to all the other classes. The values were determined as such by considering that shallow bodies of waters, up to 5 m depths are overall risky, whereas depths ranging between 5m and 15 may be risky occasionally, for instance, in severe meteorological conditions. The results are displayed in Figure 6.17. The above depth class breaks have been arbitrarily assigned, and this constitutes a factor of uncertainty in the model, for different depth classes may impact the model results (see Chapter 7, Table 7.1). The procedure is summarized graphically in Figure 6.16, and its outcome is shown in Figure 6.17.

[62] https://www.emodnet-bathymetry.eu/data-products

Figure 6.16: Summary procedure for obtaining the Geomorphological threats factor map

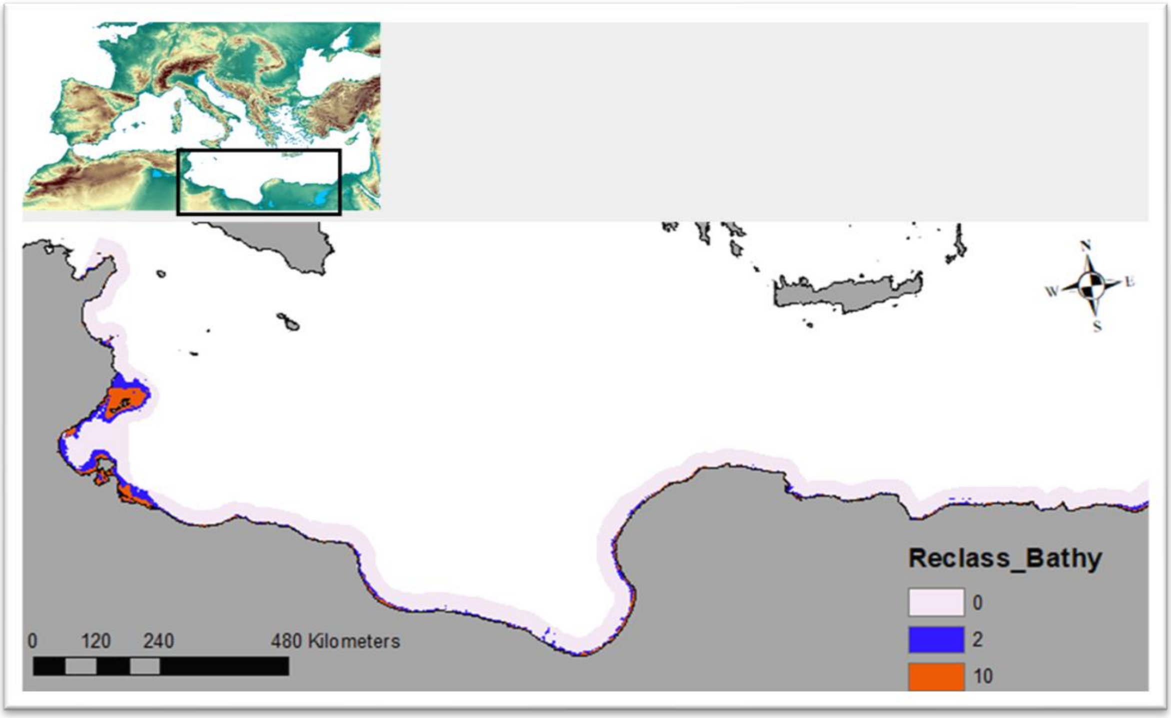

Figure 6.17: Geomorphological threats factor. The picture shows the three risk categories assigned to the bathymetry raster-layer

6.3.2 Severe meteorological and oceanographic conditions

This group includes the following factors whose implementation is described in separate sub-sections:

- Annual mean wave height
- Annual mean wind-speed
- Storminess 1: Water level maxima (i.e. maximum level reached by the water during storms on the coast
- Storminess 2: the 5-year Return Value (i.e. how often sea-storms tend to happen along different Mediterranean coastal areas)

Annual mean significant wave height

The significant wave height (Hm0) is defined as the mean wave height (trough to crest) of the highest third of the waves that occur in a given time period (Holthuijsen, 2007, pp.70-75). In this case, the annual average is considered. Larger waves cause the most beach erosion and can cause navigation problems for mariners in the past as in present days[63]. The wave height

[63] e.g. at this regard the US National Weather Service https://www.weather.gov/key/marine_sigwave

varies in relation to the geomorphology of an area (i.e. bathymetry, nature of the sediments); therefore, the same meteorological event is able to produce wave storms of different energy contents along different coasts (Mendoza et al., 2011). Overall, the higher the Hm0, the riskier the navigation for mariners; this also in light of the fact that individual waves will be higher than the Hm0. In order to generate a cost surface for this factor, it is necessary to establish (1) a suitable data source for the significant wave height, (2) a rule for how cost should vary in relation to it, and (3) procedures to implement this in ArcGIS 10.6.

Data

The multi-year wave reanalysis of the Mediterranean Sea Waves forecasting system provided by the EU Copernicus Marine Environment Monitoring Service (MEDSEA_HINDCAST_WAV_006_012)[64]. Spatial Resolution of the original file: 15 arcseconds in latitude and longitude (approx. 4.6 km).

Rule

The higher the Spectral Significant Wave Height (Hm0), the riskier the navigation for mariners, hence the higher the cost assigned.

Procedure

The 'MEDSEA_HINDCAST_WAV_006_012' data were imported from the E.U. Copernicus Marine Environment Monitoring service, clipped to the extent of the study area, and brought to the working resolution of 1 km cell size. Afterwards, the Rescale by Function tool was employed for converting the data into a cost-surface with values ranging between 0 to 10 using the 'Large' transformation function (Figure 6.19). Further transformation functions, which also assign higher preference to large input values, are possible[65]; this constitutes a factor of uncertainty in the model, for the employment of different transformation functions entails possible variation in the model outcomes (see chapter 7). The procedure is summarized graphically in Figure 6.18, and its outcome is shown in Figure 6.19.

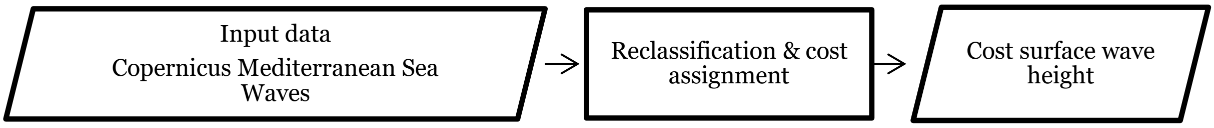

Figure 6.18: Summary procedure for obtaining the wave height factor map

64 https://resources.marine.copernicus.eu/documents/PUM/CMEMS-MED-PUM-006-012.pdf https://resources.marine.copernicus.eu/product-detail/MEDSEA_MULTIYEAR_WAV_006_012/INFORMATION

65 e.g. 'Exponential', 'Logistic growth', 'MSLarge'. https://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/the-transformation-functions-available-for-rescale-by-function.htm

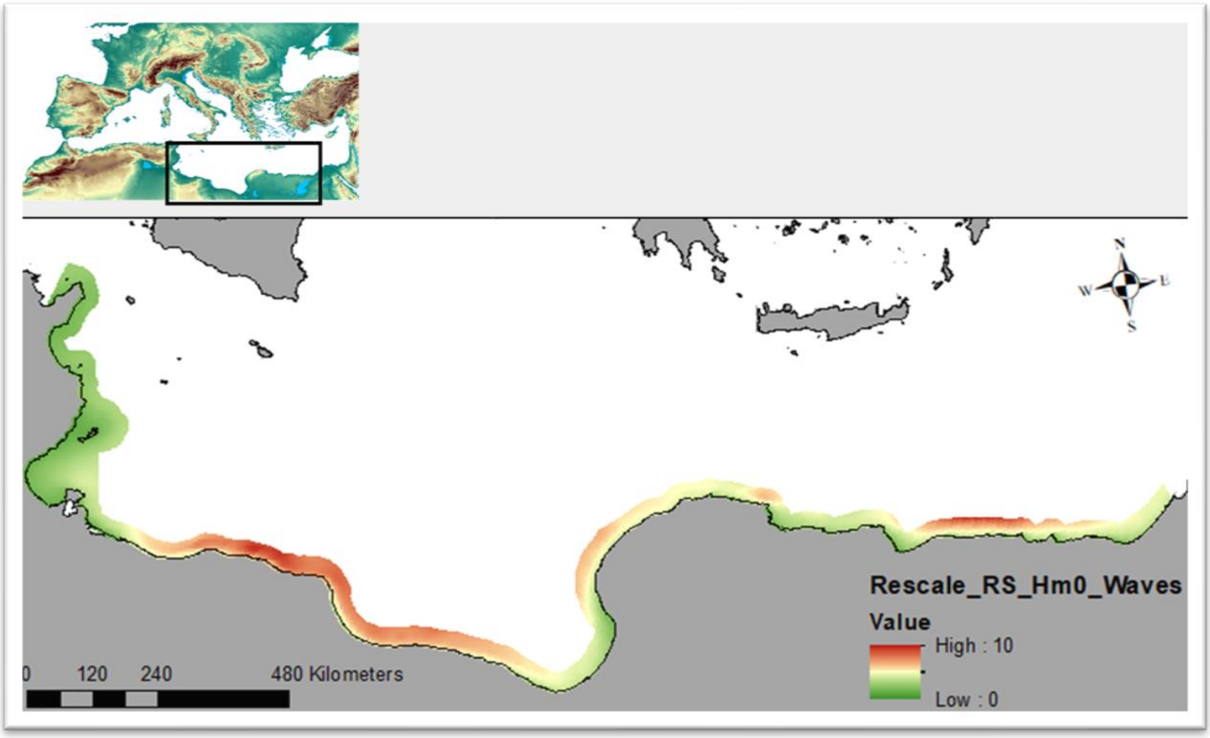

Figure 6.19: Cost surface expressing the navigation risk associated with the significant wave height (Hm0): the highest the Hm0, the highest the risk.

Annual mean wind-speed

As discussed in chapter 4, the wind speed constitutes a risk factor for sailing both at high values and extremely low ones. The best wind conditions for ancient sailing are those corresponding to Beaufort 3-4 (i.e. 3.4 – 7.9 m/s), whereas navigation becomes increasingly risky at scales greater than Beaufort 6 (i.e. 10.8-13.8 m/s), and in the absence of wind or with extremely weak ones, as the vessels may be at the mercy of the waves (Arnaud, 2005, p. 19). To generate a cost surface for this factor, it is necessary to have (1) a suitable source of data for the annual mean wind speed, (2) a rule to establish how cost should vary in relation to it, and (3) procedures to implement this in ArcGIS 10.6.

Data

The EU Copernicus Marine Environment Monitoring Service (WIND_GLO_WIND_L4_REP_OBSERVATIONS_012_003). The raster represents the global monthly averaged wind speed (m/s) calculated since April 2007 till 2017. It has been derived from the 'EU Copernicus Global Ocean Wind Observations Climatology', which includes time series of six monthly averaged wind variables calculated over global ocean with a spatial resolution of 0.25 x 0.25 degrees in latitude and longitude (ca 25 km)[66].

Rule

The risk increases at wind-speed values greater than 13.8 m/s and smaller than 1.6 m/s

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[66] More details here: http://resources.marine.copernicus.eu/?option=com_csw&view=details&tab=info&product_id=WIND_GLO_WIND_L4_REP_OBSERVATIONS_012_003&format=docpdf

Procedure

Similarly to the mean wave-height procedure, the Copernicus data 'WIND_GLO_WIND_L4_REP_OBSERVATIONS_012_003' were imported in ArcGIS, clipped to the selected study-area and resized to the working-resolution (i.e. 1km cell size). Due to the relatively low resolution of the original data, it has been necessary to employ focal statistics for calculating for each null cell in the raster the mean value from 8 neighbour-cells, and assign this mean-value to the null one through raster calculator (Figure 6.21). Afterwards, the Rescale by Function tool was employed for creating a cost-surface with values ranging between 1 and 10 (Figure 6.22). Theoretically, the symmetric Linear transformation function would have been the most suitable, as it allows to rescale the input data by mirroring a linear function around a specified value, which represents the most suitable value, with preferences decreasing linearly as the input values move in both directions from the mirrored point. In this case, the Beaufort 3/4 range (i.e. 3.4 – 7.9 m/s), which represents the optimal navigation conditions, could be set as mid-point with decreasing preferences for both lowest and highest values. The tool also enables one to set the preferred spread value, namely the speed at which the cost changes, thus making it possible to increase the risk-cost faster for the higher wind-speed values and more gradually when decreasing the wind-speed values. Although suitable as an approach, the average wind-speed values in the Mediterranean Sea only range between Beaufort 4 and Beaufort 6, having the minimum and maximum respectively set at 6.11 (m/s) and 12.44 (m/s). For this reason, the 'Large' transformation function has been preferred since it makes it possible to assign an increasingly higher cost for the greater values. The symmetric linear function may still be useful at different time–levels (e.g. seasonal), which may include broader Beaufort scales; intend to test this in future developments of the present research. The procedure is summarized graphically in Figure 6.20, and its outcome is shown in Figure 6.22.

Figure 6.20: Summary procedure for obtaining the Wind speed factor map

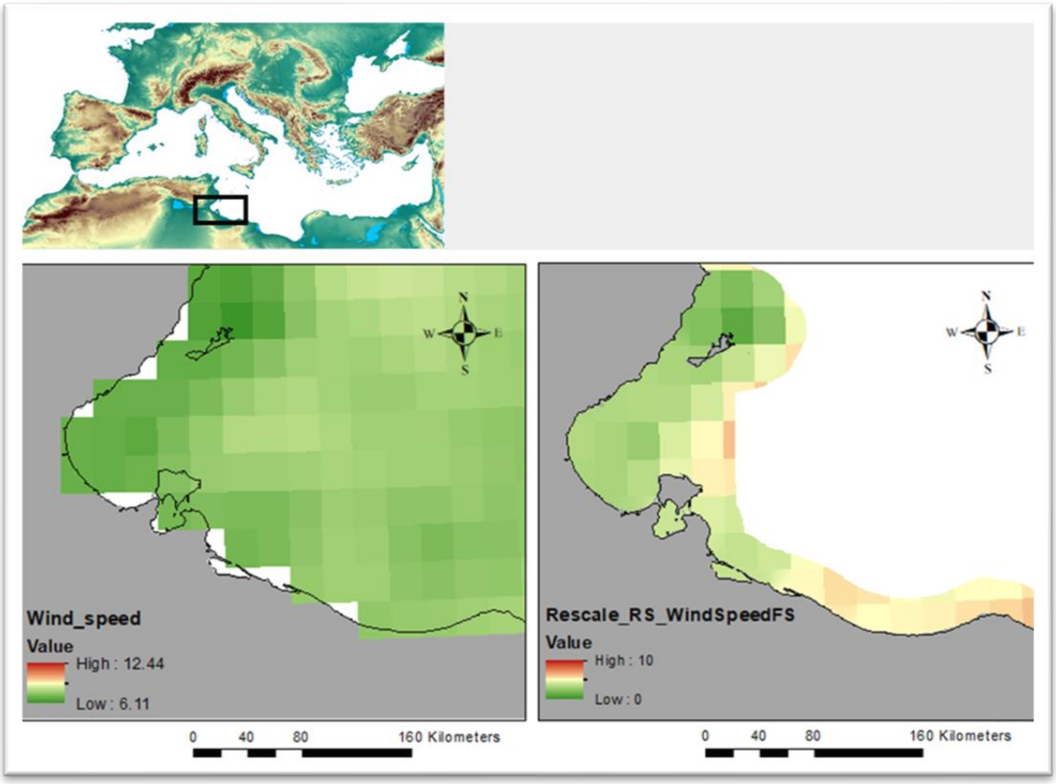

Figure 6.21: Optimization of the wind-speed raster surface: given the relatively low resolution of the input wind data, the focal statistics (FS) tool was used to assign the null-cells in the wind-speed cost-surface (to the left) the mean value from 8 neighbour-cells. To the right are the results in the normalised wind-speed cost-surface factor.

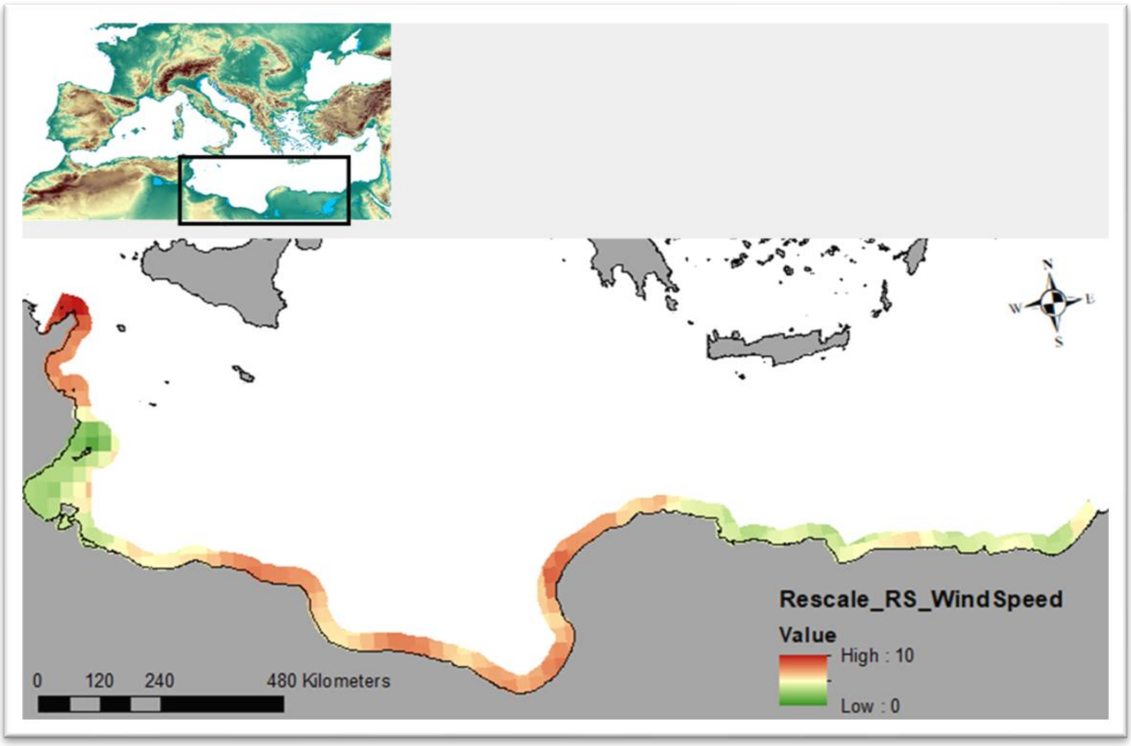

Figure 6.22: Cost surface expressing the navigation risk associated with the wind speed within the 15 NM zone

Storminess Factors (1 & 2)

A sea storm has been defined as a violent disturbance of the atmosphere, which causes an increase in wave height and sometimes sea level (i.e. storm surge) above a certain threshold for a certain period of time (See section 4.2-3 and section 5.5). The frequency with which these phenomena occur and their intensity in terms of water level maxima and storm surge vary across the Mediterranean, particularly in the littoral areas where the effects of water level maxima are most important (Lionello et al., 2017). In terms of ancient sailing, this makes these parameters an index of the relative hazard of the Mediterranean coastal sectors. The model takes into account two different factors:

- The annual water-level maxima (wlind), namely the maximum level the water can reach during a storm along the coast, which is the sum of both wave amplitude and storm surge level (Storminess 1)
- The 'return value' (rv), namely how often sea-storms tend to happen in different Mediterranean coastal areas (Storminess 2)

To generate a single cost surface for each storminess factor, it is necessary to determine (1) a suitable source for data on marine storminess along the coasts of the Mediterranean Sea, (2) a rule to establish how cost should vary in relation to the annual water level maxima and 50-year return value, and (3) procedures to implement this in ArcGIS 10.6.

Data

Lionello P, Conte D, Marzo L, Scarascia L (2017), The contrasting effect of increasing mean sea level and decreasing storminess on the maximum water level during storms along the coast of the Mediterranean Sea in the mid 21st century. Glob Planet Change, Pages 80-91[67].

Base data consists of a txt file with 607 points located along the whole coastline of the Mediterranean basin (islands are excluded). Each point has 5 attributes for the wave amplitude (wa); Storm surge level (ss); Water level (wl) calculated in 1 and 10 years, which is the sum of the previous two, 5-year return value (rv50), 50-year return value (rv5). The values refer to two 30 yearlong periods: 1971–2000, representing the past (reference), and 2021–2050 representing the future climate projections.

Rule

- Storminess 1 - The higher the annual water-level maxima along the coast, the higher the risk
- Storminess 2 - The higher the return value (i.e., the more frequent the sea-storms), the higher the risk

Procedure

The txt base-data file was imported in ArcGIS and converted into points feature-class having the 10 years water level maxima and the 50 years return value as attributes. Two raster surfaces are derived through the Inverse Distance Weighted (IDW) interpolation method. The IDW "assumes that each input point has a local influence that diminishes with distance. It weights the points closer to the processing cell greater than those further away. A specified number of points, or all points within a specified radius can be used to determine the output

[67] http://dxdoiorg/10.1016/j.gloplacha.2016.06.012

value of each location”[68]. The tool ‘Z value field’ can be used to hold the magnitude value for each point. Here two different raster surfaces were created by using the RV50 and the Wlind as Z value field respectively.

Afterwards, each of the resulting rasters was converted into a normalized cost surface, with values ranging between 1 and 10 by mean of the ‘Rescale by Function tool’. In both cases, the large function was employed among the other options for assigning higher costs the greater the values of the water-level maxima and return-value (Figure 6.24). As discussed in relation to the wind speed and wave height implementation, further transformation functions that also assign higher preference to large input values may be used[69]; this constitutes a factor of uncertainty in the model, for the employment of different transformation functions entails possible variation in the model outcomes (see chapter 7). The procedure is summarized graphically in *Figure 6.23*, and its outcome is shown in Figure 6.24.

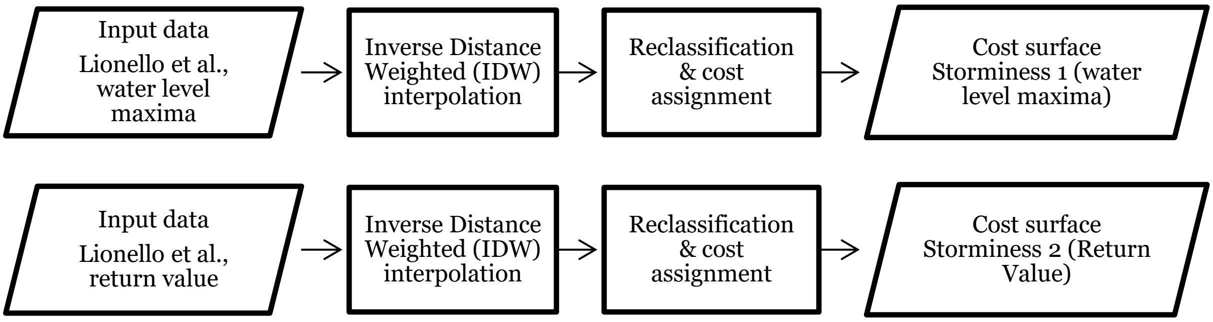

Figure 6.23: Summary procedure for obtaining the Storminess factor maps (i.e. water level maxima and return value)

[68] http://www.gisresources.com/types-interpolation-methods_3/

[69] e.g. ‘Exponential’, ‘Logistic growth’, ‘MSLarge’. https://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/the-transformation-functions-available-for-rescale-by-function.htm

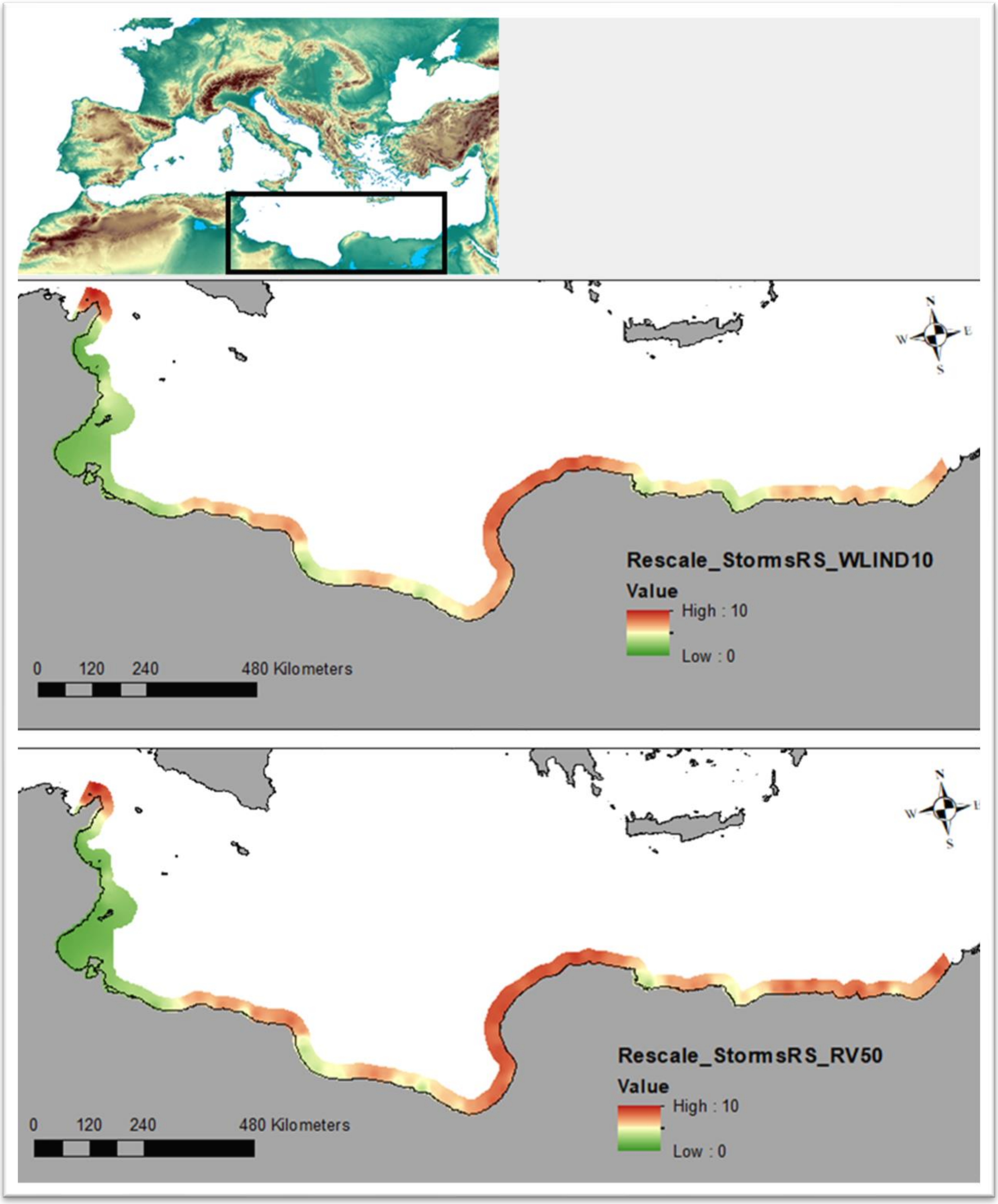

Figure 6.24: Cost surfaces expressing the navigation risk associated with the storm-incidence: the higher the annual water-level maxima along the coast, the higher the cost-risk (up); the higher the return value (i.e., the more frequent the sea-storms), the higher the cost-risk (below)

6.4 ESTABLISHING A BASE MODEL AND A PREFERRED MODEL

The cost surfaces that were generated for each of the 10 factors are combined to generate a cumulative cost surface, which indicates the relative shipwrecking probability in each cell. To this end, the ArcGIS 'Weighted-Sum' tool is employed, which requires the specification of each factor's weight; this entails postulating whether a certain factor is more or less important than another in terms of impact on the targeted phenomenon, which is problematic when the factors to compare and sum are expressed in socio-cultural or 'pseudo-costs'(Verhagen et al., 2019, p. 229). In deductive models, and with factors whose cost cannot be expressed in measurable units e.g. of time, energy, it is common practice to employ multi-criteria decision analysis, such as the Analytic Hierarchy Process (AHP)[70], to calculate the weights of factors that are not intrinsically comparable; although based on expert judgement and subjective reasoning, the AHP makes it possible to structure the evaluation process in a formalised and explicit manner (Dalla Bona 1994; Nsanziyera et al., 2018; Saaty, 1980; Verhagen, 2006). Here, in a first stage, a 'Base' model is built by weighting all input factors equally. In a second stage, a 'Preferred' model is built by assigning factors different weights based on the AHP approach (Figure 6.25). The AHP method is based on a pairwise comparison between factors, following the standard framework in Table 2 (Saaty, 1980, p. 163).

Table 6.3: Saaty 'fundamental scale' for assigning the factors' intensity of importance (Saaty 1980, p. 163)

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience & judgement slightly favour one element over another
5	Strong importance	Experience and judgement strongly favour one element over another
7	Very strong importance	One element is favoured very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation
2,4,6,8	-	Can be used to express intermediate values
Reciprocals	-	If activity *i* has one of the above numbers assigned to it when compared with activity j, then *j* has the reciprocal value when compared with *i*

The AHP produces ratio data, namely data with an equal and definitive ratio between each value and an absolute 'zero', namely a point of origin below which negative values are not

[70] Further examples of multi-criteria decision analysis are the Evidential Reasoning Approach (e.g., Guo, et al., 2008), Dominance-based Rough Set Approach (Słowiński, et al., 2007), or Aggregated Indices Randomization Method (Hovanov, et al., 2009)

possible. Therefore AHP enables to indicate how much more important one factor is over another in terms of impact on the targeted phenomenon. In order to avoid confusion, it is important to stress that the weight evaluation here does not address the higher or lower impact each factor has depending on their attribute-variation (e.g. depth is dangerous below 5 m, but it does not impact navigation at higher depths); indeed, this sort of weighting is addressed through cost-surface analysis, as described in the above pages (for the difference between weighting at attribute and criterion level see Verhagen et al., 2019, p. 229).

6.4.1 Factor weights evaluation through Saaty's Analytic Hierarchy Process

For employing Saaty AHP to assign a weight to the factor maps, we first need to specify how the standard AHP evaluation framework can be interpreted and used in this specific context. Here, a factor is favoured when deemed to increase the relative shipwrecking probability (RSP) more than the other. The criteria employed for evaluating whether one-factor impacts the overall RSP more than another are specified as follows to make the evaluation process as transparent as possible and open to future modifications:

- The factor is always impactful independently from scale, period, technology, mariners group (assigned max value).
- The factor's impact is beyond the control of the seafarer
- The factor is impactful depending on A) scale, B) time-period C) technology, D) mariners' group, E) circumstances (each letter counting +/- 1)

First, each factor is evaluated based on the above criteria. Second, the Saaty index of importance (Table 6.3) is assigned in proportion to the size of the difference between their value (Table 6.4).

Bathy = 8	Depth (i.e. bathymetry) always impacts navigation. Although different vessel types may handle depth classes differently and a certain class depth may be hazardous occasionally depending on, e.g. meteorological or oceanographic conditions, any ship would risk getting stuck or sinking in shallow waters. However, to a certain extent (e.g. knowledge of the environment and use of sounding weights), mariners may avoid geomorphological threats.
Wind speed = 8	Wind speed is always impactful independently from scale, period, mariners group, but it may be handled better depending on the technology.
Wave height = 8	Similarly to the wind speed, it is always impactful independently from scale, period, mariners group, but it can be handled better depending on the technology
Storminess (RV50) = 9	It is always impactful independently from scale, period, mariners group. Technology can help to deal with it, but it may not be sufficient to avoid the wreckage.
Storminess (WLIND) = 9	It is always impactful independently from scale, period, mariners group. Technology can help to deal with it, but it may not be sufficient to avoid the wreckage.

Shelter distance = 10	Ships start and end a journey in a port. The availability of a shelter or port to find a temporary shelter or land is an essential condition for navigation.
Shelter attractiveness = 6	Not all ports may be considered equally convenient to approach. Nonetheless, this factor is dependent on A) scale, B) time-period C) technology, E) circumstances
Roads= 5	Similarly to the shelters attractiveness, this also depends on A) scale, B) time-period C) technology, E) circumstances. Also, it does not affect all categories of mariners because a ship may enter a harbour just for a temporary shelter without the need to have the availability of a nearby inland network. Moreover, the proximity of a port to the road system is also entailed in the shelters-attractiveness (A) factor (e.g. if a port is close to a big city it is likely to be connected with roads. Similarly, if a harbour is very big with extra facilities). Despite the apparent overlapping, the attractiveness and the road proximity are implemented separately because the A is based on primary sources accounts exclusively.
Inland-Water sources = 5	Since the availability of rivers and other water sources nearby a shelter is here considered both for navigation purposes and drinkable source, the same considerations expressed for the roads apply. Also, in this case, the attractiveness includes the availability of water near a shelter, but the two factors are based on different, independent base data.
Visibility = 3	As explained in ch. 4, the mariners' preference for keeping the land in sight is not only dependent on A) scale, B) time-period C) technology, D) mariners' group, E) circumstances but it is also controversial. Since direct routes in open waters are documented and local meteorological conditions may prevent seeing landmarks anyway, this factor is assigned the lowest value.

The AHP standard pairwise comparison is performed based on the above factors-evaluation, and Table 6.4 are specified the Saaty indexes of importance based on the value-difference in the pair factors. The results are contained in Table 6.5. The same couple of elements is represented twice, in reciprocals, depending on which factor is considered first; for instance, bathymetry and wind speed have the same individual value (8); therefore, on the Saaty scale, they are assigned a 1. Whereas in the pair bathymetry-storminess, the bathymetry (value 8) presents a slightly lower preference than the storminess (value 9), therefore the storminess is assigned a Saaty scale 3 and the bathymetry the reciprocal 1/3= 0.33.

Table 6.4: From subjective evaluation to Saaty scores.

PAIRS	VALUE DIFFERENCE	SAATY SCALE
BATHY - WIND SPEED BATHY - WAVE HEIGHT WIND SPEED - WAVE HEIGHT ROADS – WATER SOURCES STORMWLIND_STORMRV50	0	1
BATHY – STORMINESS WIND SPEED- STORMINESS WAVEHEIGHT – STORMINESS SHELTATTRACT – ROADS SHELTATTRACT – WATER SOURCES	1	3
SHELT DIST - BATHY BATHY – SHELT ATTRACT WINDSPEED – SHELT DIST SHELTATTRACT-WINDSPEED WAVEHEIGHT – SHELT DIST SHELTATTRACT - WAVE HEIGHT	2	4
BATHY - ROADS BATHY – WATER SOURCES WINDSPEED – ROADS WINDSPEED – WATER SOURCES WAVE HEIGHT – ROADS WAVE HEIGHT – WATER SOURCES	3	5
SHELTERATTRACT – SHELTDIST STORM RV50 – ROADS STORMWLIND – ROADS STORM RV50 - WATERSOURCES STORMWLIND - WATERSOURCES	4	6
BATHY – VISIBILITY WINDSPEED- VISIBILITY WAVEHEIGHT – VISIBILITY SHELTDIST – ROADS SHELTDIST - WATERSOURCES	5	7
STORMRV50- VISIBILITY STORMWLIND- VISIBILITY	6	8
SHELTDIST - VISIBILITY	7	9

Table 6.5: Pairwise comparison matrix of factors based on the Saaty score assigned in Table 6.4

	BATHY	WIND SPEED	WAVE HEIGHT	STORM WLIND	STORM RV50	SHELTDIST	SHELTATT RACT	ROADS	INLAND WATER	VISIBILITY
BATHY	1	1	1	0.333	0.333	0.250	4	5	5	7
WIND SPEED	1	1	1	0.333	0.333	0.250	4	5	5	7
WAVE HEIGHT	1	1	1	0.333	0.333	0.250	4	5	5	7
STORM WLIND	3	3	3	1	1	0.333	5	6	6	8
STORM RV50	3	3	3	1	1	0.333	5	6	6	8
SHELTDIST	4	4	4	3	3	1	6	7	7	9
SHELTATTRACT	0.250	0.250	0.250	0.20	0.20	0.167	1	3	3	5
ROADS	0.200	0.200	0.200	0.167	0.167	0.143	0.333	1	1	4
WATER SOURCES	0.200	0.200	0.200	0.167	0.167	0.143	0.333	1	1	4
VISIBILITY	0.143	0.143	0.143	0.125	0.125	0.111	0.20	0.250	0.250	1

6.4.2 Factor weights calculation

In order to turn the pairwise comparison into ratio values, which may be employed as factor weights, two further steps are required. First, each pair-value is normalised, i.e. each value in the matrix is divided by the sum of the values in its column. For instance, given the first column with the bathymetry pair-values, whose sum is 13.793, each value in the cell column is divided per this number. Second, all the normalised values in a row are summed to calculate the mean, which is used as factor weight (Table 6.6). The sum of all the normalised weights must be equal to 1. If one takes the bathymetry row, the sum is equal to 0.907, which divided per the number of factors (i.e. 10) gives a mean of 0.091.

In Figure 6.25 (up) is the 'Base' Model, which indicates the shipwrecking probability produced by weighting all the factors equally, whereas in Figure 6.25 (down) is the 'Preferred' model produced by assigning to the input factors the weight-preference (given in Table 6.6) following the AHP method. As the pictures show, the Preferred model presents a generally higher RSP the closer the shore and the shelters' proximity, no matter their attractiveness value. This is due to the higher weight assigned to the bathymetry and the shelters' proximity factor, whereas the Base model presents more high-probability areas far from the shore due to the greater influence of the visibility factor (see further discussion at the end of chapter 6.5). In chapter 7, the impact each factor has on the model outcomes is addressed through sensitivity analysis more systematically by producing multiple scenarios through the removal of one factor at a time for ascertaining to which factor the model is more sensitive.

Table 6.6: Factor weight assignment based on normalised pair values from Table 6.5

	BATHYMETRY	WIND SPEED	WAVE HEIGHT	STORM WLIND	STORM RV50	SHELTER DISTANCE	SHELT ER ATTRACTIVENESS	ROADS	INLAND WATER	VISIBILITY	**MEAN WEIGHTS**
BATHY	0.073	0.073	0.073	0.050	0.050	0.084	0.134	0.127	0.127	0.117	0.091
WIND SPEED	0.073	0.073	0.073	0.050	0.050	0.084	0.134	0.127	0.127	0.117	0.091
WAVE HEIGHT	0.073	0.073	0.073	0.050	0.050	0.084	0.134	0.127	0.127	0.117	0.091
STORM WLIND	0.218	0.218	0.218	0.150	0.150	0.112	0.167	0.153	0.153	0.133	0.167
STORM RV50	0.218	0.218	0.218	0.150	0.150	0.112	0.167	0.153	0.153	0.133	0.167
SHELTDIST	0.290	0.290	0.290	0.451	0.451	0.336	0.201	0.178	0.178	0.150	0.281
SHELT ATTRACT	0.018	0.018	0.018	0.030	0.030	0.056	0.033	0.076	0.076	0.083	0.044
ROADS	0.015	0.015	0.015	0.025	0.025	0.048	0.011	0.025	0.025	0.067	0.027
WATER SOURCES	0.015	0.015	0.015	0.025	0.025	0.048	0.011	0.025	0.025	0.067	0.027
VISIBILITY	0.010	0.010	0.010	0.019	0.019	0.037	0.007	0.006	0.006	0.017	0.014

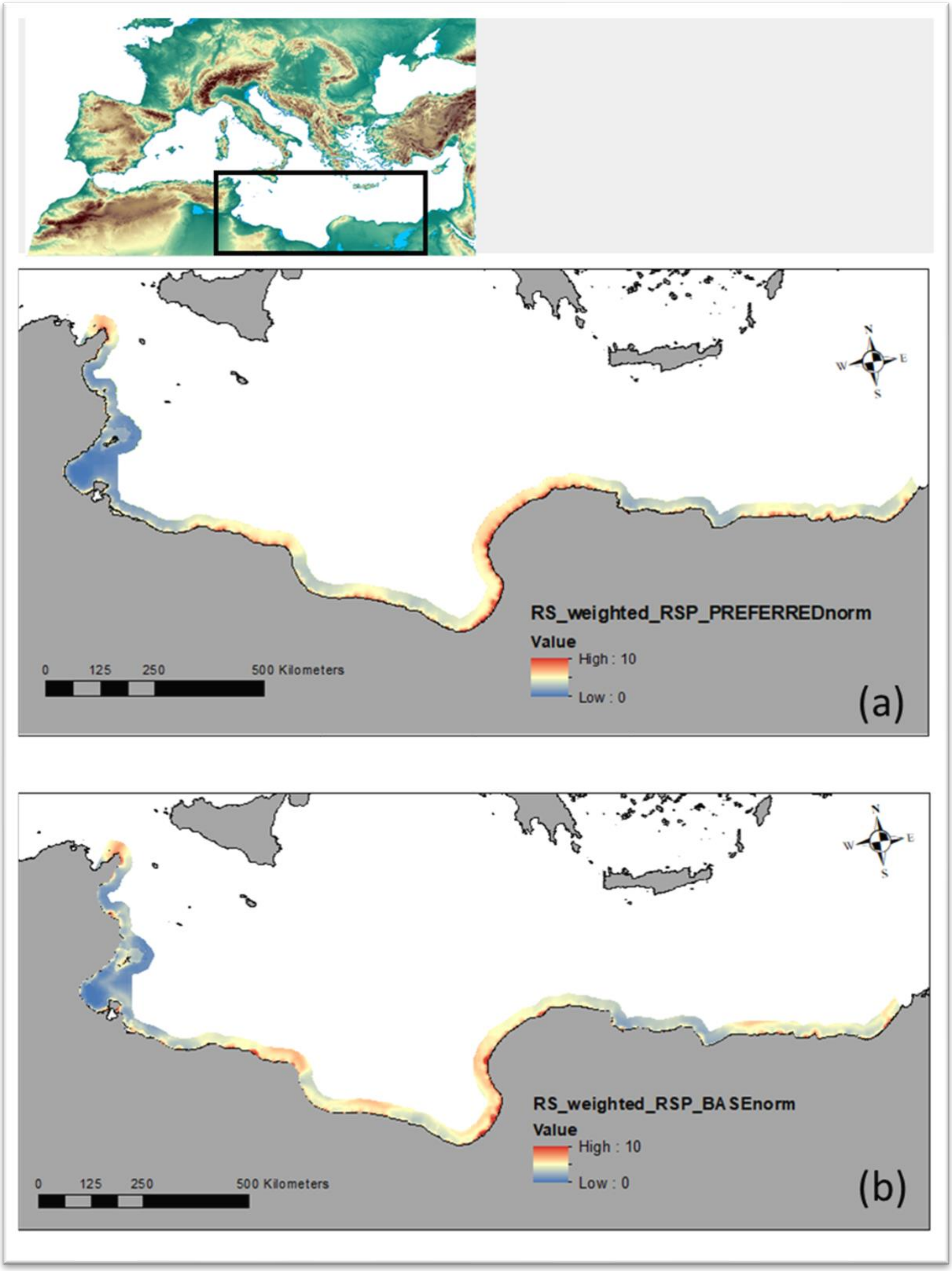

Figure 6.25: Relative Shipwrecking Probability (RSP) in the Regional Scale Base Model (a) and RSP in the Regional Scale Preferred Model (b). In the base model, factors are equally weighted; in the Preferred model, factors are weighted following the Analytical Hierarchy Process (AHP)

6.5 COMPARING ACTUAL AND PERCEIVED OPTIMAL ROUTES

As discussed in the introduction of this research and in chapter 5 one of the aims of the present model is to evidence the pitfalls of the nautical uniformitarianism principle in predictive modelling and discuss whether accounting the potential difference between actual and perceived optimal routes can improve the model performance. In this section, the transit probability resulting from the avoidance of the actual navigation hazards, which following the standard practice would be considered optimal, are compared with the Transit Probability model results. In Chapters 7 and 8, the hypothesis is tested that the highest shipwrecks occurrence may be registered in areas where a high transit probability connected to a low perceived risk corresponds in fact, to areas with high actual navigation hazards.

It is worth specifying that this model does not predict trajectories of movement (i.e. it does not take into account directions) but only isotropic areas with increased movement potential hence the optimal routes should be interpreted as 'optimal areas'. The addition of the direction of movement would change the pattern of navigation possibilities as certain areas are only navigable in specific directions (cf. Potts, 2019; Arnaud, 2005). Following the nautical uniformitarianism principle, we may derive the potential 'optimal areas' by combining the Transit Probability factors with the reversed nautical Hazard model. In other terms, whereas in the RSP model, we assign the cost to the NH components by answering the question "where is it riskier to navigate?" when calculating the optimal routes, we answer the question "where mariners would go to minimize the risks", thus assigning a higher transit preference the lower the actual risk is. The cost surface approach enables one not to prevent the passage in risky areas completely.

In order to obtain these ideal optimal areas, four steps are taken.

First, the Weighted Sum tool is employed for combining the Transit Probability factors with the exclusion of the shelter attractiveness (Chapter 6.2.2) and the visibility range (Chapter 6.2.4), since these represent in this research an attempt to address the perceived convenience of a shelter in terms of safety, facilities and connectivity (ref. Chapter 5.3.2, chapter 6.2.2) and the perceived risk associated to an assault probability. Second, the obtained raster is rescaled to a range between 0 (i.e. low transit) and 10 (high transit); the Large Function (among the other options of the 'Rescale by Function' tool) is employed as it assigns higher transit preference the higher the values. Third, the Nautical hazards cost-surfaces are summed through the Weighted sum tool and then rescaled through the 'Rescale by Function' tool by employing the 'Small' function in order to assign higher transit preference the lower the risk. The weights of the Nautical Hazards model component are computed differently here as they are aimed at inferring shipping probabilities; particularly, it is assigned a double weight to the effects of storminess along the coastline and to the bathymetry because it is assumed to be more likely that mariners would know better the geomorphological threats than the average annual wind strengths and wave values. Forth, the rescaled TP cost-surface (second step) and the rescaled NH cost-surface (step three) are combined through the Weighted sum to produce the optimal shipping areas.

In Figure 6.26, the latter are compared with the transit probabilities produced by deriving information on risks and benefits associated with the coastal proximity from the textual evidence. In both cases, it is assumed that seafarers would try minimizing the navigation risks however, by modelling separately actual and documented hazards, it is not taken for granted that mariners would know and would manage to avoid all the actual environmental threats. As discussed more in detail in Chapters 7 and 8, addressing this difference is crucial as it allows to better identify:

- where the shipwrecking probability is highest
- where it might be connected to an intense traffic, which statistically through the millennia may produce several accidents
- where instead the degree of risk due to environmental hazards is high, and one would expect a lower nautical activity. However, shipwrecks may still be present in these areas because ships could not avoid the risk, they ignored it or deliberately faced the danger for competing considerations.

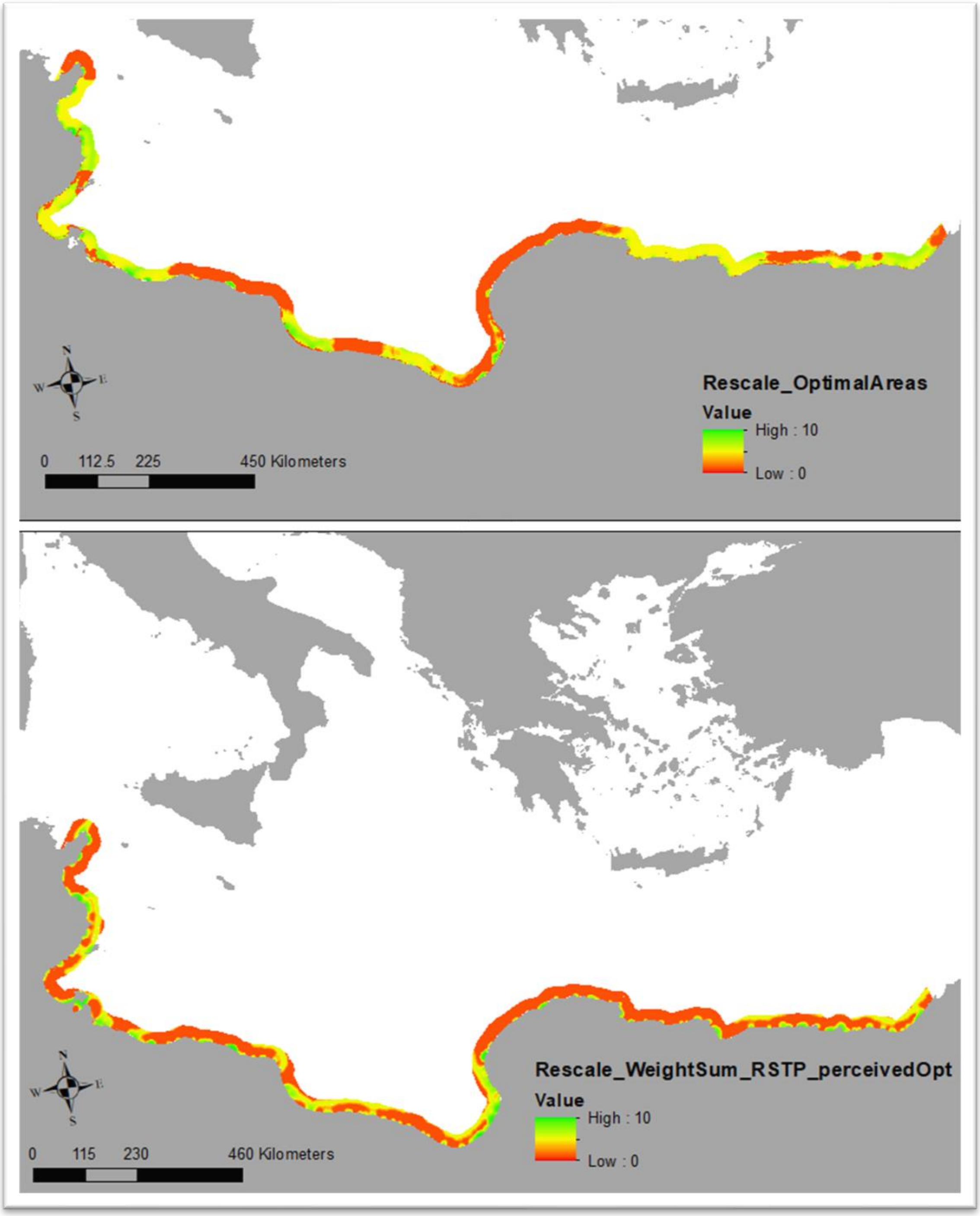

Figure 6.26: Optimal areas for sailing, which minimize the passage through environmental hazards (up), and perceived optimal ones, i.e. generated by taking into account the information on nautical risks derived from the textual evidence (down).

6.6 From regional to global: implementing a simplified Mediterranean-scale model

The spatial extent of the Mediterranean model described in this section includes, similarly to the local case study, the territorial seas as defined by the 1982 UNCLOS Convention, namely the area enclosed within the maritime delimitations of a coastal state extending 12 Nautical Miles seawards from the baselines, and the internal waters, i.e. the area of the seas enclosed between the landward side of the Straight baselines and the seaward side of the coastline. Compared to the 1982 UNCLOS territorial-waters extension, the global scale model excludes some islands (i.e. Sardinia, Corsica, the Balearics, Malta, Lampedusa, Linosa, and Pantelleria) and the Black Sea due to limitations in the input data coverage (see section 5.4.2 and Figure 5.7). For the same reason, similarly to the local scale model, a buffer of 15 NM from the natural coastline has been used in the Gulf of Sidra instead of the UNCLOS-defined zone (Figure 6.27).

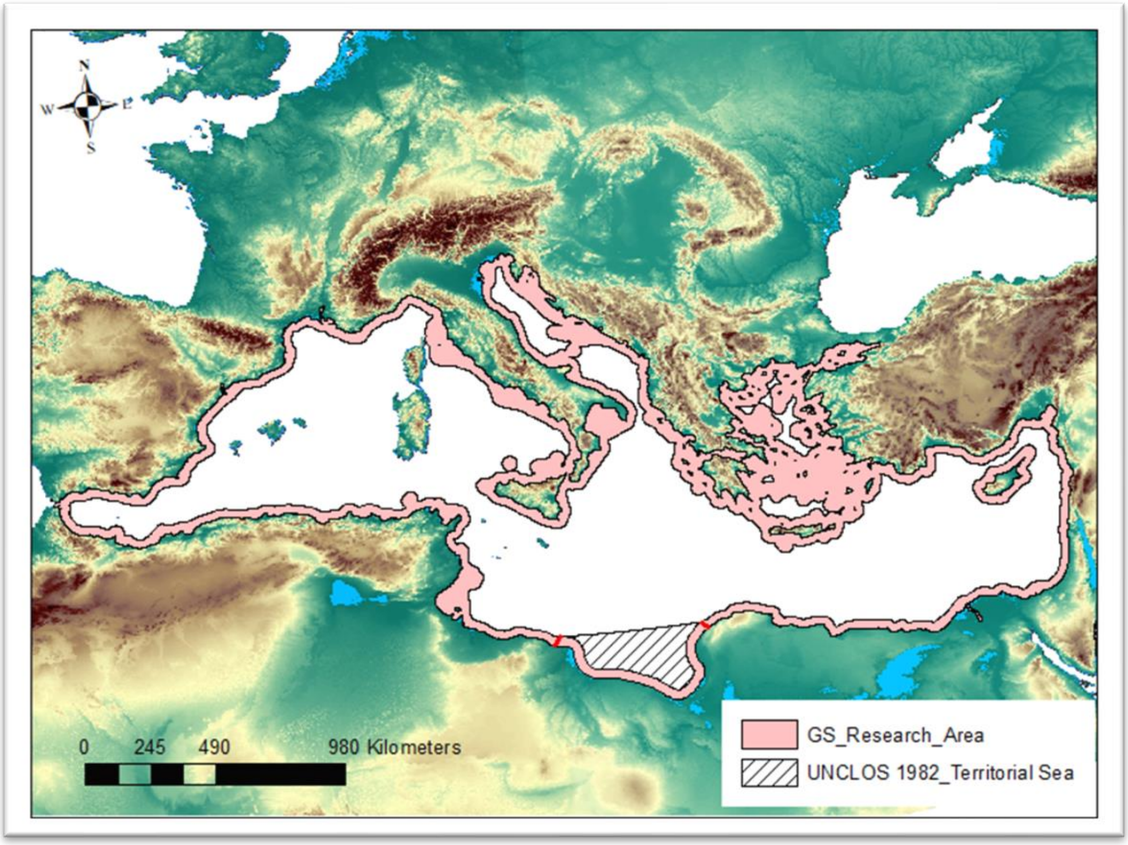

Figure 6.27: The pink areas in the map represent the global scale model extent; this corresponds to the extension of the territorial waters defined by the 1982 UNCLOS convention except for the Gulf of Sidra, where the research area was limited to the 15 NM from the natural coastline. Moreover, some islands are excluded (i.e. Sardinia, Corsica, the Balearics, Malta, Lampedusa, Linosa, Pantelleria). The two lines delimiting the Gulf of Sidra where the UNCLOS territorial sea polygon was cut and merged with the 15 NM buffer from the natural coastline are highlighted in red.

As for the chronological extent, the global scale model does not take into account a specific period; indeed, as described in Chapters 1, 4 and 5, the aim is to generate a simplified tool, which may provide an indicative map applicable in spatial planning. It may be considered a 'beta-version', open to further, targeted improvements, implementing fewer factors that may be considered valid in a long-term perspective. However, it must be noticed that even though the model aims at being chronologically inclusive and not limited in scope to specific time-periods, yet it is bound to data source constraints. Particularly, the base dataset employed for mapping the ports (i.e. Pleiades) tends to overrepresent the Classical, Roman and medieval periods while underrepresenting the modern and contemporary ones as well as some cultural settings (e.g. Islamic). This means that the navigation dynamics in post-medieval periods tend to be underexplored in the model.

The global-scale model is developed by following a slightly different procedure from the local scale one, which reflects its different scope. The theoretical part of the model that is more heavily affected by changes compared to the local-scale analysis is the transit-probability model-component, whereas the procedure followed to implement the navigational hazards model-component (section 6.3) is valid both at the local scale and global scale; therefore, it is not described again in this section Table 6.7.

Table 6.7: Mediterranean model input-factors: the Shelters Attractiveness is the only factor implemented following a different procedure than the one described for the same Regional Scale model-factors.

NAVIGATION HAZARDS MODEL-COMPONENT	
Bathymetry	Same procedure as the RS model (section 6.3.)
Annual mean wind-speed	
Significant annual mean wave height	
Storminess 1 – water level maxima	
Storminess 2 – 5 years Return value	
TRANSIT PROBABILITY MODEL-COMPONENT	
Landing sites	Same procedure as the RS model (section 6.2.1)
Landing sites Attractiveness	Different procedures at Regional and Global scales

The pre-processing step required for running the navigational hazards and the transit probability model components at the global scale consisted of changing the spatial extension as described above in the opening of Chapter 6 (in ArcGIS, this implies changing the spatial extent of the environment settings). Particularly, the territorial waters[71] and internal waters[72] shapefiles have been imported from the Maritime boundaries geodatabase provided by the Flanders Marine Institute and merged for creating a unique shapefile to use as the model

[71] Flanders Marine Institute (2019). Maritime Boundaries Geodatabase: Territorial Seas (12NM), version 3. Available online at https://www.marineregions.org/ https://doi.org/10.14284/387.

[72] Internal Waters Retrieved from: Flanders Marine Institute (2019). Maritime Boundaries Geodatabase: Internal Waters, version 3. Available online at https://www.marineregions.org/ https://doi.org/10.14284/385.

extent and mask in raster analysis. Similarly to the pre-processing steps followed for the RS model, the resulting shapefile has been further edited as follows:

- The areas surrounding the islands out of the model extent were removed
- The 1982 UNCLOS territorial-waters buffer was cut 10 km east from the present-day city of Zliten (Libya) and in correspondence to the boundary between the districts of al-Marj and Banghazi to limit the research area to 15 NM from the natural coastline only between these two locations. The resulting 15 NM buffer was merged with the previously cut UNCLOS territorial-waters shapefile (Figure 6.27).
- The same problem relating to the mismatch between present-day and Roman era coastlines discussed at the Regional scale (section 6.2) also affects the Global scale model (Figure 6.28); in order to compensate for this mismatch, the processing extent has been extended 2 NM landward. However, as discussed in the conclusions of this thesis (Chapter 8.3), neither the Regional nor the global model are suitable to address the local conditions specifically.

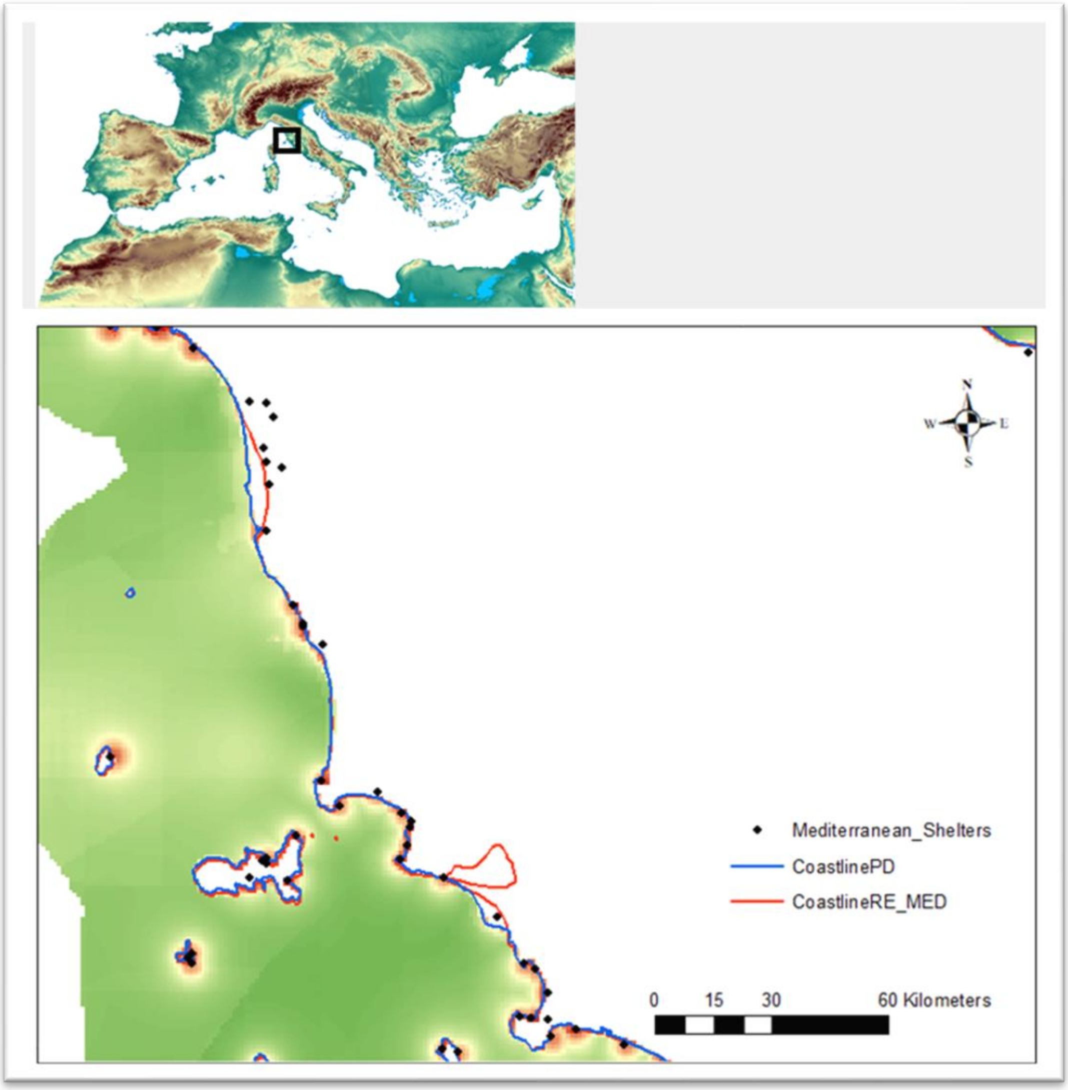

Figure 6.28: local mismatch between Roman-era and present-day coastlines

6.6.1 A simplified Transit-probability model

The transit probability model component at the Mediterranean scale is based on the presence and attractiveness of landing sites. The transit probability at landing sites is implemented according to the same procedure described in section 6.2.1 for the local case study. Whereas a different procedure is followed for the assessment of the landing sites attractiveness. At the local scale, the port convenience has been ascertained by retrieving information from textual evidence. At the Mediterranean scale, however, such a procedure would be both unfeasible and deceptive since the scope of the model is not limited to a specific period. To derive the landing-sites attractiveness, a simplified factor is considered, namely the 'attractors' proximity.

With 'attractors' one refers here to places that different categories of mariners (i.e. traders, producers, pilgrims, travellers) may be interested in reaching, which include environmental, economic, religious and cultural attractors. Since it is outside the scope of the present research to take into account the movement of different categories of agents separately, these attractors have been implemented together as a single factor[73].

To generate a cost surface for the attractors' proximity factor, it is necessary to have (1) a suitable data source for potential attractors, which include economic, religious, cultural ones (2) a rule to establish how the cost should vary with the attractors' proximity (3) procedures to implement this in ArcGIS 10.6.

Data

Pleiades, the 'The joint project of the Ancient World Mapping Center at the University of North Carolina, the Stoa Consortium, and the Institute for the Study of the Ancient World. Senior Editors**:** Roger Bagnall, Richard Talbert.

Rule

The higher the density of potential attractors around landing sites, the higher the landing-sites attractiveness, and hence the cost expressing the transit probability.

Procedure

First, a round buffer of 20 km ray around the Mediterranean landing sites was created for defining the area where to calculate the attractors' count. This buffer was chosen arbitrarily by considering the average daily time travel for heavily loaded mules[74]. This buffer represents a factor of uncertainty in the model, for different outcomes may result from the choice of a different buffer-value (Chapter 7).

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[73] Future research developments may include the employment of Agent Base Modelling (ABM) approaches for exploring differences in agents movements as well as a diachronic analysis for testing variations in the attractors' distribution across centuries.

[74] According to the Stanford Geospatial Network Model of the Roman World "mean daily travel distances have been set at 12 kilometres per day for ox carts, 20km/day for porters or heavily loaded mules, 30km/day for foot travellers including armies on the march, pack animals with moderate loads, mule carts, and camel caravans, 36km/day for routine private vehicular travel with convenient rest stops, 50km/day for accelerated private vehicular travel, 56km/day for routine travel on horseback, 60km/day for rapid short-term military marches without baggage, 67km/day for fast carriages (state post or private couriers), and 250km/day for continuous horse relays" Scheildel et al 2012: 23 (https://orbis.stanford.edu/orbis2012/ORBIS_v1paper_20120501.pdf)

Second, potential attractors have been selected from the Pleiades database, thus ignoring categories of Pleiades places that do not necessarily represent mariners' attraction. Particularly, the following have been excluded: all architectural and urban elements (e.g. 'arch', bridge) when not explicitly associated with a settlement; 'aqueducts' when not associated with a water source or settlement (e.g. 'aqueduct spring' or 'aqueduct settlement', 'aqueduct spring'). General geographical places such as 'archipelago', 'region', 'islands' or administrative boundaries and abstract limitations more in general (e.g. centuriation, frontier, limes). The only geographical locations included are lakes and rivers, which, as debated above in chapter 5.3.3 and chapter 6.2.3 may constitute potential attractors as drinkable water sources or inland transport systems. Military installations or camps are also removed because of their circumstantial and temporary nature. Moreover, the following two categories are excluded even though they may constitute places of interest for mariners or travellers: first, the 'tombs' because it is assumed that places subject to a shared devotion would be associated with sanctuaries, temples or monuments. Second, 'lighthouses' because of the controversial way their presence may be interpreted; indeed, as debated in chapter 2.2.3 and chapter 4.3.4, these installations aim at alerting mariners about the proximity of hazards and assist them in entering ports. As such, they may be interpreted as installations decreasing the risk of an otherwise risky area; at the same time, they also entail the proximity to hazardous places and cannot be simply identified with mariners' attractors. In total, 20.947 out of 36.362 places were selected in the case-study area.

Third, through the spatial join tool, the number of Pleiades attractors falling within the 20 km buffer from shelters were added as a new attribute field to the shelters and landing sites attribute table (see section 6.2.1). From here on, the procedure is similar to the procedure followed at the Regional Scale. The Kernel density tool is employed for calculating the density of shelters by weighting them proportionally to the 'population field'. Here, the number of attractors within the 20 km of a shelter was employed as 'population field' because the transit probability is assumed to increase proportionally to the number of attractors.

The Kernel density tool generates a raster surface where cells have a proportionally great value the higher the density of shelters and the bigger the number of attractors nearby. The surface value is highest at the location of the landing-site points and diminishes with increasing distance from them, reaching zero at the Kernel 'search radius'. The latter was set to 10 NM (i.e. 18520 m) for the reasons explained in section 6.2.2.

The cost surface resulting from the Kernel density tool is normalised to a range from 1 to 10 by employing the 'Rescale by Function' tool. Since the kernel density is proportional to the number of attractors, the 'large' transformation function is employed to assign a higher transit probability the higher the attractors' count. The spread factor was set at 2 and midpoint at default, based on the input raster (Figure 6.29).

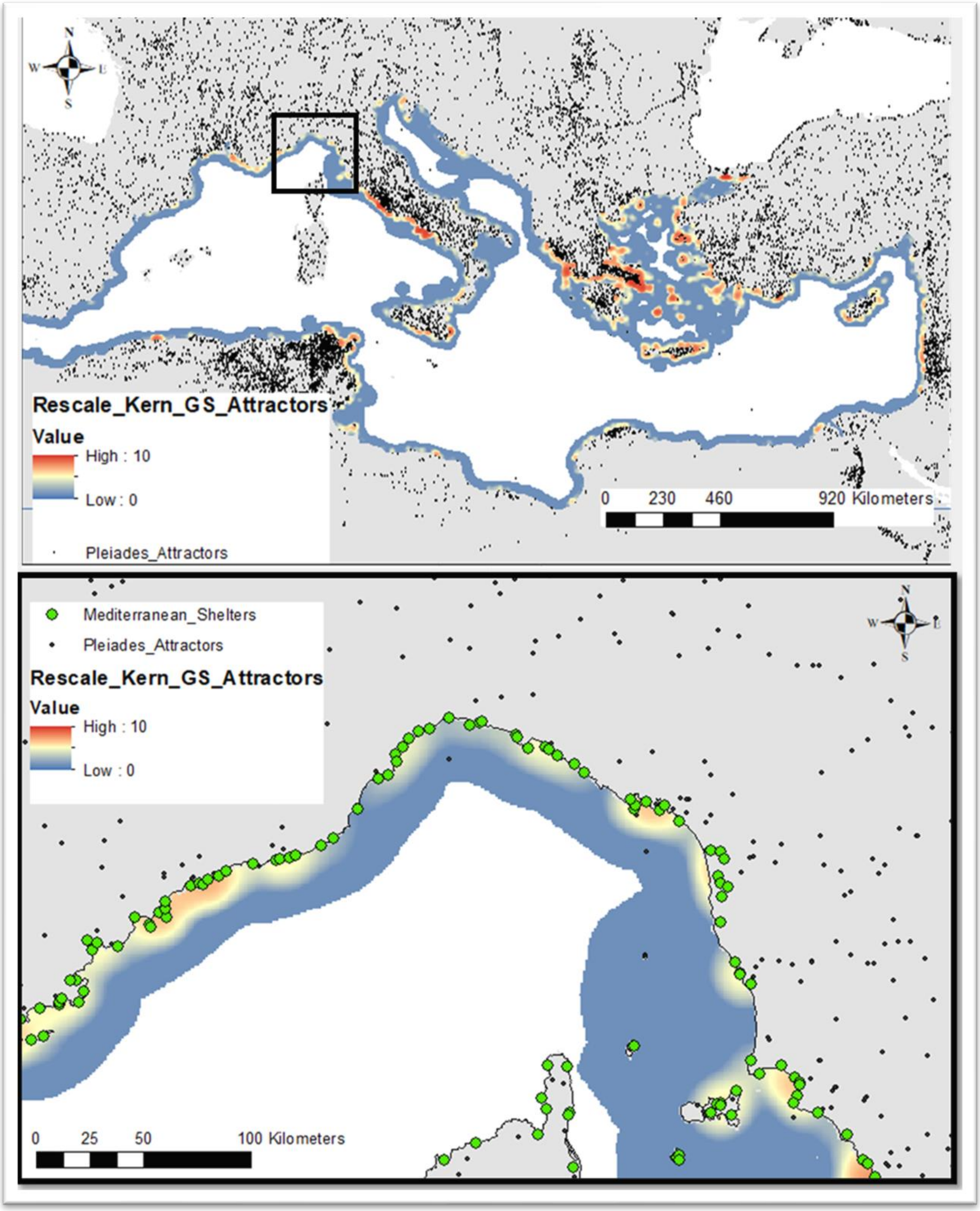

Figure 6.29: Overview of the Shelters attractiveness at Global Scale (up) and detail over the Ligurian Sea (below). Cost surface expressing the transit probability associated with the landing-site attractiveness: at Global Scale, the attractiveness increase with the number of potential attractors (black dots) in the neighbourhood of a landing site (green dots).

6.6.2 Factor weights assignment and generation of a Base and Preferred Global scales models

At the global scale, seven normalised cost-surfaces are produced for the following input factors: bathymetry, wind speed, wave height, storminess water-level maxima, storminess return value, shelters proximity and shelter attractors. These are combined to generate a cumulative cost-grid, which indicates the relative shipwrecking probability in each cell. To this end, the ArcGIS 'Weighted-Sum' tool is employed, which requires the specification of each factor's weight. Following what was discussed for the local scale model, two different outcomes are produced for the Global-scale model:

- a Base model obtained by weighting all factors equally (Figure 6.30)
- a Preferred model obtained by assigning the input factors a different weight (Figure 6.31)

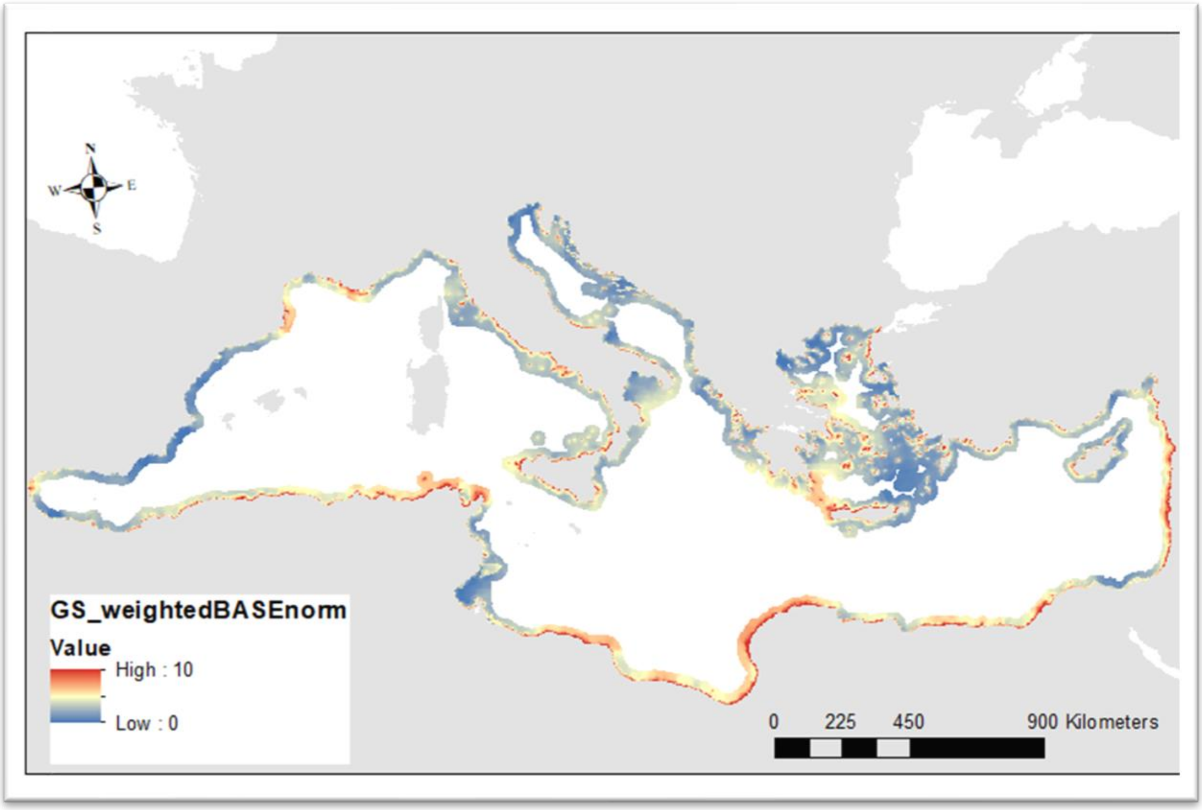

Figure 6.30: Global Scale Base Model

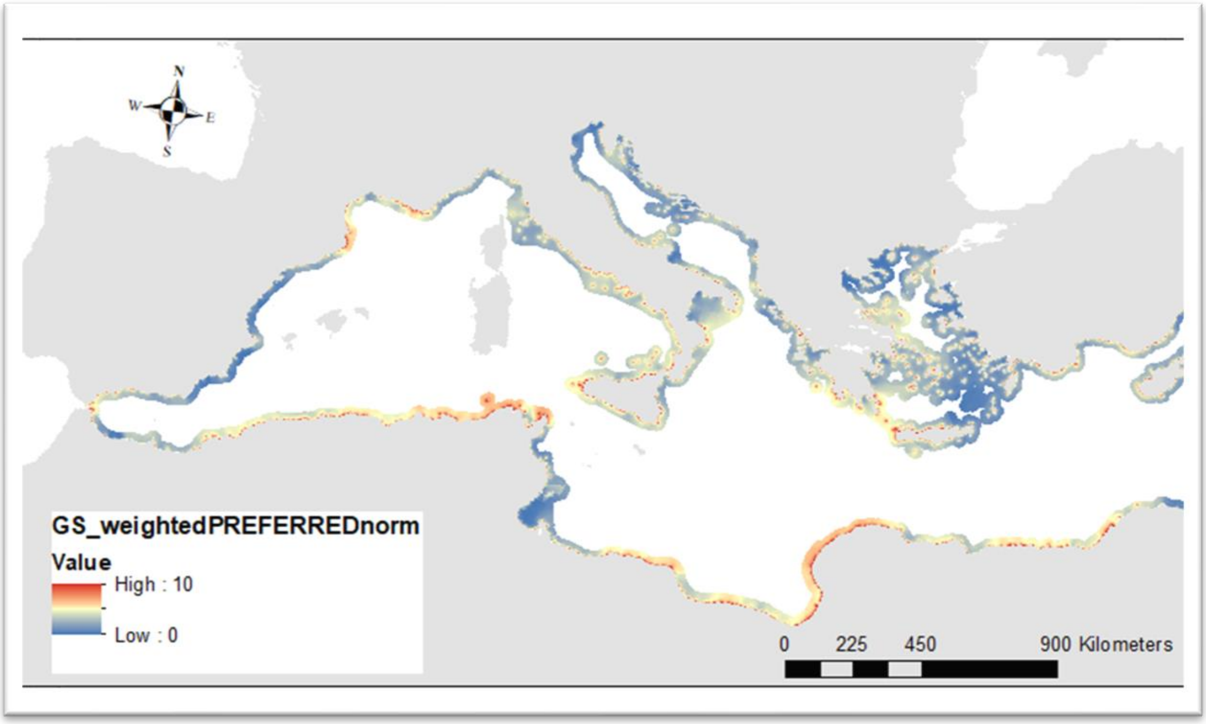

Figure 6.31: Global Scale Preferred Model

The procedure followed for assigning a weight to the input factors and their evaluation was discussed in Chapter 6.4, and it is used for the Global-scale model as well. However, since the two models differ in the number of factors implemented[75], both the normalisation of the values and the averages need to be recalculated. The results are displayed in Table 6.8 and Table 6.9.

	BATHY	WIND SPEED	WAVE HEIGHT	STORM WLIND	STORM RV50	SHELTDIST	SHELT ATTRACT
BATHY	1	1	1	0.33	0.33	0.25	4
WIND SPEED	1	1	1	0.333333	0.33	0.25	4
WAVE HEIGHT	1	1	1	0.33	0.33	0.25	4
STORM WLIND	3	3	3	1	1	0.333333	5
STORM RV50	3	3	3	1	1	0.333333	5
SHELTDIST	4	4	4	3	3	1	6
SHELTATTRACT	0.25	0.25	0.25	0.2	0.2	0.166667	1

Table 6.8: GS pairwise comparison matrix of factors based on the Saaty score assigned in Table 6.4

	BATHY	WIND SPEED	WAVE HEIGHT	STORM WLIND	STORM RV	SHELT DIST	SHELT ATTRACT	SUM	WEIGHTS
BATHY	*0.0755*	*0.0755*	*0.0755*	*0.0538*	*0.0538*	*0.0968*	*0.1379*	*0.5686*	*0.0812*
WIND SPEED	*0.0755*	*0.0755*	*0.0755*	*0.0538*	*0.0538*	*0.0968*	*0.1379*	*0.5686*	*0.0812*
WAVE HEIGHT	*0.0755*	*0.0755*	*0.0755*	*0.0538*	*0.0538*	*0.0968*	*0.1379*	*0.5686*	*0.0812*
STORM WLIND	*0.2264*	*0.2264*	*0.2264*	*0.1613*	*0.1613*	*0.1290*	*0.1724*	*1.3033*	*0.1862*
STORM RV50	*0.2264*	*0.2264*	*0.2264*	*0.1613*	*0.1613*	*0.1290*	*0.1724*	*1.3033*	*0.1862*
SHELTDIST	*0.3019*	*0.3019*	*0.3019*	*0.4839*	*0.4839*	*0.3871*	*0.2069*	*2.4674*	*0.3525*
SHELT ATTRACT	*0.0189*	*0.0189*	*0.0189*	*0.0323*	*0.0323*	*0.0645*	*0.0345*	*0.2201*	*0.0314*

Table 6.9: Factor weight assignment based on normalised pair values from Table 6.8

[75] Roads and rivers are included in the simplified shelters-attractiveness factor, and the visibility is not implemented at Mediterranean scale

6.7 Conclusions

This section gives a preliminary analysis of the model outcomes; a more systematic enquiry into model results and performance is discussed in Chapter 7 and in the general discussions and conclusions. First, as discussed in Chapter 1, it must be stressed that the shipwrecking probability is expressed on an ordinal scale in relative terms, not absolute ones; indeed, it indicates which areas have a higher RSP compared to others within the selected spatial scale. It follows that by changing the spatial extent of the model, the highest and lowest values change, and with them, the relative higher and lower probability areas. For instance, if one looks at the overall Mediterranean territorial waters, the areas presenting the highest RSP value, both in the Base and Preferred model, are the Gulf of Lion, Cap Bon and the North African coast between the Algerian city of Annaba and the Tunisian Bizerte; the Libyan waters between Tripoli and Misrata, the Sirte's Gulf and Cyrenaica, the territorial waters of Syria, Lebanon and Israel, and lastly the area surrounding Cape Maleas in Greece. Among the areas with relatively lower shipwrecking probability values are the Spanish waters. However, by running the model only within the Spanish waters, the highest and lowest values change, thus better highlighting the local variations (Figure 6.32). This has an impact on the readability and utility of the produced maps, and it is an important aspect to consider before employing this model in heritage management and spatial planning. Indeed, to better identify the relative higher probability areas and to optimize the prioritization of the areas to investigate, both the scale and the spatial extent must be carefully chosen. The model is particularly flexible since it can be easily adapted to different areas by only changing the environment settings in ArcGIS.

As for the differences between the Preferred and the Base model at the Global scale, these are less evident than at the regional scale. The main reason is connected to the global-model simplification: since the factors removed or combined (i.e. visibility, roads and rivers) were assigned the lowest weight and had a significant weight difference compared to the others, the Global model includes factors with relatively similar weights; therefore, the Preferred-model outcomes do not differ significantly from those produced by the Base model where all factors are equally weighted. Or at least these differences are not easily spotted without zooming in the models.

The results briefly outlined above need to be further analysed and tested to ascertain whether the model can successfully indicate the shipwreck's probability in Mediterranean territorial waters. In other terms, the model needs to be tested. What might be suitable strategies for testing the model outcomes? What are the limitations and challenges potentially affecting the model testing? The issue is rather problematic in archaeological computational modelling in general and in the underwater maritime domain particularly, as further discussed in the next chapter.

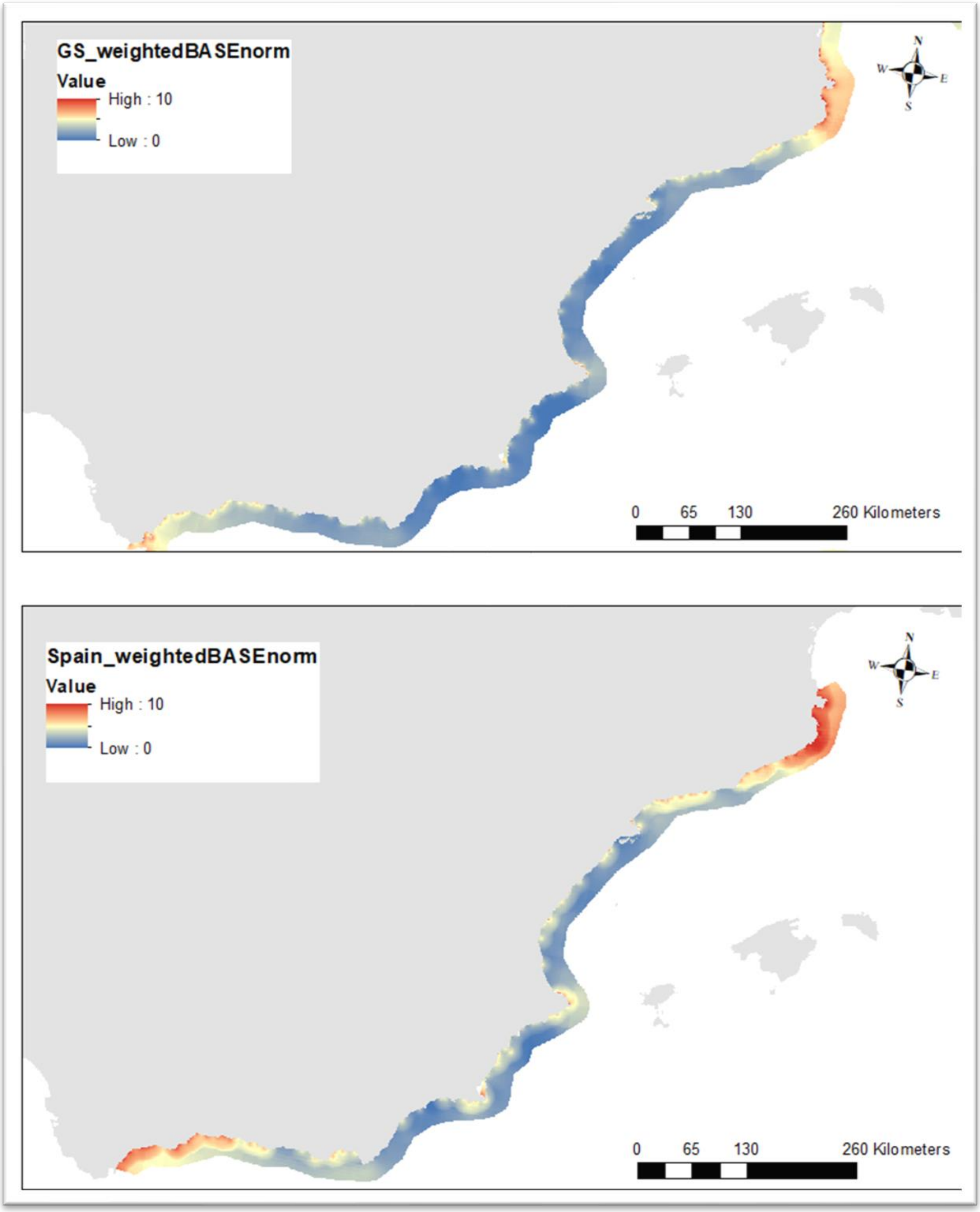

Figure 6.32: The two maps compare the RSP in Spanish waters produced by applying the Global Scale model on the entire Mediterranean (above) and limiting the extent to the Spanish territorial waters exclusively (below).

6.8 SUMMARY

This chapter describes the procedures to build the shipwrecking probability models described in chapter 5. The model was developed first at the Regional scale in the area extending between Cap Bon (current Tunisia) and Alexandria (current Egypt) up to the 12 NM zone as defined in sections 1.3 and 6.2; afterwards, at the Global scale, encompassing the Mediterranean territorial waters as defined in sections 1.3 and 6.6. The shipwrecking probabilities result from the account of movement potential and sinking prospects that are modelled into two separate model components, i.e., the Transit Probability and the Navigation Hazards, each including different factors. A GIS-based cost surface analysis approach was pursued at both scales: first, one cost-surface was generated for each of the selected input factors by assigning cell value depending on specified rules; second, the produced surfaces were brought to a common scale ranging between 0 to 10 to enable the summation; third, following the standard Analytical Hierarchy Process (AHP) by Saaty, the cost surfaces were assigned a weight depending on their alleged relevance to model shipwrecking probabilities and then combined for obtaining the final shipwrecking probability values. Two scenarios were produced both at the Regional and Global scale: a base scenario where all factors are weighted equally and a Preferred scenario where the factors are assigned different weights based on the AHP pairwise comparison.

There are two possible outcomes: if the result confirms the hypothesis, then you have made a measurement. If the result is contrary to the hypothesis, then you have made a discovery”

Enrico Fermi

7 QUALITY ASSESSMENT

This chapter aims at verifying (i.e. testing) whether the model described in Chapters 5 and 6 is a ‘good model’, which implies preliminary discussing 1) how to define what entails a ‘good’ model, and 2) how to ascertain whether a model is any good. Both issues are rather problematic in archaeological computational modelling as evidenced by the scholarship debate (see, e.g. Dalla Bona, 1994; Deeben et al., 1997, Verhagen & Whitley, 2012, 83-86; Kvamme, 1988; for an overview and literature review, see, e.g. Brouwer Burg et al., 2016; Verhagen & Whitley, 2012, pp. 83-86).

A ‘good model’ is considered to be one able to execute the task it was designed for. If the task is -as in this case - approximating a phenomenon occurred in the past, then such a verification relies upon partial hints offered by the distribution of the oftentimes scant archaeological record (Brouwer Burg et al., 2016, pp. 2-59). The latter cannot fully be considered representative of the past targeted phenomenon as the archaeological record is ‘the product of thousands of years of differential cultural and natural taphonomic processes’ (Brouwer Burg et al., 2016, p. 2). This highlights the problematic use of data-centric approaches in model testing, which are based on the comparison between the model outcomes and the empirical-observed data to find out whether they match (Viswanathan et al., 2011). The issue is pivotal in the present research. Indeed, whilst the task of the present model is to ascertain where, within the territorial waters, the shipwrecking occurrence is higher, due to the reasons exposed in chapter 2, the shipwrecks recorded in Mediterranean waters cannot be considered representative for the whole potential shipwreck-events occurred in the past centuries. First, due to the dataset biases discussed earlier. Second, because the recorded sites document the material remains of wreckage that under certain circumstances may survive, whereas the present model looks at the sinking event no matter the possible material preservation. Extending the model scope to include post-depositional processes would not necessarily help given the shipwrecks dataset biases; and the availability of additional data, would not solve this limitation either, for more data do not necessarily translate into better-informed inferences about the past (Brouwer Burg et al., 2016, p. 59). Indeed, they may be affected by some of the same biases affecting the already recorded ones: systematic underwater surveys carried out utilizing remote sensing technologies may overcome the issue of past random discoveries by divers and trawlers, but would still tend to cover limited areas and find certain materials while underrepresenting others.

A second aspect to consider for evaluating whether a model is any ‘good’, is to look at the internal consistency and the lack of logical errors (Oreskes et al., 1994; Verhagen & Whitley, 2012, p. 84). This implies wondering how confident one is about the model design and its execution. The deductive approach that was followed to develop the model in this research entails a certain degree of subjective reasoning and while describing the procedure to implement the model both at the local and global scale (chapter 6), the potential sources of uncertainty, which affect the model’s results, were noted. The question is: which among these produce a greater impact? Sensitivity analysis (SA) and uncertainty analysis (UA) are particularly useful for examining the effects of varying input parameters and values on model output and, more generally, for inquiring into the strengths and weaknesses of models. The two terms are often confused (e.g. in economics, see Leamer, 1985 and Saltelli et al., 2019, p. 31 and p. 34 for comment in this regard). SA is "the study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input" (Saltelli, 2002); in other terms, it focuses on the influence of different input factors on the model response (Lovis, 2016, p. 33). UA addresses the robustness of the prediction, namely the model persistence under perturbations, by quantifying the model uncertainty without identifying which assumptions are primarily responsible (Saltelli et al., 2019, pp. 29-31). Despite the growing body of literature on archaeological modelling, the question of uncertainty in archaeological computational models is rarely addressed (Brouwer Burg et al., 2016, p. 3; Murphy, 2012) and SA is hardly ever performed, in contrast with fields such as geology, ecology, biology where it represents an essential step of the procedure (see number of sensitivity analysis articles by subject in Saltelli et al 2019, p. 33, 38).

The present chapter aims to address these two separate matters, namely exploring the model's uncertainty by analysing the effects of varying selected input parameters and values on model output; and ascertaining whether the model executes the task it was designed for. In chapter 7.1 the potential sources of error and uncertainty in the model are presented, with particular reference to the factors of uncertainty connected to model choices given the potential pitfalls of subjective reasoning, which characterizes theory-driven models like this one. In chapter 7.2, different scenarios are produced by removing one factor at a time to see which input factor produces the greatest variation in model response when absent. In chapter 7.3 the shipwrecks data are used for testing the different model scenarios and for comparing the global scale and local scale models' performances.

7.1 METHODOLOGY ASSESSMENT

This section inquires potential sources of uncertainty in the RSP model. Following Evans (2012, pp. 309-346), these may be grouped in: a) input data uncertainty, b) model choice uncertainty, c) model mechanics uncertainty (for UA and SA in GIS-based approaches, see Brouwer Burg, 2016, pp. 59-80; Feizizadeh et al., 2014; Peeter & Romeijn, 2016, p. 37). Input data uncertainty relates to all potential sources of errors embodied in the input datasets, such as a) measurement and transcription error, b) sample size issues, c) missing data, and d) classification error. Model-choice uncertainty relates a) variables' choice, i.e. the decision to include certain factors and exclude others, the weights assigned to them, b) model structure or operations, e.g. procedural preferences in modelling the selected variables or the choice of GIS tools and mathematical transformations, and c) model scale (Lovis, 2016, p. 23). Model mechanics uncertainty refers to errors in coding and machine computing more in general (see for further explanation Evans, 2012, p. 330 and van der Sluijs et al., 2003). Since the model is static and additive, the above groups of uncertainties are introduced and summed up at each successive procedural step, thus affecting the overall model output.

A systematic multiway SA and UA, namely a global analysis evaluating the effects of a factor while all other factors are also varying (Saltelli, 2005), need to be addressed through tailored model exploration methods[76] or probabilistic analysis, which are out of the scope of the current research. This preliminary SA presented here focuses on a limited selection of model choices uncertainty factors, which are assumed to produce the greatest variations to the model, whilst the uncertainty associated to the input data and model mechanics is not specifically addressed. Particularly, since the removal of an entire input-factor is likely to produce a greater variation than single settings, multiple scenarios are produced through a 'One-factor At a Time' (OAT) approach to SA (Happe et al., 2006; Vonk Noordegraaf et al., 2003, p. 434), i.e. by removing one factor at each model run.

MODEL-OPERATIONS UNCERTAINTY

The RSP model presents numerous factors of uncertainty connected to procedure choices and GIS mechanics (see Table 7.1). Among these is the model-resolution selection, set to 1 km, which was influenced by the great degree of resolution variations in the input factors and by the sparseness of observed data employed for the model validation. These limitations would make setting finer resolutions both useless and misleading since certain parameters would show no variations at all. Although coarse at first glance, the adoption of 1 km^2 scale still enables one to meet the research goals set in Chapter 1. Particularly, as for the necessity to provide heritage managers and developers of a tool applicable in spatial planning, an area of 1km * 1km may be covered relatively quickly with remote sensing surveys, considering that the ideal survey speed with traditional high-resolution side-scan sonar is about 3 to 4 knots (i.e. 5,556 to 7,408 km/h) for acquiring sufficiently high-resolution data for archaeological purposes; this may be increased up to 10-16 knots when more advanced multi-pulse side scan systems are employed (see e.g. the 'Marine Geophysics Data Acquisition, Processing and Interpretation' standards set by Historic England[77], pp. 17-18).

As for the other factors of uncertainty connected to model-choices, which are summarised in Table 7.1, one may notice that the uncertainty connected to GIS procedural strategies and mechanics mostly relate to a) the transformation-function selection for normalizing each of the input-factor cost-surfaces, and b) the default settings variations in the GIS tools employed. As for the transformation functions, in Chapter 6, it was explained that these are used for normalizing the input raster, namely for bringing the cost surface produced for each input factor to a common scale. The function should be chosen by prioritizing the one best capturing the phenomenon being studied. Nonetheless, ArcGIS provide multiple options which may find applications in similar cases. For instance, if one wants to assign proportionally higher preference to the smaller input values, different functions may be employed: the 'Logistic decay', the 'Small' and 'MSSmall'. The former assigns preference to small input values and lets the preferences rapidly decrease until tapering off at the larger input values; the 'Small' and 'MSSmall' only differ because the MSSmall is based on specified mean and standard deviation multipliers, and it can be more suitable 'if the very small values are more preferred'[78].

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[76] e.g. the free and open-source model exploration software OpenMole developed by the French CNRS Institut des Systemes Complexes, https://iscpif.fr/projects/openmole/?lang=en

[77] https://historicengland.org.uk/images-books/publications/marine-geophysics-data-acquisition-processing-interpretation/mgdapai-guidance-notes/; for survey speed see p. 17

[78] Source: https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/the-transformation-functions-available-for-rescale-by-function.htm#ESRI_SECTION1_6C2FDA23D8094B8F99DBF3DF5E176B1D. Accessed: 04 November 2020

Similarly, when one needs to assign a proportionally higher preference to the higher input values, the 'Large', 'MSLarge', 'Logistic Growth', and 'Exponential' may be employed. Slightly different outcomes may be produced not only by selecting different transformation functions but also by varying the parameters setting of each transformation function (Figure 7.1).

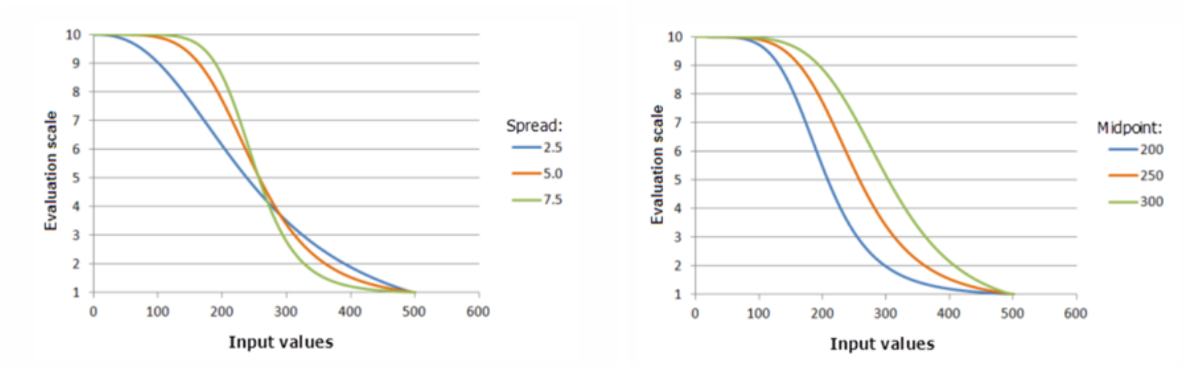


Figure 7.1: The above two graphs of the 'Small' transformation function show the effects of altering the spread value (to the left) and midpoint value (to the right) respectively. The Midpoint: defines the transition point of the function, whereas the Spread: controls how quickly the preference decreases and increases[79]

VARIABLES-CHOICE UNCERTAINTY

Besides the GIS procedures and mechanics, some factors are more dependent than others on subjective reasoning. Particularly, the modelling of a cultural factor such as the shelters-attractiveness is controversial because of the subjective strategy employed to translate this intangible factor, which is not expressed in a ratio-scale, into an adequate cost-model (Conolly & Lake 2006, p. 255; Herzog, 2010, p. 376). As for the local scale, uncertainty is connected on the one hand to the main data-source choice (i.e. the *Stadiasmus Maris Magni*), as different data sources may provide different information. On the other hand, uncertainty is linked to how the information derived from textual sources have been interpreted and modelled (Chapter 6.2.2). The six criteria identified in textual sources as factors increasing the ports' attractiveness were assigned a cardinal value ranging between 0 and 2, and the values attributed to each criterion were summed to the others for assessing the port relative attractiveness, although these values could have also been multiplied. Moreover, in lack of additional information in the *Stadiasmus*, values have been assigned based on the terminology employed for referring to the site (e.g. anchorage, roadstead, harbour etc.), whereas alternative approaches may include the assignment of a fixed value no matter the term used when information on the selected criteria are missing. Also, the choice of the Kernel density tool for assessing the shelter attractiveness entails a certain degree of uncertainty in the model depending on the search radius choice.

This last issue pertains to the Global scale as well, where the shelters attractiveness has been simplified by considering the number of potential attractors within a buffer distance from the shelters (chapter 6.5.1). This search radius has been set by considering the average horse distance and the average heavy-load carrier distance covered in one day. Different results may be obtained by setting a different search radius. Moreover, at global scale a major uncertainty

79 Source: https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/the-transformation-functions-available-for-rescale-by-function.htm#ESRI_SECTION1_141E3CAB957F42FBA04076C5ADFA0C96. Accessed: 04 November 2020

factor is represented by the chronology: the shelters attractiveness is assessed by taking into account the potential attractors no matter their period, given that the global scale aims at designing a simplified and general tool applicable in spatial planning. This approach has limitations, first because diachronic analysis may reveal significant variations; second because the Pleiades dataset overrepresents certain periods (i.e. Classical and Roman time) even though 'it is expanding into Ancient Near Eastern, Byzantine, Celtic, Early Islamic, and Early Medieval geography'[80]. Another model factor presenting a degree of uncertainty due to subjective reasoning is the bathymetry: indeed, the thresholds for determining the high and medium risk depths (i.e. below the 5 m, and between 15 and 5 respectively) were chosen arbitrarily.

Since the RSP model is static and additive, all the sources of uncertainty combined contribute to producing potentially different results, which should be enquired in all their possible interactions and dependencies by means of multiway analysis or probabilistic analysis (Saltelli, 2005). A global approach to SA is beyond the scope of the present research; nonetheless, in the following section, a one-way analysis will be performed following the 'One-at-a-Time' or OAT design to explore the scenarios produced by the complete removal of one input-factor per model run (Brouwer Burg et al., 2016, p. 14; Vonk Noordegraaf et al., 2003, p. 434). The aim is to ascertain to which input factor the model is more sensitive and what factors have the least impact and can thus be considered for removal.

[80] Available at: https://pleiades.stoa.org/places. Accessed: 04 November 2020

Table 7.1 Summary of model choices and model-mechanics uncertainty factors in the RSP model.

FACTORS	PROCEDURAL STRATEGIES	GIS MECHANICS
SHELTERS LOCATION	Scale and resolution Shelters data-source choice Rescaling-function choice	Default settings in Rescale by Function tool
PORT CONVENIENCE / SHELTERS ATTRACTIVENESS (A) LOCAL SCALE	Scale and resolution Textual evidence interpretation Data-source choice (i.e. *Stadiasmus*) A-criteria value assignment A-criteria combination method	Kernel density search radius Default settings in Rescale by Function tool
PORT CONVENIENCE / SHELTERS ATTRACTIVENESS (A) GLOBAL SCALE	Data-source selection Search radius	Kernel density search radius Default settings in Rescale by Function tool
INLAND NETWORK (RIVERS & ROADS)	Scale and resolution Data-source choice Buffer distance to shelters Kernel density choice Rescaling-function choice	Kernel density search radius Default settings in Rescale by Function tool
MUTUAL VISIBILITY	Scale and resolution Random points number Min and Maximum viewshed range- distance Observer-points offset Focal statistics fishnet-size Highest viewshed index selection inland (10%) Transit preference attribution Rescaling-function choice	Cell factor choice in Raster aggregation Digitization of the viewshed seaward edge Default settings in Rescale by Function tool
BATHYMETRY	Scale and resolution Depths risk -assignment Rescaling method	Reclassify tool – ranges
ANNUAL MEAN WIND SPEED	Scale and resolution Annual mean choice	Transformation function Default settings in Rescale by Function tool
ANNUAL MEAN WAVE HEIGHT	Scale and resolution Annual mean choice	Transformation function Default settings in Rescale by Function tool
STORMINESS (WATER-LEVEL MAXIMA & RETURN VALUE)	Scale and resolution data-period series (i.e. 50 years as for the return values, where the 5-years projection is also available. 10 years as for the water level maxima, where 1-year projections are also available)	IDW Transformation function Default settings in Rescale by Function tool

7.2 SENSITIVITY ASSESSMENT: TO WHICH FACTOR IS THE MODEL MORE SENSITIVE?

Since the model is designed by following deductive reasoning (Chapter 2), the choice to include or exclude certain factors depending on their presumed relevance on the targeted phenomenon is subjective despite being based on a systematic review of primary and secondary sources. How to interpret the information retrieved from textual evidence is debatable, as well as the process followed for assigning a weight to the input factors. Some factors have been excluded either because they are impossible to model at this moment or because they only have an impact in limited circumstances, for limited groups of agents, or at specific scales or periods in time (see section 5.2). Ascertaining whether the model would work better by adding currently excluded factors, e.g. technology, is out of the scope of the present research, whereas this chapter attempts to enquiry into model outcome variations resulting from changes in currently implemented factors.

The issue is twofold:

1) To which factor is the model more sensitive?
2) Which factors contribute to improving the model performance as defined in the opening of this chapter?

The first question implies wondering whether all the input factors are necessary and what happens to the model results if one removes one of the input factors. The second question addresses the model performance and the model validation by wondering whether certain factors have a greater impact on the results, thus improving the model performance. This does not mean ascertaining which factor has a greater impact on the targeted phenomena *in reality*, but only in the model. To be answered, the second question requires the availability of empirical data to validate the model outcomes produced at each iteration. Given the limitations and the biases affecting the shipwrecks dataset, caution must be paid when addressing the second issue, as further discussed in section 7.3.2.

To ascertain to which factor the model is more sensitive, multiple iterations are produced in both the local and the global model by employing the OAT method, namely by removing from the base model one factor at a time while keeping the others unchanged; the only exception is represented by the curve 'NOSTORM" which is produced by removing two factors in a run, namely both the storm-return value (RV50) and the storm-water-level maxima (WLIND), which combine into the storm incidence: this factor constitutes an original contribution of the present research to archaeological predictive models. This approach allows for the verification of the impact that the storminess factors have on the model both individually and combined. In total, 13 iterations are produced for the Local Scale model (Figure 7.2, Figure 7.3) and 10 for the Global Scale model (Figure 7.4, Figure 7.5). The figures show that the curves presenting the greatest difference from the others, both in terms of peaks and width, are those produced by removing the storm incidence, the wave height and the shelter distance. Without these factors, the model outcomes shift from high-risk values towards a greater number of cells with low or medium RSP values, reducing the models' ability to distinguish high-risk areas. Conversely, their inclusion enables the enlargement of the range values toward both highest and minimum values; this means that the model may be more applicable e.g. in cultural resource management (CRM) as it provides sharper distinctions between the low, medium, and high-risk areas.

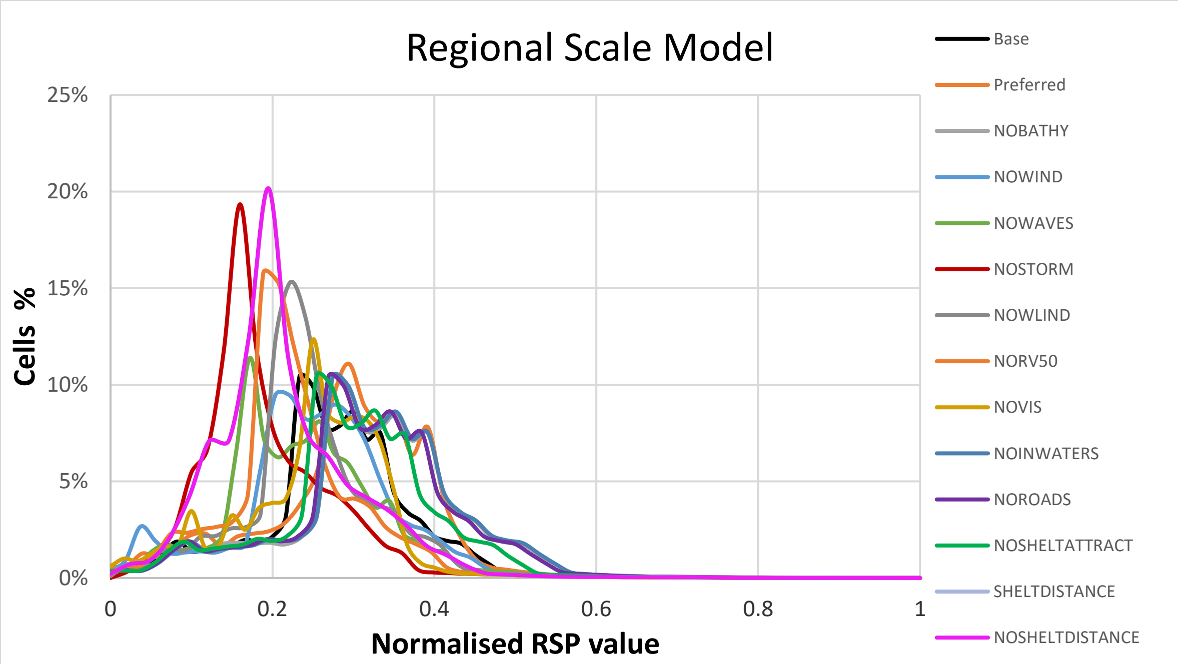
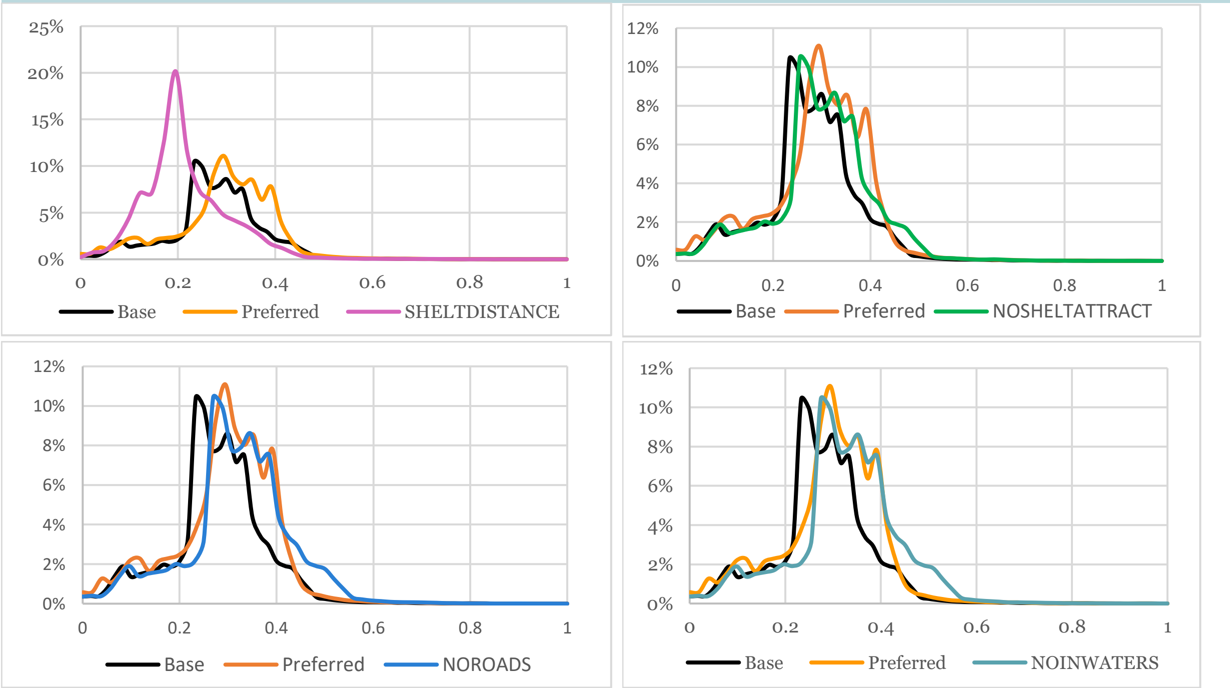


Figure 7.2: Regional-scale Model scenarios produced by removing one factor per model run. The graph shows all the scenarios plotted together. On the x-axis is the normalised cost, i.e. the shipwreck-probability value (SP value), resulting from the weighted addition of the input raster surfaces. On the y-axis are the % of cells in the weighted sum raster surface presenting the relative shipwrecking probability (RSP) value specified on the x-axis.

Regional Scale Model scenarios



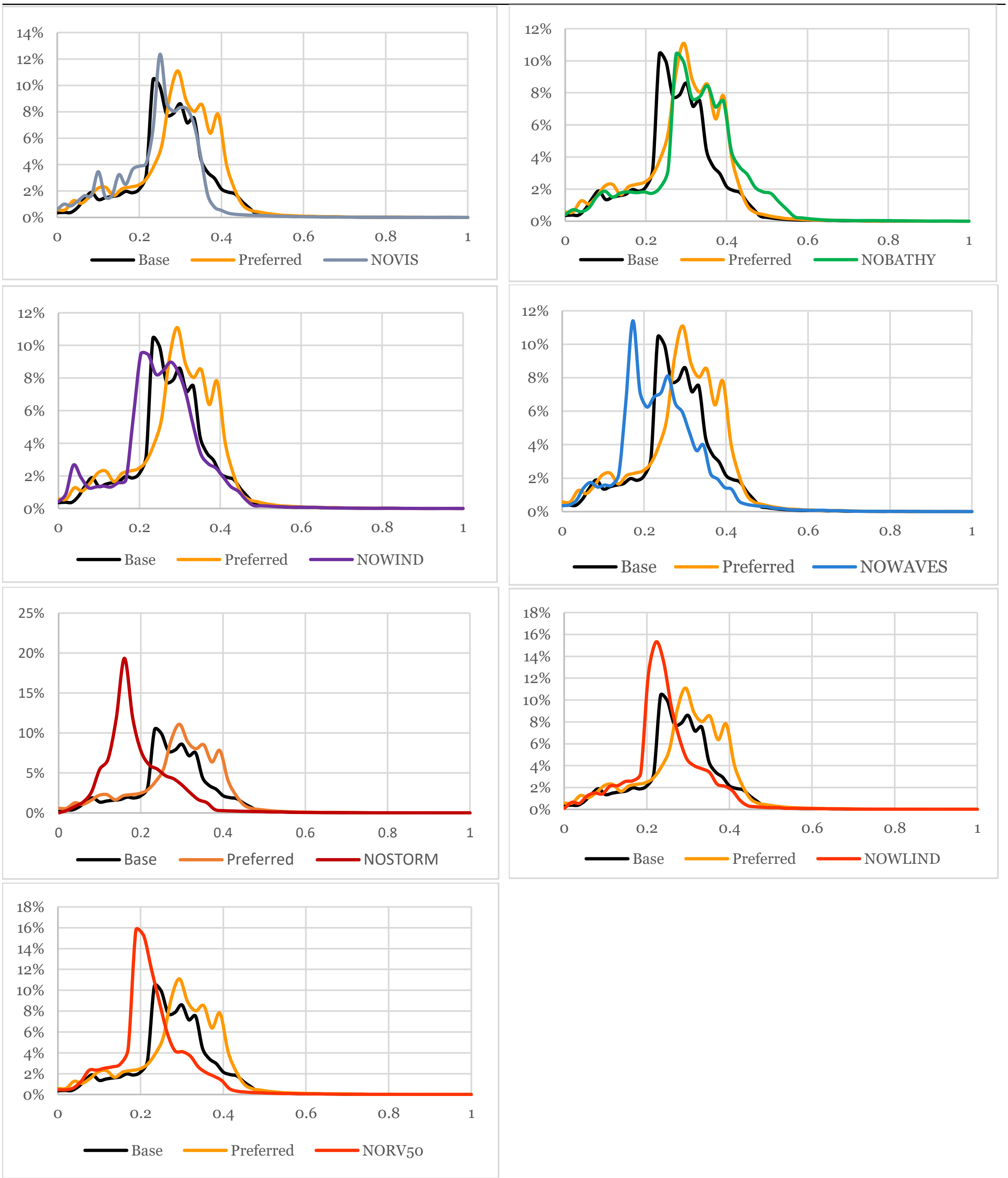


Figure 7.3: Regional-scale Model scenarios produced by removing one factor per model run. Each graph includes one scenario only, compared to the BASE (black) and the PREFERRED (orange) models. On the x-axis is the normalised cost, i.e. the relative shipwrecking probability value, resulting from the weighted addition of the input raster surfaces. On the y-axis are the % of cells in the weighted sum raster surface presenting the relative shipwrecking probability (RSP) value specified on the x-axis.

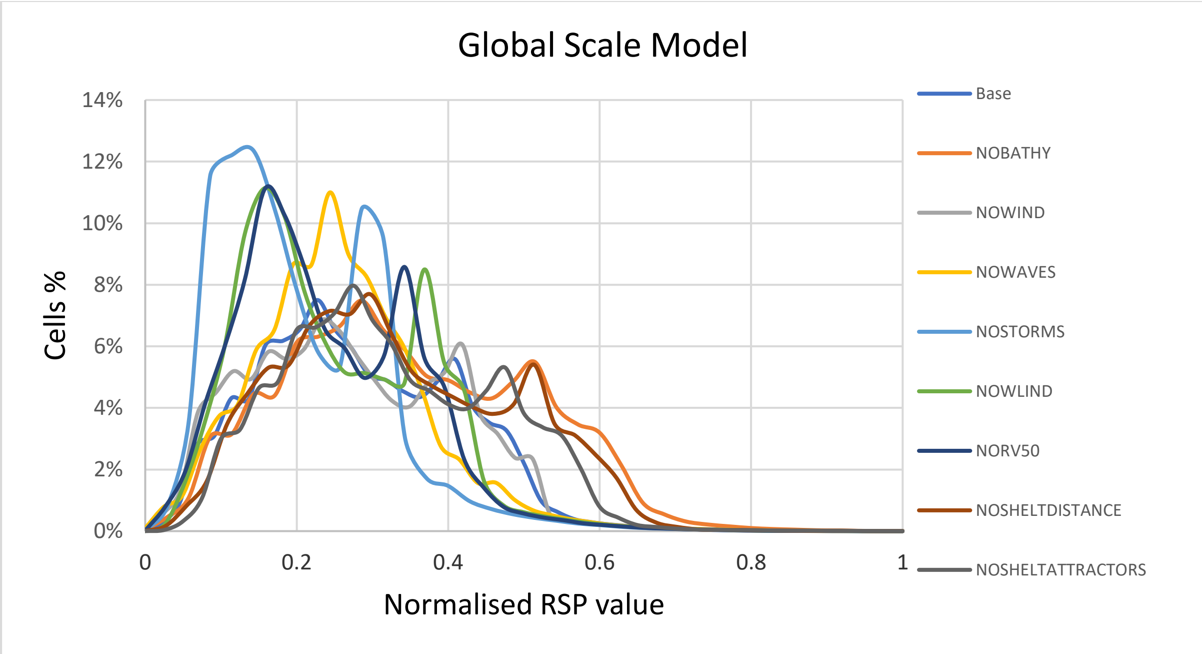
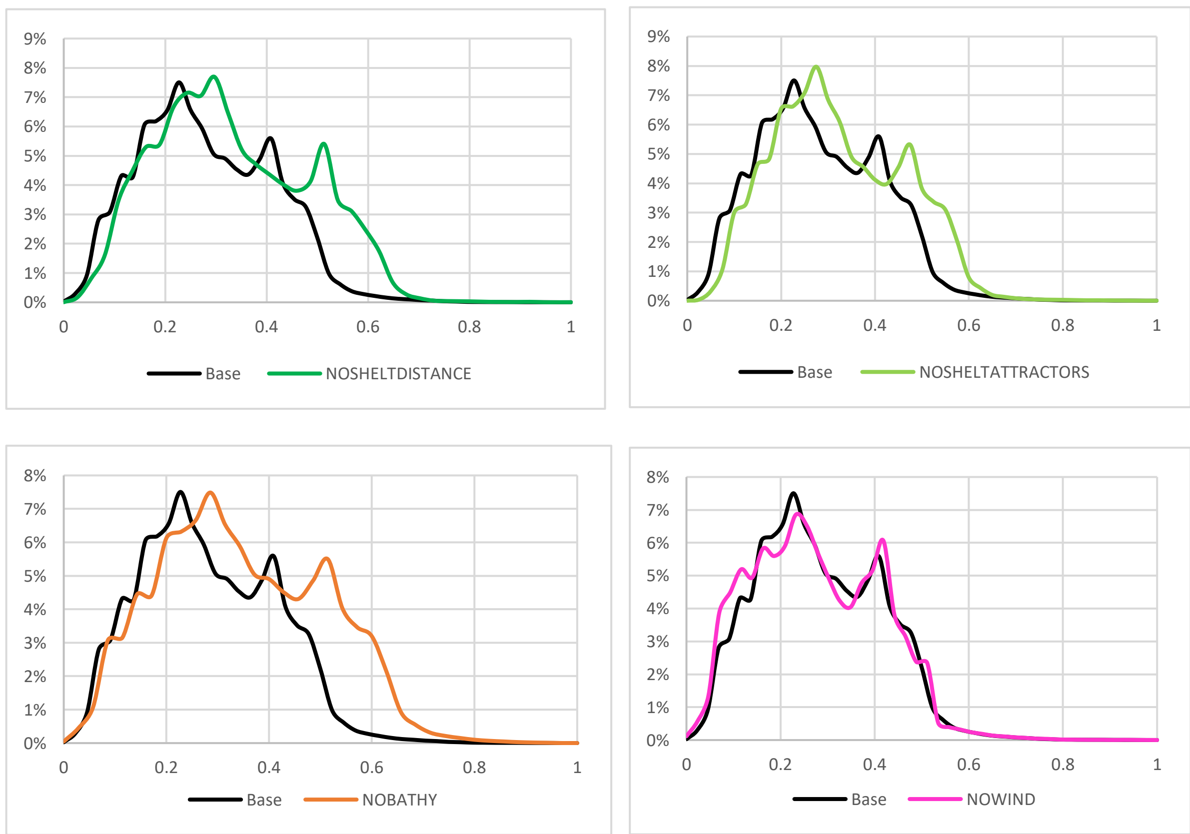


Figure 7.4: Global-scale Model scenarios produced by removing one factor per model run. The graph shows all the scenarios plotted together. On the x-axis is the normalised cost, i.e. the relative shipwreck-probability value (SP value), resulting from the weighted addition of the input raster surfaces. On the y-axis are the % of cells in the weighted sum raster surface presenting the relative shipwrecking probability (RSP) value specified on the x-axis.

Global Scale Model scenarios



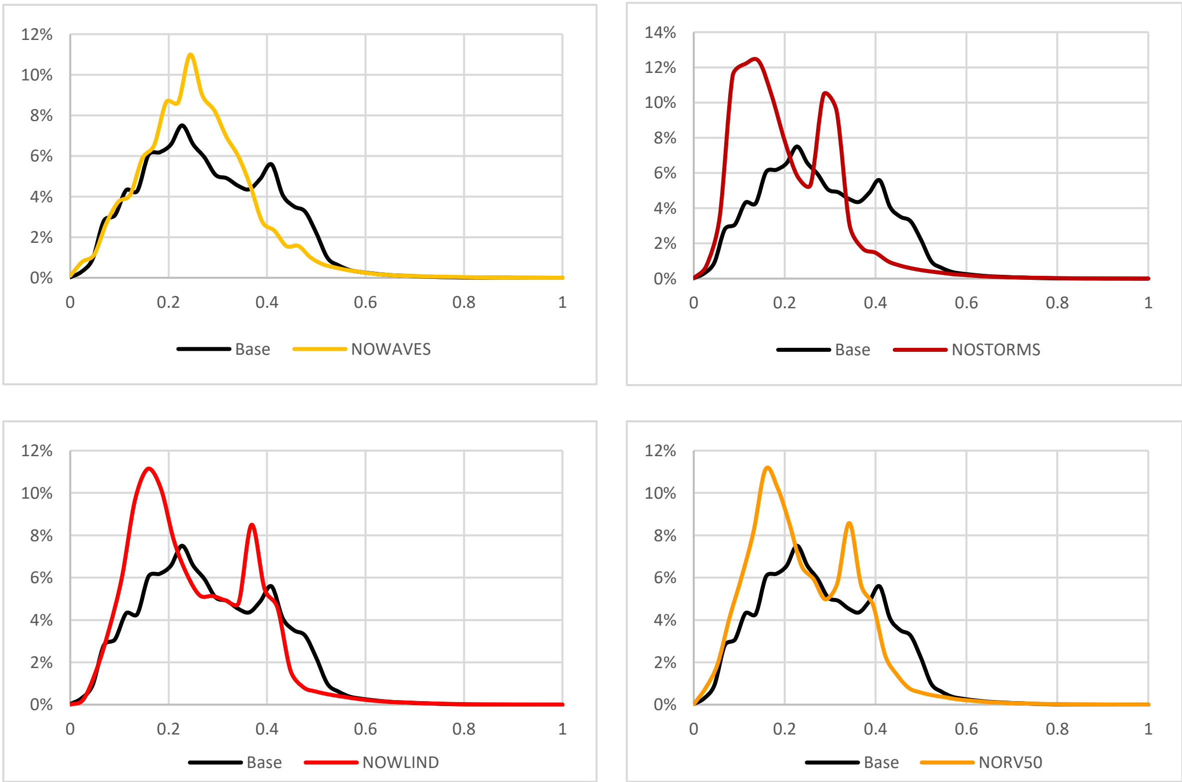


Figure 7.5: Global-scale Model scenarios produced by removing one factor per model run. Each graph includes one scenario only, compared to the BASE model (in black). On the x-axis is the normalised cost, i.e. the relative shipwreck-probability value (SP value), resulting from the weighted addition of the input raster surfaces. On the y-axis are the % of cells in the weighted sum raster surface presenting the relative shipwrecking probability (RSP) value specified on the x-axis.

This approach alone does not make it possible to ascertain what the most valid scenario is among the produced iterations; indeed, the curves only highlight to which factor the model is more sensitive, namely what factor-removal produces the greatest variation on the model outcomes from the base and preferred model used as a reference[81].

7.3 Robustness assessment

This section addresses the problematic issue of model validation introduced in chapter 7.1, which is aimed at checking a) whether there is a positive correlation between the location of recorded shipwrecks and the high-probability areas identified by the model and b) which scenario presents the highest correlation. Since the model aims at ascertaining where the shipwrecking occurrence in the past is higher, the presence of recorded shipwrecks in areas that the model indicates as having a high shipwrecking occurrence rate may support the probability for the model to be valid. In this research, the use of observed data for testing purposes presents both an advantage and a shortcoming. Since the model was built by following a theory-driven approach (Chapter 2), the problematic -and often criticised- use of the same data for both hypothesis inference and testing was avoided (Verhagen, 2008, p.

[81] At global scale the differences between Base and Preferred models are slight, therefore the preferred model is not plotted in the graphs of Figure 7.5

287)[82]. On the other hand, the biases affecting the shipwrecks dataset, which have been discussed in chapter 3 to justify the theory-driven approach, affect the testing as well despite the measures taken to reduce the dataset limitations and biases (chapter 3.4). The issue becomes evident when using the shipwrecks to test the scenarios produced in Chapter 7.3.1, as further described at the end of this section.

7.3.1 Number of classes and classification method

A preliminary step to verifying the presence of shipwrecks in high probability areas is to divide the relative shipwrecking probability (RSP) rate (i.e. the ArcGIS weighted-sum raster surface produced at each model iteration) into categories of low to high probability. There are two issues at play that may impact the interpretation of the results and the model utility: first, the number of classes to distinguish; second, the classification method used to identify the class breaks.

As for the number of classes in archaeological prediction, it is common to distinguish three categories, namely low, moderate (or medium) and high probability areas (e.g. in the Indicative Map of archaeological value for the Netherlands; Deeben et al. 2002). This number is deemed not suitable to meet the needs this model aims to address since the high-probability areas would be too broad for providing indicative insights in terms of cultural heritage management and spatial planning; moreover, a great number of details in terms of higher and lower shipwrecks probability rate, which the model provides, would be lost (Figure 7.6). The underdevelopment of maritime archaeological predictive models, particularly in the Mediterranean context, contributes to complicate the matter, for no standards or guidelines are available suggesting suitable (or required) thresholds. Because of the above considerations, 5 classes are used here for testing purposes: very low, low, moderate, high, very high. However, different numbers of classes may easily be obtained from this model to suit specific needs (e.g. producing a map identifying high-probability areas extending no more than e.g. 5% of the total model area).

[82] For a debate on the limitations of testing methods employing the same data from which the model is derived see Peeters & Romeijn, 2016, pp. 37-38; Verhagen, 2007, pp. 115-168; Verhagen, 2008, pp. 288-290; as noted by H. Peeters and J.-W. Romeijn criticisms are particularly expressed by Worrall (2010), whilst Steele & Werndl (2013) “provide a more nuanced response” (Peeters & Romeijn, 2016, p. 38)

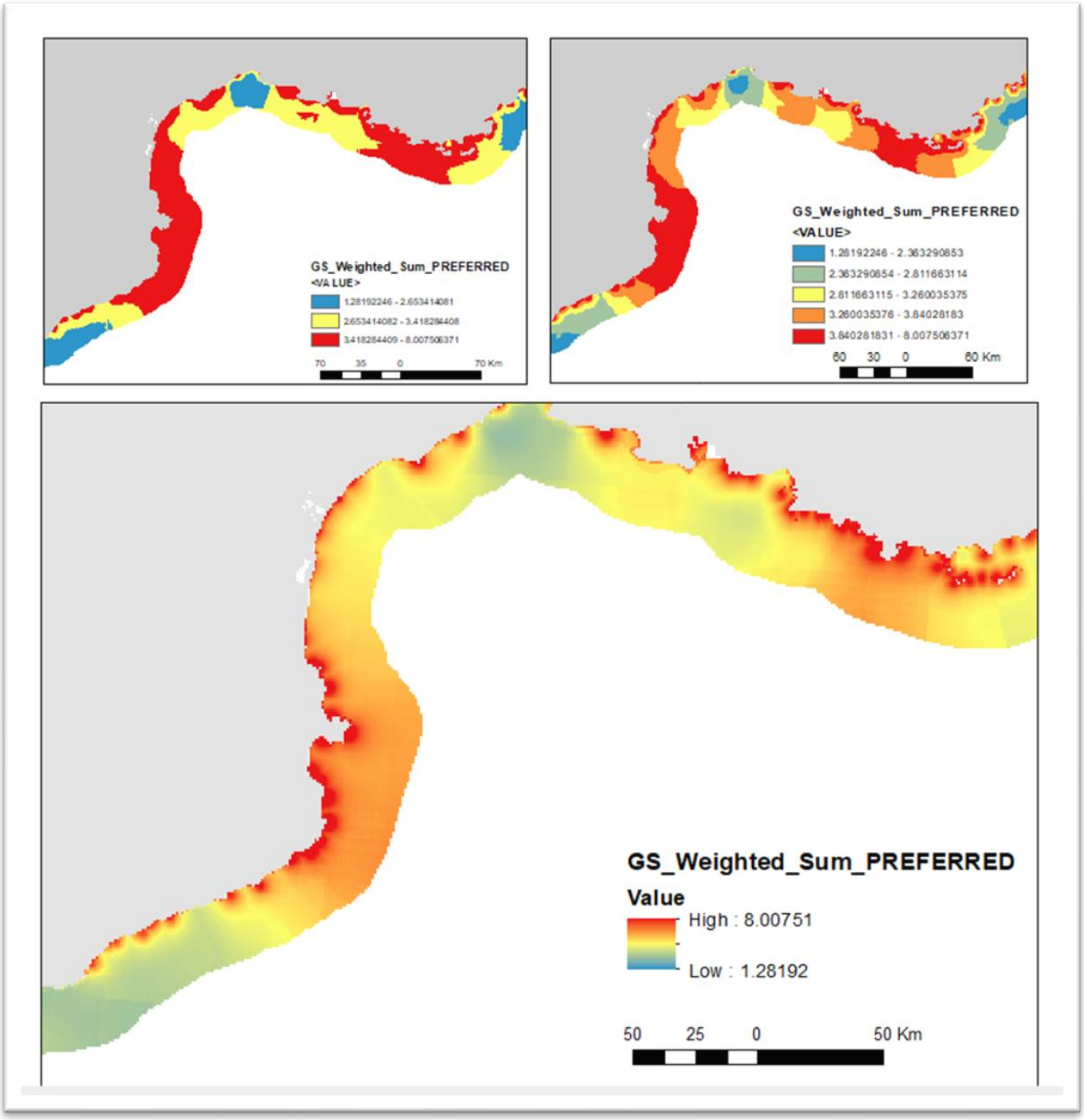


Figure 7.6: The images show the effects of varying the number of relative shipwrecking probability (RSP) classes. At the bottom, the original RSP cost-surface produced by the weighted combination of all the factors maps. Above, to the left, the same cost-surface classified through quantile in three classes; to the right in five

As for the ways for identifying the class breaks, multiple options are possible, which dramatically impact the results. Among these, the 'manual interval' and 'defined interval' are highly subjective, as the breaks are set by the user. The 'equal intervals' set breaks by dividing the range of attribute values (i.e. here the Shipwrecks-Probability) into equal-sized subranges; in this case, it underrepresents the high probability class because fewer cells have high values (Figure 7.7).

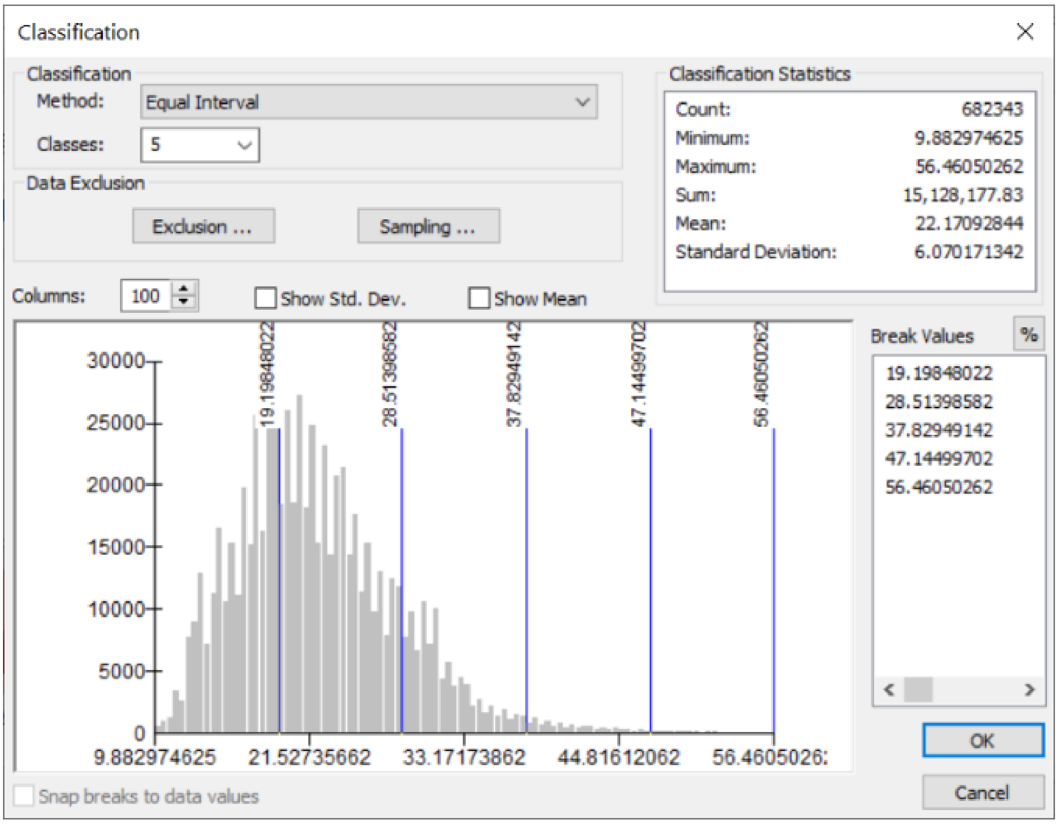


Figure 7.7: Equal Intervals classification method

The 'natural breaks' based on Jenks classification method makes it possible to minimize each class's average deviation from the class-mean while maximizing each class's deviation from the means of the other groups. In other terms, it sets breaks where increases or jumps in values occur. It is broadly employed in archaeological computational modelling (for instance, in the Indicative map of the NL). Nonetheless, it tends to quantitatively overrepresent some classes over others (Figure 7.8); moreover, it generates breaks no matter the actual increases or jumps detected in order to satisfy the required number of classes one has set.

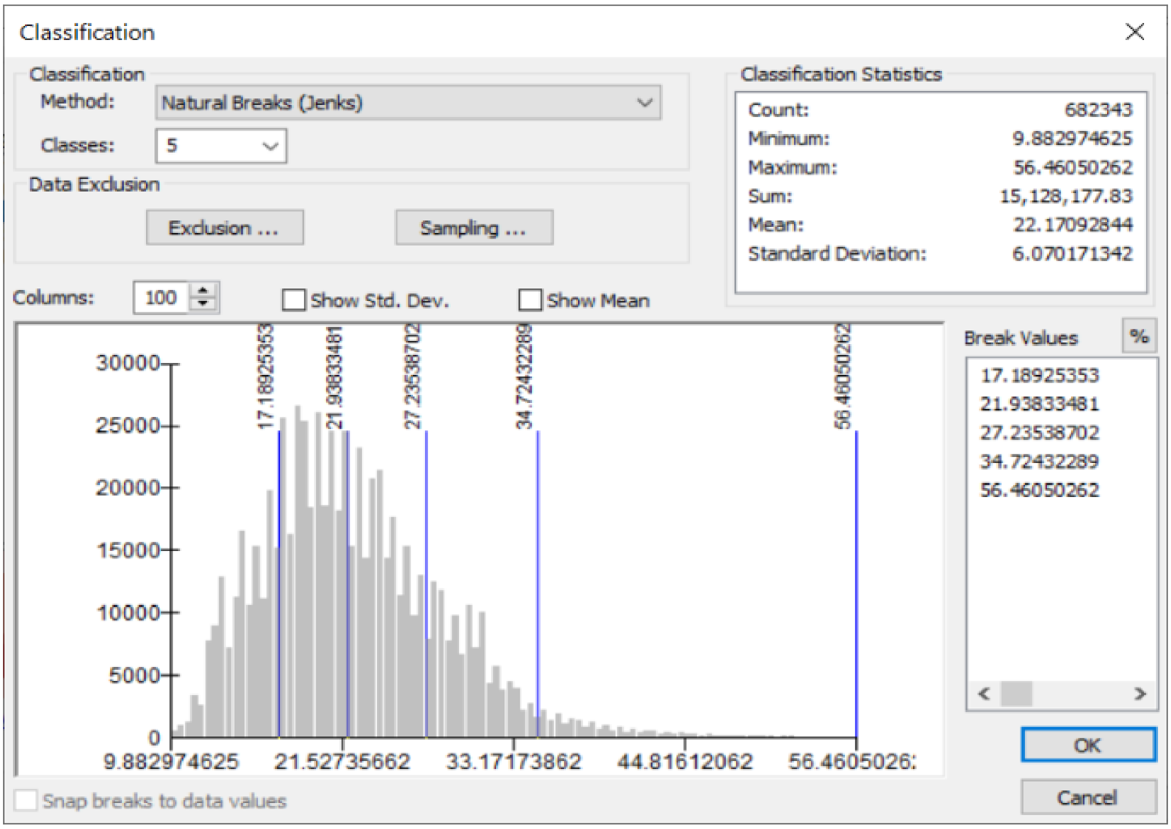


Figure 7.8: Jenks natural breaks classification method

The 'geometrical interval' classification is based on an algorithm that "creates geometric intervals by minimizing the sum of squares of the number of elements in each class. This ensures that each class range has approximately the same number of values in each class and that the change between intervals is fairly consistent"[83]. Similarly to Jenks, the geometric intervals overrepresent the high values (hence high-probability areas) since more cells are classified as having high-probability even though their wreck-probability value is not among the highest (Figure 7.9).

[83] https://pro.arcgis.com/en/pro-app/help/mapping/layer-properties/data-classification-methods.htm

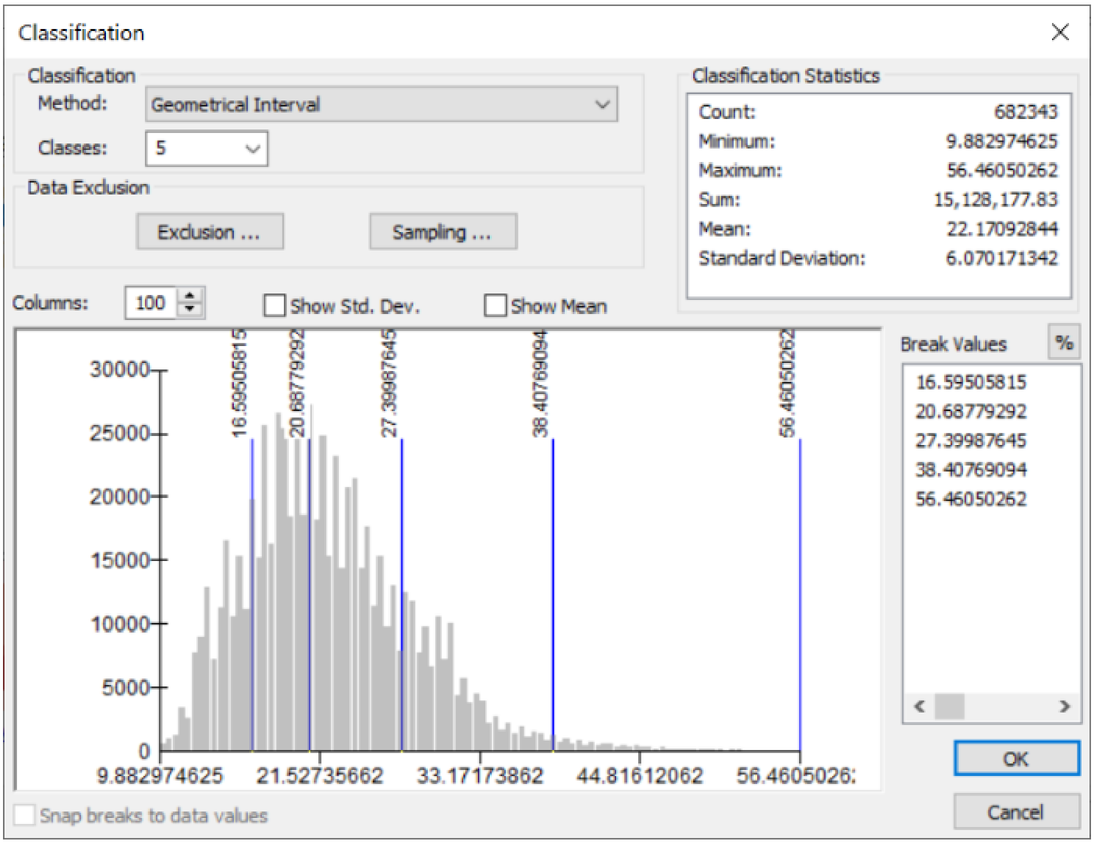


Figure 7.9: Geometrical Intervals classification method

Lastly, the 'quantile' classification creates approximately equal surface areas; namely, it assigns the same number of data values to each class. In different terms, it looks at the cell count instead of the cells' value. Therefore contrary to the equal intervals classification, with the quantile, there are no empty classes or classes with too few or too many values (Figure 7.10). For these reasons, the quantile is used here as a classification method. As for the number of classes, this research set it to five not to have an excess of meaningless classes (e.g. ten) while still providing a workable tool applicable in spatial planning and heritage management, with two high and low classes respectively and an intermediate one. However, as previously said (see Figure 7.6), this number can be easily changed and adapted to suit specific needs.

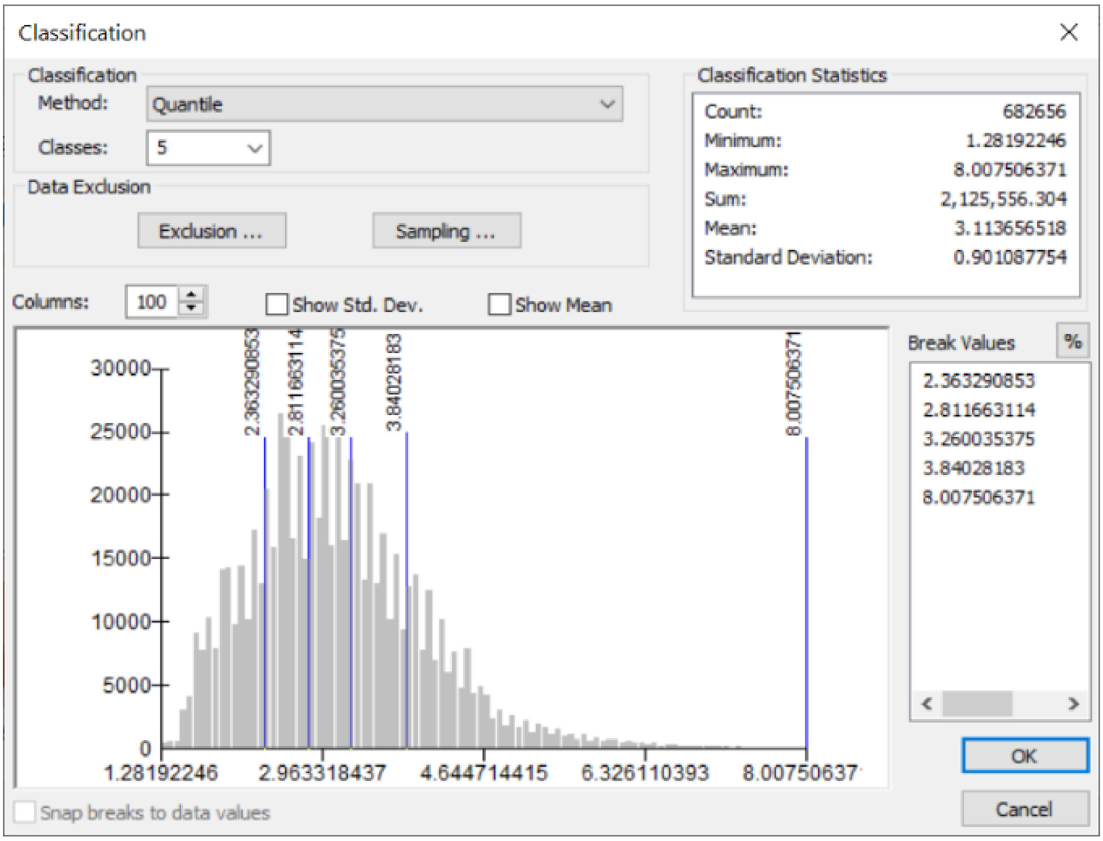


Figure 7.10: Quantile classification method

7.3.2 Testing risk classes against shipwreck locations

The assumption behind the use of recorded shipwrecks for model testing is that the higher the number of shipwrecks in high-probability areas (i.e. risk-class 5; Table 7.2), the higher the probability for the model to be true. Nonetheless, as further debated below, the use of shipwrecks for model testing may give ambiguous results, and need thus, on the one hand, to be taken as an indication instead of proof and on the other hand, to be complemented in the future with alternative approaches to assess the model performance (see section 7.4.).

Since the shipwrecks locations are only approximate (chapter 3) the mean cost value within 1 nautical miles buffer around the average ships' location was considered. This mean has been derived in GIS with the zonal statistics tool, excluding the null values (i.e. the buffer cells falling inland). Afterwards, the resulting raster value has been added to the shipwrecks-points attribute table by means of the 'Extract Values to points' tool.

The model performance is tested using Kvamme's Gain statistics (Kvamme 1983, pp. 26-52; ibid. 1988, pp. 325–428) and the Chi-squared test (Drennan, 1996, pp. 187-194). The Kvamme's Gain (Kgain) is the most commonly employed method of measuring the quality of a model, namely its predictive capability (e.g. Verhagen 2007c, Ducke, Millard et al. 2009; Zhu 2018; Rocks-Macqueen, 2014). The Kgain is obtained with the following formula:

Kgain = 1- Pa / Pt

where

Pa = the proportion of area (or area percentage)

Ps = the proportion of sites (or the site percentage) for the tested probability zone of a predictive model.

Since the Kgain is broadly adopted in archaeological predictive models worldwide (e.g. for the indicative map of the Netherlands, Deeben et al., 2002; cf also Ducke et al., 2009; Rocks-Macqueen, 2014; Zhu et al., 2018) it has the advantage of enabling the comparison of predictive performance in different models. A Kgain value close to one indicates that the model has a strong predictive capability, whereas a value close to zero indicates that the model has nearly no predictive ability. Scholars have debated how close to one the Kgain should be in order for the model to be really useful. For instance, according to Gibson, models should be able to capture 70% of sites in the high probability zones while covering 10 % of land (Gibson, 2005). Rocks-Macqueen, who addresses the problem of model performance in his PhD thesis by comparing different projects, concludes that a gain value of at least 0.7 or above is needed "to have significant precision and accuracy to reduce the possibility of gross error and to be able to work in most CRM contexts" (Rocks-Macqueen, 2014, p.41). It must also be noted that "equal gain values can be obtained with different values for accuracy and precision. A 0.5 Kvamme's gain can be reached by including 60% of the sites in 30% of the area, or by including 80% of the sites in 40% of the area" (Verhagen CAA2007, 286).

Moreover, the Kgain is affected by shipwrecks data biases. Looking at the data in

Table 7.3, one notices that the model seems to perform slightly better when removing the waves and the storm incidence among the input factors, which is both counterintuitive and misleading. Indeed, if one takes a closer look at what happens to the model by including or excluding the waves and the storms, one notices that the areas in the Mediterranean basin that are most impacted by these parameters, namely the areas where a higher risk is connected to the storm incidence and the wave height, are the North-African waters (Figure 7.11). These same waters are also the most heavily impacted by biases in shipwrecks discoveries, as only 19 sites are recorded (chapter 3). Since the Kgain is dependent upon the area considered and the number of sites, if one has a fixed and low number of shipwrecks, at the moment one includes waves and storms, the high probability areas increase in extension, thus decreasing the ships' frequency. Conversely, by removing these factors, the high probability cell numbers decrease and the ratio between the few ships recorded increases. This does not mean we should remove waves and storms to make the model perform better.

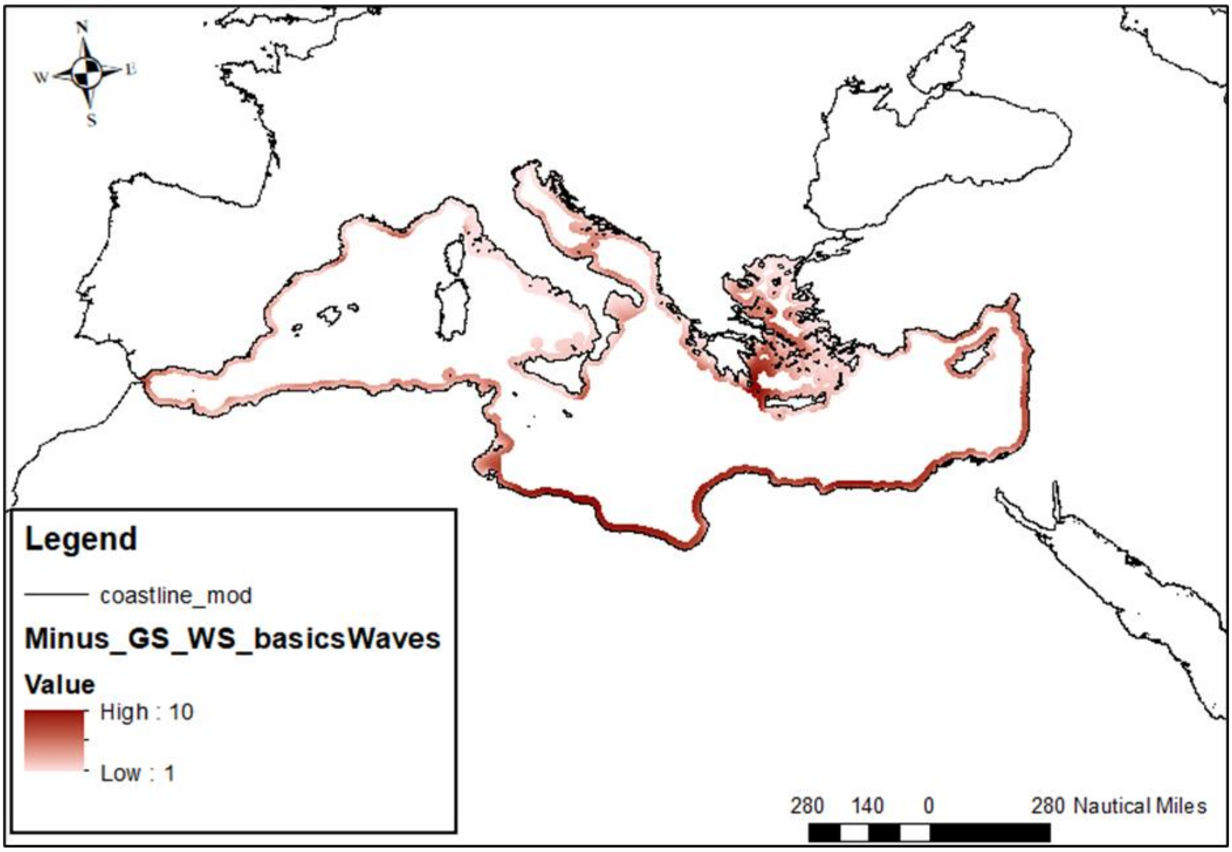


Figure 7.11: The image shows where the annual mean wave height is the highest (dark red)

Table 7.2: Class-breaks per model scenario produced through the quantile method

GS Model scenario	class 1	class 2	class 3	class 4	class 5
Base	9.88 - 16.98	16.98 - 19.89	19.89 - 22.80	22.80 - 26.99	26.99 - 56.46
Preferred	1.28 - 2.33	2.33 - 2.81	2.81 - 3.23	3.23 -3.80	3.80 - 8.01
nobathy	9.76 - 16.96	16.96 - 19.98	19.98 - 23.00	23.00 - 26.89	26.89 - 46.46
nowinds	5.75 - 12.33	12.33 - 15.71	15.71 - 18.73	18.73 - 22.81	22.81 - 51.07
nowaves	7.78 - 14.55	14.55 - 17.15	17.15 - 19.76	19.76 - 22.88	22.88 - 52.04
nostorms	4.68 - 8.44	8.44 - 10.18	10.18 - 12.20	12.20 - 15.39	15.39 - 41.71
norv50	7.87 - 13.20	13.20 - 15.08	15.08 - 17.43	17.43 - 20.87	20.87 - 47.81
nowlind	8.03 - 13.23	13.23 - 14.97	14.97 - 17.65	17.65 - 21.28	21.28 - 48.27
nosheltdist	7.82 - 15.26	15.26 - 18.15	18.15 - 20.88	20.88 - 24.68	24.68 - 46.56
noshelt attract	8.15 - 15.62	15.62 - 18.44	18.44 - 21.10	21.10 - 25.08	25.08 - 50.48

Table 7.3: The Kvamme's gain results for the GS predictive model

GS- BASE					
Class	**cells count**	**Area%**	**Ships count**	**Ships %**	**K-Gain**
1	130150	19.07%	23	2.62%	-6.27
2	136091	19.94%	45	5.13%	-2.89
3	136979	20.07%	74	8.44%	-1.38
4	142159	20.82%	137	15.62%	-0.33
5	137277	20.11%	598	68.19%	**0.71**

GS-PREFERRED					
Class	**cells count**	**Area%**	**Ships count**	**Ships %**	**K-Gain**
1	130056	19.05%	20	2.28%	-7.35
2	141169	20.68%	46	5.25%	-2.94
3	133479	19.55%	63	7.18%	-1.72
4	137962	20.21%	110	12.54%	-0.61
5	139990	20.51%	638	72.75%	**0.72**

GS-NOBATHY					
Class	**cells count**	**Area%**	**Ships count**	**Ships %**	**K-Gain**
1	146216	19.59%	59	6.50%	-2.01
2	153870	20.61%	84	9.26%	-1.23
3	154223	20.66%	110	12.13%	-0.70
4	148872	19.94%	173	19.07%	-0.05
5	143376	19.20%	481	53.03%	**0.64**

GS-NOWINDS					
Class	**cells count**	**Area%**	**Ships count**	**Ships %**	**K-Gain**
1	135668	19.72%	27	3.03%	-5.51
2	141705	20.60%	66	7.41%	-1.78
3	138566	20.14%	91	10.21%	-0.97
4	136423	19.83%	218	24.47%	0.19
5	135586	19.71%	489	54.88%	**0.64**

GS-NOWAVES

Class	cells count	Area%	Ships count	Ships %	K-Gain
1	140240	19.96%	14	1.47%	-12.56
2	142187	20.24%	44	4.63%	-3.37
3	144988	20.64%	49	5.15%	-3.01
4	142245	20.25%	117	12.30%	-0.65
5	132808	18.91%	727	76.45%	**0.75**

GS-NOSTORMS

Class	cells count	Area%	Ships count	Ships %	K-Gain
1	123464	18.09%	10	1.12%	-15.10
2	145189	21.28%	41	4.61%	-3.62
3	142091	20.82%	66	7.42%	-1.81
4	137203	20.11%	92	10.34%	-0.95
5	134396	19.70%	681	76.52%	**0.74**

GS-NORV50

Class	cells count	Area%	Ships count	Ships %	K-Gain
1	133719	19.60%	25	2.81%	-5.98
2	139999	20.52%	32	3.60%	-4.71
3	138490	20.30%	64	7.19%	-1.82
4	139333	20.42%	124	13.93%	-0.47
5	130802	19.17%	645	72.47%	**0.74**

GS-NOWLIND

Class	cells count	Area%	Ships count	Ships %	K-Gain
1	132742	19.45%	24	2.70%	-6.21
2	136234	19.97%	35	3.93%	-4.08
3	143866	21.08%	71	7.98%	-1.64
4	135069	19.79%	142	15.96%	-0.24
5	134432	19.70%	618	69.44%	**0.72**

GS-NOSHELTDIST

Class	cells count	Area%	Ships count	Ships %	K-Gain
1	137440	20.14%	41	4.61%	-3.37
2	141015	20.67%	99	11.12%	-0.86
3	140534	20.60%	170	19.10%	-0.08
4	133050	19.50%	198	22.25%	0.12
5	130313	19.10%	382	42.92%	**0.56**

GS-NOSHELTATTRACT

Class	cells count	Area%	Ships count	Ships %	K-Gain
1	133703	19.59%	23	2.58%	-6.58
2	140241	20.55%	73	8.20%	-1.51
3	137181	20.10%	83	9.33%	-1.16
4	136444	20.00%	238	26.74%	0.25
5	134774	19.75%	473	53.15%	**0.63**

Besides the Kvamme's gain, the Pearson chi-squared (χ^2) goodness of fit[84] test is employed for model testing because it enables one to measure the difference between sets of observed values and those which would be expected in a random condition; it, therefore, determines whether the deviation from the expected condition is statistically significant or may be due to chance (Drennan, 1996, pp.187-191).

The formula for calculating the chi-square is the following:

$$\chi^2 = \Sigma \frac{(O-E)^2}{E}$$

where

Σ = the sum

O = the observed values, which here correspond to the number of shipwrecks per class

E= the expected values, which here correspond to the number of shipwrecks that one may expect in a random distribution. These are calculated by proportion, based on the area percentage (i.e. if class A represents the 5% of the total area, in a random situation we would expect 5% of the total shipwrecks in this class).

The P-value represents the probability that the deviation of observed sites from expected ones is not due by chance. The results are considered significant by conventional criteria at $p < 0.05$.

[84] There are two different types of chi-squared test: the chi-square test for independence, which compares two sets of data to see if there is a relationship; and the chi-square goodness of fit, which aims to fit one categorical variable to a distribution and is most often used for model validation including this analysis. The two types are sometimes confused.

The Chi-squared value was calculated for each GS scenarios with 4 degrees of freedom, leading to a critical value of 9.49. The difference between expected and observed values is considered to be significant in all the scenarios (Table 7.4).

Table 7.4: Pearson chi-squared test calculation

GS- BASE				GS-NOSTORMS			
Class	**E sites**	**O sites**	**χ2**	**Class**	**E sites**	**O sites**	**χ2**
1	167.2	23	124.37	1	161.04	10	141.66
2	174.83	45	96.417	2	189.37	41	116.25
3	175.98	74	59.093	3	185.33	66	76.837
4	182.63	137	11.401	4	178.96	92	42.254
5	176.36	598	1008.1	5	175.3	681	1458.9
GS-PREFERRED				**GS-NORV50**			
Class	**E sites**	**O sites**	**χ2**	**Class**	**E sites**	**O sites**	**χ2**
1	167.08	20	129.48	1	174.41	25	128
2	181.36	46	101.03	2	182.6	32	124.21
3	171.48	63	68.625	3	180.64	64	75.312
4	177.24	110	25.508	4	181.74	124	18.342
5	179.84	638	1167.2	5	170.61	645	1319.1
GS-NOBATHY				**GS-NOWLIND**			
Class	**E sites**	**O sites**	**χ2**	**Class**	**E sites**	**O sites**	**χ2**
1	177.64	59	79.235	1	173.14	24	128.47
2	186.94	84	56.683	2	177.69	35	114.59
3	187.37	110	31.946	3	187.65	71	72.513
4	180.87	173	0.3421	4	176.17	142	6.6292
5	174.19	481	540.41	5	175.34	618	1117.5

GS-NOWINDS				GS-NOSHELTDIST			
Class	**E sites**	**O sites**	**χ2**	**Class**	**E sites**	**O sites**	**χ2**
1	175.71	27	125.86	1	179.26	41	106.64
2	183.53	66	75.265	2	183.93	99	39.215
3	179.46	91	43.607	3	183.3	170	0.9651
4	176.69	218	9.6587	4	173.54	198	3.448
5	175.61	489	559.3	5	169.97	382	264.5
GS-NOWAVES				**GS-NOSHELTATTRACT**			
Class	**E sites**	**O sites**	**χ2**	**Class**	**E sites**	**O sites**	**χ2**
1	189.86	14	162.89	1	174.39	23	131.43
2	192.49	44	114.55	2	182.92	73	66.053
3	196.28	49	110.52	3	178.93	83	51.43
4	192.57	117	29.656	4	177.97	238	20.25
5	179.8	727	1665.4	5	175.79	473	502.5

Although statistically significant[85], this testing still leaves many open questions, for instance, given the limitations highlighted when commenting on the Kvamme's gain results, is it possible to ascertain whether the model performs better in certain regions than in others? Is the predictive capability dependent on the chronological framework? In different terms, is the model better able to predict the presence of Roman and Classical sites than post-medieval ones? Given the scope of the study, testing the model in different Mediterranean sectors is deemed of little use as the results may not provide unequivocal indications on the model performance and may rather reflect different interacting causes such as the availability of data (e.g. due to uneven archaeological national initiatives or results sharing), the underrepresentation of certain chronologies in the shipwrecks dataset, and/or the higher or lower impact of individual input factors. The only area further tested in the section below is the one where the local scale model was developed, since here both the local and the global scale model were performed. The testing may therefore indicate whether the GS model results in a significantly different model performance.

[85] The chi-square only tests for randomness. It does not say how significant the deviation from non-randomness is.

7.4 TESTING THE GLOBAL AND REGIONAL SCALE MODELS ON AN AREA LOW IN SHIPWRECK DENSITY

As highlighted in chapter 2 the area where the local scale model is developed, namely the territorial waters between Cap Bon and Alexandria, is one of the lowest in shipwrecks number in the Mediterranean basin. A targeted literature review resulted in the identification of four more sites, in addition to the 15 that were already part of the dataset (Table 7.5)[86]. Moreover, more precise shipwreck locations were obtained by interpreting the generic coordinates provided by DARMC and OXREP in combination with information on shipwreck depth when available: in this way, it has been possible to relocate, e.g. the Apollonia shipwreck and the Mahdia shipwreck, which the approximate DARMC-OXREP coordinates place inland. Finally, to compare the shipwrecks distribution against the cost values, an average cost for the area within 1 NM buffer of each wreck site was calculated instead of using the cost-value at its precise coordinates. This to mitigate the shipwrecks-location error (chapter 3.3).

Although the testing presents limitations due to the scarce data available in this area, it is possible here to compare the outcomes of the global and local scale model and check on the one hand whether the GS model simplification entails a significant variation in model performance, on the other hand, whether the separate account of two factors expressing a potential perceived risk, namely the shelters-attractiveness implemented in the Regional case based on the textual evidence, and the implications of mutual visibility, contribute improving the model. The assumption behind the testing is that the higher the shipwrecks density in high-probability areas, the better the model. Given the limited number of sites, which are not suitable for statistical analysis (e.g. Kgain and chi-squared test), the model is deemed to be valid if the shipwrecks density in class 5 (i.e. ships count in class 5 / class 5 area) exceeds the overall shipwrecks density in the total area (i.e. total sites-count / area total).

[86] Parker and OXREP include also the shipwreck of Sidi Ahmad (Parker n. 1082), in the NW part of the homonymous harbour, E of Misurata (Libya). Particularly, Parker states "During underwater surveying for a new harbour in the 1970s, two long columns of white marble with green veins were found. The finders presumed that they must be Roman, probably from a shipwreck. Later searchers failed to relocate the site, but it may well be a wreck"(Parker, 1992, p. 403). The site is also mentioned by Russell without further details (Russell, 2012, p. 535). Since the columns were found in a port area and cannot necessarily be attributed to an ancient shipwreck in lack of further evidence, it was deemed more prudent not to consider this site in phase of model testing.

Table 7.5: Shipwrecks in the Regional Scale study area and an indication of the risk-classes where they fall depending on the model scenario (from low, 1; to high, 5).

		Risk Classes (1 to 5) in Model scenarios				
NAME	**PARKER REF**	**RM Preferred**	**GM Preferred**	**RM Base**	**GM Base**	**References**
Ain El Gazala	22	5	5	5	5	DARMC; OXREP
Alexandria 1	31	4	5	4	5	DARMC; OXREP
Alexandria 2	32	4	5	4	5	DARMC; OXREP
Alexandria late Roman	0	4	5	4	5	DARMC
Antirhodos	0	5	5	5	5	DARMC
Apollonia 1	47	5	5	5	5	OXREP
Apollonia 2	48	5	5	5	5	OXREP
Cap Bon 1	177	5	5	5	5	DARMC; OXREP
Cap Bon 2	178	5	5	5	5	DARMC; OXREP
Mahdia	621	3	3	5	3	OXREP
Mangub	645	5	5	4	5	DARMC; OXREP
Marsa el-Brega		5	5	5	5	OXREP
Marsa Lucch	660	3	4	2	4	DARMC; OXREP
Ougla, Ougia		5	5	5	5	Beltrame, 2012; Tusa, 2010
Ras Etteen 1		5	5	4	5	Beltrame, 2012; Tusa, 2010
Ras Etteen 2		5	5	4	5	Beltrame, 2012; Tusa, 2010
Salakta	1014	2	3	2	4	DARMC; OXREP
Tigre, Ras al-Hilal		5	5	5	5	Beltrame, 2012; Tusa, 2010

Table 7.6 reports the shipwrecking probability value (i.e. ratio%) in correspondence of the recorded sites in the local study area produced by the Global Scale and Local Scale model, respectively. In all the produced scenarios, the shipwreck density in all the classes 5 exceeds the overall shipwrecks density in the total area, which is equal to 0.02 %. However, when comparing the GS model and the LS model, different outcomes arise depending on the classification method employed. With the quantile, both the LS preferred and the base scenario present a higher ratio than the global scale scenarios; hence they seem to provide better results. Conversely, when employing equal intervals, the GS preferred and the RS base seem to give the best outcomes (Figure 7.12).

Table 7.6: shipwrecks density in the Base and Preferred scenarios produced by running the Global Model and the Regional Model in the local study area. The model is deemed to be valid when the shipwrecks density in high probability areas is greater than the overall density in the entire area. All the scenarios satisfy this condition; however, the highest percentages are produced by the GM_Preferred Equal Intervals, LM base Equal Intervals, RM_Preferred Quantile RM_Base quantile

RM_Preferred Quantile				**GM_Preferred Quantile**			
Classes	Cells Count	Ships count	Ratio%	Classes	Cells Count	Ships count	Ratio%
1	18673	0	0	1	13856	0	0
2	18961	1	0.01%	2	9198	0	0.00%
3	19243	2	0.01%	3	11110	1	0.01%
4	19262	3	0.02%	4	20839	2	0.01%
5	18693	13	**0.07%**	5	42359	16	**0.04%**
Tot	**94832**	**19**	**0.02%**	**Tot**	**97362**	**19**	**0.02%**

RM_Base quantile				**GM_Base Quantile**			
Classes	Cells Count	Ships count	Ratio%	Classes	Cells Count	Ships count	Ratio%
1	18514	0	0.00%	1	9995	0	0
2	18912	2	0.01%	2	8469	0	0.00%
3	20040	1	0.00%	3	8560	0	0.00%
4	19414	6	0.03%	4	21623	3	0.01%
5	17952	10	**0.06%**	5	48715	16	**0.03%**
Tot	**94832**	**19**	**0.02%**	**Tot**	**97362**	**19**	**0.02%**

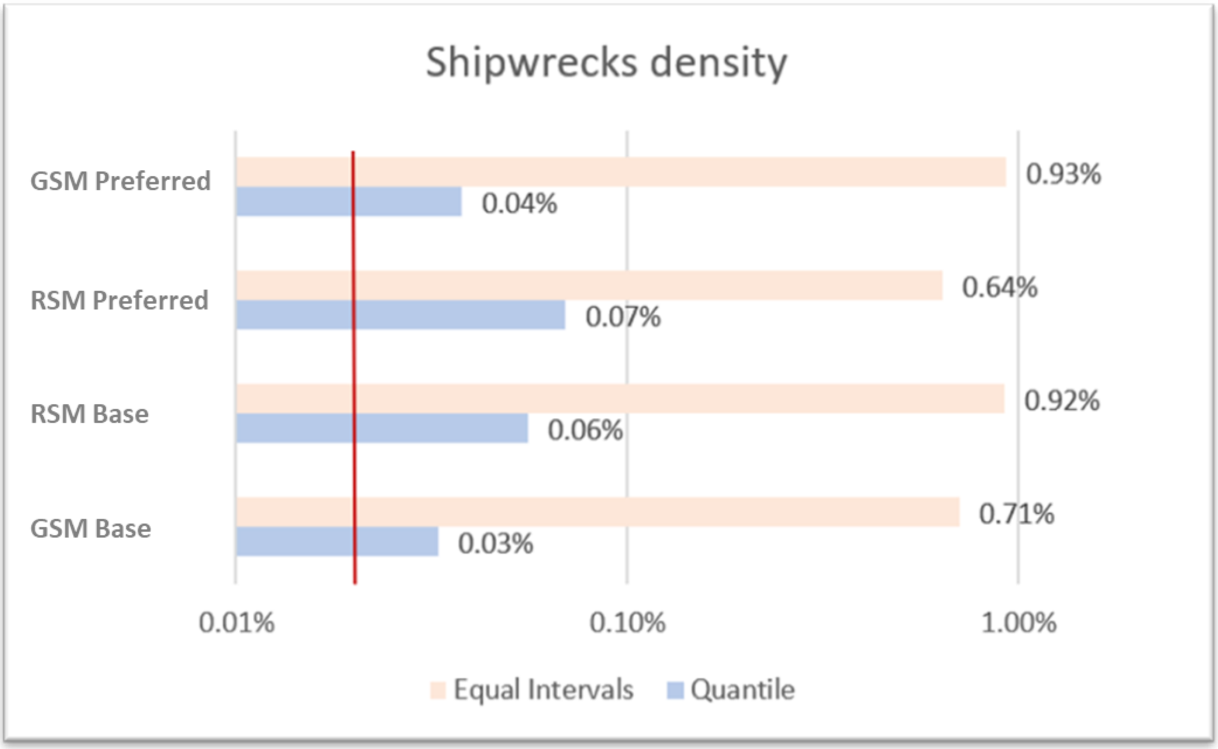


Figure 7.12: The graph shows the shipwreck density in the high probability areas (i.e. shipwrecks count per class 5 area) in the base and preferred scenarios produced through the global scale model (GSM) and the regional scale model (RSM). The red line corresponds to the average shipwrecks density in the entire area: the model is deemed valid when the density in high probability areas exceed the total shipwrecks density. Two different classification methods are employed, namely the quantile and equal intervals; the former takes into account the cells count, the latter the cell values

7.5 SUMMARY AND REFLECTIONS ON MODEL PERFORMANCE

Two issues were discussed in this chapter for evaluating model performance: first, the model's uncertainty connected to errors, subjective reasoning or decisions, which affect the model design and the model outcomes; second, the model's ability to execute the task it was designed for, namely predicting the shipwrecking probability in Mediterranean territorial waters. In section 7.1, we identified the main factors of uncertainty in the model. In Section 7.2 we produced multiple scenarios by removing one factor at a time to see to which factor the model is more sensitive. In section 7.3. we tested the model outputs against the recorded shipwrecks.

The use of global methods providing summary statistics of how variations in model inputs propagate from the inputs to the outputs to estimate how the model reacts to a change was outside of the scope of this research. Nonetheless, since the formalization of model uncertainty is an essential step in computational modelling and it is rarely addressed in archaeological models (e.g. Lovis, 2016, p. 20) an overview of potential uncertainty factors was discussed, and the 'one factor at a time local sensitivity method' was employed for exploring model variations resulting from the removal of an entire input-factor at each model run (Happe et al., 2006; Saltelli, 2005; Vonk Noordegraaf et al., 2003, p. 434). This test shows that the storm incidence, the wave height and the shelters distance produce the greatest impact on the model results, both in the Regional-scale and Global Scale models. Specifically, the inclusion of these factors decreases the number of cells with moderate values and increases those with higher values. In practical terms, this helps to distinguish more clearly, moderate risk areas from high to very high-risk ones, which is important in terms of cultural heritage management. However, this approach alone is not sufficient to establish which of the produced scenarios performs better. To this aim, in section 7.3, the recorded shipwrecks data were employed to verify that the very-high risk areas identified by the model correspond to the areas where most shipwrecks are found. After classifying the shipwrecks-probability maps in 5 zones ranging from low to very high risk, the performed tests confirm this correlation, and the chi-squared analysis confirmed the statistical significance of this result. Indeed, the deviations between observed and expected are clearly not due to chance.

In section 7.4, the global scale and local scale models were compared using two different cost classification methods, namely the quantile and the equal intervals because, as stressed in the present chapter, the number of classes produced and the classification method employed to identify the class breaks has a great impact on the results: by employing the quantile, the RM_Preferred and the RM_Base scenarios perform better. Whereas by employing the equal intervals, the GM_Preferred and the RM_Base evidence better results (Figure 7.12). Since the number of sites in this region is not large enough to conduct statistical analysis, it was simply checked whether the number of wreck sites per unit area in the very high-risk areas (i.e. class 5) exceeds the overall shipwreck density. In all the produced scenarios, the model satisfies this condition. However, caution must be paid when attempting to compare the different scenarios' performance, as well as the global scale and regional scale outcomes. Tests based on the calculation of sites number per spatial extension are particularly sensitive to data biases, which are numerous in the shipwrecks dataset available for testing, as was amply discussed in Chapter 2 and section 7.3.2. This is also the reason why a comparison of model performance in different Mediterranean regions is deemed of little use with the shipwrecks information currently available: given the uneven archaeological initiatives carried out by Mediterranean countries and the many possible reasons behind the lack of registered sites (chapter 3), the results of such comparisons would be ambiguous. Only with the availability of additional shipwrecks data detected through systematic archaeological surveys (cf. Chapter 3) more sophisticated testing methods (e.g. constrained resampling, Monte Carlo Simulation) could be employed to gain more reliable insights.

Going back to the question at the beginning of this chapter, the model is deemed to be able to perform the task it was designed for; indeed, the very-high risk areas, i.e. the area supposed to have the greatest shipwrecking probability, correspond to the regions were most shipwrecks were found, and the Chi-squared test proved that this correlation is not due to chance.

8 GENERAL DISCUSSION AND CONCLUSIONS

Archaeological prediction in maritime environments still constitutes at present an underexplored frontier in Mediterranean contexts despite the enormous utility of such technique for optimizing the analysis and the detection of the underwater cultural heritage. The principal aim of this study has been to develop a formal approach and a GIS-based methodology to assess the shipwrecking probability in Mediterranean territorial waters (i.e., the 12 NM zone as defined by the 1982 United Nations Convention on the Law of the Sea), which are the most exploited and accessible, hence in urgent need to be better preserved and monitored. In this concluding chapter, it will be discussed to what extent the primary goals of this research have been achieved. Section 8.1 is a summary of the study for the readers' benefit focusing on the contributions of this thesis to improve current archaeological predictive models in maritime contexts and specifies how the caveats identified in chapter 2.2.6 have been addressed; section 8.2 answers the research questions presented in chapter 1. Section 8.3 and 8.4 respectively address the main limitations and the future developments of this research.

8.1 A RESEARCH SUMMARY: ASSESSING SHIPWRECKING PROBABILITIES IN TERRITORIAL WATERS

As shown in Chapters 1 and 2, wondering where ships may have sunk in the past centuries presents significant multi-disciplinary insights and practical applications for preventive archaeology in maritime spatial planning (section 2.1.1). Given the challenges and the high costs of underwater archaeological operations, it is essential to design instruments supporting the archaeological desk-based assessment for prioritising, hence optimising, the areas to investigate. Besides the practical utility, archaeological predictive modelling enhances the understanding of historical, socio-economic, cultural and archaeological dynamics by enabling the formalisation and testing of hypotheses. In this study, an original and fully documented procedure to identify areas presenting a relatively higher shipwrecking probability is developed and implemented, thus providing a novel instrument for establishing the underwater archaeological potential in territorial waters.

In Chapter 2, after discussing definitions and state of the art in archaeological predictive modelling, it is highlighted the need to develop a new take on maritime archaeological prediction and overcome, on the one hand, issues pertaining to the predictive modelling practice in general (e.g. data constraints, the unheeded effects of uncertainty and subjective reasoning on the model results, poor testing, and the environmental determinism), on the other hand, more specific caveats connected to the maritime environment and seaborne connectivity prediction. The latter caveats encompass the effects of a too strict adoption of the nautical uniformitarianism principle, the oversimplification or neglect of cultural and cognitive factors, the tendency to categorise in binary terms navigation strategies, and connected to the latter, the lack of tailored methods for addressing the navigation dynamics in coastal areas.

In Chapter 3, an exploratory data analysis is carried out for enquiring into the specific limitations affecting the underwater archaeological record, which reflect the many constraints of past underwater discoveries. Using these data to infer the position of yet unknown sites risks producing tautological argumentation and self-fulfilling prophecies, as it would reinforce the current biased-archaeological pattern. Therefore, a theory-driven approach has been chosen, for it allowed using the shipwrecks' record as an independent data sample to test the model performance after taking several measures to mitigate the data biases to this aim.

Strategies included limiting the model scope to the 12 NM zone due to the paucity of sites beyond this limit, which would prevent the model testing.

The theoretical underpinnings for predicting shipwrecking probabilities in territorial waters are discussed in Chapter 4. Given that navigating in coastal areas entails both advantages and risks for seafarers, the research has inquired whether and in which circumstances the coastal proximity is considered to be safe, both in the scholarship tradition (Chapter 4.2) and in the ancient textual evidence (Chapter 4.3). The review has highlighted that opinions in the classical sources and present-day scholars differ on this topic and that, save a few exceptions, no generalised preference for either coastal approaches or direct crossings can be evidenced in the sources accessed. Instead, the choice to stay near or rather move away from the coast is circumstantial and subjective. The defining characteristics of 'coastal' navigation were also investigated, as well as how extended the coastal area could be from a mariner's perspective, thus exploring in the textual evidence the ways seafarers would sense (using all sensory input) the presence of land (sections 4.3.4, 4.3.5).

In chapter 5 are described the criteria for selecting relevant model factors and the theoretical model structure. Under the premise that the shipwrecking probability results from the combination of movement potential and sinking probabilities, this research stresses the importance of distinguishing between perceived and actual navigation hazards. Most modelling approaches derive transit probabilities by calculating the most efficient routes, namely those minimising actual navigation hazards. In contrast to this tendency, this model accounts separately, as two separate and independent model components, the actual environmental threats increasing the chance of wrecking (i.e., the Navigation Hazard model), and the multiple criteria driving mariners' actions, which include perceived pulling and pushing factors attracting or averting mariners' movement (i.e. the Transit Probability model). The movement potential was hence approached as a cognitive process based on the optimisation of opportunities and risks. Two geographical and chronological scales were considered and implemented in two separate models to serve the different needs of historical research, and cultural resource management referred to in Chapter 1: a regional model focused on Roman time navigation dynamics in the area comprised between Cap Bon and Alexandria, and a global model extending on the entire Mediterranean territorial waters without chronological limitations.

At the regional level, textual evidence was used for identifying categories of pulling and pushing factors triggering or averting mariners movement (section 5.4). Pulling factors include the possibility to spot landmarks for orientation and the proximity to shelters (i.e. different types of natural and artificial ports and anchorages), whose degree of attraction is expressed by the shelters'-attractiveness index designed for this purpose (section 5.4.2, 6.2.2). This index describes the convenience of a shelter; as such, it increases with the presence of cultural, economic and logistic attractors nearby and decreases with environmental threats that reduce the location's safety. Given that one of the goals of the present study was to address the potential difference between actual and perceived optimal routes and actual and perceived hazards, the shelters' attractiveness was implemented based on textual evidence, and the *Stadiasmus* was used as proof of concept. Hence, the risks considered in the shelters' attractiveness do not necessarily overlap with the actual threats modelled in the navigation-hazards model. As a further pushing factor, the risk of being spotted and attacked from the land was also included. The range of land visibility was implemented in a twofold manner; first, by considering the advantages in terms of orientation and wayfinding (section 5.4.4); second, the disadvantages represented by the human hazards. Unlike current maritime models, which tend to assign a generic seafaring predilection to the area in sight of land, it was assumed that mariners would try to stay as far as possible from land to mitigate the risk of being attacked while still keeping landmarks in sight. Therefore, a relatively higher transit preference was assigned to the seaward edge of the range of visibility. Among the actual navigation hazards -besides factors most often considered in maritime archaeological models such as the mean wind-speed, mean wave height and the bathymetry-, it has also been possible to implement the effects of storminess along the coast of the Mediterranean Sea, which have never before been included in historical and archaeological models. At the global scale, the model was simplified both in terms of the number of factors and the complexity of the procedures (section 5.6). Particularly, the shelters' attractiveness could not be derived from the textual evidence given the chronological span of the global model and was therefore approached in terms of attractors' density. Similarly, the range of land visibility was not included because, in most of the Mediterranean basin, the theoretical visibility range extends further than the 12 NM zone; hence the transit preference assigned to the edge of the visibility range would have no significant impact on territorial waters. This model's simplifications answer the need to provide a general tool applicable in spatial planning. Its broad scope, which is not meant to address specific chronological or geographical scales, suggests avoiding the inclusion of several factors because -as has been noted- more data makes a model more detailed, not necessarily more realistic or representative (Brouwer Burg et al., 2016, pp. 59-80).

The model-building procedures for both scales are described in Chapter 6. A multi-criteria cost-surface analysis was employed to overcome the simplistic categorization of factors as purely advantageous or purely disadvantageous, and an innovative approach, new to this research, was developed to implement the opposite implications of land visibility (Chapter 6.2.4). Preferences and weights were assigned at different levels, thus referring to the definitions used by Verhagen et al. (2019, p. 229):

- Selection level – the model factors were formally selected based on their estimated impact and (modelling) feasibility on a scale ranging from 1 to 4 (Chapter 5.3)
- Attribute level – the selected factors were assigned an increasing cost (i.e., a transit probability value or navigation probability value depending on the model component where they are included) based on a theoretical rule preliminary specified to this aim. For instance, the transit probability decreases with the distance to shelters (Chapter 6.2.1). Each factor's cost-surface was then rescaled through the most suitable GIS function to a range of 0-10 in order to be summed to produce the final shipwrecking probability value.
- Criterion level – the weight of the factors was established through multi-criteria analysis and a pair-wise comparison (Chapter 6.4). At both regional and global levels, two models were produced (Figure 1.1): a Base model, where all input factors are assigned an equal weight, and a Preferred model, where input factors are weighted based on their impact as calculated following the Analytical Hierarchy Process by Saaty (Chapters 6.4.1, 6.4.2).

Chapter 7 was devoted to the model testing and the identification and discussion of the factors of uncertainty embodied in the procedural steps. This phase was crucial because sensitivity analysis and uncertainty analysis are still unheeded in archaeology despite the exponential increase in computational methods and applications (noteworthy exceptions being Kanters, Brughmans & Romanowska 2021 and Brouwer Burg, Peeters & Lovis, 2016). [87] Since uncertainty is also dependent on subjective reasoning, and this impacts the way costs and

[87] Kanters, Brughmans & Romanowska 2021 provide a reusable script for model exploration and sensitivity analysis. Unfortunately when their paper was published this thesis was undergoing the final edits and it was not possible to employ it in chapter 7.

preferences are assigned to the selected parameters, different scenarios were produced following the OAT method (i.e. One factor At Time) to verify how the model behaves by changing or removing a factor, and which variation impacts the model most (section 7.2). Similarly, it was evidenced how the classification methods chosen for determining the risk classes affect the result (section 7.3.1).

The risk classes produced in each scenario were tested against the recorded shipwrecks by means of Kvamme's gain statistic (Kgain) and the Pearson chi-squared goodness of fit (section 7.3.2). Particularly it was ascertained whether the high probability areas identified by the model are indeed those where the actual shipwreck density is higher than the overall density in the entire research area and whether this pattern distribution is statistically significant or may be due to chance. These tests were chosen despite their limitations discussed in section 7.5 because they are the most employed in archaeological predictive modelling and, therefore, there is already a vast literature discussing their utility, limitations and result validity. As for the Kgain statistic, the scholarship has evidenced that "a Kgain value of at least 0.7 is needed to have significant precision and accuracy to reduce the possibility of gross error and to be able to work in most CRM[88] contexts" (Rocks-Macqueen, 2014, p. 41). Both the GS_preferred and GS_base models satisfy the condition with a slightly better performance of the former over the latter (i.e. Kgain equal to 0.72 and 0.71 respectively for the GS_preferred and GS_base model). The chi-squared value was calculated for each Global Scale scenario produced through the OAT method and evidenced the significance of the result (i.e. the difference between expected and observed values is significant in all the scenarios). The same statistical testing procedure was not possible at the Regional scale due to the limited number of shipwrecks recorded in the area. A general indication of model performance was based on the calculation of the shipwrecks' density in the highest risk class produced by the model against the overall shipwrecks density in the selected area: the model was considered valid when the former was greater than the latter. As both the Global and Regional models were employed in the area of the Regional study, it was possible to compare the outcomes produced by the two different modelling strategies. The results produced by the GS and RS models were compared; the RS model performs better than the GS one, which may hint at the utility of addressing the perceived risks (i.e. the shelters attractiveness and visibility analysis that the Global model does not include) to calculate transit probabilities separately from the actual environmental threats affecting sinking chances.

8.2 IMPROVEMENTS TO CURRENT MODELS

Referring back to the limitations of current predictive modelling approaches discussed in section 2.2.6, the strategies followed for overcoming them are summarized here:

1) The risk of generating biased predictions due to biased input data

The issue was dealt with by approaching the models deductively and by employing shipwreck data in the testing phase instead of using them to infer shipwrecking probabilities.

2) The relevance of the environmental input data

The pertinence of current environmental and meteorological data for modelling past climate conditions is debated and evaluated in chapter 5.4.3, and it is evidenced that the use of current data is standard practice in predictive modelling. In the opinion of most scholars, the more striking aspects of the physical environment referred to in ancient sources, particularly the

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[88] Cultural Resource Management

climate and weather, have not changed significantly since ancient times, although variations are registered at specific scales. An exception relates to the sea-level rise, which substantially affects the coastal topography. However, since the model is not aimed at addressing local conditions, the issue does not impact the overall model performance at a regional nor at a global scale. Contrary to the opinion of some scholars privileging real-time, short-range weather conditions for modelling past shipping routes (e.g. Warnking), this research has, in light of the models' broad temporal and geographical scope, privileged the adoption of long-term hindcast and forecast of such data, in order to compensate for possible climate variations.

3) Environmental determinism and nautical uniformitarianism

Instead of simply including a set of cultural factors to overcome the predominant use of environmental parameters, this study has approached the modelling of all factors, including the environmental ones, by taking into account the human agency and potential cultural preferences and differences in navigation strategy. Contrary to models that focus on the environmental affordances enabling mariners' movement, this research has investigated the circumstances and conditions under which the coast would be perceived as convenient or risky to approach. The enquiry into attractive and repulsive factors associated with the coastal proximity included places with cultural or devotional interest besides environmental and economic aspects. The analysis suggests avoiding binary categorisation (i.e. aspects purely advantageous or disadvantageous) and employing a multi-criteria approach. Moreover, instead of adopting the nautical uniformitarianism principle and taking for granted that mariners in the past would minimise the same risks that present sailors face, this model has formally distinguished perceived and actual navigation hazards. By assuming that the former may impact the seafarers' movement without being necessarily threatening while the latter increase the probability of ship losses, the model is able to identify the areas presenting the highest shipwrecking probability, namely those with both high movement potential and sinking potential, which would be otherwise counterintuitive to imagine in combination (why would ships systematically navigate areas known to be hazardous?). It must be stressed that the research is methodology-oriented rather than result-oriented and that it does not claim to provide an in-depth analysis of risk perception in antiquity.

4) Temporal and spatial scale and prediction scope

Two models have been developed at a regional and a global spatial and chronological scale to provide, on the one hand, a general tool applicable in spatial planning and cultural heritage management and on the other hand, a model of which the theoretical underpinning would be supported by the historical evidence. Although neither of the two models is suitable to address the specificities of local conditions, they satisfy the pragmatic and results-oriented need of heritage managers to rely on a tool identifying archaeological high-probability zones while meeting the necessity of archaeologists and historians to use such tools for fostering the understanding of past dynamics. These models quantify the relative shipwrecking probabilities in territorial waters and also shed light on shipping dynamics in coastal areas and on the way the coastal proximity was perceived in classical textual evidence and in the scholarship tradition accessed.

5) Problematic modelling of coastal navigation

This research inquired what would make mariners approach the shore, what distance they would keep while following coastal approaches and what the coastal navigation would have entailed (e.g. being in sight of the land, seeing landmarks, perceiving the land nearby) in order to overcome the simplistic modelling tendency to distinguish between two modes of navigation (i.e. in open waters or along the shore; cf. ORBIS). The study identified in Classical textual evidence and secondary sources the conditions attracting or averting coastal seafaring while also focusing on the factors indicating the proximity of the land. Hence, the movement potential in coastal areas was approached and interpreted as a cognitive process based on the optimisation of risks and opportunities. From a technical point of view, this research benefited from the inclusion of factors never included before in archaeological contexts, specifically those addressing the effects of storms on the Mediterranean coasts.

6) Subjectivity in variable-selection and variables-weight assignment

The model is susceptible to subjective reasoning since it was built following a theory-driven approach; however, this study describes in a fully documented and transparent manner the decisions taken and the criteria adopted for selecting the input factors, weighting and implementing them. The effects of subjective reasoning and uncertainty in the entire modelling procedure are also discussed and explored in a dedicated chapter (Chapter 7).

7) Testing of predictive models

After debating what the model validation entails and how model performance can be tested, by highlighting the issues and limitations at stake in archaeological prediction in general and in the underwater maritime environment specifically, the model performance was tested against the shipwrecks record. The latter constitutes an independent set of data as they were not employed as model input. Specific measures were taken to minimise the effects of data biases in the phase of testing.

8.3 ANSWERING THE RESEARCH QUESTIONS

In section 1.2 the relative shipwrecking probability was defined as the possibility that ships in transit would more likely sink in one location than in another, thus referring to the shipwreck-*event*, namely -borrowing Verhagen & Whitley words- an occurrence, action or behaviour bounded in space, which may have had physical consequences (conditions) that are at least partially observable today (Verhagen & Whitley, 2012, p. 72). In this research, the sinking probability implies a potential nautical threat, which does not necessarily lead to a ship-loss, as mariners may potentially avoid it, whereas to identify the locations that have the highest relative shipwrecking probability, two conditions should occur:

- a high probability of ships navigating the water-space
- a high probability of sinking due to navigation hazards

Whereas the high probability areas may result either from a high transit probability degree or from a high sinking probability, the areas with the greatest relative shipwrecking probability (RSP) are those where the two conditions together present the highest values (Figure 8.1). This seemingly incongruent synchronic occurrence of high transit probability and high navigation hazard reflects a misalignment between actual environmental hazards and perceived risks, hence between *actually* optimal routes and *assumed* optimal ones. By formally distinguishing actual and perceived optimal routes, it is possible to identify the areas with the greatest degree of shipwrecking probability, namely those with both a high transit and high nautical hazards, which would otherwise be counterintuitive to imagine combined. This hypothesis could be explored and tested at the regional scale by modelling transit probabilities without minimising the real environmental threats but rather by deriving information on risks and benefits of coastal proximity from the textual evidence. Whilst an exhaustive enquiry into risk perception in antiquity was beyond the scope of this research, the information provided in the *Stadiasmus* was employed as a proof of concept for implementing the shelters-attractiveness index. At the global scale, the overall model structure was maintained; the navigation hazards and transit probabilities were also modelled independently; however, the latter only included attractive factors (i.e. density of attractors) without specifically enquiring about perceived risks.

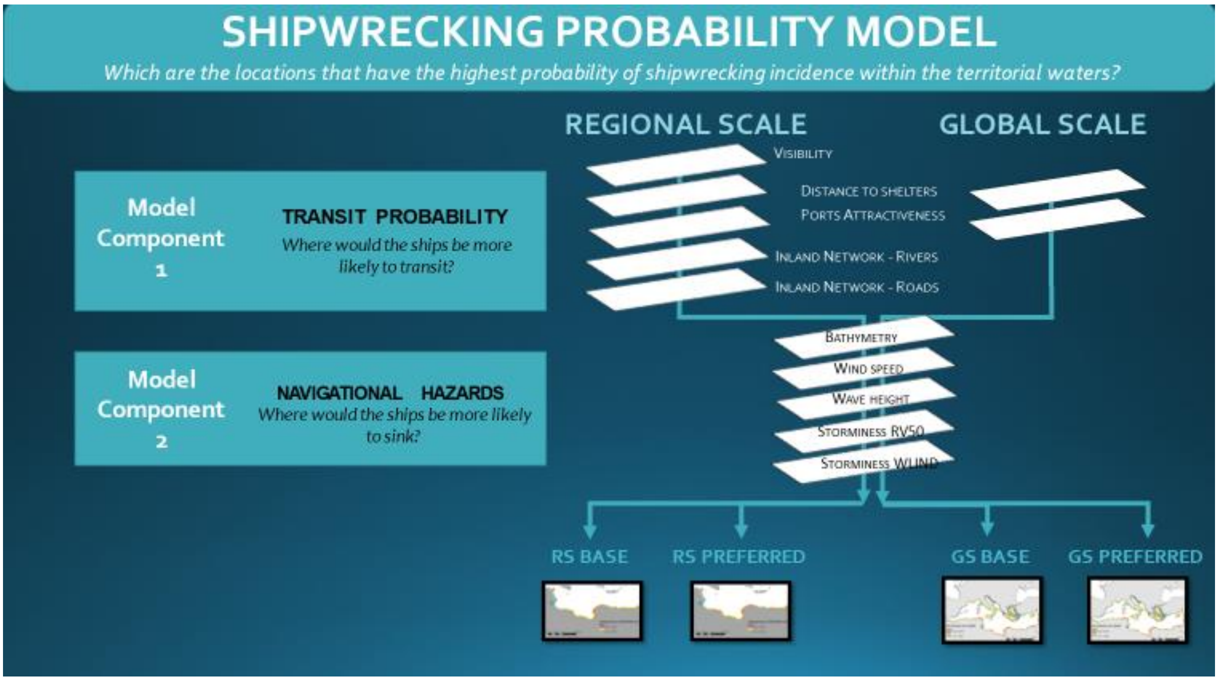

Figure 8.1: Shipwrecking Probability (RSP) models' structure

The sinking probabilities are associated with environmental conditions that scholarship consistently considers hazardous for navigation (e.g. storms, shallows, sandbanks and other unexpected geomorphological features) and for rig and oars propelled vessels more precisely (e.g. extreme wind conditions, high waves, lee shores, storms). As for the transit probability, the review of both the literature and the primary textual sources from the Classical period has evidenced that in the targeted study area, namely within the 12 NM zone, the shipping was driven by the necessity to balance advantages and disadvantages of coastal proximity. However, the categories of hazards and aids to navigation are not always easy to distinguish in binary terms as they are frequently blurred, depending on specific circumstances and individual needs and perceptions. Hence, numerous counterintuitive choices may be evidenced, such as approaching a rocky and dangerous shore to escape from the arrival of the enemy, choosing a port with fewer facilities to avoid tolls, or temporarily avoiding an otherwise safe coastal area due to adverse political conditions (Chapter 4). Although such a detailed canvas can hardly be modelled unless one focuses on a very specific research question (e.g. a specific time frame and geographical region), the above exceptions suggested discarding the deterministic assumption that the optimal and most-efficient corridor-routes in terms of length, duration, safety, would necessarily be preferred at least in the ways we would understand them nowadays. In chapter 7, a significant correlation between the high shipwrecking probability areas (i.e. class 5) and the shipwrecks data used as a control group was evidenced, thus confirming the predictive capability of the Global Scale model.

Within the debate around the environmental determinism characterising archaeological predictive modelling, this research gives an answer to the question of whether the inclusion of cultural and cognitive variables could improve the model performance and how this improvement could be tested (section 2.2.6, issue n. 3). Indeed, by referring back to Karl Popper's statement cited in the Introduction of this thesis

> "science may be described as the art of systematic oversimplification — the art of discerning what we may with advantage omit" (Popper, 1992, p. 44)

this research suggests that more than wondering how many or which types of cultural factors to include, designing a culturally based model architecture is crucial to avoid deterministic assumptions. The research highlighted a logic conundrum (section 5.1), which affects current modelling strategies and compromises the efficiency of models. This logic gap relates to the implementation of navigation hazards as areas that mariners would most likely seek to avoid following the nautical uniformitarianism principle (Deeben et al., 2002; McGrail, 1993; Irwin, 1992), and areas where vessels risk sinking while transiting there. To be more specific, mobility models minimize the transit in risky areas, whilst models focused on shipwrecks probability assign a high chance of shipwrecks presence (hence, a passage) in those same areas. Despite the plausibility of both these scenarios, this approach has two counterproductive consequences: first, it fosters the ambiguity associated with the presence of shipwrecks, as these may reflect both a nautical activity and an area of risk to navigation that the ship's captain did not manage to elude, deliberately challenged or ignored. Second, it prevents identifying the areas presenting the highest shipwrecking probability, namely those densely transited although extremely risky. By formally distinguishing the two, this model contributes to loosening the above ambiguity, and as such, it provides a useful tool for modellers interested in inductively employing the shipwrecks data to infer shipping and sinking potential in the future.

8.3.1 Comparing actual and perceived risk scenarios

The analysis of misalignments between actual and perceived risk (*Figure 8.2*) produces the following scenarios (A-D):

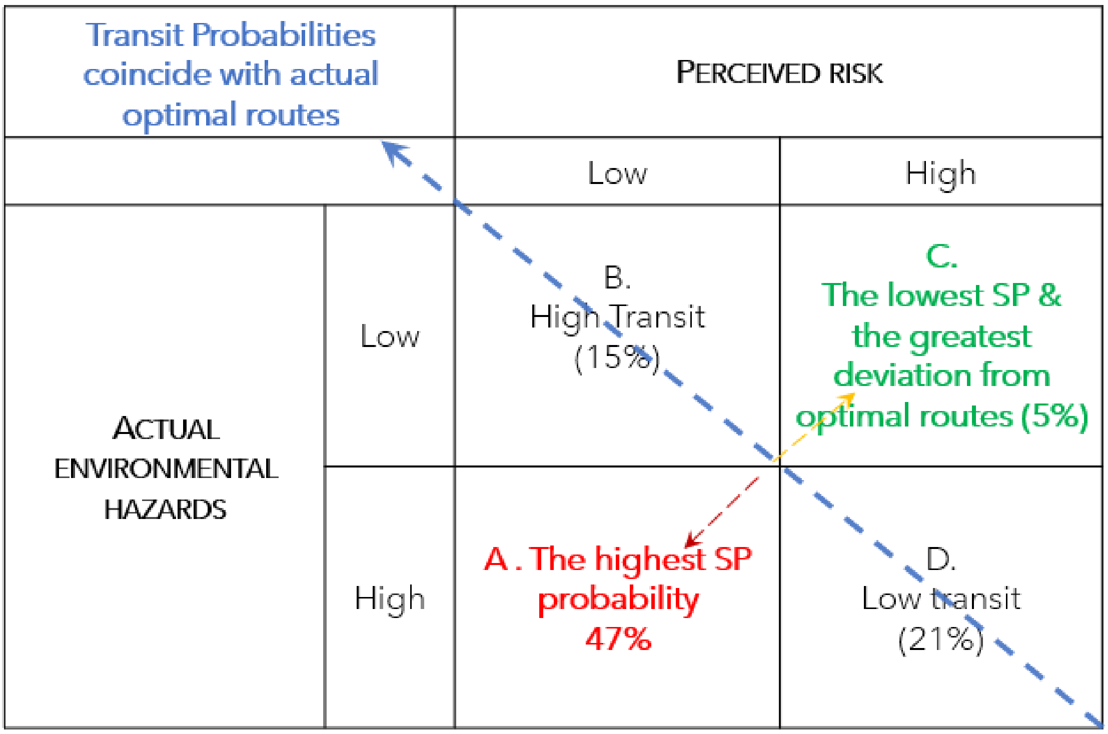

Figure 8.2.: The graph shows the four scenarios obtained based on the actual nautical hazards and the transit probabilities produced by accounting perceived risks. The percentages refer to the shipwrecks found in the correspondent areas identified by the Regional Scale model. The highest and lowest percentages matched the predicted scenario

A. When the Transit probability is high (i.e. classes 4 and 5), which implies low perceived risk, and the navigation hazard probability is high (i.e. Classes 4-5), we have the highest shipwrecking probability because mariners would not expect the threat and would go where the models driven by nautical uniformitarianism would not expect them to go. The regions satisfying these conditions are evidenced in *Figure 8.3*. Out of the total nineteen sites in the Regional case-study (section 7.4, Table 7.5), nine are registered in these areas (i.e. 47%).

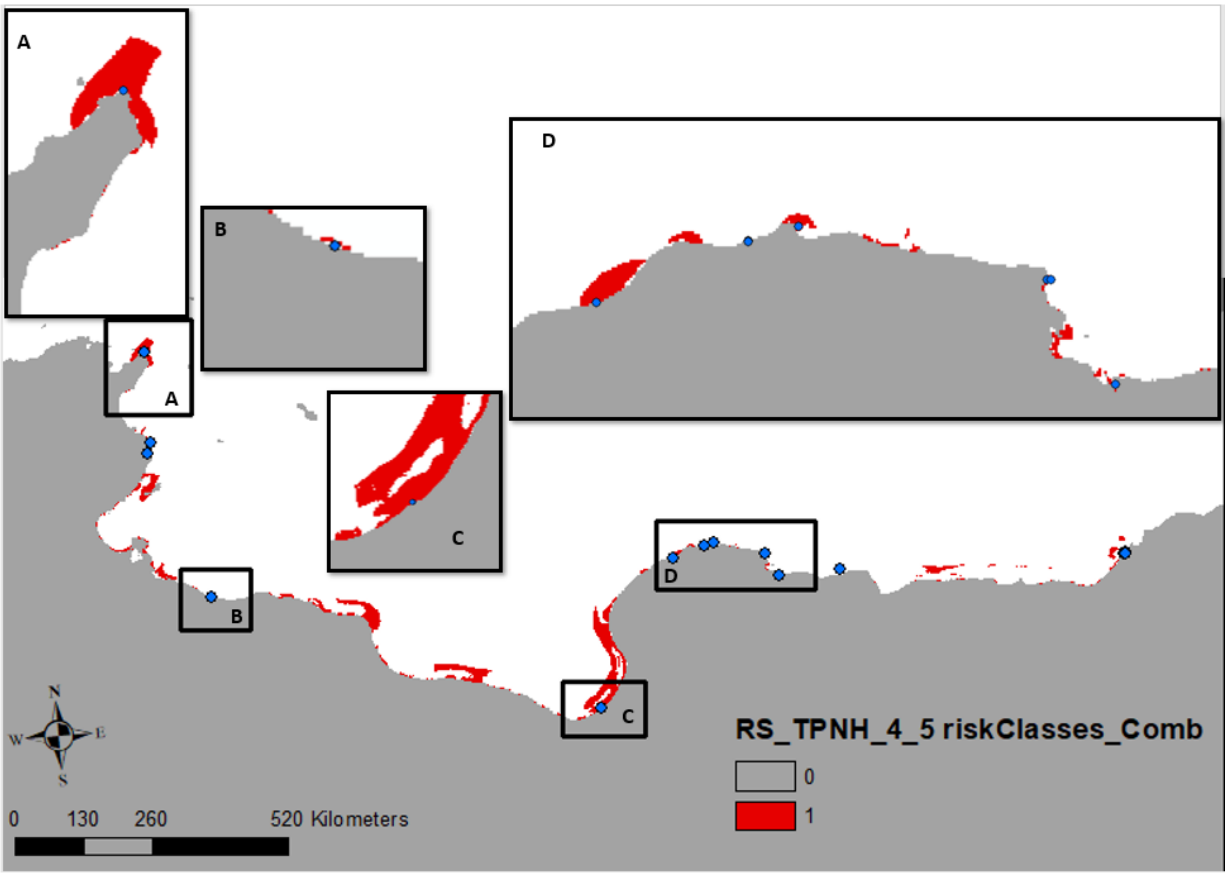

Figure 8.3: red denotes the areas where high navigation hazards (classes 4 and 5 in the RSP model) coincide with high transit probabilities (classes 4 and 5 in the SP model), which entail the highest shipwrecking probability. Nine out of the nineteen shipwrecks in the regional case study fall in these areas

B. When the perceived risk is low, and the actual hazards are low, we may expect a high degree of nautical activity, which may result in shipwrecks due to accidents that become statistically numerous over the millennia. This condition (*Figure 8.4*), reflects one of the two possible cases presenting an alignment between perceived and actual optimal routes (see also case D). Three out of the total nineteen sites in the Regional case study are registered in these areas (15%).

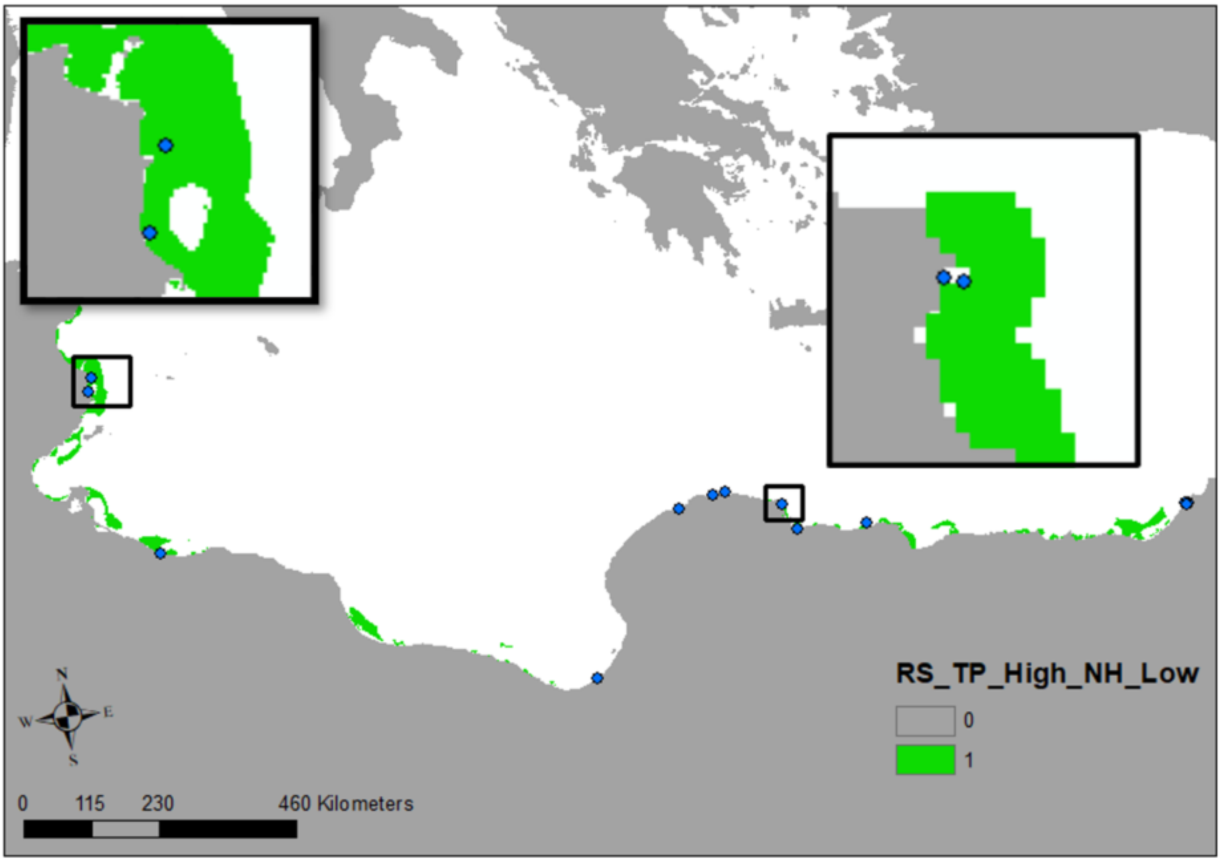

Figure 8.4: In green are the areas where high transit probabilities (classes 4 and 5 in the RSP model) coincide with low environmental hazards (classes 1 and 2 in the RSP model). Three out of the nineteen shipwrecks in the regional case study fall in these areas

C. Conversely, when the perceived risk is high -hence the transit probability is low-, but the actual hazards are low, we have the most significant deviation from optimal routes because the shipping flow may be lower than expected. The presence of shipwrecks in this area may result from accidental episodes (e.g. technological failure, human error, an assault), but given the lower movement potential, these are deemed to be statistically less numerous than in areas with equally low navigation hazards and high transit probability. This area corresponds to the one with the lowest RSP probability, and only one shipwreck out of the nineteen in the Regional study area is recorded in this zone (5%).

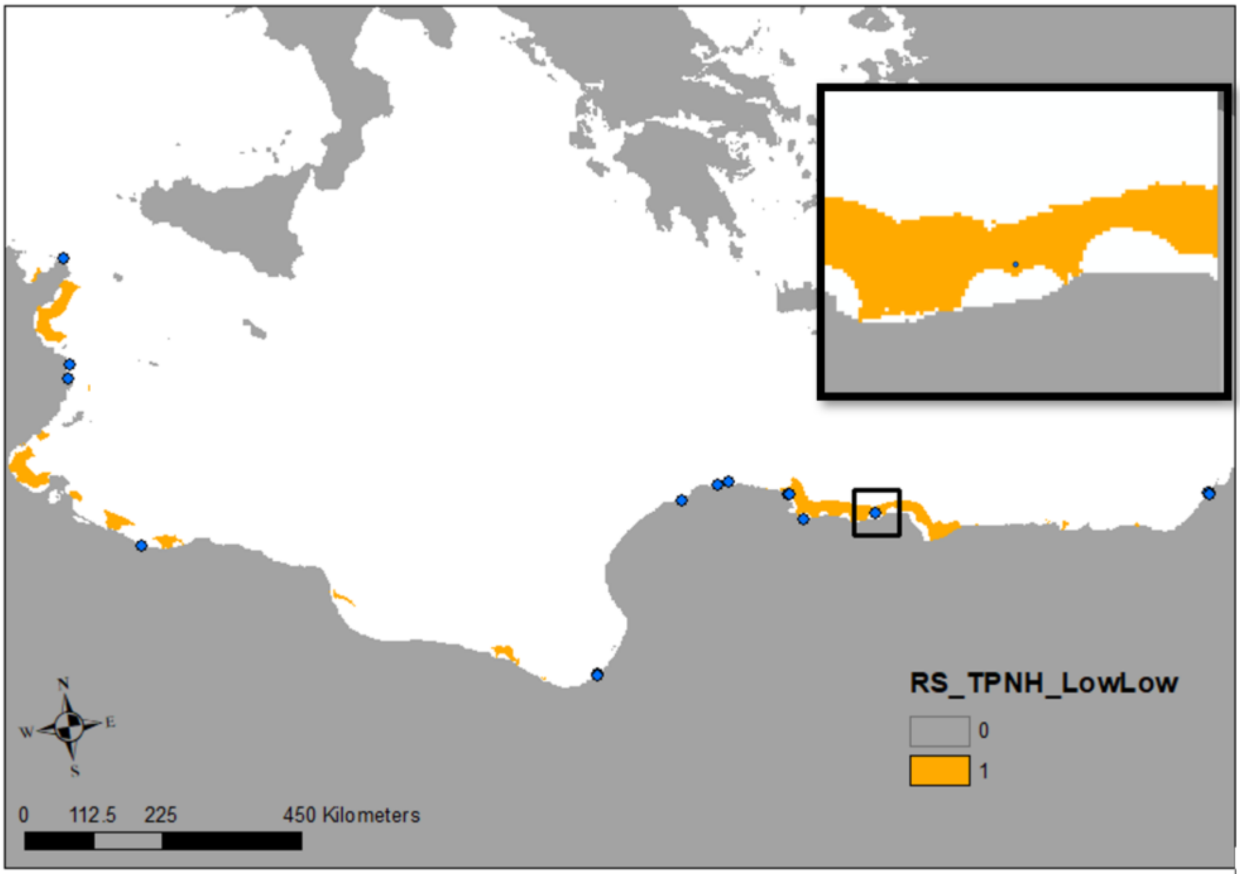

Figure 8.5: In orange are the areas where low navigation hazards (classes 1 and 2 in the RSP model) coincide with low transit probabilities (classes 1 and 2 in the RSP model), which entail a lower shipwrecking probability than expected from accounting optimal routes. Only one shipwreck is registered in these areas

D. Similarly, with high perceived risk (i.e. low Transit Probability) and high actual risk, we also have a lower than expected shipwrecks probability because mariners would avoid those areas; this is the second condition presenting an alignment with modelling based on the nautical uniformitarianism principle and the optimisation of nautical hazards. Shipwrecks in these zones may reflect unskilled mariners (i.e. ignorance) or risk-takers, namely mariners expecting the risks and deliberately ignoring them, either for competing and more important reasons, such as the necessity to run away from the enemy fleet, or for other compelling, e.g. economic advantages. Four shipwrecks out of the nineteen in the Regional study area are recorded in this zones (21%).

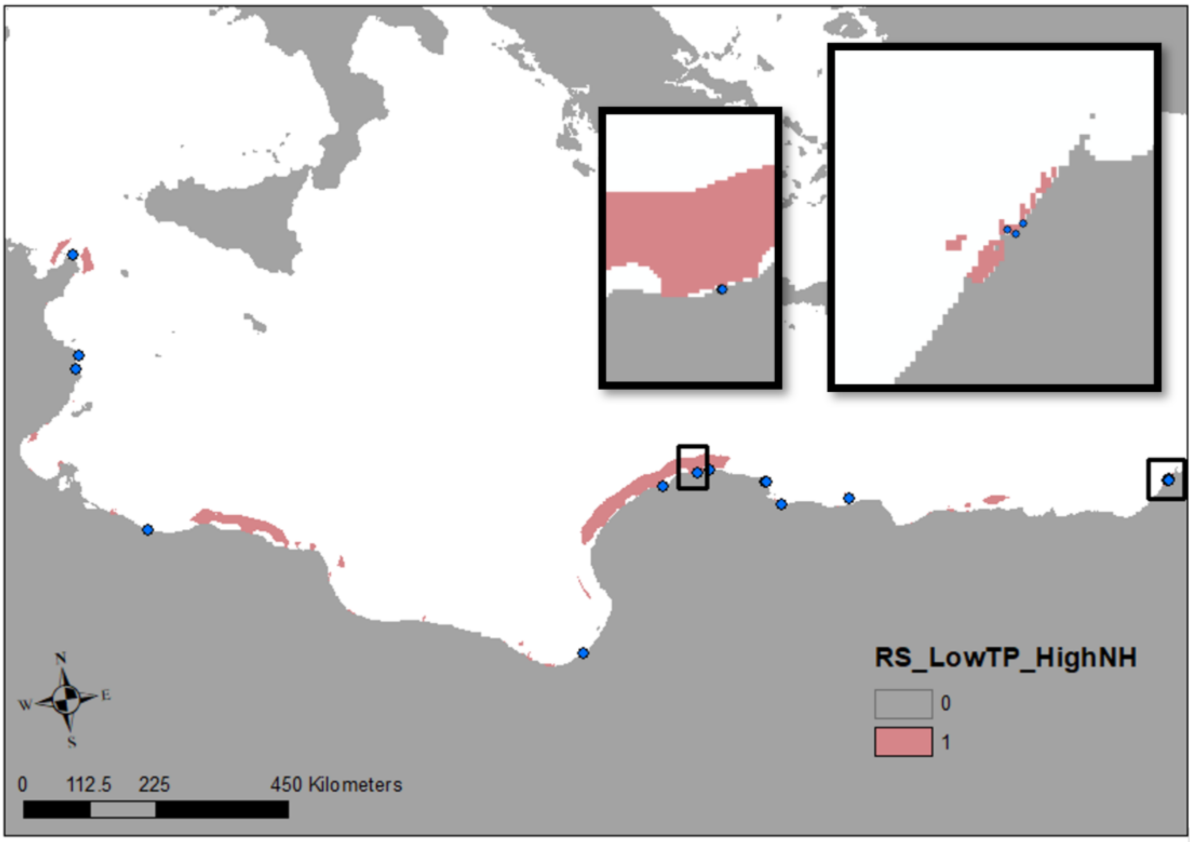

Figure 8.6: In coral are the areas where low transit probability (classes 1 and 2 in the RSP model) coincides with high navigation hazards (classes 4 and 5 in the RSP model). Four shipwrecks are recorded in these areas, although the sea space around Alexandria constitutes a known anomaly in the regional scale model for the reasons explained below in section 8.3

It is worth highlighting among the areas presenting low transit probability and high risk in this group, the striking but expected anomaly represented by the sea-space surrounding the city of Alexandria. Indeed, the regional scale model, which has in this city its eastern limit, assigns a low transit probability (classes 1 and 2 in the RSP model) and high navigation hazards (classes 4 and 5 in the RSP model) to this area. The risk degree is reported correctly; indeed already in the third century BC, it was necessary to build the famous lighthouse, or Pharos, of Alexandria, one of the seven wonders of the ancient world, for guiding ships into the port at night and allow them to avoid the numerous sandbanks in the area safely. Conversely, the transit probability around such a densely populated city (Russell, 1985), referred as *statio* in the *Piazzale delle Corporazioni* at Ostia (Rice, 2016) and that has been for centuries the primary node in the grain trade network to Rome along one of the major sea links documented in the Diocletian price edict (Parker, 2008), cannot be assumed to be low. The reason behind such anomaly is that the harbour of Alexandria is not included in the Regional case study because the *Stadiasmus* starts in Alexandria, but it provides indications from the port nearby. In the Global scale model, which employs a different method for calculating the port's attractiveness, the Transit probability around Alexandria is significantly high (Figure 8.7)

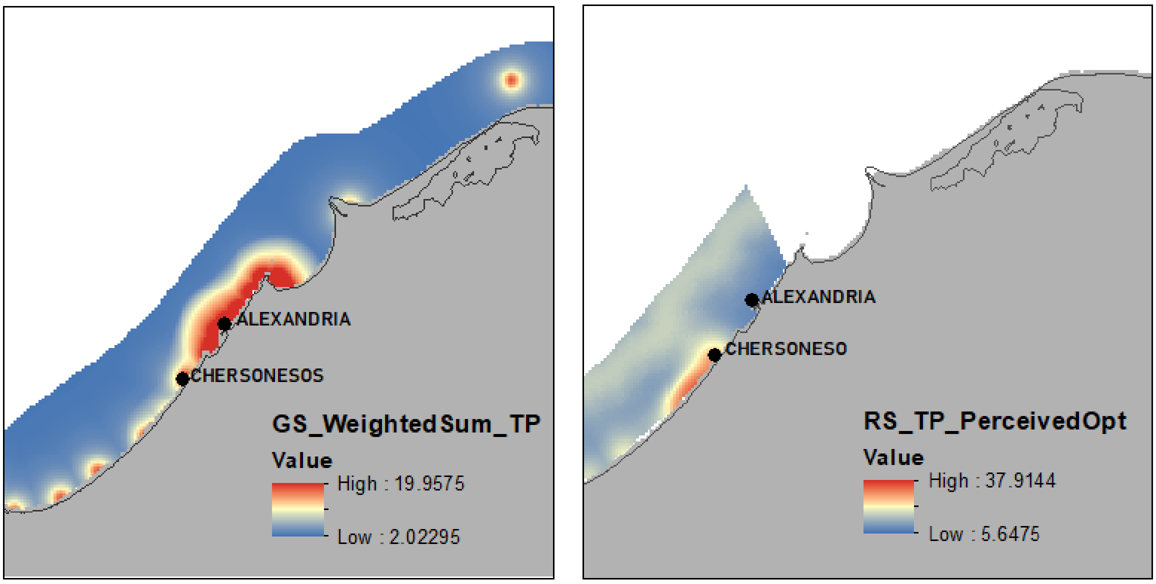

Figure 8.7: Different transit probabilities around Alexandria in the Regional scale model (to the right) and the Global scale model (to the left)

Given what has already been noted about the fact that the presence of a shipwreck may reflect both a nautical activity and an area of risk to navigation, this research has identified areas where shipwrecks are more likely to be due to high maritime activity and places where they may rather be associated to navigation hazards. Hence, besides indicating shipwrecking probabilities, the model also contributes to shed light on the ambiguity embodied in the shipwrecks presence.

8.3.2 The implications of absence: what information the model can provide

As explored in chapter 2, the *absence* of recorded sites in Mediterranean waters might be due to different conditions which vary in time and space:

a. unused routes (ships are unlikely to pass by)

b. safe routes (ships are likely to transit without sinking)

c. shipwreck-events without shipwreck-remains (ships do sink but post-depositional processes have dispersed any remains)

d. shipwreck-events with undetected shipwreck remains (shipwreck remains may lie unnoticed underwater)

e. shipwreck-events with detected but unpublished shipwreck remains

Bearing this in mind, it is crucial to ascertain what the model can predict and how to interpret the results (Figure 8.8). One may say that the model may be trusted if the identified high-risk areas correspond to regions where most of the recorded sites actually are. As the Kgain suggests this is the case, and the Chi-squared test indicates that this correlation is not due to chance; ergo, the high-risk areas where shipwrecks are not recorded yet, may represent areas with high discovery potential.

Conversely, the interpretation of low-probability areas is more ambiguous; the absence of shipwrecks in low-probability areas may be due to any of the conditions listed above and can thus not be tested at the present conditions. The presence of shipwrecks in low probability areas may either be due to circumstantial events (e.g. accidents, a human error), which do not affect the overall model-validity, or to factors that the model fails to consider or wrongly interprets.

As the model performance was tested against data, which overrepresent certain categories of remains and periods, it is possible to establish which areas have a higher probability of finding the groups included in the shipwreck dataset. The results cannot exclude for sure the presence of shipwrecks' remains where they are currently absent, as those underrepresented ship-categories may actually be present (e.g. post-medieval or modern ships). The above distinction does not necessarily constitute a downside of the model but rather an informed and targeted opportunity for improvement as explained in more detail in section 8.5.

It becomes crucial in future development of the present work (section 8.5) to model the wreck-formation processes to better predict the probability of the survival of remains. This research deliberately has not taken into account the post-depositional dynamics because the preservation potential varies depending on the type and size of materials. Hence, it is advisable to model these dynamics by addressing specific research questions at coarse scales. The identification of shipwrecking probabilities represents the essential first step in the assessment of shipwrecks-remains survival.

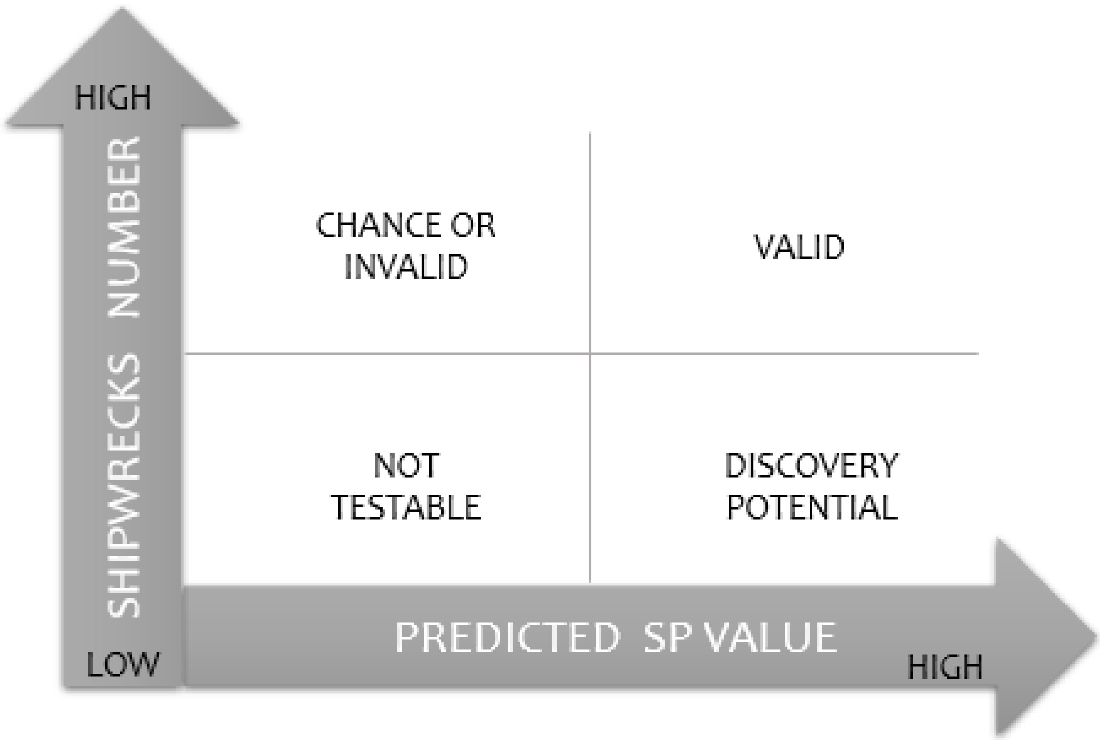

Figure 8.8: Information that the model may provide and reliability based on shipwrecks evidence

8.4 CONSTRAINTS AND POTENTIAL FOR IMPROVEMENTS

This research has adopted two different scales of analysis but still employs a bird's-eye approach, privileging approximations and averages over particular outcomes and large scales over local conditions. It focuses on developing a method to design tailored and adaptable shipwrecking probability models rather than being result-oriented; this affects both the theory development and the GIS implementation. As to the former, the heterogeneous and admittedly not comprehensive-textual evidence accessed was utilised for identifying categories of risks and benefits associated with the coastal proximity and for evidencing their blurred definitions and circumstantiality that impact the modelling architecture and its procedures. Whilst the *Stadiasmus* was employed to provide a proof of concept for the shelters' attractiveness, it was beyond the scope of this study to systematically look into coastal and spatial perception in antiquity, which is an issue that other researchers have attempted in tailored studies, and that would require the systematic analysis and comparison of multiple independent sources of evidence. Consequently, the textual sources could not be approached as rigorously as specialistic historical research would demand: the texts were accessed in English translations and the excerpts identified by querying keywords in digital libraries. This means that more documents could be found by broadening the research by looking at different terms and synonyms, retrieving other libraries, or accessing the evidence in the original language. Similarly, the survey was limited to Latin and Greek textual sources, but the screening of additional material (e.g. epigraphic, iconographic, papyrological) may return different information to compare and or complement. Despite the above limitations, this study attempts to integrate primary and secondary sources of evidence to compensate for archaeological data biases, contrary to most archaeological predictive models that do not rely systematically on historical datasets to develop their theory.

The GIS implementation developed in Chapter 6 works on macro scales and large temporal and spatial resolutions, implying that the model is inappropriate to analyse local conditions and variations (e.g. sea-level changes, the diachronic evolution of ports facilities). Technical constraints and deliberate choice dictated the selection of coarse scales. Technical limitations primarily relate to uneven input-data availability; however, increasing the data resolution would not necessarily be beneficial, e.g. when modelling weather-oceanographic conditions. Indeed, whilst an increased spatial resolution, e.g. of wind data, may overcome the effects of unknown localised wind systems found near the coastlines, the increased temporal resolution risks being detrimental when modelling historical phenomena, as long-term averages may better handle the effects of climate variations. If the model's reliability decreases with the scale, it also decreases with the distance from the coastline. Indeed, given the scope and the extension of the study, the transit probability models, both at the Global and Regional scales, were built based on the presence of supposed attractive and repulsive factors associated with the coastline; hence, the farther from the coast, the weaker the effect of these factors and hence the lower the predictive capability of the model.

8.5 FUTURE WORK

Given the inevitable limitations and constraints, but also the insights gained while developing this study, it would be worth expanding the research in the following three directions:

1) Model improvements
2) Broadening the scope
3) Applying alternative modelling strategies

Below each of these is briefly explored.

In light of the caveats expanded upon in the previous section, an obvious follow up would be applying alternative strategies for improving the model, for instance, by focusing on finer spatial-temporal resolutions. The identification of model improvements could be better informed by testing the model more efficiently through the collection of less biased shipwreck data, for instance, through targeted remote sensing surveys, particularly in the areas where no records are available yet; this would allow discerning whether the absence of sites reflects an actually low shipwreck probability, a low preservation potential or limitations in previous discoveries. With more reliable shipwrecks data, alternative and more sophisticated testing methods (e.g. constrained resampling, Monte Carlo Simulation) and model exploration software could be used for gaining insights on the model's sensitivity and performance; for instance, it would become possible to compare the model's performance in different geographical areas. Apart from testing the model against new discoveries, either purposedly found through tailored archaeological investigations or by chance, alternative approaches may include model testing against historical evidence, as discussed above with regard to the transit probability near Alexandria (section 8.3, Figure 8.7).

Even though models are, by definition, not meant to reflect the reality precisely, and as such, they cannot predict the totality of sites, the outliers or so-called idiosyncratic sites, namely shipwrecks that lie in predicted low probability areas, might suggest where the model should be improved and also hint at suitable strategies (Kvamme 2006, p. 6; Altschul 1990, Hasenstab and Resnick 1990, Altschul et al. 2004). For instance, conspicuous clusters of sites in low probability areas may reflect the impact of processes that have not been considered yet or considered unproperly. This aspect leads to the following point.

The high shipwrecking probability areas may provide the starting ground for implementing procedures to model post-depositional processes and preservation dynamics to predict the position of shipwreck remains more precisely. The model scope could also be expanded by addressing more precise research questions, for instance, referring to definite time periods or one specific phenomenon (e.g., changes in Mediterranean seafaring patterns with the spread of Islam; pilgrimage routes; patterns of movement and connectivity in relation to piracy). It would be worth exploring (and modelling) risk perception and spatial perception in Antiquity and the Middle Ages more systematically by considering multiple sources of evidence (e.g., textual, cartographical, iconographical, epigraphical). How does the risk-perception change across centuries? Is it possible to discern different patterns of movement resulting from variations in the risk perception? Lastly, although the model has been developed for the Mediterranean region, it provides a general framework and a toolkit, which might also be applied to different geographical contexts (e.g. the North Sea).

Combining different computational approaches may be particularly useful to further explore both the socio-cultural and spatial sphere of maritime interactions. The network approach to the study of archaeological and historical evidence for seaborne connectivity and mobility is increasingly employed and has brought outstanding contributions (section 2.2.5). In comparison, agent-based modelling has received less attention in the maritime historical and archaeological field. However, it might be extremely useful for analysing the interaction of different actors within the same environment (e.g. traders, pirates), and it may be useful to analyse the impact of seamanship and knowledge sharing in shaping patterns of movement.

8.6 CONCLUSION

This is the first maritime predictive model for shipwrecking probabilities in Mediterranean territorial waters and one of the few archaeological predictive models anywhere that formalises the entire procedure from theory building to testing while also addressing uncertainty factors. The fully documented ArcGIS procedure, which identifies shipwrecking probabilities in the 12 NM zone with a resolution of 1 square kilometre, is easy to reproduce, test and adapt by others. It encompasses some innovative factors, never before implemented in the archaeological domain, such as the different ways perceived and actual hazards impact shipwrecking probability modelling, the impact of Mediterranean storminess along the coast of the Mediterranean sea, and the implication of mutual visibility in coastal areas. This general model provides the foundation for including additional data to address more nuanced processes and answer more specific research questions in the future.

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APPENDICES AND SUPPLEMENTARY DOCUMENTS

Not comprised in this pdf are the digital attachments, which include the shipwrecks database combining OXREP and DARMC, and the ports database based on De Graauw

APPENDIX 1 – PRIMARY SOURCES

The following table contains a selection of excerpts from textual sources supporting the analysis of risks and benefits of coastal navigation and indicators of coastal proximity, as discussed in chapter 4. The information on the translations employed is accessible at the source links provided in the table, when not specified otherwise.

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 330 BCE	Aeschines, Against Ctesiphon, 112	Aeschin. In Ctes	ca. 330 BCE	[...] "Oaths" "Curse" This curse, these oaths, and this oracle stand recorded to this day; yet the Locrians of Amphissa, or rather their leaders, most lawless of men, did till the plain, and they rebuilt the walls of the harbor that was dedicate and accursed, and settled there and collected port-dues from those who sailed into the harbor and of the deputies who came to Delphi they corrupted some with money, one of whom was Demosthenes	https://topostext.org/work/106#112	port-dues
ca. 330 BCE	Aeschines, Against Ctesiphon, 119	Aeschin. In Ctes	ca. 330 BCE	You know of your own knowledge, and have no need of other witness, how these men have farmed out port-dues, and how they are making money from the sacred harbor	https://topostext.org/work/106#119	port-dues
Myth.	Aeschylus, Suppliant Maidens, 755	Aesch. Supp.	ca. 463 BCE	DANAUS: A fleet in getting under way is not so speedy, nor yet in anchoring, when the securing cables must be brought ashore; and even at anchorage shepherds of ships do not feel immediately secure, above all if they have arrived on a harborless coast when the sun is sinking into night	https://topostext.org/work/11#755	landing risks; harbourless coast
ca. 360 CE	Ammianus Marcellinus, History, 19.10.4	Amm. Marc.	ca. 390 CE	§ 19.10.4 And presently by the will of the divine power that gave increase to Rome from its cradle and promised that it should last forever, while Tertullus was sacrificing in the temple of Castor and Pollux at Ostia, a calm smoothed the sea, the wind changed to a gentle southern breeze, and the ships entered the harbour under full sail and again crammed the storehouses with grain.	https://topostext.org/work/493#19.10.4	land & sea breezes; nocturnal & diurnal winds
ca. 360 CE	Ammianus Marcellinus, History, 20.1.3	Amm. Marc.	ca. 390 CE	§ 20.1.3 Therefore, taking the light-armed auxiliaries, to wit the Aeruli, the Batavians, and two companies of Moesians, in the dead of winter the leader aforesaid came to Bononia, and after procuring ships and embarking all his troops, he waited for a favourable breeze and then sailed to Rutupiae, which lay opposite, and went on to Londinium, intending there to form his plans according to the situation of affairs and hasten quickly to take the field.	https://topostext.org/work/493#20.1.3	land & sea breezes; nocturnal & diurnal winds
ca. 50 CE	Anonymous, Periplus of the Erythraean Sea, 10	Per. Mar. Eryth	ca. 50 CE	Beyond Mundus, sailing toward the east, after another two days' sail, or three, you reach Mosyllum, on a beach, with a bad anchorage	https://topostext.org/work/491#10	bad anchorage
ca. 50 CE	Anonymous, Periplus of the Erythraean Sea, 12	Per. Mar. Eryth	ca. 50 CE	The anchorage is dangerous at times from the ground-swell, because the place is exposed to the north	https://topostext.org/work/491#12	dangerous anchorage; wind-direction

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 50 CE	Anonymous, Periplus of the Erythraean Sea, 20	Per. Mar. Eryth	ca. 50 CE	Navigation is dangerous along this whole coast of Arabia, which is without harbours, with bad anchorages, foul, inaccessible because of breakers and rocks, and terrible in every way	https://topostext.org/work/491#20	harbourless shore; geomorphological hazard
ca. 50 CE	Anonymous, Periplus of the Erythraean Sea, 24	Per. Mar. Eryth	ca. 50 CE	§ 24 The market-town of Muza is without a harbor, but has a good roadstead and anchorage because of the sandy bottom thereabouts, where the anchors hold safely	https://topostext.org/work/491#24	anchorage; bottom nature
ca. 50 CE	Anonymous, Periplus of the Erythraean Sea, 26	Per. Mar. Eryth	ca. 50 CE	Beyond Ocelis, the sea widening again toward the east and soon giving a view of the open ocean, after about twelve hundred stadia there is Eudaemon Arabia, a village by the shore, also of the Kingdom of Charibael, and having convenient anchorages, and watering-places, sweeter and better than those at Ocelis	https://topostext.org/work/491#26	watering (relative-quality)
ca. 46 BCE	Anonymous, Caesar's African War, 62	Caes. BAfr.	ca. 40 BCE	Cispius speedily reached his destination, whereas Aquila, lashed by a storm and unable to double the headland, gained a certain cove which was sheltered from the storm and afforded him and his squadron a fairly inconspicuous retreat	https://topostext.org/work/646	shelter during storm
ca. 50 CE	Anonymous, Periplus of the Erythraean Sea, 43	Per. Mar. Eryth	ca. 50 CE	For on the right at the very mouth of the gulf there lies a shoal, along and narrow, and full of rocks, called Herone, facing the village of Cammoni; and opposite this on the left projects the promontory that lies before Astacampra, which is called Papica, and is a bad anchorage because of the strong current setting in around it and because the anchors are cut off, the bottom being rough and rocky	https://topostext.org/work/491#43	shoals; bad anchorage
Myth.	Apollonius Rhodius, Argonautica, 1.922	Ap. Rhod. Argon	ca. 250 BCE	§ 1.922 Thence did they row with eagerness over the depths of the black Sea, having on the one side the land of the Thracians, on the other Imbros on the south; and as the sun was just setting they reached the foreland of the Chersonesus. There a strong south wind blew for them; and raising the sails to the breeze they entered the swift stream of the maiden daughter of Athamas; and at dawn the sea to the north was left behind and at night they were coasting inside the Rhoeteian shore, with the land of Ida on their right. And leaving Dardania they directed their course to Abydus, and after it they sailed past Percote and the sandy beach of Abarnis and divine Pityeia. And in that night, as the ship sped on by sail and oar, they passed right through the Hellespont dark-gleaming with eddies	https://topostext.org/work/126#1.922	breezes

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
Myth]	Apollonius Rhodius, Argonautica, 2.316	Ap. Rhod.	ca. 250 BCE	2.316"First of all, after leaving me, ye will see the twin Cyanean rocks where the two seas meet. No one, I ween, has won his escape between them. For they are not firmly fixed with roots beneath, but constantly clash against one another to one point, and above a huge mass of salt water rises in a crest, boiling up, and loudly dashes upon the hard beach. Wherefore now obey my counsel, if indeed with prudent mind and reverencing the blessed gods ye pursue your way; and perish not foolishly by a self-sought death, or rush on following the guidance of youth. First entrust the attempt to a dove when ye have sent her forth from the ship. And if she escapes safe with her wings between the rocks to the open sea, then no more do ye refrain from the path, but grip your oars well in your hands and cleave the sea's narrow strait, for the light of safety will be not so much in prayer as in strength of hands. Wherefore let all else go and labour boldly with might and main, but ere then implore the gods as ye will, I forbid you not. But if she flies onward and perishes midway, then do ye turn back; for it is better to yield to the immortals. For ye could not escape an evil doom from the rocks, not even if Argo were of iron.	https://topostext.org/work/126#2.316	use of birds
Myth.	Apollonius Rhodius, Argonautica, 4.885	Ap. Rhod. Argon	ca. 250 BCE	And soon they saw a fair island, Anthemoessa, where the clear- voiced Sirens, daughters of Achelous, used to beguile with their sweet songs whoever cast anchor there, and then destroy him	https://topostext.org/work/126#4.885	sirens
ca. 73 BCE	Appian, Mithridatic Wars, 11.77	App. Mith.	ca. 165 CE	Still they did not venture out to sea, but hugged the shore, because they were afraid of the army of Lucullus. Thus they were exposed to missiles on both sides, landward and seaward, and received a great many wounds, and after heavy slaughter took to flight.	https://topostext.org/work/496#11.77	attack-probability; unsafe shore
CA. 48 BCE	Appian, The Civil Wars, 2.9.59	App. B Civ.	ca. 160 CE	They prepared themselves for battle and began to discharge stones and darts, when suddenly the wind sprang up stronger than before, filled their great sails unexpectedly, and enabled them to complete their voyage without fear. The pursuers were left behind and they suffered severely from the wind and waves in the narrow sea and were scattered along a harbourless and rocky coast. With difficulty they captured two of Caesar's ships that ran on a shoal. Antony brought the remainder to the port of Nymphaeum.	https://topostext.org/work/498#2.9.59	dangerous costs: harbourless, rocky

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 38 BCE	Appian, The Civil Wars, 5.10.89	App. B Civ.	ca. 160 CE	89 Menodorus, apprehending that this rising storm would increase in violence, moved farther seaward and rode at anchor where, on account of the depth of water, the waves were less boisterous; and even here he had recourse to hard rowing to avoid being driven ashore. Some of the others followed his example, but most of them, thinking that the wind would soon subside, as it usually did in the springtime, moored themselves with anchors on either side, landward and seaward, and thrust out poles to prevent collisions with each other. As the wind grew more violent everything was thrown into confusion. The ships collided, broke their anchors, and were upset on the shore one after another. Cries of alarm and groans of pain were mingled together, and exhortations that fell upon deaf ears. […]So distressed were they by this unexampled tempest that those who were nearest the land feared the land, yet could not get sufficient offing to avoid collision with each other, for the narrowness of the place and its naturally difficult outlet, together with the force of the waves, the rotary motion of the wind, caused by the surrounding mountains, and the whirlpool of the deep, holding everything in its grasp, allowed neither tarrying nor escape.	https://topostext.org/work/498#5.10.89	storm; safe-depth; anchorage; waves-height; wave-strength; wind-speed; wind-direction; orography effect
CA. 36 BCE	Appian, The Civil Wars, 5.13.123	App. B Civ.	ca. 160 CE	They forthwith surrounded themselves with guards, and the ships of Octavius were anchored away from the shore, as it was said that Lepidus intended to set fire to them.	https://topostext.org/work/498#5.13.123	safe-distance assault-probability
ca. 170 CE	Apuleius, Metamorphoses, 5.11	Apul. Met.	ca. 100 CE	Don't look at or listen to those evil women, who with their murderous hostility, their disregard of the bonds of blood, you should not call sisters, as they lean from the cliff-top like Sirens and make the rocks echo with that fatal singing		sirens
ca. 350 BCE	Aristotle, Economics, 2.1347b	Aristot. Econ.	ca. 310 BCE	Accordingly they made proclamation that anyone, either citizen or alien, who had right of reprisal against any city or individual, and wished to exercise it, should have his name entered on a list	https://topostext.org/work/731	
ca. 350 BCE	Aristotle, Economics, 2.1350a	Aristot. Econ.	ca. 310 BCE	Callistratus, when in Macedonia, caused the harbor-dues, which were usually sold for twenty talents, to produce twice as much. For noticing that only the wealthier men were accustomed to buy them because the sureties for the twenty talents were obliged to show talent for talent, he issued a proclamation that anyone might buy the dues on furnishing securities for one-third of the amount, or as much more as could be procured in each case.	https://topostext.org/work/731	port-dues

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ca. 360 BCE	Aristotle, History of Animals, 8.12.7	Arist. Hist. an.	ca. 350 BCE	When quails come to land, if it be fair weather or if a north wind is blowing, they will pair off and manage pretty comfortably; but if a southerly wind prevail they are greatly distressed owing to the difficulties in the way of flight, for a southerly wind is wet and violent (-)	https://topostext.org/work/101	
ca. 335 BCE	Arrian, Anabasis of Alexander, 1.3.1	Arr. Anab.	ca. 150 CE	The shores of the island, also, were in most places too steep and precipitous for landing, and the current of the river alongside it was rapid and exceedingly difficult to stem, because it was shut up into a narrow channel by the nearness of the banks.	https://topostext.org/work/205#1.3.1	landing sites sandbanks
ca. 335 BCE	Arrian, Anabasis of Alexander, 2.1.2	Arr. Anab.	ca. 150 CE	[…] he Memnon] put in at Mytilene [in Lesbos]…part of his fleet guarded the Mytilenean harbour; other ships he despatched to the [westerly] promontory of Lesbos, Sigrion, where cargo vessels from Chios and Geraistos and Malea usually put in, and so he patrolled the coast, to prevent help from coming to Mytilene by sea	https://topostext.org/work/205	shipping control
ca. 335 BCE	Arrian, Periplus of the Euxine Sea, 32	Arr. Peripl.	ca.131 CE	Manca un pezzo] fly out to sea and having moistened their wings, fly back again to the temple where they sprinkle the pavement with the moisture and clean it	https://topostext.org/work/203	land & sea breezes; nocturnal & diurnal winds
ca. 335 BCE	Arrian, Periplus of the Euxine Sea, 4	Arr. Peripl.	ca.131 CE	§ 4 Having then sailed from Trapezus, we arrived the first day at the port of Hyssus, and exercised the foot-soldiers we found there. This body of men, as You know, consists of foot, although they have besides belonging to them twenty horsemen, who are designed for private services only. It has however been found necessary for these men sometimes to act in the capacity of those who throw javelins. Thence we sailed, at first only with the breezes which blow early in the morning from the mouths of the rivers, using however oars at the same time. These breezes were indeed cool, as Homer expresses himself, but not sufficiently strong for us, who wished for a quick voyage. A calm soon followed, when we were reduced to depend upon our oars only. Soon after a cloud suddenly arising burst nearly in an easterly direction from us, and brought on a violent storm of wind, which was entirely contrary to the course that we held, and from the fatal effects of which we had a narrow escape. For it almost instantly produced such a swell of the sea, as to make it appear hollow to the view, and caused a deluge of water to break not only over that part of the ship where the benches of the rowers were placed, but also over the part which is between them and the poop. Our situation was then truly tragical, since as fast as we pumped out the water, so fast did it burst in upon us. The swell of the sea did not however bear upon the side of our vessel; and from this circumstance we were enabled, although with great trouble and difficulty, to make use of our oars, and, after much distressful suffering, to arrive at Athenae.	https://topostext.org/work/203	land & sea breezes; wind-strength; storms; swell;

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ca. 1 BCE	Athenaeus, of Naucratis, Deipnosophistae, 14.47	Ath.	ca. 228 CE	But as for the proverbial saying, 'The ἐπιφόρημα of Abydos,' that is a kind of tax and harbour-due; as is explained by Aristides in the third book of his treatise on Proverbs	https://topostext.org/work/218#14.47	port-dues
ca. 1 BCE	Aulus Gellius, Attic Nights, 16.8	Gell. N.A.	ca. 160 CE	But when you have made some progress, then finally its advantages will become clear to you, and a kind of insatiable desire for acquiring it will arise; so much so, that if you do not set bounds to it, there will be great danger lest, as many others have done, you should reach a second childhood amid those mazes and meanders of logic, as if among the rocks of the Sirens	https://topostext.org/work/208	sirens
ca. 483 BCE	Bacchylides, Epinician Odes, 13.120	Bacchyl.	ca. 450 BCE	§ 13.120 shaking his murderous spear. But when the fearless son of the violet-garlanded Nereid withdrew from battle — as when the North wind, on the dark-blossoming sea, [125] afflicts the spirits of men beneath the waves, when it comes upon them as night begins, but it withdraws with the break of Dawn, who shines on mortals, and a gentle breeze smooths the sea;	https://topostext.org/work/16#13.120	land & sea breezes; nocturnal & diurnal winds
ca. 70 BCE	Cicero, Against Verres 2.2.185	Cic. Verr.	ca. 70 BCE	By these exportations, of which the list was read to you, he writes that the shareholders had lost sixty thousand sesterces by the five per cent due on them as harbour dues at Syracuse. In a few months, therefore, as these little insignificant books show, things were stolen by the praetor and exported from one single town of the value of twelve hundred thousand sesterces	https://topostext.org/work/131#2.2.185) - ca. 70 BCE	port-dues
ca. 70 BCE	Cicero, Against Verres 2.2.171	Cic. Verr.	ca. 70 BCE	But Canuleius, who had an agency at Syracuse, in the harbour, had also written accounts to his shareholders of many of Verres's robberies, giving instances, especially, concerning things which had been exported from Syracuse without paying the harbour dues	https://topostext.org/work/131#2.2.171	port-dues
ca. 50 BCE	Cicero, de Finibis Bonorum, 5.49	Cic. Fin	ca. 45 BCE	§ 5.49 For my part, I believe Homer had something of this sort in view in his imaginary account of the songs of the Sirens. Apparently, it was not the sweetness of their voices or the novelty and diversity of their songs, but their professions of knowledge that used to attract the passing voyageurs; it was the passion for learning that kept men rooted to the Sirens' rocky shores. […]	https://topostext.org/work/615#5.49	sirens
ca. 59 BCE	Cicero, Letters to Atticus, Att. 2.16	Cic. Att.	ca. 59 BCE	Besides, if there is anything that more than another could inflame the feeling of the aristocrats, who are, I notice, already irritated, it is this; and all the more that with port-dues in Italy abolished, and the Campanian land divided, what home revenue is there except the five per cent	https://topostext.org/work/785	port-dues (local abolition)

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ca. 60 BCE	Cicero, Letters to his Friends, 60.29.2	Cic. Fam.	ca. 60 BCE	But how much bitterness of feeling is caused to allies by that question of the publicani we have had reason to know in the case of citizens who, when recently urging the removal of the port-dues in Italy, did not complain so much of the dues themselves, as of certain extortionate conduct on the part of the collectors	https://topostext.org/work/136	port-dues
ca. 350 BCE	Demosthenes 35, Against Lacritus, 29	Dem. 35	ca. 350 BCE	While we thus approached them, we at the same time kept an eye on them to see whether they disembarked anything from the ship or paid any harbour-dues	https://topostext.org/work/435	port-dues
ca. 350 BCE	Demosthenes 35, Against Lacritus, 30	Dem. 35	ca. 350 BCE	§ 30 But when they had been in town a good many days, and we found that nothing had been disembarked from the ship, nor had any harbour-dues been paid in their name, we began from then on to press them more and more with our demands	https://topostext.org/work/435	port-dues
Myth.	Dictys Cretensis, Trojan War Chronicle, 6.5	Dict. Cret.	ca. 100 CE	Then on past the rocks of the Sirens, whom he had cleverly eluded. And then, finally, he had lost most of his ships and men to Scylla and Charybdis, that savage, whirling pool that sucks down everything within its reach	https://topostext.org/work/152	sirens
ca. 1 BCE	Dio Chrysostom, Orationes 33.35	Dio Chrys. Or	ca. 112 CE	[…] I for my part would not choose to hear even the pipes constantly; nay, if there exists a place in which there is a constant sound of pipes or song or lyres, as indeed they say is the case with the Sirens' crag, which ever resounds with melody, I could not bring myself to go and live there	https://topostext.org/work/197#33.35	sirens
ca. 1 BCE	Dio Chrysostom, Orationes 33.41	Dio Chrys. Or	ca. 112 CE	I believe it is more appropriate for a man of sense to plug his ears with wax in a city like yours than if he chanced to be sailing past the Sirens. For there one faced the risk of death, but here it is licentiousness, insolence, the most extreme corruption that threatens	https://topostext.org/work/197#33.41	sirens
Myth.	Diodorus Siculus, Historical Library, 1.67.8	Diod. Sic.	ca. 49 BCE	10 For his predecessors in power had consistently closed Egypt to strangers, either killing or enslaving any who touched its shores.	https://topostext.org/work/133#1.67.8	assault-probability unfriendly shores

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ca. 100 BCE	Diodorus Siculus, Historical Library, 1.31.1	Diod. Sic.	ca. 49 BCE	Having spoken of the three boundaries of Egypt, by which it is distinguished from the rest of the continent, we now proceed to the next. The fourth side is nearly surrounded by a vast sea, without any harbours, being a very long and tedious voyage, and very difficult to find any place of landing. For from Parcetonium in Africa, to Joppa in Coele Syria, for the space almost of five thousand furlongs, there is not one safe harbour to be found, except Pharus. Then again all along the coasts of Egypt, the sea is full of rocks and sands, not discernible by mariners unacquainted with the places; so that when they look upon themselves as safe, and to have escaped the danger of the seas, and make with great joy to land (wanting skill to steer aright), they are on a sudden and unexpectedly shipwrecked. Others inconsiderately, because they cannot see the land, in regard it lies so low, are carried either into the bogs or to the deserts. And in this manner is Egypt naturally guarded on every side.	https://topostext.org/work/133#1.31.1	lack of landing sites; risk due to poor visibility; shallows; ignorance of the places

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ca. 100 BCE	Diodorus Siculus, Historical Library, 3.40.1	Diod. Sic.	ca. 49 BCE	After sailing past these regions one finds that the coast is inhabited by many nations of Ichthyophagi and many nomadic Trogodytes. Then there appear mountains of all manner of peculiarities until one comes to the Harbour of Soteria, as it is called, which gained this name from the first Greek sailors who found safety there. 2 From this region onwards, the gulf begins to become contracted and to curve toward Arabia. And here it is found that the nature of the country and of the sea has altered by reason of the peculiar characteristic of the region; 3 for the mainland appears to be low as seen from the sea, no elevation rising above it, and the sea, which runs to shoals, is found to have a depth of no more than three fathoms, while in colour it is altogether green. The reason for this is, they say, not because the water is naturally of that colour, but because of the mass of seaweed and tangle which shows from under water. 4 For ships, then, which are equipped with oars the place is suitable enough since it rolls along no wave from a great distance and affords, furthermore, fishing in the greatest abundance; but the ships which carry the elephants, being of deep draft because of their weight and heavy by reason of their equipment, bring upon their crews great and terrible dangers. 5 For running as they do under full sail and often times being driven during the night before the force of the winds, sometimes they will strike against rocks and be wrecked or sometimes run aground on slightly submerged spits. The sailors are unable to go over the sides of the ship because the water is deeper than a man's height, and when in their efforts to rescue their vessel by means of their punting-poles they accomplish nothing, they jettison everything except their provisions; but if even by this course they do not succeed in effecting an escape, they fall into great perplexity by reason of the fact that they can make out neither an island nor a promontory nor another ship near at hand; — for the region is altogether inhospitable and only at rare intervals do men cross it in ships. 6 And to add to these evils, the waves within a moment's time cast up such a mass of sand against the body of the ship and heap it up in so incredible a fashion that it soon piles up a mound round about the place and binds the vessel, as if of set purpose, to the solid land.	https://topostext.org/work/133#3.40	water-colour; shoals; low-visible shoreline

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ca. 100 BCE	Diodorus Siculus, Library, 3.41.1.3	Diod. Sic.	ca. 49 BCE	The passage by sea is broken up by islands which, though they bear no cultivated fruit, support varieties of birds which are peculiar to them and marvellous to look upon. 4 After this place the sea is quite deep and produces all kinds of sea-monsters of astonishing size, which, however, offer no harm to men unless one by accident falls upon their back-fins; for they are unable to pursue the sailors, since when they rise from the sea their eyes are blinded by the brilliance of the sun. These, then, are the farthest known parts of the Trogodyte country, and are circumscribed by the ranges which go by the name of Psebaean.	https://topostext.org/work/133#3.41.1	local birds; sea-monsters
ca. 100 BCE	Diodorus Siculus, Library, 3.43.4	Diod. Sic.	ca. 49 BCE	§ 3.43.4 After one has sailed past this country the Laeanites Gulf comes next, about which are many inhabited villages of Arabs who are known as Nabataeans. This tribe occupies a large part of the coast and not a little of the country which stretches inland, and it has a people numerous beyond telling and flocks and herds in multitude beyond belief. 5 Now in ancient times these men observed justice and were content with the food which they received from their flocks, but later, after the kings in Alexandria had made the ways of the sea navigable for the merchants, these Arabs not only attacked the shipwrecked, but fitting out pirate ships preyed upon the voyagers, imitating in their practices the savage and lawless ways of the Tauri of the Pontus; some time afterward, however, they were caught on the high seas by some quadriremes and punished as they deserved.	https://topostext.org/work/133#3.43.4	assault-probability; pirates
ca. 100 BCE	Diodorus Siculus, Library, 3.44.6	Diod. Sic.	ca. 49 BCE	8 Furthermore, it is exceptionally well supplied with water, since a river, larger than ordinary, empties into it, and it contains in its centre an island which is abundantly watered and capable of supporting gardens. In general, it resembles most closely the harbour of Carthage, which is known as Cothon, of the advantages of which we shall endeavour to give a detailed discussion in connection with the appropriate time	https://topostext.org/work/133#3.44	watering

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ca. 100 BCE	Diodorus Siculus, Historical Library, 3.46.1.4-5	Diod. Sic.	ca. 49 BCE	[Arabia] For a divine thing and beyond the power of words to describe seems the fragrance which greets the nostrils and stirs the senses of everyone. Indeed, even though those who sail along this coast may be far from the land, that does not deprive them of a portion of the enjoyment which this fragrance affords; for in the summer season, when the wind is blowing off shore, one finds that the sweet odours exhaled by the myrrh-bearing and other aromatic trees penetrate to the near-by parts of the sea; and the reason is that the essence of the sweet-smelling herbs is not, as with us, kept laid away until it has become old and stale, but its potency is in the full bloom of its strength and fresh, and penetrates to the most delicate parts of the sense of smell. 5 And since the breeze carries the emanation of the most fragrant plants, to the voyagers who approach the coast there is wafted a blending of perfumes, delightful and potent, and healthful withal and exotic, composed as it is of the best of them, seeing that the product of the trees has not been minced into bits and so has exhaled its own special strength, nor yet lies stored away in vessels made of a different substance, but taken at the very prime of its freshness and while its divine nature keeps the shoot pure and undefiled	https://topostext.org/work/133#3.46.1	breeze-smell; indicators of coastal proximity
ca. 425 BCE	Diodorus Siculus, Historical Library, 12.62.1	Diod. Sic.	ca. 49 BCE	For when the captains of the triremes lacked the courage to bring the ships to land because of the rugged nature of the shore, he, being himself the commander of a trireme, called out in a loud voice to the pilot, ordering him not to spare the vessel but to drive the trireme at full speed to the land; for it would be disgraceful, he cried, for Spartans to be unsparing of their lives as they fought for victory, and yet to spare their vessels and to endure the sight of Athenians holding the soil of Laconia. 3 And finally he succeeded in forcing the pilot to drive the ship forward and, when the trireme struck the shore, Brasidas, taking his stand on the gangway, fought off from there the multitude of Athenians who converged upon him. And at the outset he slew many as they came at him, but after a while, as numerous missiles assailed him, he suffered many wounds on the front of his body.	https://topostext.org/work/134#12.62.1	rugged shore; hazardous landing
ca. 397 BCE	Diodorus Siculus, Historical Library, 14.49.1	Diod. Sic.	ca. 49 BCE	The admiral who had been dispatched carried out his orders with promptness and entered the harbour of the Syracusans by night while everyone was ignorant of what had taken place. Attacking unawares, he rammed the vessels lying at anchor along the shore, sank practically all of them, and then returned to Carthage.	https://topostext.org/work/134#14.49.1	assault-probability; unsafe shore

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ca. 397 BCE	Diodorus Siculus, Historical Library, 14.50.1	Diod. Sic.	ca. 49 BCE	Since his appearance took the enemy by surprise, he disabled some of the vessels anchored along the shore by ramming and others by burning, for Dionysius was unable to come to their defence	https://topostext.org/work/134#14.50.1	assault-probability;
ca. 396 BCE	Diodorus Siculus, Historical Library, 14.68.1	Diod. Sic.	ca. 49 BCE	After the battle, when strong winds sprang up and the Carthaginians were forced to haul their fleet up on land, he had a most favourable opportunity for victory; [7] for the land forces of the enemy had not yet arrived and the violent storm was driving the enemy's ships on the shore. At that time, if we had all attacked on land, the only outcomes left the enemy would have been, either to be captured with ease, if they left their ships, or to strew the coast with wreckage, if they matched their strength against the waves.	https://topostext.org/work/134#14.68.1	storm shore
ca. 359 BCE	Diodorus Siculus, Historical Library, 16.5.1	Diod. Sic.	ca. 49 BCE	In Apulia he founded two cities because he wished to make safe for navigators the passage across the Ionian Sea; for the barbarians who dwelt along the coast were accustomed to put out in numerous pirate ships and render the whole shore along the Adriatic Sea unsafe for merchants.	https://topostext.org/work/134#16.5.1	pirates; assault-probability; unsafe shore
ca. 306 BCE	Diodorus Siculus, Historical Library, 20.74.1	Diod. Sic.	ca. 49 BCE	1 As for Demetrius, after setting sail from Gaza about midnight, since the weather at first was calm for several days, he had his transports towed by the swifter ships; then the setting of the Pleiades overtook them and a north wind arose, so that many of the quadriremes were driven dangerously by the storm to Raphia, a city which affords no anchorage and is surrounded by shoals.	https://topostext.org/work/134#20.74.1	harbourless shores; city without anchorages; shoals; storm; contrary winds
ca. 1 BCE	Dionysius of Alexandria (Periegetes), Guide to the Inhabited World, 90	Dionys. Per.	ca. 125 CE	Indeed it also stretches towards the Iapygian land. From there the swell of the Adriatic grows wide and stretches towards the north, and again towards the western corner, and those dwelling nearby also call it the Ionian sea	https://topostext.org/work/201	swell

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ca. 1 BCE	Dionysius of Byzantium, Anaplous of the Bosporos, 77	Dion. Byz.	ca. 100 CE	§ 77 At the summit of the hill after Chrysorroas stands the tower of Timaia, very high, visible from all sides, and conspicuous from far at sea, built for the safety of navigators. For both parts of Pontos lack ports that can take large ships. For the long shore of the restless and turbulent sea has inlets in neither continent. From this tower flaming torches used to be kept lit at night as a guide of the correct way to the mouth of the Pontos. But the barbarians stole away confidence in the true torches by putting fraudulent torches on the shore of Salmydessos to lead sailors astray and cause shipwrecks. For the shore there is harborless and the shallows, by reason of the excess of water, are not firm for anchors, so a shipwreck is prepared for those who stray from the right road and confuse the true signs with false indications. But now all-consuming time has extinguished the lamp and much of the tower has collapsed.	https://topostext.org/work/619#77	human hazard; fake torches; shallows; harbourless shore
Myth.	Dionysius of Halicarnassus, Antiquitates Romanae, 1.56.1	Dion. Hal. Ant. Rom.	ca. 7 BCE	But Aeneas, — for the oracles seemed now to be fulfilled, — observing that the place was not only in a poor part of the land, but also at a distance from the sea, and that even the latter did not afford a safe anchorage, found himself in great perplexity whether they ought in obedience to the oracle to settle there, where they would lead a life of perpetual misery without enjoying any advantage, or ought to go farther in search of better land	https://topostext.org/work/139#1.56.1	unsafe anchorage
Myth.	Dionysius of Halicarnassus, Antiquitates Romanae, 20.9.1	Dion. Hal. Ant. Rom.	ca. 7 BCE	ca. 280 BCE For, though the ships, upon putting out from the harbour, found a land breeze and made progress, an adverse wind sprang up, and holding through the entire night, sank some of them, drove others into the Sicilian strait, and, in the case of those in which the offerings and the gold yielded by the offerings was being transported, drove them ashore on the beaches of Locri	https://topostext.org/work/139#20.9.1	untrustworthy breezes
Myth.	Euripides, Heracleidae, 425	Eur. Heracl.	ca. 429 BCE	IOLAUS: My children, we are even as those mariners, who have escaped the storm's relentless rage, and have the land almost within their reach, but after all are driven back from shore by tempests to the deep again. Even so we, just as we reach the shore in seeming safety, are being thrust back from this land	https://topostext.org/work/35#425	unpredictability; uncontrolled course
Myth.	Eusebius, Chronography, 7	Euseb. Chron.	ca. 325 CE	[…] After doing all that he was bidden, [Xisuthrus] entered the vessel with his wife, children, and closest friends. Then the deluge came. As soon as it had receded, Xisuthrus released some birds. However, when they were unable to find anything to eat or any place to perch, he took them back on board. A few days later, he again released some birds, and they too returned to the ship, but this time their claws were covered with mud. Finally, he released them a third time, and this time they did not return to the ship. By this Xisuthrus realized that the ground had become visible […]	https://topostext.org/work/531#7	birds; landfall direction; indicators of coastal proximity

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ca. 25 BCE	Flavius Josephus, Jewish Antiquities, 15.9.6	Joseph. AJ	ca. 94 CE	This city is situated in Phoenicia, in the passage by sea to Egypt, between Joppa and Dora which are lesser maritime cities, and not fit for havens, on account of the impetuous south winds that beat upon them, which rolling the sands that come from the sea against the shores, do not admit of ships lying in their station, but the merchants are generally there forced to ride at their anchors in the sea itself.	https://topostext.org/work/526#15.9.6	wind; unsafe anchorage
ca. 25 BCE	Flavius Josephus, Jewish War, 1.408	Joseph. BJ	ca. 75 CE	[...] for the case was this, that all the sea-shore between Dora and Joppa, in the middle, between which this city is situated, had no good haven, insomuch that every one that sailed from Phoenicia for Egypt was obliged to lie in the stormy sea, by reason of the south winds that threatened them; which wind, if it blew but a little fresh, such vast waves are raised, and dash upon the rocks, that upon their retreat the sea is in a great ferment for a long way. But the king, by the expenses he was at, and the liberal disposal of them, overcame nature, and built a haven larger than was the Pyrecum 1 [at Athens]; and in the inner retirements of the water he built other deep stations [for the ships also].	https://topostext.org/work/566#1.408	shelters; storm-protection; unsafe coast; adverse winds
ca. 68 CE	Flavius Josephus, Jewish War, 3.419	Joseph. BJ	ca. 75 CE	Now Joppa is not naturally a haven, for it ends in a rough shore, where all the rest of it is straight, but the two ends bend towards each other, where there are deep precipices, and great stones that jut out into the sea, and where the chains wherewith Andromeda was bound have left their footsteps, which attest to the antiquity of that fable. But the north wind opposes and beats upon the shore, and dashes mighty waves against the rocks which receive them, and renders the haven more dangerous than the country they had deserted. Now as those people of Joppa were floating about in this sea, in the morning there fell a violent wind upon them; it is called by those that sail there "the black north wind," and there dashed their ships one against another, and dashed some of them against the rocks, and carried many of them by force, while they strove against the opposite waves, into the main sea; for the shore was so rocky, and had so many of the enemy upon it, that they were afraid to come to land; nay, the waves rose so very high, that they drowned them; nor was there any place whither they could fly, nor any way to save themselves; while they were thrust out of the sea, by the violence of the wind, if they staid where they were, and out of the city by the violence of the Roman.	https://topostext.org/work/566#3.419	shelters; geomorphology; contrary winds; dangerous coast; dangerous land; unfriendly shore; assault-probability adverse winds

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 1 BCE	Greek Anthology, 10.17	Anth. Gr.	ca. 900 CE	Blest god of the harbour, accompany with gentle breeze the departing sails of Archelaus through the undisturbed water as far as the open sea, and thou who rulest over the extreme point of the beach, save him on his voyage as far as the Pythian shrine. From thence, if all we singers are dear to Phoebus, I will sail trusting in the fair western gale.	https://topostext.org/work/535	land & sea breezes; nocturnal & diurnal winds
ca. 1 BCE	Greek Anthology, 10.24	Anth. Gr., 10.24	ca. 900 CE	Holy spirit of the mighty Earth-shaker, be gracious to others, too, who cross the Aegean brine. For to me, driven swiftly by the Thracian breeze, gently hast thou granted the harbour I was fain to reach.	https://topostext.org/work/535	breeze
ca. 500 BCE	Herodotus, Histories, 2.102	Hdt.	ca. 430 BCE	He (the priests said) first of all set out with ships of war from the Arabian gulf and subdued those who dwelt by the shores of the Erythraean Sea, until as he sailed he came to a sea which could no further be navigated by reason of shoals	https://topostext.org/work/22#2.102	risk-shoals
ca. 500 BCE	Herodotus, Histories, 2.113	Hdt.	ca. 430 BCE	Now there was upon the shore, as still there is now, a sanctuary of Heracles, in which if any man's slave take refuge and have the sacred marks set upon him, giving himself over to the god, it is not lawful to lay hands upon him; and this custom has continued still unchanged from the beginning down to my own time	https://topostext.org/work/22#2.113	sanctuary; protection/asylum
ca. 500 BCE	Herodotus, Histories, 4.156	Hdt.	ca. 430 BCE	But afterward things turned out badly for Battus and the rest of the Theraeans; and when, ignorant of the cause of their misfortunes, they sent to Delphi to ask about their present ills, [2] the priestess declared that they would fare better if they helped Battus plant a colony at Cyrene in Libya. Then the Theraeans sent Battus with two fifty-oared ships; these sailed to Libya, but, not knowing what else to do, presently returned to Thera. [3] There, the Theraeans shot at them as they came to land and would not let the ship put in, telling them to sail back; which they did under constraint of necessity, and planted a colony on an island off the Libyan coast called (as I have said already) Platea. This island is said to be as big as the city of Cyrene is now.	https://topostext.org/work/22#4.156	hostile coast "adverse shore" also in euripides, iphigenia in tauris, 392

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 500 BCE	Herodotus, Histories, 4.179	Hdt.	ca. 430 BCE	The following story is also told: it is said that Jason, when the Argo had been built at the foot of Pelion, put aboard besides a hecatomb a bronze tripod, and set out to sail around the Peloponnese, to go to Delphi. [2] But when he was off Malea, a north wind caught and carried him away to Libya; and before he saw land, he came into the shallows of the Tritonian lake. There, while he could find no way out yet, Triton (the story goes) appeared to him and told Jason to give him the tripod, promising to show the sailors the channel and send them on their way unharmed. [3] Jason did, and Triton then showed them the channel out of the shallows and set the tripod in his own temple; but first he prophesied over it, declaring the whole matter to Jason's comrades: namely, that should any descendant of the Argo's crew take away the tripod, then a hundred Greek cities would be founded on the shores of the Tritonian lake. Hearing this (it is said) the Libyan people of the country hid the tripod	https://topostext.org/work/22#4.179	tritonian lake shallows; lack of visibility
ca. 500 BCE	Herodotus, Histories, 7.188	Hdt.	ca. 430 BCE	The fleet, I say, set forth and sailed: and when it had put in to land in the region of Magnesia at the beach which is between the city of Casthanaia and the headland of Sepias, the first of the ships which came lay moored by the land and the others rode at anchor behind them; for, as the beach was not large in extent, they lay at anchor with prows projecting towards the sea in an order which was eight ships deep. For that night they lay thus; but at early dawn, after clear sky and windless calm, the sea began to be violently agitated and a great storm fell upon them with a strong East Wind, that wind which they who dwell about those parts call Hellespontias. Now as many of them as perceived that the wind was rising and who were so moored that it was possible for them to do so, drew up their ships on land before the storm came, and both they and their ships escaped; but as for those of the ships which it caught out at sea, some it cast away at the place called Ipnoi in Pelion and others on the beach, while some were wrecked on the headland of Sepias itself, others at the city of Meliboia, and others were thrown up on shore at Casthanaia: and the violence of the storm could not be resisted.	https://topostext.org/work/22#7.188	storm; moorings; shelters; forecast;
Myth.	Homer, Iliad, 15.592	Hom.Il	ca. 700 BCE	Yet not even so did he avail to break them, for all he was so eager; for they abode firm-fixed as it were a wall, like a crag, sheer and great, hard by the grey sea, that abideth the swift paths of the shrill winds, and the swelling waves that belch forth against it; even so the Danaans withstood the Trojans steadfastly, and fled not (-)	https://topostext.org/work/2#15.592	

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Myth]	Homer, the Odyssey, 5.58	Hom. Od.	ca. 700 BCE	He flew and flew over many a weary wave, but when at last he got to the island which was his journey's end, he left the sea and went on by land till he came to the cave where the nymph Calypso lived. 5.58 He found her at home. There was a large fire burning on the hearth, and one could smell from far the fragrant reek of burning cedar and sandal wood.	http://perseus.uchicago.edu/perseus-cgi/citequery3.pl?dbname=GreekTexts&getid=1&query=Hom.%20Od.%205.1	smell perception (inland)
Myth.	Homer, the Odyssey, 5.388	Hom. Od.	ca. 700 BCE	He swam seaward again, beyond reach of the surf that was beating against the land, and at the same time he kept looking towards the shore to see if he could find some haven, or a spit that should take the waves aslant	(https://topostext.org/work/3#5.388	shelters/haven
Myth.	Homer, the Odyssey, 7.240	Hom. Od.	ca. 700 BCE	Nevertheless there was still much trouble in store for me, for at this point. Neptune would let me go no further, and raised a great storm against me; the sea was so terribly high that I could no longer keep to my raft, which went to pieces under the fury of the gale, and I had to swim for it, till wind and current brought me to your shores. 'There I tried to land, but could not, for it was a bad place and the waves dashed me against the rocks, so I again took to the sea and swam on till I came to a river that seemed the most likely landing place, for there were no rocks and it was sheltered from the wind	https://topostext.org/work/3#7.240	storm; being dashed against the land; ideal landing-place; river
Myth.	Homer, the Odyssey, 9.105	Hom. Od.	ca. 700 BCE	A thick mist hung all round our ships; the moon was hidden behind a mass of clouds so that no one could have seen the island if he had looked for it, nor were there any breakers to tell us we were close in shore before we found ourselves upon the land itself; when, however, we had beached the ships, we took down the sails, went ashore and camped upon the beach till daybreak	https://topostext.org/work/3#9.105	mist; invisible land; breakers; indicators of coastal proximity
Myth.	Homer, the Odyssey, 9.63	Hom. Od.	ca. 700 BCE	Here we landed to take in fresh water, and our crews got their mid-day meal on the shore near the ships	https://topostext.org/work/3#9.63	fresh water
Myth.	Homer, the Odyssey, 10.56	Hom. Od.	ca. 700 BCE	When we reached it we went ashore to take in water, and dined hard by the ships	https://topostext.org/work/3#10.56	water accessibility/refilling

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
Myth.	Homer, the Odyssey, 12.31	Hom. Od.	ca. 700 BCE	Therefore pass these Sirens by, and stop your men's ears with wax that none of them may hear; but if you like you can listen yourself, for you may get the men to bind you as you stand upright on a cross-piece half way up the mast, and they must lash the rope's ends to the mast itself, that you may have the pleasure of listening	https://topostext.org/work/3#12.31	sirens
Myth.	Homer, the Odyssey, 12.165	Hom. Od.	ca. 700 BCE	When we had got within earshot of the land, and the ship was going at a good rate, the Sirens saw that we were getting in shore and began with their singing. "Come here,' they sang, 'renowned Ulysses, honour to the Achaean name, and listen to our two voices	https://topostext.org/work/3#12.165	indicator coastal proximity; sound; sirens
Myth.	Homer, the Odyssey, 12.260	Hom. Od.	ca. 700 BCE	They all swore as I bade them, and when they had completed their oath we made the ship fast in a harbour that was near a stream of fresh water, and the men went ashore and cooked their suppers	https://topostext.org/work/3#12.260	harbours; fresh water proximity
Myth.	Homer, the Odyssey, 13.95 - 13.110	Hom. Od.	ca. 700 BCE	§ OD.13.95 […] In the kingdom of Ithaca is a certain harbor of Phorcys, the old man of the sea. In it are two jutting precipitous headlands, sloping down toward the harbor, that shelter it from the great waves of the stormy winds § OD.13.100 outside. Inside, well-benched ships stay without mooring when they reach the point of anchorage. […] § OD.13.110 […] They rowed in there, knowing it from before.	https://topostext.org/work/3#13.95	shelter during storms; harbour access; familiarity with the place
ca. 23 BCE	Horace, Odes, 3.17	Hor. Carm	ca. 25 BCE	Tomorrow a storm sent from the East, will fill all the woodland grove with leaves, and the sands with useless weed, unless the raven, old prophet of rain, is wrong	https://topostext.org/work/679	birds; weather forecast
ca. 533 CE	Iustiniani Digesta, Corpus iuris civilis 50.16.17.1	Dig.	ca. 533 CE	Publica vectigalia intellegere debemus, ex quibus vectigal fiscus capit: quale est vectigal portus vel venalium rerum, item salinarum et metallorum et picariarum	https://droitromain.univ-grenoble-alpes.fr/Corpus/d-50.htm	
ca. 48 BCE	Julius Caesar, Civil War, 3.27	Caes. Bciv.	ca. 46 BCE	By this unexpected change, the storm, which protected our fleet, beat so furiously on the Rhodian galleys, that they were all, to the number of sixteen, broken to pieces against the shore. Most of the soldiers and mariners perished among the rocks: the rest were taken up by our men, and sent by Caesar's orders to their several homes.	https://topostext.org/work/135#3.27	storm when close to shore

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 56 BCE	Julius Caesar, Gallic Wars, 3.9	Caes. BGall.	ca. 50 BCE	They knew that on land the roads were intersected by estuaries, that our navigation was hampered by ignorance of the locality and by the scarcity of harbours, and they trusted that the Roman armies would be unable to remain long in their neighbourhood by reason of the lack of corn. Moreover, they felt that, even though everything should turn out contrary to expectation, they were predominant in sea-power, while the Romans had no supply of ships, no knowledge of the shoals, harbours, or islands in the region where they were about to wage war; and they could see that navigation on a land-locked sea was quite different from navigation on an Ocean very vast and open. Therefore, having adopted this plan, they fortified their towns, gathered corn thither from the fields, and assembled as many ships as possible in Venetia, where it was known that Caesar would begin the campaign.	https://topostext.org/work/683#3.9	hazard due to ignorance of the places; paucity of harbours & landing sites; shallow; 'inexperience'; difference between navigation in narrow spaces and in open waters; seamanship
ca. 56 BCE	Julius Caesar, Gallic Wars, 3.13	Caes. BGall.	ca. 50 BCE	For their ships were built and equipped after this manner. The keels were somewhat flatter than those of our ships, whereby they could more easily encounter the shallows and the ebbing of the tide: the prows were raised very high, and, in like manner the sterns were adapted to the force of the waves and storms [which they were formed to sustain]. The ships were built wholly of oak, and designed to endure any force and violence whatever; the benches which were made of planks a foot in breadth, were fastened by iron spikes of the thickness of a man's thumb; the anchors were secured fast by iron chains instead of cables, and for sails they used skins and thin dressed leather. These [were used] either through their want of canvas and their ignorance of its application, or for this reason, which is more probable, that they thought that such storms of the ocean, and such violent gales of wind could not be resisted by sails, nor ships of such great burden be conveniently enough managed by them. The encounter of our fleet with these ships' was of such a nature that our fleet excelled in speed alone, and the plying of the oars; other things, considering the nature of the place [and] the violence of the storms, were more suitable and better adapted on their side; for neither could our ships injure theirs with their beaks (so great was their strength), nor on account of their height was a weapon easily cast up to them; and for the same reason they were less readily locked in by rocks. To this was added, that whenever a storm began to rage and they ran before the wind, they both could weather the storm more easily and heave to securely in the shallows, and when left by the tide feared nothing from rocks and shelves: the risk of all which things was much to be dreaded by our ships.	https://topostext.org/work/683#3.13	shallows and nautical architecture

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ca. 54 BCE	Julius Caesar, Gallic Wars, 5.10	Caes. BGall.	ca. 50 BCE	In the morning of the next day he divided the foot and the horse in three detachments, and sent them as flying columns to pursue the fugitives. When these had advanced a good long march and the rearguards were just in sight, troopers came from Quintus Atrius to Caesar to report that a violent storm had arisen in the previous night, and that nearly all the ships had been damaged and cast up on shore, as the anchors and cables would not hold, and the seamen and steersmen could not face the force of the storm: and so the collision of ships had caused serious damage.	https://topostext.org/work/683#5.10	storm; shore
ca. 508 BCE	Livy, History of Rome, 2.9	Liv.	ca. 19 BCE	The plebs were exempted from the payment of harbour-dues and the war-tax, so that they might fall on the rich, who could bear the burden	(https://topostext.org/work/142#2.9	port-dues
ca. 210 BCE	Livy, History of Rome, 26.42	Liv.	ca. 19 BCE	A small island at the mouth of the harbour forms a breakwater and shelters it from all winds, except those from the south-west	https://topostext.org/work/142#26.42	harbours - exposure
ca. 208 BCE	Livy, History of Rome, 27.30	Liv.	ca. 19 BCE	This place lies on the Maliac Gulf, and was formerly the seat of a considerable population, owing to its splendid harbour, the safe anchorages in the neighbourhood, and other maritime and commercial advantages.	https://topostext.org/work/142#27.30	safe anchorages

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 206 BCE	Livy, History of Rome, 28.37	Liv.	ca. 19 BCE	From there he (Mago) sailed to Pityusa, an island about a hundred miles distant from the mainland, which had at the time a Phoenician population. Here the fleet naturally met with a friendly reception, and not only were supplies furnished on a generous scale but he received reinforcements for his fleet in the shape of arms and men. Thus encouraged, the Carthaginian sailed on to the Balearic Isles, a voyage of about fifty miles. There are two islands so called; the larger one was better supplied with arms and contained a more numerous population; it also possessed a harbour where Mago thought he could conveniently shelter his fleet for the winter, as the autumn was now closing. But his fleet met with quite as hostile a reception as if the island had been inhabited by Romans. The sling which the Balearics make most use of today was at that time their sole weapon, and no nation comes near them in the skill with which they handle it. When the Carthaginians tried to approach the land such a shower of stones fell upon them like a violent hailstorm that they did not venture inside the harbour. Putting out once more to sea they approached the smaller island, which possessed a fertile soil, but fewer resources in men and arms. Here they landed and encamped in a strong position commanding the harbour, from which they became masters of the island without meeting any resistance. They raised a force of 2000 auxiliaries which they sent to Carthage and then beached their ships for the winter. After Mago's departure Gades surrendered to the Romans.	https://topostext.org/work/142#28.37	winter sailing assault probability; unfriendly shores

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ca. 204 BCE	Livy, History of Rome, 29.27	Liv.	ca. 19 BCE	[..] As he finished he threw the raw entrails of the victim into the sea with the accustomed ritual. Then he ordered the trumpeter to sound the signal for departure, and as the wind which was favourable to them freshened they were quickly carried out of sight. In the afternoon they were enveloped in so thick a fog that they had difficulty in keeping their ships from fouling one another, and as they got out to sea the wind dropped. During the night a similar fog prevailed, which dispersed after sunrise, and at the same the wind freshened. At last they descried land, and a few minutes later the pilot informed Scipio that they were not more than five miles from the coast of Africa, and that the headland of Mercurius was plainly visible. If he would give orders for him to steer for it, the man assured him, the whole of the fleet would soon be in port. When he caught sight of land Scipio offered a prayer that this first view of Africa might bring good to himself and to the republic. He then gave orders for the fleet to make for an anchorage further south. They went before the wind which was still in the same quarter, but a fog which came up about the same time as on the day before blotted out the view of the land and made the wind fall. As night came on everything became obscure, and to avoid all risk of the ships coming into collision or being driven ashore it was decided to cast anchor. When it grew light, the wind again freshened from the same quarter, and the dispersal of the fog revealed the entire coastline of Africa. Scipio enquired the name of the nearest headland, and on learning that was called Pulchrum ("Cape Beautiful") he remarked, "I accept the omen, steer for it." The fleet brought up there and the whole of the force was landed.	https://topostext.org/work/142#29.27	fog/visibility; lack of visibility; land risk rituals/ceremony at departure; african coastline visibility
ca. 200 BCE	Livy, History of Rome, 31.17	Liv.	ca. 14 BCE	The Abydenes in the first instance placed engines all along their walls and in this way not only prevented any approach by land, but also made the anchorage of the hostile ships unsafe. When, however, a portion of the wall was battered into ruins and the enemies' mines had been carried up to an inner wall which the defenders had hastily constructed, they sent envoys to the king to arrange terms for the surrender of the city	https://topostext.org/work/142#31.17	unsafe anchorage; hostile shores
ca. 199 BCE	Livy, History of Rome, 32.7	Liv.	ca. 14 BCE	They also leased out to contractors the customs dues at Capua and Puteoli and the harbour dues at the Castra Hannibalis, where a town now stands	https://topostext.org/work/142#32.7	port-dues

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ca. 190 BCE	Livy, History of Rome, 37.16	Liv.	ca. 14 BCE	He then set sail for Patara. A favourable wind carried them right up to the city, and they hoped that the suddenness of their appearance might frighten the citizens into deserting Antiochus. Afterwards the wind veered round and a heavy cross-sea arose. They succeeded by dint of hard rowing in holding the land, but there was no safe anchorage near the city and they could not lie off the harbour mouth in such a rough sea and with night coming on. Sailing past the city walls they made for the port of Phoenicus rather less than two miles away. This harbour afforded a safe shelter from the violence of the waves, but it was surrounded by high cliffs which the townsmen together with the king's troops who formed the garrison promptly occupied. Though the shore was rocky and landing difficult, Livius sent the contingent from Issa and the Smyrnean light infantry to dislodge them. As long as these light troops had only few to deal with they kept up the contest with missiles and desultory skirmishing more than with hand-to-hand fighting, but as more and more came out of the city in a constant stream and at last the whole of the able-bodied population were pouring out, Livius began to feel apprehensive lest his light troops should be cut off and the ships assailed from the shore.	https://topostext.org/work/142#37.16	no safe anchorage; competing risks: shelter in storm & assault-probability
ca. 48 BCE	Lucan, Pharsalia, 9.140	Luc. Ph.	ca. 61 CE	§ 9.140 First reached they Cyprus on the foamy brine; Then as the eastern breeze more gently held The favouring deep, they touched the Libyan shore Where stood the camp of Cato.	https://topostext.org/work/147#9.140	breeze
ca. 1 BCE	Lucian, De Saltatione, 3	Luc. Salt	ca. 180 CE	That would be as much to our discredit as to yours: for ours should be Odysseus's part, — to tear you from the lotus, and bring you back to your accustomed pursuits; to save you from the clutches of these stage Sirens before it is too late. The Sirens, after all, did but plot against men's ears; it needed but a little wax, and a man might sail past them uninjured: but yours is a captivity of ear and eye, of body and soul	https://topostext.org/work/344	sirens
ca. 50 CE	New Testament, Acts of the Apostles, 27.13-17	Acts	ca. 62 CE	When the south wind blew softly, supposing that they had obtained their purpose, they weighed anchor and sailed along Crete, close to shore. [14] But after no long time there beat down from it a tempestuous wind, which is called Euroclydon. [15] When the ship was caught, and couldn't face the wind, we gave way to it, and were driven along. [16] Running under the lee of a small island called Clauda, we were able, with difficulty, to secure the boat. [17] When they had hoisted it up, they used cables to help reinforce the ship. Fearing that they would run aground on the Syrtis sand bars, they lowered the sea anchor, and so were driven. [18]	https://topostext.org/work/146#27.13	sandbanks shallows syrtes

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 50 CE	New Testament, Acts of the Apostles, 27:17–20, 27–32	Acts	ca. 62 CE	[17] When they had hoisted it up, they used cables to help reinforce the ship. Fearing that they would run aground on the Syrtis sand bars, they lowered the sea anchor, and so were driven. [18] As we labored exceedingly with the storm, the next day they began to throw things overboard. [19] On the third day, they threw out the ship's tackle with their own hands. [20] When neither sun nor stars shone on us for many days, and no small tempest pressed on us, all hope that we would be saved was now taken away. [...] [27] But when the fourteenth night had come, as we were driven back and forth in the Adriatic Sea (Oleson translates Sea of Adria [Ionian sea]. Editor's note), about midnight the sailors surmised (**suspected, ὑπενόουν**) that they were drawing near to some land. [28] They took soundings, and found twenty fathoms. After a little while, they took soundings again, and found fifteen fathoms. [29] Fearing that we would run aground on rocky ground, they let go four anchors from the stern, and wished for daylight. [30] As the sailors were trying to flee out of the ship, and had lowered the boat into the sea, pretending that they would lay out anchors from the bow, [31] Paul said to the centurion and to the soldiers, "Unless these stay in the ship, you can't be saved."[32] Then the soldiers cut away the ropes of the boat, and let her fall off.	http://www.perseus.tufts.edu/hopper/text?doc=Perseus%3Atext%3A1999.01.0156%3Abook%3DActs%3Achapter%3D27%3Averse%3D17	land-proximity; perception; storm; sounding weights
Myth.	Nonnus, Dionysiaca, 3.1	Nonnus, Dion.	ca. 400 CE	The sailors rejoiced to see the sleepless flame of the Samian torch, and furled their sails as they came near the land; then rowing the ship towards the waveless anchorage they scored the smooth water with the tips of their oars and ran her up under shelter of the harbour	https://topostext.org/work/529	landing; indicators of coastal proximity
Myth.	Nonnus, Dionysiaca, 3.16	Nonnus, Dion.	ca. 400 CE	Sailing was now in season, Cadmos was in haste; they hauled up the ship's bridling-hawsers off the land. The mast lifting its head on high struck the upper air standing firmly. A light breeze gently rippling the sea with the breath of the morning hummed All aboard!	https://topostext.org/work/529	breeze seasonal sailing
Myth.	Ovid, Art of Love, 3.310	Ov. Ars am.	ca. 2 CE	The Sirens were sea-monsters, who, with singing voice, could restrain a ship	https://topostext.org/work/661#3.310	sirens

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 1 BCE	Pausanias, Description of Greece, 5.25.3	Paus.	ca. 174 CE	So many monsters swarm in the water that even the air over the sea is infected with their stench	https://topostext.org/work/213	sea-monsters
Myth.	Philostratus, Heroica, 717	Philostr. Her	ca. 240 CE	Protesilaos does not even allow us to listen to the stories about Polyphemos, Antiphates, Scylla, the events in Hades, and what the Sirens sang, but he permits us to smear over our ears with beeswax and to avoid these stories, not because they are not full of pleasure and able to allure us, but because they are untrustworthy and fabricated	https://topostext.org/work/222	Sirens
ca. 1 BCE	Photius, Bibliotheca excerpts, 224.36.1	Phot. Bibl.	ca. 100 CE	Some of the ships which were carrying the spoils from Heracleia were sunk by their weight not far from the city, and others were forced into the shallows by a northerly wind, so that much of their cargo was lost	https://topostext.org/work/237	adverse winds; shallows
ca. 1 BCE	Pliny the Elder, Natural History, 5.4.1	Plin. HN	ca. 77 CE	THE SYRTES: A third Gulf is divided into two smaller ones, those of the two Syrtes, which are rendered perilous by the shallows of their quicksands and the ebb and flow of the sea	https://topostext.org/work/148#5.4.1	Syrtes; shallows

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 1 BCE	Pliny the Elder, Natural History, 9.4.1	Plin. HN	ca. 77 CE	§ 9.4.1 An embassy from Olisipo sent for the purpose reported to the Emperor Tiberius that a Triton had been seen and heard playing on a shell in a certain cave, and that he had the well-known shape. The description of the Nereids also is not incorrect, except that their body is bristling with hair even in the parts where they have human shape; for a Nereid has been seen on the same coast, whose mournful song moreover when dying has been heard a long way off by the coast-dwellers; also the Governor of Gaul wrote to the late lamented Augustus that a large number of dead Nereids were to be seen on the shore. I have distinguished members of the Order of Knighthood as authorities for the statement that a man of the sea has been seen by them in the Gulf of Cadiz, with complete resemblance to a human being in every part of his body, and that he climbs on board ships during the hours of the night and the side of the vessel that he sits on is at once weighed down, and if he stays there longer actually goes below the water. During the rule of Tiberius, in an island off the coast of the province of Lugdunum the receding ocean tide left more than 300 monsters at the same time, of marvellous variety and size, and an equal number on the coast of Saintes, and among the rest elephants, and rams with only a white streak to resemble horns, and also many Nereids. Turranius has stated that a monster was cast ashore on the coast at Cadiz that had 24 feet of tail-end between its two fins, and also 120 teeth, the biggest 9 inches and the smallest 6 inches long.	https://topostext.org/work/148#9.4.1	sea-monsters; Nereid; Triton
ca. 1 BCE	Pliny the Elder, Natural History, 10.55.1	Plin. HN	ca. 77 CE	These are the birds seen all over the sea, and ships never go away from land on so long or so unbroken a course that they do not have apodes flying round them	https://topostext.org/work/148#10.55.1	birds; coastal proximity
ca. 1 BCE	Pliny the Elder, Natural History, 10.70.1	Plin. HN	ca. 77 CE	Nor should the sirens obtain credit, although Dinon the father of the celebrated authority Clitarchus declares that they exist in India and that they charm people with their song and then when they are sunk in a heavy sleep tear them in pieces	https://topostext.org/work/148#10.70.1	Sirens
ca. 50 BCE	Plutarch, Cicero, 32	Plut. Cic	ca. 110 CE	3 Disheartened at this treatment, he set out for Brundisium, and from there tried to cross to Dyrrhachium with a fair breeze, but since he met a counter-wind at sea he came back the next day, and then set sail again	https://topostext.org/work/656	untrustworthy breezes

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 255 BCE	Polybius, Histories, 1.37.1	Polyb.	ca. 130 BCE	They had crossed the strait in safety and were off the territory of Camarina when they were overtaken by so fierce a storm and so terrible a disaster that it is difficult adequately to describe it owing to its surpassing magnitude. 2 For of their three hundred and sixty-four ships only eighty were saved; the rest either foundered or were dashed by the waves against the rocks and headlands and broken to pieces, covering the shore with corpses and wreckage. 3 History tells of no greater catastrophe at sea taking place at one time. 4 The blame must be laid not so much on ill-fortune as on the commanders; for the captains had repeatedly urged them not to sail along the outer coast of Sicily, that turned towards the Libyan sea, as it was very rugged and had few safe anchorages: they also warned them that one of the dangerous astral periods was not over and another just approaching (for it was between the rising of Orion and that of Sirius that they undertook the voyage). 5 The commanders, however, paid no attention to a single word they said, they took the outer course and there they were in the open sea thinking to strike terror into some of the cities they passed by the brilliancy of their recent success and thus win them over. 6 But now, all for the sake of such meagre expectations, they exposed themselves to this great disaster, and were obliged to acknowledge their lack of judgment. 7 The Romans, to speak generally, rely on force in all their enterprises, and think it is incumbent on them to carry out their projects in spite of all, and that nothing is impossible when they have once decided on it. They owe their success in many cases to this spirit, but sometimes they conspicuously fail by reason of it and especially at sea. (As for the dangerous nature of the S. Coast of Sicily, which was well known to the pilots see also Plb. 1.54.1)	https://topostext.org/work/129#1.37.1	Shore; Storm; Lack of shelters

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 255 BCE	Polybius, Histories, 1.39.1	Polyb.	ca. 130 BCE	But next summer the new Consuls Gnaeus Servilius and Gaius Sempronius put again to sea with their full strength, and after touching at Sicily started thence for Libya. There, as they coasted along the shore, they made a great number of descents upon the country without accomplishing anything of importance in any of them. At length they came to the island of the Lotophagi called Mēnix, which is not far from the Lesser Syrtis. There, from ignorance of the waters, they ran upon some shallows; the tide receded, their ships went aground, and they were in extreme peril. However, after a while the tide unexpectedly flowed back again, and by dint of throwing overboard all their heavy goods they just managed to float the ships. After this their return voyage was more like a flight than anything else. When they reached Sicily and had made the promontory of Lilybaeum they cast anchor at Panormus. Thence they weighed anchor for Rome, and rashly ventured upon the open sea-line as the shortest; but while on their voyage they once more encountered so terrible a storm that they lost more than a hundred and fifty ships.	https://topostext.org/work/129#1.39.1	Unknown shore; Shallows; Risky land-proximity; tide
ca. 249 BCE	Polybius, Histories, 1.53.10	Polyb.	ca. 130 BCE	Considering themselves not strong enough to accept a battle, they anchored off a certain small fortified town subject to the Romans, which had indeed no harbor, but a roadstead shut in by headlands projecting from the land in a manner that made it a more or less secure anchorage	https://topostext.org/work/129#1.53.1	Legend on Tritonian Lake shallows; lack of visibility

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 249 BCE	Polybius, Histories, 1.54.1	Polyb.	ca. 130 BCE	In complete ignorance of what had happened to his advanced squadron, the Consul, who had remained behind at Syracuse, after completing all he meant to do there, put to sea; and, after rounding Pachynus, was proceeding on his voyage to Lilybaeum. The appearance of the enemy was once more signalled to the Carthaginian admiral by his look-out men, and he at once put out to sea, with the view of engaging them as far as possible away from their comrades. Junius saw the Carthaginian fleet from a considerable distance, and observing their great numbers did not dare to engage them, and yet found it impossible to avoid them by flight because they were now too close. He therefore steered towards land, and anchored under a rocky and altogether dangerous part of the shore; for he judged it better to run all risks rather than allow his squadron, with all its men, to fall into the hands of the enemy. The Carthaginian admiral saw what he had done; and determined that it was unadvisable for him to engage the enemy, or bring his ships near such a dangerous place. He therefore made for a certain headland between the two squadrons of the enemy, and there kept a look out upon both with equal vigilance. Presently, however, the weather became rough, and there was an appearance of an unusually dangerous disturbance setting in from the sea. The Carthaginian pilots, from their knowledge of the particular localities, and of seamanship generally, foresaw what was coming; and persuaded Carthalo to avoid the storm and round the promontory of Pachynus. He had the good sense to take their advice: and accordingly these men, with great exertions and extreme difficulty, did get round the promontory and anchored in safety; while the Romans, being exposed to the storm in places entirely destitute of harbours, suffered such complete destruction, that not one of the wrecks even was left in a state available for use. Both of their squadrons in fact were completely disabled to a degree past belief. (As for the dangerous nature of the S. Coast of Sicily, which was well known to the pilots see also Plb. 1.37.1).	http://www.perseus.tufts.edu/hopper/text?doc=Plb.+1.54&fromdoc=Perseus%3Atext%3A1999.01.0234 https://topostext.org/work/129#1.54.1	Hazardous coast; Rocky-shore; Assault-probability; Seamanship; Forecasting; Storm; Safe anchorages; Lack of shelters

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 130 BCE	Polybius, Histories, 6.44.1	Polyb.	ca. 130 BCE	A somewhat similar remark applies to the Athenian constitution also. For though it perhaps had more frequent interludes of excellence, yet its highest perfection was attained during the brilliant career of Themistocles; and having reached that point it quickly declined, owing to its essential instability. For the Athenian demus is always in the position of a ship without a commander. In such a ship, if fear of the enemy, or the occurrence of a storm induce the crew to be of one mind and to obey the helmsman, everything goes well; but if they recover from this fear, and begin to treat their officers with contempt, and to quarrel with each other because they are no longer all of one mind,—one party wishing to continue the voyage, and the other urging the steersman to bring the ship to anchor; some letting out the sheets, and others hauling them in, and ordering the sails to be furled,—their discord and quarrels make a sorry show to lookers on; and the position of affairs is full of risk to those on board engaged on the same voyage: and the result has often been that, after escaping the dangers of the widest seas, and the most violent storms, they wreck their ship in harbour and close to shore. And this is what has often happened to the Athenian constitution. For, after repelling, on various occasions, the greatest and most formidable dangers by the valour of its people and their leaders, there have been times when, in periods of secure tranquillity, it has gratuitously and recklessly encountered disaster	http://www.perseus.tufts.edu/hopper/text?doc=Plb.+6.44&fromdoc=Perseus%3Atext%3A1999.01.0234 https://topostext.org/work/129#6.44.1	metaphor navigation risks; storms; discord
ca. 1 BCE	Pomponius Mela, Description of the World, 1.35-36	Mela. Chor.	ca. 43 CE	§ 1.35 Syrtis is a gulf almost one hundred miles wide where it receives the open sea and three hundred miles wide where it encloses the sea. It has no ports and is frightening and dangerous because of the shallowness of its frequent shoals and even more dangerous because of the reversing movements of the sea as it flows in and out. § 1.36 On its shoreline a huge swamp receives the Triton River; the swamp itself is Lake Triton, that is, the lake of Minerva, who, as the locals think, was born there, whence it was given her epithet. They give some credibility to that legend, because they celebrate the day they think is her birthday with contests of virgins, who compete among themselves.	HatiTrust Digital Library https://babel.hathitrust.org/cgi/pt?id=mdp.39015042048507&view=1up&seq=4[89]	Syrtis; harbourless shore; shoals;

[89] Translation by F.E Romer. University of Michigan Press 1998; Latin version (https://latin.packhum.org/loc/929/1/0#0) at Pomponius Mela, De Chorographia Pomponii Melae De Chorographia Libri Tres una cum Indice Verborum, ed. G. Ranstrand

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[450 BCE	Pseudo-Xenophon, Constitution of the Athenians, 2.5	Ps. Xen. Const. Ath.	ca 360 BCE	Further, the rulers of the sea can sail away from their own land to anywhere at all, whereas a land power can take a journey of only a few days from its own territory.3 Progress is slow, and going on foot one cannot carry provisions sufficient for a long time. One who goes on foot must pass through friendly country or else fight and win, whereas it is possible for the seafarer to go on shore wherever he has the stronger power...this land, but to sail along the coast until he comes to a friendly region or to those weaker than himself.	http://www.perseus.tufts.edu/hopper/text?doc=Ps.+Xen.+Const.+Ath.+2&fromdoc=Perseus%3Atext%3A1999.01.0158	assault probability; unfriendly shores
ca. 60 CE	Seneca, Epistles, 53.1 - 53.4	Sen. Ep.	ca. 65 CE	§ 53.1 LIII. On the Faults of the Spirit You can persuade me into almost anything now, for I was recently persuaded to travel by water. We cast off when the sea was lazily smooth; the sky, to be sure, was heavy with nasty clouds, such as usually break into rain or squalls. Still, I thought that the few miles between Puteoli and your dear Parthenope might be run off in quick time, despite the uncertain and lowering sky. So, in order to get away more quickly, I made straight out to sea for Nesis, with the purpose of cutting across all the inlets. § 53.2 But when we were so far out that it made little difference to me whether I returned or kept on, the calm weather, which had enticed me, came to naught. The storm had not yet begun, but the ground-swell was on, and the waves kept steadily coming faster. I began to ask the pilot to put me ashore somewhere; he replied that the coast was rough and a bad place to land, and that in a storm he feared a lee shore more than anything else. § 53.3 But I was suffering too grievously to think of the danger, since a sluggish seasickness which brought no relief was racking me, the sort that upsets the liver without clearing it. Therefore I laid down the law to my pilot, forcing him to make for the shore, willy-nilly. When we drew near, I did not wait for things to be done in accordance with Vergil's orders, until Prow faced seawards or Anchor plunged from bow; I remembered my profession as a veteran devotee of cold water, and, clad as I was in my cloak, let myself down into the sea, just as a cold-water bather should. § 53.4 What do you think my feelings were, scrambling over the rocks, searching out the path, or making one for myself? l understood that sailors have good reason to fear the land."	https://www.loebclassics.com/view/seneca_younger-epistles/1917/pb_LCL075.353.xml?readMode=recto https://topostext.org/work/736#53.2	storm; hazardous landing; land-risk/fear

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 215 BCE	Silius Italicus, Punica, 12.13	Sil. Pun.	ca. 90 CE	She was one of the Sirens, and her singing long ruled the waves, when her boding voice sang melodious destruction across the water to hapless sailors	https://topostext.org/work/248	Sirens
ca. 1 BCE	Solinus, Polyhistor, 32.40	Solin.	ca. 300 CE	For Alexandria is approached by a treacherous harbour, with deceptive shallows and uncertain seas	https://topostext.org/work/747	risky harbour; shallows
ca. 1 BCE	Strabo, Geography, 1.3.8	Str. Geog	ca. 24 CE	This agitation of the sea produces a continual movement on its surface, which even when it is most tranquil has considerable force, and so throws all extraneous matters on to the land, and "Flings forth the salt weed on the shore." Iliad ix. 7. This effect is certainly most considerable when the wind is on the water, but it continues when all is hushed, and even when it blows from land the swell is still carried to the shore against the wind, as if by a peculiar motion of the sea itself	https://topostext.org/work/144#1.3.8	swell; turmoil
ca. 1 BCE	Strabo, Geography, 3.2.5	Str. Geog	ca. 24 CE	(Talking about Baetica) Their trade is wholly carried on with Italy and Rome. The navigation is excellent as far as the Pillars, (excepting perhaps some little difficulties at the Strait,) and equally so on the Mediterranean, where the voyages are very calm, especially to those who keep the high seas. This is a great advantage to merchant-vessels. The winds on the high seas blow regularly; and peace reigns there now, the pirates having been put down, so that in every respect the voyage is facile. Posidonius tells us he observed the singular phenomenon in his journey from Iberia, that in this sea, as far as the Gulf of Sardinia, the south-east winds blow periodically. And on this account he strove in vain for three whole months to reach Italy, being driven about by the winds against the Gymnesian islands, Sardinia, and the opposite coasts of Libya.	https://topostext.org/work/144#3.2.5	High-seas (VS coastal navigation; wind-regularity
ca. 1 BCE	Strabo, Geography, 3.5.1	Str. Geog	ca. 24 CE	The smaller island (of the Baleares) is about [2]70 stadia distant from Polentia; in size it is far surpassed by the larger island, but in excellence it is by no means inferior, for both of them are very fertile, and furnished with harbours. At the mouths of these however there are rocks rising but a little out of the water, which renders attention necessary in entering them.	https://topostext.org/work/144#3.5.1	*portuosus* shore; geomorphological hazards; risky port-access
ca. 1 BCE	Strabo, Geography, 5.2.5	Str. Geog	ca. 24 CE	(coast from Luna to Ostia)The city is not large, but the harbour is very fine and spacious, containing in itself numerous harbours, all of them deep near the shore; it is in fact an arsenal worthy of a nation holding dominion for so long a time over so vast a sea	https://topostext.org/work/144#5.2.5	Visibility; Harbours-capacity; Harbours-availability

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 1 BCE	Strabo, Geography, 6.1.5.	Str. Geog	ca. 24 CE	Off this coast lie the islands of the Liparaei, at a distance of two hundred stadia from the Strait. According to some, they are the islands of Aeolus, of whom the Poet makes mention in the Odyssey. They are seven in number and are all within view both from Sicily and from the continent near Medma. But I shall tell about them when I discuss Sicily. After the Metaurus River comes a second Metaurus. Next after this river comes Scyllaion, a lofty rock which forms a peninsula, its isthmus being low and affording access to ships on both sides. This isthmus Anaxilaus, the tyrant of the Rhegini, fortified against the Tyrrheni, building a naval station there, and thus deprived the pirates of their passage through the strait.	https://topostext.org/work/144#6.1.5	shipping control;
ca. 1 BCE	Strabo, Geography, 6.2.2.	Str. Geog	ca. 24 CE	The cities along the side that forms the Strait are, first, Messene, and then Tauromenium, Catana, and Syracuse; but those that were between Catana and Syracuse have disappeared — Naxus and Megara; and on this coast are the outlets of the Symaethus and all rivers that flow down from Aetna and have good harbors at their mouths; and here too is the promontory of Xiphonia. According to Ephorus these were the earliest Greek cities to be founded in Sicily, that is, in the tenth generation after the Trojan war; for before that time men were so afraid of the bands of Tyrrhenian pirates and the savagery of the barbarians in this region that they would not so much as sail thither for trafficking; but though Theocles, the Athenian, borne out of his course by the winds to Sicily, clearly perceived both the weakness of the peoples and the excellence of the soil, yet, when he went back, he could not persuade the Athenians, and hence took as partners a considerable number of Euboean Chalcidians and some Ionians and also some Dorians (most of whom were Megarians) and made the voyage; so the Chalcidians founded Naxos, whereas the Dorians founded Megara, which in earlier times had been called Hybla. The cities no longer exist, it is true, but the name of Hybla still endures, because of the excellence of the Hyblaean honey.	https://topostext.org/work/144#6.2.2	Assault-probability; pirates

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ca. 1 BCE	Strabo, Geography, 6.2.10	Str. Geog	ca. 24 CE	According to Polybius, one of the three craters has partially fallen in, whereas the others remain whole; and the largest has a circular rim five stadia in circuit, but it gradually contracts to a diameter of fifty feet; and the altitude of this crater above the level of the sea is a stadium, so that the crater is visible on windless days. Now if the south wind is about to blow, Polybius continues, a cloud-like mist pours down all round the island, so that not even Sicily is visible in the distance; and when the north wind is about to blow, pure flames rise aloft from the aforesaid crater and louder rumblings are sent forth; but the west wind holds a middle position, so to speak, between the two; but though the two other craters are like the first in kind, they fall short in the violence of their spoutings; accordingly, both the difference in the rumblings, and the place whence the spoutings and the flames and the fiery smoke begin, signify beforehand the wind that is going to blow again three days afterward; at all events, certain of the men in Liparae, when the weather made sailing impossible, predicted, he says, the wind that was to blow, and they were not mistaken; from this fact, then, it is clear that that saying of the Poet which is regarded as most mythical of all was not idly spoken, but that he hinted at the truth when he called Aeolus steward of the winds.	https://topostext.org/work/144#6.2.10	Wind Visibility; Vulcanic islands; smell; Forecast; Sicily
ca. 1 BCE	Strabo, Geography, 6.2.11	Str. Geog	ca. 24 CE	We have noticed the islands of Lipari and Thermessa. As for Strongyle,150 it takes its name from its form.151 […]The seventh [island] is called Euonymus;156 it is the farthest in the sea and barren. It is called Euonymus because it lies the most to the left when you sail from the island of Lipari to Sicily,157 and many times flames of fire have been seen to rise to the surface, and play upon the sea round the islands: these flames rush with violence from the cavities at the bottom of the sea,158 and force for themselves a passage to the open air. Posidonius says, that at a time so recent as to be almost within his recollection, about the summer solstice and at break of day, between Hiera and Euonymus, the sea was observed to be suddenly raised aloft, and to abide some time raised in a compact mass and then to subside. Some ventured to approach that part in their ships; they observed the fish dead and driven by the current, but being distressed by the heat and foul smell, were compelled to turn back.	https://topostext.org/work/144#6.2.11	Vulcanism; Smell; Sicily;
ca. 1 BCE	Strabo, Geography, 8.3.19	Str. Geog	ca. 24 CE	The greater part of the water is received by the Anigrus, a river so deep and so sluggish that it forms a marsh; and since the region is muddy, it emits an offensive odor for a distance of twenty stadia, and makes the fish unfit to eat.	https://topostext.org/work/144#8.3.19	Smell perception; odour-propagation; river

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ca. 1 BCE	Strabo, Geography, 10.2.16	Str. Geog	ca. 24 CE	16 Between Ithaca and Cephallenia is the small island Asteria (the poet calls it Asteris), which the Scepsian says no longer remains such as the poet describes it,'but in it are harbors safe for anchorage with entrances on either side; Apollodorus, however, says that it still remains so to this day, and mentions a town Alalcomenae upon it, situated on the isthmus itself	https://topostext.org/work/144#10.2.16	safe harbours; harbours accessibility
ca. 1 BCE	Strabo, Geography, 14.1.7	Str. Geog	ca. 24 CE	The island Lade lies close in front of Miletus, as do also the isles in the neighborhood of the Tragaeae, which afford anchorage for pirates	https://topostext.org/work/144#14.1.7	hostile shores; pirates
ca. 1 BCE	Strabo, Geography, 16.4.18	Str. Geog	ca. 24 CE	It has few harbours and anchorages, for a rugged and lofty mountain stretches parallel to it; then the parts at its base, extending into the sea, form rocks under water, which, during the blowing of the Etesian winds and the storms of that period, present dangers, when no assistance can be afforded to vessels	https://topostext.org/work/144#16.4.18	harbourless & rocky shore; geomorphological hazards; storms
ca. 1 BCE	Strabo, Geography, 16.4.23	Str. Geog	ca. 24 CE	Syllaeus was however treacherous throughout; for he neither guided them by a safe course by sea along the coast, nor by a safe road for the army, as he promised, but exposed both the fleet and the army to danger, by directing them where there was no road, or the road was impracticable, where they were obliged to make long circuits, or to pass through tracts of country destitute of everything ; he led the fleet along a rocky coast without harbours, or to places abounding with rocks concealed under water, or with shallows. In places of this description particularly, the flowing and ebbing of the tide did them the most harm	https://topostext.org/work/144#16.4.23	shallows; harbourless rocky shore;

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ca. 1 BCE	Strabo, Geography, 17.1.6	Str. Geog	ca. 24 CE	§ 17.1.6 As Alexandreia and its neighbourhood occupy the greatest and principal portion of the description, I shall begin with it. In sailing towards the west, the sea-coast from Pelusium to the Canobic mouth of the Nile is about 1300 stadia in extent, and constitutes, as we have said, the base of the Delta. Thence to the island Pharos are 150 stadia more. Pharos is a small oblong island, and lies quite close to the continent, forming towards it a harbour with a double entrance. For the coast abounds with bays, and has two promontories projecting into the sea. The island is situated between these, and shuts in the bay, lying lengthways in front of it. Of the extremities of the Pharos, the eastern is nearest to the continent and to the promontory in that direction, called Lochias, which is the cause of the entrance to the port being narrow. Besides the narrowness of the passage, there are rocks, some under water, others rising above it, which at all times increase the violence of the waves rolling in upon them from the open sea. This extremity itself of the island is a rock, washed by the sea on all sides, with a tower upon it of the same name as the island, admirably constructed of white marble, with several stories. Sostratus of Cnidus, a friend of the kings, erected it for the safety of mariners, as the inscription imports. For as the coast on each side is low and without harbours, with reefs and shallows, an elevated and conspicuous mark was required to enable navigators coming in from the open sea to direct their course exactly to the entrance of the harbour. The western mouth does not afford an easy entrance, but it does not require the same degree of caution as the other. It forms also another port, which has the name of Eunostus, or Happy Return: it lies in front of the artificial and close harbour. That which has its entrance at the above-mentioned tower of Pharos is the great harbour. These (two) lie contiguous in the recess called Heptastadium, and are separated from it by a mound. This mound forms a bridge from the continent to the island, and extends along its western side, leaving two passages only through it to the harbour of Eunostus, which are bridged over. But this work served not only as a bridge, but as an aqueduct also, when the island was inhabited. Divus Caesar devastated the island, in his war against the people of Alexandreia, when they espoused the party of the kings. A few sailors live near the tower. The great harbour, in addition to its being well enclosed by the mound and by nature, is of sufficient depth near the shore to allow the largest vessel to anchor near the stairs. It is also divided into several ports.	https://topostext.org/work/144#17.1	Alexandria's port; port capacity/depth; Pharos; Harbours-availability; Harbours-entrance; Geomorphology (shallows); environmental hazards;

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 1 BCE	Strabo, Geography, 17.1.13	Str. Geog. 17.1.13	ca. 24 CE	Such then, if not worse, was the condition of the city under the last kings. The Romans, as far as they were able, corrected, as I have said, many abuses, and established an orderly government, by appointing vice-governors, nomarchs, and ethnarchs, whose business it was to superintend affairs of minor importance. The greatest advantage which the city possesses arises from its being the only place in all Egypt well situated by nature for communication with the sea by its excellent harbour, and with the land by the river, by means of which everything is easily transported and collected together into this city, which is the greatest mart in the habitable world. These may be said to be the superior excellencies of the city. Cicero, in one of his orations,1 in speaking of the revenues of Egypt, states that an annual tribute of 12,500 talents was paid to (Ptolemy) Auletes, the father of Cleopatra. If then a king, who administered his government in the worst possible manner, and with the greatest negligence, obtained so large a revenue, what must we suppose it to be at present, when affairs are administered with great care, and when the commerce with India and with Troglodytica has been so greatly increased ? For formerly not even twenty vessels ventured to navigate the Arabian Gulf, or advance to the smallest distance beyond the straits at its mouth; but now large fleets are despatched as far as India and the extremities of Ethiopia, from which places the most valuable freights are brought to Egypt, and are thence exported to other parts, so that a double amount of custom is collected, arising from imports on the one hand, and from exports on the other. The most expensive description of goods is charged with the heaviest impost; for in fact Alexandreia has a monopoly of trade, and is almost the only receptacle for this kind of merchandise and place of supply for foreigners. The natural convenience of the situation is still more apparent to persons travelling through the country, and particularly along the coast which commences at the Catabathmus; for to this place Egypt extends.	http://www.perseus.tufts.edu/hopper/text?doc=Perseus%3Atext%3A1999.01.0239%3Abook%3D17%3Achapter%3D1%3Asection%3D13	Tolls; revenues; Egypt

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 1 BCE	Strabo, Geography, 17.1.16	Str. Geog. 17.1.16	ca. 24 CE	[...] At a little distance from Eleusis, on the right hand, is the canal leading towards Schedia. Schedia is distant four schoeni from Alexandreia. It is a suburb of the city, and has a station for the vessels with cabins, which convey the governors when they visit the upper parts of the country. Here is collected the duty on merchandise, as it is transported up or down the river. For this purpose a bridge of boats is laid across the river, and from this kind of bridge the place has the name of Schedia.	http://www.perseus.tufts.edu/hopper/text?doc=Strab.+17.1.16&fromdoc=Perseus%3Atext%3A1999.01.0239	Tolls, revenues
ca. 1 BCE	Strabo, Geography, 17.1.18	Str. Geog	ca. 24 CE	ca. 1 BCE The mouths have entrances which are not capable of admitting large vessels, but lighters only, on account of the shallows and marshes	https://topostext.org/work/144#17.1.18	shallows; vessel-type limitations
ca. 1 BCE	Strabo, Geography, 17.3.17-18	Str. Geog	ca. 24 CE	Close, in the neighbourhood (of these islands), is the Little Syrtis, which is also called the Syrtis Lotophagitis (or the lotus-eating Syrtis). The circuit of this gulf is 1600, and the breadth of the entrance 600 stadia; at each of the promontories which form the entrance and close to the mainland is an island, one of which, just mentioned, is Cercinna, and the other Meninx; they are nearly equal in size. Meninx is supposed to be the 'land of the lotus-eaters' mentioned by Homer. Certain tokens (of this) are shown, such as an altar of Ulysses and the fruit itself. For the tree called the lotus-tree is found in abundance in the island, and the fruit is very sweet to the taste. There are many small cities in it, one of which bears the same name as the island. On the coast of the Syrtis itself are also some small cities. In the recess (of the Syrtis) is a very considerable mart for commerce, where a river discharges itself into the gulf. The effects of the flux and reflux of the tides extend up to this point, and at the proper moment the neighbouring inhabitants eagerly rush (to the shore) to capture the fish (thrown up). § 17.3.18 After the Syrtis, follows the lake Zuchis, 400 stadia (in circuit?), with a narrow entrance, where is situated a city of the same name, containing factories for purple dyeing and for salting of all kinds;	https://topostext.org/work/144#17.3.17	Syrtis

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 1 BCE	Strabo, Geography, 17.3.20	Str. Geog	ca. 24 CE	The circuit of the Great Syrtis is about 3930 stadia, its depth to the recess is 1500 stadia, and its breadth at the mouth is also nearly the same. The difficulty of navigating both these and the Lesser Syrtis [arises from the circumstances of] the soundings in many parts being soft mud. It sometimes happens, on the ebbing and flowing of the tide, that vessels are carried upon the shallows, settle down, and are seldom recovered. Sailors therefore, in coasting, keep at a distance (from the shore), and are on their guard, lest they should be caught by a wind unprepared, and driven into these gulfs. Yet the daring disposition of man induces him to attempt everything, and particularly the coasting along a shore. On entering the Great Syrtis on the right, after passing the promontory Cephalae, is a lake of about 300 stadia in length, and 70 stadia in breadth, which communicates with the gulf, and has at its entrance small islands and an anchorage. After the lake follows a place called Aspis, and a harbour, the best of all in the Syrtis.[...] The intervening distance (between the recess of the Syrtis and Berenice) contains but few harbours, and watering-places are rare. The rest of the sea-coast of Cyrene from Apollonia to Catabathmus is 2200 stadia in length; it does not throughout afford facilities for coasting along it; for harbours, anchorage, habitations, and watering-places are few. The places most in repute along the coast are the Naustathmus, and Zephyrium with an anchorage, also another Zephyrium, and a promontory called Chersonesus, with a harbour situated opposite to and to the south of Corycus in Crete, at the distance of 2500 stadia; then a temple of Hercules, and above it a village Paliurus; then a harbour Menelaus, and a low promontory Ardanixis, (Ardanis,) with an anchorage; then a great harbour, which is situated opposite to Chersonesus in Crete	https://topostext.org/work/144#17.3.20	Description of the Syrtis; Syrtis-hazards Shallows; Hazardous-coast; Risks of coasting; Port-hierarchy; Coastline without landing sites & watering places
ca. 1 BCE	Strabo, Geography, 17.3.22	Str. Geog	ca. 24 CE	The rest of the sea-coast of Cyrene from Apollonia to Catabathmus is 2200 stadia in length; it does not throughout afford facilities for coasting along it; for harbours, anchorage, habitations, and watering-places are few	https://topostext.org/work/144#17.3.22	reasons for coasting

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 400 CE	Synesius, Letters, 4 (6-10)	Synesius	ca. 413 CE	As soon as he had doubled the temple of Poseidon, near you, he made straight for Taphosiris, with all sails spread, to all seeming bent upon confronting Scylla, over whom we were all wont to shudder in our boyhood when doing our school exercises. This maneuver we detected only just as the vessel was nearing the reefs, and we all raised so mighty a cry that perforce he gave up his attempt to battle with the rocks. All at once he veered about as though some new idea had possessed him, and turned his vessel's head to the open, struggling as best he might against a contrary sea. [7] Presently, a fresh south wind springs up and carries us along, and soon we are out of sight of land and have come into the track of the double-sailed cargo vessels, whose business does not lie with our Libya; they are sailing quite another course. Again we make common cause of complaint, and our grievance now is that we have been forced away far from the shore. Then does this Titan of ours, Amarantus, fulminate, standing up on the stern and hurling awful imprecations upon us. "We shall obviously never be able to fly," he said, "How can I help people like you who distrust both the land and the sea?" § 4.8 "Nay," I said, "Not so, worthy Amarantus, in case anyone uses them rightly. For our own part we had no yearning for Taphosiris, for we wanted only to live. Moreover," I continued, "What do we want of the open sea? Let us rather make for the Pentapolis, hugging the shore; for then, if indeed we have to face one of those uncertainties which, as you admit, are unfortunately only too frequent on the deep, we shall at least be able to take refuge in some neighboring harbor." [9] I did not succeed in persuading him with my talk, for to all of it the outcast only turned a deaf ear; and what is more, a gale commenced to blow from the north, and the violent wind soon raised seas mountains high. This gust falling suddenly on us, drove our sail back, and made it concave in place of its convex form, and the ship was all but capsized by the stern. With great difficulty, however, we headed her in. [10] Then Amarantus thunders out, "See what it is to be master of the art of navigation. I had long foreseen this storm, and that is why I sought the open. I can tack in now, since our sea room allows us to add to the length of our tack. But such a course as the one I have taken would not have been possible had we hugged the shore, for in that case the ship would have dashed on the coast."	https://topostext.org/work/538#4.1	Coastal-proximity; Seamanship; Perceived-hazard; 'Tolerable distance'

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 400 CE	Synesius, Letters, 51.1	Synesius	ca. 413 CE	Starting from Phykous at early dawn, late in the evening we stood in the Gulf of Erythra. There we stopped only a sufficient time to drink water and to take in a supply. Springs of pure, sweet water gush forth upon the very shore. [2] As our Carpathians were in a hurry, we took to sea again. The wind was light, but it blew continually on our stern, so that where we expected to make nothing of a run each day, we made all we needed before we were aware of it. [3] On the fifth day we saw the beacon fire lit upon a tower to warn ships running too close. We accordingly disembarked more quickly than it takes to relate, on the island of Pharos, a poor island where there are neither trees nor fruit, but only salt marshes.	https://topostext.org/work/538#51.1	Water-accessibility (quick stop); Indicators of coastal proximity
ca. 27 CE	Tacitus, Annals, 4.67	Tac. Ann.	ca. 117 CE	I would imagine that its isolation was its main attraction for him, since its coastline is without harbours and provides scant shelter for even small vessels, nor could anyone land without being seen by the sentries	https://topostext.org/work/200#4.67	dangerous coastline – attack probability
ca. 61 CE	Tacitus, Annals, 14.29	Tac. Ann.	ca. 117 CE	[…] He therefore prepared to attack the island of Mona, itself densely inhabited and also a haven for refugees, flat-bottomed boats being constructed to counter the uncertain shallows. Thus the infantry were ported across, while the cavalry waded behind, or swam their horses through the deeper water	https://topostext.org/work/200#14.29	shallows technological adaptation
ca. 69 CE	Tacitus, Histories, 2.35	Tac. Hist.	ca. 110 CE	As the anxious men fell against one another and fighters and oarsmen were thrown into confusion, the Germans leapt into the shallows, grasped the boats, and climbed aboard or dragged them under	https://topostext.org/work/199#2.35	shallows; assault probability
ca. 69 CE	Tacitus, Histories, 4.27	Tac. Hist.	ca. 110 CE	It so happened that, not far from the camp, a group of Germans began hauling a vessel loaded with grain, grounded in the shallows, to their side of the river	https://topostext.org/work/199#4.27	shallows; assault probability
ca. 69 CE	Tacitus, Histories, 5.15	Tac. Hist.	ca. 110 CE	The Germans, knowing the shallows, leapt through the water, and many of them left the attack to surround our flanks and rear, There was no close fighting as in the usual infantry battle, it was more like a naval conflict, with men struggling in the water, or if they made firm ground holding on grimly, the wounded and the whole, those who could swim and those who could not, locked together in mutual destruction	https://topostext.org/work/199#5.15	shallows; assault probability
ca. 550 BCE	Theognis, Elegies, 585	Thgn.	ca. 550 BCE	Surely there's risk in every sort of business, nor know we at the beginning of a matter where we shall come to shore; nay, sometimes he that striveth to be of good repute falleth unawares into ruin great and sore, whereas for the doer of good God maketh good hap in all things, to be his deliverance from folly	https://topostext.org/work/488#585	metaphor: unpredictable landing

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 550 BCE	Theognis, Elegies, 855	Thgn.	ca. 550 BCE	Often and often through the worthlessness of her leaders this city, like a ship out of her course, hath run too nigh the shore	https://topostext.org/work/488#855	metaphor: risk of coastal proximity when out of the expected course
ca. 300 BCE	Theophrastus, On Weather Signs, 16	Theophr. Signs	ca. 300 BCE	It is a sign of rain if the raven, who is accustomed to make many different sounds, repeats one of these twice quickly and makes a whirring sound and shakes its wings	https://topostext.org/work/749#16	birds; weather forecast
ca. 300 BCE	Theophrastus, On Weather Signs, 40	Theophr. Signs	ca. 300 BCE	All the signs which indicate rain bring stormy weather, that is to say, snow and storm, if not rain. If the raven utters a great variety of sounds in winter, it is a sign of storm	https://topostext.org/work/749#40	birds; weather forecast
ca. 431 BCE	Thucydides, Peloponnesian War, 1.142		ca. 395 BCE	3 It would be difficult for any system of fortifications to establish a rival city, even in time of peace, much more, surely, in an enemy's country, with Athens just as much fortified against it, as it against Athens; 4 while a mere post might be able to do some harm to the country by incursions and by the facilities which it would afford for desertion, but can never prevent our sailing into their country and raising fortifications there, and making reprisals with our powerful fleet	https://topostext.org/work/52#1.142	reprisal
ca. 432 BCE	Thucydides, Peloponnesian War, 1.67-4	Thuc.	ca. 395 BCE	There were many who came forward and made their several accusations; among them the Megarians, in a long list of grievances, called special attention to the fact of their exclusion from the ports of the Athenian empire and the market of Athens, in defiance of the treaty	https://topostext.org/work/52#1.67	political factors; treaties; ports
ca. 427 BCE	Thucydides, Peloponnesian War, 1.7	Thuc.	ca. 395 BCE	With respect to their towns, later on, at an era of increased facilities of navigation and a greater supply of capital, we find the shores becoming the site of walled towns, and the isthmuses being occupied for the purposes of commerce, and defence against a neighbor	https://topostext.org/work/52#1.7	description of shore
ca. 429 BCE	Thucydides, Peloponnesian War, 2.90	Thuc.	ca. 395 BCE	The Peloponnesians seeing him coasting along with his ships in single file, and by this inside the gulf and close in shore as they so much wished, at one signal tacked suddenly and bore down in line at their best speed on the Athenians, hoping to cut off the whole squadron	https://topostext.org/work/52#2.90	Assault-probability Unsafe shore

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 429 BCE	Thucydides, Peloponnesian War, 2.91	Thuc.	ca. 395 BCE	These, with the exception of one ship, all out-sailed them and got safe into Naupactus, and forming close in shore opposite the sanctuary of Apollo, with their prows facing the enemy, prepared to defend themselves in case the Peloponnesians should sail in shore against them. 2 After a while the Peloponnesians came up, chanting the paean for their victory as they sailed on; the single Athenian ship remaining being chased by a Leucadian far ahead of the rest. 3 But there happened to be a merchantman lying at anchor in the roadstead, which the Athenian ship found time to sail round, and struck the Leucadian in chase amidships and sank her. 4 An exploit so sudden and unexpected produced a panic among the Peloponnesians; and having fallen out of order in the excitement of victory, some of them dropped their oars and stopped their way in order to let the main body come up — an unsafe thing to do considering how near they were to the enemy's prows; while others ran aground in the shallows, in their ignorance of the localities.	https://topostext.org/work/52#2.91	Shallows Hazardous proximity
ca. 427 BCE	Thucydides, Peloponnesian War, 3.80.2, 81.1	Thuc.	ca. 395 BCE	But the Peloponnesians after ravaging the country until midday sailed away, and towards nightfall were informed by beacon signals of the approach of sixty Athenian vessels from Leucas, under the command of Eurymedon, son of Thucles; which had been sent off by the Athenians upon the news of the revolution and of the fleet with Alcidas being about to sail for Corcyra. 3.81.1 The Peloponnesians accordingly at once set off in haste by night for home, coasting along shore; and hauling their ships across the Isthmus of Leucas, in order not to be seen doubling it, so departed.	http://perseus.uchicago.edu/perseus-cgi/citequery3.pl?dbname=GreekFeb2011&getid=1&query=Thuc.%203.78.1	visibility; assault-probability; nocturnal navigation
ca. 427 BCE	Thucydides, Peloponnesian War, 3.81	Thuc.	ca. 395 BCE	The Peloponnesians accordingly at once set off in haste by night for home, coasting along shore; and hauling their ships across the isthmus of Leucas, in order not to be seen doubling it, so departed	https://topostext.org/work/52#3.81	visibility (night-hauling in order not to be seen)

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 424 BCE	Thucydides, Peloponnesian War, 4.8.7	Thuc.	ca. 395 BCE	The inlets the Lacedaemonians meant to close with a line of ships placed close together, with their prows turned towards the sea, and, meanwhile, fearing that the enemy might make use of the island to operate against them, carried over some heavy infantry thither, stationing others along the coast. [8] By this means the island and the continent would be alike hostile to the Athenians, as they would be unable to land on either; and the shore of Pylos itself outside the inlet towards the open sea having no harbour, and, therefore, presenting no point which they could use as a base to relieve their countrymen, they, the Lacedaemonians, without sea-fight or risk would in all probability become masters of the place, occupied, as it had been on the spur of the moment, and unfurnished with provisions. [9]	http://www.perseus.tufts.edu/hopper/text?doc=Perseus%3Atext%3A1999.01.0200%3Abook%3D4%3Achapter%3D8	Assault-probability Unsafe shore harbours
ca. 425 BCE	Thucydides, Peloponnesian War, 4.13	Thuc.	ca. 395 BCE	4 The Lacedaemonians did not put out to sea, and having omitted to close the inlets as they had intended remained quiet on shore, engaged in manning their ships and getting ready, in the case of any one sailing in, to fight in the harbour, which is a fairly large one	https://topostext.org/work/52#4.13	assault-probability; reprisal; inimical shores
ca. 425 BCE	Thucydides, Peloponnesian War, 4.14	Thuc.	ca. 395 BCE	14 Perceiving this, the Athenians advanced against them by each inlet, and falling on the enemy's fleet, most of which was by this time afloat and in line, at once put it to flight, and giving chase as far as the short distance allowed, disabled a good many vessels, and took five, one with its crew on board; dashing in at the rest that had taken refuge on shore, and battering some that were still being manned, before they could put out, and lashing on to their own ships and towing off empty others whose crews had fled	https://topostext.org/work/52#4.14	Assault-probability Unsafe shore; enemies
ca. 413 BCE	Thucydides, Peloponnesian War, 7.62	Thuc.	ca. 395 BCE	since we are absolutely compelled to fight a land battle from the fleet, and it seems to be our interest neither to back water ourselves, nor to let the enemy do so, especially as the shore, except so much of it as may be held by our troops, is hostile ground.	https://topostext.org/work/52#7.62	hostile shores
ca. 413 BCE	Thucydides, Peloponnesian War, 8.4	Thuc.	ca. 395 BCE	§ 8.4 In the meantime the Athenians were not idle. During this same winter, as they had determined, they contributed timber and pushed on their ship-building, and fortified Sunium to enable their corn-ships to round it in safety, and evacuated the fort in Laconia which they had built on their way to Sicily; while they also, for economy, cut down any other expenses that seemed unnecessary, and above all kept a careful look-out against the revolt of their confederates.	https://topostext.org/work/52#8.4	shipping control
ca. 750 BCE	Velleius Paterculus, Roman History, 1.4.1.	Vell. Pat.		[…] According to some accounts the voyage of this fleet was guided by the flight of a dove which flew before it; according to others by the sound at night of a bronze instrument like that which is beaten at the rites of Ceres.	https://topostext.org/work/727#1.4.1	birds

EVENT DATE	AUTHOR, TEXTS	Abbreviations	TEXT DATE	EXCERPT	SOURCE LINK	Themes
ca. 25 BCE	Velleius Paterculus, Roman History, 2.72.3	Vell. Pat.	ca. 30 CE	For men who had now no legal status any leader would do, since fortune gave them no choice, but held out a place of refuge, and as they fled from the storm of death any shelter served as a harbour	https://topostext.org/work/727#2.72.3	storm, the greatest risk
Myth.	Virgil, Aeneid, 2.1	Verg. Aen.	ca. 19 BCE	Tenedos is within sight, an island known to fame, rich in wealth when Priam's kingdom remained, now just a bay and an unsafe anchorage for boats: they sail there, and hide themselves, on the lonely shore	https://topostext.org/work/245#2.1	unsafe anchorage
Myth.	Virgil, Aeneid, 5.835	Verg. Aen.	ca. 19 BCE	And now drawn onwards it was close to the Sirens's cliffs, tricky of old, and white with the bones of many men	https://topostext.org/work/245#5.835	Sirens
ca. 30 BCE	Virgil, Georgics, 1.351	Virgil. G.	ca. 29 BCE	Then the cruel raven's deep cry calls up the rain, and, alone with himself, he walks the dry sands	https://topostext.org/work/672#1.351	birds; weather forecast
ca. 1 BCE	Vitruvius, Architecture, 5.12.1	Vitr. De arch.	ca. 15 BCE	HARBOURS, BREAKWATERS, AND SHIPYARDS The subject of the usefulness of harbours is one which I must not omit, but must explain by what means ships are sheltered in them from storms. If their situation has natural advantages, with projecting capes or promontories which curve or return inwards by their natural conformation, such harbours are obviously of the greatest service. Round them, of course, colonnades or shipyards must be built, or passages from the colonnades to the business quarters, and towers must be set up on both sides, from which chains can be drawn across by machinery	https://topostext.org/work/138	harbours: advantages
ca. 388 BCE	Xenophon, Hellenika, 5.1.9	Xen. Hell.	ca. 358 BCE	9 But when the ships of Eunomus were close to the shore near Cape Zoster in Attica, Gorgopas gave the order by the trumpet to sail against them. And as for Eunomus, the men on some of his ships were just disembarking, others were still occupied in coming to anchor, and others were even yet on their way toward the shore. Then, a battle being fought by moonlight, Gorgopas captured four triremes, and taking them in tow,5 carried them off to Aegina; but the other ships of the Athenians made their escape to Piraeus. [10]	https://topostext.org/work/96#5.1.9	Assault-probability; Unsafe shore enemies

APPENDIX 2 – PORT ATTRACTIVENESS

The following table contains the calculation of the attractiveness index (a-index) in the Regional Scale Model based on the *Anonymous Stadiasmus Maris Magni* (SMM) information. The criteria for calculating the a-index are described in chapter 5 and the procedures for implementing it in chapter 6. The field 'Comments & References' contains the modern place-names, when identified, the date range during which the locations are attested in the textual evidence, and the reference to the sources employed: i.e., PLEIADES[90], the Barrington Atlas (Talbert, 2000), ToposText[91], De Graauw (2017). The latter ID (i.e. DARMC_DeGraauw) serves as a cross-reference to the two shapefiles (Attachments 4a, 4b) presenting the list of ports with their attributes and geographical coordinates employed to model the shelter distance and the shelter attractiveness at Regional and Global scales, which are attached to this thesis digitally. In the following table, places follow the sequence number in the *Stadiasmus* (SMM ref); the DARMC_DeGraauw numbers are assigned following a geographical clockwise movement around the Mediterranean Sea from Northern Europe (Thulé) to the South (Notou Keras).

[90] D.J. Mattingly, R. Talbert, T. Elliott, and S. Gillies, Pleiades: A Gazetteer of Past Places, 2012 <https://pleiades.stoa.org/places> [accessed: multiple times between April 2017 and 23 November 2021]

[91] https://topostext.org/the-places

SMM ref	NAME	DESCRIPTION - NOTES	Comments & References	a-index
1	Chersoneso	a harbour	In SMM, 1 it is said to be a harbour distant two stadia from Alexandria – In Pseudo Scylax, Periplous "After Cherronesos is the Plinthinic gulf"; therefore it is unlikely to be associated with BAtlas 38 Cherronesos/Chersonesos Akra, and Pleiades: 373770 DARMC_DeGraauw 3941	8
2	Dysmay	a harbor for merchant ships not exceeding a thousand units of cargo (On the cargo unit and equivalent tonnage of this 'merchant ships' see Medas 137, Muller GGM, 1: 429-430)	DARMC_DeGraauw 3942	9
3	Plinthinae	an open roadstead, harborless	(Egypt) Kom el-Nagous? – Πλινθίνη Date range: (330 BC - AD 640) https://pleiades.stoa.org/places/727205 BAtlas 74 B2 DARMC_DeGraauw 3944	4
4	Taposiris	harborless city with a sanctuary of Osiris (just an anchorage, city and sanctuary nearby)	(Egypt) Abousir – Ταπόσειρις Date range: (30 BC - AD 640) https://pleiades.stoa.org/places/727241 Barrington Atlas: BAtlas 74 B3 DARMC_DeGraauw 3945	7
5	Chimo	a town, with rocky shoals visible (i.e. risky access and unstable seabed)	(Egypt) 3 el-Bordan – Χειμώ Date range: (330 BC - AD 300) BAtlas 73 G3 Ch(e)imo https://pleiades.stoa.org/places/716544 DARMC_DeGraauw 3946	5
6	Glaukos	ns	(Egypt) el-Imayid - Γλαυκόν άκρον Date range: (330 BC - AD 300) BAtlas 73 G3 Glaukon Akron https://pleiades.stoa.org/places/716564 DARMC_DeGraauw, 3947	
7	Antiphrai	open roadstead	(Egypt) Marina el-Alamein, el-Bahrein – Αντίφραι Date range: (330 BC - AD 640) BAtlas 73 G3 Antiphrai/Leukaspis https://pleiades.stoa.org/places/716524 DARMC_DeGraauw, 3948	6
8	Derrha	Small summer anchorage with water (size, 0; limited seasonality, i.e. 0; water, 2)	(Egypt) Derasiya? - Δέῤῥις Date range: (330 BC - AD 300) BAtlas 73 F3 Derras https://pleiades.stoa.org/places/716549 DARMC_DeGraauw, 3949	5
9	Zephyrion	harbour with roadstead (i.e. extra facility).	(Egypt) Ras Umm-el-Rakham – Ζεφύριον Date range: (330 BC - AD 300) Barrington Atlas: BAtlas 73 E2 Zephyrion Akron https://pleiades.stoa.org/places/716652 DARMC_DeGraauw, 3951	9
10	Pedone, Pezone	ns	Myrmix/Pedonia isl. (Egypt) Samra reef - Πηδωνία νήσος Date range: (330 BC - AD 300) BAtlas 73 F2 Myrmix/Pedonia Inss. https://pleiades.stoa.org/places/716603 DARMC_DeGraauw, 3952	
11	Pnigeis	"low-lying promontory, you enter to the right into a	Pnigeus (Egypt) 4 el-Gotta? – Πνιγεύς Date range: (330 BC - AD 300)	3

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		flat reef ": the approach seems hazardous/limited on one side; the access needs specific indications furthermore the promontory is not so visible	BAtlas 73 E2 Pnigeus https://pleiades.stoa.org/places/716624 DARMC_DeGraauw, 3954	
12	Phoinikous (Dydima)	Small anchorage having the depth for merchant ships; cistern with water. Two benefits and one limitation in size.	Didymai? islands (Egypt) SW Alexandria – Δίδυμαι Date range: (330 BC - AD 300) BAtlas 74 B2 Didymai? Inss. https://pleiades.stoa.org/places/727109 DARMC_DeGraauw, 3955	7
13	Hermaia	anchorage with water nearby	Hermaia Akron (Egypt) SE Ras el-Kanais - Ερμαία άκρα Date range: (330 BC - AD 300) BAtlas 73 E2 Hermaia Akron https://pleiades.stoa.org/places/716573 DARMC_DeGraauw, 3956	7
14	Leuke Akte	small anchorage for cargo ships, valid only under certain wind conditions (winds from the west). Nearby, 'a long anchorage for all kinds of ships; with a temple and water availability.	Leuke Akte (Egypt) Ras el-Abiad - Λευκή ακτή Date range: (550 BC - AD 300) BAtlas 73 E2 Leuke Akte https://pleiades.stoa.org/places/716587 DARMC_DeGraauw, 3957	10
15	Zygris	anchorage with indications to access and water in the sand	Zygris (Egypt) 5 Marsa Baqqush – Ζυγρίς Date range: (330 BC - AD 640) BAtlas 73 D2 Zygris https://pleiades.stoa.org/places/716656 DARMC_DeGraauw, 3958	6
16	Ladamanteia	Indication to access (risky accessibility) Harbor for all winds; it has water	Ladamantia (Egypt) 6 near Ras Abu Hasafa – Λαοδαμάντιον Date range: (330 BC - AD 300) BAtlas 73 E2 Ladamantia https://pleiades.stoa.org/places/716585 DARMC_DeGraauw, 3959	9
17	Kalamaios	A promontory with a lookout, with an anchorage to the right	DARMC_DeGraauw, 3960	5
18	Graias Gony	hazardous under certain wind conditions; water available.	Graias Gonu (Egypt) 2 Kom Nadoura/Marsa Berek? - Γραίας γόνυ Date range: (330 BC - AD 300) BAtlas 73 E2 Graias Gonu https://pleiades.stoa.org/places/716568 DARMC_DeGraauw, 3961	6
19	Artos	no anchorage. A hazardous place to round for reaching a nearby anchorage. Seems more a landmark	-	-
	Paraitonion	it is only mentioned the city as visible after passing Artos. No info on the landing site	Paraitonion/Ammonia (Egypt) Marsa Matruh – Παραιτόνιον Date range: (750 BC - AD 640) BAtlas 73 E2 Paraetonium/Ammonia https://pleiades.stoa.org/places/716615/?searchterm=Paraetonium/Ammonia* DARMC_DeGraauw, 3962	-
20	Delphines and Zephyrium	harbour for all winds and water	(Egypt) Umm el-Rakham - Δελφῖνες BAtlas 73 E2 Phokoussai/Delphines Inss. Date range: Delphines (AD 300 - AD 640) Phokoussai (30 BC - AD 300) https://pleiades.stoa.org/places/716622/?searchterm=Delphines%20* DARMC_DeGraauw, 3963	10

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21	Apis	a town with nearby anchorage. Water available.	Apis (Egypt) Zawiet Umm el-Rakham – Ἄπις Date range: (750 BC - 640 AD) BAtlas 73 E2 Apis https://pleiades.stoa.org/places/716526/apis DARMC_DeGraauw, 3964	9
22	Nesi	ns	DARMC_DeGraauw, 3965	-
23	Selenis	cape with a small anchorage; shoals around (limited size and hazardous access)	DARMC_DeGraauw, 3966	3
24	Azy, Asy	ns	DARMC_DeGraauw, 3967	-
25	Tyndarei	anchorage for cargo ships	Tyndareioi isl. (Egypt) Ishaila rocks - Τυνδάριοι σκόπελοι Date range: (330 BC - AD 300) BAtlas 73 D2 Tyndareioi Inss. https://pleiades.stoa.org/places/716642 DARMC_DeGraauw, 3968	6
26	Chautaion	an anchorage for small ships. It has spring water gushing out into the fields	Chautaion/Chettaia (Egypt) Marsa Gargub – Χετταία Date range: (330 BC - AD 300) BAtlas 73 D2 Chautaion/Chettaia https://pleiades.stoa.org/places/716543 DARMC_DeGraauw, 3969	6
27	Zygrai	ns	Zygris (Egypt) Marsa Baqqush – Ζυγρίς Date range: (330 BC - AD 640) BAtlas 73 D2 Zygris https://pleiades.stoa.org/places/716656 DARMC_DeGraauw, 3970	-
28	Ennesyphora	a summer anchorage; water and "a lookout on the sea"	Ainesisphyra? Akron (Egypt) Sidi Barrani - Αινησίσφυρα λιμήν Date range: (330 BC - AD 300) BAtlas 73 C2 Ainesisphyra? Akron https://pleiades.stoa.org/places/716506 DARMC_DeGraauw, 3971	6
29	Katabathmos	A high village, harbour from all winds; water.	Katabathmos Maior/Plynos Limen (Egypt) Sollum - Κατάβαθμος μέγας Date range: (750 BC - AD 640) BAtlas 73 C2 Catabathmus Maior/Plynos Limen/Tetrapyrgia https://pleiades.stoa.org/places/716540 DARMC_DeGraauw, 3972	11
30	Syke	artificial anchorage with water.	DARMC_DeGraauw, 3973	8
31	Panormos	it is a deep hollow with 'very good water' under the fig.	The name appears ten times in the SMM thus referring to five different localities Stad.M.M. 31-32 159, 262-263, 282, 285, 287, 292-293, 294 (Medas 147) According to Rougé only the sicilian locality would be a proper harbour city (Rougé 1966, 114) DARMC_DeGraauw, 3974	7
32	Eureia	a 'good roadstead' with fresh water	DARMC_DeGraauw, 3975	9
33	Petras	'it has much water in both parts'. The presence of a landing or anchorage is not specified. The two parts seems to refer to a cape or promontory	Petras Megas (Egypt) Bardia/Bardia Sliman LBY - Πέτρας μεγάλης Date range: (330 BC - AD 640) BAtlas 73 C2 Petras Megas https://pleiades.stoa.org/places/716619 DARMC_DeGraauw, 3976	2

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34	Kardamis	anchorage, only under certain wind-directions. Water on the mainland	DARMC_DeGraauw, 3977	6
35	Menelaos	harbour with water	Menelaos (Egypt) Marsa Ahora? – Μενέλαος Date range: (550 BC - AD 300) BAtlas 73 B2 Menelaos https://pleiades.stoa.org/places/716599 DARMC_DeGraauw, 3978	9
36	Katanei	white beach with water in the sand	DARMC_DeGraauw, 3979	6
37	Kyrthanion	"sail 8 stades away since there are high shoals; there is water". It does not seem to be possible to approach with the vessel. Only the water availability is accounted	Marsa el-Afarid? Libya Date range: (30 BC - AD 640) BAtlas 73 B2 Kyrthanion https://pleiades.stoa.org/places/716584/?searchterm=Kyrthanion* DARMC_DeGraauw, 3981	2
38	Antypirgos	summer anchorage; sanctuary; water	Tobruk (Libya) Date range: (330 BC - AD 640) Atlas 73 A1 Antipyrgos https://pleiades.stoa.org/places/716525/?searchterm=Antipyrgos* DARMC_DeGraauw, 3983	8
39	Small Petras	ns	DARMC_DeGraauw, 3985	-
40	Batrachos	summer anchorage; water	Gardaba (Libya) Date range: (750 BC - AD 640) BAtlas 73 A1 Batrachos https://pleiades.stoa.org/places/716536/?searchterm=Batrachos* DARMC_DeGraauw, 3986	6
41	Platea,	summer anchorage for cargo ships; water	Platea? island (Libya) Gasr al-Bomba? – Πλατέα Date range: Plateia (750 BC - AD 640) BAtlas 38 E1 Plateia https://pleiades.stoa.org/places/373874 DARMC_DeGraauw, 3990	7
42	Paliouros	water. No further info	Paliouros - Παλίουρος / Paliuris Wadi et-Tmimi (Libya) Date range: (330 BC - AD 300) BAtlas 38 E1 Paliouros https://pleiades.stoa.org/places/373868 DARMC_DeGraauw, 3989	2
43	Phaia	as above	Bomba? (Libya) Date range: (750 BC - 30 BC) BAtlas 38 E1 Phaia https://pleiades.stoa.org/places/373870 DARMC_DeGraauw, 3991	2
44	Dionysos	"from there put to shore on the left". The landing seems possible although under limited conditions	Saline (Libya) Date range: (330 BC - AD 300) BAtlas 38 E1 Dionysos https://pleiades.stoa.org/places/373781/?searchterm=Dionysos* DARMC_DeGraauw, 3992	4
45	Chersonesos	ns	(Libya) BAtlas 38 E1 Chersonesos Akra https://pleiades.stoa.org/places/373773 DARMC_DeGraauw, 3993	-
46	Azaris	"from there sail past at high tide; the rocks are high. It has water and a large river". The passage is hazardous	DARMC_DeGraauw, 3994	2

SMM ref	NAME	DESCRIPTION - NOTES	Comments & References	a-index
		and requires indications. There seem to be no landing option but water		
47	Darne	ns	Darnis (Libya) Derna – Δαρνίς Date range: (750 BC - AD 640) BAtlas 38 D1 Darnis https://pleiades.stoa.org/places/373780 DARMC_DeGraauw, 3995	-
48	Zephyrium	small summer anchorage (Both limited size and seasonality)	DARMC_DeGraauw, 3996	3
49	Chersis (Aphrodisias)	anchorage with a sanctuary	Sidi Bu Fachra (Libya) Date range: (330 BC - AD 300) BAtlas 38 D1 Chersis https://pleiades.stoa.org/places/373772/?searchterm=Chersis* DARMC_DeGraauw, 3997	7
50	Erythron	a town, no further info	Wadi el-Atrun, Latrun (Libya) Date range: (30 BC - AD 640) BAtlas 38 D1 Erythron https://pleiades.stoa.org/places/373785/?searchterm=Erythron* DARMC_DeGraauw, 3998	2
51	Naustathmos	'long open roadstead; it has water in the sand'	Marsa Hilal (Libya) Date range: (330 BC - AD 640) BAtlas 38 D1 Naustathmos https://pleiades.stoa.org/places/373862/?searchterm=Naustathmos* DARMC_DeGraauw, 3999	9
52	Apollonia	ns	Marsa Susa - Susah - Απολλωνία (Libya) Apollonia (Latin, 750 BC - AD 640) Portus Cyrenorum (750 BC - 30 BC) Σώζουσα (Sozousa Ancient Greek, AD 300 - AD 640) BAtlas 38 C1 Apollonia/Sozousa https://pleiades.stoa.org/places/373732 DARMC_DeGraauw, 4000	-
53	Phykous	anchor under limited wind conditions. It is a summer roadstead with water	Phykous (Libya) al Hamamah – Φυκούς Date range: (330 BC - AD 640) BAtlas 38 C1 Phykous https://topostext.org/place/329216HPhy https://pleiades.stoa.org/places/373872 DARMC_DeGraauw, 4002	7
54	Nausis	a town with water on the beach	DARMC_DeGraauw, 4005	8
55	Ptolemais	'it is a very large city; the anchorage is rough, and it has an island called Ilos; take care'	ad Dirsiya (Libya) – Πτολεμαΐς Date range: (750 BC - AD 640) BAtlas 38 B1 Ptolemais/Barkes Limen https://topostext.org/place/327210UPto https://pleiades.stoa.org/places/373879 DARMC_DeGraauw, 4007	6
56	Teuchira, Arsinoe	It is an ancient city of the Pentapolis	Tocra (Libya) - Taucheira/Arsinoe Ταύχειρα Date range: Arsinoe (330 BC - AD 300) BAtlas 38 B1 Arsinoe/Taucheira Taucheira (750 BC - AD 640) https://topostext.org/place/325206UTau https://pleiades.stoa.org/places/373736 DARMC_DeGraauw, 4010	2
57	Bernikide, Berenike	shoals; anchorage for small boats	Benghazi (Libya) Euesperides/Berenike – Ευεσπερίδες Date range: Euesperides (750 BC - AD 300) Εὐεσπερίδας (Euesperides: Ancient Greek, 550 BC - 330 BC)	3

SMM ref	NAME	DESCRIPTION - NOTES	Comments & References	a-index
			Euesperites (750 BC - AD 300) BAtlas 38 B1 Euesperides https://topostext.org/place/321201UEue https://pleiades.stoa.org/places/373786 DARMC_DeGraauw, 4017	
58	Rineia	ns	DARMC_DeGraauw, 4018	-
59	Pithos	ns	minor location on coast SW Benghazi Date range: (30 BC - AD 640) BAtlas 38 Pithos https://pleiades.stoa.org/places/376808/?searchterm=Pithos* DARMC_DeGraauw, 4019	-
60	Theotimaion	summer anchorage with a deep beach	Tereth? (Libya) Date range: (330 BC - AD 300) BAtlas 38 B1 Theotimaion https://pleiades.stoa.org/places/373905/?searchterm=Theotimaion* DARMC_DeGraauw, 4020	5
61	Halai	beach; no further details	DARMC_DeGraauw, 4021	4
62	Boreion	promontory with small anchorage	Date range: (30 BC - AD 300) BAtlas 38 A2 Boreion Pr. https://pleiades.stoa.org/places/373760/?searchterm=Boreion* DARMC_DeGraauw, 4022	4
63	Chersis	anchorage for limited wind conditions. Water available	Chersa/Karsa (Libya) Date range: (330 BC - AD 300) BAtlas 38 A2 Chersis https://pleiades.stoa.org/places/373771 DARMC_DeGraauw, 4023	6
64	Amastor	ns	Bu Sceriba? (Libya) Date range: (330 BC - 30 BC) BAtlas 38 A2 Amastor https://pleiades.stoa.org/places/373729 DARMC_DeGraauw, 4024	-
65	Herakleon	ns	DARMC_DeGraauw, 4025	-
66	Drepanon	high promontory with a strand of white sand and water.	Ras Carcura? (Libya) Date range: (330 BC - AD 300) BAtlas 38 B2 https://pleiades.stoa.org/places/373782/?searchterm=Drepanon* DARMC_DeGraauw, 4026	6
67	Serapeon	you will see a very large white beach, from which if you dig you will have sweet water	DARMC_DeGraauw, 4027	6
68	Diarrhoias	ns	DARMC_DeGraauw, 4028	-
69	Apis	small anchorage without additional details	Different from SMM 21 DARMC_DeGraauw, 4029	4
70	Kainon	a deserted fort with water. No harbour	Zeutina? (Libya) Date range: (330 BC - AD 300) BAtlas 38 B3 Kainon https://pleiades.stoa.org/places/373832/?searchterm=Kainon* DARMC_DeGraauw, 4031	4

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71	Euschoinos	the beach is deep, there is a round hill in the town; it has water	DARMC_DeGraauw, 4032	8
72	Hyphali	small roadstead and wide beach	DARMC_DeGraauw, 4033	6
73	Scopelites	more a landmark (elephant shape) than a proper anchorage	DARMC_DeGraauw, 4034	-
74	Pontia	'a high island called Pontia'. Seems a landmark	Date range: unspecified BAtlas 37 E2 Pontia Ins. https://pleiades.stoa.org/places/364002 DARMC_DeGraauw, 4035	-
75	Maia	small anchorage with water	Legarah reef (Libya) Date range: unspecified BAtlas 37 E2 Maia Ins. https://pleiades.stoa.org/places/363992 DARMC_DeGraauw, 4036	6
76	Astrochanda	ns	DARMC_DeGraauw, 4037	-
77	Krokodilos	summer anchorage with water	DARMC_DeGraauw, 4039	6
78	Boreon	'it is a town, the fort is deserted, the anchorage is good from the west; it has water'	DARMC_DeGraauw, 4040	8
79	Antidrepanon	promontory with water	A promontory in Libya, town of Boreum atop, mod. Bu Grada Date range: unspecified BAtlas 37 E2 Antidrepanon Akroterion https://pleiades.stoa.org/places/363923/?sea rchterm=Antidrepanon* DARMC_DeGraauw, 4041	2
80	Mendrion	no information besides the lack of water. Shall we assume then in lack of mentions the other anchorage would have water? Actually no, since also the availability is specifically mentioned. Rather, as suggested in the following point, we may derive that the anchorage would be a good one, if not for the lack of water. Less straightforward how to categorize this consequently; The attractiveness of simple anchorages has been assigned	Marsa Brega gulf (Libya) Date range: (330 BC - AD 300) BAtlas 37 E2 Mendrion https://pleiades.stoa.org/places/363996/?sea rchterm=Mendrion* DARMC_DeGraauw, 4042	5
81	Kozynthion	A rough cape; the anchorage is good, but waterless	Marsa Brega (Libya) Date range: (330 BC - AD 300) BAtlas 37 E2 Kozynthion Akra https://pleiades.stoa.org/places/363981/?sea rchterm=Kozynthion* DARMC_DeGraauw, 4043	5
82	Pegai Ammoniou	a beach	Maaten Bescer? (Libya) Date range: (330 BC - AD 300) BAtlas 37 E2 Ammoniou Pegai https://pleiades.stoa.org/places/363920/?sea rchterm=Pegai%20Ammoniou* DARMC_DeGraauw, 4045	4

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83	Automalaka	ns	DARMC_DeGraauw, 4047	-
84	Altars of the Philainoi (Arae Philaenorum)	'It is a good summer anchorage and it has water'	TroposText notes: Marsa al-Brega? (Libya) - Φιλαίνων Βωμοί The Barrington Atlas & PLEIADES reports: Graret Gser et-Trab Date Range: Less than certain: Arae Philaenorum (30 BC - AD 300) Banadedari (30 BC - AD 300) BAtlas 37 D2 Banadedari https://topostext.org/place/302190SAPh https://pleiades.stoa.org/places/363935 DARMC_DeGraauw, 4048	6
85	Cape Hippo (Hippou Akra)	rugged promontory; small anchorage and water	Ras el-Ihudia? (Libya) Date Range: (330 BC - AD 300) BAtlas 37 D2 Hippou Akra https://pleiades.stoa.org/places/363973/?searchterm=Hippou%20Akra* DARMC_DeGraauw, 4051	5
86	Eperos	'there is a harbour for small ships. There is water. This is a fort of the barbarians'	Bir en-Naim? (Libya) Date Range: (30 BC - AD 640) BAtlas 37 C1 Eperos https://pleiades.stoa.org/places/363958/?searchterm=Eperos* DARMC_DeGraauw, 4057	8
87	Korax	ns	BAtlas 37 C1 Charax/(I)Scina ? https://pleiades.stoa.org/places/363951 DARMC_DeGraauw, 4058	-
88	Euphrantai	harbour with water	DARMC_DeGraauw, 4062	9
89	Dysopos	ns	DARMC_DeGraauw, 4064	-
90	Aspis	ns	Buerat el-Hsun (Libya) Date range: (330 BC - AD 300) BAtlas 37 A1 Aspis https://pleiades.stoa.org/places/363926/?searchterm=Aspis* DARMC_DeGraauw, 4066	-
91	Taricheia	ns	Bir Bu Retma ? (Libya) Date range: (330 BC - 30 BC) BAtlas 35 H3 Taricheiai? https://pleiades.stoa.org/places/344501/?searchterm=Taricheia* DARMC_DeGraauw, 4068	-
92	Kephalai	a promontory	DARMC_DeGraauw, 4069	-
93	Neapolis, Leptis Magna	'Sailing from the open sea you see a low-lying country with islands, approaching which you see the seaside city and a white strand and beach; the city is all white. It has no harbour. Anchor safely at the Hermaion. It is called Leptis (see below)	TroposText notes: Khoms (Libya) The Barrington Atlas Directory and PLEIADES note: Lebda a Phoenician colony founded ca. 1100 B.C., Lepcis Magna became a prominent Roman city and birthplace of the emperor Septimius Severus. Date range: Lepcis Magna (Latin, 30 BC - AD 300) Leptis Magna (Latin, 30 BC - AD 300) Neapolis (330 BC - 30 BC) BAtlas 35 G2 Neapolis/Lepcis Magna	3

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			https://pleiades.stoa.org/places/344448/?searchterm=Leptis%20Magna* DARMC_DeGraauw, 4077	
94	Hermaion	an anchorage for small ships, nearby city (see above)	Cape Homs (Libya) Date range: unspecified BAtlas 35 G2 Hermaion Pr. https://pleiades.stoa.org/places/344408/?searchterm=Hermaion* DARMC_DeGraauw, 4078	6
95	Gaphara, Aineospora	cape with anchorages on both sides, with water	Marset ed-Dzeira (Libya) Date range: Gaphara (330 BC - AD 300) BAtlas 35 F2 Gaphara https://pleiades.stoa.org/places/344359/?searchterm=Gaphara* DARMC_DeGraauw, 4081	8
96	Amaraia	'It is a tower [and] small anchorage. It has river water. There are tilled lands near the river, which is called Oinoladon'.	DARMC_DeGraauw, 4082	6
97	Megerthis	city with harbour and water	mouth of Wadi Ram'l? (Libya) Date range: Less than certain: Megerthis (330 BC - AD 640) BAtlas 35 F2 Megradi/Megerthis? https://pleiades.stoa.org/places/344437/?searchterm=Megerthis* DARMC_DeGraauw, 4083	10
98	Makaraia	ns	DARMC_DeGraauw, 4085	-
99	Sabratha	a city without harbour; it has an open roadstead	Sabratah (Libya) Abrotonon/Sabratha – Αβρότονον Date range: Abrotonum (550 BC - 30 BC) Sabratha (Latin, 750 BC - AD 640) BAtlas 35 E2 Abrotonum/Sabratha https://topostext.org/place/328125UAbr https://pleiades.stoa.org/places/344282 DARMC_DeGraauw, 4088	8
100	Lokri	a town with a tall tower. No info about the kind of anchorage. It might also be a simple landmark	DARMC_DeGraauw, 4093	2
101	Zeucharis	a fort with a tower, harbour with water.	? BAtlas 35 D1 Taricheiai/Zouchis ? https://pleiades.stoa.org/places/344500/zeucharis/?searchterm=Zeucharis* DARMC_DeGraauw, 4098	9
102	Gergis	"It is a tower and has a fort, harbour, and water	Zarzis (Tunisia) Date range: Gergis (330 BC - AD 300) Girgi (330 BC - AD 300) BAtlas 35 D1 Gergis https://pleiades.stoa.org/places/344372/?searchterm=Gergis* DARMC_DeGraauw, 4101	9
103	Meninx	island of the lotus eaters. Many cities, on the metropolis there is an altar to Hercules. Harbor with water	Djerba (Tunisia) - Meninx Μήνιγξ coastal island and city of the Lotus-Eaters, Djerba, Tunisia Date range: Girba (30 BC - AD 300) Lotophagitis (330 BC - 30 BC) Μῆνιγξ (Meninx: Ancient Greek, 330 BC - AD 300) Uchium (30 BC - AD 640) BAtlas 35 C1 Meninx/Lotophagitis/Girba Ins. https://topostext.org/place/338109IMen	10

SMM ref	NAME	DESCRIPTION – NOTES	Comments & References	a-index
			https://pleiades.stoa.org/places/344440 DARMC_DeGraauw, 4103	
104	Gichtis	a city with a good harbour and water	DARMC_DeGraauw, 4113	10
105	Kidiphta	city with harbour	DARMC_DeGraauw, 4115	9
106	Takape	ns	DARMC_DeGraauw, 4121	-
107	Neapolis	city with harbour.	DARMC_DeGraauw, 4126	9
108	Thena	(see SMM 112) city with harbour 'but because of the shoals lying off them moderate sized boats sail there (i.e. limited size and risky access; city)	DARMC_DeGraauw, 4128	7
109	Acholla	(see SMM 112) city with harbour 'but because of the shoals lying off them moderate sized boats sail there (i.e. limited size and risky access; city)	Ras Botria, Boutria (Tunisia) Date range: Acholla (330 BC - AD 640) Aholla (Latin, 30 BC - AD 640) BAtlas 33 H2 Acholla https://topostext.org/place/351110UAch https://pleiades.stoa.org/places/324653 DARMC_DeGraauw, 4133	7
110	Alipota	(see SMM 112) city with harbour 'but because of the shoals lying off them moderate sized boats sail there (i.e. limited size and risky access; city)	Salakta (Tunisia) BAtlas 33 H1 Alipota?/Gummi https://pleiades.stoa.org/places/324663/?searchterm=Alipota* DARMC_DeGraauw, 4136	7
111	Thapsos	city with harbour 'but because of the shoals lying off them moderate sized boats sail there (i.e. limited size and risky access; city)	ToposText reports: Bekalta (Tunisia) – Θάψος The Barrington Atlas Directory and PLEIADES note: Ras-Dimas Date range: (330 BC - AD 640) BAtlas 33 H1 Thapsus https://topostext.org/place/356110UTha https://pleiades.stoa.org/places/324827 DARMC_DeGraauw, 4137	7
112	Kerkina	The island Kerkina lies offshore from Acholla and Alipota and Kidiphtha, […] By the city (i.e. Kerkina) are shoals; it has a harbour and water	Kerkina, island in the Lesser Syrtis, Kerkennah, Tunisia - Kerkennah - Κέρκινα Date range latin Insula Cercina: insula Cercina (Latin, 330 BC - AD 640) BAtlas 33 H3 Cercina Ins. https://topostext.org/place/347112IKer https://pleiades.stoa.org/places/324690 DARMC_DeGraauw, 4130	8
113	Leptis Minor	'it is a small city; it has conspicuous shoals, and putting in at the city is very difficult'. The kind of landing is not specified. It is assumed to be an harbour with hazardous access and city nearby	Lamta, (Tunisia) μικρὰ Λέπτις - Leptis Minor, Date range: Lepti Minus (330 BC - AD 640) BAtlas 33 G1 Lepti Minus https://topostext.org/place/357109ULep https://pleiades.stoa.org/places/324767 DARMC_DeGraauw, 4139	8
114	Thermai	'A town, and here in the same way the shoals make putting in difficult' (as above)	DARMC_DeGraauw, 4141	8
115	'promontory against which	('Ruspina' in the Graauw) an anchorage	BAtlas 33 G1 Ruspina https://pleiades.stoa.org/places/324803/?searchterm=Ruspina*	5

SMM ref	NAME	DESCRIPTION - NOTES	Comments & References	a-index
	are two islands’		DARMC_DeGraauw, 4142	
116	Adramyte	City, harborless	DARMC_DeGraauw, 4143	2
117	Aspis, Clipea	It is a high and conspicuous promontory, as if a shield. A city on it; there is a harbour toward the west. Many shoals and rocks in the sea.	Kelibia (Tunisia) Date Range: Aspis (330 BC - AD 640) Clipea (330 BC - AD 640) BAtlas 32 H3 Aspis/Clipea https://pleiades.stoa.org/places/314892/?searchterm=Aspis,%20Clipea* DARMC_DeGraauw, 4156	8
118	Hermaion Cape	ns	Cap Bon, Ras at-Tib (Tunisia) Ερμαία άκρα BAtlas 32 H2 Hermaia Akra/Mercurii Pr./Kalon Akroterion? https://topostext.org/place/371110LHer https://pleiades.stoa.org/places/315036	

APPENDIX 3 – MODEL SCRIPTS

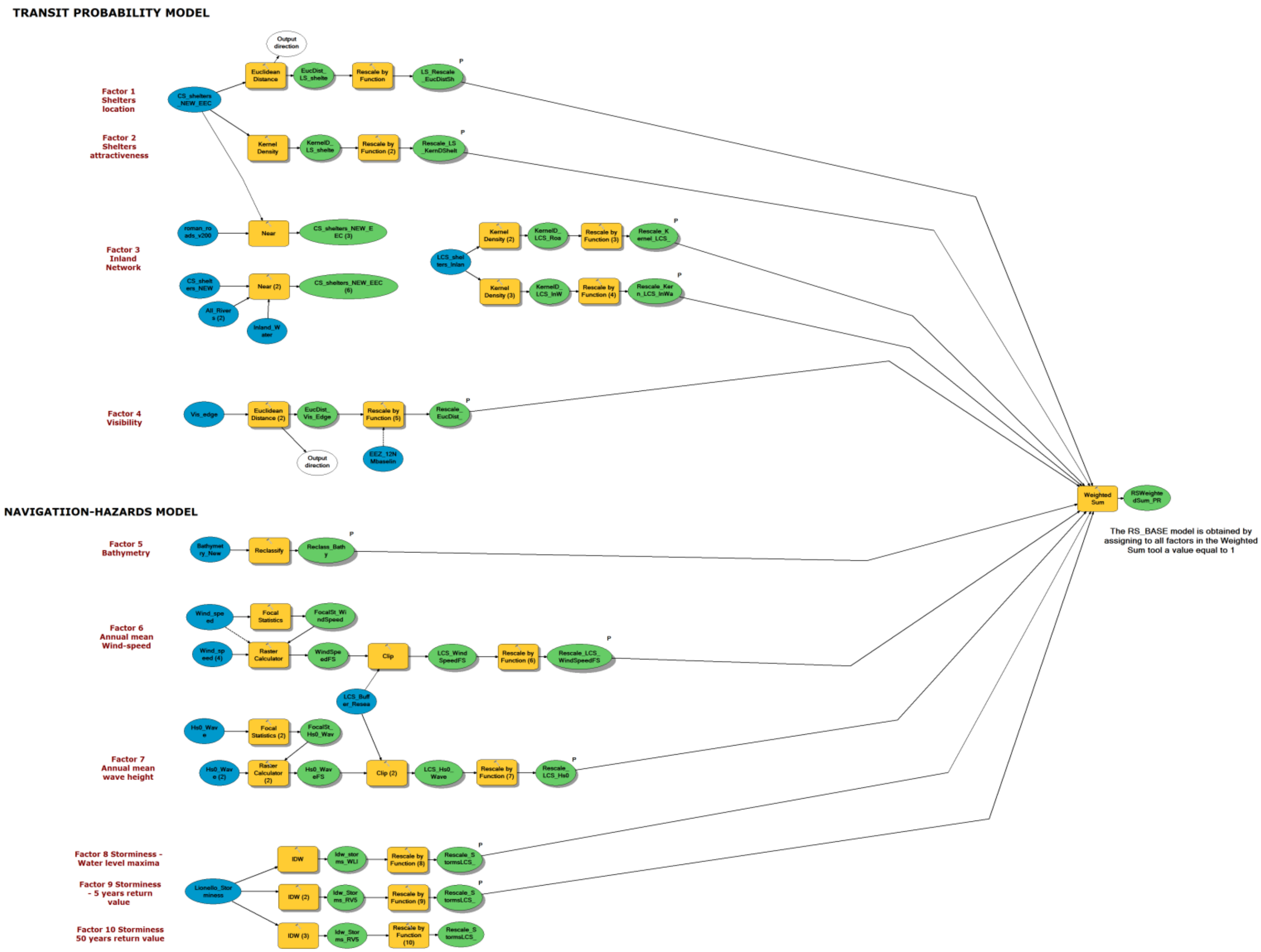
This Appendix includes three elements:

- The Model Builder structure (Attachment 3a)

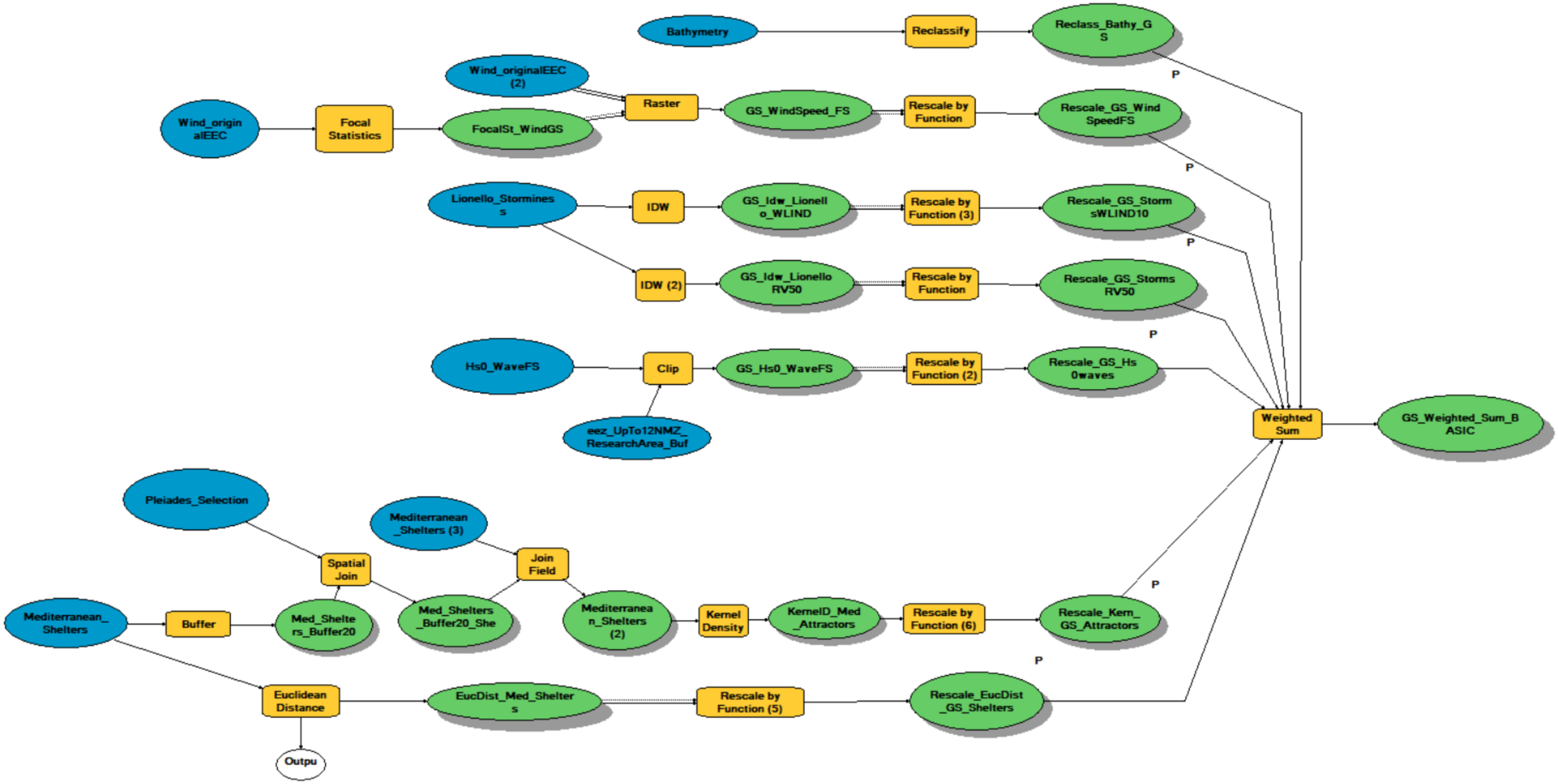
- The scripts to run the Regional and Global scale models in ArcGIS following the procedures described in detail in Chapter 6 (Appendices 3b and 3c)

- The two scripts used to run the visibility analysis presented in section 6.2.4 (Appendix 3d)

3a Model Builder schema – *Regional Scale Model (RS Model)*



Global Scale Model (GS_Model)



```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# Name:         RS_model_BASE.py
# Purpose:      Assessment of the relative Shipwrecking Probability in Mediterranean
territorial waters in Roman time
# Author:       Manuela Ritondale
# Created on:   2021-09-01 11:31:41.00000

# Generated by ArcGIS/ModelBuilder
# Usage: RS_model_BASE <RS_Rescale_EucDistShelt> <Rescale_RS_KernDSheltAttract>
<Rescale_Kernel_RS_roads> <Rescale_Kern_RS_InWater> <Rescale_EucDist_VisEdgeMB>
<Reclass_Bathy> <Rescale_RS_WindSpeedFS> <Rescale_RS_Hs0_Waves>
<Rescale_StormsRS_WLIND10> <Rescale_StormsRS_RV50>

# Description:  Regional Scale (RS) Model assessing the relative Shipwrecking
Probability in Roman time within the 12 NM zone, in the area comprised between
Alexandria (Egypt) and Cap Bon (Tunisia)
# ---------------------------------------------------------------------------


# Import arcpy module
import arcpy

# Script arguments
RS_Rescale_EucDistShelt = arcpy.GetParameterAsText(0)
if RS_Rescale_EucDistShelt == '#' or not RS_Rescale_EucDistShelt:
    RS_Rescale_EucDistShelt = "./RS_Model.gdb\\RS_Rescale_EucDistShelt" # provide a
default value if unspecified

Rescale_RS_KernDSheltAttract = arcpy.GetParameterAsText(1)
if Rescale_RS_KernDSheltAttract == '#' or not Rescale_RS_KernDSheltAttract:
    Rescale_RS_KernDSheltAttract = "./RS_Model.gdb\\Rescale_RS_KernDSheltAttract" #
provide a default value if unspecified

Rescale_Kernel_RS_roads = arcpy.GetParameterAsText(2)
if Rescale_Kernel_RS_roads == '#' or not Rescale_Kernel_RS_roads:
    Rescale_Kernel_RS_roads = "./RS_Model.gdb\\Rescale_Kernel_RS_roads" # provide a
default value if unspecified

Rescale_Kern_RS_InWater = arcpy.GetParameterAsText(3)
if Rescale_Kern_RS_InWater == '#' or not Rescale_Kern_RS_InWater:
    Rescale_Kern_RS_InWater = "./RS_Model.gdb\\Rescale_Kern_RS_InWater" # provide a
default value if unspecified

Rescale_EucDist_VisEdgeMB = arcpy.GetParameterAsText(4)
if Rescale_EucDist_VisEdgeMB == '#' or not Rescale_EucDist_VisEdgeMB:
    Rescale_EucDist_VisEdgeMB = "./RS_Model.gdb\\Rescale_EucDist_VisEdgeMB" #
provide a default value if unspecified

Reclass_Bathy = arcpy.GetParameterAsText(5)
if Reclass_Bathy == '#' or not Reclass_Bathy:
    Reclass_Bathy = "./RS_Model.gdb\\Reclass_Bathy" # provide a default value if
unspecified

Rescale_RS_WindSpeedFS = arcpy.GetParameterAsText(6)
if Rescale_RS_WindSpeedFS == '#' or not Rescale_RS_WindSpeedFS:
    Rescale_RS_WindSpeedFS = "./RS_Model.gdb\\Rescale_RS_WindSpeedFS" # provide a
default value if unspecified

Rescale_RS_Hs0_Waves = arcpy.GetParameterAsText(7)
if Rescale_RS_Hs0_Waves == '#' or not Rescale_RS_Hs0_Waves:
```

```
    Rescale_RS_Hs0_Waves = "./RS_Model.gdb\\Rescale_RS_Hs0_Waves" # provide a
default value if unspecified

Rescale_StormsRS_WLIND10 = arcpy.GetParameterAsText(8)
if Rescale_StormsRS_WLIND10 == '#' or not Rescale_StormsRS_WLIND10:
    Rescale_StormsRS_WLIND10 = "./RS_Model.gdb\\Rescale_StormsRS_WLIND10" # provide
a default value if unspecified

Rescale_StormsRS_RV50 = arcpy.GetParameterAsText(9)
if Rescale_StormsRS_RV50 == '#' or not Rescale_StormsRS_RV50:
    Rescale_StormsRS_RV50 = "./RS_Model.gdb\\Rescale_StormsRS_RV50" # provide a
default value if unspecified

# Local variables:
CS_shelters_NEW_EEC = "CS_shelters_NEW_EEC"
CS_shelters_NEW_EEC__3_ = CS_shelters_NEW_EEC
Output_direction_raster = ""
roman_roads_v2008 = "roman_roads_v2008"
CS_shelters_NEW_EEC__4_ = "CS_shelters_NEW_EEC"
CS_shelters_NEW_EEC__6_ = CS_shelters_NEW_EEC__4_
All_Rivers__2_ = "All_Rivers"
Inland_Water = "Inland_Water"
Vis_edge = "./RS_Model.gdb\\Vis_edge"
Output_direction_raster__2_ = ""
Lionello_Storminess = "Lionello_Storminess"
Idw_Storms_RV5 = "./RS_Model.gdb\\Idw_Storms_RV5"
Rescale_StormsRS_RV5 = "./RS_Model.gdb\\Rescale_StormsRS_RV5"
Bathymetry_New = "Bathymetry_New"
Wind_speed__4_ = "Wind_speed"
Wind_speed = "Wind_speed"
FocalSt_WindSpeed = "./RS_Model.gdb\\FocalSt_WindSpeed"
WindSpeedFS = "e:\\Backup\\GIS\\NEW\\final_lcs_fullmodel.gdb\\WindSpeedFS"
RS_Buffer_ResearchArea = "RS_Buffer_ResearchArea"
RS_WindSpeedFS = "./RS_Model.gdb\\RS_WindSpeedFS"
Hs0_Wave__2_ = "Hs0_Wave"
Hs0_Wave = "Hs0_Wave"
FocalSt_Hs0_Waves = "./RS_Model.gdb\\FocalSt_Hs0_Waves"
Hs0_WaveFS = "e:\\Backup\\GIS\\NEW\\final_lcs_fullmodel.gdb\\Hs0_WaveFS"
RS_Hs0_Wave = "./RS_Model.gdb\\RS_Hs0_Wave"
Idw_storms_WLIND10 = "./RS_Model.gdb\\Idw_storms_WLIND10"
Idw_Storms_RV50 = "./RS_Model.gdb\\Idw_Storms_RV50"
EucDist_RS_shelters = "./RS_Model.gdb\\EucDist_RS_shelters"
KernelD_RS_sheltersAttractiveness = "./RS_Model.gdb\
\KernelD_RS_sheltersAttractiveness"
RS_shelters_InlandNetwork = "RS_shelters_InlandNetwork"
KernelD_RS_RoadDistNorm = "./RS_Model.gdb\\KernelD_RS_RoadDistNorm"
KernelD_RS_InWater = "./RS_Model.gdb\\KernelD_RS_InWater"
EucDist_Vis_EdgeMB = "./RS_Model.gdb\\EucDist_Vis_EdgeMB"
EEZ_12NMbaseline__2_ = "EEZ_12NMbaseline"
RSWeightedSum_BASE = "./RS_Model.gdb\\RSWeightedSum_BASE"

# Process: Euclidean Distance
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1878862.30888216 82836.1616444809 2525835.27167294
3013863.6464931"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "RS_Buffer_ResearchArea"
```

```
arcpy.gp.EucDistance_sa(CS_shelters_NEW_EEC, EucDist_RS_shelters, "315000", "1000",
Output_direction_raster)
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Near
arcpy.Near_analysis(CS_shelters_NEW_EEC, "roman_roads_v2008", "", "NO_LOCATION",
"NO_ANGLE", "GEODESIC")

# Process: Near (2)
arcpy.Near_analysis(CS_shelters_NEW_EEC__4_, "All_Rivers;Inland_Water", "",
"NO_LOCATION", "NO_ANGLE", "GEODESIC")

# Process: Euclidean Distance (2)
tempEnvironment0 = arcpy.env.newPrecision
arcpy.env.newPrecision = "SINGLE"
tempEnvironment1 = arcpy.env.autoCommit
arcpy.env.autoCommit = "1000"
tempEnvironment2 = arcpy.env.XYResolution
arcpy.env.XYResolution = ""
tempEnvironment3 = arcpy.env.processingServerUser
arcpy.env.processingServerUser = ""
tempEnvironment4 = arcpy.env.XYDomain
arcpy.env.XYDomain = ""
tempEnvironment5 = arcpy.env.processingServerPassword
arcpy.env.processingServerPassword = ""
tempEnvironment6 = arcpy.env.scratchWorkspace
arcpy.env.scratchWorkspace = "D:\\Vis_Model\\Vis_ModelScript.gdb"
tempEnvironment7 = arcpy.env.cartographicPartitions
arcpy.env.cartographicPartitions = ""
tempEnvironment8 = arcpy.env.terrainMemoryUsage
arcpy.env.terrainMemoryUsage = "false"
tempEnvironment9 = arcpy.env.MTolerance
arcpy.env.MTolerance = ""
tempEnvironment10 = arcpy.env.compression
arcpy.env.compression = "LZ77"
tempEnvironment11 = arcpy.env.coincidentPoints
arcpy.env.coincidentPoints = "MEAN"
tempEnvironment12 = arcpy.env.randomGenerator
arcpy.env.randomGenerator = "0 ACM599"
tempEnvironment13 = arcpy.env.outputCoordinateSystem
arcpy.env.outputCoordinateSystem = ""
tempEnvironment14 = arcpy.env.rasterStatistics
arcpy.env.rasterStatistics = "STATISTICS 1 1"
tempEnvironment15 = arcpy.env.ZDomain
arcpy.env.ZDomain = ""
tempEnvironment16 = arcpy.env.transferDomains
arcpy.env.transferDomains = "false"
tempEnvironment17 = arcpy.env.maintainAttachments
arcpy.env.maintainAttachments = "true"
tempEnvironment18 = arcpy.env.resamplingMethod
arcpy.env.resamplingMethod = "NEAREST"
tempEnvironment19 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment20 = arcpy.env.projectCompare
arcpy.env.projectCompare = "NONE"
tempEnvironment21 = arcpy.env.cartographicCoordinateSystem
arcpy.env.cartographicCoordinateSystem =
"PROJCS['WGS_1984_UTM_Zone_33N',GEOGCS['GCS_WGS_1984',DATUM['D_WGS_1984',SPHEROID['W
```

```
GS_1984',6378137.0,298.257223563]],PRIMEM['Greenwich',0.0],UNIT['Degree',
0.0174532925199433]],PROJECTION['Transverse_Mercator'],PARAMETER['False_Easting',
500000.0],PARAMETER['False_Northing',0.0],PARAMETER['Central_Meridian',
15.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',
0.0],UNIT['Meter',1.0]]"
tempEnvironment22 = arcpy.env.configKeyword
arcpy.env.configKeyword = ""
tempEnvironment23 = arcpy.env.outputZFlag
arcpy.env.outputZFlag = "Same As Input"
tempEnvironment24 = arcpy.env.qualifiedFieldNames
arcpy.env.qualifiedFieldNames = "true"
tempEnvironment25 = arcpy.env.tileSize
arcpy.env.tileSize = "128 128"
tempEnvironment26 = arcpy.env.parallelProcessingFactor
arcpy.env.parallelProcessingFactor = ""
tempEnvironment27 = arcpy.env.pyramid
arcpy.env.pyramid = "PYRAMIDS -1 NEAREST DEFAULT 75 NO_SKIP"
tempEnvironment28 = arcpy.env.referenceScale
arcpy.env.referenceScale = ""
tempEnvironment29 = arcpy.env.processingServer
arcpy.env.processingServer = ""
tempEnvironment30 = arcpy.env.extent
arcpy.env.extent = "-388688.09822334 2650598.05584124 2804839.12216443
4457705.83672347"
tempEnvironment31 = arcpy.env.XYTolerance
arcpy.env.XYTolerance = ""
tempEnvironment32 = arcpy.env.tinSaveVersion
arcpy.env.tinSaveVersion = "CURRENT"
tempEnvironment33 = arcpy.env.nodata
arcpy.env.nodata = "NONE"
tempEnvironment34 = arcpy.env.MDomain
arcpy.env.MDomain = ""
tempEnvironment35 = arcpy.env.spatialGrid1
arcpy.env.spatialGrid1 = "0"
tempEnvironment36 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment37 = arcpy.env.outputZValue
arcpy.env.outputZValue = ""
tempEnvironment38 = arcpy.env.outputMFlag
arcpy.env.outputMFlag = "Same As Input"
tempEnvironment39 = arcpy.env.geographicTransformations
arcpy.env.geographicTransformations =
"NAD_1927_To_NAD_1983_NADCON;NAD_1927_To_NAD_1983_NADCON;NAD_1927_To_NAD_1983_NADCON
;NAD_1927_To_NAD_1983_NADCON"
tempEnvironment40 = arcpy.env.spatialGrid2
arcpy.env.spatialGrid2 = "0"
tempEnvironment41 = arcpy.env.ZResolution
arcpy.env.ZResolution = ""
tempEnvironment42 = arcpy.env.mask
arcpy.env.mask = "bathymetry_EEC1km1"
tempEnvironment43 = arcpy.env.spatialGrid3
arcpy.env.spatialGrid3 = "0"
tempEnvironment44 = arcpy.env.maintainSpatialIndex
arcpy.env.maintainSpatialIndex = "false"
tempEnvironment45 = arcpy.env.workspace
arcpy.env.workspace = "D:\\Vis_Model\\Vis_ModelScript.gdb"
tempEnvironment46 = arcpy.env.MResolution
arcpy.env.MResolution = ""
tempEnvironment47 = arcpy.env.derivedPrecision
arcpy.env.derivedPrecision = "HIGHEST"
tempEnvironment48 = arcpy.env.ZTolerance
```

```
arcpy.env.ZTolerance = ""
arcpy.gp.EucDistance_sa(Vis_edge, EucDist_Vis_EdgeMB, "", "1000",
Output_direction_raster__2_)
arcpy.env.newPrecision = tempEnvironment0
arcpy.env.autoCommit = tempEnvironment1
arcpy.env.XYResolution = tempEnvironment2
arcpy.env.processingServerUser = tempEnvironment3
arcpy.env.XYDomain = tempEnvironment4
arcpy.env.processingServerPassword = tempEnvironment5
arcpy.env.scratchWorkspace = tempEnvironment6
arcpy.env.cartographicPartitions = tempEnvironment7
arcpy.env.terrainMemoryUsage = tempEnvironment8
arcpy.env.MTolerance = tempEnvironment9
arcpy.env.compression = tempEnvironment10
arcpy.env.coincidentPoints = tempEnvironment11
arcpy.env.randomGenerator = tempEnvironment12
arcpy.env.outputCoordinateSystem = tempEnvironment13
arcpy.env.rasterStatistics = tempEnvironment14
arcpy.env.ZDomain = tempEnvironment15
arcpy.env.transferDomains = tempEnvironment16
arcpy.env.maintainAttachments = tempEnvironment17
arcpy.env.resamplingMethod = tempEnvironment18
arcpy.env.snapRaster = tempEnvironment19
arcpy.env.projectCompare = tempEnvironment20
arcpy.env.cartographicCoordinateSystem = tempEnvironment21
arcpy.env.configKeyword = tempEnvironment22
arcpy.env.outputZFlag = tempEnvironment23
arcpy.env.qualifiedFieldNames = tempEnvironment24
arcpy.env.tileSize = tempEnvironment25
arcpy.env.parallelProcessingFactor = tempEnvironment26
arcpy.env.pyramid = tempEnvironment27
arcpy.env.referenceScale = tempEnvironment28
arcpy.env.processingServer = tempEnvironment29
arcpy.env.extent = tempEnvironment30
arcpy.env.XYTolerance = tempEnvironment31
arcpy.env.tinSaveVersion = tempEnvironment32
arcpy.env.nodata = tempEnvironment33
arcpy.env.MDomain = tempEnvironment34
arcpy.env.spatialGrid1 = tempEnvironment35
arcpy.env.cellSize = tempEnvironment36
arcpy.env.outputZValue = tempEnvironment37
arcpy.env.outputMFlag = tempEnvironment38
arcpy.env.geographicTransformations = tempEnvironment39
arcpy.env.spatialGrid2 = tempEnvironment40
arcpy.env.ZResolution = tempEnvironment41
arcpy.env.mask = tempEnvironment42
arcpy.env.spatialGrid3 = tempEnvironment43
arcpy.env.maintainSpatialIndex = tempEnvironment44
arcpy.env.workspace = tempEnvironment45
arcpy.env.MResolution = tempEnvironment46
arcpy.env.derivedPrecision = tempEnvironment47
arcpy.env.ZTolerance = tempEnvironment48

# Process: IDW (3)
arcpy.Idw_3d(Lionello_Storminess, "RV5", Idw_Storms_RV5, "1000", "2", "VARIABLE 10",
"")

# Process: Rescale by Function (10)
arcpy.gp.RescaleByFunction_sa(Idw_Storms_RV5, Rescale_StormsRS_RV5, "LARGE  #  #  #
#  #  #", "1", "10")
```

```
# Process: Reclassify
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1878862.30888216 82836.1616444809 2525835.27167294
3013863.6464931"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "RS_Buffer_ResearchArea"
arcpy.gp.Reclassify_sa(Bathymetry_New, "VALUE", "-5122 -15 0;-15 -5 2;-5 1775.199950
10", Reclass_Bathy, "NODATA")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Focal Statistics
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1684204.44152047 -110592.46460735 2763795.55847953
2301407.53539265"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = ""
arcpy.gp.FocalStatistics_sa(Wind_speed, FocalSt_WindSpeed, "Circle 20 CELL", "MEAN",
"DATA")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Raster Calculator
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = Wind_speed
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = ""
arcpy.gp.RasterCalculator_sa("Con(IsNull(\"%Wind_speed (4)%\"), \"%FocalSt_WindSpeed
%\", \"%Wind_speed (4)%\")", WindSpeedFS)
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Clip
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-68163.7090209201 86631.2908979096 1982361.22536228
873277.820098501"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "EEZ_12NMbaseline"
arcpy.Clip_management(WindSpeedFS, "-1878862.30888216 82836.1616444809
```

```
2525835.27167294 3013863.6464931", RS_WindSpeedFS, RS_Buffer_ResearchArea,
"-3.402823e+38", "ClippingGeometry", "NO_MAINTAIN_EXTENT")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Rescale by Function (6)
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1878862.30888216 82836.1616444809 2525835.27167294
3013863.6464931"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "RS_Buffer_ResearchArea"
arcpy.gp.RescaleByFunction_sa(RS_WindSpeedFS, Rescale_RS_WindSpeedFS, "LARGE  #  #
#  #  #  #", "1", "10")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Focal Statistics (2)
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1869895.64425385 18147.1587830111 2604104.35574615
2139147.15878301"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = ""
arcpy.gp.FocalStatistics_sa(Hs0_Wave, FocalSt_Hs0_Waves, "Circle 6 CELL", "MEAN",
"DATA")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Raster Calculator (2)
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1869895.64425385 18147.1587830111 2604104.35574615
2139147.15878301"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = ""
arcpy.gp.RasterCalculator_sa("Con(IsNull(\"%Hs0_Wave (2)%\"),\"%FocalSt_Hs0_Waves%
\", \"%Hs0_Wave (2)%\")", Hs0_WaveFS)
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Clip (2)
arcpy.Clip_management(Hs0_WaveFS, "-1878862.30888216 82836.1616444809
2525835.27167294 3013863.6464931", RS_Hs0_Wave, RS_Buffer_ResearchArea, "-3.402823e
```

```
+38", "ClippingGeometry", "NO_MAINTAIN_EXTENT")

# Process: Rescale by Function (7)
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1878862.30888216 82836.1616444809 2525835.27167294
3013863.6464931"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "RS_Buffer_ResearchArea"
arcpy.gp.RescaleByFunction_sa(RS_Hs0_Wave, Rescale_RS_Hs0_Waves, "EXPONENTIAL  #  #
#  #  #  #", "1", "10")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: IDW
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1878862.30888216 82836.1616444809 2525835.27167294
3013863.6464931"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "RS_Buffer_ResearchArea"
arcpy.gp.Idw_sa(Lionello_Storminess, "wlind10", Idw_storms_WLIND10, "1000", "2",
"VARIABLE 10", "")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Rescale by Function (8)
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1878862.30888216 82836.1616444809 2525835.27167294
3013863.6464931"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "RS_Buffer_ResearchArea"
arcpy.gp.RescaleByFunction_sa(Idw_storms_WLIND10, Rescale_StormsRS_WLIND10, "LARGE
#  #  #  #  #  #", "1", "10")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: IDW (2)
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1878862.30888216 82836.1616444809 2525835.27167294
3013863.6464931"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
```

```
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "RS_Buffer_ResearchArea"
arcpy.Idw_3d(Lionello_Storminess, "RV50", Idw_Storms_RV50, "1000", "2", "VARIABLE
10", "")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Rescale by Function (9)
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1878862.30888216 82836.1616444809 2525835.27167294
3013863.6464931"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "RS_Buffer_ResearchArea"
arcpy.gp.RescaleByFunction_sa(Idw_Storms_RV50, Rescale_StormsRS_RV50, "LARGE  #  #
#  #  #  #", "1", "10")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Rescale by Function
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-68163.7090209201 86631.2908979096 1982361.22536228
873277.820098501"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "RS_Buffer_ResearchArea"
arcpy.gp.RescaleByFunction_sa(EucDist_RS_shelters, RS_Rescale_EucDistShelt, "SMALL
6437 2  #  #  #  #", "1", "10")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Kernel Density
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1878862.30888216 82836.1616444809 2525835.27167294
3013863.6464931"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "RS_Buffer_ResearchArea"
arcpy.gp.KernelDensity_sa(CS_shelters_NEW_EEC, "attractiveness",
KernelD_RS_sheltersAttractiveness, "1000", "18520", "SQUARE_METERS", "DENSITIES",
"GEODESIC")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3
```

```
# Process: Rescale by Function (2)
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1878862.30888216 82836.1616444809 2525835.27167294
3013863.6464931"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "RS_Buffer_ResearchArea"
arcpy.gp.RescaleByFunction_sa(KernelD_RS_sheltersAttractiveness,
Rescale_RS_KernDSheltAttract, "LARGE  # 2  #  #  #  #", "1", "10")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Kernel Density (2)
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1878862.30888216 82836.1616444809 2525835.27167294
3013863.6464931"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "RS_Buffer_ResearchArea"
arcpy.gp.KernelDensity_sa(RS_shelters_InlandNetwork, "ROAD_DIST_Norm",
KernelD_RS_RoadDistNorm, "1000", "18520", "SQUARE_MAP_UNITS", "DENSITIES",
"GEODESIC")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Rescale by Function (3)
arcpy.gp.RescaleByFunction_sa(KernelD_RS_RoadDistNorm, Rescale_Kernel_RS_roads,
"LARGE  # 5  #  #  #  #", "1", "10")

# Process: Kernel Density (3)
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1878862.30888216 82836.1616444809 2525835.27167294
3013863.6464931"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "RS_Buffer_ResearchArea"
arcpy.gp.KernelDensity_sa(RS_shelters_InlandNetwork, "InWater_DIST_Norm",
KernelD_RS_InWater, "1000", "18520", "SQUARE_KILOMETERS", "DENSITIES", "GEODESIC")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Rescale by Function (4)
arcpy.gp.RescaleByFunction_sa(KernelD_RS_InWater, Rescale_Kern_RS_InWater, "LARGE  #
#  #  #  #  #", "1", "10")

# Process: Rescale by Function (5)
```

```
tempEnvironment0 = arcpy.env.newPrecision
arcpy.env.newPrecision = "SINGLE"
tempEnvironment1 = arcpy.env.autoCommit
arcpy.env.autoCommit = "1000"
tempEnvironment2 = arcpy.env.XYResolution
arcpy.env.XYResolution = ""
tempEnvironment3 = arcpy.env.processingServerUser
arcpy.env.processingServerUser = ""
tempEnvironment4 = arcpy.env.XYDomain
arcpy.env.XYDomain = ""
tempEnvironment5 = arcpy.env.processingServerPassword
arcpy.env.processingServerPassword = ""
tempEnvironment6 = arcpy.env.scratchWorkspace
arcpy.env.scratchWorkspace = "D:\\Vis_Model\\Vis_ModelScript.gdb"
tempEnvironment7 = arcpy.env.cartographicPartitions
arcpy.env.cartographicPartitions = ""
tempEnvironment8 = arcpy.env.terrainMemoryUsage
arcpy.env.terrainMemoryUsage = "false"
tempEnvironment9 = arcpy.env.MTolerance
arcpy.env.MTolerance = ""
tempEnvironment10 = arcpy.env.compression
arcpy.env.compression = "LZ77"
tempEnvironment11 = arcpy.env.coincidentPoints
arcpy.env.coincidentPoints = "MEAN"
tempEnvironment12 = arcpy.env.randomGenerator
arcpy.env.randomGenerator = "0 ACM599"
tempEnvironment13 = arcpy.env.outputCoordinateSystem
arcpy.env.outputCoordinateSystem = ""
tempEnvironment14 = arcpy.env.rasterStatistics
arcpy.env.rasterStatistics = "STATISTICS 1 1"
tempEnvironment15 = arcpy.env.ZDomain
arcpy.env.ZDomain = ""
tempEnvironment16 = arcpy.env.transferDomains
arcpy.env.transferDomains = "false"
tempEnvironment17 = arcpy.env.maintainAttachments
arcpy.env.maintainAttachments = "true"
tempEnvironment18 = arcpy.env.resamplingMethod
arcpy.env.resamplingMethod = "NEAREST"
tempEnvironment19 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment20 = arcpy.env.projectCompare
arcpy.env.projectCompare = "NONE"
tempEnvironment21 = arcpy.env.cartographicCoordinateSystem
arcpy.env.cartographicCoordinateSystem =
"PROJCS['WGS_1984_UTM_Zone_33N',GEOGCS['GCS_WGS_1984',DATUM['D_WGS_1984',SPHEROID['W
GS_1984',6378137.0,298.257223563]],PRIMEM['Greenwich',0.0],UNIT['Degree',
0.0174532925199433]],PROJECTION['Transverse_Mercator'],PARAMETER['False_Easting',
500000.0],PARAMETER['False_Northing',0.0],PARAMETER['Central_Meridian',
15.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',
0.0],UNIT['Meter',1.0]]"
tempEnvironment22 = arcpy.env.configKeyword
arcpy.env.configKeyword = ""
tempEnvironment23 = arcpy.env.outputZFlag
arcpy.env.outputZFlag = "Same As Input"
tempEnvironment24 = arcpy.env.qualifiedFieldNames
arcpy.env.qualifiedFieldNames = "true"
tempEnvironment25 = arcpy.env.tileSize
arcpy.env.tileSize = "128 128"
tempEnvironment26 = arcpy.env.parallelProcessingFactor
arcpy.env.parallelProcessingFactor = ""
tempEnvironment27 = arcpy.env.pyramid
```

```
arcpy.env.pyramid = "PYRAMIDS -1 NEAREST DEFAULT 75 NO_SKIP"
tempEnvironment28 = arcpy.env.referenceScale
arcpy.env.referenceScale = ""
tempEnvironment29 = arcpy.env.processingServer
arcpy.env.processingServer = ""
tempEnvironment30 = arcpy.env.extent
arcpy.env.extent = EEZ_12NMbaseline (2)
tempEnvironment31 = arcpy.env.XYTolerance
arcpy.env.XYTolerance = ""
tempEnvironment32 = arcpy.env.tinSaveVersion
arcpy.env.tinSaveVersion = "CURRENT"
tempEnvironment33 = arcpy.env.nodata
arcpy.env.nodata = "NONE"
tempEnvironment34 = arcpy.env.MDomain
arcpy.env.MDomain = ""
tempEnvironment35 = arcpy.env.spatialGrid1
arcpy.env.spatialGrid1 = "0"
tempEnvironment36 = arcpy.env.cellSize
arcpy.env.cellSize = "280.984947810531"
tempEnvironment37 = arcpy.env.outputZValue
arcpy.env.outputZValue = ""
tempEnvironment38 = arcpy.env.outputMFlag
arcpy.env.outputMFlag = "Same As Input"
tempEnvironment39 = arcpy.env.geographicTransformations
arcpy.env.geographicTransformations =
"NAD_1927_To_NAD_1983_NADCON;NAD_1927_To_NAD_1983_NADCON;NAD_1927_To_NAD_1983_NADCON
;NAD_1927_To_NAD_1983_NADCON;NAD_1927_To_NAD_1983_NADCON;NAD_1927_To_NAD_1983_NADCON
"
tempEnvironment40 = arcpy.env.spatialGrid2
arcpy.env.spatialGrid2 = "0"
tempEnvironment41 = arcpy.env.ZResolution
arcpy.env.ZResolution = ""
tempEnvironment42 = arcpy.env.mask
arcpy.env.mask = EEZ_12NMbaseline (2)
tempEnvironment43 = arcpy.env.spatialGrid3
arcpy.env.spatialGrid3 = "0"
tempEnvironment44 = arcpy.env.maintainSpatialIndex
arcpy.env.maintainSpatialIndex = "false"
tempEnvironment45 = arcpy.env.workspace
arcpy.env.workspace = "D:\\Vis_Model\\Vis_ModelScript.gdb"
tempEnvironment46 = arcpy.env.MResolution
arcpy.env.MResolution = ""
tempEnvironment47 = arcpy.env.derivedPrecision
arcpy.env.derivedPrecision = "HIGHEST"
tempEnvironment48 = arcpy.env.ZTolerance
arcpy.env.ZTolerance = ""
arcpy.gp.RescaleByFunction_sa(EucDist_Vis_EdgeMB, Rescale_EucDist_VisEdgeMB, "SMALL
12000 2  #  #  #  #", "1", "10")
arcpy.env.newPrecision = tempEnvironment0
arcpy.env.autoCommit = tempEnvironment1
arcpy.env.XYResolution = tempEnvironment2
arcpy.env.processingServerUser = tempEnvironment3
arcpy.env.XYDomain = tempEnvironment4
arcpy.env.processingServerPassword = tempEnvironment5
arcpy.env.scratchWorkspace = tempEnvironment6
arcpy.env.cartographicPartitions = tempEnvironment7
arcpy.env.terrainMemoryUsage = tempEnvironment8
arcpy.env.MTolerance = tempEnvironment9
arcpy.env.compression = tempEnvironment10
arcpy.env.coincidentPoints = tempEnvironment11
arcpy.env.randomGenerator = tempEnvironment12
```

```
arcpy.env.outputCoordinateSystem = tempEnvironment13
arcpy.env.rasterStatistics = tempEnvironment14
arcpy.env.ZDomain = tempEnvironment15
arcpy.env.transferDomains = tempEnvironment16
arcpy.env.maintainAttachments = tempEnvironment17
arcpy.env.resamplingMethod = tempEnvironment18
arcpy.env.snapRaster = tempEnvironment19
arcpy.env.projectCompare = tempEnvironment20
arcpy.env.cartographicCoordinateSystem = tempEnvironment21
arcpy.env.configKeyword = tempEnvironment22
arcpy.env.outputZFlag = tempEnvironment23
arcpy.env.qualifiedFieldNames = tempEnvironment24
arcpy.env.tileSize = tempEnvironment25
arcpy.env.parallelProcessingFactor = tempEnvironment26
arcpy.env.pyramid = tempEnvironment27
arcpy.env.referenceScale = tempEnvironment28
arcpy.env.processingServer = tempEnvironment29
arcpy.env.extent = tempEnvironment30
arcpy.env.XYTolerance = tempEnvironment31
arcpy.env.tinSaveVersion = tempEnvironment32
arcpy.env.nodata = tempEnvironment33
arcpy.env.MDomain = tempEnvironment34
arcpy.env.spatialGrid1 = tempEnvironment35
arcpy.env.cellSize = tempEnvironment36
arcpy.env.outputZValue = tempEnvironment37
arcpy.env.outputMFlag = tempEnvironment38
arcpy.env.geographicTransformations = tempEnvironment39
arcpy.env.spatialGrid2 = tempEnvironment40
arcpy.env.ZResolution = tempEnvironment41
arcpy.env.mask = tempEnvironment42
arcpy.env.spatialGrid3 = tempEnvironment43
arcpy.env.maintainSpatialIndex = tempEnvironment44
arcpy.env.workspace = tempEnvironment45
arcpy.env.MResolution = tempEnvironment46
arcpy.env.derivedPrecision = tempEnvironment47
arcpy.env.ZTolerance = tempEnvironment48

# Process: Weighted Sum
arcpy.gp.WeightedSum_sa("./RS_Model.gdb\\Reclass_Bathy Value 1;./RS_Model.gdb\
\Rescale_RS_WindSpeedFS VALUE 1;./RS_Model.gdb\\Rescale_RS_Hs0_Waves VALUE 1;./
RS_Model.gdb\\Rescale_StormsRS_WLIND10 VALUE 1;./RS_Model.gdb\\Rescale_StormsRS_RV50
VALUE 1;./RS_Model.gdb\\RS_Rescale_EucDistShelt VALUE 1;./RS_Model.gdb\
\Rescale_RS_KernDSheltAttract VALUE 1;./RS_Model.gdb\\Rescale_Kernel_RS_roads VALUE
1;./RS_Model.gdb\\Rescale_Kern_RS_InWater VALUE 1;./RS_Model.gdb\
\Rescale_EucDist_VisEdgeMB VALUE 1", RSWeightedSum_BASE)
```

Appendix 3c

```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# Name:         GS_model.py
# Purpose:      Assessment of the relative Shipwrecking Probability in Mediterranean
territorial waters
# Author:       Manuela Ritondale
# Created on:   2021-09-26 12:23:18.00000

# Generated by ArcGIS/ModelBuilder
# Usage: GS_model <Reclass_Bathy_GS> <Rescale_GS_WindSpeedFS> <Rescale_GS_Hs0waves>
<Rescale_GS_StormsWLIND10> <Rescale_GS_StormsRV50> <Rescale_EucDist_GS_Shelters>
<Rescale_Kern_GS_Attractors>

# Description:  Global Scale (GS) Model assessing the relative Shipwrecking
Probability in the Mediterranean 12 NM zone
# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy

# Script arguments
Reclass_Bathy_GS = arcpy.GetParameterAsText(0)
if Reclass_Bathy_GS == '#' or not Reclass_Bathy_GS:
    Reclass_Bathy_GS = "./GS_MED_Model.gdb/Reclass_Bathy_GS" # provide a default
value if unspecified

Rescale_GS_WindSpeedFS = arcpy.GetParameterAsText(1)
if Rescale_GS_WindSpeedFS == '#' or not Rescale_GS_WindSpeedFS:
    Rescale_GS_WindSpeedFS = "./GS_MED_Model.gdb/Rescale_GS_WindSpeedFS" # provide a
default value if unspecified

Rescale_GS_Hs0waves = arcpy.GetParameterAsText(2)
if Rescale_GS_Hs0waves == '#' or not Rescale_GS_Hs0waves:
    Rescale_GS_Hs0waves = "./GS_MED_Model.gdb/Rescale_GS_Hs0waves" # provide a
default value if unspecified

Rescale_GS_StormsWLIND10 = arcpy.GetParameterAsText(3)
if Rescale_GS_StormsWLIND10 == '#' or not Rescale_GS_StormsWLIND10:
    Rescale_GS_StormsWLIND10 = "./GS_MED_Model.gdb/Rescale_GS_StormsWLIND10" #
provide a default value if unspecified

Rescale_GS_StormsRV50 = arcpy.GetParameterAsText(4)
if Rescale_GS_StormsRV50 == '#' or not Rescale_GS_StormsRV50:
    Rescale_GS_StormsRV50 = "./GS_MED_Model.gdb/Rescale_GS_StormsRV50" # provide a
default value if unspecified

Rescale_EucDist_GS_Shelters = arcpy.GetParameterAsText(5)
if Rescale_EucDist_GS_Shelters == '#' or not Rescale_EucDist_GS_Shelters:
    Rescale_EucDist_GS_Shelters = "./GS_MED_Model.gdb/Rescale_EucDist_GS_Shelters" #
provide a default value if unspecified

Rescale_Kern_GS_Attractors = arcpy.GetParameterAsText(6)
if Rescale_Kern_GS_Attractors == '#' or not Rescale_Kern_GS_Attractors:
    Rescale_Kern_GS_Attractors = "./GS_MED_Model.gdb/Rescale_Kern_GS_Attractors" #
provide a default value if unspecified

# Local variables:
Mediterranean_Shelters = "Mediterranean_Shelters"
Output_direction_raster = ""
Bathymetry = "./GS_MED_Model.gdb/Bathymetry"
Wind_originalEEC__2_ = "Wind_originalEEC"
```

```
Wind_originalEEC = "Wind_originalEEC"
FocalSt_WindGS = "./GS_MED_Model.gdb/FocalSt_WindGS"
GS_WindSpeed_FS = "e:/Backup/GIS/NEW/final_med_model.gdb/GS_WindSpeed_FS"
Hs0_WaveFS = "./GS_MED_Model.gdb/Hs0_WaveFS"
eez_UpTo12NMZ_ResearchArea_Buffer = "eez_UpTo12NMZ_ResearchArea_Buffer"
GS_Hs0_WaveFS = "./GS_MED_Model.gdb/GS_Hs0_WaveFS"
Lionello_Storminess = "Lionello_Storminess"
GS_Idw_Lionello_WLIND = "./GS_MED_Model.gdb/GS_Idw_Lionello_WLIND"
GS_Idw_LionelloRV50 = "./GS_MED_Model.gdb/GS_Idw_LionelloRV50"
EucDist_Med_Shelters = "./GS_MED_Model.gdb/EucDist_Med_Shelters"
Mediterranean_Shelters__3_ = "Mediterranean_Shelters"
Mediterranean_Shelters__2_ = Mediterranean_Shelters__3_
Med_Shelters_Buffer20 = "./GS_MED_Model.gdb/Med_Shelters_Buffer20"
Pleiades_Selection = "Pleiades_Selection"
Med_Shelters_Buffer20_SheltJoin = "./GS_MED_Model.gdb/
Med_Shelters_Buffer20_SheltJoin"
KernelD_Med_Attractors = "./GS_MED_Model.gdb/KernelD_Med_Attractors"
GS_Weighted_Sum_BASIC = "./GS_MED_Model.gdb/GS_Weighted_Sum_BASIC"
GS_DARMC_OXREP_ShipwMerged = "GS_DARMC_OXREP_ShipwMerged"
GS_DARMC_OXREP_ShipwMerged_Buffer = "./GS_MED_Model.gdb/
GS_DARMC_OXREP_ShipwMerged_Buffer"
GS_Weighted_Sum_BASIC__2_ = "GS_Weighted_Sum_BASIC"
ZonalSt_GS_WEightedSumBASIC = "./GS_MED_Model.gdb/ZonalSt_GS_WEightedSumBASIC"
ZonalSt_GS_WEightedSumBASIC_int = "./GS_MED_Model.gdb/
ZonalSt_GS_WEightedSumBASIC_int"
ZonalSt_GS_WEightedSumBASIC_int__3_ = ZonalSt_GS_WEightedSumBASIC_int

# Process: Euclidean Distance
tempEnvironment0 = arcpy.env.MTolerance
arcpy.env.MTolerance = ""
tempEnvironment1 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment2 = arcpy.env.extent
arcpy.env.extent = "-1495235.74243295 87220.8413546309 2409007.73676753
1763013.70289816"
tempEnvironment3 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment4 = arcpy.env.outputMFlag
arcpy.env.outputMFlag = "Same As Input"
tempEnvironment5 = arcpy.env.mask
arcpy.env.mask = ""
tempEnvironment6 = arcpy.env.MResolution
arcpy.env.MResolution = ""
arcpy.gp.EucDistance_sa(Mediterranean_Shelters, EucDist_Med_Shelters, "300000",
"1000", Output_direction_raster)
arcpy.env.MTolerance = tempEnvironment0
arcpy.env.snapRaster = tempEnvironment1
arcpy.env.extent = tempEnvironment2
arcpy.env.cellSize = tempEnvironment3
arcpy.env.outputMFlag = tempEnvironment4
arcpy.env.mask = tempEnvironment5
arcpy.env.MResolution = tempEnvironment6

# Process: Reclassify
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-2176068.2857 -155722.408600001 2876735.0525 2009764.7363"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
```

```
arcpy.env.mask = "eez_UpTo12NMZ_ResearchArea_Buffer"
arcpy.gp.Reclassify_sa(Bathymetry, "VALUE", "-5122 -15 1;-15 -5 2;-5 2341.129883
10", Reclass_Bathy_GS, "NODATA")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Focal Statistics
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-2673048.5323159 -556008.838512508 3198378.28734175
2686420.89771634"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = ""
arcpy.gp.FocalStatistics_sa(Wind_originalEEC, FocalSt_WindGS, "Circle 14 CELL",
"MEAN", "DATA")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Raster Calculator
arcpy.gp.RasterCalculator_sa("Con(IsNull(\"%Wind_originalEEC (2)%\"),
\"%FocalSt_WindGS%\", \"%Wind_originalEEC (2)%\")", GS_WindSpeed_FS)

# Process: Rescale by Function
arcpy.gp.RescaleByFunction_sa(GS_WindSpeed_FS, Rescale_GS_WindSpeedFS, "LARGE  #  #
#  #  #  #", "1", "10")

# Process: Clip
arcpy.Clip_management(Hs0_WaveFS, "-1878883.0546346 82904.826109698 2525855.27073785
1764044.06733634", GS_Hs0_WaveFS, eez_UpTo12NMZ_ResearchArea_Buffer, "-3.402823e
+38", "ClippingGeometry", "NO_MAINTAIN_EXTENT")

# Process: Rescale by Function (2)
arcpy.gp.RescaleByFunction_sa(GS_Hs0_WaveFS, Rescale_GS_Hs0waves, "LARGE  # 3  #  #
#  #", "1", "10")

# Process: IDW
arcpy.gp.Idw_sa(Lionello_Storminess, "wlind10", GS_Idw_Lionello_WLIND, "1000", "2",
"VARIABLE 10", "")

# Process: Rescale by Function (3)
arcpy.gp.RescaleByFunction_sa(GS_Idw_Lionello_WLIND, Rescale_GS_StormsWLIND10,
"LARGE  #  #  #  #  #  #", "1", "10")

# Process: IDW (2)
arcpy.gp.Idw_sa(Lionello_Storminess, "RV50", GS_Idw_LionelloRV50, "1000", "2",
"VARIABLE 10", "")

# Process: Rescale by Function (4)
arcpy.gp.RescaleByFunction_sa(GS_Idw_LionelloRV50, Rescale_GS_StormsRV50, "LARGE  #
#  #  #  #  #", "1", "10")

# Process: Rescale by Function (5)
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = ""
```

```
tempEnvironment1 = arcpy.env.extent
arcpy.env.extent = "-1878883.0546346 82904.826109698 2525855.27073785
1764044.06733634"
tempEnvironment2 = arcpy.env.cellSize
arcpy.env.cellSize = "1000"
tempEnvironment3 = arcpy.env.mask
arcpy.env.mask = "eez_UpTo12NMZ_ResearchArea"
arcpy.gp.RescaleByFunction_sa(EucDist_Med_Shelters, Rescale_EucDist_GS_Shelters,
"SMALL 3704 2  #  #  #  #", "1", "10")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.extent = tempEnvironment1
arcpy.env.cellSize = tempEnvironment2
arcpy.env.mask = tempEnvironment3

# Process: Buffer
tempEnvironment0 = arcpy.env.MTolerance
arcpy.env.MTolerance = ""
tempEnvironment1 = arcpy.env.outputMFlag
arcpy.env.outputMFlag = "Enabled"
tempEnvironment2 = arcpy.env.MResolution
arcpy.env.MResolution = ""
arcpy.Buffer_analysis(Mediterranean_Shelters, Med_Shelters_Buffer20, "20
Kilometers", "FULL", "ROUND", "NONE", "", "PLANAR")
arcpy.env.MTolerance = tempEnvironment0
arcpy.env.outputMFlag = tempEnvironment1
arcpy.env.MResolution = tempEnvironment2

# Process: Spatial Join
arcpy.SpatialJoin_analysis(Med_Shelters_Buffer20, Pleiades_Selection,
Med_Shelters_Buffer20_SheltJoin, "JOIN_ONE_TO_ONE", "KEEP_ALL", "OBJECTID \"OBJECTID
\" true true false 4 Long 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,OBJECTID,-1,-1;NB \"NB\" true true false 8 Double 0 0
,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,NB,-1,-1;NAME \"NAME\" true true
false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,NAME,-1,-1;NAME_MOD \"NAME_MOD\" true true false 254 Text 0 0
,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,NAME_MOD,-1,-1;COUNTRY \"COUNTRY\"
true true false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,COUNTRY,-1,-1;LATITUDE \"LATITUDE\" true true false 8 Double 0
0 ,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,LATITUDE,-1,-1;LONGITUDE
\"LONGITUDE\" true true false 8 Double 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,LONGITUDE,-1,-1;FOUND_ \"FOUND_\" true true false 254 Text 0 0
,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,FOUND_,-1,-1;MI \"MI\" true true
false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,MI,-1,-1;MY
\"MY\" true true false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,MY,-1,-1;PN \"PN\" true true false 254 Text 0 0 ,First,#,./
GS_MED_Model.gdb/Med_Shelters_Buffer20,PN,-1,-1;AUTH_ANC \"AUTH_ANC\" true true
false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,AUTH_ANC,-1,-1;AUTH_MOD_B \"AUTH_MOD_B\" true true false 254
Text 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,AUTH_MOD_B,-1,-1;DOC1_Paper \"DOC1_Paper\" true true false 254
Text 0 0 ,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,DOC1_Paper,-1,-1;DOC2_www
\"DOC2_www\" true true false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,DOC2_www,-1,-1;DOC3 \"DOC3\" true true false 254 Text 0 0
,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,DOC3,-1,-1;PLEIADES_P \"PLEIADES_P
\" true true false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,PLEIADES_P,-1,-1;DARE \"DARE\" true true false 254 Text 0 0
,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,DARE,-1,-1;TOPOSText \"TOPOSText\"
true true false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,TOPOSText,-1,-1;AM \"AM\" true true false 254 Text 0 0
,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,AM,-1,-1;PP \"PP\" true true false
254 Text 0 0 ,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,PP,-1,-1;RE \"RE\"
```

true true false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,RE,-1,-1;BW \"BW\" true true false 254 Text 0 0 ,First,#,./
GS_MED_Model.gdb/Med_Shelters_Buffer20,BW,-1,-1;QU \"QU\" true true false 254 Text 0
0 ,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,QU,-1,-1;PL \"PL\" true true
false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,PL,-1,-1;MO
\"MO\" true true false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,MO,-1,-1;CN \"CN\" true true false 254 Text 0 0 ,First,#,./
GS_MED_Model.gdb/Med_Shelters_Buffer20,CN,-1,-1;SL \"SL\" true true false 254 Text 0
0 ,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,SL,-1,-1;SH \"SH\" true true
false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,SH,-1,-1;PH
\"PH\" true true false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,PH,-1,-1;CO \"CO\" true true false 254 Text 0 0 ,First,#,./
GS_MED_Model.gdb/Med_Shelters_Buffer20,CO,-1,-1;KL \"KL\" true true false 254 Text 0
0 ,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,KL,-1,-1;FP \"FP\" true true
false 254 Text 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,FP,-1,-1;BUFF_DIST \"BUFF_DIST\" true true false 8 Double 0 0
,First,#,./GS_MED_Model.gdb/Med_Shelters_Buffer20,BUFF_DIST,-1,-1;ORIG_FID
\"ORIG_FID\" true true false 4 Long 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,ORIG_FID,-1,-1;Shape_Length \"Shape_Length\" false true true 8
Double 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,Shape_Length,-1,-1;Shape_Area \"Shape_Area\" false true true 8
Double 0 0 ,First,#,./GS_MED_Model.gdb/
Med_Shelters_Buffer20,Shape_Area,-1,-1;authors \"authors\" true true false 8000 Text
0 0 ,First,#,Pleiades_Selection,authors,-1,-1;bbox \"bbox\" true true false 8000
Text 0 0 ,First,#,Pleiades_Selection,bbox,-1,-1;connectsWith \"connectsWith\" true
true false 8000 Text 0 0 ,First,#,Pleiades_Selection,connectsWith,-1,-1;created
\"created\" true true false 8000 Text 0 0
,First,#,Pleiades_Selection,created,-1,-1;creators \"creators\" true true false 8000
Text 0 0 ,First,#,Pleiades_Selection,creators,-1,-1;currentVersion \"currentVersion
\" true true false 4 Long 0 0
,First,#,Pleiades_Selection,currentVersion,-1,-1;description \"description\" true
true false 8000 Text 0 0 ,First,#,Pleiades_Selection,description,-1,-1;extent
\"extent\" true true false 8000 Text 0 0
,First,#,Pleiades_Selection,extent,-1,-1;featureTypes \"featureTypes\" true true
false 8000 Text 0 0 ,First,#,Pleiades_Selection,featureTypes,-1,-1;geoContext
\"geoContext\" true true false 8000 Text 0 0
,First,#,Pleiades_Selection,geoContext,-1,-1;hasConnectionsWith \"hasConnectionsWith
\" true true false 8000 Text 0 0
,First,#,Pleiades_Selection,hasConnectionsWith,-1,-1;id \"id\" true true false 8000
Text 0 0 ,First,#,Pleiades_Selection,id,-1,-1;locationPrecision \"locationPrecision
\" true true false 8000 Text 0 0
,First,#,Pleiades_Selection,locationPrecision,-1,-1;maxDate \"maxDate\" true true
false 4 Long 0 0 ,First,#,Pleiades_Selection,maxDate,-1,-1;minDate \"minDate\" true
true false 4 Long 0 0 ,First,#,Pleiades_Selection,minDate,-1,-1;modified \"modified
\" true true false 8000 Text 0 0 ,First,#,Pleiades_Selection,modified,-1,-1;path
\"path\" true true false 8000 Text 0 0
,First,#,Pleiades_Selection,path,-1,-1;reprLat \"reprLat\" true true false 8 Double
0 0 ,First,#,Pleiades_Selection,reprLat,-1,-1;reprLatLong \"reprLatLong\" true true
false 8000 Text 0 0 ,First,#,Pleiades_Selection,reprLatLong,-1,-1;reprLatLong_X
\"reprLatLong_X\" true true false 8 Double 0 0
,First,#,Pleiades_Selection,reprLatLong_X,-1,-1;reprLatLong_Y \"reprLatLong_Y\" true
true false 8 Double 0 0 ,First,#,Pleiades_Selection,reprLatLong_Y,-1,-1;reprLong
\"reprLong\" true true false 8 Double 0 0
,First,#,Pleiades_Selection,reprLong,-1,-1;tags \"tags\" true true false 8000 Text 0
0 ,First,#,Pleiades_Selection,tags,-1,-1;timePeriods \"timePeriods\" true true false
8000 Text 0 0 ,First,#,Pleiades_Selection,timePeriods,-1,-1;timePeriodsKeys
\"timePeriodsKeys\" true true false 8000 Text 0 0
,First,#,Pleiades_Selection,timePeriodsKeys,-1,-1;timePeriodsRange
\"timePeriodsRange\" true true false 8000 Text 0 0
,First,#,Pleiades_Selection,timePeriodsRange,-1,-1;title \"title\" true true false
8000 Text 0 0 ,First,#,Pleiades_Selection,title,-1,-1;uid \"uid\" true true false

```
8000 Text 0 0 ,First,#,Pleiades_Selection,uid,-1,-1", "CONTAINS", "", "")

# Process: Join Field
arcpy.JoinField_management(Mediterranean_Shelters__3_, "OBJECTID",
Med_Shelters_Buffer20_SheltJoin, "OBJECTID", "Join_Count")

# Process: Kernel Density
arcpy.gp.KernelDensity_sa(Mediterranean_Shelters__2_, "Join_Count",
KernelD_Med_Attractors, "1000", "18520", "SQUARE_METERS", "DENSITIES", "PLANAR")

# Process: Rescale by Function (6)
arcpy.gp.RescaleByFunction_sa(KernelD_Med_Attractors, Rescale_Kern_GS_Attractors,
"MSLARGE  #  #  #  #  #  #", "1", "10")

# Process: Weighted Sum
arcpy.gp.WeightedSum_sa("./GS_MED_Model.gdb/Reclass_Bathy_GS Value 1;./
GS_MED_Model.gdb/Rescale_GS_WindSpeedFS VALUE 1;./GS_MED_Model.gdb/
Rescale_GS_Hs0waves VALUE 1;./GS_MED_Model.gdb/Rescale_GS_StormsWLIND10 VALUE 1;./
GS_MED_Model.gdb/Rescale_GS_StormsRV50 VALUE 1;./GS_MED_Model.gdb/
Rescale_EucDist_GS_Shelters VALUE 1;./GS_MED_Model.gdb/Rescale_Kern_GS_Attractors
VALUE 1", GS_Weighted_Sum_BASIC)

# Process: Buffer (2)
arcpy.Buffer_analysis(GS_DARMC_OXREP_ShipwMerged, GS_DARMC_OXREP_ShipwMerged_Buffer,
"1.5 NauticalMiles", "FULL", "ROUND", "NONE", "", "PLANAR")

# Process: Zonal Statistics
arcpy.gp.ZonalStatistics_sa(GS_DARMC_OXREP_ShipwMerged_Buffer, "OBJECTID",
GS_Weighted_Sum_BASIC__2_, ZonalSt_GS_WEightedSumBASIC, "MEAN", "DATA")

# Process: Copy Raster
arcpy.CopyRaster_management(ZonalSt_GS_WEightedSumBASIC,
ZonalSt_GS_WEightedSumBASIC_int, "", "", "-3.402823e+38", "NONE", "NONE",
"32_BIT_SIGNED", "NONE", "NONE", "GRID", "NONE")

# Process: Build Raster Attribute Table
arcpy.BuildRasterAttributeTable_management(ZonalSt_GS_WEightedSumBASIC_int,
"Overwrite")
```

Appendix 3d – Visibility Analysis Scripts

The following two scripts support the visibility analysis presented in Chapter 6, section 2.4. The first script has a twofold aim: detecting prominent geomorphological features visible from the sea and calculating the cumulative viewshed seaward from these prominent features. The second script is used to determine the so-called ‘p90 value’ as described in section 6.2.4 and select the observer points within the geomorphological features previously identified in stage 1 of the procedure.

```
#-----------------------------------------------------------------------------
# Name:        Visibility_Analysis_Script_1
# Purpose:     Detecting prominent geomorphological features visible from a set of
random points in the the sea; calculating the cumulative viewshed seaward from these
prominent features
#
# Author:      Frits Steenhuisen
#
# Created:     25/06/2019
# Copyright:   (c) Frits Steenhuisen, Arctic Centre RUG, 2019
# Licence:     RUG
#-----------------------------------------------------------------------------
"""
NOTES:
   user setting are:
      1) default geodatabase including full path
      2) input DEM
      3) input observer locations
      4) identifier field in observer locations (NOTE: character field)

      5) output raster name (a timestamp (__DDMMYYYYHHMM) is added to the raster name
in the geodatabase)

      6) mast height (mast height for analysis from ship locations and 0 for
landmarks)
      7) min and max range for visibility

      8) batch size, the number of observer points to be processed simultaniously.
         (In the current ArcGIS version (10.6), 12 points is a safe bet.)

"""

import arcpy, sys, math, os, time
from datetime import datetime
from arcpy.sa import *
from arcpy import env

import tempfile
tempfile.tempdir = 'C:/temp/'

# -----USER SETTINGS----------------------------------------------------------

defaultGDBname = "D:/Vis_Model/Vis_ModelScript.gdb"

inDEM = 'Case2B_DEM270mUTM33noNoData'
shipLocations = 'Case2B_ApexPointsFinal'
point_ID_field = 'pt_ID'

outRasterName = 'Case2B_VisSeaward'

mastHeight = 8
maxRange = 200000
minRange = 1500

batchSize = 12

# ---------------------------------------------------------------------------
aglOutput = ""
analysisType = "FREQUENCY"
nonVisibleValue = "ZERO"
zFactor = 1
```

```
useEarthCurvature = "CURVED_EARTH"
refractivityCoefficient = 0.13
surfaceOffset = ""
observerElevation = ""
observerOffset = mastHeight
innerRadius = minRange
outerRadius = maxRange
horizStartAngle = ""
horizEndAngle = ""
vertUpperAngle = ""
vertLowerAngle = ""
# ---------------------------------------------------------------------------

arcpy.env.workspace = defaultGDBname
arcpy.AddMessage("\ncurrent workspace (ArcGIS): " + arcpy.env.workspace)
#arcpy.env.parallelProcessingFactor = "66%"
arcpy.env.overwriteOutput = True
arcpy.CheckOutExtension("Spatial")
arcpy.env.snapRaster = inDEM
print 'hallo'
arcpy.env.extent = inDEM

#arcpy.env.extent = 'MAXOF'
#arcpy.env.cellSizeProjectionMethod = "PRESERVE_RESOLUTION"

# ----- FUNCTIONS -------------------------------------------------------------

def runVisibility(idList, locationCounter, totalLocations):
   batchStartTime = datetime.now()

   utf8_idList = [str(i) for i in idList]

   sys.stdout.write("  calculating visibility: " + str(utf8_idList) + "  (" +
str(locationCounter-1) + "/" + str(totalLocations) + ")  ")
   sys.stdout.flush()


   # make SQL expression
   # bug in tuple function, comma remains in tuples with just one item.
   if len(utf8_idList) == 1:
      listString = str(tuple(utf8_idList)).replace(',', '')
   else:
      listString = str(tuple(utf8_idList))

   #print listString

   expression = '"' + point_ID_field + '"' + ' IN ' + listString


   arcpy.Select_analysis(shipLocations, 'obsPts', expression)

   tmpViewshed = arcpy.sa.Visibility(inDEM, 'obsPts', aglOutput, analysisType,
nonVisibleValue,
                        zFactor, useEarthCurvature, refractivityCoefficient,
surfaceOffset, observerElevation,
                        observerOffset, innerRadius, outerRadius, horizStartAngle,
horizEndAngle, vertUpperAngle, vertLowerAngle)

   arcpy.env.overwriteOutput = True
   tmpViewshed.save('tmpVSras')
   tmpPLUSras = arcpy.sa.Plus('baseSumRaster','tmpVSras')
```

```
    tmpPLUSras.save('tmpPLUSras')

    arcpy.CopyRaster_management('tmpPLUSras', 'baseSumRaster')

    print(str(datetime.now() - batchStartTime))

    return()

# -----MAIN---------------------------------------------------------------

def main():
    startTime = datetime.now()
    idList = []

    print("\ncalculating viewsheds for individual locations in the input features...
\n")


    # CREATE NULL RASTER (to summarize all least cost paths)
    print("\n  Create constant (0) raster as base\n\n")
    baseRaster = arcpy.sa.Con(inDEM, 0, 1, 'VALUE > -1000')
    baseRaster.save('baseSumRaster')

    locationCounter = 0
    countResult = arcpy.GetCount_management(shipLocations)
    totalLocations = int(countResult.getOutput(0))


    viewshedCursor = arcpy.SearchCursor(shipLocations)


    for location in viewshedCursor:

        currentID = location.getValue(point_ID_field)
        #print currentID
        locationCounter += 1

        if len(idList) < batchSize:
            idList.append(currentID)
            #print idList, locationCounter

        else:
            runVisibility(idList, locationCounter, totalLocations)
            idList = []

            # add the location from this iteration
            idList.append(currentID)
            #print idList, locationCounter

    if len(idList) > 0:
        locationCounter += 1
        print 'process remaining points...'
        runVisibility(idList, locationCounter, totalLocations)



    timeStamp = datetime.now().strftime("%d%m%Y%H%M")
    finalRasterName = outRasterName + '__' + timeStamp
    arcpy.CopyRaster_management('baseSumRaster', finalRasterName)
```

```
    usedTime = datetime.now() - startTime
    toPrint = "\nDONE...\n\nused time: " + str(usedTime) + "\n"
    print(toPrint)


    raw_input("\n\nPress Enter to EXIT...")


#-----RUN MAIN---------------------------------------------------------------
if __name__ == '__main__':
    main()
```

```python
#-------------------------------------------------------------------------------
# Name:        Visibility_analysis_script_2

# Author:      Frits Steenhuisen
#
# Created:     25/06/2019
# Copyright:   (c) Frits Steenhuisen, Arctic Centre RUG, 2019
# Licence:     RUG
#-------------------------------------------------------------------------------
"""
NOTES:


"""

import arcpy
from datetime import datetime
from arcpy.sa import *
from arcpy import env
import numpy as np

import tempfile
tempfile.tempdir = 'C:/temp/'

# -----USER SETTINGS------------------------------------------------------------

defaultGDBname = "D:/Vis_Model/Vis_ModelScript.gdb"

inValueRaster = 'case2B_VisNoSea_NoZero'

zonalFC = 'Case2B_Fishnet10kmOptimized'
zonal_ID_field = 'ZoneStat_ID'

outZonalFC = 'CAse2B_zonalStat'
# ------------------------------------------------------------------------------

fieldNameList = ['cell_count', 'np_MIN', 'arcpy_MIN', 'np_MAX', 'arcpy_MAAX',
'np_MEAN', 'arcpy_MEAN', 'np_AVERAGE', 'np_MEDIAN', 'np_STD', 'arcpy_STD', 'np_P75',
'np_P90']

# ------------------------------------------------------------------------------



arcpy.env.workspace = defaultGDBname
arcpy.AddMessage("\ncurrent workspace (ArcGIS): " + arcpy.env.workspace)
#arcpy.env.parallelProcessingFactor = "66%"
arcpy.env.overwriteOutput = True
arcpy.CheckOutExtension("Spatial")


# ----- FUNCTIONS --------------------------------------------------------------



# -----MAIN---------------------------------------------------------------------

def main():
   startTime = datetime.now()

   print("\ncalculating zonal statistics and add stats value to zonal FC attr
```

```
table...\n")

    # COPY in_FC to out_FC
    print("\n  Copying in zonal FC to temp FC\n\n")
    arcpy.Copy_management(zonalFC, 'tmpFC')
    print('Done copying....\n')


    # make out file
    outFileName = outZonalFC + '.txt'
    outFileObject = open(outFileName, 'w')
    headerLine = 'zoneID\t'

    for n in fieldNameList:
       headerLine += n + '\t'
    headerLine = headerLine.strip('\t')
    headerLine = headerLine + ('\n')
    print headerLine
    outFileObject.write(headerLine)


    countResult = arcpy.GetCount_management(zonalFC)
    totalZones = int(countResult.getOutput(0))
    counter = 0

    zoneCursor = arcpy.SearchCursor('tmpFC')

    for zone in zoneCursor:

       currentID = zone.getValue(zonal_ID_field)
       #print currentID
       counter += 1
       print '   zone ' + str(counter) + ' of ' + str(totalZones)

       arcpy.MakeFeatureLayer_management('tmpFC', "lyr")
       expression = '"' + zonal_ID_field + '" = ' + "'" + currentID + "'"
       arcpy.SelectLayerByAttribute_management("lyr", "NEW_SELECTION", expression)

       tmpRas = ExtractByMask(inValueRaster, "lyr")


       tmpArray = (arcpy.RasterToNumPyArray(tmpRas, '', '','', 0)).flatten()
       tmpArray_no_zero = tmpArray[tmpArray != 0]

       #print tmpArray_no_zero, str(np.size(tmpArray_no_zero))

       if np.size(tmpArray_no_zero) > 0:
          cell_count = np.size(tmpArray_no_zero)

          a_min = np.amin(tmpArray_no_zero)
          a_max = np.amax(tmpArray_no_zero)
          a_mean = np.mean(tmpArray_no_zero, axis = 0)
          a_median = np.median(tmpArray_no_zero, axis = 0)
          a_average = np.average(tmpArray_no_zero, axis = 0)
          a_std = np.std(tmpArray_no_zero)
          a_p75 = np.percentile(tmpArray_no_zero,75)
          a_p90 = np.percentile(tmpArray_no_zero,90)

          # get the same parameters directly from the raster object...
          arcpy_min = arcpy.GetRasterProperties_management(tmpRas, "MINIMUM")
```

```
            arcpy_max = arcpy.GetRasterProperties_management(tmpRas, "MAXIMUM")
            arcpy_mean = arcpy.GetRasterProperties_management(tmpRas, "MEAN")
            arcpy_std = arcpy.GetRasterProperties_management(tmpRas, "STD")


            #print '\n'
            #print a_min, a_max, a_mean, a_median, a_average, a_std
            dataLine = currentID + '\t' + str(cell_count) + '\t' + str(a_min) + '\t' +
str(arcpy_min) + '\t' + str(a_max) + '\t' + str(arcpy_max) + '\t' + str(a_mean) +
'\t' + str(arcpy_mean) + '\t' + str(a_average) + '\t' + str(a_median) + '\t' +
str(a_std) + '\t' + str(arcpy_std) + '\t' + str(a_p75) + '\t' + str(a_p90) + '\n'

        else:
            dataLine = currentID + '\t0\t0\t0\t0\t0\t0\t0\t0\t0\t0\t0\t0\t0\n'

        outFileObject.write(dataLine)
        print dataLine



    outFileObject.close()

    arcpy.TableToTable_conversion(outFileName, defaultGDBname, 'statsTable')
    arcpy.JoinField_management('tmpFC', zonal_ID_field, 'statsTable', 'zoneID')


    print("\n  Copying temp FC to out zonal FC\n\n")
    timeStamp = datetime.now().strftime("%d%m%Y%H%M")
    outName = outZonalFC + '__' + timeStamp
    arcpy.Copy_management('tmpFC', outName)
    print('Done copying....\n')


    usedTime = datetime.now() - startTime
    toPrint = "\nDONE...\n\nused time: " + str(usedTime) + "\n"
    print(toPrint)




    raw_input("\n\nPress Enter to EXIT...")


#-----RUN MAIN-----------------------------------------------------------------
if __name__ == '__main__':
    main()
```

Appendix 4 – Digital Attachments

The digital attachments include:

4a Regional Scale Ports

An Excel file with the list of the project ports based on De Graauw (2017) at Regional Scale

4b Global Scale Ports

An Excel file with the list of the project ports based on De Graauw (2017) at Global Scale

4c Shipwrecks Database

An Excel file with the Mediterranean shipwrecks based on the combination of OXREP (Strauss, 2007) and DARMC (McCormick, 2012)

4d Shipwrecking Probability Model scenarios

The raster layers (ESRI GRID) with the Shipwrecking Probability model scenarios