THE POWER OF LOCATION: PREDICTIVE MODELING AND GIS

A Thesis

by

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ABSTRACT

In the past two decades, nautical archaeology has turned its attention to identifying and locating the ships used during the Atlantic Slave Trade. While the archival evidence exists, only a small number of these ships has been found, and even less have been excavated. Spatial analysis tools like GIS can be a powerful tool to help further this research. This thesis is an exploration of how predictive modeling and GIS could make the identification of slave wrecks plausible, and an overview of the ethical issues that surround the use of GIS within the context of the African Diaspora.

With more representative sampling of ships, archaeologists can continue analyzing the slave trade not only from the archival documents of the owners, but also from the artifacts of those on board. Locating and identifying wrecks that are suitable for excavation will add invaluable data to the understanding of this journey; yet, numerous ethical issues must be taken into consideration. As this data deals with a crucial element of the African Diaspora, the larger anthropological community must involve the present descendants of these captives. If GIS is used in a larger theoretical context, it should also actively engage with present-day community stakeholders.

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CHAPTER I

INTRODUCTION: OVERVIEW OF THE TRANS-ATLANTIC SLAVE TRADE

Introduction

Archaeology has the ability to contextualize those who are not present in the historical narrative. The wrecks of slave ships are exemplary of this fact, as they have the potential to supplement the archival history with concrete archaeological data on the millions of captives shipped into slavery. The artifactual evidence can reframe the written history in the voices of those with untold stories. The value of a shipwreck is similarly multifaceted, as it represents the technological capabilities of its time while tying all its artifacts together to the same point in time. However, until 2008 very little academic attention had been paid to slave wrecks (Webster 2008a, 1-2). To date, there are 1,011 recorded slave wrecks lost at sea, 433 of which were engaged in slaving at the time of sinking. The dearth of data on this topic needs to be addressed (Webster 2008b, 6). Even though the journey of captives across the Atlantic is an important narrative, supplemented by oral histories and artifacts in the destination ports, it is rarely addressed by material culture from the ship itself. With more representative sampling of ships, archaeologists can continue analyzing the slave trade not only from the archival documents of the owners, but also from the artifacts of those imprisoned on board. Locating and identifying wrecks that are suitable for excavation will add invaluable data to the understanding of this journey. Geospatial Information Systems (GIS) can be used to help contextualize archival data to locate the wreck remains in the ocean floor.

This thesis is an exploration of how predictive modeling and GIS could make the identification of slave wrecks plausible, and an overview of the ethical issues that surround the use of GIS within the context of the African Diaspora. Using documented non-slaving wrecks off the coast of Rhode Island, a sample workflow was generated, examining the issues that an archaeologist with little exposure to GIS would encounter in the creation of such a toolset. The GIS model is intended to be a proof of concept and an example of a workflow, rather than a fully-fleshed working model, as any model should be adapted and tested for regional suitability.

Finding and investigating slaving vessels will not only reshape the Trans-Atlantic narrative, it may also yield archaeological evidence for the scale of the slave trade and the impact it had on West African communities. Evidence suggests that the Gold Coast population decreased between the seventeenth and eighteenth century (Kea 1982; Manning 2013). Debate still surrounds the question of the magnitude of the slave trade and the volume of specific countries' participation (Eltis and Richardson 1997). Understanding the construction and material culture of these ships is critical to grounding the available documentary evidence, which has been interpreted to support multiple conflicting hypotheses.

Background

The Trans-Atlantic Slave trade started incrementally. Captive Africans were bought or captured, and sold in Europe by the middle of the 15th century. By the end of that century, they were sent overseas to the Americas (Curtin 1969, 15-50). As Native

Americans died from European diseases for which they did not have immunological defenses, during the 16th century the settlement of the Americas drove up the demand for slave labor to work the new sugar, tobacco, rice, and cotton plantations. This dramatically shifted the pathways for human trafficking, switching the focus from European destinations to an ever-increasing number of agricultural fields in South America and the American Islands. The use of African slaves on the Spanish and Portuguese sugar plantations in the Mediterranean and Atlantic was carried over to develop the new plantations, especially in Brazil (Rawley 2005, 9). Both the Spanish and the Portuguese initially brought captive Africans to the Americas by way of Europe, but this traffic was soon supplanted by a direct route from the coastline of West Africa to the Americas (Curtin 1969, 15).

Calculating the total number of captives trafficked into slavery is a guessing game. As Basil Davidson states in *Black Mother,* "The short answer is that nobody knows or ever will know: either the necessary records are missing or they were never made." (1961, 89). In *The Atlantic Slave Trade: A Census,* published in 1969, Philip Curtin examined oft-cited numbers of 15 million and 20 million and concluded that the numbers were lower (Curtin 1969, 3-14). Projecting that approximately 11.8 million captives had departed Africa and 9.4 million arrived in the Americas, he started a vigorous debate over the "numbers game", which has only expanded with the introduction of computer modeling (Eltis and Richardson 1997, 2). Voyages previous to the Iberian Union in 1580 are not as well documented as the later ones, but the archives still show an active trade focusing on captives from the coastal regions (Curtin 1969, 96-

104). With the discovery of new shipping records and the development of databases, there have been efforts to not only quantify the magnitude of the slave trade and its impacts on both coasts but also humanize this moment with autobiographies of slaves (Eltis and Richardson 1997, 3). Captive Africans represent the largest migration to the Americas prior to the increase in immigration to the U.S. in the late 18th century (Curtin 1969, 3).

The Trans-Atlantic Slave Vessel Database has compiled a list of almost 36,000 ships that once carried African slaves during 1514 – 1866 (2016). Several nations are represented, including but not limited to Portugal, Great Britain, Netherlands, United States of America, France, Spain, Denmark, and other Baltic states. According to the Database, Portugal transported the most human cargo across the Atlantic, with Great Britain also playing a key role in the slave trade in this period (Webster 2008a, 1). As many of these nations have archival records from their ports, military, and economic transactions, documentary evidence can play a key role in locating and identifying archaeological shipwreck sites (Webster 2008a, 2).

Sources

Almost all our understanding regarding the slave ship itself comes from written accounts, primarily told from the perspective of those who benefited from the trade. Most come from ship logs, letters, company and naval reports, newspaper articles, and bills of sale. These can be somewhat problematic; for instance, precise details on ship tonnage varied from port to port and can be unreliable (French 1973, 441). Registered tonnage differs from measured tonnage, and each are calculated independently from the other (Davis 1962). Port authorities also kept written records of ship arrivals and their cargo. This includes documentation from Barbados, Jamaica, and many other colonial destinations for these ships. British, Portuguese, and Dutch companies' correspondence, ledgers, and accounts also survive in the U.K. National Archives from this period (2016b). Predictably, the archival evidence comes from European sources. While these sources are instrumental in identifying and contextualizing a ship, the archival evidence can not only be contradictory, but also sparse on tangible details like ship construction and its effect on those on board. The voices of the captives transported across the sea – those without access to pens, paper, or the language of their captors – are rarely found within this documentation.

In this thesis, I relied on contemporary newspaper articles and national records like the annual U.S. Life-Saving Service reports to narrow down the location of wrecking incidents. In addition to these, local dive communities and maritime historians were consulted.

Using archival evidence to locate slave wrecks

In 1974, Leif Svalesen found the shipwreck of the Norwegian slave trader *Fredensborg* in the water of southern Norway chiefly through archival research (2000, 13-20). While Svalesen was a diver and not an archaeologist, he worked with local historian Hartvig Dannevig to comb through archival evidence for this ship. Beginning with documents from a maritime court of inquiry, Svalesen, Dannevig, and two others used this information to narrow the search to a geographic range. As the area was too large to search by diving alone, they added oceanographic information and information from local fishermen to further narrow the search area. After a year of archival research, they identified the most likely location of the wreck. Upon finding some artifacts, they contacted the Norwegian Maritime Museum, which confirmed that their finds matched the cargo the *Fredensborg* was reported to carry (Svalesen 2000, 13-20). The museum then excavated the wreck, utilizing both experienced archaeological divers and volunteer amateur divers (Svalesen 2000, 173-175).

Other excavations of slave wrecks also started with investigations into the historical records. In 2004, the *Trouvadore* project utilized archival data to locate potential areas where the Spanish slave ship may have sank (Sadler 2008). The project began with the publication of two dispatches, one from 1849 and one from 1878, both referring to the sinking of two ships off the Turks and Caicos Islands (Sadler 2008, 57). These two ships, the *Trouvadore* and the *Esperanza*, were not mentioned by name in the 1849 dispatch from the Council President, Frederick Forth. Writing to London, President Forth references an oral tradition among the workers that linked their heritage to two shipwrecks (Sadler 2008, 57). The 1878 letter, meanwhile, accompanied two statues sent to the Smithsonian by a resident of the island, George Judson Gibbs. He expresses the belief that these were found on board of a Spanish slaver, *Esperanza*, which sank off the Caicos islands in 1841 (Sadler 2008, 57). Further research at the Public Record Office in London showed that the 1841 wreck was the Spanish brigantine *Trouvadore*, whereas the Portuguese *Esperanza* sank earlier in 1837. Although a wooden wreck was discovered within the survey area, the researchers have yet to positively identify the ship, and are currently seeking archival evidence of other ships that wrecked in the area (Sadler 2008, 68).

Another example of a slave wreck excavation originating from the archives is the search for the Portuguese slaver *São José*. In 2011, archival research yielded the captain's account, and helped researchers correct an earlier misidentification of a shipwreck site off South Africa. Later that year, the ship was proven to be *São José* (Slave Wrecks Project, 2015).

Archival research is sometimes an onerous task, demanding a knowledge of not only the source material but also the culture of the original author (Ahlström 1997; Svalesen 2000). It must be constantly contextualized for a meaningful interpretation, and GIS requires further interpretation and extrapolation of archival data. Due to the layering of interpretation, archival data is not and should not be treated like the metaphorical X on the map. Rather, it should be treated like a highlighter, throwing possible areas and locations into relief. As with all types of contextualized information, an archaeologist should be cognizant that even though GIS is presented in the format of a map, it often represents numerous interpretations derived from collaborative research.

By utilizing the documentary evidence, archaeologists can seek out physical evidence and material culture. However, documentary evidence alone rarely provides enough context to identify a shipwreck. The wrecks that leave archival evidence are those that had economic or societal value, ones that "cast a shadow on dry land, with traces and leads in archiving" (Ahlström 1997, 208). Not every shipwreck will have an archival presence; the earlier the shipwreck, the less likely it is to leave an archival record. This holds true for medieval and earlier wrecks. More importantly, documentary evidence cannot be utilized conclusively without artifactual evidence, although a 2013 review of *International Journal of Nautical Archaeology* articles found that when investigations begin with historical research, archaeological data is used primarily as a supplement (Harpster, 592-600). Rather, the two data sets should act as complements. Drawing on this, it is imperative that the documentary evidence be treated as subjective and contextually linked, and not as the final truth. Most archival text was written to communicate between not only contemporaries, but contemporaries with the same cultural background. As such, crucial details to modern day researchers are often glossed over or omitted entirely as self-evident to the intended audience (Ahlström 1997, 209).

Problems inherent in excavation

That few slave wrecks have been found and excavated may be tied to the problems inherent in ship identification. While beginning with documentary evidence to locate a slave wreck may not be the ideal strategy according to some authors, it is one of few definitive ways to identify a ship as a slaving vessel. Compounding this issue, the paucity of identified slaving vessels has prohibited a broader analysis of the features of slaving vessels. New research has focused on highlighting some of the similarities both in artifact assemblage and construction methods (Glickman 2015).

When slavery became outlawed by a number of countries later in the eighteenth century, all construction in the upper-works to hold slaves was made more temporary and less noticeable to avoid naval attention (Webster 2008b). The Anglo-Dutch Treaty of 1823 listed the following traits of a slave ship:

1. Iron shackles
2. Ventilation gratings (vs. slide hatches), and ventilation holes above the water line
3. Spare bulkheads and other planks to construct temporary decks and structures for the slaves
4. Native canoes to expedite landings; waiting for local canoes to be loaded with captives and other cargo could leave a slave ship exposed in port (Ward 1969).

This gives very few structural and artifactual cues to positively identify a wreck as part of the trans-Atlantic slave trade. While shackles are the prevailing symbolic artifact for a slave wreck, non-slaving ships were also known to carry them. Compounding this archaeological problem, slave ships were commonly repurposed cargo vessels, and along the other legs of the Trans-Atlantic route, carried additional trade goods and employed removable decking to allow more space within the hold (Webster 2008b). These trade goods, when taken as a whole, may help identify ships that were part of the slave trade.

Artifactual evidence that may indicate a ship was once a slaver include trade goods to exchange for captives, such as the following: beads; bale seals from fabric bales; dyewood; iron and copper bars; firearms; ivory; and manillas (Glickman 2015, 64). Manillas are a West African metal currency shaped like a horseshoe; they were originally formed from bronze or copper, but were made of lead, pewter, iron, and tin later in the slave trade (Herbert 1984, 125-132). Cowrie shells are often overlooked in shipwreck contexts, but may be an important indicator due to their use on the African continent as a form of currency (Glickman 2015, 68). Finally, additional stone or pig iron ballast and ventilation gratings may also survive the marine environment.

Artifacts may also be used in conjunction with ship construction to tentatively identify a slaving vessel as well. However, most of the vessels used were common merchantmen types, such as caravels and naos (Glickman 2015, 28; Cook 2012, 71) in the early years. During the height of the trade, a variety of vessel types were used, including ships, brigs, schooners, and sloops; although some had lighter framing patterns than their traditional cargo-vessel counterparts, this may not be standard (Glickman 2015, 35-45). The diversity of ships continued after the trade was outlawed by Britain, dominated by faster ships that could avoid capture by the naval patrols. This included incorporating a few steamships into the trade (Klein 2010).

Given the diversity in ship construction and artifact assemblages, documentation remains one of the best methods available for identifying a slaver. As such, exploring methods that can help spatially analyze where wrecking incidents occurred is vital to gathering more archaeological evidence.

CHAPTER II

INTRODUCTON TO GIS

Introduction to GIS

Geographic information systems (GIS) are spatial analysis technologies used to combine multiple types of data sets into a coherent map. The utility of the technology has made it a commonplace tool in the archaeological toolkit. A GIS can be used not only to expedite mapping, but also to develop and test social hypotheses (Wescott and Brandon 2000, 1 – 5). However, the application of GIS to represent, model, and predict human interaction with the landscape has raised questions about the assumptions held by researchers and the methodologies used (Conolly and Lake 2006, 1 – 10; Eve 2014, 7 – 27; Green 2011, 9 – 21).

What is GIS?

A geographic information system is comprised of several factors. James Conolly and Mark Lake identify three important components: software, hardware, and the GIS operators (2006). The software requires a database, a mechanism to link attribute data to a spatial object, and a ‘geoprocessing engine’ that allows for alteration of information in both the spatial database and the attribute database. The software package chosen, which will be discussed later, will also require hardware to be installed on the computer running the GIS software. However, with advent of the web and 3-D modeling software, distributing maps and spatial information has become markedly easier.

Conolly and Lake rightly identify the GIS operator as the most critical component of the system (2006). The framework of the research question, the choice of data, and the analysis are as critical to the result as the data. Each of the above choices impacts the resulting product, and can create misleading or skewed results (DeMers 2002, 123).

Types of data

There are two types of data used in GIS: **vector** and **raster.** Vector data consists of discrete points, lines, and polygons, whereas raster data, comparatively, consists of a gridded matrix of pixels (Conolly and Lake 2006, 27). While these are commonly used together in map products, each operates very differently. As such, their applications in modeling also vary. Vector data relies on x and y coordinates to define an object, either as a single point, a line consisting of segments in between points (also known as nodes), or polygons created from these lines. The boundaries between objects are solid, and intersections are defined by shared nodes (Conolly and Lake 2006, 27). An analogous comparison would be the familiar paper map, with bounded forest polygons, discrete state lines, and city points. While raster pixels also have x and y values, these values refer to the row and column of a specific cell, which then contains another value, z, to differentiate it from the surrounding pixels. Much like a mosaic formed of the same size tiles, a raster dataset can be used to form polygons, points, and lines, although they will appear pixelated. For instance, a discrete vector point can be represented in raster as a single cell. While the vector point has more locational accuracy, the point can still be represented in a raster format. This provides different functional abilities for raster data.

Vector advantages and disadvantages

While this thesis focuses primarily on utilizing raster data, a brief overview of the opportunities made available by vector data can help contextualize why raster data was used for this model. The spatial precision provided by vector data makes the mapping of discrete objects feasible. To use an example from nautical archaeology, a vector format would be preferable to mapping the location of timbers and the deposition of cargo. In this context, the arrangement of the artifacts and the negative area of space in between them are discrete entities that an archaeologist can analyze and infer data from. In a broader sense, vector can also be used to show and analyze trade routes and networks (Wheatley and Gillings 2002, 134 – 135). Also, unlike raster data, vector data allows for a range of scales to be represented in the same data model without being bound to a minimum resolution (Conolly and Lake 2006, 30)

Vector data has disadvantages, however. Vector constructs (point, line, polygon), by being so precise, do not allow for fuzzy boundaries. Further, if a value is attributed to a polygon on a map (say, a survey area), there is no way to represent any distribution of that value within. Whereas raster data represents space broken into specific units of measurements, vector implies the space in between and portrays it as a solid, uniform block despite any internal differences or muddled boundaries (Tomlin 2013, 26-27; DeMers 2002, 20-21). Finally, even with contour lines, interpolating elevation and depth heights with vector data requires generating additional models, like TINs (triangulated irregular networks), which may need to be exported to raster data in order to be used in further computations (Conolly and Lake 2006, 108 – 111; Wheatley and Gillings 2002, 113).

Raster advantages and disadvantages

Raster cells, unlike vector shapes, can define multiple entities in a uniform manner. For instance, a road and a building can be differentiated from each other by content (normally, by a different color based on the z numerical value), but each are composed by the same size and shape cell. By prioritizing uniformity over locational accuracy, different types of data can be layered, analyzed and represented in a final spatial product (DeMers 2002, 14). Since the spatial aspect of the cell can be represented by its location in the grid, the z value, traditionally representative of elevation, can therefore be aspatial. It can represent traditional geographic indicators, like elevation or bathymetry, but it can also represent the spatial relationship between aspatial topics, like artifact density. Further, raster data allows for fuzzy boundaries, rather than arbitrarily defining spatial areas. For instance, an archaeologist can show how density of pot sherds changes within a field instead of defining a boundary of where the artifact is found, or can use raster to show the mixtures of soil types over a site plan (Conolly and Lake 2006, 30). Critically to nautical and maritime archaeology, the ability of raster data to show a diversity of ranges within a region becomes highly useful when trying to incorporate the concept of flow. The gradation allowed by raster data captures more data than a linear equivalent (DeMers 2002, 22; Tomlin 2013, 25-27). Finally, raster data easily incorporates data from aerial and other remote-sensor imagery (DeMers 2002, 22). There can only be one z value for the entirety of the cell, however, so the size of the grid is a critical choice for the developer.

GIS in archaeology

The applicability of GIS has grown steadily in many fields of study and likewise in archaeology. GIS have been commonplace in archaeology and anthropology for over two decades. Conolly and Lake (2006) assign five basic tasks that GIS can help archaeologists accomplish:

1. **Spatial data acquisition:** a GIS user can obtain and integrate spatial datasets like topographic maps, locations, site plans, satellite imagery, and geophysical data
2. **Spatial data management:** GIS provides storage and retrieval of data, creation of metadata, and the editing of new datasets
3. **Database management:** the user can construct databases and create links between spatial and non-spatial databases
4. **Spatial data analysis:** the user can use the combination of datasets to examine and create new data, including predictive modeling
5. **Spatial data visualization:** finally, the user can create visual aids, interactive map data, and printable paper maps.

Interpreting an archaeological site includes the analysis of contextual spatial data, both internally to the site and externally to the greater socio-economic landscape. This spatial data may be qualitative, like soil typology, or quantitative, like number of artifacts (Conolly and Lake 2006, 14 – 16). It can also be linked to aspatial attributes of artifacts and sites, allowing various attributes to be studied by location distribution.

Recently, GIS has been used to develop 3-D representations of excavation units (Riel 2016), in augmented reality analyses for archaeologists and tourists alike (Eve 2014, 25 – 31), as a tool to conceptualize time and rate of change within cultural landscapes (Green 2011), and to quantitatively reconstruct the shoreline of Thera, now Santorini (Oikonomidis et al. 2016). More commonly, GIS is also encountered in other contexts, like cultural management resource databases, spatial plans of archaeological excavations, and in landscape archaeology (Conolly and Lake 2006, 33 – 45). In landscape archaeology, GIS has been used to create predictive models to measure the likelihood of site occurrence in unsurveyed lands (van Leusen et al. 2005).

Predictive models in archaeology

One of the applications of GIS is predictive modeling, where a known relationship between factors is projected onto an unknown place, either temporally or geographically (Wescott and Brandon 2000). This supplies archaeologists with a tool to identify potential sites terrestrially, as demonstrated by Ben Ford (2007), as well as within a maritime context. A predictive model has been intensively used by the Dutch Archaeological Heritage Management to locate archaeological sites within the

Netherlands, and to incorporate the possibility of excavation into the planning process. Initial models were broad, examining landscape variables such as soil type; however, later works focused on more linear infrastructure construction or local area studies. These models are implemented when the Dutch government is planning the long-term development of the land, and when assessing the potential effect of specific projects (van Leusen et al. 2005). The same model was adapted to the underwater area of the Netherlands, focusing on wrecks that would have been quickly covered by sediment. However, no publications have reviewed the efficacy of the maritime extension of this model.

The first Dutch predictive model was set in the eastern Netherlands in the Rijssen-Wierden area (Anlum and Groenewoudt 1990, Brandt et. al. 1992), and was reanalyzed in 2009 (van Leusen et. al.). Seventy-six archaeological sites were compared to 80 random control points. Correlations between eight geographic variables and archaeological were determined, and five were tested: soil textures, geomorphology, ecological border distance, distance to water, and distance to a different ecological zone. These five factors were weighted between 0 and 3, depending on which was more likely to be found associated with the studied archaeological site values (Brandt et. al. 1992). These factors were added together, yielding ranges from 0 – 13 (van Leusen et. al. 2009). These were then grouped into four categories, with the lowest sums assigned poor archaeological potential and the highest values assigned as favorable for archaeological excavation (Brandt et. al. 1992).

Ford’s terrestrial model followed the same basic steps to identify potential locations for Chesapeake shipyard locations (2007). Numerous resources were needed for the shipyard, but many of these (cordage, sails, ironworks, pine trees for masts and spars, pitch, turpentine) could be imported. Access to oak, however, was critical to shipbuilding and could help determine the shipyard’s placement. Other weighed factors include: sheltered areas of water for construction; wide swaths of shoreline; deep water; stable soil; a slope of 4% - 7%; and within eight kilometers (4.97 miles) of an urban center. Finally, the land had to be owned by a shipbuilder. Using 95 known locations of shipyards, Ford tested the importance of each location statistically. 79% were located within eight kilometers of a town; 67% had access to sheltered waters; and all the shipyards were within 1.1 kilometers (0.07 miles) of soils that would promote oaks. Additionally, Ford found that soils that promoted tobacco-growing were avoided (2007, 131). Areas suitable to oak growth were assigned a value of 5; places within eight kilometers of a city limit were assigned a 5, and areas between eight and sixteen kilometers were assigned a 2; areas with a slope between 6 and 8º were assigned a 3, and slopes of 4 – 6º and 8 – 11º were assigned a 1. Soils considered beneficial to the growth of tobacco were given a score of -2. These values were added together, ranging from 0 – 15; low scores range from 0 to 3, moderate scores between 4 – 7, and high scores over 8. Nine of the high probability areas were studied, resulting in one positive identification and three possible locations (2007, 128 – 132).

GIS in nautical archaeology

While predictive models are not common in nautical archaeology, the utilization of GIS has been successfully adapted within the field. In Northern Ireland, GIS has been used to combine bathymetric features, seabed contours, and marine bottom type together with historical and archival evidence of shipwrecks (Breen et al. 2007). From this analysis, the authors could examine the wreck distribution not only spatially but temporally, using the distribution to analyze the causes of wrecking such as natural hazards and weather. They also made inferences regarding the economic pathways by incorporating historical data on the cargoes, their origins, and their possible ports (Breen et al. 2007). Another study, conducted on the Egadi Islands, concluded that the popular GIS software provided by ESRI, ArcGIS, could integrate data from side-scan sonar and sub-bottom profiling, as well as magnetic and bathymetric information, into a thematic map. While GIS did not reveal the anomalies, the researchers found that it could assist greatly in planning the excavations (Gravili and Ialuna 2006).

Possibilities for predictive modeling in nautical archaeology

Conceptualizing wreck site formation and wreck processes is not new to nautical archaeology (Muckelroy 1976; Ward et al. 1999; Gibbs 2006). Keith Muckelroy, in his publication 40 years ago outlining the process of wrecking and deposition on the seafloor, emphasized understanding the ship and its contents prior to the wrecking incident, and any post-depositional salvage or archaeological interactions that have occurred to the site (1976). Subsequent studies have elaborated both on the quantifiable natural effects that occur on shipwreck sites and the impact of indirect and direct human intervention (Ward et al. 1999). Gibbs further distinguishes between *catastrophic shipwrecks* and *intentionally abandoned* shipwrecks (Gibbs 2006). For this study, only catastrophic shipwrecks, those that were lost unintentionally, were analyzed.

Through cultural resources surveys, nautical archaeologists also created a methodology of predicting historic shipwreck “cluster” locations for the Bureau of Ocean Energy Management (Science Applications, Inc. 1981). While GIS was not a component of this analysis, the methods used were very similar to conceptualizing a GIS model.

There are three immediate uses for predictive modeling in nautical archaeology: to use archival and physical evidence to narrow down the likely location of a ship’s sinking, to understand how the ship and its debris field settled on the seabed during the wrecking incident, and to analyze the wrecks that may be at risk of either cultural or environmental damage. The first option was used to create a sample model below.

Predictive modeling in raster

For the scope of this project, predictive modeling in raster data best matches the datasets available for analysis. Archival evidence rarely gives details further than a general area, which may be too large for surveys, but may mention the area where a ship sank. As remote sensing surveys are normally limited by time and money (Murphy and Saltus 1990), archival sources are frequently backed up by local knowledge and oceanographic data (Svalesen 2000, 17 – 18). Raster data not only has the capability to model the fuzzy boundaries given by archival data, but it also has the capability to model the flow of currents, bathymetric depths, and incorporate digital images generated by side-scan sonar data (Kaeser and Litts 2010).

In the process of creating a predictive model, there are inherent uncertainties and assumptions the model developer accepts. These assumptions happen at every step of the process, from observation, interpretation, measurement, and data manipulation (Shi 2010, 3 – 26). Generally speaking, the more handling that data requires, the more error is introduced into the database created (Burrough and McDonnell 1998, 220-264). Since errors are probably included in the datasets themselves, whether a factor of scale, resolution, coverage, observer bias, age of the data, relevance of the data, or the format of the data (Burrough and McDonnell 1998, 222-225), these may be compounded by the modeling processes performed on them. These problems fall into three primary areas: the accuracy of the spatial data itself, the quality of the model, and the appropriateness of the model for the data (DeMers 2002, 29). If unaddressed, these factors can proliferate into costly errors and render a model useless.

What programs are available to use GIS?

Numerous software options exist to operate and manipulate GIS data. The existing champion, ArcGIS, is created by Esri. While some aspects of ArcGIS are available online, the cost of the software can be prohibitive to small archaeological organizations and independent contractors. Free alternatives, like QGIS and GRASS GIS, are available for download as well. As an open-source software, QGIS and GRASS

GIS can be changed and distributed, encouraging collaborative volunteer efforts to fix errors and increase ease of access. Finally, Discovery Software's STEMgis has been discussed as a GIS that supports a range of spatial and temporal data (Green 2011, 47). While other alternative GIS programs exist, ArcGIS is the most commonly encountered purchased software. QGIS and GRASS GIS are the most commonly encountered free GIS software.

CHAPTER III

PREDICTIVE MODEL METHODOLOGY

There are many types of predictive models, from simple pass-fail tests, weighted linear analyses, and fuzzy weighted linear regression models. In this chapter, I propose a pass-fail workflow, and I encourage other nautical and maritime archaeologists to adapt it to their own studies to see if the results could be useful.

Nature of the data

Data can come from **primary** or **secondary** sources. For archaeology, much of the primary data comes from excavation and survey. While there are problems inherent in primary (or "raw") spatial data collection and interpretation, this study will focus on secondary source implementation. Secondary spatial data has already been processed and interpreted, whether digital or paper-based, and inherently has assumptions presented as fact (Conolly and Lake 2006, King 1996). However, using secondary data greatly reduces the time commitment, and is already a practice inherent within archaeology. As with terrestrial archaeology, using secondary data necessitates anticipating errors (Conolly and Lake 2006).

Tracing the slave trade through historical records also adds another level of secondary data. Retrieving and researching old maritime records is a time consuming process, especially when the ship is foreign (Science Applications, Inc. 1981). The material may be poorly organized, and may only be available in distant and hard-to-access archives. Newspapers are a helpful source of information, but without digitization may be time-consuming and hard to access. Within the documentary evidence, ship location is often vague. Recording longitude was only made possible in the late 18th century (Science Applications, Inc. 1981).

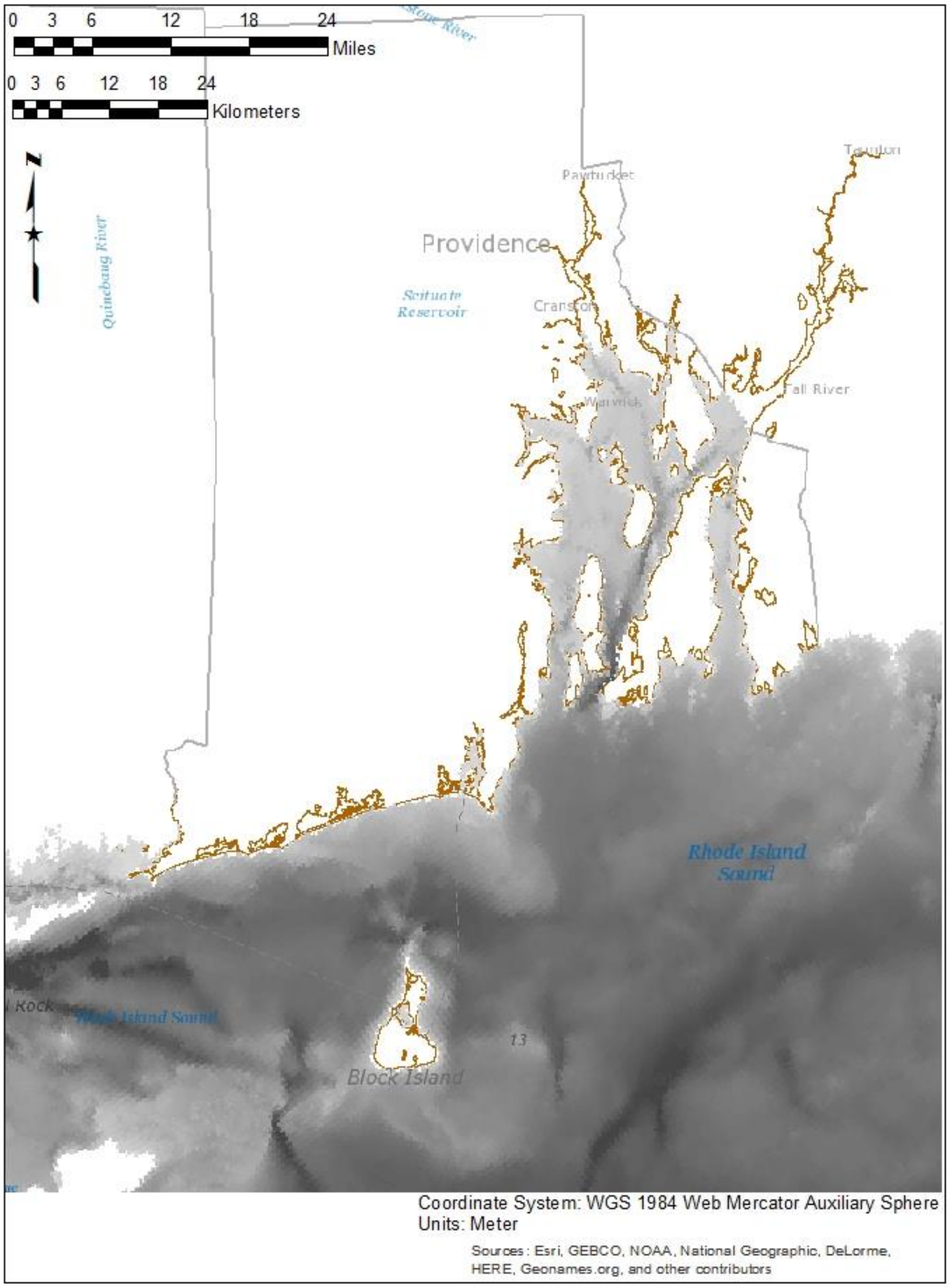
Converting archival data into raster data involves two additional levels of interpretation. The archaeologist must determine the range of space mentioned in the documentation. A knowledge of that location's history is instrumental, as place names can be highly regional; for instance, a New York Times article from 1899 reads that "a large four-masted schooner lies sunk off Whale Rock early this morning" (New York Times, 16 February 1899). The third level of interpretation lies in quantifying that textual data, which, in this example, is the area around a specific rock approximately a half-mile (0.73 kilometers) off the coast of Narragansett, Rhode Island. Adding a spatial dimension to the phrase "lies sunk off" is an inherently subjective process. Taking this and other sources which may narrow this range, the archaeologist then quantifies that phrase into a measurable distance. Through this process, the archaeologist has already started interpretation prior to creating the model. As Michael DeMers states in *GIS Modeling in Raster*, "the process begins by conceptualizing our real world and then converting it to a cartographic abstraction of that reality" (2002, 11). Understanding this distinction is crucial, as GIS models can be presented as mathematically valid truth built on incorrect assumptions. Like all other investigations in archaeology, the model creator should be methodical in noting any assumptions or interpretations built into the data in the accompanying report.

After the data is interpreted into an abstraction, it then will be converted into a digital equivalent through **tessellation**, which DeMers defines the division of geographic space so that it can be represented inside a computer (2002, 11). These tessellations can be squares, parallelograms, or hexagons; however, the square is commonly chosen due to the simplicity of performing operations on it. By deciding on raster data, this geographic data is divided into spatial packets, or **quanta**, which are then analyzed through the GIS operations (DeMers 2002 ,11; Kemp 1993, 364).

Previous publications have reviewed digital data repositories, both federal, local, and educational, as well as methods to convert paper maps into digital data (Conolly and Lake 2006, DeMers 2002), and I will not review them here. Luckily, as the technology becomes increasingly affordable, there are more accessible versions of both digitized analog maps and spatial data sets available to the archaeologist. Like knowing the traditional archival resources available for a region, archaeologists should also research the digital archival resources available for the study area. Comparatively, archaeologists should also understand the origin, methods, resolution, and projection of their digital data, as without these data can be easily misconstrued (DeMers 2002, 25). These are often coded within the data's metadata, a separate text file that is normally available within the data download or as a separate link to download with the data.

Reviewing the metadata can help contextualize the z value of the grid cell. As stated, the z value of the grid cell can represent a myriad of different variables. While some can be straightforward, like land elevation, others like bathymetry can be deceptive. For instance, the bathymetry grid used in this project was generated from soundings taken from the National Ocean Service (NOS) and the NOAA Coastal Relief Map (CRM), projected at a scale of approximately 90 meters (0.056 miles) in resolution. However, the data does not address the water level that the soundings were generated from. Given that the NOS data was produced from soundings from 1965 to 1975, and the CRM was generated in 1998, fluctuation from the surface of the water must be considered. It is not clear what is considered the zero point from which the measurements were taken. The scale of these data ranges from a positive value of 89 to -2,719 (The Nature Conservatory, 1999). All positive values occur very close to shore, as shown in Figure 1.

Similarly, if data was converted from a vector format into a raster format, more than one data value can be linked to a cell, but only one will be represented. GIS programs have a few methods of creating raster data from vector data. For instance, the z value can represent an average of the data within the cell or the data located most centrally in the cell. This means that when datasets are superimposed, the same two points may not be compared (DeMers 2002, 23). This leads to a loss of accuracy, and should be considered when analyzing a raster model.



Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 1. *Bathymetry layer. White and light gray shade values represent positive values.*

Quality of the model

Models are conceptualized representations of real-world systems and their interactions. To construct a model, a series of assumptions must be made to simplify the complexity of the moving components (DeMers 2002, 43), much like Muckelroy's flow diagram is a simplification of the wrecking process (1976, 282).

Creating a model

As with most models, the designer should first start by defining the goal of the project, or the intended spatial information product (SIP), and the audience. Both help define the types of assumptions and data manipulations performed throughout the process. This is also important to clarify what data are needed for the model. It is tempting, when on data repository sites, to download all the data sets. However, even though the data set is available, it should not drive the model (DeMers 2002, 25). In *GIS Modeling in Raster*, DeMers (2002, 124) lists five reasons why existing data sets should not be the starting point for creating a model:

1. If the data set is not compiled for the research question, the data may not fit the necessary accuracy or scale;
2. data sets will include too many irrelevant themes;
3. commonly, the data will be incomplete for a specific model;
4. external data may bias the methodology and the maker's conceptualization; and
5. sampling and area coverage may be inadequate.

Secondly, the developer should consider properties of the map itself. This below list is by no means extensive, but the following factors should be considered.

Grid size: (DeMers 2002, 26) While in the past, this was primarily related to the computing power of the processor, this now can be driven by the needs of the model. Choosing the proper resolution revolves around the objects that need to be mapped and the size of the area to be mapped. It is recommended that four grids should be allocated for each object to be mapped; but this can lead to skinny and long objects, like rivers (and specifically timbers), being missed. However, if the grid size does not also mesh well with the overall area being mapped (i.e., is far too small), then the model will work sluggishly and format awkwardly. Finally, if remotely sensed data is a key component of the analysis, matching the grid cell to the pixel size may be another factor in choosing an appropriate size if it fits the rest of the model. This should only be applied if the pixelated data is a critical factor.

Data measurement scale: There are four types of data, as Conolly and Lake outline (2006,46).

1. **Nominal**, or descriptive categories
2. **Ordinal,** or ranked data
3. **Interval**, continuous data with an arbitrary ‘0’
4. and **Ratio**, continuous data with a fixed ‘0’.

For instance, the bathymetry data mentioned earlier in this chapter would count as ratio data, as the zero is a fixed datum to which other values are measured. The type of analyses one can perform is determined by the scale of the data used, and they can only be compared to each other. Comparisons outside of their order require additional computations to avoid the proverbial apples and oranges problem (DeMers 2002, 79). One way to compare different sets of data is through logistic regression analysis (Conolly and Lake 2006, 183; Stopher and Meyburg 1979; Menard 2002).

Map algebra: (DeMers 2002, Chapter 4; Conolly and Lake 2006, 187-189) Map algebra refers to combining and altering raster grids by mathematical operations cell-by-cell, otherwise known as point operations (Conolly and Lake 2006, 188; Tomlin 2013, 43). This necessitates that the data are in the same resolution, so they can be “stacked” and calculated correctly (Conolly and Lake 2006, 187).

There are numerous types of operators in map algebra, including arithmetic, relational, and Boolean. Arithmetic encompasses the basic addition, subtraction, multiplication, division, and modulus, which only works for integers (DeMers 2002, 46). Relational operators analyze if something is greater than (or equal to), less than (or equal to), or equal to. Normally, if true, the output is equal to 1; if false, the output is 0. Boolean operators are similar, insofar that they evaluate the contents of the cell; they rely on three operators: ‘&&’ for and; ‘|’

for or; and ‘!’ for not. There are several other categories of operators, some of which expand on the Boolean methodology, including those to remove areas with no data and those that can multiply entire tables by one number. Refer to DeMers for a full breakdown (2002, 45-52).

Functions (DeMers 2002, 52–55): Operators are components of functions, which can be categorized in a number of ways. Two specific types of functions will be discussed here:

Local functions operate cell-by-cell, where a grid cell or function in one matrix interacts with a corresponding cell**;** and

Global functions, alternatively, change the whole matrix.

Functions, in turn, are components of statements, which operate similarly to programming languages (DeMers 2002, 54). Local functions also have a set of potential operators, which can vary from trigonometry to statistical; one of the most commonly used sets of operators for local functions **reclassify** cells based on user input. Similarly, another tool is to **resample** grid matrixes, which changes the cell size of the matrix. Both functions will be discussed in the sample workflow.

Sample workflow

To explore the applicability of modeling shipwrecks, I chose a well-documented and well-researched area. The coast of Rhode Island has approximately 3.2 shipwrecks per linear mile, and an active maritime and diving community (Science Applications, Inc. 1981, 219). As such, the locations of many wrecks are highly documented, allowing the ability to test the data (Clancy 2010, Jenney 2008). Many of the located wrecks are motorized vessels rather than sailing vessels, which changes their sailing patterns, especially near port areas. However, the ability to test this data against specific locations outweighs the need to use solely wind-powered vessels. The spatial information product aims to use archival and natural data to limit the survey area. This map intends to take the historical area of sinking, and analyze factors within that boundary to highlight areas where a wreck is likely to happen. The intended audience is other nautical archaeologists.

Next, contributing factors needed to be identified and grouped together. See Table 1 for a full breakdown of the factors and their effects, based on existing models of wreck site deposition (Muckelroy 1976; Ward et al. 1999; Gibbs 2006). These factors are both spatial and aspatial; could be demonstrated in vector and raster; and are both specific and general. Although the impulse is to immediately indicate those with spatial factors, it is important to not limit the contributing factors. There may be data that could be converted into spatial data, or be used as an aspatial multiplier (DeMers 2002, 132 – 133).

Factor	*Predepositional or Postdepositional?*	*Why?*	*Effect*
Bathymetry	Post	If at an angle, ship will spill down to deeper depths. Deeper the water, the greater the debris field.	Move in the direction of the decline. Wider artifact distribution at deeper depths.
Island Topography	Pre	Some areas may be hazardous, like reefs.	Move in the direction of the decline.
Currents	Both; surface wave motion on surface, tidal currents at depth	May drive a ship into an obstacle.	Move in the direction of the current.
Criminal activity/salvage	Post	Site destruction.	Variable.
Benthic Cover	Post	Affects conservation and visibility of timbers and artifacts.	Variable with sediment.
Seafloor sediments	Post	Affects conservation and visibility of timbers and artifacts.	Hard beds may be poor conditions for preservations; fine layers may allow for quick coverage of timber.
Boat traffic	Post	Dependent on activity of boat and depth of channel.	Depth dependent, move in the direction of the boat activity.
Commercial vessels	Post	*See above*	*See above*
Recreational boater activities	Post	*See above*	*See above*
Recreational SCUBA diving activities	Post	Increases likelihood of salvage. Locals will know about this. More likely to flag for local historians. Would be a popular SCUBA spot.	Increase visibility; more likely to be around sites of interest.
Cargo	Both	Affects wrecking process; may have been salvaged; affects conservation of timbers.	-
Water Temperature	Post	Affects conservation of timbers and artifacts.	Variable depending on temperature.
Water Salinity	Post	Affects conservation of timbers and artifacts.	Variable depending on salinity.

Table 1. *An overview of possible factors to include in the predictive model.*

These factors were then grouped together into two categories, natural and human.

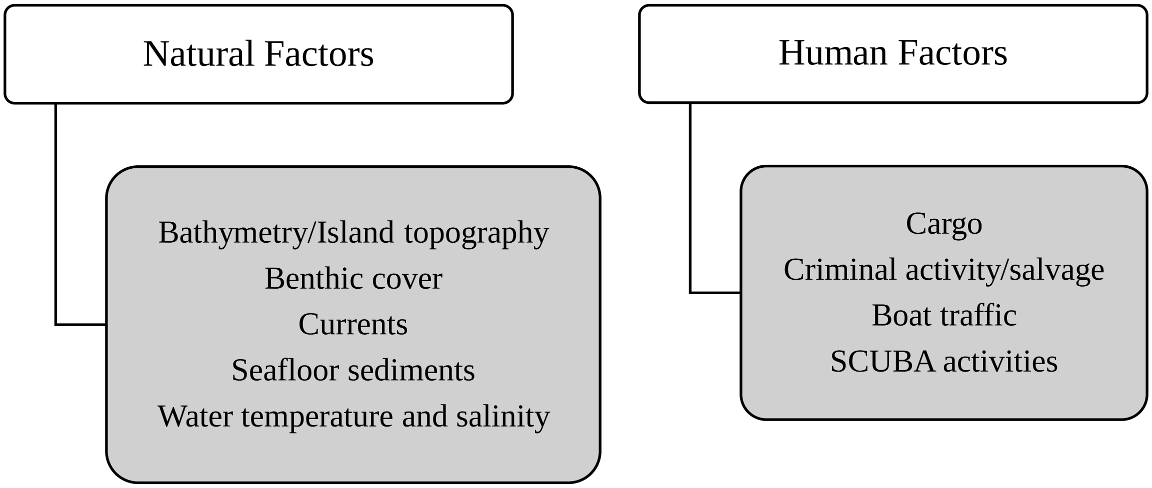


Table 2. *Groupings of possible factors.*

After identifying the factors, I returned to my research question to identify how the factors contributed. I found two that consistently affect wrecking incidents: the bathymetric depth, which is correlated with island topography, and the current speed. Many of the ships ran aground during fog or bad weather conditions. While the other factors have noticeable effects on wrecks, these were all post-depositional or made changes that did not significantly migrate the boat into a new grid cell.

Overview of the data: currents

Based on the premise that a ship will move or drift in the direction of a current during periods of distress, oceanographic surface current data was obtained through the Northeast Ocean Data Portal (Northeast Regional Ocean Council, 2016). This data was collected by the School of Marine Science and Technology at the University of

Massachusetts, Dartmouth from 1978 to 2013, and collated on February 29, 2016. This current data has two bands of data; one to measure the speed of the current in meters per second, and the other to measure the direction of the current by compass degrees. The speed data set ranged from a high speed of 1.0939 meters per second (approximately 3.5889 feet per second, or 2.12 knots) to a low of 0.00096 meters per second (0.0033 feet per second, or 0.018 knots).

These data present a few interpretation problems. One major question is the applicability of modern current data to historical events. Can we project the values collected between 1978 to 2013 into the past as accurate numbers? The answer, reasonably, is no. However, the hypothesis that areas where the current is faster historically may be applied to the past. Although the speed with which currents move varies yearly (Walczowski et al. 2012, 867), the 40 years that this dataset encompasses actually increases its applicability. The long view here can tell us, if not the speed at which the historic currents were borne, the areas where currents tend to be strongest. This means that the dataset is not useful as ratio data, but is useful as integer data. To do this conversion, current speeds local to the area need to be determined.

Additionally, the question of incorporating directionality is posed. Currents would skew the vessel's location in the direction of the current while sinking, and bottom currents would lead to post-depositional erosion and possible sedimentation depending on the benthic cover. It would also yield a larger debris field (Ward et al. 1999, 564 – 566). However, the data are limited by historic boundaries. To test the hypothesis regarding where currents tend to be the strongest, the directionality is not needed.

Finally, the dataset is projected to the GCS North American 1983, and each unit is projected to 0.002 decimal degrees.

Overview of the data: bathymetry and topography

The bathymetry data has already been used as an example earlier, but a quick review is in order. The data set was created from NOS soundings taken from 1965 to 1975, and the NOAA Coastal Relief Map (CRM) created in 1998. The scale of these data ranges from a positive value of 89 to -2719. This dataset’s resolution is 90 meters (0.56 miles), and it is projected to the NAD 1983 datum (The Nature Conservatory, 1999).

The same question of applying modern data to historical times exists in this context as well. As ocean levels change yearly, this data set should be taken as an indicator of shallower areas and, similarly, converted into an integer dataset.

Other needed data

Other miscellaneous data were used to clip the above datasets to historical areas. The Rhode Island Continually Updated Shoreline Product was used to create a buffer around possible areas of sinking (RIGIS, 2016). It was initially projected to NAD 1983. Finally, to validate the model, coordinates for known shipwrecks from avocational diver observation were converted into a vector point feature (Clancy 2010). Please note that no unpublished wreck coordinates were used in this dataset.

Creation of a workflow

With a defined goal and a grasp on the interrelation of factors, a basic outline of a workflow can be drafted. There are a few approaches one can take in the creation of a workflow, as outlined in an overview of Dutch archaeological predictive modeling (van Leusen et. al. 2005, 31):

1. the presence/absence model
2. the ordinal/interval (Boolean multivariate)
3. and ratio (probabilistic multivariate)

I chose to create a simple pass-fail model to test against the longitude and latitude of known shipwreck locations, as compiled by the local Rhode Island diving communities (Clancy 2010, Jenney 2008). This method has two benefits. While the other two rely on logistical regression and weighted variables, without a greater analysis of the shipwrecks of this region and the historical conditions under which they sank, it is hard to ensure the variables are weighted correctly. Without a more precise understanding of the historic climatic interaction of this area, a weighted map can only represent what is possible rather than what is probable. This, in turn, can be easily misconstrued as a definitive model, rather than an estimation (van Leusen et al. 2005, 31). Secondly, unlike terrestrial data, shipwrecks represent a discrete and limited site. While there may be a preponderance of wrecks along difficult to navigate areas, seeking out a single wreck for further research from archival sources requires highlighting the likely areas where they may be found. This model is not intended to replace further research and survey, but rather give it a focal area.

As such, the basic outline of the workflow resembles this:

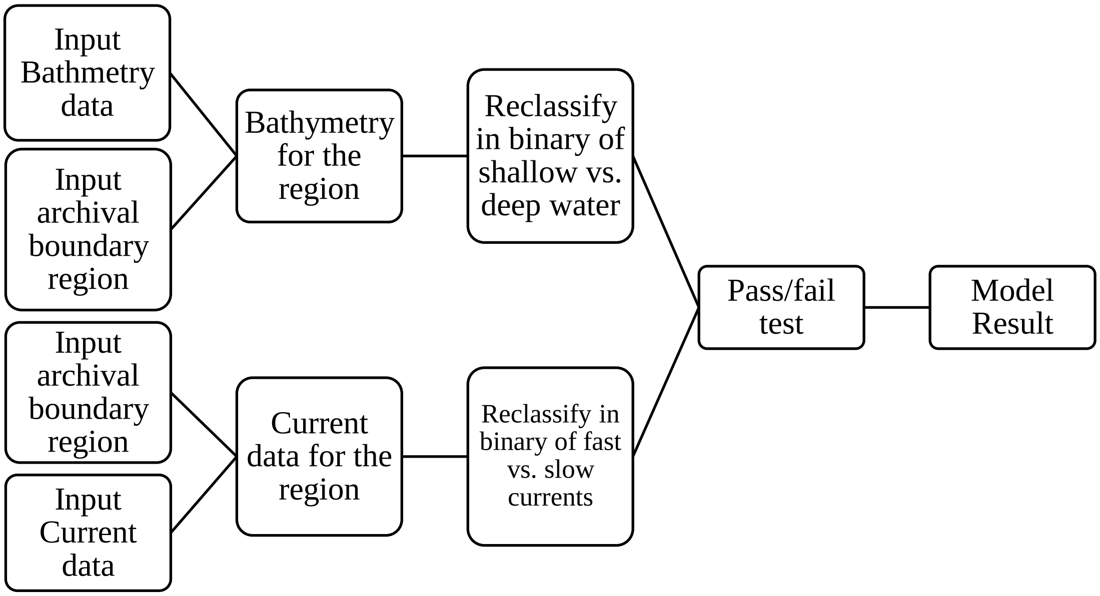


Figure 2. *Basic overview of suggested workflow*

Even with the conceptual workflow, the actual workflow in GIS looks slightly different. There are conversions, reprojections, and other steps necessary to realize the above model. These can be seen in Appendix 3.

Running through the workflow

This model was processed in ArcGIS, which requires the Spatial Analyst extension. If ArcGIS is not available to an archaeologist through their affiliated organization, there are similar tools within QGIS, such as the raster calculator in the raster menu.

Initially, the scope of the coastline to be analyzed was determined. Of the shipwrecks known by coordinates and archival evidence, the documents revealed that the farthest sank seven miles (approximately 11 kilometers) from the Rhode Island shore. The Rhode Island Continually Updated Shoreline Product (RI CUSP) vector file was projected to the spatial reference, WGS 1984 Web Mercator Auxiliary Sphere, and then used to generate a seven-mile buffer through the Geoprocessing tool kit.

The current data was also projected to the same spatial reference; however, as a raster dataset, it was projected using the Project Raster function. This gave the raster a resolution of 256 meters (0.15 miles). The reprojected raster was clipped to the area of study, and analyzed to find the regional minimum and maximum. This yielded a span of values from 0.001 to 0.3 meters per second (0.003 – 0.984 feet per second; 0.002 – 0.583 knots).

Here, the developer faces the question of what counts as a high, or dangerous, current. On the open ocean, current speeds are between 0.1 and 0.5 mps (0.3–1.5 fps; 0.25–1 knots), reaching 1.5 mps (5 fps; 3 knots) in some areas of the Gulf Stream (Duxbury 1996, 145). Longshore currents, meanwhile, are created from waves striking the shore at a slight angle, with the resulting energy moving parallel to the shore rather than against the shore (Duxbury 1996, 193). Other nearshore currents, like riptides, move seaward (Duxbury 1996, 194). Over time, this can change the shape of small islands and coastlines (Pilkey 1983, 91). Longshore currents can be either slower or faster than their open ocean counterparts, and move in a southerly direction along both North American coasts (Duxbury 1996, 193). The currents around Narragansett Bay and the coast of Rhode Island are slower than those on the open ocean, ranging from 0.0010 to 1.0939 mps (0.0033 – 3.5889 fps; 0.018 – 2.12 knots).

The Gulf Stream was charted by Benjamin Franklin and his cousin in 1769, noting that it moved approximately 3 – 4 miles per hour, or 1.3 to 1.8 meters per second (Cohn 2000, 130). The historically recorded speeds are roughly comparable to modern speeds on the Gulf Stream. However, this may not apply to the longshore currents, as these can be affected by eddies created by differential temperatures in larger oceanic currents (Duxbury 1996, 195). For the model, the goal is to identify areas where the currents are strongest. To use this data set in a historical context, I am assuming that the current speeds have maintained a static variability in recent history.

Using the zonal statistics as table feature, we know that the mean of the current data is 0.0695 mps. However, viewing the graph of the data under "Reclassify" shows that the data are skewed by outliers in high current areas, making the mean a less accurate measure of central tendency than the median, 0.0605 mps. While the median is a better measure of central tendency, I opted to reclassify everything above the mean as "fast" due to its higher value. As such, everything greater than or equal to 0.0695 was reclassified as a 1, and everything less than was reclassified as a 0.

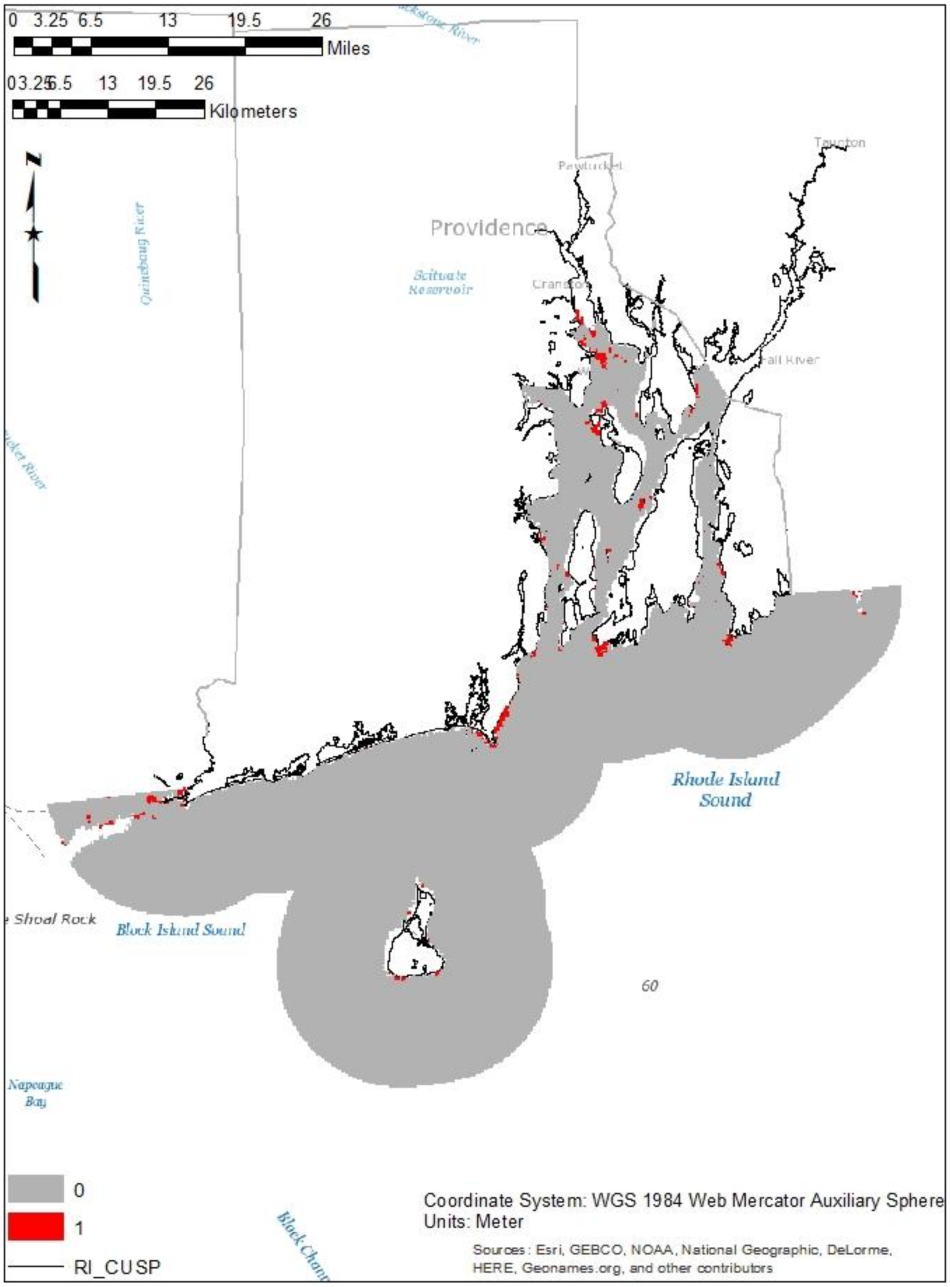
The bathymetric data was reprojected to the same spatial reference, yielding a resolution of 251 meters (0.156 miles). Since these resolutions are slightly incongruent, one dataset must be resampled so both have the same resolution. The developer can choose to resample the lower resolution to the higher resolution, which keeps the fidelity of the higher resolution dataset. However, by doing so, the developer can imply a level of false accuracy to the lower resolution data. As such, I resampled the bathymetric data to the larger resolution of 256 meters (0.159 miles) using the resample tool. Then the data was clipped to the extent of the seven-mile boundary around the coastline.

Again, a choice had to be made concerning what depth constitutes shallow water. Given that water depth is highly variable year from year, and the zero in the data set represents a mean water level, assigning a depth where it is likely for a ship to run aground is highly subjective. For the purposes of this exercise, I chose a depth of 4 meters (approximately 13 feet) or higher to classify as a risk for a ship to run aground. If construction details for a ship are available, it is possible that the ship's draught could be entered; however, the water depth variability and differentials in registered tonnage will still make this calculation a best guess, rather than hard math. The data was reclassified, with values below -4 meters reclassified as a 0, and values above -4 meters reclassified as a 1.

After, these results are input into the raster calculator in a simple pass-fail equation:

*"RI_Currents_Surface_Clipped_Reclass_1" * "RI_Bathymetry_Resampled_Clipped_Reclass_1"*

As each dataset was reclassified into a binary set, wherever one of these two values equals zero, the region will come up as a zero, thereby failing the test.



Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 3. *Initial results of pass-fail test. The red areas indicate possible locations for shipwrecks.*

Appropriateness of the model

There are a few ways to analyze these data, but quantification is not needed to see by way of Figure 3 that this initial test did not work. Isolating and optimizing the weak link in this model was the next step. However, in the pursuit of loosening constraints, the original data model must be consulted to ensure that the intent remains the same (DeMers 2002, 154–156).

Comparing the data layers in Figures 4 and 5, it is clear that the reclassified bathymetric data is a map of mostly zeros. There are a few options for changing the values. Similar to the current data, the mean can be used as a dividing line. In this case, it is -27.96 meters (91.73 feet). Alternatively, we can focus on an area with the most shipwrecks to see at what depth they currently sit at. From the data in Appendix 1, at least eight ships ran aground on the southern shore of Block Island. Drawing a polygon around this region, we can isolate the shipwrecks from this area and use the "Extract Multi Values to Points" tool. This gives us the results in Table 3.

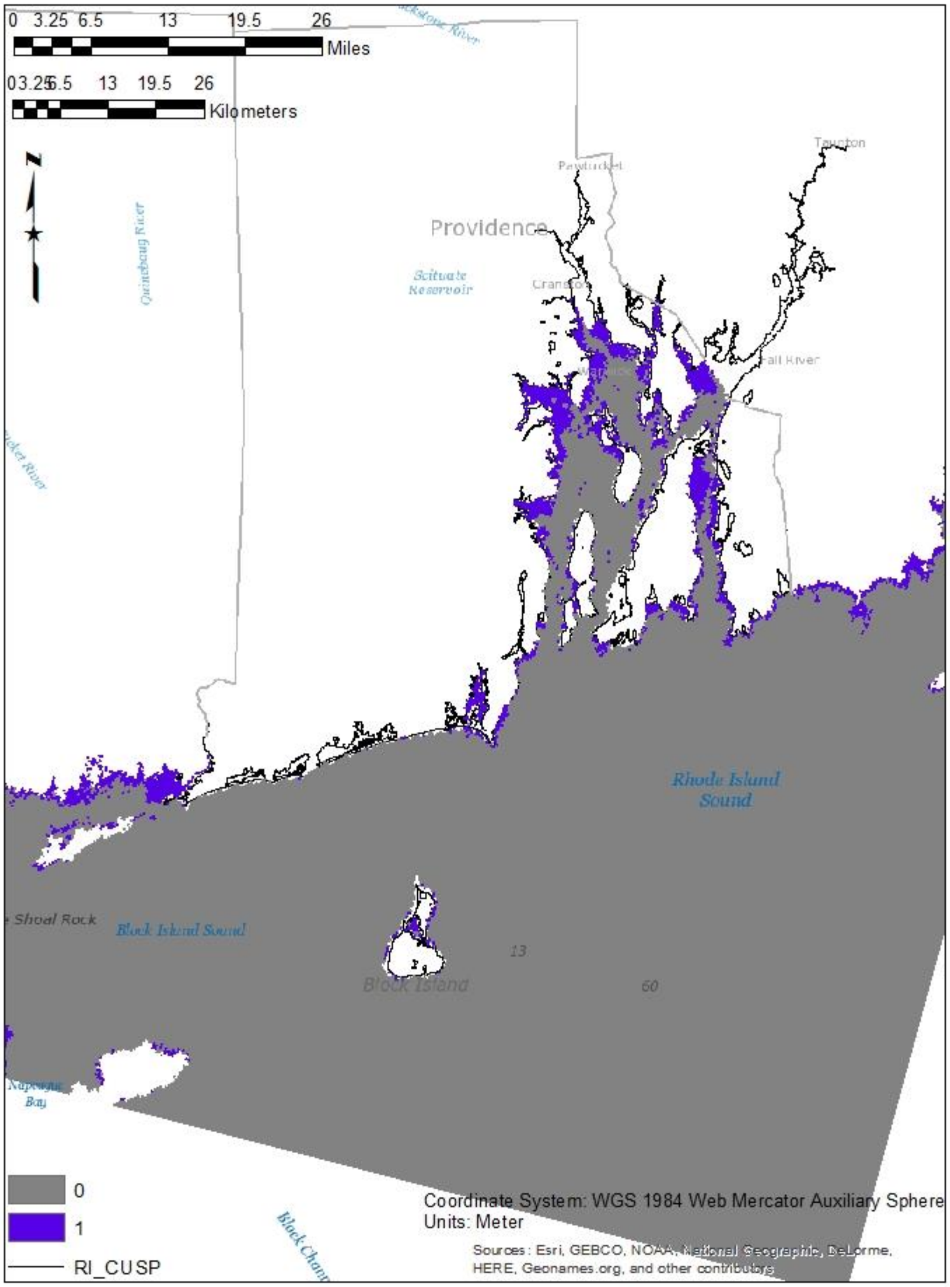


Figure 4. *Initial bathymetry layer with the -4-meter delineation, after being reclassed into possible locations (1, denoted by the purple), and less possible locations (0, denoted by the gray).*

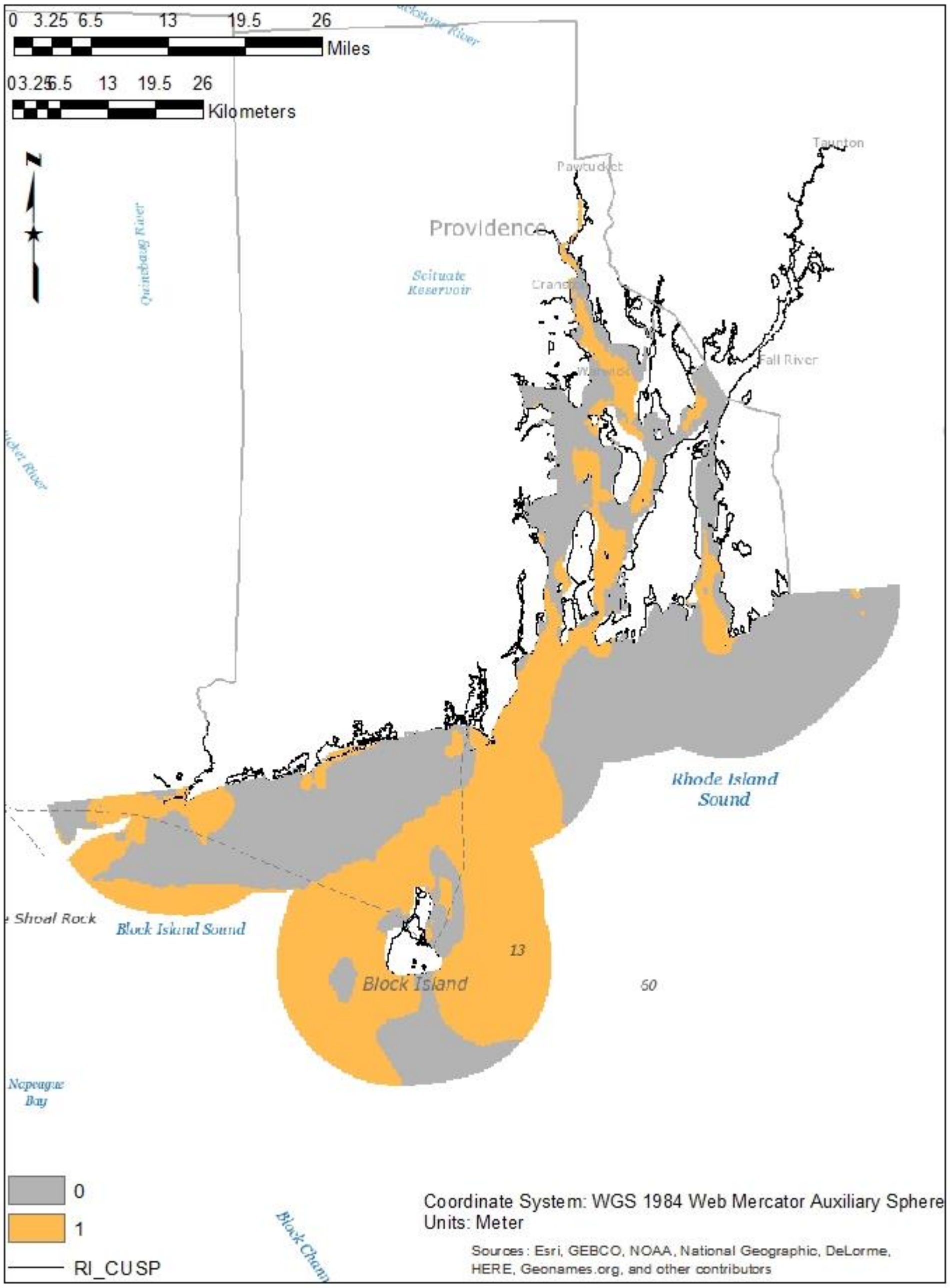


Figure 5. *Currents layer, after being reclassed into possible locations (1, denoted by the orange), and less possible locations (0, denoted by the gray).*

Vessel	*Location*	*Latitude*	*Longitude*	*Depth*
USS Leyden	Block Island RI	41.1475	-71.564333	No Data
Meteor	Block Island RI	41.146117	-71.58445	No Data
Spartan	Block Island RI	41.161333	-71.542767	No Data
Grecian	Off Block Island RI	41.074317	-71.538517	-27.02869034
Idene	Off Block Island RI	41.112467	-71.489917	-26.73840523
Essex	Block Island RI	41.148333	-71.550817	-6.767851353
Palmetto	Off Block Island RI	41.140567	-71.594933	-6.228220463
Lightburne	Block Island RI	41.14955	-71.5473	-5.69284153

Table 3. *Raster values from vessels on the south edge of Block Island*

Note that the depth values range between -5.69 meters and -27.03 meters. The larger values (-9999 meters) are the values returned for the areas where there was no raster data to draw on, discussed further in chapter 4. Barring the No Data values, there are three ships that fall under -7 meters (-22.97 feet) and two more that fall under the mean, -27.9 meters (-91.73 feet). Figure 6 shows the results of using the mean as the dividing line. Reclassifying the bathymetric raster layer using the mean, the resulting pass/fail results appear as in Figure 7. Although the model now works, the interpretation of the model changed, as will be discussed in chapter 4.

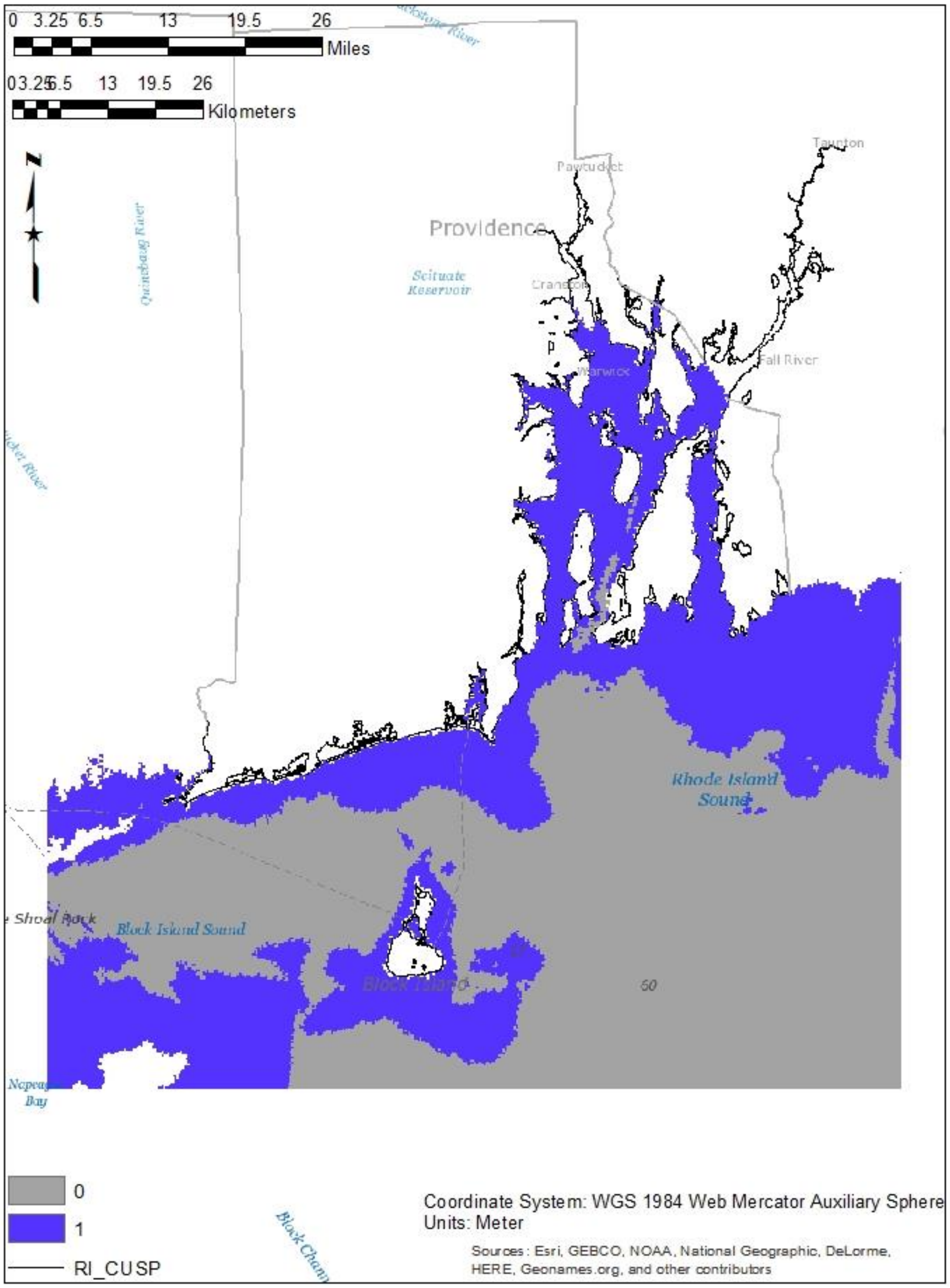


Figure 6. *Bathymetry layer with the -27.9-meter delineation, after being reclassed into possible locations (1, denoted by the purple), and less possible locations (0, denoted by the gray).*

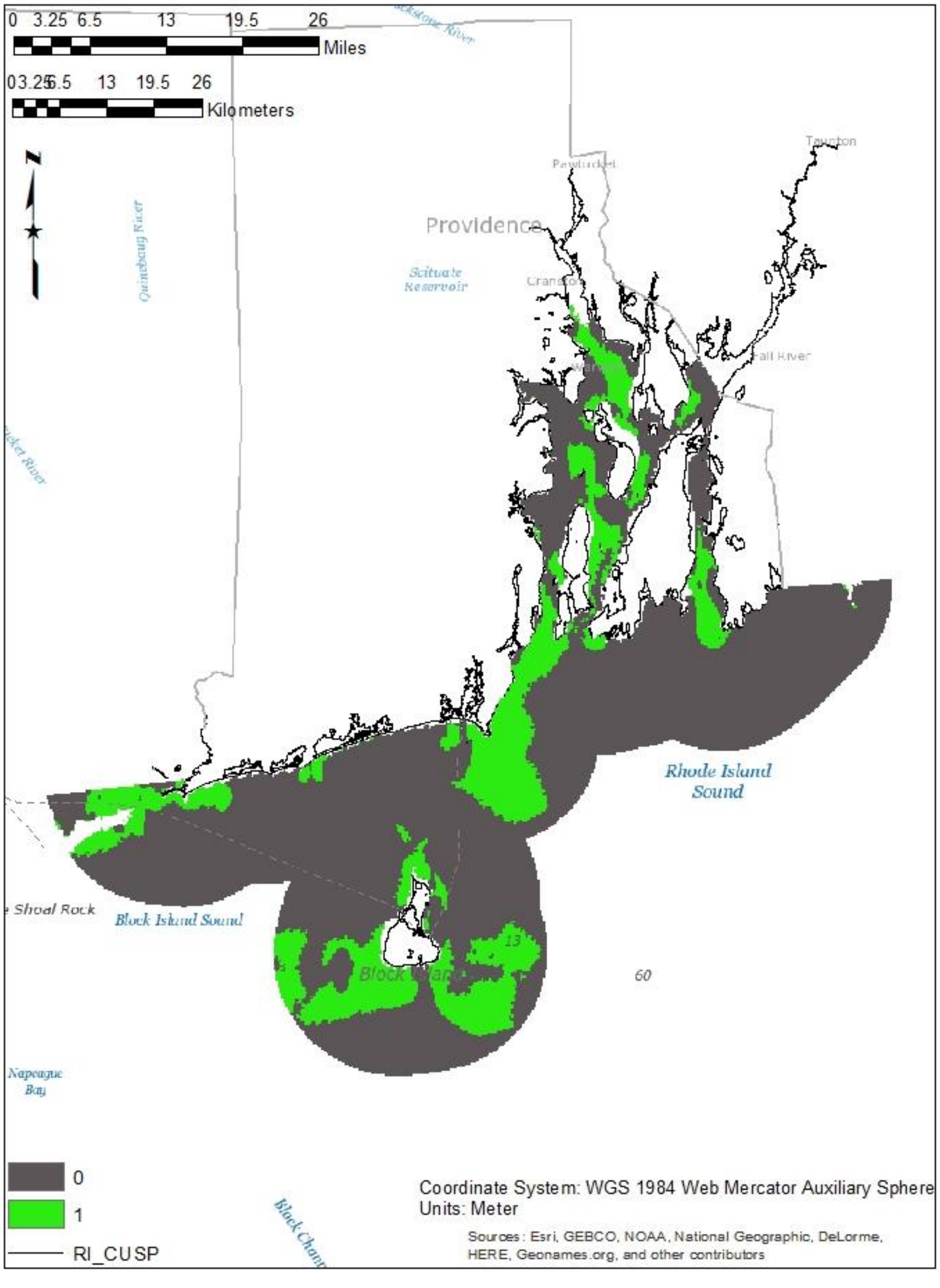


Figure 7. *Final results of pass-fail test. The green areas indicate possible locations for shipwrecks.*

CHAPTER IV

ANALYZING AND APPLYING THE DATA

Predictive models, by their nature, need to be tested and refined. Verhagen (2009a, 63) outlined the following criteria to judge models by:

1. The model provides a framework by which to explain patterns.
2. It should be reproducible, with clear steps.
3. It should be optimized to give the best possible prediction for the data set.
4. It should perform well in future situations
5. It should specify the uncertainty level in the predictions.

The first two deal with the qualitative structure of the model, and can be addressed by conscientious decision making and detailed reports. The latter three criteria can be quantitatively addressed.

There is a difference between performance, validation, and testing (Verhagen 2009b, 72). A model's performance relates to the accuracy of its predictions for the data it was constructed for; validating a model requires comparing it against a test data set, which may or may not be new data; however, in order to test a model, it must be compared with new, independently collected data. It is also important to note that models can be sample test dependent if not tested against outside, independently collected data, and can therefore be overly optimistic in results (van Leusen et al. 2005, 34).

Ideally, the model will be tested against blind observations, made independently from the creation of the model. However, this rarely happens. More commonly, the model is tested against existing evidence or by looking directly for confirmation (van Leusen et al. 2005, 54). Another concern for terrestrial predictive modeling is spatial autocorrelation, where a stronger degree of significance may be observed due to similar and interrelated geographical characteristics. The same characteristics play into shipwrecks. For instance, strong currents may be due to the interplay between the shoreline and nearby sandbars; however, these are also key factors that would lead to an increase in wrecking incidents (van Leusen et al. 2005, 66).

Statistical assessment

One of the primary ways to validate a model is by using Kvamme's gain equation (Kvamme 1988, 329). This equation calculates the utility of the predictive model, ranging from high positive values to negative lower values, through the following equation:

$$G = 1 - \frac{proportion\ of\ area\ where\ sites\ are\ predicted}{proportion\ of\ observed\ sites\ within\ predicted\ area}$$

Equation 1. Kvamme's gain calculation

Since a random sample would theoretically have 50% of the known sites in 50% of the area, the equation would yield a 0.

To calculate, some values will need to be pulled from the model. By using the Extract Multi Values to Points tool again, the developer can create a table with the raster values within it. Since the ships sunk off the southern coast of Block Island were used to generate the bathymetric data, they were withheld in the test of this model. Five wrecks generated a No Data value, as the projection read them as on land; they were reassigned a zero value, as the points were not inside the model's area for passing. The proportions were calculated as follows.

Value	*Ships*	*Proportion*
Fail - 0	16	0.7272
Pass- 1	6	0.2727
Total	22	1

Table 4. *Percentage of wrecks observed*

Secondly, the percent total area needs to be calculated. By opening the raster's attribute table, one can view the pixel count for both layers.

Value	*Area (Pixels^2)*	*Percent Area*
0	39,119	0.7802
1	11,018	0.2198
Total:	50,137	1

Table 5. *Area calculation*

These can then be applied to Kvamme's gain equation, giving the following:

$$G = 1 - \frac{21.98}{27.27}$$

$$G = 1 - .81$$

$$G = .19$$

Equation 2. *Kvamme's gain as applied to the model.*

As demonstrated, this model was not very effective.

To analyze the model's components and see which parameter was relatively effective, each individual component can be run through the K_j-parameter, developed by Wansleeben and Verhart (1992). This equation can also be used in place of Kvamme's gain, as it measures accuracy slightly more than it measures a model's precision (Verhagen 2009b, 76). However, for this formula to be effective, the proportion of sites in an observed area to the total number of sites must be larger than the proportion of the area with sites to the total area. The currents layer does not match this requirement, as shown in Table 6. See Appendix 2 for an overview of the formula, and its application to the individual layers.

Value	*Bathymetry*	*Currents*
Predicted area (pass)	41,852	22,583
Proportion (pass)	0.42	0.44
Non-predicted area (fail)	59,090	29,183
Proportion (fail)	0.59	0.56
Ships in predicted area	17	7
Ships outside of predicted area	5	15
Proportion of ships inside prediction area	0.77	0.32

Table 6. *Analysis of raster layer details.*

The K_j test shows that the bathymetry was by far the most effective level.

Discussion

It is imperative that the model is analyzed and reinterpreted in light of the intended research question. Each separate component should be analyzed separately and in conjunction. Errors can occur within the accuracy of the spatial data itself, the quality of the model, and the appropriateness of the model for the data (DeMers 2002, 29). To analyze the model, a review of these areas is necessary.

Spatial data

Data accuracy can be divided into three separate groups: thematic accuracy, positional accuracy, and temporal accuracy (Aalders 1996). The No Data values that were returned show one source of error. Since this map dealt solely with bathymetry, wrecking incidents that occurred on the shoreline or near the shoreline on previously underwater areas were not able to be modeled. This could be rectified by using a joint topography and bathymetry layer, or by adding a topography layer separately. However, as the shoreline is the area of the most interest, the bathymetry and topography layers should match. Another source of the No Data values was the slight buffer around the coastline in the currents map, as shown in Figure 8. Outside of this, all datasets were at appropriate scales and resolutions for this form of manipulation.

There is a mismatch in the temporal component of this data, which could have led to the failure of the currents layer to predict the site locations. The variability of surface currents through time may be too great to accurately project data from this century into the past. Another source of error may be the use of the mean rather than the median to delineate between areas of high currents versus low currents. The use of a middling value to determine high and low values may not be suitable for this operation. Further examination of the current speeds at which other shipwrecks occurred can deepen the understanding of how this spatial feature effects wrecking events.

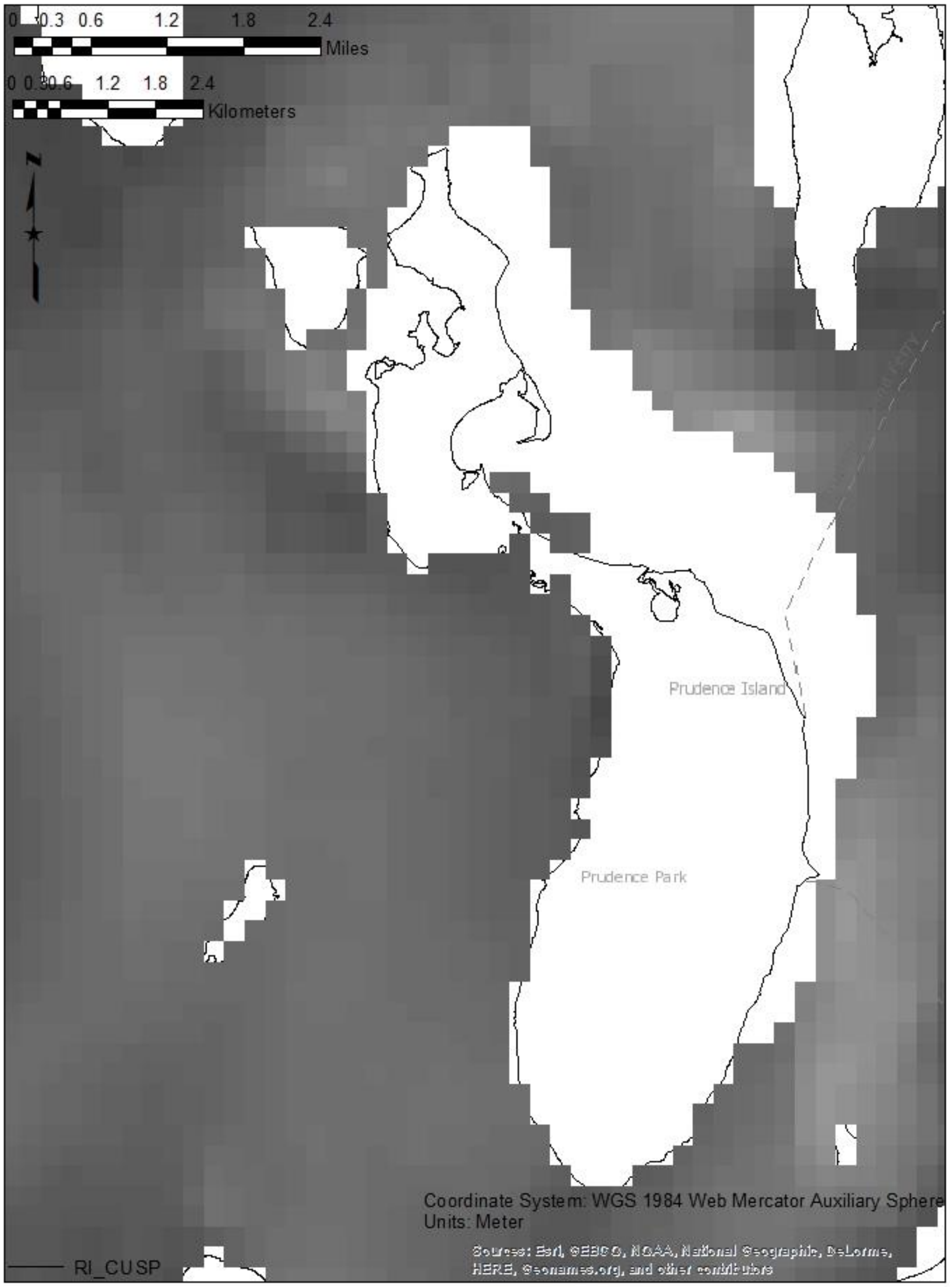


Figure 8. *Closeup of current dataset, as compared to the coastal boundaries.*

Quality and appropriateness of the model

There are many factors here that can be further studied to optimize the model. Although reinterpreting the mean for the bathymetric data yielded better results, it is highly problematic as the mean is subjective to how the dataset is clipped. Further, it invalidates the initial premise: that the shallower the water, the more likely a ship is to run aground. Objectively, 27 meters can be considered deep, offshore water depths. By using the mean, the model was adapted to fit the available data, rather than testing a hypothesis. Instead of testing for shallow areas, the model now tests on an arbitrary point in the water column. Even though it yielded good results, archaeologically it is a meaningless factor.

The relative lack of known location for deep-water wrecks may be due to their inaccessibility, rather than their absence, yet the predictive model would not mark those areas as likely for excavation. To address this, a weighted linear model may be more effective than a pass-fail model. This could be a graduated screening model, where the lowest value a cell has for each factor is the cell's overall value, or a summation model, where the cell's overall value is a sum of each factor. Bayesian inference allows for the revision of models based on observed evidence and beliefs by using confidence levels. This can allow archaeologists to give a higher weight to inputs they have greater faith in, separating what van Leusen calls "expert judgement" and observations (van Leusen et al. 2005, 65)

Fuzzy logic can also be incorporated, where variables are placed on a range, rather than decided based on a binary code (van Leusen et al. 2005, 65). It allows for uncertainties, making it applicable to “real world” issues. It has been used in numerous archaeological applications, like storing uncertain age, gender, and other data on human remains in cemeteries (Crescioli et al. 2000), reconstructing Roman pathways from imprecise or incomplete excavation data (de Runz et al. 2013), and analyzing site maintenance in Peru (Malinverni and Fangi 2009).

Applications

Even though this specific model did not fare particularly well, GIS predictive modeling has been applied within terrestrial archaeological contexts and has great potential in nautical archaeology. Terrestrially, it is often used in “location-allocation analyses” where a set of observations about cultural interaction with environments are codified and used to predict the possible locations of yet-undiscovered archaeological sites (van Leusen et al. 2005, 26). Primarily, it is used to prioritize an area’s probability to have an archaeological site present (van Leusen et al. 2005), focusing on prehistoric areas that had been previously undocumented. This is analogous to the efforts in the U.S. to locate wreck sites along the Atlantic seaboard, and can be used to test and refine these methodologies (Science Applications, Inc. 1981). However, the efficacy of using predictive models to estimate the probability of site location is contested and criticized as being reductionist (Wheatley 2004).

Predictive models can also be used to hypothesize the state of conservation. No two wreck incidents are identical, but by using GIS to combine the spatial and aspatial data, predictive modeling can be applied at numerous levels in the frameworks constructed by Muckelroy's original wreck formation processes (1976), Ward's modified wreck formation focusing on environmental factors (1999), and possibly even Gibbs's modified wreck formation focusing on cultural interaction (2006). By correlating this information in GIS, an archaeologist can make inferences that could help construct an appropriate conservation and excavation strategy.

Finally, predictive models can aid the location and excavation of ships from archival evidence, especially those directly engaged with the slave trade. Important archaeological comparisons of artifacts and ship construction methods have been done to help classify ships as slave wrecks without archival identification (Webster 2008b, Glickman 2016). Yet of the known slave wrecks, the ship's name has been what classifies the wreck as a slaver. If more slave wrecks are to be found, the search must begin in the archival record. In the Trans-Atlantic Slave Trade Database alone, over 1,000 ships are listed as shipwrecked.

Due to the tumult that happens during a shipwreck, location information found within logs and letters tends to be a vague area, rather than a specific set of coordinates. Additionally, information can be found in unusual places. A letter regarding the 1870 sale of artifacts, for instance, discussed "two African idols, found on board the last Spanish slaver…wrecked in the year 1841 at Breezy Point on the Caicos Islands" (Sadler 2008). Logs and letters, however, have the distinct advantage of telling a story, which could include details on the wrecking incident itself.

This exercise on known Rhode Island wrecks can inform this process. While pass-fail models are attractive, they are limited in their abilities. A graduated screening or summation model as used in other terrestrial applications may be more proficient. Using the data from sets like the Rhode Island wrecks to run these models can show correlative trends, which can then be used to refine the assessment of probability. By using weighted linear analyses and incorporating “fuzzy” logic, many of the uncertainties encountered in this process can be reduced or properly defined. Further factors may be found contributory through additional iterations.

For this process, I propose a sample workflow: using initial sources like those compiled by the Trans-Atlantic Slave Trade Database, known archival evidence is assembled and reviewed. Factors that contributed to the wrecking incident, likely trade paths, and area of sinking are acknowledged and quantified spatially, if needed. The method of modeling is determined, either through graduated screening, summation, or pass-fail. The model is run, and limitations to the data sets are addressed. If there are known shipwrecks in the region, checking the model against these locations may help refine it. Prior to excavation, more information on high probability areas can be sought out, including past geological or oceanographical surveys.

CHAPTER V

ETHICAL CONSIDERATIONS

While creating a predictive model for slave wrecks involves applied usage of data and archaeological science, the purpose and impact of the subject should not be lost in the technicality of the methodology. This chapter is dedicated to exploring the ramifications of the excavation of slave shipwrecks not only in an archaeological context, but within the communities affected by the slave trade.

GIS, data, and interpretation

The concern that GIS masks subjective data interpretation in a cloak of reality has been raised numerous times (Berry 1995; Conolly and Lake 2006; Shi 2010). As Dr. Julian Thomas contends, there is a persistent ability to assume “data assembled are data understood” (Thomas 1993, 26). While data can be processed objectively, construed spatially, and interpreted quantitatively, such a processual approach must not be taken to use this conjecture anthropologically. Furthermore, models are inherently simplistic conceptualizations of real-world systems and their interrelations, no matter how well-packaged the final product is (DeMers 2002, 147). Archaeologists should be direct about their assumptions and cognizant of the limitations of their data.

The implications of using GIS as a tool or as a science has been discussed in both archaeology and geography (Wheatley and Gillings 2002, Conolly and Lake 2006), especially in discussions about the pitfalls of cultural resource management adaptation of predictive modeling (Wheatley 2004). Archaeological predictive models tend to be separated by purpose into two categories, correlative and explanatory (van Leusen et al. 2005, 30). However, Wheatley notes that correlative predictive models, that is, models that test for spatial relationships, can be substituted for explanations of past human behaviors (Wheatley 2004, 6). This not only reduces all behaviors as reactionary to the environment, but also removes the social sphere through which humans understand their surroundings.

This concern primarily focuses on the interpretation of prehistoric sites, and does not necessarily have the same basis in correlative models used in the context of the slave trade. Due to the inherent mobility of a ship, spatial relations between other places are hard to judge. Further, if information about where a ship wrecked is found within an archival source, the cause of the wreck may also be documented. Finally, ships are inherently bounded by the ocean, and in transport the social spheres are created within the interior context of the ship. Each wreck is an entity within itself. By applying a correlative approach to finding wrecked slaving vessels, the research is based on locating a known entity with a known social structure. The factors that are being analyzed by the model are not inherently cultural.

Predictive models are also correctly criticized for prioritizing visible sites, as the models are created based on known quantities and thus may not be an accurate approximation of undiscovered sites with unknown qualities (Wheatley 2004, 9). As the models are based on inductive reasoning, they function on the assumption that known archaeological remains are representative of all archaeological remains (van Leusen et al. 2005, 31). Terrestrially, this can lead to misguided sampling and excavation strategies, and may have the same effect in nautical contexts. van Leusen goes further and divides predictive models into the possible and the probable, categorizing almost all archaeological examples as possible (2005, 30). As such, results should never be construed to be the proverbial "x" on the map.

Finally, the context within which the model is created matters. While new methods can be and are being developed, many of the initiatives come from cultural resource management rather than academia. Due to the interaction of legal necessities and construction demands, methodology within archaeological heritage management will have specific goals closely tied to deadlines (van Leusen et al. 2005). These goals should always be explicit and analyzed closely before a method is adopted wholesale into an academic context.

Interacting with history

Stepping away from problems inherent in the model, the developer also needs to ensure the model is appropriately placed within the modern social context. People's interaction with history goes further than reading an academic article, or visiting an historic monument. We are simultaneously agents, actors, and subjects of history, living and changing the impact and implications of the past. Michel-Rolph Trouillot defines these roles as follows:

Agents: occupants of structural positions (such as wives, workers, priests),

> **Actors:** those working within an intersecting spatial and temporal context, and affecting that same context
>
> and **Subjects**, as people conscious of their own impact within history, with their narrative shaping the story (Trouillot 1995, 23).

As subjects, the power of narrative relies on the intentions and the voices of the people involved. Trouillot invokes the example of workers on strike: if workers collectively decide to abstain from work the next day, the workers' reasoning behind that decisions matter. If they avoid work due to a bad snowstorm, the incident has little impact; comparatively, if their absence is a resistance due to poor working conditions, their collectivism takes a new place in history (Trouillot 1995, 23).

Through focusing on how history is produced rather than the nature of history, Trouillot identifies junctures where the narratives are not told (1995, 27). These silences can happen at four stages throughout the creation of historical and archaeological records: where the facts are **created** in the sources or in the material culture; the **assembly** of facts into archives or data sets; how the facts are **retrieved** in the narratives or interpretation created from them; and the facts' **retrospective significance**, or history created from these facts themselves (Trouillot 1995, 27 – 29).

It is important to note that silences that occur in the fact creation or assembly differ from silences within the retrieval or retrospective significance because they are directly tied to real-time power imbalances. This is easily seen historically within the context of the archival records regarding the slave trade. The documents are written almost entirely by those who stand to gain from emphasizing the trade aspect of slavery and by dehumanizing captives as cargos. Archaeology has the potential to address the silences inside of fact creation, but it is an imperfect field subject to misinterpretation and selective data gathering. While gathering a wider variety of source material, like diaries and archaeological evidence, helps address these imbalances, the attachment and weight of meaning to some facts over others means that some are silenced (Trouillot 1995, 50).

Archival choices also have a real impact on the experience of slavery; the sheer volume of debate on the amount of people exported during the Trans-Atlantic Slave Trade should be evidence enough of the inability of the archival record to tell their story (Eltis and Richardson 1997). As the act of making a predictive model necessitates the assembly of facts, it is one of the junctures where silences could occur (Trouillot 1995). It is imperative, while using a tool like GIS, to remember that in our search to discover an untold story we are still constructing and refining a narrative. If the purpose of excavating slave wrecks is to add voice to the silent in history, the method must not conceal another.

Finally, the model acts as a method of retrieval of these facts. One ship may be prioritized for excavation over another, which could alter the story. There are very few ways to mitigate this bias, but the bias should be explicit.

The threat of looting

A relevant concern from creating a GIS map of shipwrecks is preventing this data from becoming an exploited public resource. Publishing archaeological site locations, such as shipwrecks, can be disastrous for preserving cultural heritage. Treasure hunting and modern salvage operations have torn a hole in the maritime record of slave vessels. Many of publicly popular ships, like Spanish treasure ships and pirate ships, had similar ports of call and were roughly contemporaneous. At least four slave wrecks – *Henrietta Marie*, *Adelaide*, *Whydah*, and *Queen Anne's Revenge* – have been found by commercial firms looking for more lucrative wrecks (Webster 2008a). The *Fredensborg*, as discussed earlier, was sought out and excavated for non-commercial reasons – but not by an archaeologist (Patterson and Robin 2000, Svalesen 2000). Given this, the publication of shipwreck locations must be handled with the utmost caution.

Such concerns could be addressed by storing the information in an online data repository, such as the Digital Index of North American Archaeology (DINAA), which restricts access and follows state and federal guidelines for accessing specific location data (DINAA 2016). If a version of the map were to be made public, the information can be kept to a low spatial resolution, to ensure that shipwrecks would be hard to find by diving communities. An example of this is NOAA's wrecks and obstructions database, which opts to obscure the locations of wrecks by using a buffer zone around the exact location. However, as demonstrated, many active diving communities know and share shipwreck locations among themselves, regardless of academic and governmental efforts to protect maritime heritage. Divers need to be treated as an active player in shipwreck management plans and execution.

CHAPTER VI

CONCLUSION

To engage in discovering the past is to look at past power imbalances in the context of current imbalances (Trouillot 1995, 53).

GIS is a powerful tool; it operates across wide spatial and temporal boundaries. It can develop models that may assist in translating archival information into focus areas to be analyzed. However, constructing the model does not begin inside the GIS program, but rather with the archaeologist's conceptual model. This model, by nature of the data available, will continually be tweaked and revised in the process, but these tweaks can easily invalidate the purpose of the model in light of the research question. Conceptualizing scale and desired information product are both important to correctly designing and interpreting GIS models; similarly, even spatial data components change on a temporal level. This should be addressed in the creation and incorporation of factors. Due to the potential for errors to propagate, all decisions, assumptions, and exclusions must at least be mentioned, and any that may have impacted the results discussed. One concern regards the quality of data entering the system; however, another concern regards the choice of model being created.

This pass-fail model shows that these factors can be combined and analyzed together in a meaningful way, but also shows areas that need future development. Other combinatorial operations need to be run on this data set to test their predictive capability. Additionally, other types of shorelines should be tested to see if the same factors apply and should be weighted equally. A more complex analysis on how currents operate historically along the shoreline is needed to assist future models. Finally, limitations within using secondary data collected for other purposes should be explicit in each study. Even with these limitations, GIS can be an important tool to aid the search for more archaeological information on the slave trade. Predictive modeling may provide a way to parse and coalesce known data into actionable locations.

The slave trade had a broad and lasting impact on nearly every continent; it involved descendent communities on every shore. Paul Gilroy used the slave ship itself as a chronotope, a physical representation of the transition in both time and space of the transnational African Diasporic culture (Gilroy 1993). Through his work, Gilroy framed the journey into slavery as critical to understanding the current geographic, political, and social positions of African-Americans (Gilroy 1993). These are concepts that, in the pursuit to save money on excavation and develop new methods to protect our historical heritage, archaeologists may overlook. Given the ease with which GIS models can be misunderstood, it is important to not only properly contextualize the data within the model, but also contextualize the model within the realm of study.

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APPENDIX 1. LIST OF SHIPWRECKS USED.

This list was compiled using two websites: *Shipwrecks of Rhode Island*, compiled by David Clancy, and the Beavertail Lighthouse Museum Association's *Rhode Island Shipwreck Data Base*, compiled by Jim Jenney. *Shipwrecks of Rhode Island* provided locations, where BLMA's *Rhode Island Shipwreck Data Base* cited bibliographies for the wrecks.

Vessel	***Location***	***Archival Locations***	***Date***	***News source***
Addie M Anderson	Narragansett Bay	"off Whale Rock"	2/15/1899	New York Times 16 February 1899
Black Point bow	Point Judith		5/5/1945	New York Times 10 May 1945
Black Point stern	Point Judith		5/5/1945	New York Times 10 May 1945
Cape Fear	Castle Hill	"halfway between Castle Hill on the Newport Shore and Rose Island"	10/29/1920	New York Times 30 October 1920
Essex	Block Island	"aground at Block Island"	9/26/1941	Newport Mercury & Weekly News (NMWN) 3 October 1941
Grecian	North Block Island	"five miles, 173 degrees true, from the Block Island southeast light"	5/27/1932	NMWN 3 June 1932
Hercules	Off Misquamicut		12/14/1907	U.S. Life Saving Service Annual Report, 1909
Lightburne	South Block Island	"Ran ashore on a reef off Block Island"	2/17/1939	NMWN 17 February 1939
Lydia Scholfield	Castle Hill	"On the washbowl" "Ashore near Castle Hill"	4/19/1891	Newport Daily News 20 April 1891
Mary Arnold	Off Charlestown	"7 miles west of Point Judith"	11/24/1940	NMWN 29 November 1940
Meteor	South Block Island	"Rocks of the south side of Block Island"	7/10/1926	New York Times 11 July 1926

Vessel	***Location***	***Archival Locations***	***Date***	***News source***
Metis	Off Watch Hill	“6 miles off shore”	8/30/1872	New York Times 31 August 1872
Montana	North Block Island	"3 mi north of station, 1.5 mi offshore"	1/21/1907	U.S. Life Saving Service Annual Report, 1908
Onondaga 2	Off Watch Hill	"Off Watch Hill"	6/30/1918	New York Times 30 June 1918
Palmetto	South Block Island	"Black Rock on the southern part of Block Island"	3/23/1858	New York Times 23 March 1858
Progress	Off Charlestown	"went down in 51 feet of water just off Charleston Beach"	11/23/1940	NMWN 29 November 1940
Puszta	North Block Island	"Grounded on the north side of this [Block] Island"	4/17/1934	Lowell Sun 17 April 1934
Rhode Island	Narragansett Bay	"between Whale Rock and the Bonnet, about 5 miles northerly from Narragansett pier"	11/6/1880	Newport Daily News 6 November 1880
Spartan	East Block Island	"stranded during fog on the east side of Block Island, 1.75 mi southeast of the station"	3/19/1905	U.S. Life Saving Service Annual Report, 1906
USS Leyden	South Block Island	"South side of this island"; "200 yards from shore, 1 mile west of the Southeast Light"	1/21/1903	Boston Globe 22 January 1903 *and* U.S. Life Saving Service Annual Report, 1904

APPENDIX 2. COMPONENT K_J-PARAMETER CALCULATIONS.

K_J-parameter equation

$$Kj = \sqrt{\%\ of\ sites\ in\ observed\ area\ \frac{\%\ of\ sites\ in\ the\ observed\ area - \%\ area\ with\ sites}{\%\ area\ without\ sites}}$$

Bathymetry layer:

$$Kj = \sqrt{0.77\ \frac{0.77 - 0.41}{0.58}}$$

$$Kj = \sqrt{0.77 \times 0.61}$$

$$Kj = .69$$

Currents layer:

$$Kj = \sqrt{0.32\ \frac{0.32 - 0.44}{0.56}}$$

$$Kj\ is\ not\ calculable$$

Pass-fail analysis:

$$Kj = \sqrt{0.27\ \frac{0.27 - 0.22}{0.78}}$$

$$Kj = \sqrt{0.27 \times 0.54}$$

$$Kj = 0.14$$

APPENDIX 3. WORKFLOW