Seascape corridors : modeling routes to connect communities across the Caribbean Sea
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Discussion

Island to island movement was an essential part of life for Amerindian peoples in the Caribbean. To explore inter-island mobility, this research brought together archaeology, ethnohistory, experimental and experiential archaeology, as well as computer modeling to show how people may have moved themselves and their materials between islands in the past. It has shown that least-cost pathway modeling can provide new insights into pre-Columbian inter-island connection in the Lesser Antilles. As a part of the Netherlands Organization for Scientific Research (NWO) Island Networks Project (project number 360-62-060), I have tried to demonstrate how least-cost pathway, or optimal route, analysis can benefit the study of island networks from the Archaic Age to the early colonial period in the Caribbean (2000 BC – AD 1600). In conjunction with the project's other research (Breukel forthcoming; Hofman *et al.* forthcoming; Laffoon *et al.* 2016; Mol *et al.* 2014; Scott *et al.* in press), this work provides a range of evidence that demonstrates relationships between materials on different islands extend beyond the physical movement of objects. These pathways broaden analysis of island networks and allow for more detailed discussions of how canoers may have moved between places in the past.

To analyze inter-island travel in the Lesser Antilles I evaluated how environmental constraints, such as wind and current, and social factors likely influenced connections between Archaic Age, Ceramic Age, or early colonial peoples. Route modeling is an additional layer of analysis that can supplement existing lines of data. By tying modeled routes as closely as possible to archaeological sites used in the pre-Columbian and early colonial Lesser Antilles, I was able to determine direct and indirect connections, seasonal shifts, and possible links between site placement and route trajectories. By comparing routes between sites on various islands I also indicated new ways to look at known connections.

Replicating canoe pathways can suggest how seafarers chose their routes and can provide insight into the function and use of the social connections between islands in the past. These routes, if indeed connected to canoer choice and social relationships, can demonstrate sections of the rich and varied possible mental navigation maps relied upon by generations of canoers to maintain inter-island interaction networks. Together, modeled routes and archaeological evidence can be used to link the exchange of materials from one island to another to the process of how peoples moved in the past.

8.1 A Brief Review

The previous seven chapters have worked towards establishing the ways in which least-cost analysis theory and methods can be applied to sea-based movement. In Chapter 2 I briefly discussed theories of movement in archaeology. While there are many studies that refer to visual connections between navigators at sea and the shore, only a few works speak to the specifics of sea-based navigation (*e.g.,* Agouridis 1996; Brughmans *et al.* 2017; Friedman *et al.* 2009; Lamarche 1993). Fewer still have discussed how past peoples would have conceptualized movement on water (Crouch 2008; Ingold 2009; McNiven 2008). The process of choosing and using known pathways is similar on land and sea, with people holding the location of a place within their minds and communicating this position and steps on how to get there to others (*sensu* Frake 1985; Samson and Cooper 2015; Terrell and Welsch 1998; Tilley 1994). How this knowledge was transmitted may have changed across generations, both in teaching the location of wayfinding points and the associated meaning of sites and navigation markers. As cultural trends changed, individuals learning from their predecessors likely incorporated their own meaning or understanding of points into their individual and shared communal mental map (*sensu* Ingold 2011). However, the fundamental subliminal transmission and/or outright communication of where travel corridors were and how to use them likely cemented connections between inter-island communities. The knowledge of these corridors and sites on various islands would have supported the existence of preferred canoeing routes. This idea supports the construction of least-cost paths within each case study.

In Chapter 3 I provided a brief history of island canoes in the Caribbean. This included a summary of the archaeological evidence of seafaring materials that has been found to date (*e.g.*, Fitzpatrick 2013; Ostapkowicz 1998; Schwabe 2001) and ethnohistoric accounts of canoe use (*e.g.,* Columbus 1493 cited in Hulme and Whitehead 1992; Davies 1595; Drake 1585; Fitzpatrick 2013). To understand how vessels have been used in the past I discussed experiential archaeological approaches to canoe use (Bérard *et al.* 2016; Horvath and Finney 1969).

Throughout this dissertation, I also explored if and how computer modeling could provide new insights into canoe travel corridors. To place the use of least-cost pathway modeling on seascapes in context, I discussed least-cost pathway methods as they have been applied to landscapes. In part, this was to demonstrate both the capability of least-cost pathway analysis and the organization of route modeling in landscape research. Land-based approaches to least-cost pathways analysis have shown that route modeling can hypothesize how people choose to move between sites, as well as the physical and social cost to travelers. I provided a similar lens to apply to modeling past seafaring practices in the Caribbean.

In the past, works have focused on analyzing the true cost of water-based movement through computer modeling (*e.g.*, Altes 2011; Arcenas 2015; Callaghan 2001, 2003; Cooper 2010; Davies and Bickler 2015; Irwin *et al.* 1990; Leidwanger 2005; Montenegro *et al.* 2016; Safadi 2016), although few researchers used the same technique (see Table 1). These researchers relied on various methods, including developing their own programs or using existing tools in GIS software packages, to analyze the difficulty of sea travel in different regions around the globe (see Chapter 3). In almost every case the tools used to calculate seafaring costs have been developed independently by each new researcher in the field (see Table 1). Researchers also focused on various types of one-way movement, from long distance colonization routes to short hops between islands or along coastlines. The method used in this study builds upon the spirit of previous works, while also developing a more rigorous technique suitable for modeling directed reciprocal voyages. I have focused on specifics of reciprocated inter-island movement that had yet to be explored in depth by sea-based least-cost pathway modelers. In part, I evaluated the structure of inter-island interaction in the region, assessing how the mobility of peoples and materials may have influenced social relationships, and vice versa.

The method used to approach generating the least-cost pathways was a modification of the isochrone method developed by Hagiwara (1989), which looks at travel between two points as if people head out from an origin point in the direction that allows the furthest length of travel in a set amount of time. To achieve this result, the model constructs bands of distance achieved in set time periods outwards from the origin node. The furthest distance from the node is selected as the first leg in a least-cost route. This process is repeated until the destination has been reached. As such, every leg of a journey is based on traveling in the optimal direction towards a termination point. Wind and current data forms the surface on which the isochrone bands are calculated. Social considerations, represented by the use of known sites, are incorporated as origin and termination points for the canoe pathways.

I worked with Jan Hildenbrand (2015) to develop a tool that could be used to generate optimal canoe routes. Hildenbrand's tool is the result of discussions of the research requirements, including directed point to point routes, reciprocal travel, the need for adaptable cost surfaces, utilization of modern wind and current data to construct past pathways, variation in the time or season in which routes were modeled, control of the sampling of the underlying environmental data, and the inclusion of canoe speed. Hildenbrand's tool creates least-cost routes that can be suggestive of navigation choices made by pre-Columbian Amerindian canoers by recalculating route direction based on changing environmental conditions at each time step, just as a navigator might re-orient his vessel to take advantage of better currents. This method can be modified to consider environmental influence at different weights as well, making it an apt tool to analyze canoe travel that was propelled by wind and current force, alongside a set canoe speed replicating a crew paddling a vessel forwards. After the isochrone tool's development, I evaluated the underlying environmental data, through the use of the current tool developed by Jan Athenstädt in conjunction with this research, and was the beta tester for the user interface and application of the tools to archaeological evidence.

Hildenbrand's tool combines current and wind data at discrete points. Interpolated over the ocean where canoers may have paddled, this can represent the surface of an ever-changing sea. This use of isochrones was also beneficial as it minimized the time it takes to construct routes by focusing on the furthest point of movement in one time period, rather than movement through every pixel between the origin and termination points. Unlike landscape modeling, which often uses one static DEM, modeling sea routes requires the use and production of several cost surfaces. In essence, each route between two points at a specific time represents a unique cost surface. The ability of the Hildenbrand isochrone tool to generate pathways in this manner eased the requirements for computational power that would plague a more traditional least-cost pathways approach to seascape modeling.

The isochrone tool sets itself apart from other implementations of isochrone-like methods used to analyze sea-based movement in the Caribbean (*e.g.*, Cooper 2010) by using accurate wind and current data that can be resampled seasonally. Cooper (2010) uses an isochrone map to determine the difficulty of moving across Cuban seascapes, but there is no explicit discussion of changes over seasonal periods. This is perhaps due to the use of anecdotal data to supply cost information for sea travel in his work (Cooper 2010; see Table 1). Even Leidwanger's (2013, 2014; Table 1) work with isochrones showing the time cost in moving between different ports in the Mediterranean does not deal with seasonality. In both examples, isochrone rings were used to measure the general time cost to movement in all directions without constructing specific least-cost pathways (Cooper 2010; Leidwanger 2013, 2014; see Chapter 3; Table 1). The resulting modeled routes allowed for a comparison between the possible pathways of material or social links between specific islands.

Though modeled routes only represent possible least-cost canoe travel corridors, they can suggest how difficult it would have been to travel between islands even under optimal conditions. This allows for the use of these pathways to analyze the hypothetical structure of inter-island relationships. Some of these connections affirmed pre-existing assumptions of exchange partners (*e.g.*, Hofman *et al.* 2014). Other canoe routes indicated regions worthy of future study to evaluate possible inter-island connections in the archaeological record, such as the routes from Long Island to Saba that pass by St. Kitts (see Chapter 5). Generating least-cost routes using the Hildenbrand isochrone tool allowed me to substantiate hypotheses regarding mechanizations behind ties between different communities. I hope that by demonstrating that this method has been used successfully, other researchers will consider applying isochrone least-cost pathway modeling to their areas of study.

To better evaluate the ability of the model to produce usable canoe routes, I chose to focus on three micro-regional case studies and limited the location and number of origin and termination points. These case studies focused on possible canoe movement within the northern Lesser Antilles in the Archaic Age, between the Greater and the Lesser Antilles in the Late Ceramic Age, and from mainland South America to the Windward Island in the Late Ceramic Age/early colonial period and showcased what inter-island travel would have been like across these various geographic layouts. Navigation preferences, such as route time costs and trajectories, were assessed over the three case studies. I looked at movement within a small cluster of neighboring islands (see Chapter 5), within a prolonged arc between islands spread out over 50 km apart with a break in the middle (see Chapter 6), and across a large expanse of sea from the mainland coast to islands 70 km away with few opportunities to meet in-between islands (see Chapter 7). These three geographic layouts allowed me to evaluate the effectiveness of the Hildenbrand tool in different settings, where the distance between islands may have provided more opportunities for seasonal differences, where there was a high concentration of sites with similar materials, and where there is a gap in the archaeological record. Together these case studies explore the maximum length of voyages across the major channels and passages in this region.

The first case study (see Chapter 5) focused on lithic exchange in the Leeward Islands of the northern Lesser Antilles, specifically mapping routes associated with the distribution of Long Island flint (Davis 2000; Knippenberg 2007) during the Archaic

Age (2000 – 400 BC). It also included sites on other islands, stretching from Antigua to Anguilla (Hofman *et al.* 2014; Knippenberg 2007). Sites known to contain Long Island flint were used to generate pathways with Hildenbrand's isochrone tool. Despite prior assertions that many of these settlements were in contact with one another, routes modeled for Chapter 5 indicate that movement between islands may not have been as direct as researchers may have imagined. Instead of traveling straight to the destination point, least-cost routes often followed indirect paths that passed the coastlines of other islands. In many cases, the layout of these routes coincided with other examined nodes or known archaeological sites that were not included as origin points within this case study. This was the first indication that the layout of modeled routes may be able to indicate indirect connections as well as the location of some sites used in later periods.

The second case study (see Chapter 6) focused on the movement of goods from the Greater Antilles (specifically the eastern end of Hispaniola and Puerto Rico) to the Leeward Islands (movement from or towards Saba and Anguilla) during the Late Ceramic Age (AD 1250 – 1400) (Allaire 1990; Bright 2011; Hofman and Hoogland 2011; Hofman *et al.* 2008b). Sites from this period were chosen based on the presence of specific stylistic elements in assemblages that acted as dispersal or recipient areas. These stylistic elements were reflections of the so-called Taíno material culture from Hispaniola and Puerto Rico. Taíno-inspired or influenced objects included three pointers, ceramic stylistic elements and morphology, drug paraphernalia like speculum, and other objects that were created in response to political and social influences in the Greater Antilles (Hofman and Hoogland 2008a). House trajectories, or the structure of habitation areas, at sites like Kelbey's Ridge reflected those found in the Greater Antilles (Hoogland and Hofman 1993). The movement of these elements across the Anegada Passage suggests that there was likely some level of connectivity between the two island chains. At this moment, there is no definitive archaeological evidence for a reciprocated exchange of materials from the Lesser Antilles back into the Greater Antilles.

The third case study (see Chapter 7) examined travel between the South American mainland, specifically Guyana, and the Windward Islands of the Lesser Antilles during the Late Ceramic Age and the early colonial period (AD 1250 – 1600). Modeled routes tracked the possible dispersal of material and language from South America into Grenada and St. Vincent. I evaluated the corridors through which mainland ceramic stylistic elements were adopted and adapted based on the cost associated with reciprocal connections between nodes off the coast of the Guianas and on the Islands. These pathways proved to be strong indicators of contact points between canoers who may have passed through these travel corridors and in-between islands. Routes that ran past Trinidad and Tobago indicate the locations of possible stopover points used by mainland Kaliña and island Kalinago peoples, which is supported by historic accounts (Boomert 2011; Goodwin 1990; Hofman *et al.* 2009; Hoogland and Hofman 2008).

These case studies demonstrated that modeled routes over varying distances showcased similar trends, either in terms of seasonal differences or annual similarities, and the connection between routes and site locations. The link between hypothetical canoe travel corridors and site locations that pre- and postdate pathways is one of the most valuable findings in this work. By evaluating how possible canoe travel corridors were routed through the pre-Columbian Caribbean and connecting them to known archaeological sites, we can further support the existence of inter-island relationships in the region.

8.2 Observations on Research Questions

This dissertation has answered the primary question posed in the introduction regarding how computer models of cost-based sea travel could enhance our understanding of connectivity amongst pre-Columbian and early colonial Amerindian island communities and has demonstrated that computer-aided optimal path modeling can help archaeologists gain a better perspective on how these communities were tied together by the sea. The case studies present possible answers to the three sub-questions that relate to the broader issue of connectivity. These sub-questions are: 1) What are the possibilities or limitations for traveling between islands and how does this reflect seasonal variation? 2) How did people move between two distant islands? Did canoers follow indirect pathways to stop at intermediate islands, or were people more likely to move between islands without using stopover points? and 3) How did sea pathways influence navigation and can these computer-generated routes reveal portions of ancient navigators' mental maps? The answer to these questions are explored in the three themes. The following sections detail observations on these three research questions and the themes connected with them through the lens of each case study.

8.2.1 Seasonality

The modeling completed in this dissertation demonstrates that examining how seasonal environmental changes affect the path location of modeled routes can augment island mobility studies. Changes in underlying current force and direction shift the outcomes of these least-cost canoeing corridors, influencing when routes head in certain directions. If canoers were using optimal routes similar to those seen here, the change in current flow and the trajectory of travel corridors likely impacted their ability to connect with certain island communities. This may be the first use of a sea-based isochrone method in archaeology that applied to both the creation of set pathway and the seasonal fluctuations of routes.

This analysis uncovers a possible method to assign seasonal rhythms that can be set to specific months or even periods within months. Analysis of the placement and timing of optimal reciprocal routes can build on existing ideas of when lithic material was sourced or ceramic materials were exchanged, and can assign a season to the exchange of specific materials. For example, movement from the Windward Islands towards mainland South America was slightly easier at different times of year and peoples may have preferred to travel south in fall (see Chapter 7). This possible preference for certain seasonal optimal routes could also indicate that return voyages from mainland South America reflected these trends as well, leading to voyages heading north in the winter, when southbound travel was more difficult. Seasonal differences in route cost and trajectory may have dictated rhythms not only of who was moving when but also how long people choose to stay on certain islands, impacting social relationships of canoers traveling between several locations.

Canoers likely chose which route to use based on seasonal and daily changes in current and wind, along with social and economic factors not modeled here. The lack of notable current variation between seasons in the Leeward Islands and the eastern Greater Antilles (see Chapters 5 and 6) suggests that canoers paddling along least-cost corridors in these regions may have had more freedom to move against weaker currents than peoples traveling against currents in the south of the archipelago. Conversely, as mentioned above, crews traveling across the channel between the mainland and the Lesser Antilles faced stronger seasonal currents (see Chapter 7). As a result, real-world canoers following these routes in the northern half of the archipelago would appear to have had more flexibility when choosing launch times and days to visit different islands for social and economic reasons. This may have enabled crews moving between islands in the north to plan seasonal mobility cycles based more on the availability of resources offered on different islands than on the currents that connected them.

The seasonal trend of routes also influenced the position of pathways. Often, changing the launch month affected the time cost and/or the trajectory of the canoe pathways between the same islands, indicating that crews could have exploited different seasonal travel corridors to reach different islands or friendly sites. Hypothetical canoe routes that moved past an in-between island in one season may not connect with the same island later in the year. Communities planning on moving between sites either to take advantage of a seasonal mobility cycle or to connect with known persons on other islands would have had to plan accordingly if they wanted to limit their time on the water. Through the years, knowledge of these seasonal changes to optimal canoe routes would have transferred between individuals and grown into a community mental map of best routes in the region. Thus, while seasonal route layouts may reveal potentially important stopover sites and islands, they do not necessarily reveal which seasons supported inter-island interactions, especially in cases where current differences are negligible.

Trends observed in the underlying cost surface, discussed at the beginning of every case study, show that movement in each cardinal direction is easier at certain times of the year. These insights suggest that if canoers choose to follow optimal paths they would have headed in different directions during different periods. For example, in Chapter 5 underlying current direction and force show movement from Saba towards Long Island was easier in June, while movement from Long Island may have been easier in August. Though these values were largely smoothed over in returns from the route tool, the canoe pathways generated for this work also suggest that real-world canoers may have had an easier time moving from Long Island to Saba than from Saba to Long Island (see Chapter 5), likely because of the current flowing to the west in this region. This could indicate that if real-world crews were following paths similar to the least-cost routes generated here they may have been able to travel west from Long Island with ease while encountering more difficult or longer routes when returning to Saba. These same canoers looking to make the return voyage may have waited on Saba until a more optimal time or path trajectory could be achieved. Due to weather concerns crews could have waited several hours, days, or months before making the second leg of their voyage.

Once I established that routes could be clustered, and thus separated for further evaluation, I wanted to test the possibility of these travel corridors being split on seasonal themes. The seasonal nature of sea-based mobility as apparent in the modeled routes contributes to the discussion of annual rhythms used by Caribbean Amerindian seafarers for the purposes of inter-island interaction. Previous research (Hofman and Hoogland 2003; Hofman *et al.* 2006) has suggested the existence of Caribbean travel periods by analyzing seasonally-available materials in site assemblages. As such, I initially focused on analyzing routes on a seasonal basis to study access to seasonal resources and the possibility of annual mobility trends. I wanted to evaluate whether routes launched in certain time periods could be banded together on the basis of their time cost or trajectory. Routes forming travel corridors at certain times of year may hint at the existence of seasonal mobility periods, which are evaluated in this work. This follows in the theme of previous sea-modeling research, which often mentions the importance of seasonal components (Callaghan 2001; Leidwanger 2013). In comparison to previous research in the Caribbean, which discussed what seasonal periods resulted in the highest rates of success for colonization efforts (Callaghan 2001; Altes 2011), I approached how seasonal ranges affected island-to-island voyaging. It is probable that the same seasons that might result in the highest rates of colonization success may not equate to the best time to carry out reciprocal voyages. This allowed me to discuss the intricacies of inter-island mobility across seasons using directed site-to-site optimal routes rather than exploration corridors.

Looking at movement from Anguilla, modeled pathways passing below the Virgin Islands, above the Virgin Islands, or through the Virgin Islands responded in a small way to shifts in seasonal currents. Again, routes running by different islands may have encouraged crews using pathways similar to the least-cost routes modeled here to set off in different months when travelling towards sites in St. Johns, St. Thomas, or even Isla De Culebra. These trends may have also encouraged seasonal interaction with communities in the Virgin Islands, as it did with St. Croix, and may also have impacted the gateway status of sites in the Virgin Islands exposing communities in the Leeward Islands to Greater Antillean materials (Crock and Petersen 2004; Crock *et al.* 2008). In these cases, the location of sites on stopover islands may indicate places that were used as seasonal habitation or as hubs within a larger network whose interaction with the outside world was dictated by annual mobility rhythms.

Routes passing in between islands can be expanded to apply to routes connecting sites on different islands. Movement between sites on either side of a passage may have taken on a seasonal component that influenced inter-island interaction. Results of the model suggest when people visited certain sites and how long they may have remained on a particular island. Seasonal costs denote what extended routes are most probable during multi-leg journeys, which in turn can suggest practices for indirect mobility. While I observed possible indirect movement in every case study, this type of connection manifested in various ways depending on the region (see section 8.2.2).

On mainland South America and the Windward Islands routes (see Chapter 7) crews may have traveled north or south depending on the season, affecting when people were more likely to be in contact with Trinidad or Tobago for possible prolonged stopovers. Tobago's position between the Guianas and the Lesser Antilles would have made it a prime point of connection in a seasonal mobility cycle through the region (see Chapter 7). Shifts in time cost through various seasons depending on the direction of travel suggest that there was a seasonal component to route planning. For example, movement of modeled routes in autumn was more likely to include Tobago in routes from the Windward Islands to Guyana, indicating that crews adhering to optimal routes might have left at this time of year to stop on the island (see Appendix D). More work needs to be done to evaluate the time cost trends in other regions around the Caribbean to see how fluctuations of seasonal time costs may have affected stopover times.

Seasonal trends also affected a crew's ability to connect with both mainland and island coastlines. In cases where Amerindian peoples wanted to avoid contact, the lack of connection with the coastline when traveling in certain seasons may have been a benefit. For example, the Kalinago peoples who wanted to avoid adversaries on the mainland coast of Venezuela may have chosen to travel during November, when routes were more likely to run away from the mainland coast. Conversely, when crews wanted to make landfall, either to connect with other peoples or rest at in-between sites, they may have chosen to travel during April, when routes passed near mainland coastlines. The scarcity of material on in-between sites may be explained by this seasonal trend of route trajectories pushing further into the Atlantic, making travel to islands or intermediate stops more difficult than moving through the ocean. This trend can be explored further in future research.

Seasonal travel periods could also affect the safety level of voyages. Routes that did not pass by coastlines would have inhibited a crew's ability to take advantage of stopover points. If actual canoers did follow near to the trajectories of these modeled least-cost routes, crews may not have come within close visual range of land for long stretches. For instance, seasonal differences around Puerto Rico moved the optimal sea paths farther away from the coast, which would limit a crew's ability to follow closely along the coastline. A route's propensity to stay in proximity to the island coastlines may have been a boon to crews who followed it, as the pathway would have enabled individuals to rest when required or visit with friendly groups to exchange ideas and materials. The inability to rest or break a voyage, especially on the longer voyages as those from the Guianas to the Windward Islands, would have increased the time-cost of the trip. The ability of crews to follow along coastlines was also dependent on the heading of the route, suggesting that seasonal travel periods also existed in the northern Lesser Antilles (see Chapter 5).

Although these seasonal trends are not always apparent in the context of each case study due to the varying strength in currents, these modeled pathways, alongside archaeological evidence, provide additional ways to evaluate when people moved as well as where. These seasonal trends were likely incorporated into a mental map of Amerindian canoers, increasing the complexity of region's wayfinding traditions. The seasonal trajectory of these routes played a role in determining the connection between seafarers, navigation patterns, and site locations, influencing the areas of interaction within the Lesser Antilles.

8.2.2 Canoe Pathways and Site Placement

It is probable that canoe travel corridors spanned generations and marked long-standing ties between peoples, materials, and places (Hofman *et al.* 2014). These cross-period links suggest that islands in the Caribbean were highly interconnected and that interaction between communities was subject to the location of canoe travel corridors. As potential travel corridors represented by the modeled least-cost canoe routes could have been used by navigators over several generations, they can be used to evaluate sea-based mobility trends through time.

A good indication that Amerindian seafarers used these routes is the link between route trajectories and the location of archaeological sites. The generated routes are of particular interest because they expose a connection between route and site placement in a way not seen in past modeling efforts. For example, research by Callaghan (2001, 2008) focused mainly on undirected colonization voyages through the Caribbean Sea, which prevented a discussion of a relationship between site placement and route trajectory. Similarly, Callaghan and Bray (2007) mentioned possible midway stopover points, but only in the context of an undirected voyage. Other works, which focus on directed voyaging to uncover colonization and population dispersal patterns in the Pacific (*e.g.,* Montenegro *et al.* 2016), do not discuss there-and-back voyages. As this is also the only work that focused on stopover or in-between sites passed by inter-island routes, the analysis of the optimal routes discussed here provides new insight into the connections between site placement in the islands and route trajectory.

In this respect, pathways constructed for this work that focus on direct connections between known archaeological sites may point more specifically to connections between optimal routes and in-between stopover or habitation areas.

Extended route costs and the lack of available rest areas support the use of possible stopover points on routes across the Anegada Passage or from Guyana to Grenada. If indeed real-world crews were paddling near where these modeled optimal routes were generated, they could take shelter behind or navigate around islands. Such patterns indicate that stopover points were an important part of a least-cost voyage. It is no surprise that many routes across these channels seek out the few in-between islands when possible, as coastlines disrupt current flow. Traveling these routes, paddling past or being pushed to move near other islands may have encouraged inter-island connections.

The location of several sites, not included as nodes in this work, near generated least-cost canoe routes suggest that some Amerindian sites were established either to take advantage of passing canoe trade or to influence it. For example, the sites of Sugar Factory Pier on St. Kitts and Hitchman's Shell Heap on Nevis may have been part of a broader inter-island exchange network due to their location along possible routes between Long Island and Saba (see Chapter 5). Canoers following trajectories similar to the modeled routes would have passed near enough to these in-between islands and sites to incorporate them into a canoeing corridor. Any archaeological evidence, or lack thereof, must be considered against social factors of the time, which in this case provide reasons for inter-connection and avoidance (*sensu* McNiven 2008; Munn 1996).

Indirect routes can suggest whether real-world canoers moving along these least-cost routes between two islands were on a true one-to-one reciprocal voyage or if crews were visiting multiple islands as stopover points on a longer journey. For example, the use of sites on St. Croix suggest that connections between Greater Antillean communities ran through intermediary gateway sites rather than making direct contact with the Lesser Antilles (*sensu* Hofman and Hoogland 2004, 2011; see Chapter 6). Movement through this island may have been structured as part of a larger interaction sphere rather than just contacting one island. Similarly, movement of Long Island flint through the northern Lesser Antilles may have been organized so that several islands were visited in the process of exchange (see Chapter 5). One specific example of this phenomenon is the passage of modeled routes from Long Island to Saba by Monserrat or St. Kitts. The indirect movement of routes past these two islands could suggest that the process of resource movement was also not direct. This argument for drawn-out connections has also been suggested for materials moving from Long Island to Saba but passing through Anguilla and St. Martin (Hofman *et al.* forthcoming). The process of movement through Anguilla and St. Martin, while incurring a slightly larger cost, is feasible. Mobility patterns that linked multiple islands or stopover points may have formed a large circle of connected nodes, as is the case for movement between the Kula ring exchange in the Pacific (Leach and Leach 1983; Liep 1991; Munn 1986). If we accept that all routes modeled would have been physically possible, a direct one-to-one or reciprocal relationship is possible based on the returned time costs.

Differences in materials could reflect which direction people moved to or from an island. For example, Saban assemblages with Long Island flint indicate travel to the east (see Knippenberg 2007), while sites on Saba with Taíno-influenced materials suggest movement from the west (see Chapters 5 and 6). In reality, communities from several sites around the region engaged in indirect travel to Saba. Canoers that followed the modeled least-cost paths could have first passed through other islands before arriving to exchange materials on Saba. Furthermore, there is not always evidence of exchange reciprocity in site assemblages. There is possible evidence of reciprocal exchange, in the form of flint exported from Long Island. Additionally, the exportation of St. Martin greenstone, although not addressed in this work, formed another bridge between islands and supported the flint mobility network. St. Martin greenstone was also worked on and exported from Saba (Knippenberg 2007: 246-250; see also Hofman *et al.* 2014), further tying this island into the broader Lesser Antillean lithic network. However, whether greenstone material was ever directly transported from Saba to Long Island is unclear. Due to the position of Long Island as the clear source of flint in the area, it is more apparent that this material was exported directly to Saba.

The number of known sites encountered by these hypothetical pathways support the relationship between route trajectory and inter-island relationships. It is likely that indirect routes can indicate the location of stopover sites if there is a canoe travel corridor that passes close enough to an island's coastline. Opportunities for crews to visit stopover points may suggest a break or pause in a route's time cost to engage in stopover activities. This is especially relevant for crews crossing from Hispaniola to the Lesser Antilles, as the route tool was unable to generate least-cost pathways between these two points. Thus, the model showed direct travel between these two areas was highly unlikely, if not impossible. There were likely many stopover points on the coasts of Puerto Rico as well as the smaller islands between the Greater Antilles and the Leeward Islands. An example of this is in the trajectory of indirect routes across the Anegada Passage, which may have determined who was in contact with the Virgin Islands to the north of the channel or with St. Croix to the south (see Chapter 6). As there are no clear time cost benefits associated with traveling to or from Saba instead of Anguilla, the routes modeled here cannot definitively state which island's sites acted as a gateway for Taíno materials in the northern Lesser Antilles (see Chapter 6). In fact, it is possible that sites on both Anguilla and Saba acted as gateways to different areas within the region. The layout of routes between the Greater Antilles and the Leeward Islands can point to which islands and sites materials likely passed through while in transit. Routes leaving from Anguilla were more likely to come through the Virgin Islands. Routes departing from Saba often traveled past St. Croix. The location of and materials found at sites within the Virgin Islands, like Cinnamon Bay on St. John and Tutu on St. Thomas, and on the north coast of St. Croix, such as the Salt River site, support the movement of Greater Antillean materials through these islands. It is possible these islands acted as the initial points of distribution for Greater Antillean goods and ideas before they were moved into the Leeward Islands (see Chapter 6).

Indirect routes can sometimes be broken into sections. Each portion of the pathway, before and after a route intersected an in-between island, can be considered as a leg of one protracted voyage. For example, as discussed above, modeled routes that ran close to St. Croix suggest that the indirect least-cost pathways may have been broken to take advantage of the convenient stopover location for rest, resupply, or interaction with island inhabitants (see Chapter 6). This may also have applied to routes passing St. Kitts or Montserrat (see Chapter 5). These segments of least-cost routes can inform on where crews might naturally stop over to break a journey or indicate areas that may have been preferred for long term habitation due to their placement along an existing travel corridor.

Opportunities for crews to visit stopover points may suggest an extension in a route's time cost while canoers rested or visited with other communities. Generally, the uninterrupted time costs returned for optimal routes modeled for these case studies represent only the direct travel cost. However, there are some routes that move directly between two nodes that have similar time costs to routes passing through a node on an in-between island. For example, the time cost of a direct voyage between St. Martin and Anguilla to Saba is similar to that of a voyage between St. Martin and Anguilla to Saba that stops at Baie Orientale (see Chapter 5; see Appendix B). These "equal" routes would have been a part of a communal or individual mental map (see section 8.2.3), providing canoers with the option of choosing to stop over rather than travel directly. This may have fostered connections between communities on these three islands. As mentioned above, crews may also have wanted to stop for reasons that had nothing to do with social connections, deciding mid-voyage to break at an island. Stopover potential may impact the time frame for voyages heading directly between two sites passing an island on the way, as is the case with routes through St. Martin (see Chapter 5), or may occur for pathways that are targeted off a direct or typical course, like those through St. Croix (see Chapter 6).

Use of extended stopover areas corresponds to the idea that people not only visited sites to gather resources but also inhabited them for short periods, perhaps seasonally, as well (Hofman and Hoogland 2003; Hofman *et al.* 2006). In some cases, routes banded together to form travel corridors may indicate which season promoted a direction of travel or collection of specific resources. Results in Chapter 5 showed that there was a higher reliability and regularity in route time costs moving east to Long Island from Saba than the reciprocal journey. As a result, it is possible that planning routes towards Saba was more important because there were fewer options for the reciprocal voyage and people may have been more seasonally aware of when to move. These trends demonstrate the possibility of seasonal canoe travel corridors also acting as canoeing direction periods.

Possible travel corridors that emerged through many different modeled routes may also suggest that those seasonally advantageous pathways past specific islands in the Anegada Passage were not used merely as short-term stopover points but as seasonal habitation sites as well (see Chapter 6). The cost to travel across the Anegada Passage, how that cost is minimized by introducing stopover points, and the seasonal response to waiting for better currents on these in-between islands suggest that there may have been annual rhythms to interaction or occupation of islands between Puerto Rico and the Leeward Islands. The possible convergence of seasonal route use and the length of voyages could have encouraged stopovers, indicating that these islands played a role as a gateway site in distributing materials or cultural elements from the Greater Antilles to communities in the Lesser Antilles (Hofman and Hoogland 2011) or that peoples who inhabited these islands were able to exert influence over passing canoes. The evidence of habitation on islands like St. Croix indicate communities on islands visually separated by the sea were active members of regional social networks (see Crock *et al.* 2008; Faber-Morse 2004; see also Chapter 6), would support this argument.

Areas with limited or, as yet, no archaeological evidence make it difficult to prove the existence of stopover points located off modeled routes. In some cases, a true absence of archaeological materials and not just lack of archaeological survey or research on the coastlines of in-between islands may indicate that indirect routes that passed close to these areas were not connected with island occupation or crew rest areas. In other cases, sites used as resupply areas are not found as their presence is recorded only as small areas of ceramic scatter or single use hearths (*sensu* Bintliff 2000). However, it is also important to note that the lack of recovered evidence does not preclude the existence of short-lived stopover sites. For example, there is limited archeological evidence of Cayo ceramic culture on Trinidad, which could indicate that Trinidad was not a stopover site on routes from South America to Grenada and St. Vincent during the end of the Late Ceramic Age/early colonial period (see Chapter 7). It is also possible to explain the absence of Cayo material on Trinidad by canoers choosing routes that actively avoided the island.

Evidence of interaction between peoples on Tobago and Cayo or Koriabo potters (Boomert 2016) suggests there may have been a few sites that acted as long-term connectors between the mainland and the Windward Islands. These possible connections through Tobago are supported by the similarity in pottery styles, such as Suazan Troumassoid rim indentations on ceramics (*e.g.,* Boomert 1995, 2016) that date to the years before the period focused on in Chapter 7. As indicated by the frequency of modeled routes passing the island, it is possible that canoers coming north from South America choose to stop over on Tobago to rest after the long voyage. This has been reported by early accounts of European chroniclers in the area (Boomert 2008). Trends in language adoption and adaption noted in ethnographic work may also point to areas of connection and avoidance among Amerindian communities.

Lack of archaeological evidence could also suggest purposeful avoidance, although this dearth of data needs to be conspicuous to draw inferences from its absence (Fowles 2008). The displacement of Carib peoples from Trinidad and Tobago into islands like St. Vincent (Boomert 2002) could have motivated mainland canoe crews to avoid traveling through the Galleons Passage between Trinidad and Tobago. It is possible that navigators chose routes that would not pass by hostile groups in the Orinoco area and Trinidad. Historic accounts report that there was an antagonistic relationship between the Windward Island Kalinago communities and the Arawak peoples from the mainland. The disruption of routes around the time of Kaliña and Kalinago exchange may be explained by this increased antagonism (Boomert 2008). This trend of avoidance may have forced canoers to choose to launch their vessel at times when routes would head east of Tobago, which fits with Amerindian canoeing practices mentioned in ethnohistoric accounts (Boomert 2008, 2016).

Environmental factors also work against the recovery of materials that would confirm the existence of these stopover points and indirect routes. Apart from the factors discussed in Chapter 3, which refer to the low levels of preservation for materials like canoes and paddles that relate directly to seafaring (Cooper 2004; Ostapkowicz 1998), there are other issues that affect access to intact assemblages or surface finds. Points of connection showing inter-island interaction have been obscured by sea-level rise, erosion, and human interference (Cooper 2010, 2012, 2013; Cooper and Peros 2010; Glassow *et al.* 1988; Hofman and Hoogland 2016). Surveys along Caribbean coastlines have not always captured the full scope of where people may have interacted, either because of lack of survey or survey bias by the archaeologists (de Ruiter forthcoming). Future surveys should focus on the coastlines of in-between islands and researchers should look for evidence of settlements or short use campsites.

The process of material mobility and transport can also be obscured within the archaeological record. Our ability to determine whether materials passed through direct exchange or through stopovers is hampered by the similarity of archaeological material evidence that links sites in the region. Though there has been work done to connect lithic and ceramic sourcing and provenance (*e.g.*, Hofman *et al.* 2008c; Knippenberg 2007), the direct flow of these materials and the trajectory routes that would have moved them are unclear. This was true for all case studies, particularly in terms of the dissemination of lithic materials and ceramic stylistic elements.

Many links between archaeological sites are determined by observing their ceramic or lithic materials, shared stylistic elements, and/or morphology (see Davis 2000; Hofman *et al.* 2006, 2014; Keegan and Hofman 2017; Knippenberg 2007). In many cases, the similarities in these materials are shared between several islands, thus obscuring the exact process of proliferation of stylistic traditions. Because the order in which peoples moved from one landmass to the next is obscure, it is almost impossible to determine whether these materials were moved directly between two islands or if their presence in an assemblage is the result of indirect exchange. Indirect exchange can refer to the movement of materials through more than one site before the materials were deposited into the archaeological record. However, the travel corridors identified here are an important new source of evidence for future analysis of material mobility in the Lesser Antilles.

For example, it is impossible to determine if Long Island flint was exchanged between communities on more than one island before being deposited into an assemblage (Davis 2000; Hofman *et al.* 2006, 2014; Knippenberg 1999, 2001, 2006; see Chapter 5). Similarly, as there are no clear one-to-one relationships between ceramic materials or Taíno objects in site assemblages across the Anegada Passage, there are also numerous possible connection points canoers could have used to move these materials. As such, reciprocal connections between the Greater and the Lesser Antilles are difficult to model (see Chapter 6). Finally, reciprocal connections between South America and the Lesser Antilles are also problematic, as the mainland stylistic elements that link Koriabo and Cayo pottery are difficult to trace (see Chapter 7). Ethnographic accounts (Petersen *et al.* 2004; Whitehead 1995) and linguistic connections (Boomert 2008; Hoff 1994; Hofman 1993) point towards a sustained multi-directional relationship between the Kalinago and Kaliña peoples, but based on the archaeological evidence alone the extent of these interactions is unclear. Modeling optimal routes based on materials that can be connected to several sites may suggest where communities were likely to canoe and where these avenues of mobility were reciprocal, sketching out a directed inter-island mobility network.

These networks can extend beyond the time period of the case study in question, linking pathways to sites dating to different periods. In all case studies, the trajectories of routes indicate where these stopover points could be located both before, during, and after the period modeled. In the case for routes in the Greater Antilles and the Lesser Antilles, many of the indirect routes returned by the model passed by sites that we know were used in later periods (see Chapters 5 and 6). For example, some routes from Long Island's Flinty Bay to Antigua's Jolly Beach pass by the Ceramic Age site of Anse á Le Gourde on Guadeloupe that postdates exchange modeled in this work. In a few cases, pathways even meet Guadeloupe's coastline near the site before turning back to reach the termination point at Jolly Beach. Similarly, many modeled routes between mainland South America and the Windward Islands pass by sites that were in use during earlier periods. This includes movement past the Saladoid site of Blanchisseuse on Trinidad. The placement of these sites along routes from other periods suggests two things: first, the location of routes is tied to site placement, and second, sites may have formed because they were along routes present in Amerindian mental maps of the region. Because canoe crews may have had reasons to pass by known sites, the links between route trajectory and site placement across time periods should be further explored.

8.2.3 Modeled Seafaring Practices, Navigation, and Mental Maps

The possible existence of travel corridors, the use of seasonal periods, and the connection between settlements and canoe routes indicate that there may have been a deeper connection between seafarers and the seascape they traveled upon. Those looking to paddle between islands likely could not rely on random choices on where to move. These seafarers had to have a deeper and sustainable knowledge of current trends and settlement or resource locations on different islands. The final set of questions asked in this work dealt with the relationship between modeled sea-based least-cost pathways and navigation techniques. Particularly, my interest was on exploring the role mental navigation maps may have played for canoers traveling routes similar to the ones generated for each case study. Did sea pathways influence navigation? If so, is there a link between the generated routes and the construction of possible mental maps? Though difficult to approach through routes alone, this work provides a preliminary assessment of how computer-generated routes might suggest past navigation techniques.

Routes that were repeated through several runs of the model suggest that pathways can be banded together to form a likely corridor of movement that could be followed by Amerindian canoers. Canoers would have made progress towards their destination by working within the geographic range of the corridor, shifting the canoe's heading in response to wind, current, wave direction, or wave height. Navigators could use these corridors to travel directly or indirectly towards their destination and use them to return when their business on the other island was concluded.

These possible navigation corridors differ from region to region. Archaic Age movement was measured through the clustered layout of the Leeward Islands (see Chapter 5). This placement allowed for a high level of inter-visibility between islands and canoers passing islands and/or Archaic Age sites. Canoes moving through areas with this concentration of visible landmarks had a safety net for their voyages and ready connections on which to affix their mental maps. The layout of the islands prevented most routes from moving too far off course. Many routes modeled for this case study followed currents along outer edges of the island cluster instead of out to sea. In contrast, the Greater and the Lesser Antilles Island sites (see Chapter 6) are in an extended arc. In many cases pathways across the large divide of the Anegada Passage did not intersect with an island that could provide a break between the current's push and the open sea. Other pathways came close to islands like St. Croix and the Virgin Islands that could be used as possible stopover points. Navigation may have been more difficult because of a lack of landmarks over the greater distances. Challenges posed to crews by lack of visible landscapes may have been removed by relying on celestial navigation.

Similarly, modeled routes from Guyana to the Windward Islands (see Chapter 7) show that real-world canoers may have faced long stretches of open sea without the option to stop or navigate using landmarks. As there may have been a preference to avoid Trinidad and Tobago for reasons discussed above, navigation over these broader was perhaps problematic. These increased distances likely resulted in the use of different navigation techniques, such as celestial navigation (Agouridis 1997; Bilić 2009; Lamarche 1993) or wave reading (Lewis 1994; Tingley 2016). Celestial skill sets, like those observed among Pacific seafaring communities (*e.g.*, Gladwin 2009; Lewis 1994; Oatley 1977), probably existed among Amerindian navigators as well (*e.g.*, Lamarche 1993). Celestial navigation may have extended the range of voyages by allowing crews to rely on the position of the sun, moon, or stars to guide their way when land was out of view and to identify their situation within the seascape and relation to landing points or areas of cultural importance (*e.g.*, Lamarche 1993; Lewis 1994). The location of islands at night underneath certain stars also enabled crews to identify the position of "their" island in the dark. These techniques made knowledge of the location and progression of celestial bodies as important as information on currents and the geographic relationship between islands.

This approach to navigation also made it possible for crews to extend voyages beyond a single day, allowing for canoes to launch before sunrise and after sunset. Night voyaging has been tested in a recent experimental voyage conducted by the Karisko project (Bérard personal communication 2014). The results of this experiment proved that crews in vessels like those used by pre-Columbian navigators could safely canoe by night, though modern atmospheric conditions and light sources from buildings on nearby Martinique may have affected this visibility. As there was no noticeable difference in time costs between day and night travel, it is possible that optimal routes could have been launched at any point within a 24-hour period. Much like seasonal similarities in time costs, this may have freed voyagers to pick routes that responded to safety concerns, such as leaving in the night using celestial navigation and landing in the day when harbors became more visible.

There are several things to learn from the layouts of these pathways. Modeled routes occurring in the same area during certain periods demonstrate that corridors of movement likely existed on the sea, mirroring those theorized by least-cost pathway modeling on landscapes (*e.g.,* Anderson 2012; Rademaker *et al.* 2012; Surface-Evans 2012; Whitley and Hicks 2003). Determining the possible location of these corridors is a step towards reconstructing Amerindian mental navigation maps. Comparing several routes trajectories and co-occurrence with intermediate sites can indicate a canoe corridor's existence within a mental navigation map (see Appendices B, C, and D). Frequency of sites along these routes may point to the likelihood of Amerindian canoers developing mental navigation maps.

It is possible that these shared information systems helped to guide seafarers through the Lesser Antilles. Certainly, these studies demonstrate that such knowledge was required to aid navigation, as mental maps probably included the use and maintenance of optimal routes. Without knowledge of currents and wind patterns that would impact these optimal routes (*sensu* Lewis 1994; Tingley 2016), peoples may have suffered from prolonged voyages that went off course or into danger. More work could be done to connect hypothetical routes to possible land or sea markers to test the theory of how wayfinding maps may have been used in this region from the Archaic Age to the early colonial period.

The consistency of later period sites along the pathways returned by the model present an argument for the existence of a wayfinding tradition in this region. It is probable that navigators benefitted from generations of seafarers sharing knowledge of the location of travel corridors, resources, or sites (*sensu* Agouridis 1997; Ingold 1993, 2011; Terrell and Welsch 1998: 59; Terrell *et al.* 1997), which were then incorporated into other mental maps. Just as Pacific seafarers needed to remember the location of far-flung islands to increase the success of colonization efforts (Irwin *et al.* 1990; Montenegro *et al.* 2016), Archaic Age and Ceramic Age voyagers also had to note which islands crews canoed by in various seasons. Over time, these mental maps enabled crews to pinpoint areas of high-probability landfall and safe harbor (*sensu* Ingold 2000, 2011; Terrell and Welsch 1998; Tilley 1994). Shared navigation points enabled canoers to build camps and settlements in areas where they could take shelter from environmental pressures.

The link between route layout and maintenance of the travel corridor was made clear in each case study, where the position of stopover points along several modeled travel corridors indicates the pathways were used over several generations. For example, although there is little evidence of Archaic Age sites on the northeast coast of St. Kitts (de Ruiter forthcoming), routes like those generated with the isochrone tool may have been pushed west by the current into St. Kitts when traveling westward from Flinty Bay, Long Island (see Chapter 5). The link between routes from Long Island to Saba and the in-between island of St. Kitts, if followed by real-world canoers, provided a tangible opportunity for crews to affix meaning to a landmark. The position of Sugar Factory Pier on St. Kitts would have taken advantage of the trajectory of many optimal routes, suggesting a possible tie to the larger networked mental map. This is some support for the notion that St. Kitts was possibly included in the mental wayfinding map of regional navigators who would come to use the island more heavily in the Ceramic Age.

Comparisons with sites present on modeled routes from later periods in the Lesser Antilles could help to determine if canoe corridor locations were used over decades or centuries. In some ways, the travel corridors may be connected with the longstanding cultural associations of monuments (sensu Schlanger 1992). For example, Schlanger (1992) suggests that persistent places can be established through corridors of movement or once occupied areas that support later visitation, thus setting up re-use that informs subsequent activity and re-visitation.

Modeled routes allow us to understand how a seafaring mental map could have stretched over several generations (*sensu* Samson and Cooper 2015; Terrell and Welsch 1997; Tilley 1994). Thus, for example, the Ceramic Age site of Anse á La Gourde (ca. AD 450 – 1350), on the coast of Guadeloupe is also located off Archaic Age modeled canoe pathways that run south from Flinty Bay, indicating that canoers developed an association with the area, and eventually chose to establish a permanent site there. The position of the site near the turning point for indirect routes from the north hints that Anse á La Gourde would have played a key role in the lithic network connecting Long Island to the west coast of Antigua (see Chapter 5).

Another example of a site that may have been connected to the trajectory of optimal least-cost routes is Blanchisseuse on Trinidad. Modeled routes from Guyana Point B to Grenada pass close to this site. In fact, routes often pivot north towards the Windward Islands directly off the coast of Blanchisseuse. Though this site predates the period of focus for canoers carrying Koriabo ware from the mainland (Late Ceramic Age/early colonial period), these modeled routes indicate that Saladoid canoers from the Guianas could have used this site as a rest area before crossing the channel to Grenada. The knowledge of how to cross from this area into the islands may have existed in the mental map of regional navigators into the Late Ceramic Age/early colonial period.

These hypothetical travel patterns may have been recorded as part of larger or macro-regional mental navigation maps. Knowledge of the location of canoe travel corridors would have been invaluable to seafarers in the region to sustain links between different communities or seasonal outposts. This process is seen in other regions around the globe, from the training of medieval navigators to use currents to their advantage year after year (sensu Frake 1985) to voyagers in the Pacific using their skills to maintain links with friendly sites (Terrell and Welsch 1998). The process of educating new navigators about these links likely happened during the process of voyaging, relaying both technical skills and cultural associations (*sensu* Crouch 2008; Ingold 2011; Lewis 1994). Experiencing the movement through seascapes for themselves would have encouraged individual navigators to add their own associations to a broader communal map, as was done by individuals moving through landscapes (*sensu* Tilley 1994). The repetitive use of these pathways probably cemented the knowledge of their position and purpose in the minds of navigators, though the exact position and feelings associated with routes may have shifted from year to year (*sensu* Ingold 2011).

Differences in travel direction also affected how crews used mental navigation maps to plan seasonal routes and when to collect materials from different islands. Canoers looking to make a specific connection in non-optimal travel periods could have used their knowledge of the environment to push against currents. Crews applying skill and technique at the right moment may have been able to overcome adverse seasonal conditions to arrive at their target. Alternatively, Amerindian canoers could have made selective choices regarding when to travel. Navigators who planned reciprocal voyages must have paid close attention to current flow and seasonal shifts as they may have affected when crews could leave on a particular trip (*sensu* Lewis 1994; Tingley 2016). It is likely that real-world crews waited out poor travel seasons on an island when heading in a certain direction. Least-cost pathways crossing the opposite way could show routes accrued lower time costs during the same period. The archaeological materials from sites used as origin and termination points suggest navigators must have known how to sail there-and-back when canoeing in this region. This would require experienced navigators to possess highly developed mental maps including knowledge of the seasonal variations of routes (*sensu* Agouridis 1997). Relying on this knowledge would have increased the likelihood of vessels successfully reaching their destination.

Stylistic elements from traditions in the Greater Antilles, the Lesser Antilles, and the South American mainland (see Allaire 1990; Bright 2011; Hofman *et al.* 2008b; Righter *et al.* 2004) suggest a common reliance on canoe technology and navigation practices. Communities from these regions would have had the opportunity to pass on knowledge of navigation markers for the surrounding islands (*sensu* Cooney 2003; Ingold 1993; McNiven 2008; Terrell *et al.* 1997). Seafarers from the Guianas likely shared navigational markers with the Windward Islands canoers (*e.g.*, Callaghan 1993, 1995, 2003, 2011). Communities in the Leeward Islands could have traded information on how to move about the region to new arrivals from the Greater Antilles. Sharing information likely made voyages a success for crews entering new areas and allowed for communities from different regions to engage in return or reciprocal voyages (*sensu* Ingold 2000; Tilley 1994). The translatable knowledge of canoe toolkits between seafaring communities on different islands and in different regions allowed canoers to make reciprocal connections.

The creation of mental wayfinding maps would have been essential to the maintenance of these connections. In turn, the maintenance of these connections would have been necessary to support the extended exchange of materials, stylistic elements, and peoples that moved through the region. In the future, it may be possible to further link the existence of a communal mental map to the location of these routes. Though these maps likely held different meanings to the individuals who used them, the shared cultural tradition of navigation corridors bonded seafaring peoples to one another. Currently, the location of travel corridors demonstrated by these hypothetical canoe routes can point to a systematic approach to seafaring that could have been observed by Amerindian canoers.

8.3 Limitations

The primary limitation of the model was the impossibility of examining corridors of movement over multiple generated routes and comparing all route connections between every node within the case studies. Modeling between origin and termination points produced hundreds of routes that moved in the same direction within a single area, creating a travel corridor. Pathways were generated for roughly 240 different seascapes per unidirectional route for one month, with each modeled seascape corresponding to a three-hour period within that time frame. For example, the first case study, which has a total of 10 sites, resulted in a possible total route return of 28,800 for just the outward connections from one site over all possible years and months to model. This is substantially different from traditional least-cost pathway studies, where routes are judged by their placement over a static landscape and one route, or sometimes even tens of routes, are produced for unidirectional least-cost paths. Though this work was able to analyze routes based on changing sea surfaces from the interpolation of wind and current data and high-resolution datasets, the computer costs required to model all possible routes across all possible cost surfaces was too great to be completed.

The canoe pathways modeled here stand as a starting point for the exploration of reciprocal voyaging in the Caribbean. Through a comparison of route trajectory and the location of known sites, the modeled pathways allow for the reinterpretation of inter-island connections. During my analysis of the modeled canoe pathways, it became apparent that indirect routes, or pathways not closely conforming to the Euclidean distance, were a vital aspect of this study. As such, this study is only the first step toward modeling routes between islands in the region. The resulting direct and indirect routes provided new insights into inter-island connections in these regions.

Connections between modeled pathways and the coastlines they pass can propose new areas for survey or indicate possible areas of past interaction. There are limiting factors, however. It is possible that real-world canoers moving between areas close to the origin and termination points used in the case studies would have stopped only for as long as it would have taken to replenish their supplies or rest. This has been reported by some ethnohistoric accounts (see Boomert 2002, 2016; Menkman 1939). Finding evidence of brief stopovers in the archaeological record would be difficult for many reasons. First, the site could be easily missed or misrepresented by surveys (de Ruiter forthcoming), as it is possible that though people returned to the same beaches they may not have camped in the same locations. Second, as mentioned previously, sites in the region may have been obscured by environmental changes, such as sea level rise, and manmade alterations, such as coastal development (Cooper 2010, 2012, 2013; Cooper and Peros 2010; Glassow *et al.* 1988; Hofman and Hoogland 2015).

The routes modeled for this study are based on modern current data and may not truly reflect the surface of the sea that existed during the periods evaluated. However, the relative stability of bathymetry from the late Archaic Age onwards in the Caribbean ensures that routes modeled between the archaeological sites used here represent plausible canoe routes for Archaic and Ceramic Age communities (Callaghan 2001). Other researchers who have modeled this region have also used modern data to reflect past currents (*e.g.,* Altes 2011; Callaghan 2001, 2003; Cooper 2010). Early attempts at modeling canoe routes in the Caribbean region represented colonization efforts that would have been in use much earlier than the pathways represented here. The canoe pathways created here stand as a first step towards understanding movement between islands for a wide range of other purposes.

Greater access to current information for areas further south than that provided by the AmSeas3D data set would have been beneficial (see Chapter 7). More work will need to be done to determine what data sets can best showcase currents of the coast of South America for use by the Hildenbrand (2015) isochrone tool. This includes a more in-depth analysis of how current is affected by tidal force closer to a larger landmass. Current data collected off the coast of South America will also need to be compatible with the AmSeas3D data set to ensure that these two sources of information can be used in tandem. An analysis on how the change in a possible additional dataset's resolution affect routes modeled here should also be considered so as to ensure the use of proper sampling rates by the model.

Moving forward, it will be important to run routes for more than six years of current data (2010 to 2015), used here to show the difference between route time costs and layouts generated. Tests on whether there are differences outside of 2010 to 2015 should be conducted to see if these years are representative of a longer time span. Climate change and sea level rise may impact underlying current data, which in turn can influence the cost surfaces on which modeled routes are based. In this sense, it may also be worthwhile to test modern current information from further in the past as Callaghan did with the United States Navy's Marine Climatic Atlas of the World (Callaghan 2001). In the coming years, researchers have the potential to recreate past current patterns that may allow for resampling of the environmental data. Incorporating new methods to calculate past currents could influence the trajectories generated by this model. The routes modeled here may need to be updated once past currents for these periods can be accurately generated at the time resolution equal to the AmSeas3D dataset (see Chapter 4).

8.4 Future Work

Predicting the location of sites is not a goal of this research. However, there seems to be a link between least-cost routes and site location. Consistent with land-based least-cost pathway analysis (*e.g.*, White and Surface-Evans 2012), these efforts can be used as a platform to judge the strength of connection between site nodes and passed sites (*e.g.*, see Borck 2012 for an example of statistically correlating en route site location with route placement to test whether the modeled route was actually an historic travel corridor). In the future, more modeling should be done to identify possible connections between modeled route trajectories and site location. This hypothesis could be tested by running the model to connect several nodes on large sections of island coastlines. If a pattern emerged between ease of movement or low time costs and site placement it could support this hypothesis. If known sites are not at the end of the optimal routes demonstrating the lowest costs, it could indicate that my assumption of ties between route layout and site location should be reevaluated. If sites are tied to lower cost routes, it could bolster the analysis provided here. Looking at coastlines passed by modeled routes can also provide options for new areas to survey for archaeological evidence of stopover points or missed sites. Another function of this work is to suggest the possible transfer of materials along direct connections. Modeling least-cost pathways across the Anegada Passage is one way to identify or hypothesize the point from which materials and ideas were exported. Research into the exchange of artifacts or stylistic traditions across the Anegada Passage is limited by the fact that there are no known production centers, origin points, or dissemination areas that can be explicitly tied to the export of materials and stylistic traditions. Though much of these materials was produced locally (Hofman and Hoogland 2008), Taíno stylistic elements are so ubiquitous throughout the Greater Antilles that the origins of objects cannot be identified from stylistic evidence alone. Modeling routes between areas known to contain these materials can help to suggest possible corridors through which Taíno cultural elements were disseminated. These routes can augment research on connections between the Lesser and Greater Antilles.

In the case of movement from Saba to St. Croix discussed in Chapter 6, researchers could continue to look at these avenues of mobility. The Taíno materials that identify connections across the Anegada Passage are often stylistically similar and made from local materials that may not reflect exportation from the Lesser Antilles, making one-to-one relationships between islands difficult to discern based on stylistic elements.

At present, it is difficult for researchers to determine if material connections passing through St. Croix originated in Saba or Anguilla (Hofman personal communication 2017). Routes modeled from these two islands can perhaps suggest that one of the islands had a closer relationship with St. Croix. Furthermore, further application of the route tool to pathways through the Anegada Passage may confirm whether certain sites within the Leeward Islands were better connected to islands in the west or if connections into the Lesser Antilles were alike in cost or social preference. These examples show that more work should be done to determine whether there is a true absence of archaeology supporting these connections or if materials that underpin or confirm the existence of these routes can be found. This could include combining route modeling with lithic analysis or network studies.

Furthermore, broadening the scope of this research to include the connections between the Leeward and Windward Islands could lead to a better understanding of macro-regional interconnections. These pathways could be used to explore links between the Greater Antilles and the Windward Islands, as indicated by the Cayo complex that shows similarities to both Koriabo and Greater Antillean stylistic elements (Bright 2011; Hofman and Hoogland 2012). Routes modeled between the Greater Antilles, the Leeward Islands, and the Windward Islands may provide some answers to the movement of Amerindian potters, who were in many ways responsible for the spread of ceramic styles. It is probable that routes already modelled across the Anegada Passage are a strong representation of canoe routes between these two island groups, as people were unlikely to travel directly from the southern Lesser Antilles to the Greater Antilles without seeking port to replenish supplies or rest.

Future work on reciprocal voyaging in this area should include an analysis of sites off the coast of Puerto Rico to expand our knowledge of how people moved across the Anegada Passage. This analysis could be tied to the hypothesized political domains of caciques across the island (*sensu* Curet and Stringer 2010; Siegel 2011; Torres 2010). Examples from Chapter 6 showed that routes modelled between the northern Lesser Antilles and a southeast point on Puerto Rico have lower cost in comparison with routes ending at other nodes on the island. This could indicate that caciques in the southwest of the island had a greater influence over goods coming in from the Lesser Antilles. Comparing these routes with pathways to the south of Puerto Rico that move through the Virgin Islands shows that there is not a clear indication that one travel corridor was favored over another. In this case, there may not have been a clear-cut distribution center on the eastern half of Puerto Rico.

An additional line of research would be to analyze potential departure points from the Greater Antilles. Calculating routes between Puerto Rico and the coast at several points over multiple seasons would reveal potential minimal time cost travel corridors that could uncover potential distribution centers for the Dominican Republic Taíno materials whose style and manufacture influenced potters, lithic producers, and objects at other sites. Additionally, adding more origin and termination points to Hispaniola's and Puerto Rico's coastline could identify stopover points in addition to the routes suggested here. For example, the points added to the Playa Grande site in the Rio San Juan region of Hispaniola are connected with the production and exportation of jadeite material to the Lesser Antilles (Knippenberg 2007; Knippenberg *et al.* 2012). New points could then be used to evaluate the locations of Taíno distribution centers. These points may also stand as areas that received materials from the Lesser Antillean reciprocal exchange, if such a link existed. Routes run from these locations could suggest areas for future archaeological survey. Though there has been no systematic approach to proposing site prediction, the trajectory of modeled routes with support from ground trothing may uncover as yet unknown sites. The nature of prominent sites or points of micro-regional material import and export can influence our understanding of how peoples moved through the larger area. It could also indicate whether site location and canoe routes were tied to the function of communities within the broader mobility and exchange network.

Adding additional sites to conduct an everywhere-to-everywhere least-cost path analysis may provide insight into the connection of site placement and routes. The presence of sites near beaches that show high concentrations of the termination of least-cost or optimal routes may indicate a tie between environment-based routes and community-based sites. Before taking this approach, more work on the viability of this kind of modeling, including the extensive computation requirements, should be conducted.

In addition to adding sites, it may also be worthwhile to broaden the scope of inquiry to include not only how pathways manifest themselves over seasons but also the result when launching at different times of day. In analyzing the three case studies I did not observe a clear indication of possible launch time preferences amongst the optimal routes. This may be because most voyages exceed 24 hours, and thus take place over the entire daily tidal range affecting canoes. As indicated by the tables showing route variance in Chapter 5, it is unlikely that leaving at different times of day precluded voyaging between certain points as many examples show a difference in travel time from less than one hour to less than six hours (see Appendix B: Tables 1 to 20). Again, this suggests that like seasonal preferences, it may be that individual canoers were less bound by the time costs of routes than by their destinations and the social conventions of voyaging. However, it may be that further analysis of route launch times reveals a preference for leaving under certain tidal influences. These tidal influences may also link back to seasonality, highlighting the importance of comparing generated optimal routes against environmental data.

In order to better understand past navigation practices and the existence of mental maps, evaluating visibility from the canoe is key. Visibility research done in the area (see Brughmans *et al.* 2017; Callaghan 2008; Friedman *et al.* 2009; Smith 2016; Torres and Rodríguez Ramos 2008), as well as ethnographic or historic accounts of how visibility can impact island sightings in the Caribbean (see Boomert 2011; Curet 2005; Torres and Rodríguez Ramos 2008), clearly suggest that more research needs to be done to consider sighting landmarks from vessels on the sea (see Appendix D). Taking an emic approach may prove beneficial for understanding the meaning or function of specific land- or seamarks. Interviewing mariners from around the Caribbean may provide key insights into traditional navigation techniques that are, or have been, used along the coastlines referred to in this work. Furthermore, contacting individuals from the Kalinago Territory in Dominica could help to place canoeing in context with traditional canoe building and seafaring practices.

Working with modern experimental voyages, such as those conducted by the Karisko project, could provide insight into the methods of wayfinding or visual relationships used by pre-contact and early colonial Amerindian navigators (see Bérard *et al.* 2016). References to drawn or mental navigation maps used by Pacific Islanders (Gladwin 2009; Lewis 1994; Tingley 2016) or known land- or seamarks used by Mediterranean seafarers (Agouridis 1997; Broodbank 2000, 2013) may prove useful in understanding how Amerindian canoers worked with environmental cues to safely travel between islands. It is probable that seafarers in the Caribbean were using similar techniques to mark out, remember, and maintain travel corridors. Researchers should also consider how to properly incorporate and analyze views from the sea, where the height of the observer restricts the possible visibility from canoes. This analysis may be connected with works evaluating navigation, including celestial navigation and wayfinding (*e.g.*, for navigation, see Agouridis 1997; Bérard *et al.* 2011; Fitzpatrick 2004, 2013; Lewis 1994; for celestial navigation, see Agouridis 1997; Bilić 2009; Lamarche 1993; Oatley 1977; for wayfinding, see Ingold 2000; see Appendices B, C, D). What is visible from vessels likely affected how canoers planned voyages and will be an important consideration when reconstructing the details of pre-Columbian navigation practices in the future.

Focusing specifically on celestial navigation, it may be possible to model what skyscapes were visible above the canoe. These connections between route trajectory and the position of celestial bodies was likely used by Amerindian navigators, and can be a way to further enhance our understanding of communal mental maps that centered around the continual use of optimal routes. Configuring these skyscapes may involve the use of computer programs such as Stellarium (*e.g.*, Brown 2015), which can project the position of stars, moon, and sun into the past, or the inclusion of ethnographic research into the identification of stars as navigation points. Stellarium in the past has been used to explore the relationship between peoples and the stars in archaeological contexts, pre-historic pyramids in Nepeña Valley, Peru (Benfer and Ocás 2017). Though these efforts have primarily focused on land-based views, there is no reason this technique could not be applied to evaluating the relationship between canoers and stars at several points along a path.

Evaluations of skyscapes could benefit the analysis of the current work, which touches on what relationships might exist between sea pathways and the islands that they pass. Celestial navigation can also be incorporated into viewsheds that include both the skyscape and landscape that are visible from the canoe, as often the position of the stars in relationship to islands is an important factor in navigation for seafarers (*e.g.*, Lewis 1994; Oatley 1977). In fact, as many voyages modeled for this work last over 24 hours, it is probable that canoers had to remember the position of islands, currents, and celestial bodies to safely follow set travel corridors between islands.

Furthermore, the Hildenbrand (2015) isochrone tool may be used in conjunction with traditional network analysis techniques to provide additional information about the inter-island ties connecting nodes when studying regional exchange. For example, the work of Broodbank (2000) and Rivers *et al.* (2011) on proximal point analysis, fixed radius network analysis, maximum entropy model, and other network models show the values of evaluation based on social factors and Euclidean distance measures. Adding the cost to movement revealed by least-cost routes can provide another layer to this approach, allowing for the consideration of the difficulty of travel often obscured when basing pathways on social relationships or Euclidian distance measures alone.

It is important to continue applying the Hildenbrand tool in other contexts to see if it is effective elsewhere. In future, this method can be applied to regions around the globe to determine the viability of this model in different water environments. This method may be of particular interest to those researching inter-island connections between communities in the Pacific. For example, reciprocal least-cost pathways may be useful in analyzing the Kula exchange ring (Leach and Leach 1983) or the practice of maintaining long distance exchange networks that has yet to be discussed by sea-based models from that region. This method could also be compared to sea-based routes generated for Roman travel in the Mediterranean, as was done for the ORBIS project (Arcenas 2015). As the resolution used in this analysis is finer-grained than other approaches to interpolating cost surfaces and the Hildenbrand (2015) tool can easily change time depth or iteration levels, this approach may provide a better understanding of route trajectory and cost than is offered by the gridded output of the ORBIS model. Use of this tool to the same resolution depends on the availably and quality of wind and current data sets from these regions.

As the Hildenbrand tool has been adapted to incorporate wind influence, it might be used to test movement of vessels using sails as well. Research evaluating the interaction between European sailing vessels and canoes from the Caribbean region could also use this method to test how technology affected route placement. This may offer opportunities to evaluate the possible divide between pre-Colombian and post-colonial seafaring practices in the Caribbean. Global case studies on smaller sail-powered vessels could also be analyzed using the Hildenbrand (2015) tool. This includes modeling vessels in the Mediterranean (*sensu* Arcenas 2015; Liedwanger 2013) or the Pacific (*sensu* Davies and Bickler 2015; Montenegro *et al.* 2016), where the research has focused on colonization efforts more than reciprocal voyages. This application may be able to provide insight into the connection between route placement and site layout in these regions as well.

Over the course of this work, I have demonstrated that modeling sea-based pathways is an advantageous additional step to other forms of traditional archaeological analysis when evaluating inter-island or island-to-mainland movement in the pre-Columbian Caribbean. The three regional examples, in which settlements and resource bases were selected to act as nodes, represent three distinct layouts and backdrops of interaction. Reflecting small centralized seasonality networks, broader regional connections across large passages, and even mainland-to-island links that would have taken several days, these geographic foci allowed me to evaluate how baseline mobility costs might have affected movement and the maintenance of social networks. Determining the cost and trajectory of routes similar to those that may have been used by past Amerindian navigators helped to determine what mechanizations of travel could have influenced interaction.

To further evaluate these mechanizations, I posed a series of questions targeted at assessing patterns apparent in routes generated for each case study. These questions, further explored in this chapter, showcase the many ways in which modeling routes do form a base for judging possible inter-island connections. In fact, many of the travel corridors modeled here suggest the location of possible interactions as well as seasons that may have been preferred, even if only minimally, by past Amerindian mariners. Modeled routes following similar corridors also showcase how canoers may have been able to rely on the consistency of wave patterns to form a mental navigation map to help them traverse the sea. Specific details of possible connections uncovered in this work, such as those between Long Island and La Désirade, can point to instances where further comparison between routes and materials may be useful. The evaluation of routes within the context of these overarching themes allowed for the questions posed at the start of this work to be answered.

Modeling sea-based interaction in the Caribbean furthers our awareness of the costs associated with maintaining social relationships across island channels. This type of modeling allows for a discussion of the movement of peoples, materials, and ideas between islands with ample opportunities to analyze possible travel corridors. The archaeological evidence that supports inter-island interaction between Amerindian communities throughout the Lesser Antilles is tied to human and material mobility as well as resource procurement of lithic, bone, shell, or ceramic resources originating in specific islands or regions. On their own, the presence of these materials cannot tell us the trajectory of the routes objects passed through before being deposited in assemblages. Stylistic elements that evolved out of inter-island links can indicate which communities were in contact but cannot define who was in contact directly or trace how the characteristics developed. The origins of some materials are better known than others, but the presence of similar materials throughout the Caribbean indicates how important canoe movement would have been to Amerindian peoples.

Though not expected, the seasonality of route trajectory was a stronger indicator of travel than mere least-cost alone. The existence of indirect routes also pointed to islands that possibly played a prominent role in inter-island travel and sites that could have been stopover points for canoe crews. For future applications of this model, route placement should be evaluated for its ability to distinguish links between canoers and coastal communities. Archaeologists can also use the canoe corridors modeled here as a suggestion of where to conduct future archaeological research. Canoe pathways created for this work contribute an additional layer to the analysis of navigation between the Caribbean islands from the Archaic Age to the Late Ceramic Age. Modeling least-cost pathways through the sea helps us to understand the possibilities of canoe travel, indicating where as well as how often optimal routes occurred. In turn, these optimal routes can expose connections between travel corridors and site locations and propose the existence of a mental framework for voyaging that helped maintain these pathways and habitation areas over generations.

Without the use of least-cost pathway modeling, these facets of Amerindian voyaging would be obscured by the surface of the sea and by archaeological evidence that points to exchange without being able to identify specifically how materials were used or moved from one island to another. The findings of this work demonstrate that least-cost pathways analysis is an appropriate method to test the fluctuating mobility corridors that supported inter-island interaction and exchange in the pre-Columbian and early colonial Caribbean. The generated pathways can suggest the who, why, and how of the physical relationships between inter-island communities and enhance our understanding of past social connectivity between the peoples of the Lesser Antilles.