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

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Caribbean Canoes and Canoe Modeling

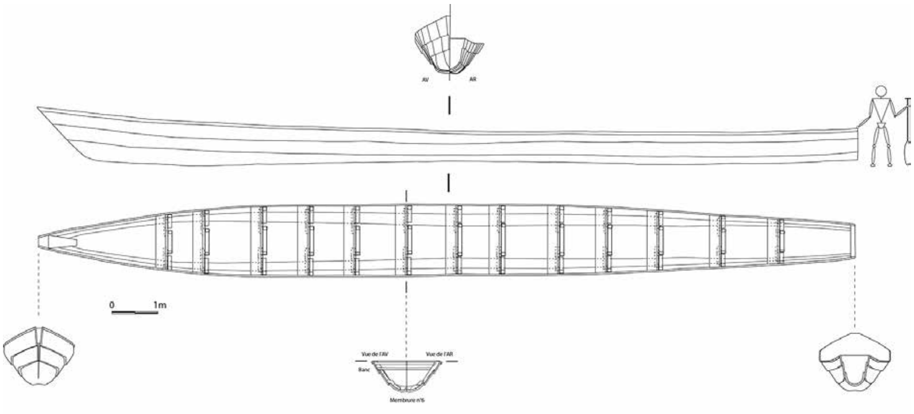
Archaeology, ethnography, ethnohistory, and experimental or experiential archaeology can provide some basis for understanding the physical links between Lesser Antillean Amerindian sites. This understanding can be enhanced through the computer modeling of least-cost sea-based pathways, which aim to calculate the optimal route between two locations (*sensu* Surface-Evans and White 2012:3). Mapping the physical relationship between archaeological sites can reveal trends in past human movement that are currently only partially uncovered by other lines of evidence. The routes these computer models create can help turn the Caribbean Sea from a blank space to a human environment rich with history, travel, and social meaning. Specifically, modeling can reveal the role movement across the sea may have played in linking specific communities and sites. It can also add to our understanding of possible mental maps (*sensu* for mental map theory outside anthropology, see Gould and White 1974; Lynch 1960; Richards 1974; for archaeology and anthropology, see Ingold 2000: 219-242, 2009, 2011: 141-153; Kirby 2009; Tilley 1994; Wiebe 1989; for geography, see Lowenthal 1961; for cognitive physiology, see Tolman 1948; Tolman *et al.* 1946; Trowbridge 1913; see Chapter 2) that seafaring peoples constructed, relied on, and shared.

Other researchers have also used least-cost pathway methods to construct models that hypothesize the existence of sea-based travel corridors. The variety of techniques used by different researchers demonstrates the fluidity of modeling least-cost corridors through the sea and the importance of linking generated routes to archaeology and ethnohistory. This chapter provides a brief overview of previous research in order to place the canoe routes generated by the isochrone model in a global seafaring computation context.

A discussion of what carried peoples between islands forms the base for our understanding of what sort of travel, and thus routes, were possible between the islands in the Lesser Antilles. The presence of Amerindian canoes has been documented through evidence of maritime activity and seafaring technology found in the archaeological record (Callaghan and Schwabe 2001; Ostapkowicz 1998). Ethnohistoric and ethnographic accounts also refer to canoes used by Caribbean Amerindian peoples. These works elucidate the function of the canoe by describing their shape and use (for ethnohistoric accounts, see Davies 1595; Drake 1585; Columbus 1493 cited in Hulme and Whitehead 1992; Layfield 1590 cited in Hulme and Whitehead 1992; Hulme and Whitehead 1992; Perry and Keith 1989; for ethnographic records, see Honeychurch 1997a; Taylor 1938). This functionality has been tested through experiential or experimental archaeology (Bérard *et al.* 2016). This knowledge provides a framework for assessing what routes returned by the model should be considered viable and representative of real-world seafaring practices. Archaeological findings underpinning the case studies will be detailed at the beginning of each chapter.

3.1 The Canoe as a Base for Modeling

To gain a better understanding of pre-Columbian seascapes it is important to discuss the canoes of the Amerindian wayfinders. The arrival of Europeans in the Caribbean, combined with a shift in maritime technology, altered the seafaring toolkit used in the region and there are few examples of pre-Columbian canoes that survive today (Callaghan and Schwabe 2001; Frederick 2014; Ostapkowicz 1998; Taylor 1938). Alongside archaeological evidence, reconstructing canoes (see Figures 2 and 3) and associated accoutrements can help to define what was possible when moving between the islands of the Lesser Antilles in the past.



KANAWA "AKAYOUMAN"

Figure 2: Drawing of Kanawa Akayouman, an experimental vessel used by the Karisko project (Bérard et al. 2016: figure 3; see below).

Figure 3: Image of Kanawa Akayouman in action (image Karisko) (Bérard et al. 2016: figure 6; see below).

Full reference figures 2 and 3: Bérard B., Billard J.-Y., L'Etang T., Lalubie G., Nicolizas C., Ramstein B. and Slayton E., 2016, « Approche expérimentale de la navigation précolombienne dans les Antilles », Journal de la Société des américanistes, 102 (2), pp. 171-204.

3.1.1 Canoes: What we Know

The relative absence of seafaring materials in assemblages makes it difficult for Caribbean archaeologists to identify the location of canoe travel corridors, where canoes were constructed, and when they were used (Callaghan 1999; Callaghan and Schwabe 2001; Ostapkowicz 1998). There are only a few whole or fragments of canoes recovered from the broader pre-Columbian Caribbean region (Callaghan and Schwabe 2001). Of those finds, many vessel remains are coastal canoes or river canoes from South America, Florida, Cuba, and the Bahamas, (Callaghan 1999, 2001; Cooper 2010; Granberry 1955; Keegan 1997; Lovén 1979; McGoun 1993, Palmer 1989; Ober 1894; Seidemann 2001). While these examples provide an approximation of what canoes in the Caribbean were like, it is difficult to rely on them as a complete representation of these vessels due to the fragmentary nature of the recovered canoe segments. Archeologists have drawn on examples from surrounding areas to analyze possible vessel types in the Caribbean to fill out the shape of pre-Columbian Caribbean canoes used for inter-island travel (Callaghan 1999; Seidemann 2001). However, Callaghan and Schwabe (2001) state that these canoe fragments do not wholly match those described by early chroniclers in the region (Fitzpatrick 2013: 109). As such, these fragments must be weighed against ethnohistoric and ethnographic accounts.

Though not directly connected with seafaring communities in the Lesser Antilles, it is possible that the style of canoe used by groups from the mainland Americas resembled types used by islanders. Canoes from Florida, like type 1a, are dugout canoes, or vessels made from one tree that have been hollowed out using fire, hot stones, and axes (Callaghan 1999; Honeychurch 1997a; Taylor 1938; see Figure 4). Callaghan (1999) has suggested that the early examples of canoes found in Florida exemplify expediently or rough-crafted canoes. The oldest example of this type of vessel is from DeLeon Springs and has a radiocarbon date ca. 4000 BC (Callaghan 1999: 13). Vessel like type 1a may be representative of canoes from across the Caribbean region dating to this period.

The Ye'Kwana style vessel, or type 1c, is produced by the Ye'Kwana peoples from the Upper Orinoco area in Venezuela (Callaghan 1999; see Figure 4). This style has been used by many groups from around "the State of Amazonas, south of Puerto Ayacucho" (Callaghan 1999: 15). This canoe is typically 5.6 meters or 18.4 feet in length (Callaghan 1999), which is half the size of some estimates for Pre-Columbian canoes in ethnohistoric sources (Peck 2002: 2). Vessel type 1c is comparable to another example from the Orinoco region, the type 1d or Warao type (see Figure 4). The Warao, whose name

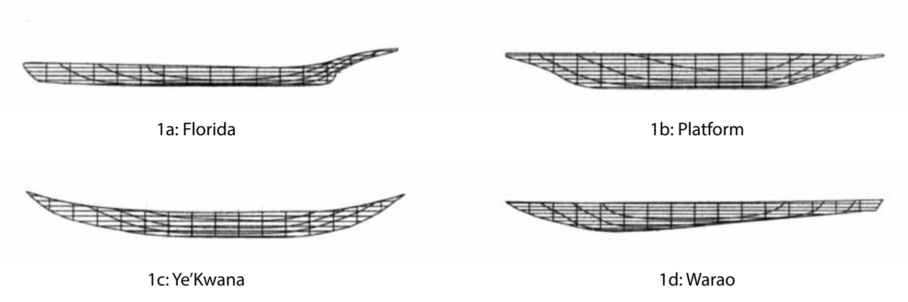


Figure 4: Image of canoe types from the Caribbean region, both the islands and the mainland (Callaghan 1999: figure 1, courtesy of the Northern Mariner).

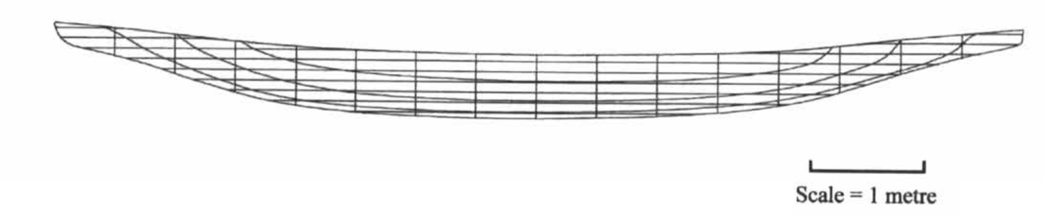


Figure 5: Depiction of the Stargate Canoe recovered on South Andros Island, Bahamas (Callaghan 2001: figure 2. Image taken from Current Anthropology, 42(2), University of Chicago. Copyright 2001 by The Wenner-Gren Foundation for Anthropological Research. Ail rights reserved ooii-3204/2ooi/4202-ooo7).

translates as canoe people, were considered the best canoe builders in historic times (Callaghan 1999: 15). The Warao type is more maneuverable than the Ye'Kwana style, but has a smaller carrying capacity (Callaghan 1999). This may indicate the Warao type was preferred by peoples from the Orinoco traveling through the sea.

Vessel type 1b, or the Belize platform style, is found throughout Central America (Callaghan 1999). This vessel shape allows for stable travel with a large carrying capacity (Callaghan 1999). Type 1b most resembles historical accounts of the canoes used by Amerindian peoples and was likely similar to the kind encountered by Columbus (Callaghan 1999: 15). It, along with the Ye'Kwana type, resembles the Stargate Canoe found in the Bahamas more closely than types 1a and 1d (see Figures 4 and 5).

The Stargate Canoe, found in the Bahamas, demonstrates the rough shape of Amerindian pre-Columbian canoes (Fitzpatrick 2013; Ostapkowicz 1998) and was likely used for coastal travel as opposed to sea voyaging (Callaghan 2001; Callaghan and Schwabe 2001; see Figure 5). The Stargate Canoe is similar in design to those from the Upper Orinoco River basin, including modern examples made by the Ye'Kwana (Callaghan 2001; Fitzpatrick 2013).

In cases where segments of canoes are recovered from island sites, it is often not possible to discern the size or shape of the vessel. Two canoe fragments were found in the partially submerged site of Los Buchillones on Cuba (Cooper 2004: 94, 2008: 181; Fitzpatrick 2013: 109). Because the two pieces measure 1.5 m and 2 m, respectively, they do not provide a complete picture of what the canoe would have been like (Fitzpatrick 2013a). In this case, drawing from the ethnographic record (Callaghan 1999; 2001) and considering the stability of modern canoes over longer distances (Bérard *et al.* 2016) may prove useful in determining the capability of pre-Columbian Lesser Antillean canoes.

Due to the incomplete recovery of canoe vessels from the Caribbean, it is impossible to say how these vessels were made and if vessels were augmented with planks or outfitted to host sails. According to ethnographic and ethnohistoric accounts, all canoe vessels start as dugouts (see Fitzpatrick 2013; Honeychurch 1997a; McKusick 1960; Taylor 1938). Archaeologists have found evidence of tools, such as wedges, which could have been used to make planks for canoes (Breukel forthcoming). Although there is no evidence of planks themselves in the archaeological record (Fitzpatrick 2013: 116), there are ethnographic accounts that support the addition of planks or boards to the sides of vessel (du Tertre 1667; Fitzpatrick 2013a: 116; McKusick 1960; Taylor 1938: 142). Plank canoes, in which the hull of a dugout canoe is spread further outward and additional siding is added, are ideal for sea voyages (Arnold 1997). Building

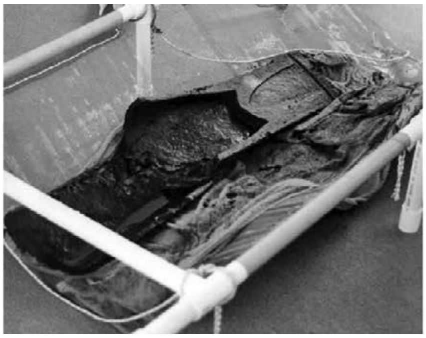


Figure 6: Remains of the Stargate Canoe recovered from South San Andros Island, The Bahamas (Image Richard Callaghan in Fitzpatrick 2013: figure 5).

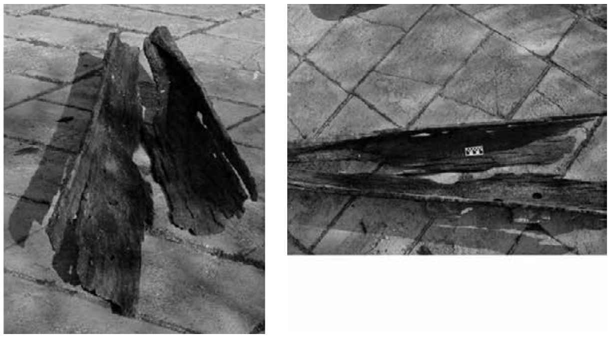


Figure 7: Image of Amerindian canoe fragments recovered from Los Buchillones, Cuba (Image Jago Cooper in Fitzpatrick 2013: Figures 3 and 4).

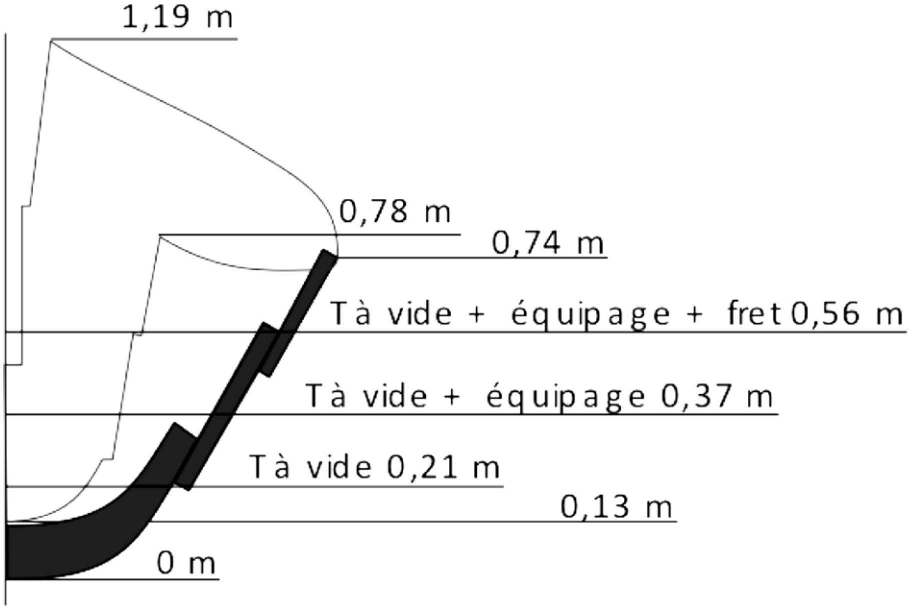


Figure 8: Depiction of planking style used on the Karisko project's Kanawa Akayouman (Bérard et al. 2016: figure 4. Bérard B., Billard J.-Y., L'Etang T., Lalubie G., Nicolizas C., Ramstein B. and Slayton E., 2016, « Approche expérimentale de la navigation précolombienne dans les Antilles », Journal de la Société des américanistes, 102 (2), pp. 171-204).

up the sides of the vessel protects both crew and cargo from rough seas (Bérard *et al.* 2016; McKusick 1960: 5; Honeychurch 1997a; Taylor 1938).

In drawings of these vessels composed by early chroniclers, the canoe seems to be of one piece, with no clear signs of planking (see Figures 9 and 10). This has inspired some to assume that there was no planking on these vessels (Frederick 2014). Modern reconstructions of canoes are made both with and without additional siding. Those without planking capsize frequently (Frederick 2014; Sardo personal communica-

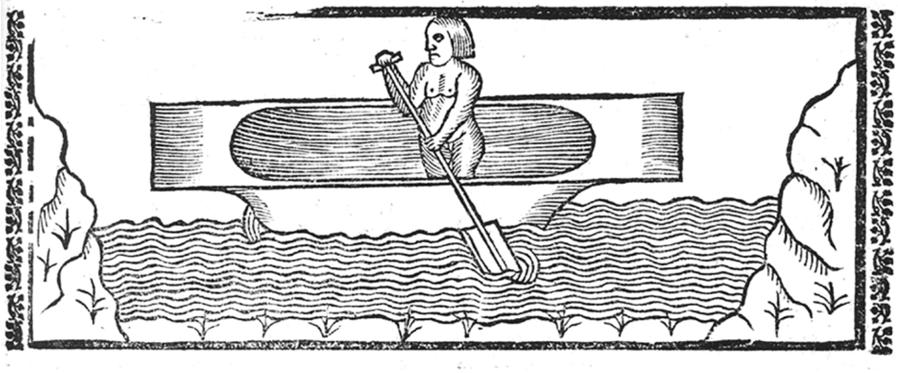


Figure 9: Print of a sole Amerindian in a canoe. Image by Gonzalo Fernández de Oviedo y Valdés (Fernández de Oviedo y Valdés and de Oviedo 1950).

tion 2016), which aligns with accounts of early chroniclers (Columbus 1493; Lovén 2010: 417). However, use of this technique in vessels constructed for the experimental canoeing group the Karisko project documents its success (see Bérard *et al.* 2016). It is a possible planking was used to shore up the sides of the vessel to help prevent capsizing (Taylor 1938). However, there is no way to confirm this technique was used by Lesser Antillean voyagers in the pre-Columbian era (Fitzpatrick 2013).

Because of the scarcity and fragmentary nature of canoes in the archaeological record, the ethnographic and early historic accounts that exist are extremely valuable. A review of text documents from the early colonial period shows that despite the variety of sources regarding early encounters in the Caribbean, there are only a few different descriptions of canoes. Columbus (1493) first describes canoes in this manner:

> "*They came to the ship in canoes, made of a single trunk of a tree, wrought in a wonderful manner considering the country; some of them large enough to contain forty or forty-five men, others of different sizes down to those fitted to hold but a single person. They rowed with an oar like a baker's peel, and wonderfully swift. If they happen to upset, they all jump into the sea, and swim till they have righted their canoe and emptied it with the calabashes they carry with them.*" (Columbus 1493 cited in Hulme and Whitehead 1992: 13).

Another description of a canoe, or *canoa,* comes from Columbus's 1493 letter to the Spanish royals who sponsored his voyage:

> "*in all the islands they have very many canoes, which are like rowing 'fustes', some larger and some smaller, and some are greater than a 'fusta' with eighteen benches. They are not so broad, because they are made of a single log of wood, but a 'fusta' would not keep up with them in rowing, since their speed is incredible; and in these they navigate all the islands, which are innumerable, and carry their merchandise. I have seen some of these canoes with 70 or 80 men in it, each one with his paddle.*" (Columbus 1493 cited in Hulme and Whitehead 1992: 13).

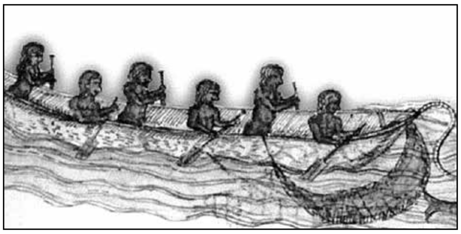


Figure 10: Print of Taínos travelling in a canoe. The image is from the Historia general y natural de las Indias printed in 1535 and written by Drake (Berleant-Schiller 1998).

Columbus also suggested that he encountered a "handsome dugout or canoe, made of one timber as big as a fusta of twelve rowing benches" (Beckwith and Farina 1990: 133; Dunn and Kelley 1989: 187; Fitzpatrick 2013:115; Jane and Vigneras 1960: 78). Peck (2002: 2) has stated that a fusta fitting twenty-four rowers may have been forty feet long, if accounting for extra storage space at bow and stern (Fitzpatrick 2013: 116).

The majority of ethnographic sources written between 1492 and 1650 provide similar descriptions of canoe construction (Columbus 1493 cited in Hulme and Whitehead 1992; Davies 1595; Drake 1585; Perry and Keith 1989). This follows the scarce evidence of canoe building that supports dugouts being constructed from one log (Lovén 1935: 417). For example, Drake (1585) describes canoes as "hogges trowghe," referring to the hollow shape of animal troughs used in Europe during this period (Hulme and Whitehead 1992: 54). The fact that the canoe was made from a single log seemed to impress the Europeans (Davies 1595; Drake 1585 cited in Berleant-Schiller 1998; Hulme and Whitehead 1992). Information on the size of these canoes in the Caribbean is more prevalent in historic sources (*e.g.*, Columbus 1493 cited in Hulme and Whitehead 1992; Davies 1595; Layfield 1590 cited in Hulme and Whitehead 1992). Some reports even suggest that canoes could reach "ninety-six feet long and eight feet broad" (Berna´ldez, in Jane 1988, II: 124 cited in Fitzpatrick 2013:114; McKusick 1960: 7).

Like the style of construction, the size of the crew is often left to speculation in ethnohistoric reports. For example, Gonzalo Fernández de Oviedo y Valdés, in his work Historia general y natural de las Indias published in 1535, mentions the general size of the canoe before the arrival of Europeans and their introduction of sails, including how many could fit within one:

> "*I've seen them large enough to carry forty-five men, wide enough to hold a wine cask easily between the Carib Indian archers… Sometimes they paddle standing, at times sitting, and kneeling when they feel like it. Some of these canoes are so small that they hold no more than two or three Indians, others hold six, others ten, and on up.*" (de Oviedo y Valdés 1535).

Most records indicate the use of smaller vessels, with specific reference to vessels which hold between one and 30 people (Davies 1595; Fitzpatrick 2013; Hulme and Whitehead 1992; Peck 2002). However, canoes could be built to serve larger groups, for example the 80-person capacity canoes described by Columbus (Columbus 1493; Columbus 1493 cited in Hulme and Whitehead 1992), or canoes holding 100 to 150 people (Deagan and Cruxent 2002b; Fitzpatrick 2013; McKusick 1960; Rouse 1992; Stevens-Arroyo 1988). These large canoes would only have served very specific functions, such as cultural displays or as war canoes, and were likely little used (McKusick 1970).

The size of a canoe crew is likely related to whether it served an 'every-day' or small-crewed trade or fishing trip or a ceremonial voyage, which required more crew members to paddle the larger vessels. Dr. Chana (1494), the surgeon appointed to Columbus's fleet, states that once the fleet had cornered a group of four men, two women, and a boy in a canoe with the intent to take them prisoner. This excerpt highlights the skill of some Amerindian seafarers, as it describes how a small group of six, not including the child, was able to maneuver adequately enough to momentarily stave off an attack by several Spanish boats. The fact that women were a part of this small crew shows that there were opportunities for both men and women to use canoes and possibly learn the basic mechanics of seafaring.

The makeup of crews probably varied depending on the purpose of the voyage. For example, war parties likely consisted of only men, while migrating communities would have included women and children as well (Boomert and Bright 2007). There is evidence of young men being involved heavily in canoe voyages (Lai and Lovell 1992; Weston personal communication 2015). This heavy engagement was possibly part of their training and induction into the larger seafaring and wayfinding traditions (Golledge 1999; Krisel 2000; Lai and Lovell 1992; Weston personal communication 2015).

Changing the number of people in the vessel can affect the speed of a canoe (Bérard *et al.* 2016) and the ratio of male to female and adult to child paddlers can affect the energy outputs of the crew. Evidence of this physical activity can be seen on the upper arm bones of canoers' (Weston personal conversation 2015), where the intense routine of paddling lead to musculature that left stressors on the bone (Lai and Lovell 1992). These musculoskeletal markers indicate that a wide section of the community was involved in these practices and highlight the importance of seascapes within various Amerindian societies. Furthermore, they indicate that many canoers paddled frequently, perhaps to maintain social connections between communities spread throughout the Lesser Antilles. Skeletal remains are just one line of evidence that points to the necessity of exploring the intricacies that helped shaped these pathways.

3.1.2 Paddles and Propulsion

Canoeing required an intense physical effort by seafarers because these vessels were powered by paddling. No matter who was propelling the vessel forward, everyone used a paddle to do so. As mentioned earlier, Columbus describes these paddles as similar to "bakers peels" (Parry and Keith 1984: 30), or the wooden tools used to remove bread from brick ovens. These oars were "laid in banks" along each side of the canoe (Layfield 1590 cited in Hulme and Whitehead 1992: 59; Layfield 1598). The oars themselves are:

> "*made like a long battle doore, saving that their palmes are much longer than broade, growing into a sharpe point, with a rising in the middest of them a good way… The shankes of these oars are of equal bignesse, and at the top crosset, like a lame mans crutch. These they use always with both their hands, indirectly they find cause to steer this way and that.*" (Layfield 1590 cited in Hulme and Whitehead 1992: 59).

This description is useful as it hints at the layout of the canoe and how much space would have been taken up by each paddler to wield the oar properly.

Though canoe paddles do not offer much information on the nature of canoe construction, they can suggest how and where canoes were used. Paddles were first described by du Tertre (1667, see McKusick 1960: 6) as having "a handle like a spade, with a small crosspiece of wood across the top" and a "blade… 2.5 feet long" (Fitzpatrick 2013: 109). This shape has been supported by ethnographic accounts (Taylor 1938) and archaeological remains. Paddles were decorated in various styles, though following the same overall shape (Ostapkowicz 1998). It is also possible that the decorations on these paddles indicated the status or position of the paddle's owner (Ostapkowicz 1998:119). These designs largely go unmentioned by very early chroniclers, bringing into sharp relief the lack of detail pertaining to canoes in reports from early histories.

The number of paddles that have been found around the islands is of great value to the archaeological understanding of sailing (Ostapkowicz 1998). Canoe paddles have been found in the Bahamas (4), Cuba (2), Dominican Republic (1), Haiti (1), and Grand Turk (1) (Beeker and Foster 1997; Conrad *et al.* 2001: 10; de Booy 1913: 2-5; Fitzpatrick 2013: 109-111; Granberry 1955; Harrington 1915, 1921:208; Lovén 1935: 417-419, 2010: 417; Olsen 1974; Ostapkowicz 1998: 118-122). Many recovered paddles in archaeological contexts are only fragments of the whole (Conrad *et al.* 2001; Fitzpatrick 2013: 109; see Figure 11). As they were likely the only means of propulsion prior to the Spanish arrival in the region (Rouse 1992: 16), evaluating the effectiveness of these paddles is significant. Paddles and their design may have affected the speed at which people were able to travel and the seasonal capabilities of vessels.

Although the number of paddles, or paddle fragments, recovered limits our understanding of their function in the Caribbean, comparisons with other paddle types from around the world can contextualize how paddles were used. It is likely that the style of paddle differed depending on the use or type of canoe (Fitzpatrick 2013), be it for river or ocean travel, fishing or ceremonial use. These ocean-going paddles distinguish themselves from traditional river-based paddles due to their lancet shape, which allows for quick removal from the water and allows for crews to achieve greater speeds (Lovén 2010: 417-418). River paddles are often shorter and more suited to calmer currents (Fitzpatrick 2013).

Experimental archaeology teams, like the Karisko project, have recreated canoe paddles based on archaeological evidence, ethnohistoric accounts, and ethnographic reports (Bérard *et al.* 2016; see Figures 11 and 12). The performance of these paddles as a stand-in for pre-Columbian canoer speeds and capability can help to determine the capacity of modern canoers. As such, the performance of canoes and paddles highlights the possible speeds achieved by vessels. This is the basis for the speed settings for virtual vessels modeled within least-cost pathway programs.

Figure 11: Image of canoe paddle from Manantial de la Aleta. "Canoe paddle blade (PNE-01-A-0235). Length 51 cm. The blade is lancet-shaped; the pointed tip would have been to the left and the handle to the right" ((source: Conrad et al. 2001: Figure 21; courtesy of the Journal of Caribbean Archaeology).

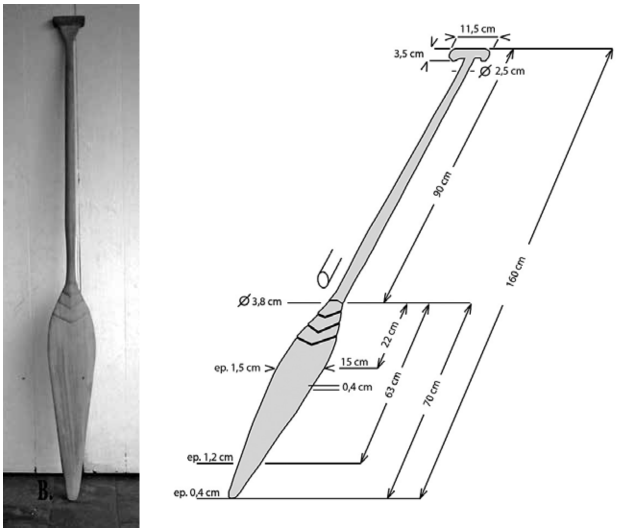


Figure 12: Modern reconstruction of Amerindian paddle for experimental use by the Karisko project (dessin B. Ramstein, cliché et DAO B. Bérard) (Bérard et al. 2016: figure 5. Bérard B., Billard J.-Y., L'Etang T., Lalubie G., Nicolizas C., Ramstein B. and Slayton E., 2016, « Approche expérimentale de la navigation précolombienne dans les Antilles », Journal de la Société des américanistes, 102 (2), pp. 171-204.).

Figure 13: Print of Amerindians leaving for the sea in a canoe. The image is from the Historia del Mondo Nuovo printed in 1565 and written by Girolamo Benzoni (Benzoni 1857).

Likely, early colonial representations of how individuals were spaced within the canoe do not reflect the actual relationships between the canoers or the canoers and the objects they were transporting. However, these images do provide some insight into how the vessels were propelled with paddles. Most images, like the one seen below (see Figure 13; see also Figures 9 and 10) show a series of paddlers resting towards the edge of the canoe with one set apart towards the back of the vessel. Canoers are often perched on the edges of the canoe near its rim (see Figure 13). From the drawing printed in 1565 by Benzoni (1857), we get some sense of how the canoe was propelled by forward-facing paddlers with an oarsman at the rear (see Figure 13). The placement of people in these images, as well as the designation of a rear oarsman, is consistent with the position of canoers within modern experimental voyages, like the Karisko project. Taking a seat near the rim of the vessel allows for easier mobility of the paddle and helps to balance the vessel (Bérard 2012).

3.1.3 To Sail or not to Sail

There is no archaeological evidence to suggest that any boat technology in the region of the Greater or the Lesser Antilles used the sail existed prior to European contact (Callaghan and Schwabe 2001; Fitzpatrick 2013b; Ostapkowicz 1998). There are conflicting historical reports as to whether sails were used in this time period (Callaghan 2011a; Fitzpatrick 2013a; McKusick 1960a; Seidemann 2001). For example, de Oviedo y Valdés (1478-1557) commented on the use of sails by Amerindians, specifically stating that "they sail (or navigate) with sails of cotton" (de Oviedo and de los Ríos 1851: 170-171; Edwards 1965; Thompson 1949: 71). However, de Oviedo y Valdés arrived more than twenty years after the islanders had seen the first Spanish ships with their sails (Edwards 1965: 352) and it is possible that he saw sails used by canoeing communities influenced by European arrival in the region.

There are some ethnographic sources that report that the sail was in use among native communities before the introduction of Europeans in the area (McKusick 1960). Honeychurch (1997a), however, postulates that it was not until the arrival of the Spanish and the adoption of aspects of their seafaring technology such as sails that Amerindian sailors were able to completely harness the wind, as the technological properties of the canoe prior to encounters with Europeans did not lend themselves to stabilizing a sail. Europeans introduced the sail either intentionally or by providing inspiration for copying almost immediately after Columbus's voyage to Hispaniola (McKusick 1960a). This technology, alongside material goods and stylistic elements, likely spread through the island networks by the Amerindians moving to the smaller islands at the turn of the sixteenth century (Holdren 1998; McKusick 1960a). The first recording of sails is from 1605 and the first mention of awnings is only slightly earlier in 1598. For example, John Stoneman (1625) recounts the story of how a Spanish priest, Friar Blasius's, introduced sails to the Amerindians of Dominica in 1605 (Edwards 1965; McKusick 1970; Fitzpatrick 2013). His story was recorded as follows:

> "*wee perceived in the cannoa a Friar, who cried aloud in the Latine tongue, saying O beseech, as you are Christians, for… I am a Preacher of the Word of G-d, A Friar of the Order of Franciscus in Sivill, by name Frair Blasius. And that he had been there sixteen moneths a Slave unto those Savages… We demanded of him then, how he got so much favour to preserve his life, his Brethren murthered: Hee answered, because hee did shew the Savages how to fit them Sayles for their Cannoas, and so to ease them of much labour often in rowing, which greatly pleased the Savages as appeared, for we saw them to use sayles in their Cannoas, which hathe not beene seene before.*" (Stoneman 1625: 4).

Some researchers have argued that the interpretations of descriptions of sails in historic material may not be tied to seafaring technology (Callaghan 2011a; Fitzpatrick 2013; McKusick 1960).

For example, Callaghan (2001) has suggested that the mention of sails could have referred to awnings. This is supported by the work of de las Casas (1875: 108-111), who records meeting canoes using awnings. Fitzpatrick (2013: 112) has suggested that the climate of the Caribbean may have supported the use of awnings or shelters on canoes to shade canoers. One chronicler, Dr. Layfield (1598), documented the use of a woven material, citing that material as "wicker" or "leaves" for use as awnings (Layfield 1590 cited in Hulme and Whitehead: 59). However, the passage that mentions the awnings does so in conjunction with the use of leaves to protect against rain, citing the awning as "a broad shield" to guard against the weather (Layfield 1590 cited in Hulme and Whitehead 1992: 59; Layfield 1598). This could mean that such items were not used as sails. It is of course also possible that the references to awnings could have also been about sails or a precursor to a sail.

Unfortunately, much like their canoe counterparts, whatever organic materials went into making awnings or sails were not preserved and no archaeological evidence has been found to support either claim (Honeychurch 1997a). The local materials that would have been used to make sails or awnings is unclear. As stated above, chroniclers recorded the use of cotton to make sails or awnings (de Las Casas' 1875: 108-111; de Oviedo y Valdés and de los Ríos 1851: 170-171). Stoneman's account of the Spanish friar from 1605 indicates that the Amerindians of Dominica got the material to make their sails from Spanish shipwrecks where "linen cloth and other merchandiser was cast on shoare" (McKusick 1970; Stoneman 1625: 4). Honeychurch (1997a) supposes that even if the Amerindians were making the cotton material required it would not have been in the quantity necessary to make a sail. Columbus may have also weighed in on this debate, noting one canoe had drawn up under a shelter or shed made of wood and covered with big palm leaves, so that "neither sun nor water could damage it" (Beckwith and Farina 1990: 133; Dunn and Kelley 1989: 187; Fitzpatrick 2013: 115; Jane and Vigneras 1960: 78).

This record indicates that while the adoption of sails was early, it may have required some mutual understanding and cooperative cultural transmission between the Spanish and the Amerindian canoe builders. It is also possible that the diffusion of knowledge concerning sails affected various groups of Amerindians at different rates. This may have affected the introduction of sails into the region.

The seafaring models calculated in the case studies do not use sail-based canoe travel and rely instead on paddling for motor activity. This is because the use of sails by Amerindian canoers throughout the Caribbean is not confirmable based on conflicting reports and possible observer misinterpretation. Until archaeological remains of sails are found, or stronger textual evidence emerges, I took the more conservative route of modeling based on motor activity that is confirmed.

3.2 Modeling Land and Sea Routes

Previous sea route models have focused on unidirectional drift colonization voyages (Altes 2011; Callaghan 2001). Drift voyages can refer to modeled least-cost routes that are undirected, where vessels move forward using current, wind, and in some cases a force equivalent to human paddling without aiming for a final destination. While this prior research explored the initial settlement in the Caribbean Islands (Altes 2011; Callaghan 2001), the current study aims to assess possible later routes. The routes representing possible reciprocal sea movement will be hypothesized and analyzed in the case study chapters (see Chapters 5, 6, and 7).

3.2.1 The Origins of Optimal Modeling Methods

Applying GIS-based methods to archaeological research questions connects a "spatial understanding" with "natural and anthropomorphic phenomena" (Conolly and Lake 2006), for example, the changing spatial positions of an individual affect how they perceive their environment (Ingold 2000; Tilley 1994). How someone interacts with their environment can be affected by their position within it (see Chapter 2). If they perceive a hill to be too hard to climb, their understanding of how much energy it takes to travel up it or around it may impact their path between two locations. Thus, the cost of movement in energy (*i.e.* calories) or time can also influence route choices (*e.g.*, Bell and Lock 2000; Bell *et al.* 2002; Herzog 2013; Llobera 2000; Surface-Evans and White 2012; Tobler 1993; van Leusen 1999). Surface-Evans and White (2012: 2) crafted a fitting description of least-cost pathways when they referred to them as "a means of reconstructing extinct connections between peoples and places, connections that are at the heart of many complex social, political, and economic questions of interest to archaeologists." In least-cost pathway models, humans possess knowledge of the wider landscape and will choose to travel on an optimal path (Surface-Evans and White 2012). Least-cost pathway analysis assumes that humans will want to economize their movements to fit with the principle of least effort (Kingsley 1949; Surface-Evans and White 2012). For example, works by Bell and Lock (2000) on an Oxfordshire Ridgeway in England, Herzog (2013) on the Nutschied Ridgeway in Germany, and Llobera (2000) on an area of the Yorkshire Wolds all approach the creation of least-cost pathways using calculations to suppose the cost in energy of traversing different slope gradients, with preference given to walking over low angles of slope.

Initial tests into modeling human movement across the landscape were developed as early as the 1950's (Imhof 1950). Using algorithms to model movement across a landscape was widely adopted in mobility research in archaeology (see Bell and Lock 2000; Borck 2012; Carballo and Pluckhahn 2007; Conolly and Lake 2006; Kantner 2012; Llobera 2000; Lock and Pouncett 2010; Marble 1996; Surface-Evans and White 2012; Tobler 1993; van Leusen 1999; Wheatley and Gillings 2002; White and Surface-Evans 2012). In most approaches to spatial analysis cost surfaces are generated to determine the difficulty of movement through landscapes (*e.g.*, Surface-Evans and White 2012: 5). Cost, or friction, surfaces usually refer to a gridded raster surface used to determine the cost of movement across an area (Surface-Evans and White 2012: 3). These can then be translated into least-cost pathways that detail how difficult it is to move from point A to point B in a certain region with certain parameters or defining factors.

These cost surfaces are based on Digital Elevation Models (DEM) (Conolly and Lake 2006; Tobler 1993; Wheatley and Gillings 2002). DEM's contain information on elevation and slope (Herzog and Posluschny 2011: 238-240). These factors commonly form the base of least-cost pathway analysis (Herzog 2010). The general search for pathways can be calculated in different ways depending on whether the goal of the program is to search all cells within a cost surface for the best path or to zoom in on least-cost pathway steps in stages (Kantner 2012; Lock and Pouncett 2010; Surface-Evans and White 2012: 3-4).

There are two main algorithms that dictate path selection that have been used in archaeology, Dijkstra's algorithm and A*algorithm (Surface-Evans and White 2012).

Proposed by Dutch computer scientist Edgar Dijkstra in 1959, Dijkstra's algorithm is designed to identify the lowest cost path between an origin point and every other point within a grid (Herzog and Posluschny 2011: 237; Surface-Evans and White 2012). Most archaeologists use this method, as it is included in most standard GIS software packages, either fully or partially in the calculation of least cost (Herzog 2014; Herzog and Posluschny 2011). Engineered by Hart, Nilsson, and Raphael in 1968, the A* algorithm is an adaption of Dijkstra's algorithm and implements a distance-plus-cost heuristic function to define its search for which points to pass through when creating a least-cost pathway (Surface-Evans and White 2012: 4). Programs using the A* algorithm begin by following the direction of the path with the known least cost. If it encounters a different path with a least cost it can switch to that route, and so on until the destination point is reached (Surface-Evans and White 2012). Though it has potential for use by archaeologists (*e.g.*, Livingood 2012), the A* algorithm has not been used widely within archaeological research (Surface-Evans and White 2012). Most of the land- and sea-based works discussed here use the Dijkstra algorithm, due to the its inclusion in most GIS software packages and shorter run time (Cormen *et al.* 2001; Herzog 2014; Surface-Evans and White 2012: 4). The current study applies the A* algorithm to the analysis of least-cost pathways to function within an isochrone model.

Many analyses of movement between sites and across different terrains have relied on cost-surface analysis, in the style of Dijkstra's work (*e.g.*, Gaffney & Stančič 1991; Tobler 1993). Movement between two points is assigned a cost relating to the degree of slope and distance crossed using an algorithm set by the archaeologist or the GIS program. The cost to travel across a slope can be expressed as:

$$mass \times gravity \times height\ ascended$$

The ratio between the two changes in potential energy is equal to "*Mgyi* : *Mgyz*" (Bell and Lock 2000:88). The change in potential energy is based on to the change in elevation, as gravity forces and the mass of the individual are assumed to be unchanging (Bell and Lock 2000). The equation $\tan \theta_1 : \tan \theta_2$ expresses the change in angle of an individual moving up, down, or across slope (Bell and Lock 2000).

Most cost surface methods use walking as the mode of transport (*e.g.,* Bell and Lock 2000; Kondo and Seino 2011; Lock and Pouncett 2009; Minetti et. al. 2002; Tobler 1993; van Leusen 2002), and most of the algorithms that calculate movement over a landscape rely on equations like Bell and Lock's (2000) to calculate movement. Researchers have approached movement across a landscape through a cost surface that represents a cost in either time or energy to the walker. Unfortunately, the methods that calculate either time cost or energy cost can return very different results for the same data set (Kantner 2012). For example, in cases where energy cost is prioritized, routes seeking slopes with less steep angles can be lengthy (Rademaker *et al.* 2012). Calculating shorter time paths may not favor easier slopes in the same way. These differences can affect how archaeologists evaluate pathway connections between past communities (Surface-Evans and White 2012). Because it is impossible to say whether groups prioritized optimal least-cost time or energy routes, the decision to use either method is left in the hands of researchers.

The earliest algorithms to calculate movement included slope as a factor. Imhof (1950) developed the following equation to calculate the cost of walking across a landscape for the Swedish military (Kantner 2012):

$$V = 6e^{-3.5|S+.05|}$$

Where V is walking velocity in km/hr, e is the base of natural logarithms, and S is the slope measured in vertical change over horizontal distance.

In this equation, the walking velocity across a landscape is directly based on slope. Tobler (1993) adapted Imhoff's (1950) equation for his hiker's walking calculation that has become a staple in archaeological least-cost pathway analyses (*e.g.,* Borck 2012; Gorenflo and Bell 1991; Kantner 1997, 2012; Livingood *et al.* 2012). Tobler's (1993) hiking equation is:

$$S = {}^{dh}/_{dx} = \tan\theta$$

$$W = \Big(6exp\big(-3.5 \times abs(S + 0.05)\big)\Big)$$

$$Travel\,Time = {}^{D}/_{W}$$

Where *W* is walking velocity (km/hr) for each cell, D is the distance across each cell, and S is the slope of that cell.

Both equations produce a cost to the traveler in km/hr . The returned costs for these equations help to establish both the optimal route mapped on the landscape and the cost in time to complete this pathway. Knowledge about route length would have been invaluable to past travelers because it would help them plan for what journeys were advisable and what supplies they would need to bring with them to sustain them throughout their journey.

Other calculations look to determine exactly what those supply needs would be. These algorithms calculate optimal routes by evaluating pathways with the least-cost in caloric expenditure to the traveler. Duggan and Haisman (1992) developed an equation for calculating movement across slopes in terms of energy expenditure based on research by Pandolf and colleagues (1977). Pandolf *et al.* (1977) based their research on direct observation of human movement in a laboratory (Kantner 2012). The algorithm created by Duggan and Haisman (1992) is:

$$M = 1.5W + 2.0(W + L)\left(\frac{L}{W}\right)^2 + n(W + L)(1.5V^2 + 0.35VS)$$

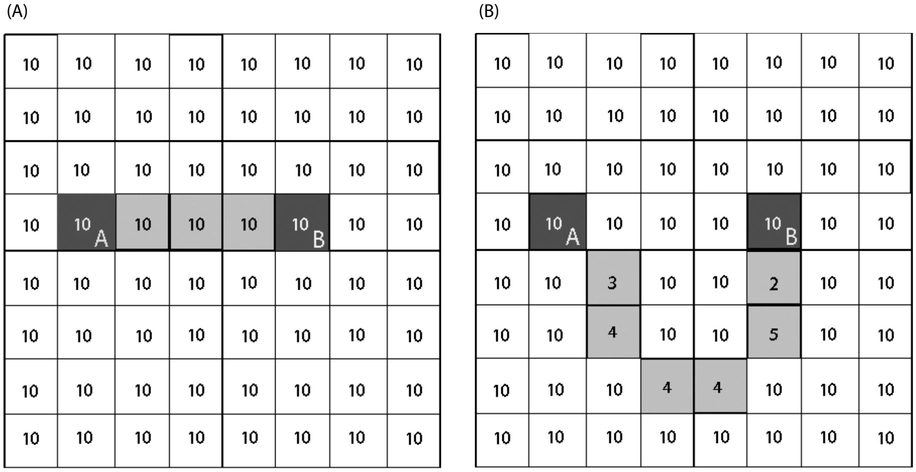
Where M is used energy or metabolic rate in watts (kilojoules/minute), W is the walker's weight in kilograms, L is weight of carried items in kilograms, is terrain factor, is speed of walking, and is slope.

Van Leuven (2002) updated Pandolf *et al.*'s (1977) and Marble's (1996) equation by adding a factor, S+6, so that the lowest cost values for terrain are slopes of 6 percent going downhill. Other studies by Santee *et al.* (2001), Kramer (2010), and Rademaker *et al.* (2012) have also explored how Pandolf *et al.*'s (1977) algorithm can be applied to archaeology (Kantner 2012). Other equations that aim to identify the cost in energy expended when crossing terrain to determine a least-cost path can be found in the broader cost path and human biology literature (*e.g.,* Brannan 1992; Ericson and Goldstein 1980; Hare 2004; Herhahn and Hill 1998; Kramer 2010; Kantner 2012; Llobera and Sluckin 2007). Many researchers avoid using energy-focused algorithms due to the number of variables, not all of which can be known (Kantner 2012).

Once the time cost or energy cost surface values have been determined and assigned to all cells within a grid, they can be used to create least-cost paths in GIS software packages. Within GIS programs such as ArcMap and QGIS, this grid is referred to as a raster. Raster grids are a series of geospatially linked squares, or cells, that are assigned values. In least-cost pathway analysis, these values express how difficult it would be for an individual to cross that cell. Traveling from one cell to another is directly related to the ease of moving between raster cells (Llobera 2000). Routes are calculated by evaluating which raster cells have a lower cost than their neighbors within the base grid. Travelers are more likely to pass through areas of high accessibility, reflected in movement through lower cost cells within the raster (Helbing *et al.* 1997).

Raster cells between the origin and termination points are selected based on choosing the overall least-cost route either by evaluating the entire cost surface or by selecting progression to the least-cost square cell by cell (Bell and Lock 2000; Llobera 2000; Tobler 1993; van Leuven 2002). This can be an important point of distinction for those modeling human behavior, as the former choice will represent trips done by people with knowledge of the whole region and the latter may generate routes as if travelers do not know the area. If the cells between two points have an equal cost, the route between them will appear as a straight line. If these cells do not have equal cost values, routes will appear to follow topographic features, or in the case of seascape modeling, currents or winds. An example of the trajectory of these two possible types of least-cost paths can be seen below (Figures 14 A and B ; see also Surface-Evans and White 2012: Figure 1.1 and 1.2).

The way in which modeled routes pass through cells can influence pathways resulting from a cost surface. Least-cost pathway modeling can either be isotropic,



(A)

10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10
10	10 A	10	10	10	10 B	10	10
10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10

(B)

10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10
10	10 A	10	10	10	10 B	10	10
10	10	3	10	10	2	10	10
10	10	4	10	10	5	10	10
10	10	10	4	4	10	10	10
10	10	10	10	10	10	10	10

Figure 14: (A: left) shows movement across a landscape where all cells have a uniform cost. (B: right) shows movement through a landscape where all cells do not have uniform costs (adapted from Surface-Evans and White 2012: Figure 1.1 and 1.2).

where routes to and from the origin point return an equal cost, or anisotropic, where the cost is different depending the direction the individual is traveling (Conolly and Lake 2006:215; Wheatley and Gillings 2002: 152-153). Both methods are used in archaeological approaches to least-cost pathways (Kantner 2012). Many archaeologists have moved towards assessing movement using Tobler's (1993) algorithm, which allows for anisotropic calculations (*e.g.,* Borck 2012; Kantner 1997, 2012; Marble 1996; Taliaferro *et al.* 2010; White 2012). For example, anisotropic movement would assume that communities living at the base of a hill would have a more difficult time visiting their neighbors living on the ridge than vice versa. Movement with or against slope can drain the energy levels of individuals at different rates (Wheatley and Gillings 2002). This cost difference probably affected where and in what direction past peoples moved. These considerations of movement with or against slope also need to consider the totality of the trip, meaning there-and-back journeys. The total cost of a trip may change when comparing the combined costs of reciprocal travel.

However, there is no guarantee that the difficulty in crossing up or down a slope would be viewed as disadvantageous by the peoples using these routes in earlier periods. Other factors besides the environment can weigh more heavily on landscape movement decisions. It is also true that some anisotropic calculations may not be viable because individuals carrying heavy loads may have spent the same time traveling down a steep slope as they would have moving upslope (Kantner 2012; Marble 1996; Wheatley and Gillings 2002: Figure 7.4). Anisotropic modeling, however, is essential when evaluating sea-based routes due to the strength of current force which can ease or inhibit canoe travel depending on the direction the vessel is headed.

Modeled least-cost pathways indicate hypothetical routes. Moreover, resulting pathways represent only a possible movement between two points and are not an absolute value of cost (Harris 2000). Pathways generated between archaeological sites or assemblages can help confirm or disprove archaeological hypotheses. In some cases, routes linking archaeological materials give rise to new questions concerning past interconnection. However, modeled routes are only one source of information for archaeological research, and should not be taken as the sole justification for a hypothesis, as least-cost pathways can be spatially or topographically deterministic (Harris 2000). Models can also undervalue, or completely miss, cultural or social norms that would have dictated travelers go another route. These factors can be acknowledged before analysis of routes, including sea voyages, even if not directly included in the model.

3.2.2 Previous Attempts to Model Sea Routes

Though the material and cultural exchange that resulted from voyages through the Lesser Antilles has been well documented (*sensu* Hofman *et al.* 2007, 2010; Hoogland and Hofman 2008), analyzing physical remains of inter-island exchange is only one avenue for research. Researchers have recently begun to consider seascapes as a surface for modeling past movement, which will allow them to approach the sea as a lived space and not only a platform for the exchange of materials.

The sea is a prime example of a diverse environment with an intricate surface on which movement occurs. Therefore, the sea should be viewed as a complex entity, rather than an empty space to be ignored or easily crossed (Broodbank 2002). To presume that movement through the dynamic sea environment is uniform ignores the many variables involved (Llobera 2000: 88). Variables such as wind, current, and speed of the vessel can influence the trajectory of a vessel and may have forced least-cost pathways to run in a specific direction or real-world canoe crews to choose one travel corridor over another.

Researchers who have modeled sea routes have typically generated a route time cost rather than an energy cost (*e.g.,* Altes 2011; Arcenas 2015; Callaghan 2003; Cooper 2010; Irwin *et al.* 1991; Leidwanger 2011; Slayton 2013). In order to do this, they have relied on various sources and forms of environmental data and have chosen to use different methods for translating that environmental data into cost surface, or friction surface, proxies (see Table 1). These sources were typically produced by government agencies, such as the United States Navy or the National Oceanographic Atmospheric Administration (NOAA) (Callaghan 2003; Davies and Bickler 2015; Slayton 2013). Due to the fragmented nature of data collection by these agencies, and sometimes different projects within the same agency, researchers rely on data sets with different cell resolutions and data (see Table 1).

Perhaps in response to these different data sets and the desire to model different types of voyaging, each researcher has developed their own approach to this method (*e.g.,* Callaghan 2003; Davies and Bickler 2015; Irwin *et al.* 1991; Montenegro *et al.* 2016). Some researchers rely on preexisting land-based tool kits in programs like ArcGIS (*e.g.,* Altes 2011; Gustas and Supernant 2016), while others rely on programs they have developed themselves. These various methods each offer unique perspectives on the possible past actions of navigators in different environments around the globe.

The method of modeling sea-based routes using computer processing and GIS-referenced data sets was first applied to island connections in the Pacific. Levison *et al.* (1973) carried out this pioneering work, which modeled sailing and colonization patterns. Later works, such as that by Irwin *et al.* (1991), further developed route modeling techniques to study colonization patterns and also focused on long voyages that were aimed at making landfall (Irwin *et al.* 1991). The genesis of these earlier works coincides with the development of the land-based least-cost pathway models we would recognize today.

In the decades following the publication of these works, many methodologies focused on adapting theories from landscape least-cost pathway analysis (see Table 1). In the Pacific, there have been several works that have built on the initial explorations of Levison *et al.* (1973) and Irwin *et al.* (1991) (*e.g.*, Avis *et al.* 2007; Callaghan 2003; Davies and Bickler 2013, 2015, Di Piazza *et al.* 2007; Evans 2008; Fitzpatrick and Callaghan 2013; Montenegro *et al.* 2006, 2007). Studies applying least-cost pathway theory to sea routes include efforts to model movement through the northwest coast of Canada and the United States (Gustas 2017; Gustas and Supernant 2016; Safi *et al.* 2016). Other works focus on modeling the movement of sailing vessels (Arcenas 2015; Leidwanger 2013) and the difficulty of bringing them into port (Safadi 2016) in the Mediterranean. There have been several studies which focus on retracing canoe movement through the Caribbean and in Lake Nicaragua (Altes 2012; Benfer 2017, 2018; Callaghan 2001; Cooper 2010). Recent studies have focused on visibility from the sea or sea routes (Brughmans 2017; Callaghan 2008; Friedman *et al.* 2009; Smith 2016; see Appendix A).[1]

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[1] References to an appendix in this work refer to the appendix for Slayton's PhD Dissertation Appendix, which can be found through the Leiden University Library, DOI: https://doi.org/10.17026/dans-zfu-tscq.

Year	Authors	Region	Wind Data	Res.	Current Data	Res	Type of Movement
1973	Levison, Ward, and Webb	Pacific (South)	Quarterly Surface Current Charts, Marine Division, British Meteo. Office, 1947, 1956	5 °, monthly averages	Quarterly Surface Current Charts, Marine Division, British Meteo. Office	5 °, monthly averages	Drift
1985	Wild	Sunda-Sahul	NA	NA		Reconstructed coastline	Drift
1990	Callaghan	Caribbean	Marine Climate Atlas of the World, U.S. Navy, 1995	1 °	Marine Climate Atlas of the World, U.S. Navy, 1995	1 °	Drift
1990	Irwin, Bickler, and Quirke	Pacific	Quarterly Surface Current Charts, Marine Division, British Meteo. Office, 1947, 1956	5 °, monthly averages	NA	NA	Directed
1995	Callaghan	Caribbean	Marine Climate Atlas of the World, U.S. Navy, 1995	1 °	Marine Climate Atlas of the World, U.S. Navy, 1995	1 °	Drift
1999	Callaghan	Caribbean	Marine Climate Atlas of the World, U.S. Navy, 1995	1 °	Marine Climate Atlas of the World, U.S. Navy, 1995	1 °	Drift
2001	Callaghan	Caribbean	Marine Climate Atlas of the World, U.S. Navy, 1995	1 °	Marine Climate Atlas of the World, U.S. Navy, 1995	1 °	Drift
2003	Callaghan	Pacific (North)	Marine Climate Atlas of the World, U.S. Navy, 1995	1 °	Marine Climate Atlas of the World, U.S. Navy, 1995	1 °	Drift
2003	Callaghan	South American West Coast	Marine Climate Atlas of the World, U.S. Navy, 1995	1 °	Marine Climate Atlas of the World, U.S. Navy, 1995	1 °	Drift
2005	Rahn	Orkney Islands	None	NA	None	NA	Directed
2006	Montenegro, Callaghan, and Fitzpatrick	Atlantic and Pacific	NCEP/NCAR reanalysis project, Kalnay *et al.* (1996)	1.9 ° 2° resolution daily	ECCO (MITgem)	1° at high latitudes, 1°*0.3° in tropics, 10-day averages	Drift, paddle drift
2007	Avis, Montenegro, and Weaver	Pacific (Western)	NCEP/NCAR reanalysis project, Kalnay *et al.* (1996)	1.9 ° 2° resolution daily	ECCO (MITgem)	1° at high latitudes, 1°*0.3° in tropics, 10-day averages	Drift
2007	Di Piazza, Di Piazza, and Pearthree	Pacific	Laboratoire d'Océanographie Dynamique et de Climatologie	1991-1999 1° grid; weekly summaries	NA	NA	Directed

Table 1 (continued on next page): Table showing existing seafaring modeling and simulations (Updated from Davies and Bickler 2015: Table 1).

Year	Authors	Region	Wind Data	Res.	Current Data	Res	Type of Movement
2007	Callaghan and Bray	Caribbean coastal area	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Drift
2008	Callaghan	Caribbean	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Drift
2008	Fitzpatrick and Callaghan	Indian Ocean	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Drift
2008	Evans	Pacific	SSM/I with ECMWF blended by NASA (DAO)	2.5° 2. 6° hourly	NA	NA	Directed
2008	Indruszewski and Barton	Baltic Sea	Wind data encountered during experimental voyage of Ottar (2004)	10° 10°	NA	NA	Directed
2008	Montenegro, Avis, and Weaver	Pacific	NCEP/NCAR reanalysis project, Kalnay *et al.* (1996)	1.9 ° 2° resolution daily	ECCO (MITgem) 1993-2005	1° at high latitudes, 1°*0.5 between 12° and 20°, 1°*0.3° in tropics, 10-day averages	Drift
2010	Cooper	Caribbean	None	NA	Data from experiential canoe trip from Cayo Hijo de Guillermo Este and Los Buchillones, (Callaghan 2001, Callaghan 2006; Callaghan and Bray 2007).	NA	Time Banded/ Isochrone
2011	Callaghan	Caribbean	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Drift
2012	Altes	Caribbean	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Drift
2013	Leidwanger	Mediterranean	www.windfinder.com, Wind and Wave Atlas of the Mediterranean Sea 2004	0.5° -1 °	Wind and Wave Atlas of the Mediterranean Sea 2004	0.5° -1 °	Time banded
2013	Fitzpatrick and Callaghan	Pacific (Western)	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Drift
2013	Davies and Bickler	Global	NOAA Blended Sea Winds (Zhang *et al.* 2006)	0.25°	NOAA Ocean Surface Currents Analyses – Real time (OSCAR)	0.33°	Directed, Drift
2013	Slayton	Caribbean, Mediterranean	None	NA	NOAA Global Drifter program, 2010-2015	5°, 3 hourly	Directed

Table 1 (continued).

Year	Authors	Region	Wind Data	Res.	Current Data	Res	Type of Movement
2014	Bar-Yosef Mayer, Kahanov, Roskin, and Gildor	Mediterranean	Mediterranean Pilot 1988, Weather and the Mediterranean 1964	NA	Mediterranean Pilot 1988	NA	Drift
2014	Leidwanger	Mediterranean	www.windfinder.com, Wind and Wave Atlas of the Mediterranean Sea 2004	0.5° -1 °	Wind and Wave Atlas of the Mediterranean Sea 2004	0.5° -1°	Time banded/ Isochrone
2014	Montenegro, Callaghan, and Fitzpatrick	Pacific	Marine Climatic Atlas of the World, U.S. Navy, 1995, ERA Interim Reanalysis developed by the European Centre for Medium-Range Weather Forecasts	1°, 1° between 1979 and 2011, 6 hour intervals	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Downwind or Directed
2015	Arcenas	Mediterranean	United States Imagery and Mapping Agency	5°	NA	NA	Directed
2015	Callaghan	Mid-Atlantic	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Drift
2016	Safi, Dolan, and White	Salish Sea	None	NA	NA	NA	Directed
2016	Montenegro, Callaghan, and Fitzpatrick	Pacific	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Marine Climatic Atlas of the World, U.S. Navy, 1995	1°	Directed
2016	Smith	Irish Sea / Celtic Sea	None	NA	Coastal Flooding by Extreme Events (CoFEE) Model	0.0185°	Directed
2017	Gustas and Supernant	Pacific Northwest Coast	None	NA	None	NA	Directed
2017	Baumann	Mediterranean	Modern Era-Retrospective Analysis for Research and Applications (MEERA) 100 m layer from the Global Wind Atlas	0.001°	None	NA	Directed

Table 1 (continued).

These researchers approached the modeling of routes differently, using several forms of environmental data and methodology. Many of these methods are limited by their reliance on licensed modeling software, the spatial extent of the study region, modern coastal boundaries, restricted vessel or navigation options, ability to represent only directed or drift voyages, deterministic or problematic environmental data (Davies and Bickler 2015), and a reliance on modern environmental data. Due to the availability of modern environmental datasets the resolution of data is different for models focusing on wind- or current-powered vessels (see Table 1). As such, it is difficult to categorize these works into methodological subsets. Though I will not give a detailed overview of all works referenced in Table 1, I will break the various methods used by these researchers into the type of pathways they generated.

Many approaches to modeling routes in the Pacific use programs that have been specially built to model sea-based pathways (Callaghan and Fitzpatrick 2013; Davies and Bickler 2015; Irwin *et al.* 1991; Montenegro *et al.* 2016). Pacific models have focused on directed sailing aimed at uncovering colonization routes and based on the assumption of prior knowledge of island location. Though different from modeling drift voyages, which make no assumption of prior knowle.g., these Pacific models are similar to the method used in this study, as many of those are centred on directed routes towards islands (*e.g.,* Davies and Bickler 2013, 2015; Di Piazza *et al.* 2007; Evans 2008; Irwin *et al.* 1991; Montenegro *et al.* 2016). Whether a voyage is directed or a drift voyage affects the level of human influence found in the model.

Researchers modeling Pacific and Mediterranean seafaring focused on vessels with sails. As such, they favoured wind data more heavily than current data for the creation of the friction or cost surface equivalent (Arcenas 2015; Irwin *et al.* 1991; Leidwanger 2013; Levison *et al.* 1973). Vessels in some Pacific models (Davies and Bickler 2015; Irwin *et al.* 1991) could tack, *i.e.* seek the best wind conditions available to reach optimal speed. Human decision-making was also a part of these models. Voyagers had the option of turning around for home after 20 days at sea if no islands were encountered (Irwin *et al.* 1991) or could set new headings after other set times (Davies and Bickler 2015). Though the navigator's ability to choose vessel heading was limited, the ability of vessels to change direction enables these methods to inject a human element not found in programs where vessels cannot tack (Callaghan and Fitzpatrick 2013; Montenegro *et al.* 2016; Slayton 2013). Because these wind friction surfaces were regenerated at the start of every new day (Davies and Bickler 2015; Irwin *et al.* 1991), the model allowed for some variability in sailing conditions. Turning around or tacking with the wind would have been vital considerations for sailors traveling over the longer periods and distances in the Pacific.

Montenegro, Callaghan, and Fitzpatrick (2016) built on this theory by allowing for routes to be based on short hops. In this case, modeled sailing vessels sought out the shortest distance to landfall with nearby islands while progressing to their final destination. Here, modeled decision making is geared towards identifying corridors of 'shortest routes between coastlines' that may have impacted larger trips. In cases where researchers look to model shorter distances, as is the case the current work, the need for fine grained resolution of environmental data is necessary. Early modeling efforts in the Pacific typically had a lower resolution for environmental data, because of the larger cell size at which the data was collected, than what has been used in the past two decades (Davies and Bickler 2015). As a result, researchers were not able to evaluate how the change in wind affected vessels as frequently (see Table 1). For example, Irwin's *et al.* (1991) original model used a friction surface with a cell size of 5° squares based on wind data for the months of July and January. In later works, Davies and Bickler (2015) ran models with a resolution of 0.25° for wind and 0.33° for current. This greatly increased the accuracy of the underlying cost surface.

As in the Pacific examples, researchers modeling sea routes in the Mediterranean have focused on seafarers using sailing vessels. This requires models to prioritize wind data over current data, which is shown in works by Arcenas (2015) and Leidwanger (2013). However, researchers evaluating mobility in the region have approached modeling these sailing routes using different methods. Arcenas (2015), who developed the seafaring model used by the ORBIS program, takes a more traditional least-cost pathway friction surface approach. This surface is limited to directional travel across set lines between port cities. The seasonal variation in cost to these lines is the only change in travel cost represented. To model routes along these set lines Arcenas (2015) used the equation:

$$T = \frac{F1(Vwind)}{F2(Vwind)}$$

where F1 (Vwind) is distance and F2 (Vwind) is the average velocity of travel time.

The original equation was adapted for use within the computer modeling framework used by the broader ORBIS program, and F2 (Vwind) was simplified to make use of wind-roses or speed-roses (Arcenas 2015). The simplification of F2 (Vwind) weakened the freedom of the vessels to choose an independent least-cost route. The resolution of Arcenas's model was set at a cell size of 5° squares and the wind data was averaged month by month. The larger cell size is problematic for accurately modeling routes, as the Mediterranean would contain only a handful of cells. The small number of cells is likely responsible for the rigidity of routes along the set grid of pathways between ports (Davis and Bickler 2015; Irwin *et al.* 1991).

Other methods of modeling sea routes focus on canoes, which were influenced more by current than by wind. This change is seen in Richard Callaghan's work in the Caribbean. Like his research in the Pacific, Callaghan modeled drift voyages. Callaghan relied on environmental data obtained from American Navy pilot charts (Defense Mapping Agency Hydrological Topographic Center 1982) and the United States Navy Climatic Atlas (United States Navy 1995), which has a resolution of 1° or 2° squares (Callaghan 2001, 2003). These grid sizes matched the needs of Callaghan's focus on connections from the mainland to the Antilles (Callaghan 2001). Callaghan's research in the Caribbean also explores how the use of different vessels would have affected a voyage's time costs (Callaghan 2001).

Although the vessel and environmental types in Callaghan's early work differ from earlier Pacific examples, such as Irwin, Bickler, and Quirke (1991), the method of environmental data being randomly selected at the start of every 'day' within the model is similar. Thus, the environmental data used as the base for these routes are static, not sequential. This tactic may be better applied to deeper time depths or greater modeling distances or coarser resolution of environmental data, where the random generation of currents may result in similar returns based on sequential environmental data. This method can also be said to apply to other researchers' work, where the data collected is calculated to form averaged isochrone models.

Unlike the previous examples where researchers modeled routes, Leidwanger (2013, 2014) and Cooper (2010) marked movement in bands of time. In studying the Mediterranean, Leidwanger (2013) created maps that showcased the length of voyages from to an origin point to all sections of coastline within the study area. He adapted wind data to a series of vectors that were then made into a raster grid and analyzed using ArcGIS (Leidwanger 2013, 2014). Leidwanger (2013) supported his use of environmental constraints with information on experimental voyages conducted in a replica of a Greek sailing vessel, modeled after a ship found in Cyprus dating to 300 BC. The vessel's sailing capabilities were based on physically observed data from the ship's performance. Though wind data was not the only environmental factor considered, the weights used to establish a cost surface were not fully articulated in the article.

Computer modeling of sea-based routes is a relatively new approach to studying connections between island communities in the Caribbean. Attempts to model movement through the Caribbean have general taken two approaches, either looking at the general difficulty to movement (Cooper 2010) or analyzing the likelihood of undirected movement across larger expanses of sea (Altes 2011; Callaghan 1999, 2001, 2003, 2008). Caribbean researchers have mostly focused on drift voyages (*e.g.*, Montenegro *et al.* 2006; Avis *et al.* 2007). For example, Altes (2011), who modeled colonization routes in the Caribbean, used ArcMap to run analyses of sea-based cost-surfaces, with the intent of creating pathways from South America to Florida. The cost surface resolution cell size for this model was 1° (Altes 2011). The force of the current applied in Altes's model is not specified and no wind information was added to the model. Like the model used in the present work, Altes (2011: 115) also made a point of leaving space for islands within the surface to avoid least-cost routes running through them. This is not typically discussed in other works referred to in the Table 1. The current redirect influences the vessel every 27 km within the cost surface (Altes 2011). This isodistance method, which calculates cost over set distances, is like the isochrone method used in the current study. The pathways generated in Altes's (2011) study conformed to those produced in undirected drift models.

Cooper (2010) created an anisotropic cost surface in ArcGIS to compare movement around Cuba. He combined landscape and seascape, which he termed islandscape (Cooper 2010). Results from Cooper's modeled time fronts highlighted the greater efficiency of utilizing coastal waters to move materials and peoples. Though he did reference the use of a cost surface for sea areas, Cooper (2010) did not provide explicit information on the nature of the associated water friction layer. He stated that the surface was derived from digitized water maps and interviews with local fisherman (Cooper 2010: 30). How this data would relate to current flow is unclear. However, the focus on travel time instead of physical cost in his research is consistent with the isochrone method used in the present study.

Altes and Cooper established the possibility using computer modeling to test for seafaring links in the region. Though typically focusing on broader success rates of voyaging between two areas, these works help to identify possible canoe travel corridors for colonial seafaring (Altes 2011; Callaghan 1999, 2001, 2003, 2008). These modeled pathways suggest the level of Amerindian canoers' capability to overcome the challenges of canoeing over long distances and for extended periods, indicating the skill and perseverance of pre-Columbian canoers. These efforts form the base for future modeling efforts, including those looking to establish possible corridors of movement between islands in the Caribbean.

3.2.3 Incorporating Archaeological Evidence

A human, or non-environmental, element was included in the setup of routes modeled for this study to ensure that pathways reflect these factors. Using known archaeological sites as the origin and termination points of pathways links the model to human action. The model further reflects human influence by assuming canoers knew various site locations, similar to the way sites are treated within a landscape (*e.g.*, Bell and Lock 2000, Llobera 2000; Surface-Evans and White 2012). However, many sites involved in the Lesser Antillean Archaic Age, Ceramic Age, and early colonial period inter-island exchange networks are unknown, as not all surfaces in the region have been surveyed. Environmental incidents, such as landslides, coastal erosion, and sea level rise have also obscured the location of sites (Bright 2011; Cooper 2010, 2012, 2013; Cooper and Peros 2010; Glassow *et al.* 1988; Hofman and Hoogland 2015; Siegel *et al.* 2015; Wilson 1989). Inclusion of missing sites as origin and termination points would increase the accuracy of suggested least-cost pathway networks and could impact how canoe routes between islands are analyzed (Bright 2011; Johnston 2002). However, this work only focuses on known sites in order to fit within the NWO Island Networks Project. A review of published archaeological evidence, including work done as a part of the NWO Island Network Project (Breukel forthcoming; Hofman *et al.* forthcoming; Laffoon *et al.* 2016; Mol *et al.* 2014; Scott *et al.* in press), particularly the existence of sites, informed the placement of nodes for this study.

Evidence of exchange can support inter-island movement (Hofman and Hoogland 2011; Hofman *et al.* 2008a, 2008b, forthcoming). The placement of archaeological sites can show the basic structure of canoe travel corridors that linked neighboring islands. Connections between site placement and the location of canoe mobility corridors has been discussed in other works (*sensu* Hofman and Hoogland 2004; Hofman *et al.* 2006, 2007; Rouse 1986, 1992), though without identifying the specific layout or base cost to these connections. Materials in assemblages can show how seafaring peoples living on islands across a channel from one another were linked. Similar materials found on opposite sides of a channel have demonstrated that communities canoeing between islands were sometimes better connected than communities on the same island, or even that coastal communities were better connected than inland sites (Bright 2011; Hofman *et al.* 2007; Rouse 1992). The presence of these materials can inform on the mechanisms of the mobility of peoples, goods, and ideas between islands.

Cross-channel connections and the transportation of materials between islands indicate that island Amerindian communities were oriented towards the sea and maritime connections (Bright 2011). Amerindian peoples' probable focus on maritime activity highlights how vital canoes were to these communities. Canoes would have been integral to social life as they were used to connect communities with other peoples and materials. The archaeological material underpinning each regional example of reciprocal canoe routes tied to Amerindian mobility through the Lesser Antilles will be discussed at the beginning of each case study chapter.

3.3 Conclusion

Combining archaeology, historical accounts, and experimental or experiential archaeology provide a strong background for the application and analysis of computer-modeled canoe routes through the Lesser Antilles in the Archaic Age, the Ceramic Age, and the early colonial period. This is particularly true for social aspects, which are essential to supplement the largely environmentally-driven nature of computer modeling. Canoers were motivated not only by ease of movement but also by the need to sustain and maintain community ties and connections with allies or family on other islands and the exchange or movement of materials.

Analysis of modeled least-cost pathways must also include consideration of the possible social motivations of canoe crews and navigators. These motivations are suggested through the archaeological record and ethnographic accounts, like those that express the technology and capability of sea vessels. Combined with theoretical approaches to understanding movement and the construction of mental maps (*sensu* Ingold 2000, 2011; Lynch 1960; Richards 1974; Tilley 1994; Trowbridge 1913; Wiebe 1989), the physical and psychological nature of seafaring can be weighed against the results of computer modeling. Ideas of how people remember past routes can support the re-use or maintenance of inter-island routes constructed by computer models. The integration of hypothetical physical routes and mental routes may point towards new understandings of social motivations and the actions of canoers.

Experiential voyages, like those conducted by the Karisko project (Bérard *et al.* 2016), can help to enhance our understanding of the human experience in canoes, the capability of voyagers, and how crew members relate to one another. These social functions may impact several aspects of voyaging, and should be included in modeling hypothetical routes, in terms or finding rest periods and stopover places for voyagers. These factors can help to identify where peoples may have wanted to travel and can support or contradict generated least-cost paths, which can be used to discuss what is possible and form a base on which ideas of voyaging and the creation of navigation maps can be placed.

Least-cost pathway analysis, social preferences for voyaging, and the historical record can provide additional methods to analyze archaeological evidence of inter-island interaction. Though cost-benefit analysis may not return definitive routes used in the past, they are one way to bolster or critique archaeological arguments by suggesting the possible layout of past movement. It is also possible that peoples would have chosen not to travel by the most direct or optimal route (Surface-Evans and White 2012). However, sea-based least-cost paths are one of the few ways to recreate past movement between islands, an aspect of Caribbean life that is obscured by the nature of the archaeological record of coastal environments and the relative absence of evidence of seafaring technology from sites.

Sea-based least-cost pathways can explore possible routes of connection through the modeling of reciprocal voyages under finer-grained cost surface resolution than has been used in the past. Some earlier studies in the Caribbean region applied modeling to drift voyages, which removed some of the human element from the results while more accurately suggesting colonization routes. The model developed for this work creates directed voyages that, while limited in terms of how they connect seafarers and sites, in a small way reconstruct the possible mental maps of past sailors and canoers. The specifics of this method and the base it runs on are detailed in the next chapter.