Computer Simulations of Ancient Voyaging

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Introduction

For those interested in ancient voyaging many questions cannot be answered with the available data. What was the probability of chance discovery of islands? What were the likely levels of success for voyages given particular seasonal variations in the marine environment? What were the survival rates? What navigational difficulties were encountered? Some of these questions can be answered in qualitative terms, but if accurate comparisons and assessments are to be made, quantitative data are necessary. While computer simulations of ancient voyaging can provide such evidence, its interpretation can also be a problem.

A small number of such simulations have been attempted, some more appropriate to the issues of interest than others. These simulations are discussed briefly below. But the primary focus of this essay is to point out some of the major considerations in developing simulations of ancient voyaging and to examine the results. The example used here is the prehistoric peopling of the Caribbean islands and subsequent contact with the mainland.

Existing Computer Simulations

Computer simulations have allowed us to go beyond some rather simplistic, uniformed and often just plain wrong assumptions about ancient voyages of discovery and exploration. An example of this is Andrew Sharp's argument that prehistoric methods of sailing and navigation throughout the world were never good enough to enable anyone to discover a new island, fix its location, sail home, and then either lead a deliberate voyage of colonization back to their discovery or tell other people how to get there.' Although the variables involved in setting up a simulation sometimes seem overwhelming, much depends on the questions asked. More general questions that assess whether chance or intentional exploration was involved in discovery, or what level of navigational difficulty might be involved in a particular passage, are more likely to be answered than are very specific questions, such as on which small island would landfall be made on initial discovery.

This latter type of question was one asked by *National Geographic's* team of computer and other specialists in 1986 about which of the Bahama Islands likely was the first on which Columbus landed. While the effort was generally considered successful, it

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was probably unnecessary to amass such a team since the outcome was the same as that proposed by Gustavus V. Fox in 1882.[2] Sometimes, if data such as logs exist, answers of this specificity may not require computer simulations at all.

Computer simulations have been successfully developed to study more general maritime topics, primarily in the Pacific. Michael Levison, Gerald Ward and John Webb designed the first experiment of this kind in the late 1960s.[3] The simulation examined the possibility that Polynesia was colonized from Melanesia or from South America, as Thor Heyerdahl espoused, by drifting with the prevailing winds and currents.' The results of 101,016 simulated voyages demonstrated that with only a few exceptions, undirected drift voyages could not account for the colonization of Polynesia from either source.

A version of the program was run that assumed that the intention of the crew was to maintain a general eastward bearing. This experiment ran 8052 simulated voyages. It was shown that, of all Eastern Polynesia, the Marquises Islands would have had the best chance of being colonized first from West Polynesia, despite the Marquises being about twice the distance from West Polynesia as the Society Islands, also in East Polynesia. The finding corresponds remarkably well with the pattern of colonization for East Polynesia based on historical linguistics. Further, the dates for human occupation in the Marquises are even now the earliest in East Polynesia. The results of this model continue to be indirectly supported by a large and growing number of ethnographic and experimental observations of navigational skills and efficient voyaging canoes of the Pacific Islanders', as well as by increasingly detailed studies of the combined effect of static and dynamic environmental parameters, strategies of exploration, and the rate of prehistoric expansion, as evidenced by a growing body of radiocarbon dates from islands across the South Pacific.

More recently, Geoffrey Irwin of the University of Auckland devised a second simulation program. The Auckland team utilized the same wind and current data as Levison and his co-workers, but their computer canoes were programmed for interactive sailing strategies. These included two versions that permitted navigation by dead reckoning, thus providing the option of return trips either by dead reckoning or by following the Polynesian tradition of latitude sailing.'

The results seem to bear out Irwin's earlier conclusions that human expansion across remote Oceania was neither a unidirectional process, despite being characterized by a macroscopic "bow-wave advance" from west to east, nor a cumulative result of countless haphazard one-way voyages. Rather, the simulation has strengthened the evidence for a much more complicated, but safer, multidirectional process of navigation that occurred initially against, then across, and finally down the prevailing winds. This complex pattern suggests that the overriding concern of early colonists was the safety of being able to backtrack to their points of departure, and not the speed or range of exploration. Nevertheless, this strategy was quite clearly evident to anyone closely looking at Levison, Ward and Webb's simulation and comparing archaeological data. In fact, the strategy had been anticipated without any benefit of a simulation by Edward Dodd.'

A third simulation, developed at the Australian National University in Canberra, utilized ethnographic data for the performance characteristics of Indonesian bamboo rafts to plot drift voyages from Timor to northern Australia – parameters relevant to the initial colonization of Sahulland in the Late Pleistocene.' Given known wind and current patterns nearly all rafts ended up on the Australian coast, most within a week to ten days. When Pleistocene sea levels were considered, it was impossible for a raft to miss Australia.

A fourth simulation study, and one that is ongoing, is my own work, which deals with the initial colonization of the Caribbean islands and subsequent trade and contact patterns.[9] I will present the results of some of this work as examples of the problems to consider when developing a simulation and interpreting the final results.

Development of a Simulation Program

When applying this type of research, several factors must be determined or estimated. These include type of watercraft and propulsion in use at relevant time periods; how these watercraft perform under various sea conditions; how the present maritime environment, with respect to winds and currents, corresponds to that of the past; the result of past fluctuations in sea levels; and the likelihood that any of the crew would survive the voyages of interest. A detailed discussion of all of these considerations is beyond the purpose of the present work, which is meant only as an example of what is possible.

The first problem in this type of analysis is to make a reasonable assumption about the watercraft that may have been used at relevant time periods. The earliest human occupation known in the Caribbean Islands dates to approximately 3000 BC for Cuba and 4000 BC for Hispaniola.[10] The only circum-Caribbean region with archaeological data that can be used to make assumptions about watercraft at that time is Florida.

Florida has a wealth of prehistoric canoes due to the excellent preservation in its wet sites. Lee Ann Newsom and Barbara Purdy defined four styles of Florida canoes on the basis of shape; these are simply termed Styles One, Two, Three and Four. The earliest radiocarbon age for a Florida canoe is *circa* 4000 BC. This canoe, from DeLeon Springs, has an upward curving bow, is relatively thin, shows charring on the interior, and falls into the Style Two category.[11] The next oldest radiocarbon determination of a Florida canoe is *circa* 3000 BC. This canoe, also from DeLeon Springs is classed as Style One, and has average dimensions of 3.6m x 40.6cm.[12] These canoes are fire hollowed with no attempt to modify the bow and stern. This style may represent unfinished or expediently crafted canoes.

Given the evidence for early canoes, it is reasonable to assume that dugout canoes of at least this level of technology had a wider distribution in the circum-Caribbean region, and were not limited to Florida, when the Caribbean islands were first colonized. This is particularly likely since the whole purpose of canoes is transport between places.

Style Three (figure 1a), with dates overlapping Style One, is one of the most interesting for this study. The bow in this style is worked into a platform. These canoes are primarily found on the Atlantic Coast, St. Johns River, and large lakes. The platform is believed to have been designed to navigate in large waves. It also prevents splitting.[13] The length of these canoes ranges from roughly 3.3 to more than nine metres and the width is about forty centimetres.

The historic distribution of a similar design (figure 1b), with both bow and stern worked into platforms, appears to have been very wide. It includes much of the mainland around the Gulf of Mexico and the Caribbean Sea, as well as the Caribbean islands. Archaeologically, it is depicted in the Maya regions of Central America at least as early as

700 AD.[14] The style is still used in some areas of Central America today, although usually with the stern modified for use with an outboard motor. Because of its broad distribution, seagoing design and relatively early date, it is reasonable to use it in this analysis.

As part of a larger study, canoes of the platform type were recorded in Belize, Central America.[15] Only one canoe of this type will be presented in this discussion. It is moderate in size compared to the very large dugouts reported at contact by Europeans, but is within the size range of most of the Florida sample. This vessel measured 6.9 x 1.35 x 0.63 metres and accommodated a crew of nine. For the later prehistoric periods, we can assume that canoes in the Caribbean were similar, if not identical, to those depicted in historic documents. These sources point to the Mayan style of platform canoe without making an assumption about any direct contact between the Antilles and the Mayan region.

The capabilities of all four of the above canoe types, Florida Style Three, Maya, Warao, and Ye'kwana, were used in simulations. The capabilities of primary interest were speed, capacity, and the effects of wind. There are a number of software programs that can quickly calculate these variables. The results of these analyses are discussed below.

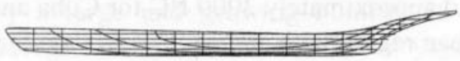


Figure 1a: Florida

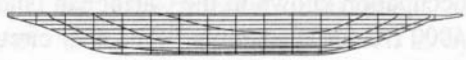


Figure 1b: Platform

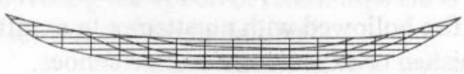


Figure lc: Ye'Kwana

Figure Id: Warao

The Ye'Kwana are a Carib-speaking group currently occupying the Upper Orinoco, in the Rio Ventuari region of Venezuela. They are considered the best boatmen in the region and the only group that crosses watersheds on a regular basis. It is considered by some to be high status to own a Ye'Kwana canoe. Actually, this basic style is used by a number of groups throughout the State of Amazonas, south of Puerto Ayacucho. The Ye'Kwana however, seem to make the finest version (see figure lc). The size of this craft (5.6 metres in length) is common, although some range from about half this size to much larger. Larger canoes tend to have truncated sterns to accommodate outboard motors. Stability is another factor that can be analysed once a detailed set of lines drawings are generated. What the figures tell us includes the loads the canoes can take in terms of displacement in salt and fresh water; speed and effort required; and seaworthiness. Since the programmes used here can quickly scale a craft, if a common dimension like LOA is chosen, then accurate comparisons of possible loads can be made between vessels.

The second vessel considered here is a Warao canoe from the Orinoco delta in Venezuela (figure 1d). The Warao in historic times have been considered among the best canoe builders in South America. Their own name for themselves means "canoe people." Since the delta lacks many important resources, the Warao produced canoes for other groups as well. Before the 1920s, the Warao mainly occupied the smaller remote *caños* of the delta, after which some, under the influence of missionaries, moved to the middle sections of some of the larger *caños.* Warao canoes of comparable length to the Ye'Kwana canoes do not have the same carrying capacity, but they require less power and are more manoeuvrable. These are features that would be of more importance to smaller groups living along the narrow, maze-like smaller *caños.* The Warao are also noted for their seafaring to Trinidad across some very rough waters.

The third canoe is Mayan from southern Belize (figure lb). This general style is fairly common in Central America and closely resembles some of the vessels described in early historic documents from the Caribbean, much more so in fact than the other three types of canoes shown here. Because of the widespread distribution of these canoes I suspect that they have a great antiquity. They are very stable, capable of carrying large quantities of goods, but require more effort to move than the other types. Canoes of this style, though larger, are likely to have been the kind encountered by Columbus along the coast of Central America. They seem well designed for long-distance trade.

The final type of canoe I want to discuss here is Style Three from Florida (figure la). The figure shows a generalized vessel based on average dimensions of canoes recovered archaeologically. Radiocarbon dates of 3000 BC have been obtained for vessels of this type. In terms of effort required to move these vessels and their capacity, this type is comparable to Warao canoes, although it is less manoeuvrable. Some of the Florida canoes also have a platform at the stern, making them similar to the Mayan. One major difference is that the beam is much narrower in the Florida type. This may actually be due to the narrowness of available trees in Florida rather than an element of conscious design.

This information was then used in a simulation model of the Caribbean environment based on data used to compile the *Atlas of Pilot Charts for Central American Waters.* [16] The environmental factors considered are winds, currents, gale and hurricane frequencies, and sea-swell conditions. Wind directions are weighted by their observed frequencies and randomly selected to calculate a route. The procedure is largely based on simulation models used to investigate Polynesian dispersal." This approach does not hypothesize unusual conditions or major changes in past environments other than lower sea levels in the early prehistoric period. I have argued elsewhere that during the period centred (around 6000-5000 BC), wind conditions similar to the present summer were likely more prevalent throughout the year.[18] The analysis has taken this into consideration.

Results and Interpretation

Three thousand drift voyages were simulated from each of several points around the mainland coast. The following figures show minimum sighting distances rather than actual coastlines. The results for the Platform Style canoe only are presented here and are as follows. For a 300-nautical-mile stretch of the Venezuela/Colombia coast there is a 0.3% chance of an undirected vessel successfully reaching Cuba with April environmental conditions (figure 2). Interestingly, April is the only month in which no tropical storms have ever been recorded anywhere in the North Atlantic, including the Caribbean Sea.[19] The success rate drops to 0.1% along the same stretch of coast in October. The vast majority of drift voyages from this staging area would end up in the vicinity of Panama, the Yucatan Peninsula, or being swept through the Yucatan Strait into the Gulf of Mexico.

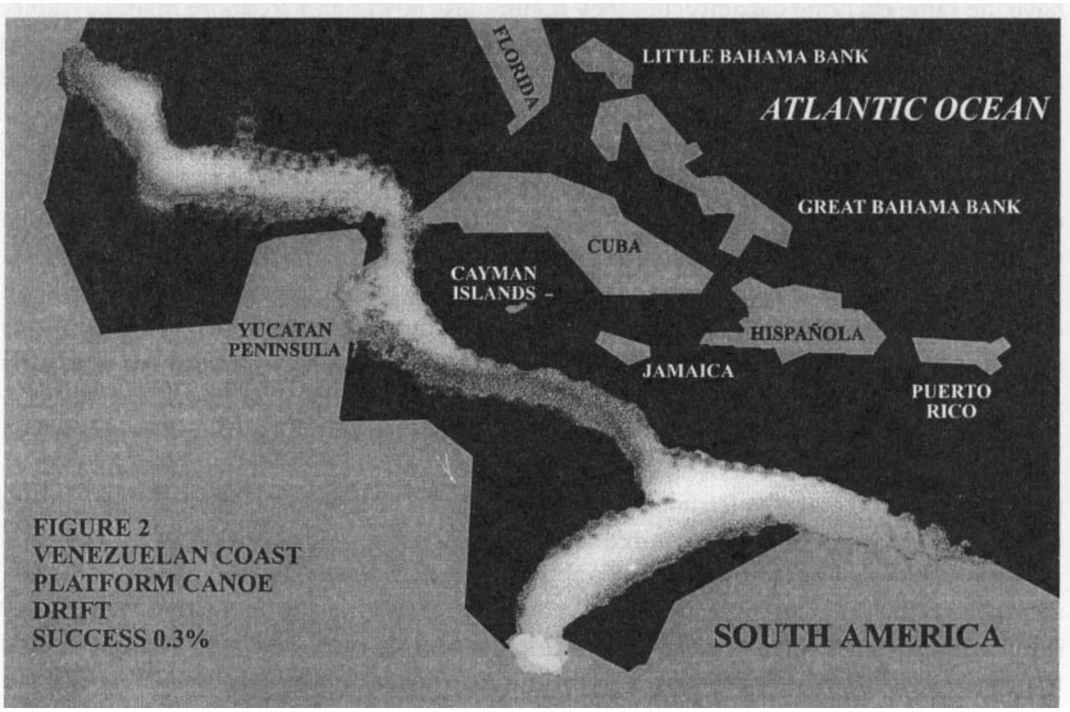


FIGURE 2
VENEZUELAN COAST
PLATFORM CANOE
DRIFT
SUCCESS 0.3%

For the northern Central American coast, successful drift voyages were limited to a small point east of Isla Mujeres off the Yucatan Peninsula (figure 3). This limitation is due to the complexity of wind and current patterns in the immediate area. The success rate was 0.1%, limited to April conditions. Moving the start position as little as ten miles north or south of Isla Mujeres eliminates any chance of success. The majority of drift voyages from this staging area would either be swept onto the shores of the Yucatan or through the Strait, missing the islands altogether.

Results for drift voyages from the eastern Gulf coast were surprising in light of the fact that no good archaeological evidence connects the area with the Antilles during the prehistoric period. High levels of success are possible from a point just out of sight of Key West, Florida. Again, the limited area from which success is possible is due to the complexity of local wind and current patterns. Given April conditions, 90.7% of all drift voyages from this point ended on the Cuban coast. Success rates for both October and January were 37.4%, while success in July dropped to 20.3%. Yet similar to the case for the Yucatan Peninsula, moving even five miles off this starting point eliminates any chance of success. Unsuccessful drift voyages here are swept back to Florida, through the Strait of Florida, or become caught in the complex counter-current off southwestern Florida.

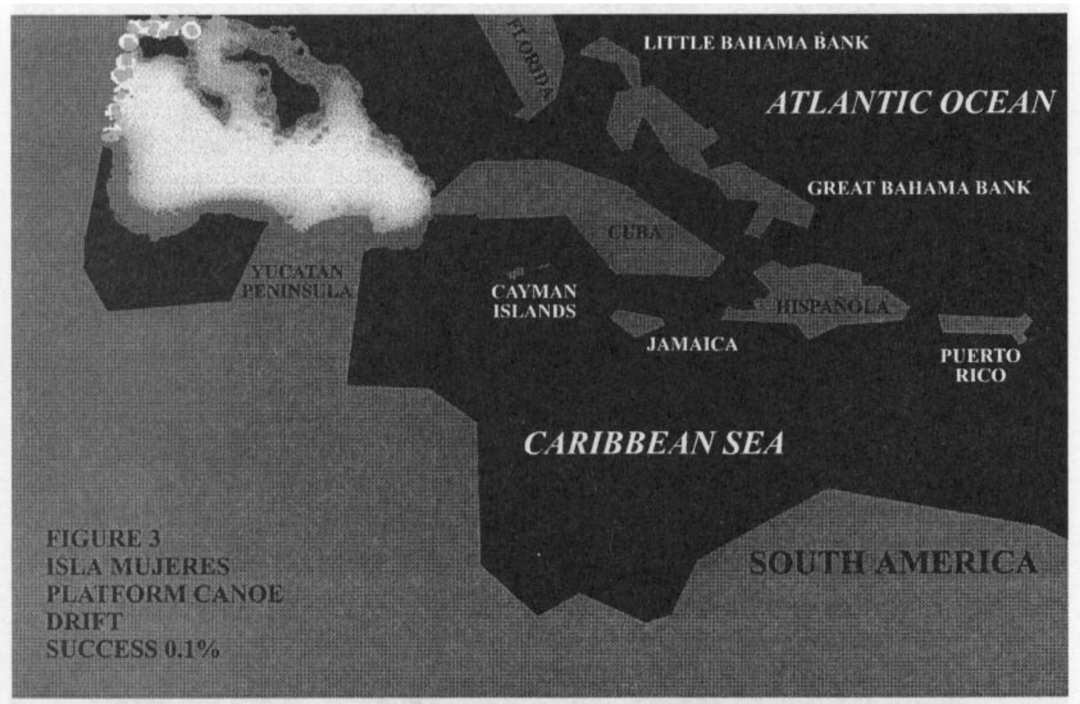


FIGURE 3
ISLA MUJERES
PLATFORM CANOE
DRIFT
SUCCESS 0.1%

Despite the low success rates for drift voyages from the South American coast, such voyages are likely to have taken place, given the time depth of human occupation and the long stretch of coast from which success is possible. Although there is likely to be some crew loss, it would not necessarily prevent the establishment of a colony. Drift voyages from the Yucatan Peninsula have a lower probability of success than the South American case, which is further lowered by the very restricted area from which success is possible.

It is much more difficult at present to decide where to rank the drift voyages from off Key West. Despite a high possibility of success, the starting point is very restricted. To what extent this would lower the probability of success in comparison to other areas cannot, at present, be determined. Since Florida is not currently considered a source for Antillean populations, this may not be an issue. On the other hand, it does raise the question of why there is not more evidence of contact between Florida and Cuba.

Considering the question of intentional voyages to the Greater Antilles, differentiating between mainland areas becomes more difficult. The configuration of the target area from South America is greater than from the other two. There is a window 80° wide from that coast compared to 50° from northern Central America and 75° from the eastern Gulf coast. More important is the variation in the paddling speed that must be maintained to reach the Greater Antilles. Success is possible from all three areas if a speed of 3.4 knots is maintained as a daily average (figure 4). This was determined to be the maximum that canoe paddlers could maintain in eight-hour shifts over long periods.20

FIGURE 4
VENEZUELAN COAST
PLATFORM CANOE
DIRECTED
SPEED 3.4 KN

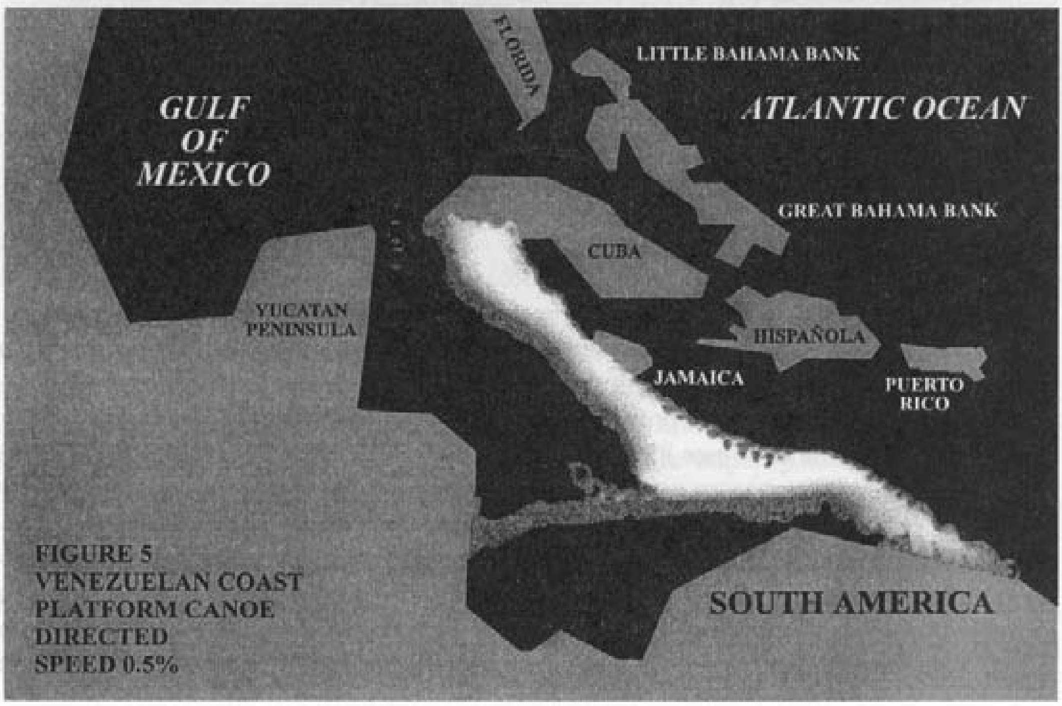
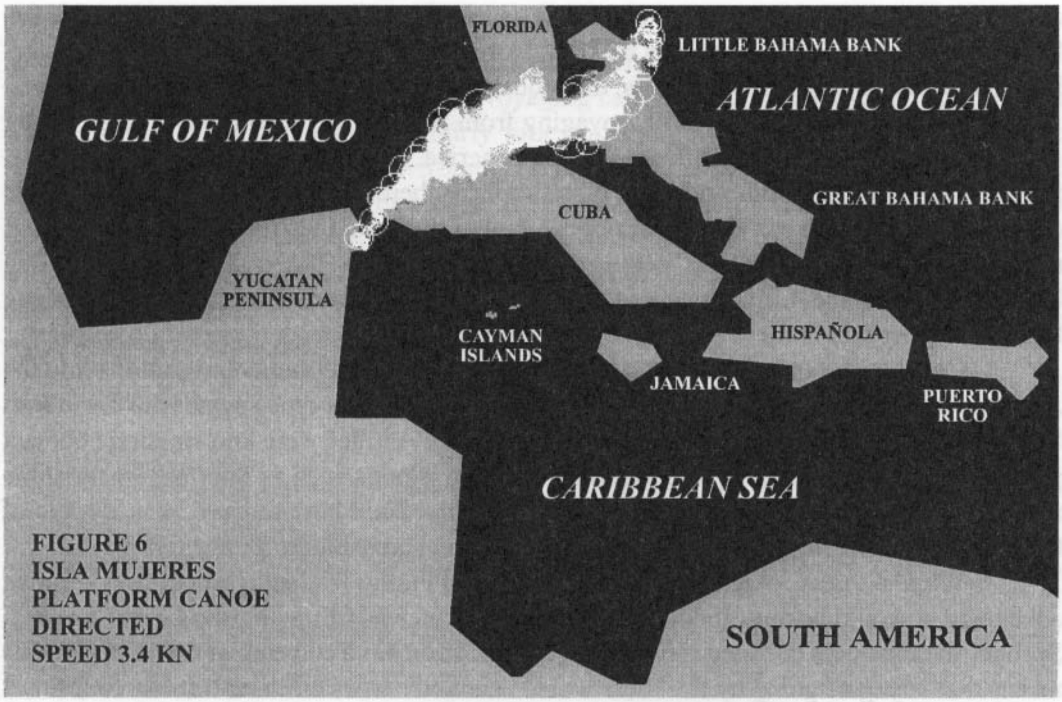


FIGURE 5
VENEZUELAN COAST
PLATFORM CANOE
DIRECTED
SPEED 0.5%



Nevertheless voyagers from South America who simply maintained a northerly bearing and an average daily speed of 0.5 knots would still generally make landfall in the Greater Antilles (figure 5). From most points off the coast of northern Central America, an average daily speed of at least 1.2 knots must be maintained even knowing the correct bearing to the islands. Only 0.2% of attempts to reach Cuba from off Isla Mujeres would be successful even if a speed of 3.4 knots were maintained without course changes (figure 6). Virtually any paddled speed in a southward direction from southern Florida would result in success.

Although the programme gives success rates for vessels, it does not include calculations of crew survival. Work in Polynesia, however, has provided a means of estimating this risk. It is clear that risk is determined by length of time at sea. Lengthy drift voyages in open boats due to shipwreck or other misfortune are well known for the Pacific Ocean under conditions similar to the Caribbean.[21] The maximum recorded drift seems to be on the order of seven to eight months. There are several voyages recorded that covered distances of *circa* 3000 miles over a period of six to ten weeks and a great number that went shorter distances. Levison, Ward and Webb used the survival probabilities presented by McCance and his colleagues to represent the cumulative percentage of crew losses.[22] These probabilities are based on 27,000 persons lost at sea.

From this, the danger to crew for drift voyages is as follows. Successful drift voyages from the South American coast took from four to five weeks with a probable crew loss of ten to twelve percent. This means that one or two people out of a crew of eight to ten could be expected to die on route. This could still result in a viable founding population, according to Birdsell, or the ability to make a return trip.[28] The probability of crew loss in drift voyages from the Yucatan Peninsula is about one percent and is insignificant. Expected crew loss for drift voyages from off Florida range from one to twenty-five percent. For intentional voyages from all areas, the probability of crew loss is less than one percent.

In terms of navigation skill, voyaging from South America directly to the Greater Antilles would be simpler than from Central America. Again, the question arises of why, if travelling between Florida and Cuba is so simple, is there so little evidence for prehistoric contact? Certainly, the early dates for dugout canoes in Florida testify that technology was sufficient for sustained contact between Cuba and Florida. The difficulty in travelling between Florida and Cuba does not appear to be any greater than crossing the Mona Passage, across which there appears to have been close ties during the ceramic period.[24]

Considering the ceramic period, when it is known that human migrations into the Antilles were from South America, it appears likely that direct crossings of the Caribbean Sea were undertaken. Once the locations of the Greater Antilles were known, direct contact was possible between the Venezuelan mainland and islands such as Puerto Rico, as some researchers have suggested.[25] The Lesser Antilles need not always have been a route of travel. Even moderate size canoes could make a direct crossing in four to five days.

While a direct route between Venezuela and Puerto Rico may not at first seem an advantage, it would be only about two-thirds the distance as following the Lesser Antilles. Second, the channels between the Lesser Antilles often have currents of three knots. This means that voyagers going by this route would encounter cross currents three to four times the strength of those faced in a direct crossing. Third, the deep valleys and high land of some of the Lesser Antilles, such as Dominica, produce heavy squalls that are a danger to vessels. Overall, a direct route is shorter, safer, and less rigorous than one along the Lesser Antilles. If voyages are in April, there is little danger of encountering tropical storms in the open sea. The expected loss of crew over a four- or five-day period is less than one percent.

Conclusions

The results of a simulation and their interpretation are fine in themselves, but it is desirable to have some way to verify the results. Although the Caribbean example I have presented is prehistoric, verification is possible by examining historic records, which are available beginning with the voyages of Christopher Columbus and continue in the form of media and rescue vessel reports of ships at drift in the region. Some of these not only support the patterns indicated by the simulation program but even suggest that for drift voyages from northern South America to the Greater Antilles, the simulation may underestimate the chances of success.

In many cases where computer simulations can shed light on issues of voyaging, contemporary historical documents do exist for verification. In these situations the simulation is much more powerful in terms of the types of questions that can be asked of it. An example is the use of a simulation to locate Japanese wrecks from the Edict Period on the Canadian Northwest coast. In this case the program can be used to predict where actual wrecks may be located, or it can be run backwards to see where an historically-recorded wreck likely first ran into trouble. The latter would be of interest to determine if known wrecks were engaged in breaking the edict on foreign trade and contact or simply had the misfortune of being caught in an unseasonable coastal storm,

Computer simulations of ancient voyaging can shed light on a variety of problems and questions. They are, however, fairly time consuming to develop. This limitation is becoming less the case as more environmental data become available in electronic media. Further, with a little forethought programs can be developed with enough flexibility to accommodate questions and problems not originally anticipated or to examine issues from entirely different time periods. In the near future, I envision the availability of standard simulation packages with considerable flexibility, thus eliminating the necessity for most researchers to develop their own programs.

NOTES

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