Prehistoric trade between Ecuador and West Mexico: a computer simulation of coastal voyages

Richard T. Callaghan*

The author studies prehistoric sea travel along the coast between West Mexico and Ecuador using a computer simulation incorporating the performance characteristics of sailing rafts. The model predicts that while northward voyages may have taken as little as two months, southward voyages would have entailed at least five months and may have required a strategy that took the rafts offshore for as long as a month.

Keywords: West Mexico, Ecuador, trade, sailing rafts, navigation

A variety of evidence shows that contact occurred between Ecuador and West Mexico (Figure 1) from 400 BC to the sixteenth century, even if such contact was not necessarily continuous. The evidence comes from metallurgy (Hosler 1988; Hosler *et al.* 1990), shaft

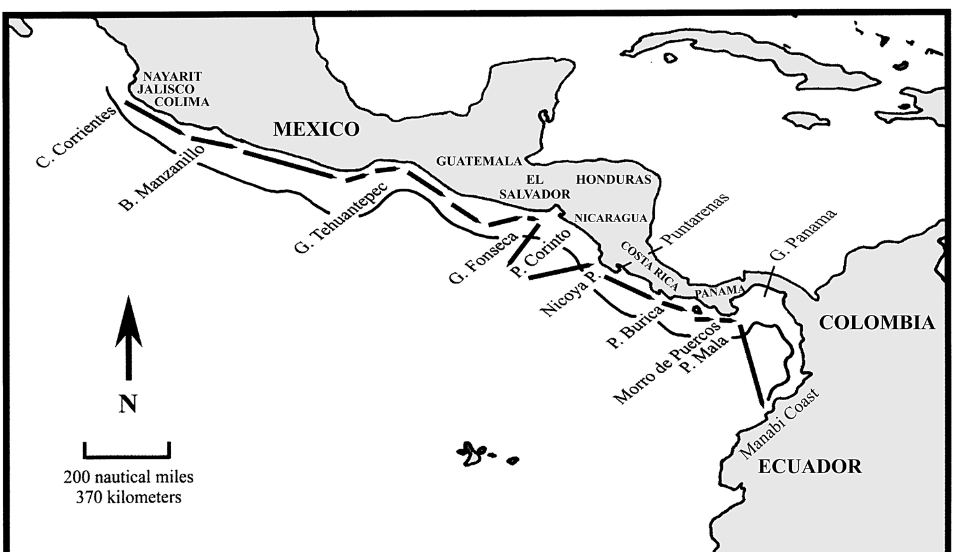

Figure 1. Pacific Coast from West Mexico to Ecuador showing suggested return voyage to the Manabí Coast and maximum sighting distances of land.

* *Department of Archaeology, University of Calgary, Calgary, Alberta Canada T2N 1N4 (Email: rcallagh@ucalgary.ca)*

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tombs and mortuary offerings (Kan *et al*. 1989), ceramic technology and style (Piña Chan 1989:33-38), language (Swadish 1967), design motifs (Meighan 1969), ethnographic sources (West 1961), costume (Anawalt 1992), and a number of other features (Zevallos 1987), and indicates that contact occurred sporadically from 400 BC to 400 AD, and around 800 AD, 1200 AD, 1300 AD, and 1600 AD (Anawalt 1992).

Computerised simulation programs have been used to investigate a number of archaeological and historical problems, including population dispersals (Levison, Ward & Webb 1973; Thorne & Raymond 1989), exploration strategies (Irwin *et al*. 1990), population origins (Callaghan 1999; 2003a), maritime trade and interaction (Callaghan 2001) and trans-Pacific contacts between Japan and North America (Callaghan 2003b). A computer simulation designed to answer various problems relating to prehistoric and historic voyaging is used here to investigate the difficulty of maintaining contact between Ecuador and West Mexico and to determine the level of skill necessary to make these trips safely.

The simulation program

The simulation program used here is a much more advanced version of the one used in Callaghan 1999 and 2001. This second-generation program is based on the United States Navy Marine Climatic Atlas (US Navy 1995) and has been expanded to include all of the world's seas and oceans with the exception of Arctic waters. The data is organised in a finer resolution of one degree Marsden squares (one degree of longitude by one degree of latitude) rather than two degree Marsden squares. In particular, this allows the effects of smaller and more variable currents to be accurately reflected in the outcomes. The advanced program also automatically shifts to the database for the following month after the month originally selected for has expired. This feature better reflects the reality of changing wind and current conditions over long voyages. A conversion to spherical co-ordinates has also been added in order to increase positional accuracy outside of the tropics. Finally, the program allows the operator to change the heading of a vessel during a voyage to reflect decisions made by the crew. This last feature is important when assessing the level of skill required to reach a selected target.

In its basic operation, the program makes a random selection of direction and speed for wind and current from the Marine Climatic Atlas (US Navy 1995) database. These data are compiled from ship reports and other sources since the early nineteenth century. A course is chosen for the vessel, unless undirected drift voyages are being investigated. Performance data, calculated using either naval architecture programs or field tests, are then used to calculate the ratio of vessel velocity to true wind velocity. Wind and current forces are allowed to affect the vessel for a twenty-four hour period, and a new position for the vessel is then calculated. A new heading is chosen every twenty-four hours to move the vessel in the desired direction.

Watercraft

The results of extensive research conducted by Clinton Edwards (1965a, 1965b, 1969, 1978) indicate that sailing rafts, sailed canoes, and paddled canoes were likely to have been used by Ecuadorian merchants during the period under consideration. Sailing canoes, which would have been more effective than paddling over long distances, appear not to have been adopted in northern Ecuador until the time of Spanish contact in the early part of the sixteenth century (Edwards 1965a: 356). Unfortunately, as Edwards points out, there is little archaeological evidence that suggests a preference for any of these watercraft in any possible prehistoric trade with West Mexico. Most of the pertinent data is from ethnographic and historical sources. However, given the lengthy distances involved in this problem, over 1800 nautical miles (c. 3450 km) in a straight line, and given that sailing rafts are safer, more comfortable, and capable of carrying larger cargoes than dugout canoes (Doran 1978; Edwards 1969: 8), they were chosen for this voyaging simulation.

Zevallos (1987: 17-25) argues the balsa sailing raft is of indigenous Ecuadorian invention and that it was in use for trade to the north and south by Valdivia times (c. 3000 BC). Sailing rafts appear to have had a distribution from the Sechura Coast of Peru to the Manabí coast of Ecuador, and possibly as far north as Cabo de Galera (Edwards 1969:4). Both the sails used on these rafts at the time of European contact and the dagger boards used to steer them are clearly of aboriginal design, one foreign to Europeans (Edwards 1965b: 66-81). These dagger boards are positioned between the logs of the balsa raft and are raised or lowered in order to steer the craft and balance the sail (see Estrada 1988; Baleato 1988). The size of the rafts varies considerably, from small fishing craft capable of being used as "lighters" carrying cargo of up to half a ton between vessels and shore, to large merchant craft carrying 60 to 70 tons of cargo.

Historic records show these craft sailing from Guayaquil to Lima in the south and from the same point to Panama in the north. These are distances of over 600 nautical miles (1100 km). The southward voyage to Lima reportedly took two months. This would have been the more difficult of the two voyages, as the rafts would have been sailing against both wind and current no matter what the time of year. Prehistoric pottery recovered in the Galápagos Islands has been identified as being 90 per cent originating on the Ecuadorian coast (Holm 1988: 184-185). The Galápagos Islands are 522 nautical miles (840 km) from the South American coast well out of sight of land, suggesting some knowledge of oceanic navigational methods. Modern replicas of balsa sailing rafts have sailed from Ecuador to within 400 nautical miles of Australia (Estrada 1988: 347).

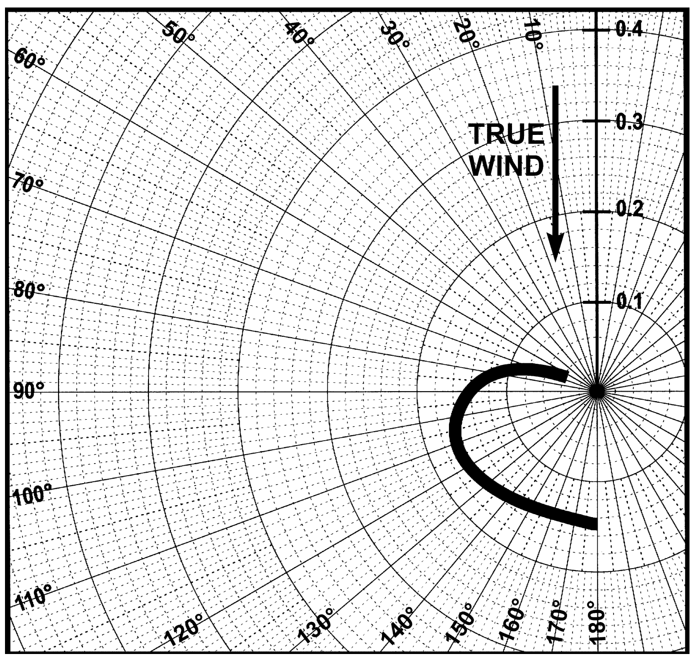

Figure 2. Polar diagram of raft sailing performance (after Doran 1978). The radial scale gives the ratio of vessel velocity to true wind velocity.

However, the origin of the sailing rafts used in northern

Peru and Ecuador is the subject of some controversy. Their distribution in the Americas is very restricted, while sailing rafts with very similar attributes, such as steering mechanisms and other features, are widespread in south-east Asia, and south-east China (McGrail 2001: 264, 294 and 351). Many scholars believe that the sailing raft was introduced to South America from Asia, a point of interest that has less impact on this research than does the striking similarity in the design and the operational features of the sailing rafts used in Ecuador and those used by Taiwanese fishermen. Doran (1978) constructed a replica of the Taiwanese sailing raft and calculated its sailing performance for varying angles to the wind (Figure 2). Given the close similarity of the South American and Taiwanese craft, the sailing performance figures for Doran's replica have been used here.

The experiments

Fifty voyages were simulated from the Manabí coast of Ecuador to Jalisco in West Mexico beginning in each month of the year, for a total of 600 northward voyages. The same was done for return trips from Jalisco to the Manabí coast. One of the goals of these simulations was to discover sailing strategies that would allow for such things as greater trading opportunities or shorter periods offshore if such were required. The strategy used was to try to stay within sighting distance of the coast throughout the voyages. The solid line paralleling the coast in Figure 1 is the maximum theoretical sighting distance. However, in the majority of cases identifiable landmarks are only visible from about 30 nautical miles (56 km) off the coast (National Imagery and Mapping Agency [NIMA] 2000a, 2000b). Another goal was to determine which month was optimal with respect to shortening the length of the voyage. Additional voyages were simulated to determine whether a strategy of sailing far to the west before turning eastward toward the mainland would shorten or otherwise facilitate the voyage. This is how the Portuguese solved the problem of sailing down the African coast.

The marine environment

In the summer months, the rate of the current between Cabo Corrientes in northern Jalisco (Figure 1) and Bahia de Manzanillo along the central coast of Colima is variable, but its set is always north-west following the coast (NIMA 2000a). It is strongest inshore and increases strength as it flows north to the cape. Further down the lower Mexican coast, the trade winds prevail from the north-west, usually paralleling the coast. The Gulf of Tehuantepec has strong north winds that often blow during the winter months. The west coast of Mexico is characterised by both land and sea breezes. During the day the sea breezes blow from the south-west, while the land breezes at night are not as regular in direction or in force. The rainy season extends from May to November, while the rest of the year is dry. Most of the precipitation is in the form of heavy showers or thunderstorms. September has the most rainfall.

Along the coasts of Guatemala, El Salvador, and Honduras as far as the Gulf of Fonseca, the north-eastern trade system dominants from December to May. These are generally gentle winds. From May to November the predominant winds are from the south and south-west. Sea and land breezes are common during this season and south-west squalls occur occasionally. Thunderstorms occur frequently during the rainy season. Some of the middle sections of this region experience a type of secondary dry season with a decrease in rainfall for a few weeks in the summer. Thundershowers account for most of the precipitation. Generally, the current along this section of coast sets west, but local areas often have eddies affecting its direction. Currents in this area can be highly variable from year to year, making prediction difficult. It is also considered wise to stay off the points of land.

At Fonseca the rainy season runs from May to October, with frequent heavy squalls and variable weather conditions. During periods of settled weather, the prevailing winds are variable from the north-east. October to February brings strong north winds, which may last more than a week. Otherwise light and variable winds predominate. South-east from Fonseca, at Puerto Corinto, strong currents from the north-east are a hazard.

A marked wet and dry season continues to Puntarenas near the Necoya Peninsula, with the rainy season running from April through November. Winds at this time are from the south-west, often reaching gale force with heavy rain in September and October. Although calms prevail in the dry season, violent squalls with heavy rain occur often. North winds in February and March are considered dangerous. Near Puntarenas, currents set to the west.

From Punta Burica to Punta Mala in Panama, north-east winds predominate from November to April shifting to the southwest from June to September. The prevailing winds vary locally from November to April, which is the dry season. Seasonal winds are irregular, modified by land and sea breezes. Occasional calms and squalls occur. The Equatorial Countercurrent causes an east set around Morro de Puercos. This is joined by the current from the west side of the Gulf of Panama near Punta Mala. It then flows to the south-west and, eventually, to the west.

The Peruvian Current influences the climate for the rest of the coasts of Panama, Colombia and Ecuador (NIMA 2000b). Prevailing winds along the northern part of the Colombian coast are from north-west to north-east and are very predictable between December and April. From May to August these winds alternate with south-west winds. The prevailing wind in September and October is from the south-west but frequently changes to the north. From December to February, gales occasionally occur from the north or north-east.

The south coast of Colombia is characterised by south-west winds from April onwards, which become increasingly steady until September. They then become less steady as they are replaced by north winds in February and March. From August to December, the south-west wind is dependable. Gales are extremely rare in this region.

Along the coast of Ecuador, the prevailing winds are south to west, these being steadiest between June and November. North winds occasionally occur from late January to early April. Gales are practically unknown, but thunderstorms and heavy squalls sometimes occur. The northerly Peruvian Current influences the coastal currents but its influence is replaced in the early part of the year by a southerly flowing current along the coast of Ecuador.

The question arises, is the data from the US Navy Marine Climatic Atlas (US Navy 1995) applicable to the time period of interest here? Proxy data such as pollen and oxygen isotope cores can shed light on past precipitation. Precipitation is a product of atmospheric and oceanic circulation and so can be used to gauge changes in these systems. Metcalfe *et al.* (2000: 717), in their review of Late Pleistocene – Holocene climate change in Mexico, state that modern summer dominant rainfall pattern was established sometime after about 9000 years ago. They conclude that significant climate changes have occurred in Mexico during the period, but that: "[t]*he magnitude of these changes, especially in the Holocene, has however been smaller than in other parts of the northern hemisphere…*" (p.713). Their review of data from central Mexico shows a number of dry intervals over the last 3000 years with a particularly severe one about 1000 years ago (2000: 710). The same conditions are also indicated in Central America (2000: 716). The drying trends may have been associated with a lessening of Pacific storms associated with el Niño events (2000: 702). Interestingly, evidence from Ecuador (Haug *et al*. 2001: 1306) indicates the establishment of el Niño periods only in the past 5000 years. The peak densities of such events lie between c.3500 and 2600 years ago and then in the past 660 years – roughly bracketing the period of trade between Ecuador and West Mexico.

In South America, the climatic data of interest comes from Lake Titicaca (Cross *et al.* 1999) and Colombia (Marchant *et al.* 2002). In the Americas, climatic change south of the equator often appears to be anti-correlated with that north of the equator. Cores from Lake Titicaca (Cross *et al.* 1999) indicate that lake levels have been relatively constant for the past 2100 years. This again suggests conditions for voyaging were similar to present. For Colombia it has been suggested (Van der Hammen 1974) that the modern climate, at least in the east, was established about 4000 years ago. However, Marchant *et al.* (2001) find indications of continued vegetational response to environmental change since 3000 BP, noting that some of the changes are probably due to human impact rather than climate alone.

With the establishment of the modern summer dominant rainfall pattern in the north 9000 years ago and the el Niño periodicity 5000 years ago, modern climatic patterns were in place along the Pacific coast of Latin America. As I have argued elsewhere (Callaghan 2001) for the Caribbean region, major variations in the overall circulation patterns are not expected but differences from the present exist at the level of seasonal patterns. Summer or winter conditions prevailed for longer or shorter periods than now. For maritime travellers, the main result is most likely to be a change in the timing of stages of the voyage between West Mexico and Ecuador. A secondary effect would be that a lessening of el Niño activity during most of the period of interest would have lead to fewer storms, making sea travel safer.

Results and discussion

Table 1 gives the durations for voyaging from the Ecuadorian coast to Jalisco calculated for the start of each month of the year. The shortest trip north would be possible starting in May and would last on average 47 days. This assumes that the voyagers did not stop for any significant time along the coast. There was no problem sailing close to the coast for the entire journey. If sailors left Ecuador in any month other than May, the time at sea increased by fewer than eleven days – not a major difference in sailing time. Presumably voyages north would have taken longer, owing to relatively frequent stops to trade and re-supply.

Although the duration of northbound voyages are similar all year round, weather conditions are likely to have favoured departure in specific months or seasons. A departure in April or May allowed voyagers to take advantage of south-west winds as far as the Azuero Peninsula of Panama. Not only are these winds favourable to a northerly passage, they also make it easy to remain inshore. Similarly, favourable south-west winds blow as far as the Gulf of

Table 1. Voyaging times from the Manteño Coast of Ecuador to Colima Mexico.

Starting Month	Mean Duration in Days	Range
January	59	57-63
February	57	56-60
March	52	51-53
April	51	49-55
May	47	46-51
June	52	49-54
July	53	49-56
August	55	50-59
September	52	51-57
October	54	50-58
November	54	51-60
December	53	50-59

Table 2. Voyaging times from Colima Mexico to the Manteño Coast of Ecuador.

Starting Month	Mean Duration in Days	Range
January	187	175-203
February	148	136-166
March	103	96-124
April	97	93-110
May	131	120-167
June	218	198-242
July	357	341-385
August	138	115-156
September	198	178-215
October	226	205-236
November	185	171-231
December	198	169-235

Tehuantepec until September or October, although gales might be encountered, particularly near Fonseca, as might squalls and thunderstorms further north. From Tehantepec north, the prevailing winds are less favourable, but sea breezes from the south-west near the shore during the day can be taken advantage of and the current becomes favourable. Overall weather conditions favour a spring departure with an arrival in Jalisco by September or October.

The ethnographic sources cited above (West 1961) indicate a five or six month stopover in the region of Jalisco. This would indicate that a return trip would start about March or April. Table 2 gives the length of time for voyages with departures by each month. March and April departures result in the shortest return voyages of a little under three-and-a-half months. However, beyond the Gulf of Tehuantepec, sailing rafts would have to sail for at least two months in the open ocean without the option of making landfall regardless of the date of departure. The necessary strategy (Figure 1) is to make brief excursions out to sea before returning to land. The only way to avoid such a long time spent far offshore would be to extend the duration of voyage to about five months.

Thirty voyages were simulated using this strategy. The shortest durations necessitated a departure between February and April. Voyagers could stay inshore as far as Guatemala, reaching it in about 65 days. From there, a short, week-long trip out to sea brought them back to land near the current location of San Salvador. It was possible to stay inshore for another week before heading out to sea just north of Fonseca. Vessels had to sail southward for about 260 nautical miles (480 km) and then east for 300 nautical miles (450 km) making landfall at the Nicoya Peninsula after about thirty days. From there, coastal sailing was possible to the Azuero Peninsula, which could be reached in roughly three weeks. A final, two-week excursion into the open sea would bring the voyagers home to the Manabí coast.

The necessity of sailing out to sea, beyond any possibility of sighting land, suggests some form of oceanic navigational method was known to Ecuadorian voyagers rather than a total reliance on visual pilotage. This is also suggested by archaeological recoveries from the Galápagos Islands (Holm 1988).

Northward sailing is thus a relatively easy task, while southward sailing is a lengthy endeavour requiring considerable navigational skills. Given the difficulty of the return trip, the main trade item sought must have been very valuable. Ecuadorian traders supplied *Spondylus* shells to the huge market south of their lands (Norton 1988). *Spondylu*s was used for ritual purposes and this item was highly valued and considered essential. The mollusc does not occur in the colder waters to the south, and its distribution in areas north of Ecuador is sporadic. It is found in the area around Jalisco. These lengthy expeditions (on the order of a year and a half in duration) probably only took place when Ecuadorian and other nearby sources were depleted.

Method

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