Cultural Responses to a Late Holocene Climatic Oscillation in the Mariana Islands, Micronesia: Lessons from the Past

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Abstract

Archaeological data from south-central Guam are presented to show that technological and social adaptations enabled the ancestral Chamorros of the Mariana Islands, Micronesia, to remain mobile farmer-fishers despite a major climatic oscillation, from the Medieval Warm Period (MWP, c. 800-1350 C.E.) to the Little Ice Age (LIA, c. 1350-1900 C.E.). For several centuries people responded appropriately to increased aridity and harvest shortfalls during the LIA but tolerance limits for stresses to their cultural system were exceeded during violent clashes with Spanish colonizers in the late 17th century.

Key Words: *Mariana Islands, climate change, cultural adaptations, prehistoric archaeology*

Introduction

This paper[2] is about a prehistoric cultural system that persisted in the Mariana Islands of Micronesia for nearly a millennium before Spanish conquest and colonization. Archaeological data from south-central Guam are presented to show how technological and social adaptations enabled the ancestral Chamorros, whose descendants are the indigenous people of the Marianas today, to remain mobile farmer-fishers despite the environmental challenges presented by a major climatic oscillation, from the Medieval Warm Period (MWP, c. 800-1350 C.E.) to the Little Ice Age (LIA, c. 1350-1900 C.E.). During the MWP, more reliable rainfall produced relatively favorable agricultural conditions that were associated with settlement expansion in the large southern islands including Guam. With the onset of LIA-associated aridity, a function of higher El Niño frequency and intensity, agricultural productivity declined. In response, the islanders made appropriate technical adjustments in settlement pattern, crops, and ceramics to buffer against harvest shortfalls. They also adjusted socially. As island resources were increasingly contested, kinship affiliations became more exclusionary and defensive/offensive alliances formed and re-formed. These modifications manifest a kind of adaptive escalation, as in van Valen's (1973) "Red Queen Principle": more intensive responses to familiar factors enable a system to persist. Systemic tolerances for internal and external perturbations were exceeded during the late 17th century, when disruptions to subsistence and settlement patterns were sustained over the thirty-year-long wars of resistance to Spanish colonization, ultimately resulting in pacification by the early 18th century.

The paper is organized as follows. First, physical environmental challenges for human life in the Marianas are reviewed, followed by summaries of pre-colonial Chamorro history and customs and the formative centuries of Chamorro culture, called the Latte Period by archaeologists. Key findings from the Manenggon Hills archaeological project, Guam, are then presented, interpreted as behavioral responses to significant changes in climate, reflecting a process of adaptive escalation that encompassed the entire archipelago prior to Spanish entry. The paper concludes with a comment on contemporary concerns about climate change and its human dimensions.

Marianas Geography

Situated in the northwestern Pacific between 13 and 21 degrees North Latitude, the Mariana archipelago comprises 15 volcanic islands, and numerous sea mounts and shoals occur in the vicinity (Fig. 1). The Marianas are products of the clash of the Pacific and Philippine tectonic plates that has elevated the eastern edges of the Philippine plate, along which arc-like formations of volcanoes, some extinct, others still active, are arrayed.

At 212 mi^2 (549 km^2), Guam is the largest island in the Marianas and in Micronesia; Saipan and Tinian are about half that size, Rota even smaller, and tiny Aguiguan is little more than an elevated limestone rock. In the prehistoric past and today, people have preferred living in the southernmost islands, which are also the largest, oldest, and best watered within the archipelago.

Arid Climate

A drought is a deficit in rainfall, whether on a seasonal basis or over longer periods. In the Marianas, the dry season is from about December to June and the rainy season begins around July and continues through November, although rain-

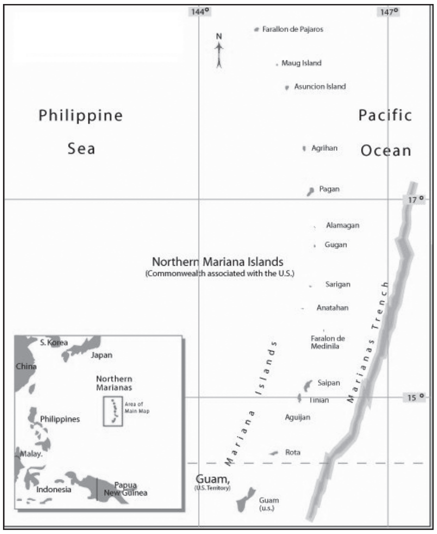

Figure 1. The Mariana archipelago in the western Pacific Ocean.

fall is highly variable in the transitional months of November and June. On average, Guam and Rota receive comparable amounts of annual rainfall (c. 100 in, 2540 mm), while Tinian and Saipan receive about 10 in (254 mm) less; islands farther north in the archipelago are progressively drier. Climatologist Mark Lander (1994, i) has commented on Guam's relatively arid climate:

> *Despite the relatively high annual rainfall amounts, Guam suffers deleterious effects of drought almost every dry season: dessication [sic] of grasslands, desiccation and defoliation of some species of trees, significant reduction of stream flow, and significant reduction of the water level in many of Guam's wells. Wildfires burn thousands of acres during many dry seasons. Every three or four years, the dry season is especially dry and prolonged. Wildfires and stress to local crops are thereby aggravated and prolonged...*

Severe droughts in the Marianas come with the El Niño/Southern Oscillation (ENSO) every 4-7 years. "Exceptional dryness during the dry season and a prolongation of dryness into the early part of the rainy season are an effect that ENSO episodes have upon Guam and all of Micronesia" (Lander, 1994, i).

Ancestral Chamorro cultural adaptations to marked seasonality and frequent drought likely included growing a variety of crops that produce storable fruits, nuts, and tubers, and rice, and less desirable wild foods (e.g., Indian mulberry fruits and Federico palm nuts). Year-round crops such as coconuts and giant swamp taro helped fill in gaps in seasonal plant production, and seasonally aggregating fish and large-bodied pelagic fish could be stored by drying or pickling.

Typhoons

In Micronesia, tropical cyclones (typhoons in the western Pacific) account for c. 30% of the world's total, the highest of any region (Abbott, 1996). The Mariana archipelago lies within a geographic zone that, on average, annually receives between three and four of these storms (Lander, 2004). Typhoon winds can be extremely destructive, although the extra rainfall helps to make up for annual deficits. Typhoons form most often during the wet season but can arise any time of year, and some of the deadliest storms in recent times occurred in the dry season. There is recent evidence that typhoon intensity is correlated with ENSO (Camargo and Sobel, 2005); Guam's typhoon risk is one year in three for El Nino years and about one in ten for non-El Nino years (Lander, 2004). Salt-laden winds disrupt plant reproduction cycles and destroy buildings. Flooding and erosion are other results, the extent and precise location of the damage depending upon the strength and direction of the winds and storm surge. Islands at the periphery of the circulation may receive rain but little wind damage, and often only one island is severely affected by a given storm.

While modern measures against typhoons include technologically sophisticated early warning systems and concrete structures, prehistoric adaptations likely included taking refuge in caves and high ground during storms and dispersed crop planting patterns aimed at minimizing losses. Other measures probably included maintaining wide networks of social relationships within and between neighboring islands that enabled people from badly affected areas temporarily to move in with relatives in unaffected parts of the island(s), as well as to obtain stock for replanting decimated gardens. Storing foods in large pots, subterranean pits, and caches in rock shelters would also have buffered against local typhoon damage to crops.

Other Environmental Challenges

Remoteness, smaller landmasses,[3] narrow and non-continuous fringing reefs, earthquakes, volcanic eruptions, and sea level fluctuations are also Marianas environmental challenges for human occupation. A problem with remoteness is that if re-supplies are needed, they can be obtained only at great cost, or not at all. The nearest large land masses (the Philippines and Papua New Guinea) are about 1600 mi west and south, respectively. Ocean-going canoes, the technology available prehistorically, carry relatively small cargoes, and, despite highly developed local navigation traditions, tropical seas are treacherous. Given these realities, longstanding reciprocity between people on nearby, or even distant, islands makes adaptive sense (Alkire, 1978).

Larger landmasses exhibit greater habitat diversity and species richness than smaller land masses (for tropical islands see Pielou, 1979, 174-184). Smaller island size restricts the number and kind of animals (including humans) that can be supported without outside subsidies (Pulliam, 1988, 1996). In the Marianas the only native mammal was a small forest-dwelling fruit bat. Native land birds are also small, and individuals rarely congregate, reflecting dispersed sources of food and shelter. Not surprisingly, birds did not comprise a significant dietary element in the Pacific during prehistoric times (Steadman, 2006).

Several kinds of marine life are supported by the fringing reefs, bays, and estuaries of the Mariana Islands, and large fish occur in the seas surrounding the far northern islands and at distant shoals (Starmer 2009). While pelagic species were accessible from ocean-going canoes, inshore resources were taken by nets and spears. Southern islands reefs are more developed but are narrow and patchy, and sheltered waters are rare. Despite the apparent abundance of marine resources here, they were likely insufficient as the sole support of human groups. Geographer Tim Bayliss-Smith (1975, 13) calculated that to support a community of 30 persons dependent only on inshore marine resources would require a minimum of 17.2 km of reefs and reef flats c. 200 m wide. The perimeters of Guam, Rota, Tinian, Saipan total approximately 296 km (Bryan, 1971; Karolle, 1993). Using Bayliss-Smith's 17.2 km, these islands could have supported about 516 people as "strandlopers." Whether this would have been a sufficient population size to remain viable over the long term needs to be investigated, considering the environmental perturbations that occur regularly in the Marianas. The earliest non-agricultural visitors to the Marianas probably utilized some local plant resources and fished from distant shoals in addition to taking inshore species. Since several thousand people lived in the Marianas at European contact (Underwood, 1973), the subsistence base was likely mainly agricultural with marine resources supplementing for protein and calories.

Earthquakes are felt frequently throughout the Marianas, some quite severe, while less frequent volcanic eruptions occur in the far north. Prehistoric cultural adaptations to strong earthquakes were likely similar to those for typhoons, such as geographically wide kinship networks for temporary refuge, storing foods and expanding diet breadth to include wild resources. Sulphurous fog (vog) from volcanic eruptions generally drifts west but occasionally affects islands as far south as Guam, causing eye, throat and lung irritation, and the highly acidic vog burns and dries crops. Close proximity to volcanic sources of vog adds to the reasons to avoid the northern islands for permanent settlement, although in the past, as now, people probably visited for short periods. Unlike other volcanically active areas such as the Philippines, where nitrogen-enriched soils are continuously utilized despite eruption-associated dangers, the steep and rocky northern Marianas lack favorable soils for agriculture. Nonetheless, in addition to fishing grounds, these smaller islands likely served as refuges after major storms in the south and from some inter-group conflicts.

Globally and in the Pacific, sea level has been far from constant during the Holocene epoch (the last ten thousand years) — on millennial, century, and shorter time scales. As the post-Pleistocene earth warmed, glacial melt water pulsed into the ocean basins. About 7500 years ago, the last of these pulses raised sea level in the southern Marianas six feet (two meters) higher than today (Dickinson, 2000, 2001). The mid-Holocene highstand peaked in the Marianas between 4750 and 2750 years ago (Dickinson, 2000:739), after which began the post-mid-Holocene sea level drawdown that radically altered shorelines, enlarged strand areas, and affected fresh water hydrology. Large saltwater lagoons contracted into shallow estuaries and sand beaches appeared or expanded, a process that appears to have accelerated around 2000 years ago (Dickinson, 2000, 207 and see below).

With these changes, island flora and fauna changed too, creating opportunities for some species, difficulties for others. By c. 3500-3700 years ago, coastal portions of Guam, Rota, Saipan and Tinian had become marginally habitable, and the first visitors from island southeast Asia began to arrive. These early arrivals appear to have been transient rather than permanent, long-term residents,[4] utilizing the diverse marine resources and nearby plant species at the emerging land/sea interface, albeit insufficient to support the number of people necessary to maintain a viable population (see Hunter-Anderson, 2005). Sea level decline of some 40 cm about 2000 years ago, widening existing shorelines, would have enabled the establishment of permanent settlements, as suggested by archaeological sites of this age that contain the earliest human interments (DeFant and Eakin, 2009). Preliminary analysis of these skeletal remains, as well as their unique grave goods, suggest a different population from that of the Latte Period, implying that more than one population influx occurred in the Marianas in the last 2000 years.

Throughout the Pacific Basin, a sea level decline of unknown amount c. 600 years ago (Nunn, 2007; Nunn et al., 2007) occurred at the transition from the MWP to the LIA. No direct study of this decline's effects, if any, upon the Marianas environment has been conducted. At shorter time scales, sea level fluctuates seasonally and during ENSO episodes by more than 1.5 feet (46 cm) (Lander, 2004). Accommodating these changes would have included a diverse fishing technology and flexible land use practices, as annual and monthly observations warranted.

Marianas Climate during the Last Millennium: The MWP-LIA Oscillation

In addition to local environmental fluctuations, regional climate changes have occurred during human occupancy of the Marianas. The most pronounced of these is the century-scale oscillation between warmer, wetter climate and cooler, drier climate, namely, from the Medieval Warm Period to the Little Ice Age. This global phenomenon included the Pacific Basin (e.g., see Bradley et al., 2003; Nunn, 2007), with a variety of local consequences. Figure 2 shows global, century-scale temperature changes using 18 different proxies from north and south hemispheres. According to these data, the MWP was significantly warmer than the bimillennial average during most of the period 820-1040 AD, and the Little Ice Age was significantly cooler than the average during most of 1440-1740 AD).

Paleoclimate in the Marianas has not been studied but paleoclimatic proxy data for the western Pacific region can be consulted as an indirect indication. In eastern China the climate was warmest between 1100-1200 C.E., peaking at c. 0.3-0.6 degrees C higher than today (Nunn, 2007, 66, citing Ge et al., 2003) and southern Japan temperatures were c. 1 degree C higher than today between 800 and 1200 C.E. (Nunn, 2007, 67, citing Kitigawa and Matsumoto, 1995). While aridity in China and Japan is also noted for the MWP, a different situation may have prevailed more to the south, including the Marianas. Nunn (2007, 68) has inferred that c. 900-1100 C.E., high rainfall characterized climates in New Guinea, Indonesia, and the Philippines. Since Marianas climate now resembles that of the northern Philippines, this could mean that MWP climate was also wetter in the Marianas at this time. The higher rainfall may have derived from an extended La Niña-like state in the Pacific Basin during the MWP (Mann et al., 2005, cited in Allen, 2006).

The transition to the LIA c. 1350 C.E. was turbulent in many Pacific locales, including lowered sea levels, increased storminess, and cooler sea surface and land temperatures.

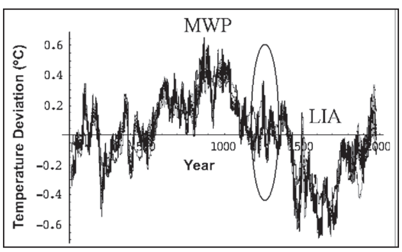

Figure 2. Global temperature variations over the last two millennia C.E.; the Medieval Warm Period preceded the Little Ice Age, with Transition (oval outline) beginning c. 1350 (after Loehle and McCulloch, 2008, Fig. 2).

Some of the most dramatic changes occurred in the central and eastern Pacific (Nunn et al., 2007). In the Marianas, the transition may have had less dramatic landscape effects, although this issue has not been investigated. However, analyses of marine shell assemblages from archaeological sites on Guam's west coast, as well as time-progressive seaward placement of prehistoric sites beginning c. 1027-1293 C.E. and continuing through late prehistory (Amesbury, 1999, 2007, Table 3) suggest that people were responding to declining sea level as strand areas enlarged through progradation.

During the LIA, Pacific climates were cooler, sea levels lower, and the El Niño weather system was more active than it had been during the MWP. In the western Pacific, rainfall was more variable, with longer and more frequent droughts (Nunn, 2007). It is possible that there was a shift to a more prolonged El Niño-like state during the LIA. The Marianas are located in an area with some of the most extreme deviation from average rainfall during El Niño warm phases (Gagan et al., 2004). This fact, combined with indications that ENSO events were more common and more severe during the LIA (Anderson, 1992; Camargo and Sobel, 2005), makes it likely that crop harvests in the Marianas were less abundant and less reliable than during the MWP.

The LIA may also have brought more typhoons to the islands along with more frequent ENSO droughts (Camargo and Sobel, 2005). Chinese historical records indicate there were more typhoon landfalls in coastal Guangdong, southern China during this period (Liu et al., 2001). During cooler periods, such as the LIA, typhoon tracks apparently shift south, resulting in fewer landfalls in Japan and east-central China and more landfalls along China's south coast. Considering the origins and typical pathways of typhoons in Micronesia, the Guangdong data imply increased typhoon frequencies in the Marianas during the LIA. Higher typhoon incidence would have compounded the problems of drought and soil aridity by increasing soil erosion.

Pre-Colonial History and Customs

No ethnography records the late prehistoric Chamorro cultural system but early European travelers' accounts indicate that late 16th and early 17th century Chamorro society was minimally stratified, with higher ranked people living on the coasts and lower ranked people in the "jungles and hills" (Driver, 1983, 213). There were regional feasts involving food displays, dancing, and competitive games of skill, and local feuding was endemic. The early reports and later accounts based on family traditions no longer practiced, what anthropologists refer to as "memory culture" (e.g., Freycinet,1829; Cunningham, 1992), indicate that land was al-located flexibly within a matrilineal kinship pattern. The aboriginal diet included roots and tubers (mainly taro and yams), tree crops (e.g., coconuts and breadfruit), fish (both inshore and pelagic), and shellfish. Paddling canoes were used inshore and swift outriggers (the Chamorro "flying proas") plied the open sea (Driver, 1983; Cunningham, 1992; Lévesque, 1992).

The c. 3000 year-long prehistoric era ended with Ferdinand Magellan's brief and violent encounter with the Chamorros in 1521, followed shortly by Legazpi's claiming of the Marianas for Spain in 1565 and formal colonization in 1668. By 1700 C.E., the bloody Spanish conquest was essentially complete; the Chamorros had resisted with stealth, spears and sling stones for thirty years, but guerilla tactics ultimately proved no match for the Spanish military and a determined band of Jesuit missionaries (for details see Carano and Sanchez, 1964; Hezel, 1989; Lévesque, 1992; Rogers, 1995).

During the government's *reducción* program, the three thousand survivors were settled into a few parish villages on Guam and Rota. The newly converted performed daily religious obligations, which included supplying the priests with food and domestic services. The Spanish destroyed the native sailing canoes to prevent escapes, and without access to their customary fishing grounds, the islanders ceased ocean fishing nor were they able to freely visit other islands. Animal husbandry of introduced livestock replaced the specialized knowledge and customs associated with sea faring. Over the ensuing years the Hispanicized Chamorros learned to fear their abandoned sites, grew foreign crops such as corn and tobacco, changed house-building styles, and adopted Spanish vocabulary. Customs from this historic "antigo" period are viewed now as integral to Chamorro culture, less alien that of the prehistoric past.

While historic records help to characterize the outlines of the late prehistoric ancestral Chamorro cultural system, the processes that shaped its evolutionary trajectory are better explored archaeologically.

Archaeology

For clues to earlier cultural system states, the archaeological record can be "decoded" using ecological principles and ethnographic knowledge (Binford, 2001). The goal is to build realistic models of the cultural adaptive processes and to test these models against a variety of independent data. This kind of archaeology has been called processual (Johnson, 2004), in contrast to older approaches that stress the expression of ideas embodied in artifacts and features (e.g., pottery forms, burial practices, ornaments), taken as signs of ethnic origins. Processual archaeology seeks to both describe and explain cultural similarities and differences in all the materials left by a cultural system, not just in its presumed ethnic markers.

Archaeological pattern recognition studies that illuminate changing cultural adaptations help archaeologists discover the dynamic organization of past cultural systems. The Marianas archaeological record manifests a major shift from what Kurashina (1991) has termed a "narrow-spectrum economy" in which human activities were restricted to the shoreline ecotone (a zone of overlapping plant and animal species from two adjacent ecosystems), to a "wide-spectrum economy" that incorporated additional terrestrial resources from inland riverine ecotones, effectively expanding the geographical scope of the local cultural system from the sea to the interior in the larger islands. This pattern reflects the change from the Pre-Latte to the Latte Periods first recognized by Spoehr (1957). Kurashina proposed that "population pressure" motivated the adoption of a wide-spectrum economy during the Latte Period but, as will be shown later, this factor alone fails to account for climate-linked cultural adjustments during late prehistoric times.

The Latte Period

Permanent occupation of the Marianas appears to have begun about two thousand years ago. The first human burials date to this time (DeFant and Eakin, 2009), and a greater variety of artifacts were used, related to land-based activities as well as to inshore and offshore fishing (Reinman, 1977; Hunter-Anderson, 2005). By the first millennium C.E., intrinsic population increase and/or continuing in-migration resulted in more and different kinds of archaeological sites. By c. 800 C.E., *latte* architecture had been adopted, along with several kinds of volcanic stone tools (adzes, pounders, abraders) related to agriculture and sturdier ceramics reflecting a subsistence focus upon boiled tubers (Butler, 1990). Longer cooking times in stronger pots also could relate to the practice of reconstituting dried foods such as rice, breadfruit and fish. Late in the period, very large ceramic vessels for storing food and water were added to the ceramic inventory (Moore, 2002).

The 'Meaning' of *latte*

No eye-witness drawings of functioning *latte* house foundations have been found, but early written accounts, beginning with Legazpi's in 1565, indicate that stone pillars supported wood dwellings with thatched roofs. At some coastal sites very large *latte*-supported structures sheltered canoes and others were dormitories for youth (for details see Cunningham, 2005). While stonework is common among many Micronesian groups, the distinctive form of stone posts with capstones is unique to the Marianas (Hunter-Anderson, 1997).

Figure 3. A large *latte* set at the Urunao site, northern Guam.

Archaeologically, an intact *latte* feature or set (many are now incomplete or disturbed) consists of two parallel rows of tapered stone pillars topped by hemispherical capstones enclosing a rectangular space. Large stone mortars, thought to have been used to husk rice, are often found in or near *latte* sets. Figure 3 shows a *latte* set in northern Guam. None of the capstones is in place atop its pillar, presumably due to earthquakes over the centuries after abandonment of the site during early Spanish times. Several large mortars are present at the site.

In the 1920s, archaeological interest in the Marianas resulted in fieldwork by Hans Hornbostel (n.d.), who excavated several prehistoric sites and mapped the distribution of *latte* ruins on Guam and Rota. Later surveys have located *latte* in nearly every island habitat, from ridge tops to valley terraces to wetland margins to back-beaches, most with close access to fresh water (Hunter-Anderson, 2005). Late in the Latte Period, *latte* were erected in the far northern part of the archipelago (Egami and Saito, 1973).

The use of stone in Latte Period architecture is beyond the simple need to support a house; after all, dwellings had been built in the Marianas without stone posts for many centuries before the pillar and capstone style came into use, and wood post structures continued to be built during the Latte Period (Hunter-Anderson, 1994, 2007; Peterson and Carson, 2009). The adaptive significance of *latte* (notwithstanding their structural support function) is that they were long-lasting markers of resource claims when the builders and users could not be present. In this interpretation, *latte* were part of a symbolic system that helped to regulate competition for land and other critical resources. That *latte* architecture never went "out of fashion" but continued into early historic times, when some of the largest stones were hewn (Morgan, 1988, 134-140), suggests competitive escalation (see below) aided by iron tools; a similar process may have occurred in 19th century Yap with ever-larger "stone money" and modern technology (Gilliland, 1975).

Specific adaptive contexts in which *latte* and other Latte Period practices were adopted can be explored by considering detailed archaeological findings from the Manenggon Hills project in south-central Guam. These data indicate a complex relationship between local geography, large-scale climatic processes, and human ingenuity in solving problems.

The Manenggon Hills Archaeological Project

Data from the Manenggon Hills project derive from archaeological investigations conducted in the early 1990s by Micronesian Archaeological Research Services; detailed results are contained in Hunter-Anderson (1994). Comprising 1350 acres (5.5 km^2) or 1% of the island's total land area, the project area is located about one mile (2.5 km) inland from the east coast of Guam (Fig. 4).

Forty-nine of the 84 prehistoric sites found yielded datable charcoal. Sixty-one prehistoric occupations at these sites ranged from the 5th through 17th centuries C.E. (Fig. 5).

These data show that while people were present before the start of the Latte Period, there was an apparent occupational hiatus until c. 800 C.E. and light usage of the area until the 1100s C.E. when the number of occupations per century increased exponentially over three centuries and then declined

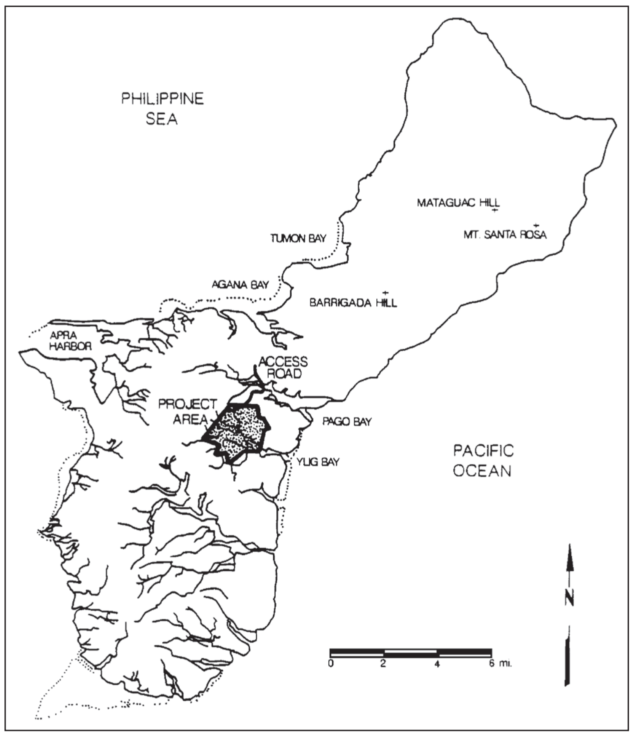

Figure 4. Manenggon Hills project area (stippled) comprises 1% of Guam's land area.

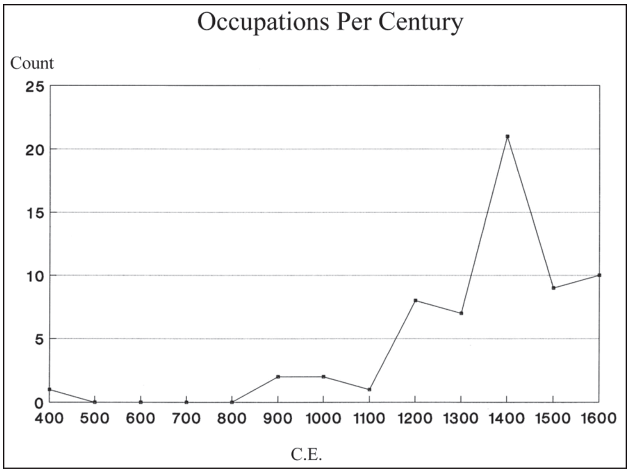

Figure 5. Dated site occupations per century in Manenggon Hills project area; some sites were occupied during more than one century.

radically in the 1500s to nearly the same number before the jump in the 1400s. Could this pattern simply represent a rapid rise and fall in regional population, or something else?

An analysis of the kinds of sites utilized provides some clues. For a first-order pattern recognition study of land use over time, the sites were classified into three types, Storage/Camp, Habitation, and Rockshelter. Habitation and Storage/Camp sites included open localities (as opposed to Rockshelters, where living space was severely limited). Open sites with aboveground features, such as *latte* sets, embedded stone mortars, and/or hearthstones were termed Habitations. The underlying logic was that since people had taken the trouble to install "site furniture" (Binford, 1979) at these sites, they had stayed longer and performed a greater variety of activities at them than they did at locations without site furniture. Also, the labor investment represented by permanent features suggests repetitive use of these sites.

Storage/Camp sites were defined by the presence of one or more subterranean pits and no aboveground features. The storage function of some of the pits was inferred from their round-bottom shape and lack of charcoal within the pit fill. Other kinds of pits were shallower and their fill contained abundant charcoal; these were interpreted as earth-ovens where food was prepared for relatively large groups. It is possible that the smallest pits were agricultural planting pits, for example, pits at the site dated to the 400s C.E., the earliest site found in the project area (Moore, 2005).

A Rockshelter designation was given to sites with cultural deposits that had accumulated under large limestone boulders. From their limited artifact assemblages, these small sites may have afforded temporary refuge from the weather and/or for caching equipment such as gardening tools, sleeping mats, and water jugs, and thus provided logistical support for longer stays in the immediate area.

Table 1 shows the site counts (in parentheses) and percentages of sites by type during the 900s-1600s C.E. Highlighted percentages of site types in the table show a change in proportions of Habitation vs. Storage/Camp sites from the 1200s through the 1500s. During the 1200s and 1300s, Habitation sites were well over 50% of the total whereas beginning in the 1400s and into the 1500s, Storage/Camp sites were over half of the total and Habitation sites a third or less. This reversal in proportions of dominant site types appears to be unrelated to population increase. In the bottom row of the table, bold numbers in parentheses are site totals during the 1400s (21) and 1500s (9), showing that regardless of the decline in total sites, the proportions of Habitation and Storage/Camp sites remained similar through these two centuries.

Figure 6 depicts this information graphically. Storage/Camp sites account for most of the rise in occupations during the 1400s, and this site type remained dominant in the 1500s, although total numbers of occupations declined. Finally, in the 1600s just prior to abandonment of the area, site proportions returned to a configuration like that of the 1200s-1300s. While not precise, these data indicate a general picture of changes in land use beginning about the time of the transition to the LIA.

The project area was abandoned after the 1600s, possibly due to the Spanish incursion associated with radical changes in residence and land use patterns.

Table 1. Site types occupied by century (multiple dates indicate some sites were occupied for more than one century; see Hunter-Anderson, 1994:IV, 1.9-1.13).

CENTURY	**900s**	**1000s**	**1100s**	**1200s**	**1300s**	**1400s**	**1500s**	**1600s**
SITE TYPE								
Storage/Camp	100 (2)			25 (2)	29 (2)	57 (12)	56 (5)	40 (4)
Habitation		100 (2)	100 (1)	62 (5)	57 (4)	29 (6)	33 (3)	50 (5)
Rockshelter				13 (1)	14 (1)	14 (3)	11 (1)	10 (1)
TOTAL	100 (2)	100 (2)	100 (1)	100 (8)	100 (7)	100 (**21**)	100 (**9**)	100 (10)

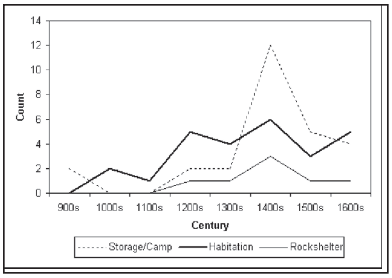

Figure 6. Manenggon Hills sites by type, 900s-1600s C.E.

Explaining Changes in Dominant Kinds of Sites over Time

From the above analysis it is clear that a simple hypothesis of population increase over time (from whatever source: immigration and/or intrinsic increase) does not explain the changes in proportions of site types, nor the addition of Rockshelters to the land use system beginning in the 1200s, since this kind of site is not strictly residential. Further, the curve of site occupations is not S-shaped as would be expected for population increasing until carrying capacity is reached. The archaeological facts suggest changes in land use, i.e., *in the organization of activities*, especially after the 1300s.

When interpreting any local data set, it is wise to consider larger contexts. For example, trends in Manenggon Hills land use took place during a time in the Marianas which saw, among other developments, the rise and spread of *latte* architecture and buried caches of sling stones; more durable and larger ceramic bowls and jars; and the addition of rice to the crop inventory (Hunter-Anderson et al., 1995). Not all these practices began at once; for example, latte architecture and sling stone caches appear before large ceramic vessels and the cultivation of rice. When these data are arrayed chronologically (Fig. 7), a sequence of cultural responses related to century-scale changes in climate, although general and imprecise, emerges.

A climate-based interpretation for these observations is that the MWP was a favorable time for agriculture on Guam, followed by a less-favorable time for agriculture, and that the ancestral Chamorro cultural system changed in response, although not radically. For example, in the early Latte Period, which coincides with the beginning of the MWP, island populations expanded along the coasts and into upland areas, as noted by Kurashina (1991). Harvests were relatively reliable, and, to offset temporary losses from typhoons and local demographic imbalances, cultural practices included widespread kinship networks within and between the islands. This helped to spread agricultural risks and lessen social tensions by providing mobility options in times of temporary stress.

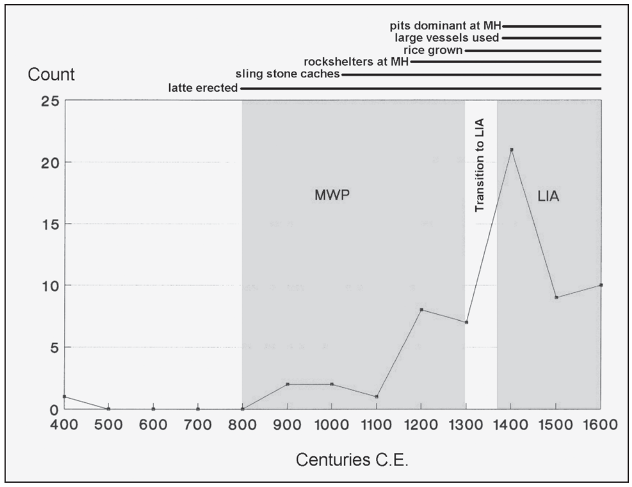

Figure 7. Manenggon Hills (MH) occupations over time, temporal spans of Latte Period cultural practices.

Swift sea-going canoes facilitated these tactics. *latte* architecture and its associated customs helped regulate competition for productive land.

During the climatic transition to the LIA, weather events became even less predictable than before. As noted above, detailed information on sea level and temperature changes is unavailable for the Marianas but increased interior land use in southern Guam may have been prompted by agricultural difficulties related to these changes. Higher elevations receive more rainfall, a geographic factor favoring more plantings in upland locales such as Manenggon Hills. Rice was added to the Marianas crop inventory at this time, reflecting a need to increase storable produce in addition to any symbolic value rice may have had. Imported as a domesticate, possibly from the Philippines, rice could be grown at the edges of interior wetlands, including those at Manenggon Hills.

The number of site occupations apparently increased rapidly at Manenggon Hills and peaked at the beginning of the LIA. The increase was not only numerical; there was a reversal site type proportions, with a higher proportion of Storage/Camp sites with pits than Habitation sites (Table 1). This shift could represent additional efforts in food production and storage by drying and preserving of produce near where it was grown. In this upland locale, rainfall would have been somewhat higher and harvests somewhat better; on the other hand, more labor was involved, particularly with the cultivation of rice, and the costs of food production generally were increasing. These conditions would have required on-site vigilance to prevent thefts from stores and fields. Another technological adjustment during the LIA was the addition of large ceramic vessels, likely for food and water storage; these pots were still in use during early historic times (Moore, 2002).

Despite all these efforts, total agricultural production in the Marianas probably declined over the LIA centuries, made up for in part by intensive use of marine resources including those of the far northern islands and distant shoals. Competitive tactics, including widespread use of *latte* architecture, as well as maintaining sling stone and spear fighting skills, would have escalated as land encroachments became a serious threat to food security. Sling stones have been found in early Latte Period sites, but caching them at potentially contested sites later in the period suggests more regular use of these weapons.

Cultural adjustments during the LIA, not as easily seen in the archaeological record but expected under the circumstances, include the contraction of once-wide-reaching social networks and the formation of unstable defensive/offensive alliances. Such alliances would reflect the perceived strength or weakness of territorial groups at given times, judged in part by wealth displays at regional ceremonies and the ability to construct and maintain *latte* features. Social network contraction minimizes sharing obligations and may have accompanied the emergence of minimal social stratification within larger territories on Guam, for example in the Manenggon/Ylig drainage. Occupants of inland areas like Manenggon Hills may have been re-defined as lower-ranking, distant relatives of higher ranking coastal families, bound to one another through kinship histories. Inland dwellers' agricultural labor would have been critical to the success of the larger cooperating group, and in-kind reciprocity is likely to have characterized their personal relationships, as suggested in the Pobre account of Rota.

Supporting the proposed contraction of larger inter-island social networks in the Marianas during the LIA are the findings of Graves et al. (1990, 227), who analyzed chemical composition and vessel forms in Latte Period pottery. Their study found similarities in pottery from Guam and Rota, on the one hand, and in pottery from Saipan and Tinian, on the other, as if residents in each island-pair limited their social interactions, including exchanges of pottery, to the nearer island. The assemblages from which the ceramic samples came were not dated precisely enough to distinguish when they were produced within the Latte Period. According to the theory favored here, these sub-regional separations occurred late in the Latte Period although it is also possible that geographic pottery differentiation began during the MWP or transition, and then intensified during the LIA; clearly, more dating refinement and research into this issue is needed. Nonetheless, it seems reasonable to see the forming of large island/small island "partnerships" as a variant of a strategy by populations on smaller landmasses to minimize deficits or vulnerabilities, generally by linking with larger populations on a larger land mass, thus increasing access to the resources available to participants (see Pulliam, 1988, 1996; Kelman, 2009).

The Red Queen Principle

The persistence of older practices and addition of new ones aimed at solving similar problems in the face of environmental changes in the Marianas appears to conform to the "Red Queen Principle" in ecology (van Valen 1973) (Fig. 8).

Figure 8. 'A slow sort of country!' said the Queen. Now, here, you see, it takes all the running you can do, to keep in the same place.' Lewis Carroll quoted in Bak (1996, 122).

The Red Queen Principle is based on observations that competitive interactions between co-evolving species produce intensified behavior that over time results in the maintenance of each species but at greater cost. Consider forest trees competing for sunlight, resulting in height increases for all trees with no net increase in sunlight for any, even as they spend more resources in order to sustain their height (see Heylighen, 2009). Under this analogy, the ancestral Chamorros' response to the challenges of LIA climate, specifically drought, less reliable rainfall, and more damaging storms, was "running faster." One of the costs of running faster was some social adjustments such as more well-defined social stratification and a redefinition of close kin. This had the effect of lessening obligatory burdens but also increasing local labor demands.

In cultural evolutionary terms, a perturbed self-organized system, such as that of the ancestral Chamorros, at first responds by trying to maintain stability within existing capabilities and, if these are inadequate, addition and re-organization of some components, enabling the system to continue in a modified but still recognizable form. Ironically, the practices that had served the Chamorros well during the shift from the MWP to the LIA may have increased their vulnerability to attacks by the Spanish. For example, territorial rivalries reduced the Islanders' ability to mount effective military defenses against the Spanish, as former alliances shattered and failed to re-form. While the Spanish burned village food stores and residents scattered, agricultural cycles and reciprocal exchanges were disrupted, and critical labor shortages developed, as young men were involved in guerilla-style raids and retreats. It is hardly surprising that after three decades of such asymmetrical conflict, women and children were the first to seek assistance from the priests, who offered protection and food for the price of conversion to Catholicism (see Rogers, 1995; Lévesque, 1992).

Final Thoughts

This paper has connected century-scale environmental dynamics and prehistoric cultural changes inferred from a well-studied case of the Marianas archaeological record of the last millennium. In this relatively simple cultural system, where energy sources were entirely local, human behavioral adjustments to environmental perturbations could be made that allowed the system to persist without radical changes, albeit at greater human cost. Adaptive success here required adequate environmental knowledge and the ability to act on it. Is our own very complex cultural system capable of persisting for so many centuries, given inadequate knowledge of our environment and of each other? For example, Kunstler (2005) points to the serious implications of a declining oil supply while the Odums (2001) offer a hopeful view of the future through careful management of all energy sources. In view of our present experience of "information overload," environmental and otherwise, caution and humility will likely produce a better outcome than a headlong rush to radical action.

Endnotes

1. rhunter1@unm.edu.
2. I wish to thank Thomas Heyd for inviting me to participate in his Symposium on the Human Dimensions of Climate Change; this paper is a revision of my presentation at the symposium. I also acknowledge the inspiration of my colleagues involved in the study of Pacific Islands archaeology, especially the 'women from MARS,' with whom I spent many interesting years indulging our taste for adventure, intellectual and physical. Thanks as well go to Patrick Nunn, who is leading the way to a better appreciation of environmental variability in the Pacific Islands, and of its challenges for indigenous and modern cultural systems. I am grateful for the comments of two anonymous reviewers, which I believe helped make this a better paper.
3. In discussing island sizes, I have followed Prof. Nunn, who advises that "smaller" is preferable to "small" as being perhaps less subject to definitional quibbles of what "small" means.
4. My suggestion that the first island occupants were impermanent residents is new and perhaps difficult for some to imagine, given the distance traveled to reach the Marianas if voyagers were sailing east from the Philippines (they may have shortened the distances traveled by island-hopping northeastward through Palau and Yap). Pacific Islanders are well known for their navigation skills that enable them routinely to sail over very long oceanic distances, and there is every reason to suppose earlier peoples from the same, albeit earlier, island Southeast Asian cultural tradition were just as capable.

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