Assessing the role of climate change and human predation on marine resources at the Fatu-ma-Futi site, Tutuila Island, American Samoa: an agent based model

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Abstract

In the tropical Pacific, climate change has been implicated as a causal variable in the development of a variety of social processes, including resource scarcity, cultural diversification, changes in spatial organization, and conflict. Hypotheses concerning the effects of climatic variability on cultural change can be better evaluated once links between environmental processes and subsistence patterns are established. Here we present data on approximately 1500 years of shellfish exploitation at the Fatu-ma-Futi site, Tutuila Island, American Samoa. We generate an Agent Based Model to test hypotheses regarding resource exploitation and the effects of climate change on near-shore marine fauna. To date, little archaeological data regarding prehistoric marine resource use in Samoa is available, demonstrating the need for more field research. Integrating models generated from foraging theory and agent based computer simulations provides a new technique for modeling social and ecological processes in complex environments.

The potential impacts of prehistoric human populations and natural climatic phenomena on island ecosystems and human cultural change have long been recognized by archaeologists working in Oceania (e.g. Athens and Ward 1993, 1997; Kirch 1983, 1997; Kirch and Hunt 1997; Steadman 1995; Anderson *et al.* 2006; Field 2004; Nunn 2000a, 2000b). Understanding the effects of environmental variability on Pacific islands requires constructing models that distinguish between the empirical result of human impacts and those related to natural climate variability. Furthermore, environmental variability occurs at scales varying from global phenomena to more localized processes that must be assessed in each context. The situation is made even more complex with recognition that prehistoric habitat alteration is likely influenced by numerous processes occurring simultaneously (Rietz 2004:65-66; Wolverton 2001).

Documentation of climate change in the Southern Hemisphere, including the islands of the tropical South Pacific, has been hindered by a lack of instrumental and proxy climate records, with twice as many reconstructions available from the Northern Hemisphere (Jones *et al.* 2001:663). Nevertheless, increasing numbers of multi-proxy records for the tropical Pacific are being constructed (e.g. Cobb *et al.* 2003; Jones *et al.* 1998; Mann *et al.* 1999; Linsley *et al.* 2000; Hendy *et al.* 2002) and offer the potential for a better understanding of past local climate variability in the central Pacific (Allen 2006). In order to critically assess the relationship between cultural changes, including variability in spatial organization, competition, and subsistence, formal links between climate and the empirical expectations of the archaeological record must be established. Consequently, a detailed understanding of marine-resource use in the prehistoric Pacific is necessary.

Recent research in the West Polynesia region, including the islands of Fiji and Samoa (Figure 1), examines the relationship between climate and environmental variability and changes in settlement (Pearl 2004), competition (Field 2004), landscape alteration (Pearl 2006), and ceramic diversity (Cochrane 2004; Cochrane and Neff 2006). Exploring the mechanistic relationship between climate change and marine resources is essential for providing the necessary link between environmental variability and cultural changes (Allen 2006:531).

In Samoa, given the relative paucity of archaeological research in the archipelago over the last 20 years and the difficulty associated with locating well preserved faunal remains, the use of marine resources (and subsistence in general) are not well documented (but see Nagaoka 1993 for an exception). However, recent excavations at Fatu-ma-Futi, on Tutuila Island recovered substantial mollusc and fish assemblages in a stratified sequence covering the last ca. 1500 years (Addison 2006; Addison and Asaua 2006; Morrison 2006).

This paper begins by briefly outlining the evidence for climate change in the tropical central Pacific over the last millennium. Next, we discuss the integration of foraging models and Agent Based Modeling (ABM) to better distinguish human impacts to prey populations from natural changes induced by climatic phenomena. We use the Fatu-ma-Futi shellfish assemblage as a case study to assess the usefulness of the models presented below.

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Background to the problem

One of the greatest challenges facing archaeologists researching the effects of climate and environmental variability is distinguishing the results of natural perturbations from the effects of human induced changes. Nunn (1991, 1999) has also expressed this dilemma when discussing the history of Pacific coastal landscape alterations during the period of human occupation. Indeed, zooarchaeologists have long recognized the potential of environmental changes to affect prey populations in complex ways that must be disentangled from the effects of human predation. For example, studies of prehistoric fish use on Mangaia (Butler 2001), and Rotuma (Allen *et al.* 2001) address the potential effects of habitat alteration on the abundance of archaeofauna. Relevant environmental variables discussed by these authors include hillside erosion (Butler 2001:96) and changes in siltation and salinity in the near-shore environment (Allen *et al.* 2001:67).

Foraging theory models (Stephens and Krebs 1986) have proven robust for documenting declines in foraging efficiency and changes in habitat use in a variety of ecological contexts (Allen 1992, 2002, 2003; Cannon 2003; Morrison and Hunt 2007; Nagaoka 2001, 2002; Wolverton 2001). These models provide a theoretical basis for examining temporal shifts in resource exploitation as a result of human resource depression, environmentally induced decreases in prey abundance, and changes in harvesting technology.

Foraging Theory Models

Although space limits a detailed discussion of the application of foraging theory to archaeological research (for details see Allen 2002, 2003; Broughton 1994; Butler 2001; Morrison and Hunt 2007; Nagaoka 2001, 2002), resource depression is generally indicated in the archaeological record by: 1) a decreased amount of large-bodied prey relative to smaller prey; 2) an increase in the use of less profitable habitats; 3) an increase in taxonomic diversity; and 4) a decrease in the average age and size of exploited taxa.

Relevant studies applying foraging theory to shellfish populations include, Anderson (1981), Raab (1992), and Morrison and Hunt (2007). These authors, among others have demonstrated instances of resource depression through the application of foraging theory models (but see Bird and Bliege Bird 1997; Thomas 2002 for important theoretical considerations). Numerous other studies
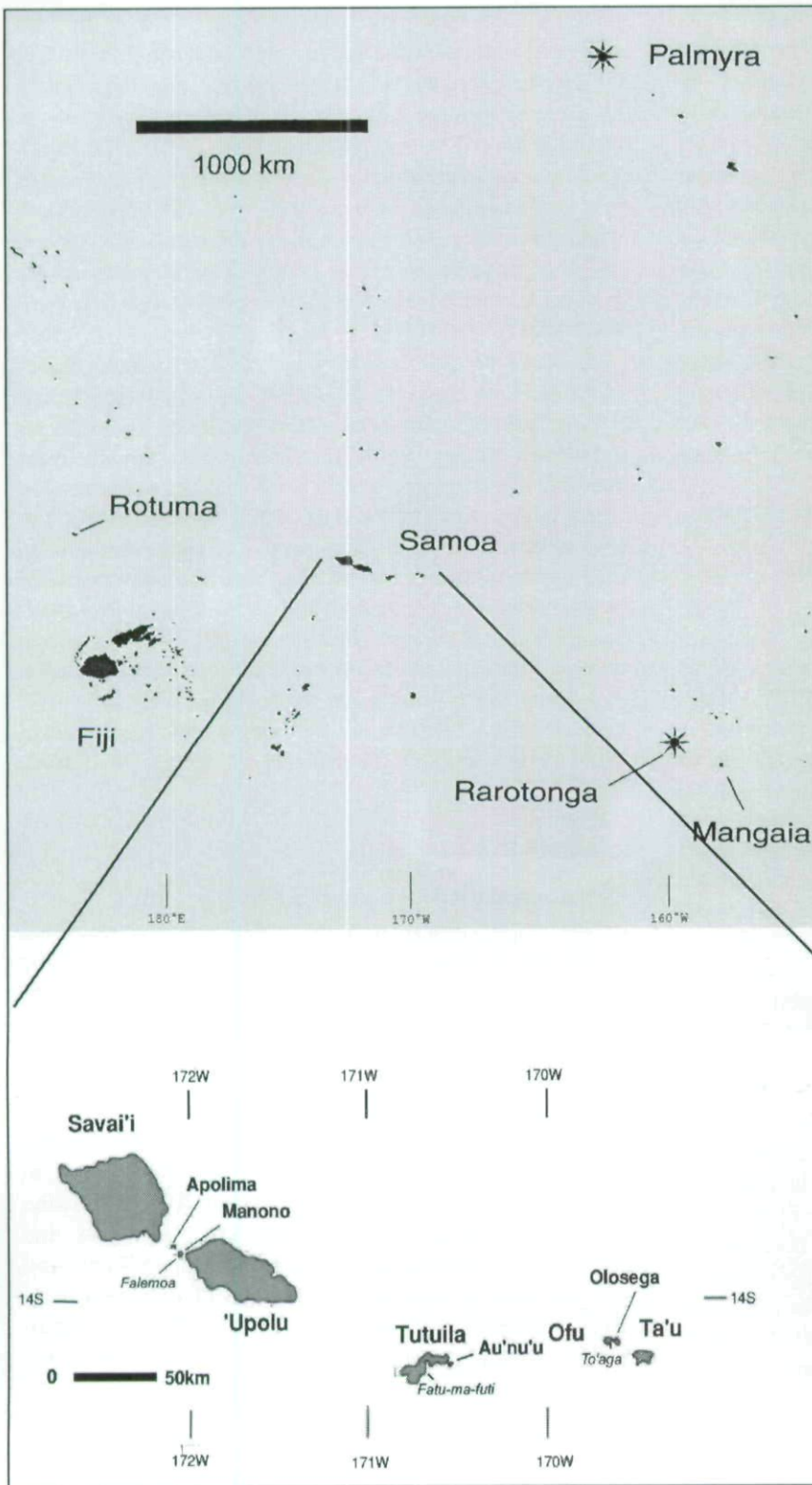

Figure 1. Central Pacific Ocean with locations discussed in the text.
* = location of coral proxy data discussed in the text.
Inset = the Samoan Islands with the location of archaeological sites discussed.

have also measured human impacts to mollusc populations through changes in species composition, and decreased prey size, and age (e.g. Swadling 1976, 1986; Jerardino 1997; Mannino and Thomas 2001; Milner *et al.* in press). While some of these researchers do not operate from an explicit foraging-theory framework, many of the applications are indeed compatible with the logic of foraging theory.

Understanding the complex relationship between human predators and their prey requires properly modeling the environmental contexts of these interactions. Without taking the local ecological history into consideration, archaeologists may incorrectly assign resource shifts to the direct result of human predation when in fact the distribution of taxa is actually a consequence of an environmental circumstance or a combination of foraging pressure and environmental change. As a result, researchers should assess the role climate change and other natural processes play in the archaeological distribution of species. Paleo-climatic reconstructions from the central Pacific suggest periods of climate variability over the past 1000 years that may have affected marine resource use (and subsistence in general) on Pacific Islands.

Climate change in the Tropical Pacific over the last 1000 years

Working with a combination of proxy reconstructions, Nunn (2000a; 2000b) and Nunn and Britton (2001) hypothesize that a drop in temperature and an increase in precipitation and El Niño Southern Oscillation (ENSO) frequency during the transition between the Little Climatic Optimum (LOC) and the Little Ice Age (LIA) caused marine ecosystem stress with consequences for human subsistence and settlement (Nunn 2000a, 2000b). Additionally, Nunn has also argued for a regional sea-level fall of up to 75 cm at 680–625 cal BP (Nunn 1998; Nunn 2000b).

Reviewing multiple proxy reconstructions from coral cores in the central Pacific, Allen (2006) suggests a more locally variable relationship exists between global climate change and region-specific trends. In particular, the climatic patterns documented during the LCO and LIA in the temperate Northern Hemisphere data do not correlate well for the tropical central Pacific (Allen 2006: 521; Cobb *et al.* 2003:275; Jones *et al.* 1998: 462; 2001:664). The following section focuses only on climate proxy records from reconstructions in the tropical Pacific (Figure 1). These records suggest the possibility of increased environmental variability including changes in sea surface temperature (SST) and increased ENSO frequency and magnitude after approximately 1300 AD. Coordinated environmental changes could have had detrimental effects on marine resources in Samoa as well as elsewhere in the central Pacific.

Increased sea surface temperature in the Tropical Pacific

Linsley *et al.* (2000) present reconstructions from a coral proxy record from Rarotonga, Southern Cook Islands (Figure 1). Results demonstrate that, in the period

1726–1765 AD, mean annual sea surface temperature was 1–1.5° C higher than the long-term mean (p. 1146–1147). Supporting evidence for warmer-than-normal Southern Hemisphere SSTs during the Little Ice Age also come from studies of Great Barrier Reef coral cores. Working with a series of 8 coral cores spanning 420 years, Hendy *et al.* (2002) document sea surface temperatures during the 18th and 19th centuries that were as warm or warmer than SSTs during the 20th century. They suggest that the cooling recognized for more temperate regions during the LIA was possibly limited to higher latitudes (p. 1512). The coral-based climate reconstructions also point to higher levels of sea surface salinity (SSS) in the 1565–1870 AD period, which the authors suggest are likely the result of advection and wind driven evaporation from a latitudinal temperature gradient and amplified atmospheric circulation (Hendy *et al.* 2002:1511).

Cobb *et al.* (2003)'s long coral-based climate reconstruction from Palmyra Island, in the equatorial central Pacific provides important new evidence for warmer conditions during the 17th century and cooler, drier conditions from approximately 1149–1220 AD, compared to recent temperatures (Cobb *et al.* 2003:274; Allen 2006:525). Importantly, these results suggest that climate conditions in the central Pacific and in the high-latitude Northern Hemisphere are connected in complex and less-than-straightforward ways (Bradley 2000). For example, borehole temperature reconstructions from Taylor Dome, Antarctica suggest that mean temperatures were up to 3°C warmer during the Little Ice Age compared to the Medieval Warm Period (or LCO) (Broecker *et al.* 1999: 1134; Bradley 2000: 1355).

Amplified ENSO variability

Climate characteristics indicated by the central Pacific reconstructions also include increased ENSO frequency and magnitude in the late 12th and early 13th century, and the mid-17th century (Cobb *et al.* 2003:275; Allen 2006:526-527). Evidence from the Palmyra core suggest that during the 17th century, ENSO events were not only stronger, but also more frequent in occurrence when compared to the 20th century (Cobb *et al.* 2003: 273; Allen 2006:526). Other less extreme increases in ENSO events are recognizable in the Palmyra reconstruction during the 12th and early 13th centuries (Cobb *et al.* 2003: Fig. 6; Allen 2006:526). Nunn (2000b) has also suggested that both storminess and precipitation increased after 1300 AD leading to floods, soil erosion, land degradation, and the loss of important near-shore marine fauna across a variety of Pacific Islands. Field's research on the development of competition and fortification in the Sigatoka Valley, Fiji suggests that increased ENSO frequency after 1300 AD played a key role in the appearance of ring-ditch defensive fortifications and competition in the valley (Field 2004).

Recent hydrological studies on ENSO-related cyclones indicate that storms during El Niño events produce higher amounts of stream discharge and flooding (Terry *et al.* 1998; 2001). Rapid rates of precipitation over very short periods of

time can result in soil saturation and potentially catastrophic over-bank flooding (Terry *et al.* 2001: 276-279). As Nunn (2000a) has suggested, increased precipitation would have likely led to higher sedimentation and increased water turbidity from flood runoff with a resulting loss of lagoon organisms (p. 723).

Increased SST, ENSO frequency, and coral bleaching

Increased ENSO events can have negative consequences for marine productivity through the effects of higher-than-average sea surface temperature. ENSO-related SST changes of only a few degrees as well as increases in ocean salinity and/or water turbidity lead to coral bleaching which often results in large scale coral reef death (Barton and Casey 2005; Hoegh-Guldberg and Fine 2004; Wilkinson *et al.* 1999:188).

Natural disturbances associated with storminess as a result of increased ENSO frequency and coral bleaching has a flow-on effect on mollusc diversity as well as the abundance of other nearshore marine species living in coral habitats. Working at Takapoto Atoll, in the Tuamotu Archipelago, Addessi (2001) documents an approximately 80% decrease in the abundance of the large clam *Tridacna maxima* due to coral bleaching events over less than five years. Likewise, on Moorea in the Society Islands, Augustin *et al.* (1999) recorded a significant decrease in mollusc diversity from 1971 to 1995. The change in mollusc diversity is attributed to the transformation of substrate resulting from storm events associated with strong El Niño years, related coral bleaching, and human induced disturbances (Augustin *et al.* 1999:294). Additional studies of modern coral bleaching, linked to strong ENSO events in 1997/1998, document the loss of coral habitat complexity, with detrimental long-term effects on reef fish communities (Garpe *et al.* 2006; Booth and Beretta 2002).

The review of climate change data presented above suggests that increased ENSO frequencies, and possibly warmer than average SSTs after 1300 AD, may have resulted in widespread coral bleaching and subsequent habitat loss for important near-shore marine species (Allen 2006:530). We hypothesize that if large scale coral reef bleaching occurred in prehistoric Samoa, it may be measurable in the archaeological record as changes in the faunal assemblages. Specifically, as foragers attempted to offset declining encounter rates of mollusks inhabiting coral habitats, an increase in the use of taxa recovered from other habitats should be evident. While it is certainly possible that additional environmental impacts related to climate change, such as increased water turbidity from amplified storm events, changes in sea surface salinity, and declining sea-level (e.g. Nunn 2000a, 200b; Nunn and Britton 2001; Addison and Asaua 2006), would have likely affected mollusc species in complex ways, below we only generate hypotheses regarding coral bleaching.

In the following section foraging theory hypotheses are assessed with a shellfish assemblage from the Fatu-ma-Futi Site, Tutuila Island, American Samoa. A later section outlines the development of an Agent Based Modeling (ABM) computer simulation and its application to the same assemblage. Although more spatially resolute climate information should be acquired at the appropriate scale, this kind of modeling will play an important role in testing the dynamic sufficiency of hypotheses of subsistence pattern and help refine our understanding of the relationship between environmental variability and human impacts to marine areas.

Case study: the Fatu-ma-Futi shellfish assemblage

Fatu-ma-Futi Village consists of some 20 houses located on a narrow (maximum width 50 m) coastal shelf ca. 250 m long and ca. 3 masl. The village is tucked between steep slopes and the ocean on the east side of the entrance to Pago Pago harbor. In 2003–2006 some 75 m² were excavated in conjunction with a sewer system project. The fieldwork is not completed and results remain to be fully reported (but see Addison and Asaua 2006; Addison and Valentin 2006; Asaua 2006; Morrison 2005; Morrison 2006; Valentin 2006; Walter and Addison 2005).

An abundance of artifacts including turbo shell fish hooks, formal lithic tools and debitage, over 150 kg of shellfish remains, several thousand fish bones, and vertebrate remains were recovered. Detailed topographic mapping and geologic sampling were also conducted to explore the landscape history of the coastal plain. While systematic analysis of the stratigraphic context for the radiocarbon dates is still underway, at present it appears that the earliest occupation of the coastal plain likely began around 1500 cal BP, corresponding to Layer IV. Layer III was deposited around 1000 cal BP. Layer II dates to approximately 620–300 cal BP. Finally, Layer I dates to 300–100 cal BP. A historic layer, not included in the analysis here, caps the deposit.

The stratified archaeological deposits at Fatu-ma-Futi[1] are >1 m thick. Some 30 radiocarbon determinations make these deposits the most chronologically controlled in Samoa. The deposits are interpreted as follows:

- 1500 cal BP: intermittent use of a newly formed beach area for marine procurement and perhaps other activities, temporary buildings indicated by small-diameter post holes, lithics made of coarse (probably local) rock;

- 1000 cal BP: permanent habitation with large-diameter post holes and successive layers of coral-gravel paving, burials oriented parallel to the shore;

- 600–700 cal BP: extensive lithic manufacture with fine-grained high-quality basalt (from quarries elsewhere on Tutuila), continued permanent habitation, burials oriented perpendicular to shore;

- 500 cal BP to historic period: continued permanent habitation with burials perpendicular to shore.

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1. American Samoa Historic Preservation Office site number AS-25-055.

Shellfish remains were identified using reference collections for the Pacific at the University of Hawai'i, Manoa and shell manuals for the Pacific region (Abbott and Dance 1982; Cernohorsky 1972). All identifications were made to the lowest taxonomic level possible. Remains were quantified by weight (g) (Table 1), with sub-samples of major species recorded by MNI and NISP in order to establish relationships between various quantification measures.

Species	I	II	III	IV	Total
Anadara antiquata	18.5	35.1	113.5	–	167.1
Anadara sp.	–	23.7	11.2	–	34.9
Arca avellana	7.2	–	0.8	–	8
Arca sp.	7.2	6.6	1.8	–	15.6
Asaphis violascens	178.4	447.4	798	24.3	1448.1
Astraea spp.	3.9	20.7	1.2	–	25.8
Atactodea striata	269.1	460.5	961.1	18.5	1709.2
Buccinidae	48.2	21.8	–	–	70
Cantharus spp.	1.5	9	9.6	1.6	21.7
Cantharus undosa	27.7	3.9	26.8	–	58.4
Cardita variegata	5.6	5.8	5.6	1.2	18.2
Cassidula sp.	4.3	–	–	–	4.3
Cerithidae	–	0.5	–	–	0.5
Cerithium columna	3.4	2.8	11.8	0.9	18.9
Cerithium nodulosum	180.4	8.7	76.7	–	265.8
Cerithium spp.	51.1	32.1	36.2	2.2	121.6
Chama spp.	9.6	14.2	7.3	–	31.1
Chlamys spp.	15.8	–	–	–	15.8
Conus ebraeus	6	–	–	–	6
Conus spp.	384.6	160.4	282.9	4.4	832.3
Cymatidae	–	–	38.7	–	38.7
Cymatium nicobaricum	6.4	6.2	–	–	12.6
Cymatium spp.	39.1	22.9	17.6	–	79.6
Cypraea annulus	203.3	169.1	101.5	6.4	480.3
Cypraea arabica	17.8	10.3	79.3	–	107.4
Cypraea caputserpentis	5.2	1.8	22.9	–	29.9
Cypraea depressa	–	20.9	–	–	20.9
Cypraea maculifera	14	–	–	–	14
Cypraea spp.	890.5	486.3	366.3	–	1743.1
Drupa morum	8.9	10	–	22.1	41
Drupa ricinus	1.4	4.6	33.2	–	39.2
Drupa spp.	23	7.9	23.7	–	54.6
Fragum sp.	–	1	–	–	1
Gafrarium tumidum	49.7	74	373.7	34.2	531.6
Glycymeris sp.	–	30.5	–	–	30.5
Hippopus hippopus	112.1	–	–	–	112.1
Lambis lambis	62.1	–	–	–	62.1
Lambis scorpius	–	–	44.1	–	44.1
Latirus sp.	–	–	3.9	–	3.9
Liotina sp.	0.6	–	–	–	0.6
Lunella cinerea	27.2	28.8	57.3	1.5	114.8
Melampus spp.	0.9	–	2.8	–	3.7
Mitra decurtata	2.6	–	–	–	2.6
Mitra retusa	–	0.4	–	–	0.4
Mitra sp.	1	–	–	–	1
Modulus spp.	7.9	0.8	2.6	0.8	12.1

Species	I	II	III	IV	Total
Morula sp.	1.5	–	1.5	–	3
Morula uva	4.6	0.9	–	–	5.5
Muricidae	16	–	26.4	–	42.4
Mytilidae	17.5	8.6	10.8	5.8	42.7
Naticidae	0.6	0.7	–	–	1.3
Nerita planospira	–	–	3.3	–	3.3
Nerita plicata	19.3	13	32.2	–	64.5
Nerita polita	222	342.7	746.6	77.2	1388.5
Nerita signata	–	–	0.5	0.4	0.9
Nerita spp.	71.5	14	23.1	7.7	116.3
Neritina turrita	–	–	0.9	–	0.9
Oliva spp.	–	–	38	–	38
Patellidae	7.1	10.9	27.8	1.7	47.5
Periglypta reticulata	40.3	105.4	158.8	5.8	310.3
Periglypta sp.	14.9	27.5	3.7	–	46.1
Spondylus sp.	–	95.5	19.8	–	115.3
Strombus mutabulis	27.7	11.8	15.1	–	54.6
Strombus spp.	74.9	57.6	58.7	1.2	192.4
Tectus pyramis	4.1	56.9	20.1	–	81.1
Tellina palatum	22.2	5.8	11.9	–	39.9
Tellina scobanata	2.8	4.8	27.4	–	35
Tellina spp.	15.6	0.3	6.7	0.6	23.2
Terebra spp.	–	–	14.3	–	14.3
Thais spp.	253.6	112.5	–	13.7	379.8
Thais tuberosa	14	–	–	–	14
Tridacna maxima	1030.7	1794	2780.9	26	5631.6
Tridacna spp.	151.9	–	7.7	55.3	214.9
Trochus maculatus	758.2	645.8	892.6	98.3	2394.9
Trochus niloticus	7.5	–	60.7	–	68.2
Trochus spp.	–	–	–	2.7	2.7
Turbo crassus	841	618.9	1286.6	21.8	2768.3
Turbo setosus	1378.5	1315.2	2432.8	123	5249.5
Turbo spp.	109.4	74.3	324.5	80.2	588.4
Vasum ceramicum	245.7	528.1	1388.2	–	2162
Vasum spp.	67.5	52	344.8	23.1	487.4
Vexilum sp	–	–	3.7	–	3.7
Nassaridae	2.3	0.1	–	–	2.4
Total	8119.1	8026	14282.2	662.6	31089.9

Table 1. Shellfish remains by stratigraphic layer and weight (g) from Fatu-ma-Futi.

Testing resource depression using diversity measurements

In the following analysis we assess changes in foraging efficiency at the Fatu-ma-Futi site by analyzing taxonomic diversity. Diversity has been used to measure resource depression by numerous scholars (e.g. Allen 1992; Broughton and Grayson 1993; Grayson and Delpech 1998; Nagaoka 2002). We use three tests of diversity: richness, evenness, and heterogeneity. Richness refers to the number of taxa included in the diet breadth. As preys diminish in abundance due to human predation or environmental variables, more taxa may be included in the diet (Nagaoka 2002:104). Measurements of species richness can be

assessed by counting the number of taxa (NTAXA) found in the assemblage. Evenness refers to the relative contribution of taxa. A highly even assemblage contains taxa that contribute to the entire assemblage in near equal ratios, while uneven assemblages are dominated by a few items. Evenness indices are generated using a variation of the Shannon's diversity index which is calculated as: $E = -\Sigma (p_i)$ $(lnp_i)/lnNTAXA$ (where p_i refers to the proportional contribution of each taxon). Heterogeneity takes into consideration the combination of richness and evenness. Values generally vary between 1.5 and 3.5 with low diversity indicating uneven assemblages (Allen 1992: 333). Heterogeneity (H) is calculated as $H = -\Sigma(p_i)(lnp_i)$.

Analyses were conducted at the taxonomic level of genus in order to avoid the possibility of counting the same taxon twice (see Allen 1992:332).

Results

Results of the richness analysis (assessed by plotting the NTAXA across the excavation strata) demonstrate an increase in richness at layers III and I (Figure 2). However, the overall trend in the assemblage is not statistically significant ($r_2 = -0.8$, sig. 0.2). While in general NTAXA is not correlated with sample size ($r_2 = 0.8$, sig. 0.2), it is likely that the low abundance of molluscs recovered in layer IV is influencing the NTAXA result.

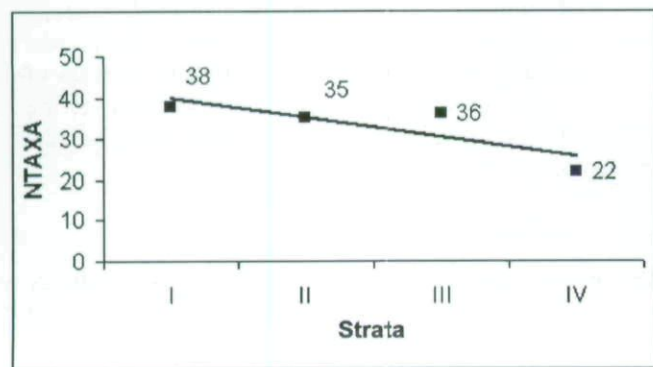The evenness analysis suggests stability in the

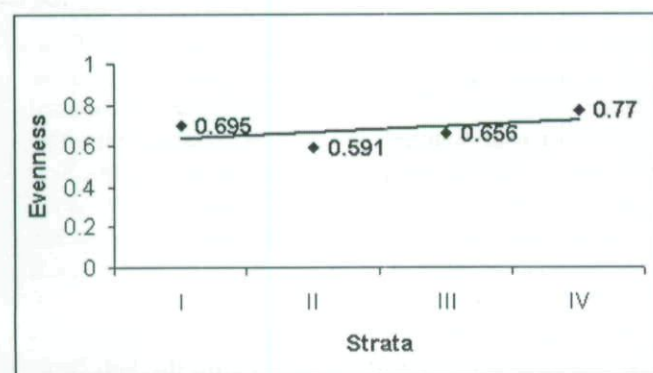Figure 2. NTAXA by stratum in the Fatu-ma-Futi mollusc assemblage.

Figure 3. Evenness by stratum in the Fatu-ma-Futi mollusc assemblage.
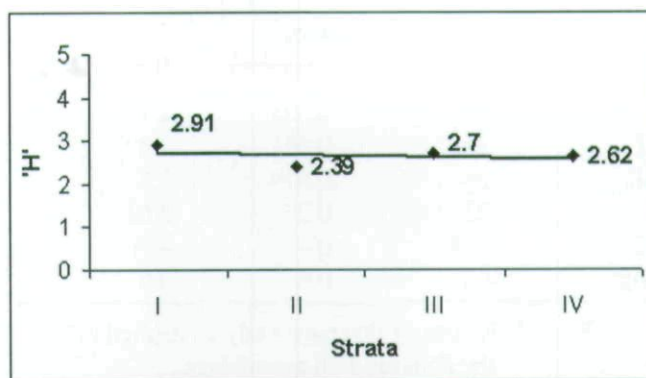

Figure 4. Heterogeneity by stratum in the Fatu-ma-Futi mollusc assemblage.

proportional contribution of mollusc items in the assemblage ($r_2 = 0.4$, sig. = 0.6) (Figure 3). The results demonstrate that exploitation of mollusc taxa did not change substantially through time, with generally intermediate to high levels of evenness characterizing the assemblage. Evenness is not correlated with sample size ($r_2 = -0.4$, sig. = -0.6).

Coral Reef		
Astraea spp.	*Cantharus* spp.	*Cantharus undosa*
Cardita variegata	*Cerithium nodulosm*	*Cerithium* spp.
Conus ebraeus	*Conus* spp.	*Cymatidae*
Cymatium nicobaricum	*Cymatium* spp.	*Cypraea annulus*
Cypraea arabica	*Cypraea caputserpentis*	*Cypraea depressa*
Cypraea maculifera	*Cypraea* spp.	*Drupa morum*
Hippopus hippopus	*Lambis lambis*	*Lambis scorpius*
Latirus sp.	*Liotina* sp.	*Mitra decurtata*
Mitra retusa	*Mitra* sp.	*Nerita signata*
Strombus mutabulis	*Tectus pyramis*	*Tridacna maxima*
Tridacna spp.	*Trochus maculatus*	*Trochus niloticus*
Trochus spp.	*Turbo crassus*	*Turbo setosus*
Turbo spp.	*Vasum ceramicum*	*Vasum* spp.
Vexilum sp.		
Soft Sediment		
Anadara sp.	*Arca avellana*	*Arca* sp.
Asaphis violascens	*Atactodea striata*	*Cerithium columna*
Fragum sp.	*Gafrarium tumidum*	*Glycymeris* sp.
Nassaridae	*Oliva* spp.	*Periglypta reticulata*
Periglypta sp.	*Tellina palatum*	*Tellina scobanata*
Tellina spp.	*Terebra* spp.	
Rocky Shoreline		
Drupa ricinus	*Lunella cinerea*	*Morula* sp.
Morula uva	*Nerita plicata*	*Nerita polita*
Patellidae	*Thais* spp.	*Thais tuberosa*

Table 2. Habitat classifications used in Agent Based Model for mollusc taxa from Fatu-ma-Futi.

Analyses			
Layer	NTAXA	Evenness	Heterogeneity
I	38	0.695	2.91
II	35	0.591	2.39
III	36	0.656	2.7
IV	22	0.77	2.62
r2	-0.8	0.4	-0.4
Sig.	0.2	0.6	0.6

Table 3. Results of diversity analyses applied to the Fatu-ma-Futi assemblage.

Similar to the evenness analysis, heterogeneity is also stable in the assemblage (r_2 = -0.4, sig. = 0.6). While heterogeneity is only very slightly higher in Layer I, the analysis does not show an overall trend in increased diversity through time (Figure 4). Again, heterogeneity is not correlated with sample size (r_2 = 0.6, sig. = 0.4).

Together, the results of the three diversity analyses (richness, evenness, and heterogeneity) applied to the Fatu-ma-Futi molluscan assemblage do not suggest that human impacts affected taxonomic diversity (Table 3). The diversity results show that molluscs are present in near equal proportions. Below we compare the archaeological assemblage with the result of the Agent Based Model simulations in order to assess the possible role of climatic factors on the structure of the Fatu-ma-Futi assemblage.

The Agent Based Model

Models are simplified representations of complex phenomena and processes (Winterhalder 2002:201; Wise 2001:112; Richerson and Boyd 1987). While the uses of models diverge widely according to the needs of the modeler, as heuristic devices they tend to vary according to three basic qualities: generality, realism, and precision (Winterhalder 2002:212; Levins 1966). During model development, a decision must be made to maximize the benefits of one of these characteristics at the expense of another. Models with large scale applicability may sacrifice realism and complexity. In contrast, when a model is made overly complicated, it becomes difficult to assess the variables responsible for a particular result (Richerson and Boyd 1987:33-34). Simulation models are most useful in archaeological research as tests of the sufficiency of an explanation or to deduce additional test implications (Madsen *et al.* 1999:268).

Recent Agent Based Models developed by Epstein and Axtell (1996), Kohler and Carr (1996), Madsen *et al.* (1999), and Shepardson (2006) attest to the advantages of computer simulation over traditional mathematical models in population biology and ecology. As an historical science, archaeology shares a number of characteristics in common with evolutionary biology. Testing hypotheses in these sciences is much less straightforward than in the a-historical

sciences such as chemistry and physics (Dunnell 1982). Experimental parameters in chemistry can be manipulated, with the results being continuously observable. In archaeological research, it is impossible to manipulate variables or observe the behavior that led to the patterns in the archaeological record. Consequently, developing hypotheses and testing predictions is much more difficult and speculative.

Agent based computer simulation is useful for modeling the effects of environmental variability on resource use because multiple ecological conditions can be simulated while foragers and prey interact in manifold and complex ways (e.g. Stone 1990). Using local environmental conditions as backdrops for predator-prey interactions gives consideration to the role of environmental variability in changing the abundance and distribution of prey. Zoological species are affected by temporal patterns in surrounding environments as well as by direct human predation.

To assess how environmental events associated with climate change might affect marine resource foraging and the structure of the archaeological record, an ABM simulation wherein a hypothetical environment was populated with micro-habitats representing different prey was developed in the Python programming language. Foragers were programmed to choose prey according to various criteria, such as species density and size. The environment was designed so that certain micro-habitats grow back at different rates per model iteration. Differences in resource grow-back rates were intended to simulate environmental events associated with hypothesized climate change and coral bleaching. As more data on the specific aspects of climate change becomes available, temporal trends in the model can be used to assess the composition of the archaeological record.

Model assumptions and parameters

Habitats are ranked according to overall mean energy acquired. Here the environment is separated into three broad zones with different resource values (Figures 8-11; Table 2). Molluscs from the Fatu-ma-Futi assemblage were classified according to the same three Habitats: 1) Coral, Soft Sediment, and Rocky Shoreline. Taxa that could not be placed in only one habitat were not included in the analysis. Based on prey size as a simple measurement of energetic return, the Coral Habitat is ranked the highest. In the Fatu-ma-Futi assemblage, several of the largest taxa, such as *Tridacna*, *Turbo*, and *Trochus* are found living on the hard substrate or nearby coral sand of coral reef habitats. The next highest ranked habitat according to size is the Soft Sediment Habitat, which includes intertidal bivalves, such as *Anadara antiquata*, and *Gafrarium tumidum*. Finally, the Rocky Shoreline Habitat contains predominately small molluscs such as *Nerita* and *Morula* species.

At commencement, the Coral Habitat corresponds to an area with resource values of 50 (rows 1-3), the Soft Sediment Habitat corresponds to the region with resource values of 40 (rows 4-6) and the Rocky Shoreline Habitat consists of an area where resource values vary between 0, 10, and 20

(rows 7-10). These habitats are chosen for simplicity rather than realism and must be treated as heuristic model parameters rather than realistic reconstructions. It is important to note that the ranking of habitat zones by prey size alone can be problematic especially when taxa have the potential for mass capture (Madsen and Schmitt 1998; Jones 2004). Moreover, recent ethnographic studies also indicate that prey size for molluscs can have an affect on field processing and subsequent shell transportation back to a central place (Bird and Bliege Bird 1997; Thomas 2002). As a result, studies comparing the contribution of large and small bodied prey in archaeological record may encounter biases. More complex modeling based on the relationship of prey size and probability of field processing and transport based on central place foraging models (e.g. Cannon 2003), as well as susceptibility to mass capture is currently being pursued by the authors.

The agent rules for this model are:

1. 50 agents begin by randomly populating a graded resource environment;

2. Agents move to the closest unoccupied square with the highest resource values;

3. Agents harvest the resource.

Two environmental scenarios – stability versus variability – that might lead to different outcomes in the archaeological record were explored. While each simulation was allowed to run for 50 iterations, for simplicity only the results for 10 of those iterations are presented here. The Stability model and the Environmental Variability model begin with the exact same environments (Figures 5, 7) yet differ in respect to the rate at which the Coral Habitat grows back. In the Stability Model, all habitats are allowed to grow back per iteration to their initial starting point. If an agent moves to the Coral Habitat and harvests resources, the square will always grow 50 units. Squares not harvested will increase at a constant rate per iteration equal to their initial resource value. While we recognize that human exploitation can lead to declining abundance of prey species, by focusing only on the hypothesized environmental effects of climate change we have simplified the variables responsible for the model outcome.

As discussed above, many researchers have demonstrated in modern studies, coral bleaching events can result in drastic reduction of coral habitats with measurable effects on the fauna living within (Augustin *et al.* 1999; Addessi 2001; Booth and Beretta 2002; Garpe *et al.* 2006). Consequently, the Environmental Variability model limits the growth rate of the Coral Habitat to approximately ⅓ of its initial resource value. If a forager move to the Coral Habitat and harvests 50 resource units, the corresponding cell will only grow back to 12 units upon the next iteration. However, both the Soft Sediment and Rocky Shoreline habitats are allowed to grow back at their initial rates. Consequently, foraging behavior in the Environmental Variability model is a consequence of both foraging decision and changing resource distribution related to environmental variability stemming from hypothesized climate change.

Results: comparing archaeological data with the ABM

Inspection of the Stability model indicates that agents spend the majority of their time foraging in the Coral Habitat (Figures 5, 6). Agents who commenced in other zones eventually make their way to the Coral Habitat, all choosing only to abandon the latter when more optimal opportunities present themselves elsewhere. When environmental factors are not present, foragers spend more time in the resource rich Coral Habitat.
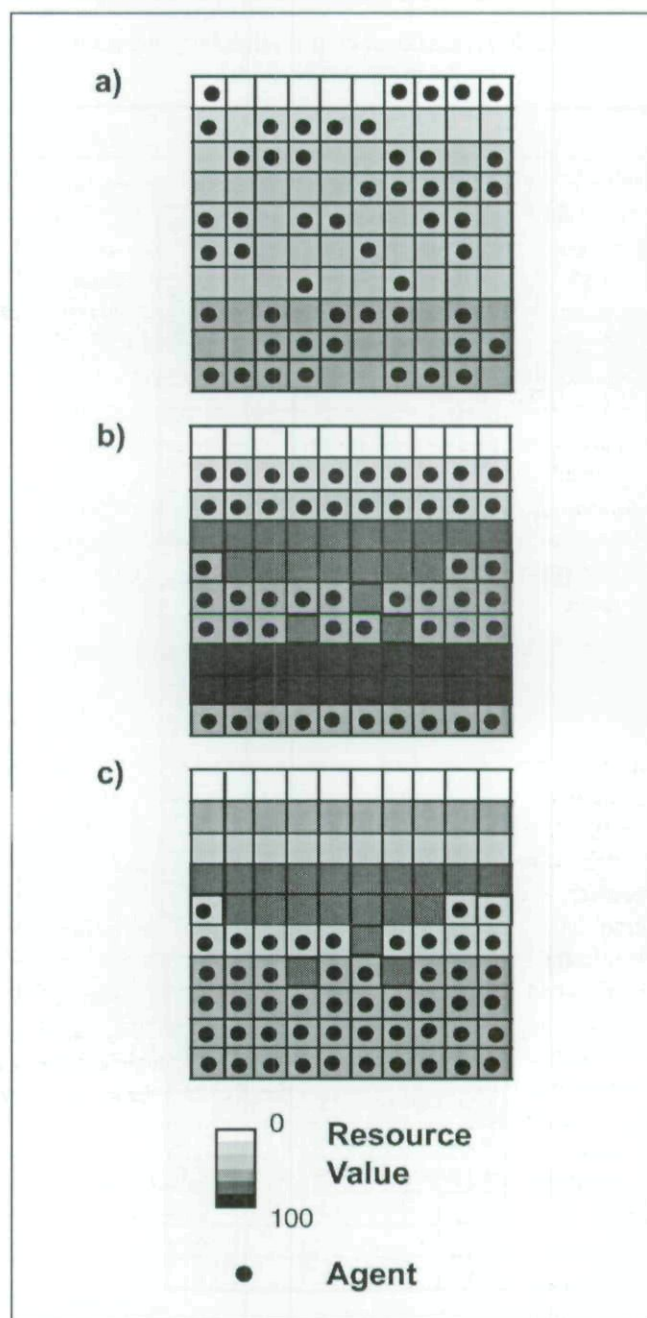

Figure 5. Agents and environments for the Stability model: a) at the starting point agents are randomly placed in various habitats, b) after 3 generations foragers have exploited portions of the coral habitat and begin foraging other habitats, c) after 10 generations, the coral habitat has recovered and foragers return.
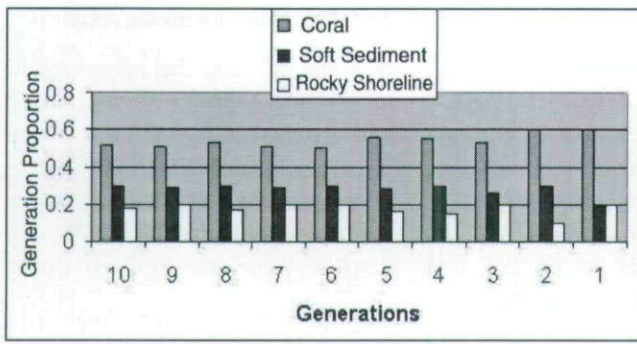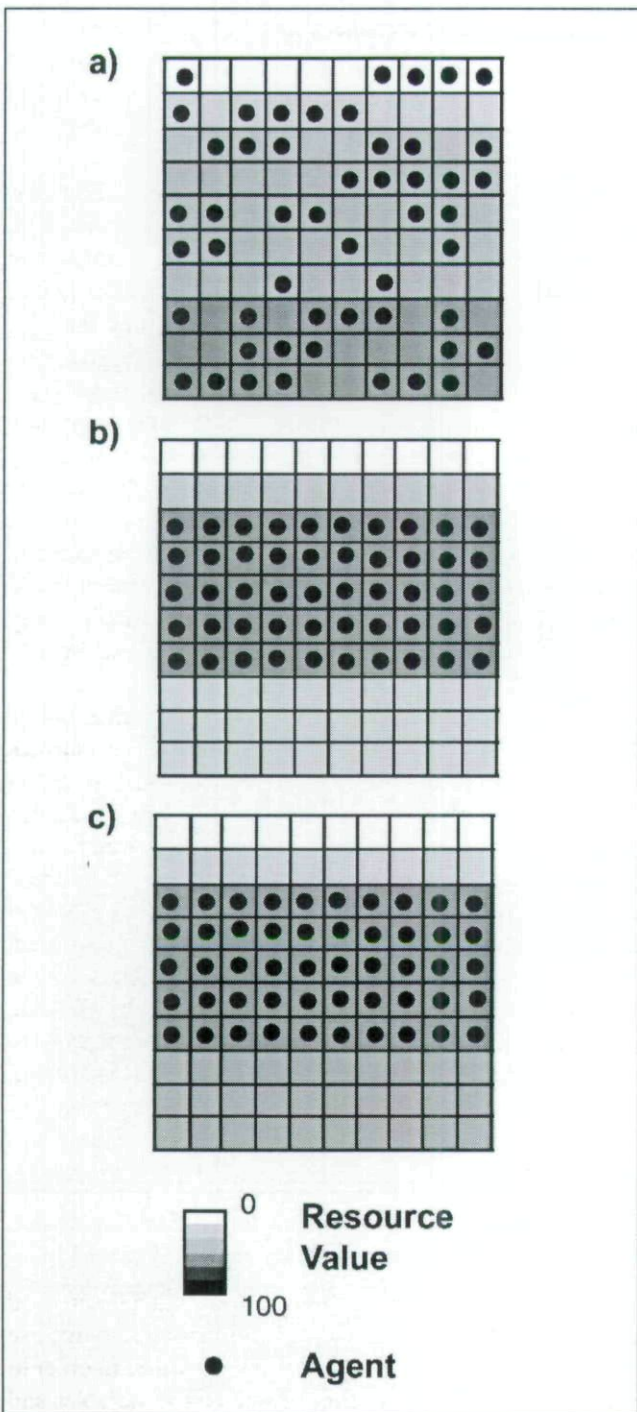
Figure 6. Proportional contribution by generation for the Stability model.

Figure 7. Agents and environments for the Environmental Variability model: a) at the starting point agents are randomly placed in various habitats, b) after 3 generations, the coral habitat has declined in productivity and agents forage predominately in the soft sediment and rocky shoreline habitats, d) after 10 iterations, the coral habitat has not recovered and foragers continue to harvest soft sediment and rocky shoreline resources.

In contrast, the Environmental Variability Model simulates an environment where resources are negatively affected by hypothesized events such as coral bleaching. In contrast to a stable environment, foragers can not rely on the Coral Habitat to grow back to its original resource value. Analysis of the simulation results demonstrate that under these conditions foragers spend the majority of their time in the Soft Sediment Habitat with the Coral Habitat used significantly less (Figures 7, 8).
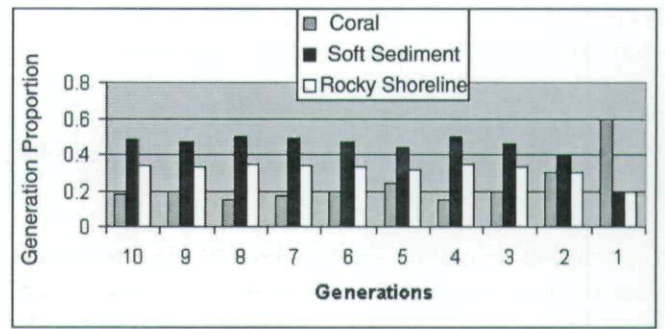

Figure 8. Proportional contribution by generation for the Environmental Variability model.
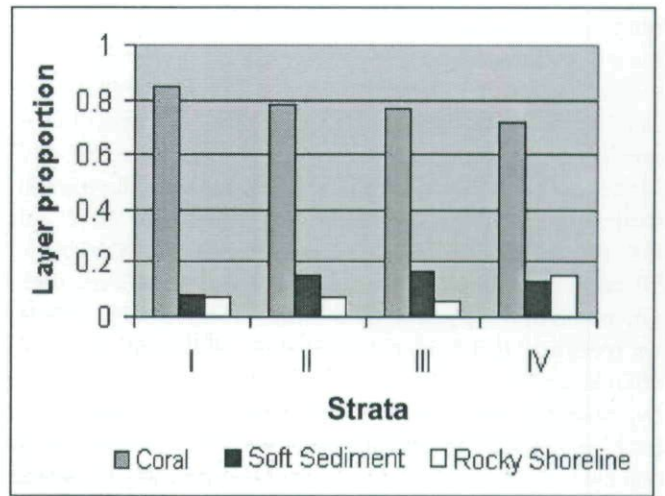

Figure 9. Proportional contribution by stratum for the Fatu-ma-Futi mollusc assemblage.

Evaluation of the proportional contribution by layer for the archaeological data (Figure 9) demonstrates that the Coral Habitat dominates with the Soft Sediment and Rocky Shoreline Habitats present in fairly stable frequencies (Figure 9). In short, there appears to be very little temporal variation in habitat use at Fatu-ma-Futi. Comparison of the archaeological data with the Stability model indicates a high degree of coherence between the simulation runs and the archaeological data, with the Coral Habitat used in much higher frequency. The proportional relationships between the habitats also remain stable. Consequently, the archaeological data appears to support the results of the Stability model.

Discussion

Our results here suggest that neither human predation or climate change appear to have influenced the structure of the Fatu-ma-Futi shellfish assemblage. While in general, faunal remains from Samoa are scarce, comparison of Fatu-ma-Futi with other shellfish assemblages from the archipelago provide some interesting patterns. For example, faunal assemblages from Falemoa, Manono (Janetski 1980) and To`aga, Ofu (Nagaoka 1993) both suggest relative stability in marine resource use through time.

The structural composition of the marine faunal assemblage at the Falemoa site, on the small island of Manono indicates that species use through time was stable. (Janetski 1980). Janetski argues that predation pressure may have led to a decrease in the productivity of the reef environment because 'density figures for both shell and bone reflect a general decrease in dependency on reef collecting through time' (Janetski 1980: 118). The use of density figures alone to infer predation pressure may be misleading because changes in mollusc and fish density may be tracking other cultural or environmental factors such as variable sedimentation rates, settlement shifts, and changes in on-site activities (Nagaoka 1993: 207).

The best documented and most extensive Samoan faunal assemblage comes from the To'aga site on Ofu Island (Hunt and Kirch 1997; Kirch and Hunt 1993; Nagaoka 1993). The bulk of excavated faunal materials are molluscs and fish, with over 165 kg of shellfish remains and 2196 fish bones analyzed. Nagaoka's (1993) analysis suggests substantial stability in marine resource use through time. The rank ordering of the assemblage indicates that faunal exploitation was focused on a few important marine taxa. The invertebrate and fish assemblages illustrate this with a few taxa dominating across space and time (Nagaoka 1993:207). In reference to the To'aga marine environment, Hunt and Kirch (1997) have suggested that the stability of marine resource use could, in part, be due to the high natural productivity of the nearby reef environment and its ability to withstand human predation (p. 119), a situation which seems to differ from other island settings (e.g. Dye and Steadman 1990).

Given the evidence for climate change indicated in the paleo-reconstructions from proxy data and the proposed effects of ENSO variability on marine molluscs, why does there appear to be little change in the structure of the mollusk assemblages at Fatu-ma-Futi, Falemoa, and To'aga? A few important points are worth consideration. First, the effects of atmospheric circulation patterns such as ENSO can vary greatly over relatively short geographical distances (Salinger et al. 1995; Folland et al. 2003; Allen 2006), and over multi-decadal time-scales (Salinger et al. 2001; Folland et al. 2002), two points that may be particularly relevant for the islands of Samoa. Analyzing climate trends in the South-West Pacific, Salinger et al. (1995) have distinguished four climate regions that exhibit marked differences in temperature and precipitation in relation to variation in ENSO state. The islands of Samoa – located in the vicinity of the South Pacific Convergence Zone (SPCZ) – appear only slightly affected by changes in ENSO phase. Meteorological data from the region show a weak correlation with the Southern Oscillation Index (SOI) (Salinger et al. 1995: 298), attesting to the need for proxy records that are more locally based.

While the general effect of changes in sea level, SST, and ENSO frequencies can be modeled, other environmental factors, such as tectonic isostacy, topographic features, and variability in island geography, occurring at smaller spatial scales can lead to locally distinct conditions that must be assessed in each context. Daly (2006:Table 1) suggests that while general circulation patterns provide a large scale backdrop for a region's climate, other physiographic features, such as elevation, water bodies, and topography must be accounted for to assess the suitability of any climate dataset to a particular locale. The potential for oxygen isotope analysis to measure changes in SST and analyses of shell chemistry could help resolve these issues since aragonite/calcite percentages measured through x-ray diffraction are directly proportional to variations in SST (Cohen et al. 1992).

Coral bleaching, a complex phenomenon that, while closely linked to ENSO and increased sea surface temperature, is an outcome of coral stress which does not always occur within a particular temperature parameter. There is some evidence to suggest that shallow water corals in American Samoa and elsewhere can tolerate large temperature fluctuations over short periods of time (Craig et al. 2001; Brown and Suharsono 1990). Environmental location and habitat characteristics also appear to be relevant variable in coral bleaching susceptibility (D'Croz and Mate 2004). Furthermore, many factors contribute to coral bleaching including SST, light, sedimentation, pollution, salinity, and disease, variables that together may create a synergistic result leading to bleaching (Barton and Casey 2005: 549).

Conclusion

In this article we have suggested that both climate and humans predation can affect patterns of marine resource use in different, often archaeologically unclear ways. In order to properly assess the relationship between these variables and

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to tease apart the roles each may play in patterning the faunal record, a first step is to acquire more resolute and spatially appropriate proxy climate data. Local environmental variability must also be taken into consideration as the effects of regional climate change are ultimately influenced by other physiographic factors occurring at various spatial scales (Daly 2006). Environmental variability on regional and local scales must then be linked to prey populations through biological and life history data for taxa recovered in the archaeological record. Integrating forager prey and habitat choice with prey-species life-history data is facilitated through the use of agent-based computer simulation for modeling multiple environmental scenarios on variable spatial and temporal scales. Finally, more faunal assemblages are needed from stratified sites with well-defined chronology from around Samoa. Archaeological field research in Samoa must include the recovery and analysis of faunal assemblages as key goals for future projects.

Because marine resources were fundamental to prehistoric subsistence in the Pacific, documenting the timing and cause of trends in resource use is relevant to many other social processes, including cultural diversification, competition, cooperation, and human spatial organization. At present, marine resource use and subsistence patterns in general are poorly understood for Samoa. Furthermore, climate patterns in the central Pacific may vary with those of other parts of the world in locally distinct ways (Allen 2006). Developing models that link climate change to subsistence will ultimately help construct methods, and appropriate analytical procedures useful for building archaeological explanations.

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