

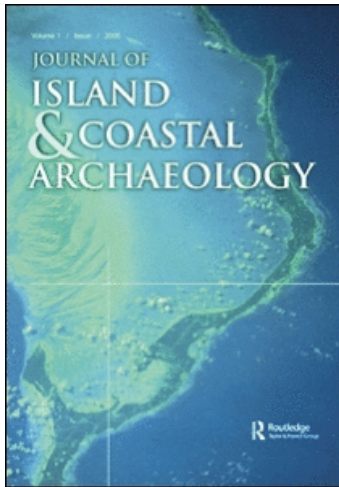
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Examining Causes and Trends in Marine Trophic Level Change: 1500 Years of Fish Exploitation at Fatu-ma-Futi, Tutuila Island, American Sāmoa

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ABSTRACT

*Excavations at Fatu-ma-Futi, Tutuila Island, American Sāmoa reveal a rich cultural deposit spanning approximately 1500 years (1620–150 cal BP). Abundant cultural material was recovered, including a large assemblage of fish remains. We present our analysis of a sample of the fish remains, including a trophic level analysis applied to the assemblage to document patterns in fish community structure and composition. Results indicate relative stability in the mean trophic level of fish families exploited through time. A minor decrease in trophic level is documented between 300–100 cal BP. The relative abundance of fish feeding classes suggests that two inshore herbivore families, surgeonfish (*Acanthuridae*) and parrotfish (*Scaridae*), increase through time. Further research is needed to document the extent to which these patterns result from environmental, cultural, or methodological variables.*

Keywords zooarchaeology, marine food webs, faunal analysis, subsistence, coral reefs

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Emerging evidence from the Fiji/West Polynesia region suggests that early island inhabitants relied significantly on marine organisms for a large part of their subsistence (e.g., Burley 1999; Field et al. 2009). However, some data indicate that reliance on marine resources in certain island environments may have diminished through time (Allen 2003; Allen et al. 2001; Field et al. 2009; Kirch and Yen 1982). Others have argued that these patterns in subsistence resulted in broader cultural changes including increased upland settlement (Morrison and Cochrane 2008; Pearl 2004) conflict and competition (e.g., Field 2004), and even migration into new island environments (e.g., Anderson 2001, 2003). Moreover, recent theoretical models have focused on the complex interconnections between subsistence regimes, island biogeography, habitat sustainability, and the migration and abandonment of island landscapes (e.g., Giovas 2006; Keegan 1995; Kennett et al. 2006).

Few studies have systematically explored trends in fauna use across the Sāmoan Archipelago, but it is clear that marine resources were important food items, ranked highest in abundance among the few faunal assemblages documented (Janetski 1980; Morrison and Addison 2008; Nagaoka 1993). In this paper, we provide new data on approximately 1500 years of fish remains (1620–150 cal BP) from Fatu-ma-Futi, Tutuila Island, American Sāmoa. An analysis of mean trophic level exploitation is applied to the fish assemblage. Examining patterns in trophic level exploitation is a useful heuristic device for addressing a number of issues, including trends in fish community structure, human and natural impacts to marine ecosystems, predator prey relationships, and changes in fishing technology. Additionally, a number of recent studies on prehistoric dietary patterns in the Oceanic region have focused on the analyses of stable isotope ratios in archaeological bone samples (e.g., Field et al. 2009; Leach et al. 2000, 2003; Valentin et al. 2006). Combining quantification of archaeological faunal material with data derived from isotopic composition studies will help to specify the variables responsible for changes in these isotope relationships and provide a better

background for understanding the nature of subsistence trends.

TROPHIC LEVEL ANALYSIS AND ARCHAEO-FISH ASSEMBLAGES

Trophic level analysis has recently been used to examine patterns in fish use in archaeological and modern contexts and offers researchers a new tool for measuring changes in fish species composition (Reitz 2004; Reitz et al. 2009; Quitmyer and Reitz 2006; Wing and Wing 2001). In a historic period study, Pauly et al. (1998) assigned fish species to trophic levels according to their feeding position on the marine food web. Primary producers occupy trophic level 1, while benthic and herbivore species, as well as invertebrate mollusks, occupy level 2. Carnivorous fish families such as jacks (*Carangidae*), tuna (*Scombridae*), and snappers (*Lutjanidae*) occupy higher trophic levels ranging from 3 to 5.

Using mean trophic level data on global fisheries statistics reported from 1954 to 1994, Pauly et al. (1998) reported a global decrease in trophic level exploitation which they suggested was the result of a gradual shift in fish catch from high trophic piscivores to lower level invertebrates and planktivores (Pauly et al. 1998:860). These changes are thought to be the direct outcome of overharvesting and mismanagement of large-bodied high trophic level fish. Jackson (2001:5415) also noted an increasingly apparent global trend in the use of smaller fish species.

While declining mean trophic levels in modern fishery landings data is often considered to be a sign of the depletion of high trophic level organisms and an indication of declining marine ecosystem health in general, there are reasons to believe that the situation is more complex. For example, changes in mean trophic levels may occur through the addition of lower level fish species without significant decreases in upper level trophic taxa. In a number of instances, this process, termed “fishing through marine food webs”, has demonstrated that mean trophic levels can decline even in cases where upper

trophic species actually increase (Essington et al. 2006). Other potential methodological problems associated with mean trophic level analysis include difficulties associated with acquiring the appropriate level of taxonomic resolution (Caddy et al. 1998). Since fish species within a given family can vary according to feeding behavior and consequently trophic level, identifications often need to be made to the level of genus or species. In archaeological studies, this requirement is often difficult to meet and thus provides another source of methodological bias.

Most archaeological studies employing trophic level analyses have been limited to researchers working in the West Indies (e.g., Wing 2001; Wing and Wing 2001) and the southeast coast of the United States (e.g., Quitmyer and Reitz 2006; Reitz 2004; Reitz et al. 2009). Several studies document decreases in mean trophic levels in pre-European Native American contexts, suggesting that the trends reported by Pauly et al. (1998) are not exclusive to modern commercial economies. However, the causes of declining trophic levels when measured against archaeofaunal data are difficult to determine and may be a combination of human induced impacts, changes in fish capture technology, and climate and/or local environmental variability (Reitz 2004:65–67; Wing and Wing 2001:7–8). As noted by a number of archaeologists studying prehistoric marine ecosystems and studying contemporary marine faunal populations, natural habitat changes can greatly affect the composition and abundance of fish and mollusk species (Agustin et al. 1999; Booth and Berreta 2002; Garpe et al. 2006, Kirch and Yen 1982, Leach 2006; Morrison and Cochrane 2008).

It is also important to recognize that fish communities have complex ecological relationships and predator prey interactions that are independent of human activity. The abundance of many inshore prey species is also strongly influenced by the distribution of piscivorous fish predators (Hixon and Beet 1993). The distribution and abundance of fish taxa in prehistory was clearly the result of complex causal factors, including both

natural and human induced habitat alteration, direct predation by humans, and competitive exclusion between predator and prey fish species (Reitz et al. 2009).

MATERIAL AND METHODS

The Fatu-ma-Futi Site

Fatu-ma-Futi Village is located on Tutuila Island in the center of the Sāmoan Archipelago (Figure 1). The village is perched on a narrow coastal shelf ~200 m long and <50 m wide (Figure 2). Stratigraphic excavations revealed a rich deposit (Addison et al. 2008) with evidence of basalt tool manufacture, houses, cooking features, burials, and midden deposits. In 2005–2006 and 2008 extensive excavation (~70 m²) was conducted to explore the Fatu-ma-Futi deposits. Nearly 40 radiocarbon dates were acquired from charcoal, human bone, and marine shell samples, making it one of the best-dated archaeological sites in West Polynesia. Details regarding the initial excavation results are reported by Addison et al. (2008). Results from the analysis of invertebrate remains recovered from the excavations can be found in Morrison and Addison (2008).

The earliest occupation of the coastal plain began around 1600 cal BP and corresponds to Layer IV (Figure 3). The sedimentary and cultural materials recovered from within this stratum suggest that the area was being used for temporary marine procurement on a newly formed beach (Addison and Asua 2006). Layer III was deposited around 1000 cal BP and provides evidence for permanent habitations, burials, and extensive midden deposits, a pattern continuing until historic times. Layer II dates to ~700–600 cal BP and contains abundant basalt lithic debitage and formal tools. Layer I dates to around 300–100 cal BP, and corresponds to the Protohistoric and Early Historic periods. Several historic and modern construction fill layers cap the subsurface deposits across most of the coastal plain.

Fatu-ma-Futi is an important site for addressing both local and regional topics. No other coastal habitation has yet been found

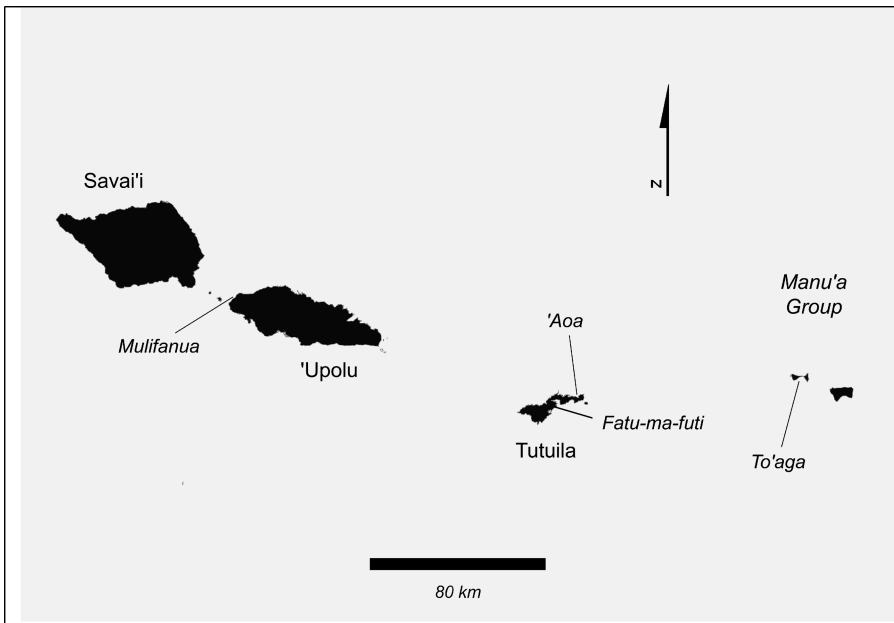


Figure 1. The Islands of Sāmoa with key archaeological sites.

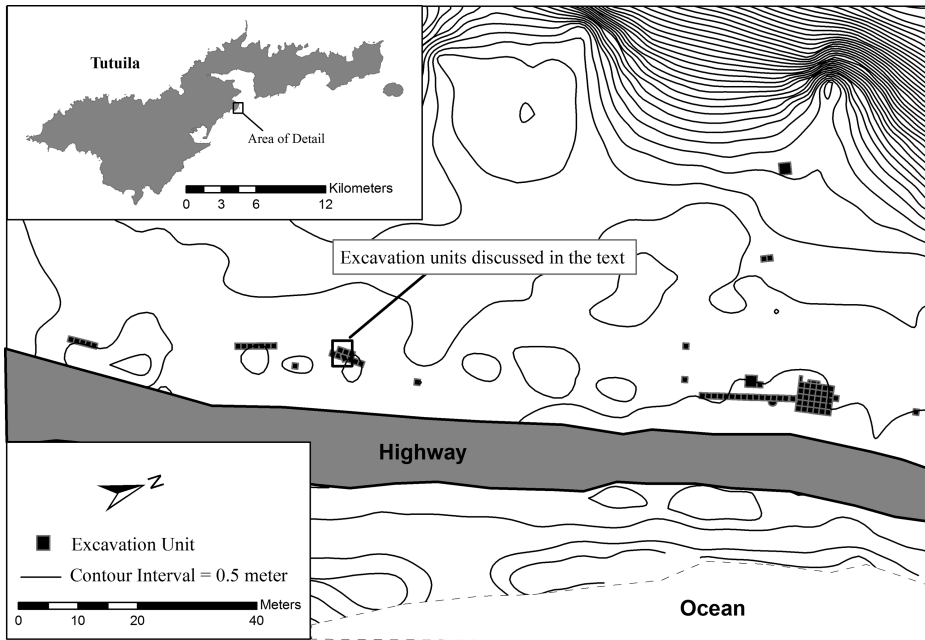


Figure 2. The Fatu-ma-Futi coastal plain with the location of the excavation units discussed in the text.

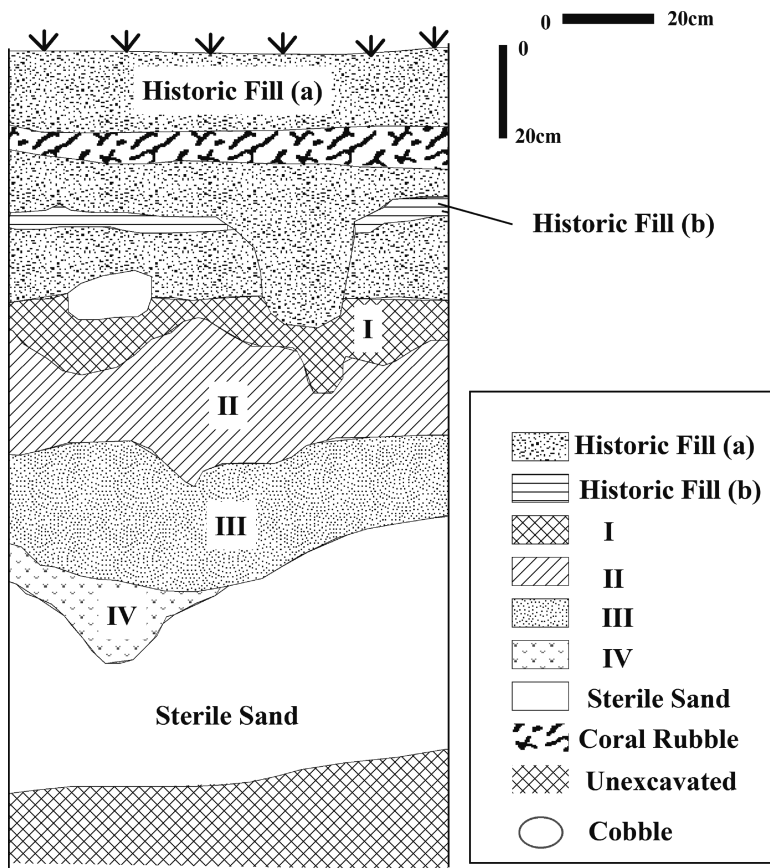


Figure 3. Excavation profile for unit 16 (west wall).

on Tutuila with the same diversity of material present. Additionally, the deposit spans the “Sāmoan Dark Ages” (Davidson 1979; Rieth 2007; Rieth and Addison 2008), a little-known period when ceramics were no longer used and surface features were rare, but which is thought to be influential to proto-historic Sāmoan socio-political systems. Regionally, the period of occupation at Fatu-ma-Futi coincides with the initial settlement of East Polynesia, Tokelau, and some of the Polynesian Outliers. Because of size, geographical location, and ecological complexity, Tutuila has been suggested a likely origin for some of these colonists (Addison 2004).

Fish Analysis Methods

The analysis presented here focuses on 100% of the identifiable fish remains recovered from four of the eight excavated 1×1 m units yielding fish remains (Units 2, 6, 16, and 11). Excavations were conducted by natural stratigraphic units and arbitrary 10 cm sub-units within strata. The fish assemblage was recovered by wet screening with 1/8-inch screen mesh. Remains were identified by Morrison using fish reference collections at the University of Hawai‘i, Mānoa and the Bishop Museum in Honolulu, Hawai‘i. Identifications were made using a combination of

Table 1. Number of fish bones by anatomical element.

Element	Total
Dentary	144
Premaxilla	122
Maxilla	42
Quadrate	101
Articular	77
Pharyngeal	194
Dorsal Spine	329
Anal Spine	18
Dermal Spine	20
Vertebra	10
Scale	29
Tooth	18
Palantine	4
Scute	11
Total (NISP)	1119

the five common cranial elements (dentary, premaxilla, maxilla, quadrate, and articular), and a number of distinctive elements which are unique to certain fish families (Table 1). The number of identified specimens (NISP) and the minimum number of individuals (MNI) were calculated separately for all excavation units and then aggregated together for the final analyses. Consequently, all results discussed in the remainder of the paper refer to the aggregated remains from all four excavation units (following Davidson et al. 2000).

A total of 6,231 individual fish bones (NISP) were analyzed, with 1,119 bones identified to 17 discrete fish families (MNI = 264; Tables 2–3). Of the 5,112 bones not identifiable beyond the gross category of unidentified fish, 34.5% ($n = 1763$) were vertebrae or spines. Fish processing procedures and calculation of MNI followed the methods outlined in Leach (1986, 2006). No attempt was made to increase MNI by attempting to size match paired elements for reasons discussed by Leach (1986). The complete database of the fish remains is available from the senior author upon request.

Although an estimated 3500 fish bones from the remaining four excavation units await further analysis, the four units reported here contain the densest fish remains recovered in the excavations. While both natural and cultural depositional processes can vary greatly over small spatial distances (Davidson et al. 1998), the eight excavated units are contiguous and display uniformity in depositional history. Grayson (1984) and others (e.g., Allen et al. 2001; Butler 1994) have noted that positive correlations between NISP and MNI often exist in faunal assemblages. To employ the larger assemblage, NISP was used for all of the analyses.

Information on trophic levels and feeding habits (Table 4) was obtained from the Web site www.fishbase.com (Froese and Pauly 2008) and from other published reports (e.g., Allen 1992a; Allen et al. 2001; Butler 1994; Leach and Davidson 2000; Leach et al. 1988). Mean trophic level at the family level was calculated by averaging trophic information for all of the species from American Sāmoa available on fish base. Mean trophic level for a given time period was calculated as:

$$TL_i = \sum (TL_{ij}(NISP_{ij}) / \sum NISP_i$$

RESULTS

Mean Trophic Level

Analysis of patterns in the mean trophic level of fish remains recovered in the assemblage (Figure 4) indicates a pattern of stability from ~1600 cal BP (Layer IV) to ~300 cal BP (beginning of Layer I). The index values are not correlated with sample size (Spearman's rho; $r_s = 0.20$; $p = 0.800$; two-tail test). A minor decrease in mean trophic level from 2.9 to 2.67 occurs between layers II and I, the latter dating to ~300–100 cal BP. An increase in the relative abundance of herbivore families in Layer I seem to account for the minor decrease in trophic level. However, inspection of the abundances of the two herbivore families—surgeonfish (Acanthuridae)

Table 2. Number of identifiable specimens (NISP) recovered from Fatu-ma-Futi.

Taxon	I	II	III	IV	Total
Acanthuridae	9	95	202	9	315
Scaridae	7	76	201	14	298
Serranidae	1	38	112	4	155
Labridae	1	34	91	2	128
Balistidae	0	26	26	6	58
Lethrinidae	1	10	26	0	37
Carangidae	2	13	18	2	35
Holocentridae	2	7	8	2	19
Diodontidae	0	3	10	4	17
Lutjanidae	0	3	13	1	17
Elasmobranchii	1	4	4	0	9
Muraenidae	0	4	4	0	8
Belonidae	0	2	0	2	3
c.f. Lethrinidae	0	1	2	1	4
Scorpaenidae	0	0	3	0	3
c.f. Labridae	0	1	1	0	2
c.f. Pomacentridae	0	0	2	0	2
Cirrhitidae	0	0	2	0	2
Pomacentridae	0	0	1	1	2
Scombridae	0	1	1	0	2
Anguilliformes	1	0	0	0	1
Mugilidae	0	1	0	0	1
Sub-Total	25	319	727	48	1119
Unidentified Fish	75	2270	2360	407	5112
Total Fish (NISP)	100	2589	3087	455	6231

and parrotfish (Scaridae)¹—indicates that these two taxa are always ranked first or second in the assemblage and no dramatic compositional changes affecting these high ranking taxa are evident.

As previously mentioned, various complicating factors can make uncritically assigning causation in trophic level changes the result of overfishing precarious (Caddy et al. 1998; Essington et al. 2006). While trophic level analysis provides a useful starting point for documenting trends in fish use, more detailed examination of assemblage composition is necessary to elucidate the causes of trophic level trends. It is plausible that

habitat alterations, either natural or human induced, affected suites of taxa corresponding to certain feeding and/or habitat classes. Analysis of changes in the exploitation of fish species aggregated by feeding behavior was conducted to further explore patterns in the structure of the assemblage. Aggregating fish families according to feeding habits is useful because fish that feed on similar resources generally occupy similar habitats, have similar predator-prey relationships, and can often be caught using analogous fishing methods. Ecological studies have also documented an inverse relationship between piscivore population numbers, maximum

Table 3. Minimum number of individuals recovered at Fatu-ma-Futi.

Taxon	I	II	III	IV	Total
Acanthuridae	2	12	23	8	45
Scaridae	3	11	33	5	52
Serranidae	1	8	23	3	35
Labridae	1	6	13	2	22
Balistidae	—	9	8	2	19
Lethrinidae	1	5	9	—	15
Carangidae	1	4	5	1	11
Holocentridae	2	7	8	2	19
Diodontidae	—	2	3	1	6
Lutjanidae	—	1	7	1	9
Elasmobranchii	1	3	2	—	6
Muraenidae	—	3	2	1	6
Belonidae	2	2	—	1	5
c.f. Lethrinidae	—	—	1	—	1
Scorpaenidae	—	—	3	—	3
c.f. Labridae	—	—	1	—	1
c.f. Pomacentridae	—	—	1	—	1
Cirrhitidae	—	—	2	—	2
Pomacentridae	—	—	1	1	2
Scombridae	—	1	1	—	2
Anguilliformes	1	—	—	—	1
Mugilidae	—	1	—	—	1
Total	15	75	146	28	264

abundances of prey fish, and recruitment survivorship (Hixon 1991; Hixon and Beets 1993).

Fish taxa were classified according to three feeding categories: 1) herbivores feeding primarily on algae and detritus; 2) omnivores/benthic carnivores that consume a diversity of invertebrates, worms, and crustaceans; 3) and piscivores that feed primarily on other fish. Inspection of the relative contribution of fish corresponding to different feeding behaviors was conducted using a series of relative abundance indices.

The Herbivore Index is calculated as:

$$\frac{\sum \text{NISP Herbivores}}{\sum \text{NISP All Taxa}}$$

The Omnivores/Benthic Carnivore Index is calculated as:

$$\frac{\sum \text{NISP Omnivores/Benthic Carnivores}}{\sum \text{NISP All Taxa}}$$

and

The Piscivore Index is calculated as:

$$\frac{\sum \text{NISP Piscivores}}{\sum \text{NISP All Taxa}}$$

The results show a general increase in the relative proportion of herbivorous fish in the assemblage, especially in Layer I, between about 300 and 100 cal BP (Figure 5). Sample size is not correlated with the trend (Spearman's rho $r_s = -0.20$; $p = 0.800$;

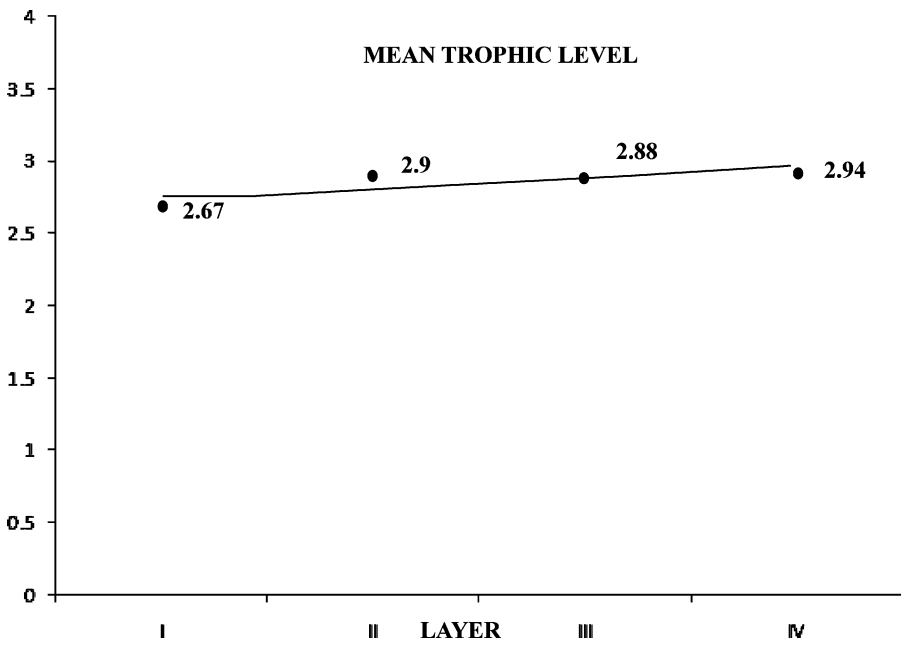


Figure 4. Mean trophic level by excavated layer.

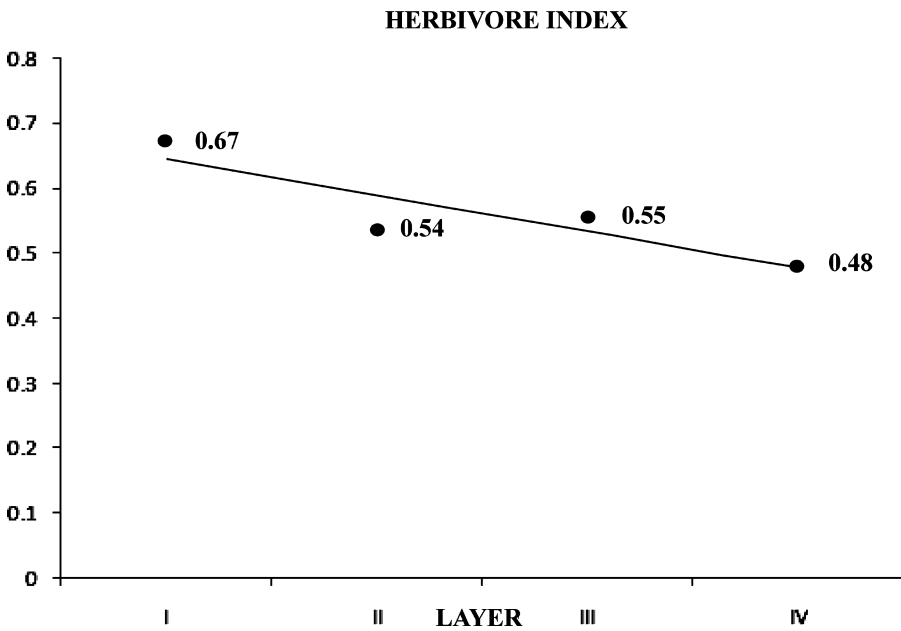


Figure 5. Relative abundance of herbivorous fish recovered at Fatu-ma-Futi.

Table 4. Dietary preference, habitat, and trophic level (TL) of fish families from Fatu-ma-Futi.

Taxon	Dietary Preference	Habitat	TL
Acanthuridae	Herbivore	Inshore	2.39
Balistidae	O/BC	Inshore	3.28
Belonidae	Piscivore	Inshore	4.5
c.f. Labridae	O/BC	Inshore	3.51
c.f. Lethrinidae	O/BC	Inshore	3.55
c.f. Pomacentridae	O/BC	unknown	2.812
Carangidae	Piscivore	Offshore	3.91
Cirrhitidae	Piscivore	unknown	3.75
Diodontidae	O/BC	Inshore	3.5
Elasmobranchii	Piscivore	Offshore	—
Holocentridae	O/BC	Inshore	3.64
Labridae	O/BC	Inshore	3.51
Lethrinidae	O/BC	Offshore	3.55
Lutjanidae	Piscivore	Offshore	3.88
Mugilidae	O/BC	unknown	2.575
Muraenidae	Piscivore	Inshore	4.02
Pomacentridae	O/BC	unknown	2.812
Scaridae	Herbivore	Inshore	2.04
Scombridae	Piscivore	Offshore	4.04
Scorpaenidae	Piscivore	unknown	3.75
Serranidae	Piscivore	Inshore/Offshore	4.04

Data from Allen 1992a; Allen et al. 2001; Butler 1994; Froese and Pauly 2008; Leach and Davidson 2000; Leach et al. 1988. O/BC = omnivore or benthic carnivore.

two-tail test). The omnivore/benthic carnivore index (Figure 6) suggests that after initial occupation around 1600 cal BP (Layer IV), the contribution of taxa classified as omnivore/benthic carnivore declined relative to other classes, reaching lowest abundance by approximately 300–100 cal BP (Layer D). Sample size is not correlated with the abundance index (Spearman's rho; $r_s = 0.20$; $p = 0.800$; two-tail test). Piscivorous fish relative abundance generally remains stable with a very slight decline in Layer I (Figure 7). However, sample size is correlated with the abundance index (Spearman's rho; $r_s = 1.00$; $p < .001$; two-tail test).

The feeding behavior analysis suggests that the relative abundance of herbivorous fish increased through time in the assemblage. While the increase is

most evident in Layer I, the two herbivorous fish families—surgeonfish and parrotfish—always make up the majority of the assemblage. Examining the rank order abundance of fish families helps to illuminate whether the patterns documented in the trophic level and fish feeding analyses are the result of finer scale patterns in single fish families or if more general patterns in suites of taxa have occurred.

Inspection of the rank order abundance of fish families recovered (Table 5) suggests that of the two herbivore families that dominate the assemblage, surgeonfish relative abundance is driving the overall trend of increasing herbivore fish abundance. The percentage contribution of surgeonfish increases in every excavated layer, ultimately making up 36% of the fish in Layer I. In

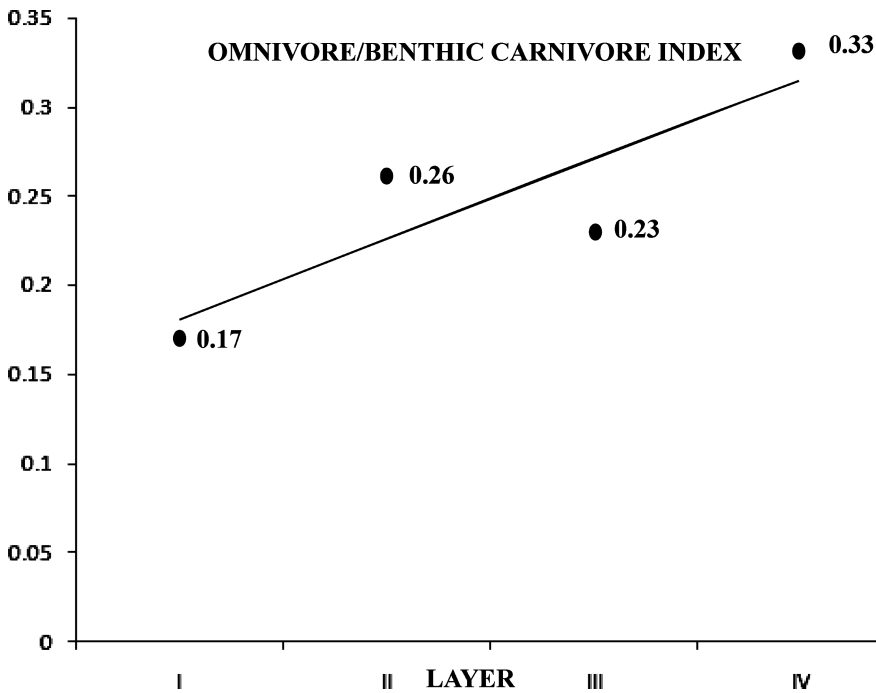


Figure 6. Relative abundance of omnivorous/benthic carnivorous fish recovered at Fatu-ma-Futi.

contrast, parrotfish, the only other herbivore fish family represented, remains fairly stable through time and always makes up between 23% to 29% of each layer. The percentage contribution of the most abundant piscivore family—sea bass and groupers (*Serranidae*)—decreases from 15% in Layer III (~1000 cal BP) to 4% in Layer I (~300–100 cal BP). Almost all other fish families remain relatively stable and show no clear temporal patterns.

DISCUSSION

Based on the analyses presented above, fishing at the Fatu-ma-Futi site focused primarily on inshore herbivores species of surgeonfish and parrotfish. Except for groupers and sea bass (*Serranidae*), which decline in relative abundance from Layer III to Layer I, piscivorous fish were never hunted frequently and offshore fish species did not contribute substantially to the overall catch. The gradual

decline in trophic exploitation documented in the Fatu-ma-Futi assemblage from 300 to 100 cal BP, is largely the result of a relative increase in the low trophic level herbivore surgeonfish family. This can more adequately be considered an example of “fishing through the food web” rather than “fishing down the food web” since no dramatic decrease in high trophic level taxa has been documented (see Essington et al. 2006).

Comparable results are reported by Nagaoka (1993) in her analysis of fish remains from the Toaga Site, Ofu Island American Sāmoa. Toaga was initially settled by 2500 cal BP (Rieth et al. 2008) and was probably continuously occupied into the early historic era. However, the chronology of the last 1000 years of the deposit is poorly understood. Nagaoka (1993) identified 2196 fish bones with the bulk of these remains consisting of the families porcupinefish (*Diodontidae*), surgeonfish, parrotfish, sea bass and groupers, and squirrelfish (*Holocentridae*). The results indicate relative stability in fish

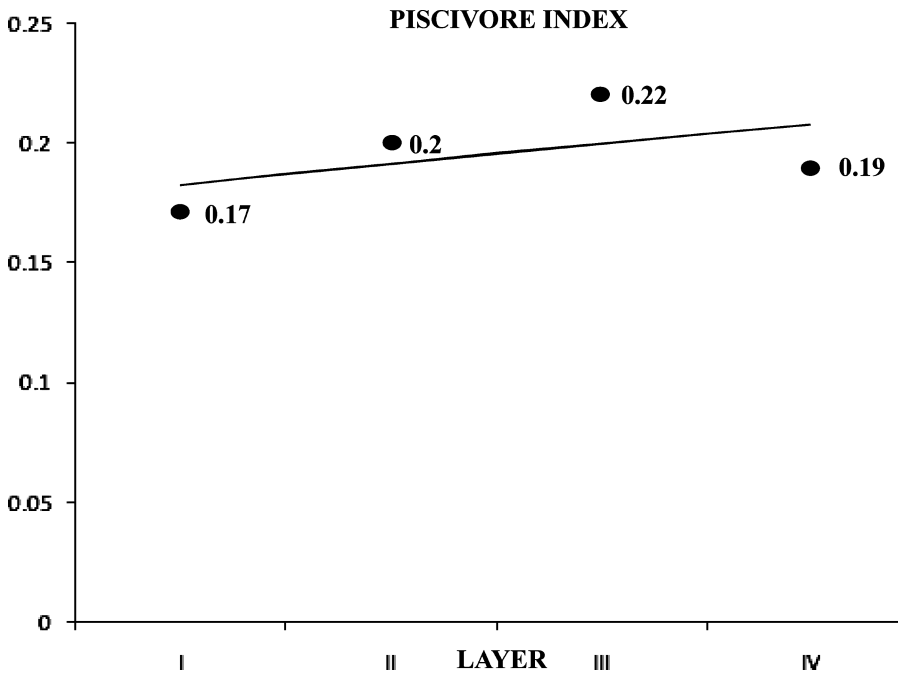


Figure 7. Relative abundance of piscivorous fish recovered at Fatu-ma-Futi.

compositional structure through time, reflecting a high degree of productivity and sustainability in the nearby marine ecosystem (Hunt and Kirch 1997:119). Recent research

on invertebrate remains recovered from Fatu-ma-Futi also demonstrates very little variation in mollusk foraging through time (Morrison and Addison 2008).

Table 5. Rank order abundance of fish families recovered from Fatu-ma-Futi.

Taxon	I	II	III	IV
Acanthuridae	1 (36%) [H]	1 (30%) [H]	1 (28%) [H]	2 (19%) [H]
Scaridae	2 (28%) [H]	2 (23%) [H]	2 (27%) [H]	1 (29%) [H]
Serranidae	6.5 (4%) [P]	3 (12%) [P]	3 (15%) [P]	4.5 (8%) [P]
Labridae	6.5 (4%) [O/BC]	4 (11%) [O/BC]	4 (13%) [O/BC]	7 (4%) [O/BC]
Balistidae	—	5 (8%) [O/BC]	5.5 (4%) [O/BC]	3 (13%) [O/BC]
Lethrinidae	6.5 (4%) [O/BC]	—	5.5 (4%) [O/BC]	—
Carangidae	3.5 (8%) [P]	—	—	7 (4%) [P]
Holocentridae	3.5 (8%) [O/BC]	—	—	—
Diodontidae	—	—	—	4.5 (8%) [O/BC]
Elasmobranchii	6.5 (4%) [P]	—	—	—
Belonidae	—	—	—	7 (4%) [P]

Bold numbers indicate ranks, percentage contribution in parentheses. Feeding class indicated in brackets.

In contrast to the results from Fatu-ma-Futi and Toaga, evidence for decreasing abundance of both piscivores and omnivores/carnivores has been noted from excavations on nearby Rotuma, which date between approximately 1400–1000 cal BP (Allen et al. 2001). Allen (1992a, 1992b, 2002) has also documented a decrease in offshore fishing at Moturakau, Aitutaki, Cook Islands (occupied from approximately 650 cal BP into the late prehistoric/early historic period (Allen and Wallace 2007), which she suggests may be related to a decreasing availability of pearl shell for the manufacture of fish hooks (2002:200). Similar declines in the contribution of offshore taxa have been noted from the Society Islands (Davidson et al. 1998; Leach et al. 1984) and the Marquesas Islands (Davidson et al. 2000; Dye 1990; Rollett 1989). The importance of offshore pelagic fishing in the Mariana Islands is also well documented (Leach et al. 1988).

To understand the potential causes responsible for the high number of herbivore taxa recovered from all excavated layers at Fatu-ma-Futi, a number of hypotheses are presented below. While most of the discussion focuses on characteristics of the natural environment, other causal factors include cultural innovations in fishing technology and human predation. Analytical biases related to identification methods and taphonomic processes are also briefly considered.

Modern studies on the relationship between biomass and trophic group distributions of reef fish in American Sāmoa demonstrate that the spatial patterning and abundance of fish species corresponds closely to the location of food resources. In Tutuila Island's near-shore environment today, overall fish biomass is dominated by herbivores of the surgeonfish and parrotfish families (Sabater and Tofaeono 2007). Herbivore biomass is highly correlated with the presence of filamentous and coralline algae which are important food resources for herbivorous fish. In contrast, a number of piscivore species show a high correlation with live coral reef habitats (Sabater and Tofaeono 2007). The results of modern studies are important as they demonstrate that spatial and temporal variation in the distribution and

health of coral reefs may have also had a significant impact on the abundance of fish families in the past.

Since the distribution of food resources and habitat is closely correlated with the structure and biomass of fish communities, it is useful to explore variables that may have led to changes in coral reef environments and potentially led to an increase in herbivore food resources. Natural environmental perturbations leading to the degradation of coral reef environments are particularly important for stimulating the growth of turf algae. Booth and Beretta (2002) found that coral bleaching due to elevated sea surface temperature resulting from the El Niño event of 1997/1998 led to a decrease in recruitment of fish species that normally associate with live coral habitats. However, in similar studies, transient herbivore taxa with a wider range of feeding habits increased dramatically within six months of the bleaching event (Garpe and Ohman 2003; Garpe et al. 2006).

As corals die, their live tissues are rapidly replaced by turf algae creating habitats favoring roaming herbivores. Craig (1996), and Craig et al. (1997) suggest that severe coral reef damage in American Sāmoa from a combination of hurricanes, crown-of-thorn starfish (*Acanthaster* sp.) invasions, mass sedimentation events, and coral reef bleaching, has created a suitable environment for the growth of turf algae, leading to an increase in the abundance of the blue-banded surgeonfish (*Acanthurus lineatus*) in the waters today.

While the degradation of coral reef habitats has been shown to create a favorable environment for herbivorous species, coral reef degradation often leads to a decline in the abundance of predator piscivores that live and feed in these complex environments (Booth and Beretta 2002; Sabater and Tofaeono 2007). Declines in the abundance of predatory fish are often a direct consequence of habitat reduction. Although predator-prey relationships among fish species can be quite intricate because of the tremendous species diversity and extreme structural complexity of coral reefs habitats (Hixon and Beets 1993:78), it is plausible that as predatory piscivore species decreased in abundance,

herbivore prey species increased due to the combined effects of the loss of key predators and an increase in the feeding environment.

Even though the effects of human over-harvesting are not observable in the Fatu-ma-Futi assemblage, recent theoretical and methodological advances modeling resource depression of marine and terrestrial fauna may be combined with trophic level analysis in future studies (e.g., Allen 2002; Butler 2001; Morrison and Hunt 2007; Nagaoka 2001; Reitz 2004). Allen (2003) suggests that resource depression can be measured by looking at the proportion of large- to small-bodied prey, patterns in diet breadth, and changes in prey size and age composition. Wing and Wing (2001) have augmented trophic level analysis by investigating changes in prey size, and overall reef biomass to better assign trophic level decline as a result of harvesting pressure.

It is also possible that patterns in catch composition may reflect changes in fishing technologies practiced in the past (Allen 1992a, 1992b, 2002; Dye 1990:73; Leach et al. 1996). The relationship between capture technology and fish feeding behavior has been investigated both ethnographically (e.g., Kirch and Dye 1979) and in archaeological contexts (Allen 1992a; Allen et al. 2001; Butler 1988, 1994; Davidson et al. 1998; Leach et al. 1996). In general, piscivores are more likely to be taken by angling with hook and lure technology. Omnivores and benthic carnivores are captured by a variety of methods, including nets, spears, and occasionally hooks. Herbivores are usually captured with spears and nets (Allen 1992a:396, Allen et al. 2001:65; Butler 1994:83). However, variation in fishing technology may lead to changes in fish exploitation which may not have archaeological correlates and therefore may be difficult to recognize in archaeological contexts (Allen 1992b; Butler 1994; Leach and Davidson 2000).

Finally it is important to consider how analytical biases associated with the recovery, identification, and analysis of archaeological assemblages affect the results presented here. For example, the two most abundant fish families in the Fatu-ma-Futi assemblage were identified predominately with the use

of unique anatomical elements that most fish families do not have. Therefore, the number of identified bones from these fish families would be significantly reduced if only the five common cranial bones were used for identification (see Allen 1992a; Davidson et al. 2000; Fitzpatrick and Kataoka 2005, for similar discussions). In fact, the removal of the dorsal spine from the identification would result in the complete absence of surgeonfish, attesting to the low recovery rate of this family when based on cranial elements alone (Nagaoka 2005). Additionally, the use of 1/8-inch screen may affect the recovery of some smaller species and elements. For example, LeFebvre (2007) demonstrated a clear relationship between the recovery of small fish and the use of 1/16-inch screen size in her analysis of a West Indian fish assemblage. Taphonomic processes are also important sources of biases that must be considered. The identifiable elements of Scaridae are particularly robust and may therefore have a higher probability of preservation in archaeological contexts.

CONCLUSIONS

The trophic level analysis of the fish assemblage from Fatu-ma-Futi indicates relative stability in the exploitation of fish families at this site through time. Two inshore herbivore families—Acanthuridae (surgeonfish) and Scaridae (parrotfish)—dominate every excavated layer in the deposit. Although there is a slight drop in trophic level during the period 300-100 cal BP, the pattern seems to be the result of a relative increase in herbivorous fish species rather than a dramatic decrease in high trophic level piscivores.

Although analytical biases associated with differential bone preservation, screen size, and identification may play a role in these results, a variety of studies from Oceania and elsewhere offer comparable scenarios. For example, the inshore herbivore parrotfish (Scaridae) often make up the bulk of many Pacific Island and Caribbean fish assemblages (Fitzpatrick and Kataoka 2005; Fitzpatrick and Keegan 2007; Leach and Davidson 2000; Leach et al. 1996). Although the abundance

of surgeonfish (Acanthuridae) at Fatu-ma-Futi is rare when compared to many other Pacific Island fish assemblages, similar results were reported from Tikopia Island (Kirch and Yen 1982). Furthermore, these same fish families are among the most prominent in most early Lapita faunal assemblages (Butler 1988:112, 1994:87). Butler (1994:87) noted that eastern Lapita sites are dominated by herbivore families. Offshore fish were never common in any of the Lapita assemblages analyzed. The dominance of herbivores in Lapita assemblages is likely related to the distribution and structure of marine habitats but probably also relates to cultural factors associated with initial colonizing populations.

We suggest that shifts in subsistence trends should be closely related to the specific ecological and geographical characteristics of the islands themselves as well as historically determined ecological events that may vary at different spatial scales (Field et al. 2009; Giovas 2006; Kennett et al. 2006). As a consequence, it is important to look at regionally specific trends in dietary patterns. Determining causal factors in dietary trends will require disentangling cultural and ecological variables. In some instances, human actions lead to habitat alterations and resource depression of prey species, and in other circumstances, natural phenomena force humans to alter their subsistence strategies and adjust to new ecological circumstances (Reitz et al. 2009). A multidisciplinary approach that integrates trophic level studies with other types of archaeological, paleoenvironmental, and geomorphological data will be necessary to gain more fulfilling explanations of the patterns documented with archaeological datasets.

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END NOTE

1. New molecular data indicate that the family Scaridae should technically be classified as Labridae (Westneat et al. 2005).

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