A Long-term Perspective on Biodiversity and Marine Resource Exploitation in Fiji's Lau Group[1]

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Abstract: I present research investigating biodiversity and human interaction with the local environment through three perspectives on diverse islands in Fiji's Lau Group. First, I generated long-term data on marine diversity and exploitation through zooarchaeological analyses of fauna from sites spanning the region's prehistoric human occupation. The study areas are representative of regional fauna and local geographic variation in island size and structure. Each island also varies in terms of human occupation and degree of impacts on marine and terrestrial environments. Second, my ethnographic work recorded modern marine exploitation patterns by Lauan communities. Third, marine biological surveys documented living faunas. Together this information is used to explore the marine environment over the three millennia of human occupation. Using data derived from my multipronged study I discuss potential causes of ecological change in this tropical marine setting. My findings include the following: (1) data indicate that relative intensity of human occupation and exploitation determines modern composition and biological diversity of marine communities because human disturbance occurred more extensively on larger islands than on smaller islands in Lau; (2) Lauans appear to have targeted similar suites of marine fauna across their 3,000 years of history on these islands; (3) Lauans have had a selective effect on marine biodiversity because particular species are/were targeted according to local standards of ranking and preference; (4) marine resources existing today have withstood over 3,000 years of human impacts and therefore may have life history traits supporting resilience and making conservation efforts worthwhile.

Marine ecological studies are increasingly taking into account the biological complexity of the past to identify causes of environmental change and demonstrate achievable goals for resource management and restoration (Jackson et al. 2001, Pandolfi et al. 2003). Adding an archaeological dimension expands the concept of biodiversity by generating long-term perspectives on human-environmental interactions. The most productive scientific programs combine multiple approaches and methodologies to enhance understanding of environmental changes that are critical locally and globally (Jennings and Polunin 1996, Kronen and Bender 2007). Resource exploitation viewed through the lens of historical ecology has been explored through recent research on marine and island ecosystems, including, for example, the work of Thomas (2002, 2007*a*,*b*) in Kiribati, Fitzpatrick and Donaldson's (2007) study focused on anthropogenic impacts in Palau, Rick and Erlandson's (2008) broad collection of case studies on human-marine environment interactions across the globe, and Steadman's (2006) massive work reconstructing avian historical biogeography in the tropical Pacific islands. These works demonstrate that multidisciplinary historical approaches hold much

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promise for the future of research on island and marine ecosystems worldwide.

Perhaps one of the biggest debates among archaeologists and biogeographers who study the Pacific islands has centered on natural versus human causes of environmental change. Strong arguments have been made on both sides of the debate (Nunn 2000, Butler 2001, Allen 2006, Steadman 2006, Morrison and Cochrane 2008). Determining causality from archaeological data is difficult due to equifinality, the principle that a single outcome—resource change and depletion—can result from different causes. Some researchers have concluded that, "... scientists should stop arguing about the relative importance of different causes of coral reef decline: overfishing, pollution, disease, and climate change. Instead, we must simultaneously reduce all threats to have any hope of reversing the decline" (Pandolfi et al. 2005:1725). Pandolfi and colleagues view the methods of historical ecology as especially valuable in providing comparisons between the past and the present, while also providing a baseline for determining if restoration efforts succeed "in ameliorating or reversing change" (Pandolfi et al. 2005:1726). (According to this framework, indicators of success would include the return or presence of key groups such as parrotfishes, grazing sea urchins, mature complex coral colonies, sharks, turtles, large jacks, and groupers [Pandolfi et al. 2005].)

Historical ecology fundamentally denies an either/or dichotomy of human versus natural induced changes in the environment; rather, environmental change should be approached through an understanding of the "landscape," the human-environment interaction sphere (Crumley 1994, Balée 1998, Balée and Erickson 2006). This perspective argues that the landscape is imbued with meaning and is the product of the collision between nature and culture, which may be examined as a form of architecture, or material culture (Balée and Erickson 2006). I adopt this approach, extending the concepts of historical ecology and landscape to the "seascape," associated with islands in Fiji's central Lau Group.

My multidisciplinary research in the Lau Islands contributes a more robust understanding of biodiversity and long-term human interactions with the local marine environment through three perspectives on four diverse islands. This multipronged approach incorporates data derived from ethnographic, archaeological, and marine biological research with the aims of characterizing the reef environment, documenting species and biological diversity, and identifying potential changes in the marine ecosystem. The Fiji Islands are rich in cultural and biological history, with human occupation extending back to approximately 3100 B.P. (Nunn et al. 2004, Nunn 2007). Fiji's Lau Group is an archipelago of 80 islands, located about 200 km east and 100 km south of the main Fijian islands of Viti Levu and Vanua Levu (Figure 1). The Lau Group is composed of volcanic and coralline limestone islands that are located relatively close together and support extensive reef systems, rich in marine faunal resources. The region has an incredible diversity of marine life and a vibrant traditional culture that is actively engaged in marine-oriented subsistence activities, making it an ideal location to focus research examining marine biodiversity and human exploitation of marine environments over a broad temporal scale. Food is still largely locally derived in this contemporary Pacific community, and, compared with other areas in Fiji, the coral reefs of Lau have had relatively little impact by tourism, extensive modern developments, commercial fishing, and high population levels. Moreover, central Lau has been the subject of archaeological and ethnographic research by myself and others, which has laid the groundwork for this project (Hocart 1929, Thompson 1940, Best 1984, O'Day et al. 2003, O'Day 2004, Thomas et al. 2004, Jones et al. 2007*a*,*b*).

To explore biodiversity and marine exploitation over the past three millennia, this study investigated four diverse islands in the Lau Group, including Lakeba, Nayau, Aiwa Levu, and Aiwa Lailai (Table 1). Each island varies in terms of human occupation and the degree of impacts on marine and terrestrial environments. Lakeba is the largest of the

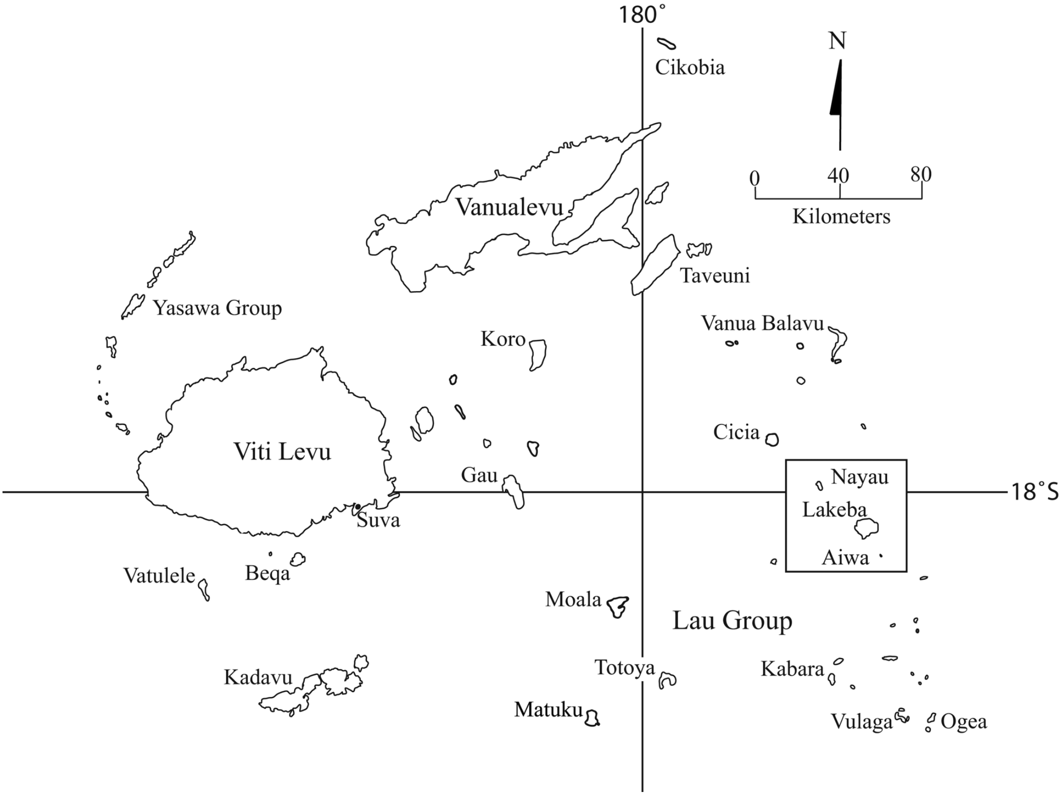

FIGURE 1. Map of the Fiji Islands with the study area indicated in the square.

study sites (55.84 km^2) and is occupied by about 2,100 people. Nayau (18.44 km^2) has a population of approximately 400 people. In contrast, the small islands of Aiwa Levu (1.21 km^2) and Aiwa Lailai (1.0 km^2) are currently uninhabited, lack a freshwater source, and are used primarily as temporary camps for fisher-people from Lakeba (12 km away). Geologically the Aiwas consist entirely of limestone and have very little agricultural potential. Lakeba is the most varied topographically and geologically, having limestone regions and large areas of volcanic soils and bedrock (andesitic and dacitic lava) where freshwater is locally available and agriculture is practiced extensively. People living on Lakeba and Nayau maintain dryland and wetland agricultural crops (especially taro, cassava, sweet potato, and yam). Conversely, Aiwa supports diverse native forests with little if any area suitable for agriculture (Jones et al. 2007*b*). The archaeological sites on these four islands span central Lau's prehistoric occupation, extending from the Lapita period to European contact in 1774 (Best 1984, Jones 2007). Like Lakeba, Nayau is almost entirely modified by human occupation, with continuous man-made features across the landscape (including gardens, habitation sites, trails, and resource-collection areas). The Aiwas also exhibit signs of use islandwide, but this is limited to light surface scatters of artifacts and ecofacts (stone tools, *Tridacna* shells, and midden, for example). The reefs surrounding each of the four islands are similar in terms of structure and potential habitat. However, modern development and occupation on Lakeba are much more intensive than that on Nayau (and the uninhabited Aiwas), therefore Lakeba's inshore reefs are likely the most

TABLE 1

Summary of Environmental, Physical, and Archaeological Characteristics of the Lau Study Islands

Characteristics	Lakeba	Nayau	Aiwa Levu	Aiwa Lailai
Island size and elevation	55.8 km^2 215+ m	18.4 km^2 160+ m	1.2 km^2 50+ m	1 km^2 30+ m
Reef area	61 km^2	20.15 km^2	ca. 36.1 km^2 (with multiple fringing reefs)	ca. 37 km^2 (multiple fringing reefs)
Geology	Large outcrop of Lau volcanics (andecites-dacites with some basalts) and weathered limestone	Geological composite of exposed volcanics and weathered raised reefal limestone	Weathered raised reefal limestone	Weathered raised reefal limestone
Human occupation and archaeological sites	Modern: 8 villages and the Lauan capital/chiefly seat of power Prehistoric: Intensive occupations (gardens and habitation sites) spread continuously across the island; 209 sites identified ranging from coastal villages, rockshelters, caves, and fortified hillforts	Modern: 3 villages Prehistoric: Less-intensive occupation than Lakeba; 34 archaeological sites identified, consisting of inland rockshelters, hilltop fortified villages, and open villages on the beach	Modern: No occupation; currently used as a temporary fishing camp Prehistoric: 7 sites, including two caves, a fortified hilltop occupation, and four rockshelters of varied uses/occupation types; the landscape exhibits some signs of use (surface scatters of artifacts and ecofacts) islandwide	Modern: No occupation; very rarely used as a fishing camp, although the reef is frequently exploited, along with that surrounding Aiwa Levu. Prehistoric: One rockshelter site with extensive occupation, but the landscape exhibits signs of use islandwide
Archaeological sites excavated by the author and area excavated	None; Best (1984) extensively excavated 5 highly stratified sites and conducted test excavations at 5 sites	Excavations at 13 sites; 3 m^2 at the Lapita-period site of Na Masimasi, a deep stratified continuous Lapita occupation; an additional 13 m^2 was excavated, and 17 shovel tests, at mid-late prehistoric sites	12 m^2 excavated at 5 sites (6 m^2 at Aiwa 1, the island's largest rockshelter and permanent occupation site; this site had very good preservation and highly stratified, deep subsurface deposits)	3 m^2 excavated at one long-term occupation site, Dau Rockshelter; this site exhibited very good preservation and a stratified deposit

heavily exploited of the study islands. It is interesting that Lauans travel to exploit reefs near their islands. This was very likely the case in the past as well. For example, 17.7 km east of Lakeba is an area of shallow water where a reef encloses a lagoon; this reef is called Bukatatanoa, a well-known Lakeban fishing ground that is five times the size of the reefs surrounding Lakeba. Fisherpeople travel there in small boats almost daily. Although the most obvious and frequently exploited marine areas are those in close proximity to the villages, Lauans do not look upon the sea as a barrier; rather they utilize a variety of environments and frequently move beyond their home shores.

MATERIALS AND METHODS

My research contributes to the understanding of biodiversity through three perspectives. First, zooarchaeological analyses of animal bones and shells provide long-term data on marine diversity and exploitation. Second, ethnographic work recorded modern marine exploitation patterns by Lauan communities. Third, I compare my archaeological and ethnographic data to information derived from the examination of living marine faunas through detailed biological surveys of the reefs surrounding the study sites. Together this information is used to understand and characterize the causes and rates of ecological change in this tropical marine context over the past 3,000 years. I view the data described herein as a starting point for the understanding of these complicated processes. Although research on these topics is preliminary, I have begun to generate a description of the marine environment and human exploitation patterns based on three datasets. At this point my primary goal is to determine if there is evidence for changes in marine biodiversity and, if so, what the relationship is between these shifts and human exploitation over time in each of the island settings.

Archaeology

Since 2000, 23 sites on the four islands have been excavated and analyzed as part of this research project (O'Day et al. 2003, Jones 2007, Jones et al. 2007*b*). Archaeological work has generated a basic chronology of human occupational history on each island. All excavations were conducted in 10 cm levels, using trowels and following natural stratigraphy whenever possible. All sediments were dry screened through nested sieves of 1/2 inch (12.8 mm), 1/4 inch (6.4 mm), 1/8 inch (3.2 mm), and 1/16 inch (1.6 mm) mesh.

Zooarchaeological analysis followed standard procedures described in O'Day (2001) (publications by me from 2001 to 2004 are listed under my former name of Sharyn O'Day; fish bone identifications were based on all diagnostic elements [not limited to so-called "special elements"], including atlases, vertebrae, cranial elements, spines, scales, and "special elements") and utilized my comparative collection housed at the University of Alabama at Birmingham's zooarchaeology laboratory. (I have assembled a comparative collection of animal bones, especially fishes and invertebrates [>2,500 specimens], to identify Pacific archaeological materials to the most specific level possible. The collection includes multiple individuals of the most common central Pacific families, genera, and species and a variety of size and age classes. The majority of these fishes are from Fiji and Lau in particular, but the collection also includes fishes and invertebrates from numerous islands in Micronesia, the Philippines, Tahiti, Hawai'i, Okinawa, and the Caribbean.) The bones of all taxa were counted, weighed, and modifications recorded. The number of identified specimens per taxon (NISP) is the basic specimen count used; this includes bones and shells that were not identified to a specific taxonomic level. The minimum number of individuals (MNI) was determined by paired elements and size and age classes whenever possible, following calculations described by Reitz and Wing (1999) and O'Day (2001). (Specifically, I estimated MNI based on paired elements and evidence for symmetry, age and/or body sizes. MNI was estimated for the lowest taxonomic level within a systematic hierarchy. Each provenience [feature, natural stratigraphic layer, and site]) was considered separately with attention to stratigraphy when appropriate, in an effort to generate conservative MNIs. Within a given provenience [layer, unstratified unit, or feature] excavation levels were considered together to estimate MNI.) Measurements of faunal remains, particularly the fish bones, were taken in an effort to illuminate long-term changes in the size and makeup of exploited marine species assemblages. The anterior width of complete fish vertebral centra from both identified and unidentified remains was measured for comparative purposes and to estimate the average weight and size of fishes in the assemblages. This procedure is based on the assumption that both the identified and unidentified fish vertebrae represent a cross section of the species present in the assemblage (Pandolfi et al. 2003, Newsom and Wing 2004).

Shannon's *H*, diversity or niche breadth measure, was used to quantitatively determine the variety of animals consumed or exploited at each of the analyzed sites over time. The formula used follows Krebs (1999:463). ($H' = -\Sigma[p_i][\log_e p_i]$ is the formula for Shannon's *H*, where H' is the information content of the sample and p_i is the relative abundance of individuals or resources for each taxon in the collection.) Because this diversity measure ranges from 0 to ∞, it can be standardized on a scale from 0 to 1 by using an evenness or equitability measure (V'). Equitability (V'), or the evenness with which taxa were exploited, and the relative importance of each taxon was also calculated. (The equitability formula used in the analysis is following Reitz and Wing [1999]. Because this is a comparison of fauna representative of a wide range of organisms that have varied numbers of elements, diversity and equitability calculations are based on MNI estimates; this places diverse organisms on a more uniform basis.) V' is calculated on a scale of 0 to 1, thus values close to 1 indicate an even distribution of taxa, and lower values suggest a dominance of one taxon.

Ethnography

Modern Lauan fishing expeditions provided opportunities to record species diversity and the sizes of collected modern fishes. In total, the ethnographic aspect of my research was conducted over 10 months in Fiji between 2001 and 2007. (Over the course of my research I devoted about 3 months full-time to archaeology and the remainder of my time to both archaeology and ethnography, with the majority of my time spent doing ethnography.) Fieldwork ranged in duration from 1 month to 4 months. The fish catches also serve as population cross sections of the existing fauna because Lauans frequently collect a wide range of inshore species with gill nets, which are not size and species selective. For this study, I recorded the numbers of modern taxa that are collected and eaten on each island. A variety of fisherpeople were interviewed to determine what marine resources are targeted and why, and to discuss local conservation issues. I recorded how the catch is processed, divided up, consumed, and discarded.

Over the course of this research on Lakeba, Nayau, and Aiwa, I accompanied fisherpeople, including individuals and groups, on over 50 fishing expeditions to record information on modern marine-oriented subsistence activities. Different types of fishing trips were documented (in notes, video recordings, and still photos) at a variety of times and locations on all four of the study islands. Following Thomas (2002:186), fishing expeditions were formally documented by collecting the following information: (1) members composing group; (2) collection strategy; (3) occasion for which the group is collecting; (4) target prey; (5) actual prey, location, count, weight, and SL (standard length) of collected items; (6) collection area (marine zone, type description, location); (7) date, time, moon phase; (8) search time; (9) handling time, processing time; (10) general weather and tidal conditions; (11) how the catch is divided up; (12) items consumed on shore or during fishing; (13) patterns of flesh and tissue disposal on the beach; (14) who will consume the fish.

Biological Surveys

Using both formal surveys with standardized methods and informal surveys, marine biologists and I inventoried the marine vertebrates and invertebrates on each island (Maragos and Cook 1995, DeVantier et al. 1998). A variety of coastal ecosystems (inshore, forereef, mangrove, sea grass flats, bays, fringing reefs, and platform reefs) were surveyed and described. The majority of survey transects were positioned on reef flats, areas that are frequently fished when in close proximity to villages. Inshore areas located farther from the villages and on the currently uninhabited islands of Aiwa Levu and Aiwa Lailai were also sampled. In total, 18 sites were surveyed with line-transect methodologies on Lakeba, Nayau, Aiwa Levu, and Aiwa Lailai (Jones 2009*a*). Transects on Lakeba measured 200 m long and those on Aiwa Levu, Aiwa Lailai, and Nayau measured 100 m in length from shore, and all transects extended 10 m deep. Visual scans for fish extended 5 m on either side of the transect line and above to the surface of the water. Invertebrate scans included an area extending 1 m on either side of the transect line. Five forereef scuba dives were conducted around Lakeba, ranging from 18 to 26 m deep. In addition, 15 informal surveys were conducted on Lakeba, Nayau, Aiwa Levu, and Aiwa Lailai at various tide levels and during both day and night.

RESULTS

Archaeological Research

RADIOCARBON DATING AND CHRONOLOGY. Earlier archaeological research on Nayau, Aiwa Levu, and Aiwa Lailai developed a chronology for the islands by obtaining accelerator-mass spectrometer (AMS) radiocarbon (^{14}C) dates from seven sites. The Nayau chronology was based on six AMS dates from excavations of 12 mid-late prehistoric archaeological sites (mid-late period archaeological sites in my study area include primarily fortified sites and rockshelter occupations ranging in time from about 600–280 cal B.P. Most of these radiocarbon dates cluster around 710–540 cal B.P.) and therefore extended only to ca. 700–600 cal B.P. (O'Day et al. 2003). On Aiwa Levu and Aiwa Lailai, 11 AMS dates provided evidence of over two millennia of human activity and occupation, extending from 2,710 to 10 cal B.P., with most of the dates suggesting site occupations before 500 cal B.P. (Jones et al. 2007*b*). However, none of these dates is from Lapita occupations; therefore my recent determinations from the Lapita-period site of Na Masimasi are critical for providing a more complete chronology of the study area, with dates ranging from the first human occupation of the islands through the contact and historic periods. Radiocarbon determinations from Na Masimasi were provided by Beta Analytic, Inc., Miami, Florida, and are on a single bone or piece of charcoal (Table 2). The conventional ^{14}C age is adjusted for ^{13}C/^{12}C ratios. (Calibration for atmospheric variation in ^{14}C follows OxCal version 3.3 and INTCAL98 Radiocarbon Age Calibration [Bronk Ramsey 1995, Stuiver et al. 1998].) The two dates are similar, according to a conventional ^{14}C age determination, suggesting an early occupation of Nayau by about 2,580 ± 40 years B.P. (A recent article by Beavan Athfield et al. [2008] discussed potential problems with the radiocarbon dating of human bones and suggested that these same problems apply to the dating of chickens, dogs, and pigs, animals that like humans have diets of mixed terrestrial and sea biota. The authors argued that it is necessary to predetermine the type of diet associated with both humans and domestic animals that are processed for radiocarbon dates via isotope studies. This should be done in advance of interpreting the radiocarbon results. I have submitted 61 archaeological samples of bone from a broad range of Lauan fauna for isotopic analysis. The results are currently pending, but I plan to use the data to evaluate the Beavan Athfield et al. arguments in relation to data from central Lau.)

ZOOARCHAEOLOGICAL DATA. To compare local marine exploitation patterns and prehistoric environments on each island over the past 3,000 years, I have summarized the archaeological sites excavated, radiocarbon dates, and the total number of fishes and invertebrates identified in terms of count (NISP), minimum number of individuals (MNI), measures of diversity and equitability

TABLE 2

AMS Radiocarbon Dates from Nayau, Aiwa Levu, and Aiwa Lailai, Lau Group, Fiji

Beta no.	Material Dated	Island, Site	Unit, Layer/ Level	Measured ^{14}C Age (years B.P.)	^{13}C/^{12}C Ratio (o/oo)	Conventional ^{14}C Age (years B.P.)	OxCal Cal B.P. (2σ)
235993	Metatarsal, *Homo sapiens*	Nayau, Na Masimasi	D8, II/8	2,400 ± 40	−14.5	2,570 ± 40	2,760–2,700 and 2,640–2,610
235994	Charcoal	Nayau, Na Masimasi	G6, III/13	2,630 ± 40	−28.0	2,580 ± 40	2,760–2,700 and 2,630–2,620
164249	*Gallus gallus*	Nayau, Waituruturu E	1, I/1	470 ± 40	−19.5	560 ± 40	650–580 and 570–510
164248	*Ptilinopus porphyraceus*	Nayau, Waiturututru E	1, II/2	490 ± 40	−21.1	550 ± 40	650–580 and 570–510
164247	*Pteropus samoensis*	Nayau, Waiturututru E	1, II–III/3	610 ± 40	−19.9	690 ± 40	690–620 and 610–550
164253	*Homo sapiens*	Nayau, Qaranilulu	1, I/2	550 ± 40	−15.7	700 ± 40	710–620 and 610–550
165468	*Pteropus tonganus*	Nayau, NukutubuRS2	1, II–III/3	100.6 ± 0.8 % modern C	−19.2	50 ± 60	280–180 and <150
173059	*Homo sapiens*	Nayau, NukutubuRS2	1, IV/1	280 ± 40	−16.6	420 ± 40	540–420 and 380–320
164251	*Pteropus tonganus*	Aiwa Levu, Rockshelter 1	2, I/1	180 ± 40	−19.2	280 ± 40	470–280 (.91) 170–150 (.04)
164258	*Pteropus samoensis*	Aiwa Levu, Rockshelter 1	4, II/3	260 ± 40	−19	360 ± 40	510–310 (.95)
164260	Wood charcoal	Aiwa Levu, Rockshelter 1	2 (oven), II/5	210 ± 40	−25.7	200 ± 70	430–360 (.06) 330–10 (.89)
164261	Wood charcoal	Aiwa Levu, Rockshelter 1	2 (oven), III/10	580 ± 40	−25.6	570 ± 40	650–510 (.95)
164252	*Homo sapiens*	Aiwa Levu, Rockshelter 1	2, III/13	2,090 ± 40	−11.8	2,310 ± 40	2,440–2,410 (.01) 2,370–2,290 (.68) 2,270–2,150 (.33)
165466	*Pteropus samoensis*	Aiwa Levu, Cave 2	2, I/1	860 ± 40	−18.9	960 ± 40	960–760 (.95)
165467	*Pteropus samoensis*	Aiwa Levu, Cave 2	3, II/2	1,530 ± 40	−19.1	1,630 ± 40	1,690–1,670 (.02) 1,610–1,410 (.94)
165465	*Gallus gallus*	Aiwa Levu, Cave 2	1, II/2	2,180 ± 40	−12.5	2,380 ± 40	2,710–2,630 (.16) 2,620–2,590 (.01) 2,500–2,330 (.78)
165469	*Ducula pacifica*	Aiwa Levu, Goat Rockshelter	1, II/5	370 ± 40	−20.3	450 ± 40	550–430 (.92) 360–330 (.03)
172192	*Pteropus tonganus*	Aiwa Lailai, Dau Rockshelter	1, IIIb/4	1,410 ± 40	−10.5	1,510 ± 40	1,520–1,310 (.95)
172191	*Gallus gallus*	Aiwa Lailai, Dau Rockshelter	2, IV/5	2,060 ± 50	−19.1	2,300 ± 50	2,460–2,150 (.95)

(*H* and *V*), and the most common fish families identified (Table 3) as these data relate to general periods of prehistory. (The NISP listed in Table 3 includes fish bones that were not identifiable below the level of class; the percentage of specific fish identifications, that is, to the level of family and below, varies from 7% to 26%, depending on the site. For example 23% of the fish bone from the mid-late period sites from Nayau was identifiable to the level of family, genus, or species.) The same classes of data are provided for invertebrates in Table 4. These tables provide comparisons of the marine resources that were exploited prehistorically over the entire prehistoric human occupation of the study sites; the detailed individual site data are published in O'Day et al. (2003), Jones et al. (2007*a*), and in a forthcoming manuscript currently under review (Jones 2009*b*). Although the argument could be made that the amalgamation of data from multiple sites, especially the 12 mid-late period Nayau occupations, is too general to contribute useful information, I argue that the summary *H* and V' values are both relevant and appropriate for the following reasons. Intersite variation of identified fish remains is minimal within the time periods. Moreover, within the mid-late Nayau assemblages, 80% of the identified fish bones by count were recovered from two virtually contemporaneous fortified rockshelter occupations (Waiturututu East and Waiturututu West produced the majority of the mid-late period Nayau fish remains; these sites also contributed over half of the MNI, 87 individuals [see O'Day et al. 2003].) The mid-late period sites include fortified occupations and rockshelters, all of which likely had similar functions and durations of occupation. Finally, the mid-late Nayau occupations all occur inland, away from the coast, and according to the zooarchaeological analysis the occupants of all these sites exploited the inshore areas as their primary animal food source.

The comparative abundance of fauna in terms of primary and secondary data is evident in the total amalgamated NISPs and MNIs from sites representative of each time period. The Lapita site of Na Masimasi on Nayau has a relatively low overall MNI (59) for bony fishes (Figure 2). In contrast, the NISP from the site (7,570) is very high and abundant enough to interpret the marine faunal assemblage with some degree of confidence (Reitz and Wing 1999). The low number of MNI from Na Masimasi is due to an extremely high frequency of vertebrae in the assemblage and the somewhat preliminary nature of fish bone identifications. I anticipate that the fish MNI will increase meaningfully when my analysis is complete. Nevertheless, the other sites yielded ample MNI, and all of the sites produced sufficient numbers of NISP to conduct interpretative analyses. There are four major trends that are evident in the faunal data.

First, the identified vertebrate taxa (and especially the families of fishes exploited) from the early to late period sites are dominated by tangs, grouper, parrotfishes, triggerfishes, and emperorfishes (Table 3, Figures 2–5). These families are common in Pacific island archaeological assemblages and in material identified from Fiji (Leach and Davidson 2000, Thomas et al. 2004, Jones et al. 2007*b*). Porcupinefish occur in high frequencies in the early period sites on Lakeba and Nayau but were less frequently identified in sites from mid-late time periods and in deposits from other islands. Second, for fishes, the V' values suggest that there is an even distribution of taxa (note that values close to one indicate an even distribution). The marine vertebrate taxa exploited remained even over time, and diversity (*H*) was moderate to high, ranging from 0.88 to 2.03. The number of taxa remains high across temporal periods (28–33).

Third, for invertebrates, the diversity and equitability measures are variable (*H* ranges from 0.88 to 2.03 and V' ranges from 0.25 to 0.6), much more so than in the fish data (Table 4). Sites associated with the early time periods on Nayau and Aiwa produced assemblages dominated by particular species (Figure 6); for example, Na Masimasi's invertebrate assemblage is primarily composed of the small fighting conch (*Strombus gibberulus*). On Aiwa Levu and Aiwa Lailai, the invertebrates are dominated by turban snails (*Turbo* spp.) throughout the sites (Figures 7 and Figure 8). Aiwa's sites have high diversity

TABLE 3

Summary of Fish Bone Data from Archaeological Sites on Aiwa and Nayau (Sites Listed from Early to Late Period)

Site(s)	Island	Age[a]	Site Type	NISP	MNI	No. of Taxa	H, V'[b]	Dominant Fish Families[c]	Reference
Aiwa 1 (units 1–4, III–IV), Dau Rockshelter, Cave 2	Aiwa Levu and Lailai	Early (2,500–960 cal B.P.)	Rockshelters	3,138	110	28	3.29, 0.99	Acanthuridae (tangs), Scaridae (parrotfishes), Labridae (wrasses), Serranidae (groupers)	Jones et al. (2007*b*)
Na Masimasi	Nayau	Early (2,610–2,760 cal B.P.)	Beach site/ Lapita occupation	7,570	59	33	3.21, 0.92	Tangs, groupers, Diodontidae (porcupinefishes), parrotfishes	O'Day et al. (2003)
12 sites	Nayau	Mid-late (600–280 cal B.P.)	Fortified sites and rockshelters	3,054	175	31	3.34, 0.97	Tangs, Balistidae (triggerfishes), groupers, parrotfishes, Lethrinidae (emperorfishes)	O'Day et al. (2003), Jones et al. (2007*a*)
Aiwa 1 (units 1–4, I–II and all of units 5–6), Goat Rockshelter	Aiwa Levu	Late (550–280 cal B.P.)	Rockshelters	1,665	86	30	3.27, 0.96	Tangs, groupers, parrotfishes, triggerfishes, emperorfishes	Jones et al. (2007*b*)

[a] Age ranges based on AMS radiocarbon dates with OxCal cal B.P. correction.
[b] H, Shannon-Wiener measure of diversity; V', equitability value.
[c] Fishes listed in rank order of abundance.

TABLE 4

Summary of Invertebrate Data from Archaeological Sites on Aiwa and Nayau (Sites Listed from Early to Late Period)

Site	Island	Age	Type	NISP	MNI	No. of Taxa	H, V'	Dominant Invertebrate Taxa[a]
Dau Rockshelter	Aiwa	Early (2,460–1,310 cal B.P.)	Rockshelter	1,804	782	18	1.71, 0.6	*Turbo* sp., *Modiolus auriculatus*, *Cellana* spp.
Na Masimasi	Nayau	Early (2,610–2,760 cal B.P.)	Beach site	1,732	1,026	32	0.88, 0.25	Strombidae (esp. *Strombus gibberulus*), *Turbo* spp.
12 sites	Nayau	Mid-late (600–280 cal B.P.)	Fortified sites and rockshelters	2,625	1,703	35	2.03, 0.57	Turbinidae (esp. *Turbo* spp.), *Cypraea* spp., *Strombus* spp., *Modiolus auriculatus*
Aiwa 1	Aiwa	Mixed (2,370–280 cal B.P.)	Rockshelter	2,726	1,001	21	1.63, 0.54	*Turbo* sp., *Cellana* spp., Chitonidae

Note: Biomass was based on the weight of the shell.

[a] Invertebrates listed in rank order of abundance.

levels comparable with those of the mid-late period Nayau sites (Figure 9). Exploitation patterns in terms of diversity and equitability for invertebrates are different than those of fishes. The number of taxa represented in the invertebrate assemblages varies from 18 to 35; again, this is more variable than that documented in the fish assemblages.

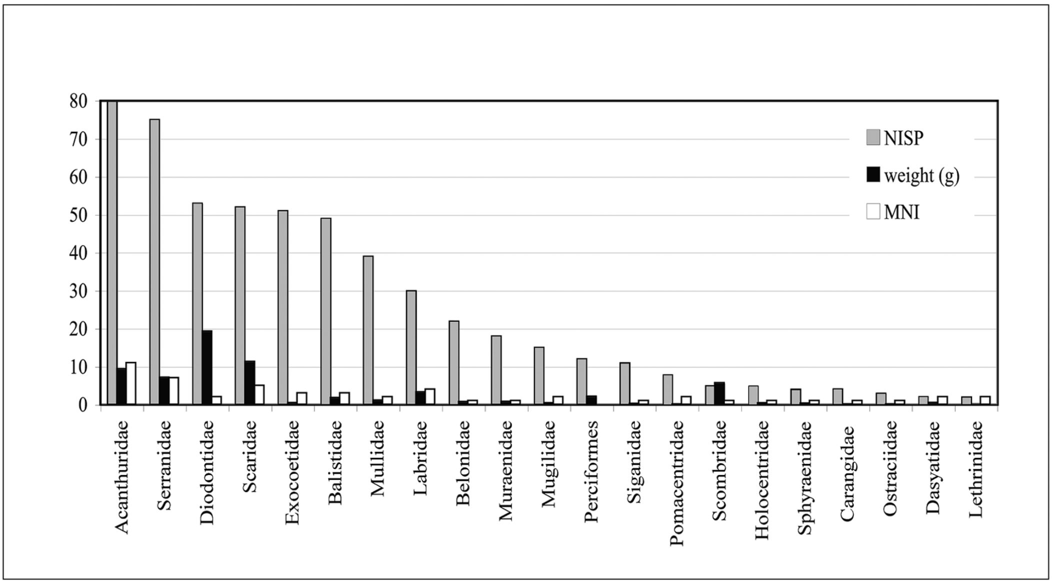

FIGURE 2. Early Nayau fish remains from the Lapita site of Na Masimasi, listed by family.

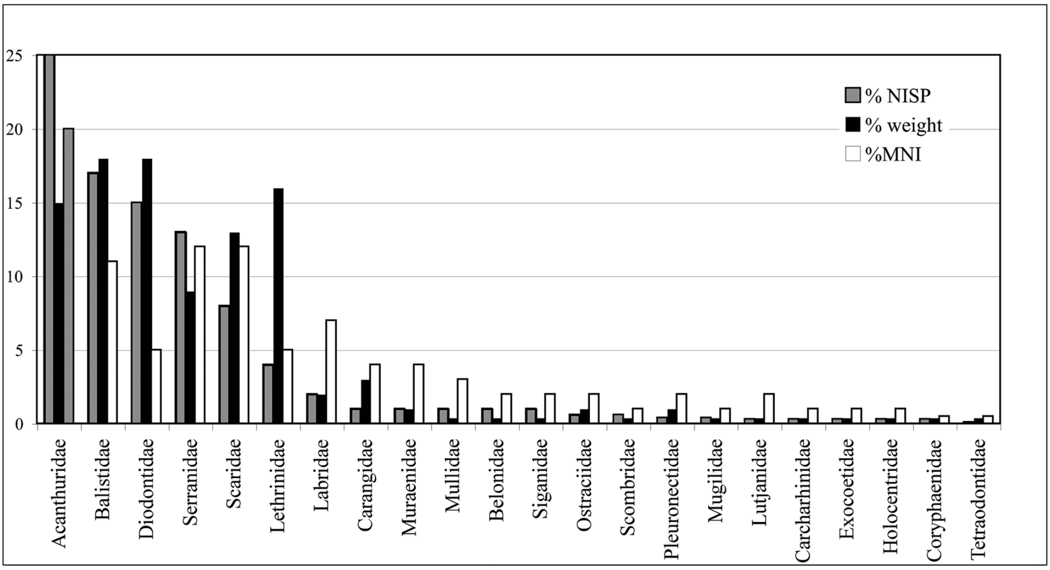

FIGURE 3. Mid-late Nayau archaeological fish taxa, listed by family.

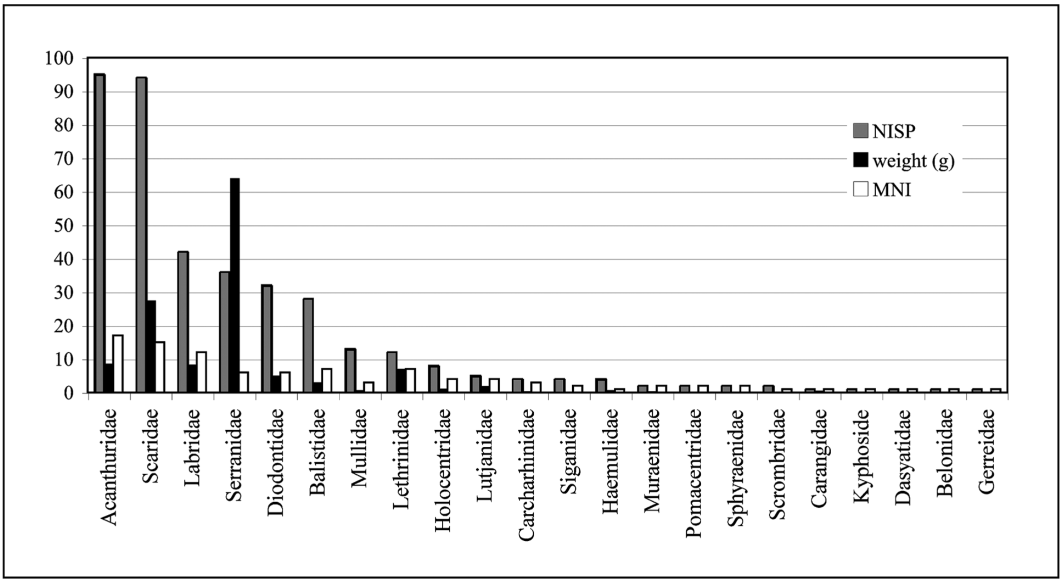

FIGURE 4. Early Aiwa Levu and Aiwa Lailai fish remains, listed by family.

Fourth, it is surprising that measurements of more than 2,500 fish vertebrae, used as a proxy for fish body size and weight, reveal that the fishes collected and consumed at the earliest occupations sites were actually smaller than those consumed later in prehistory (Table 5). This trend is particularly evident on Nayau where the Lapita site of Na Masi-

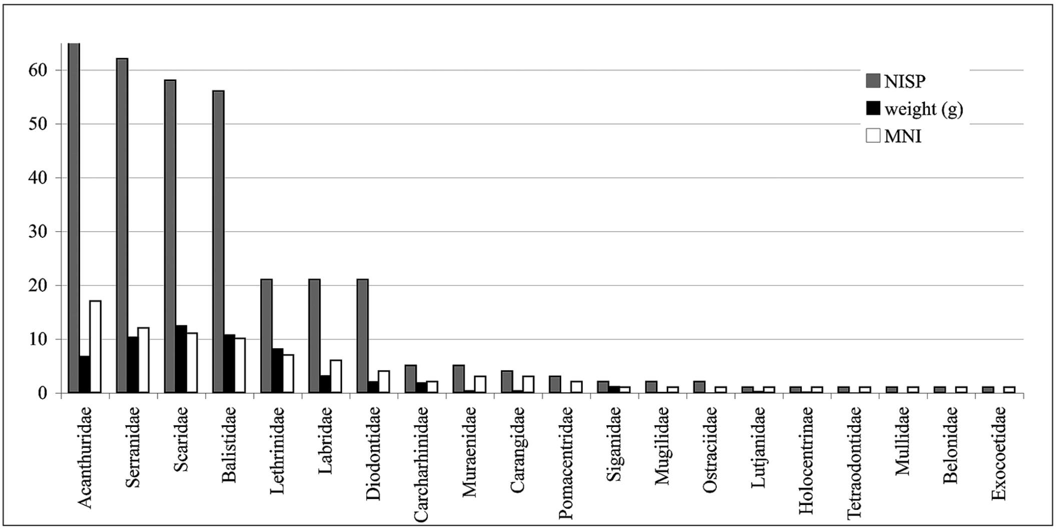

FIGURE 5. Mid-late Aiwa Levu and Aiwa Lailai fish remains, listed by family.

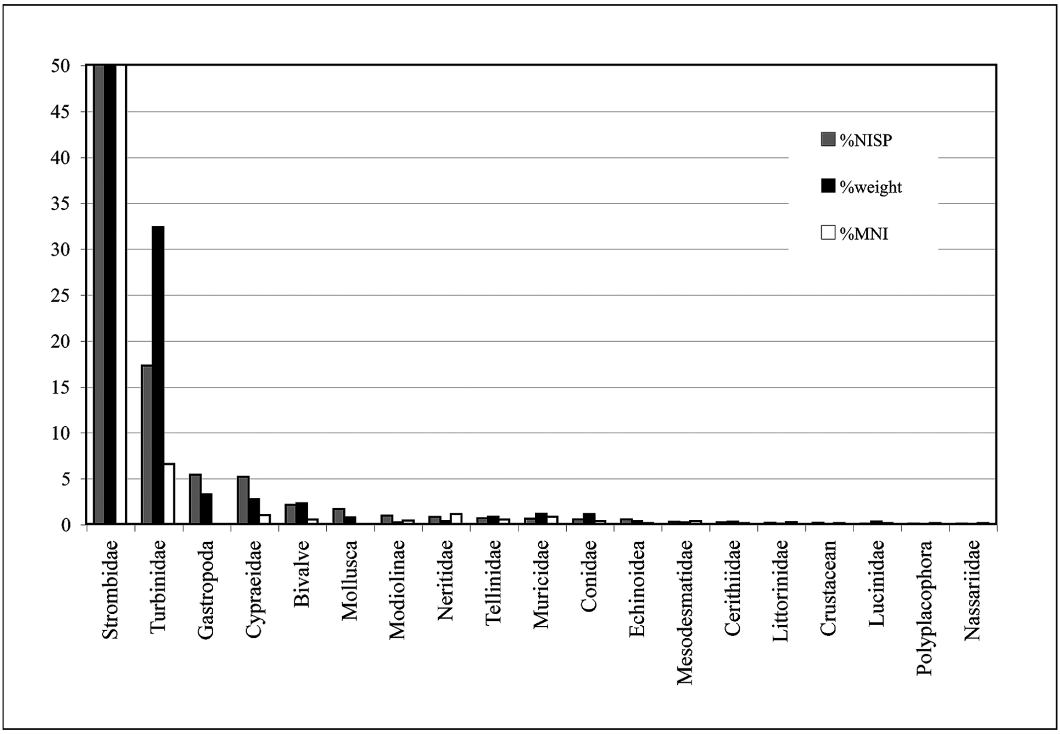

FIGURE 6. Early Nayau shellfish taxa from the Lapita site of Na Masimasi, listed by family.

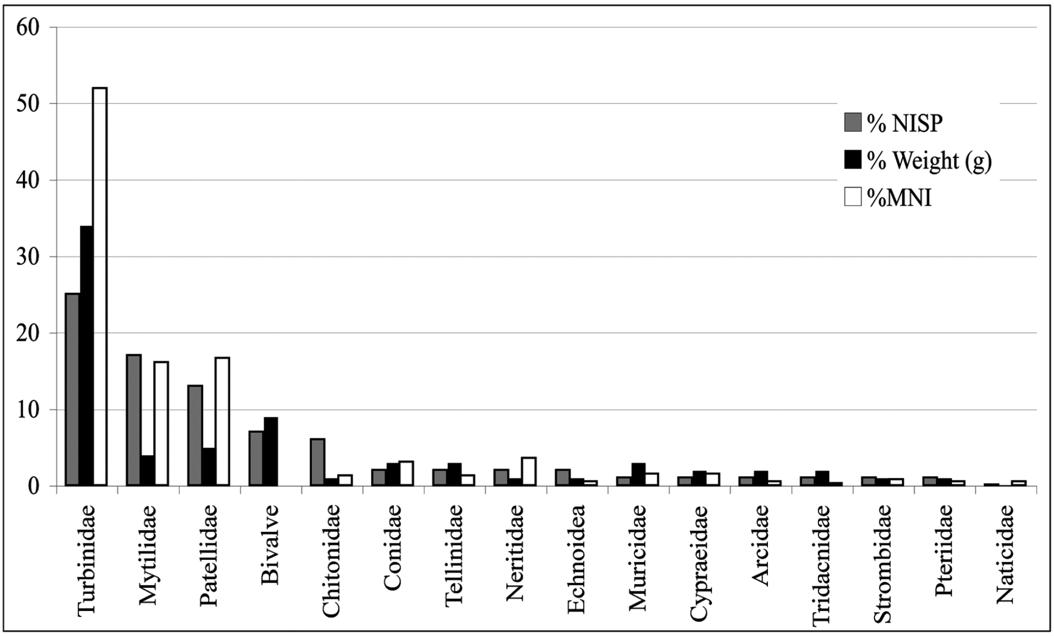

FIGURE 7. Early Aiwa Lailai shellfish remains, listed by family.

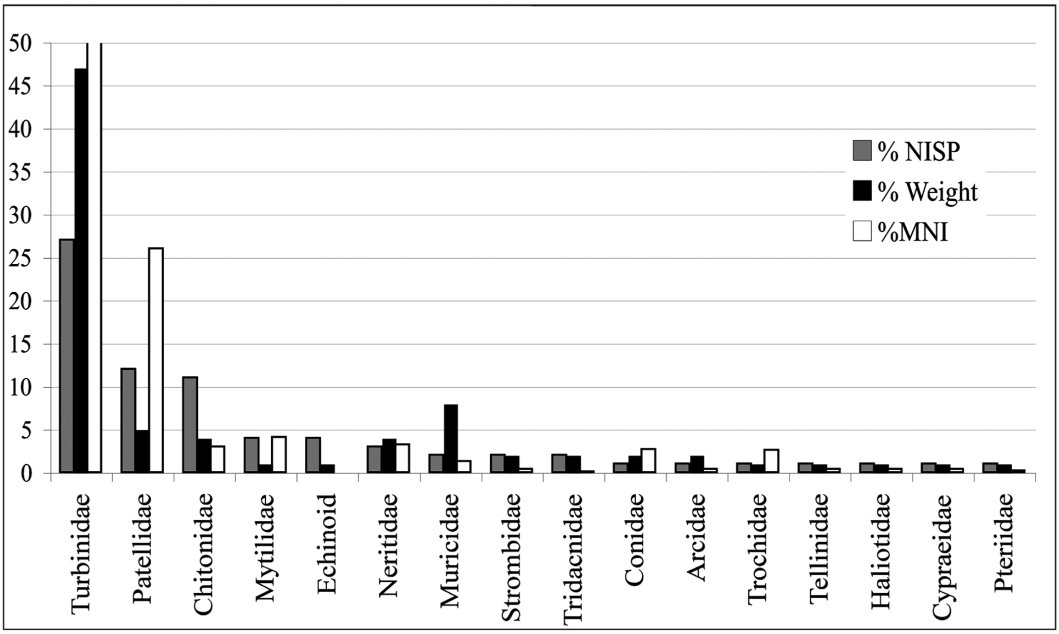

FIGURE 8. Summary of shellfish from the site of Aiwa 1, Aiwa Lailai, representing mixed time periods. Data listed by family.

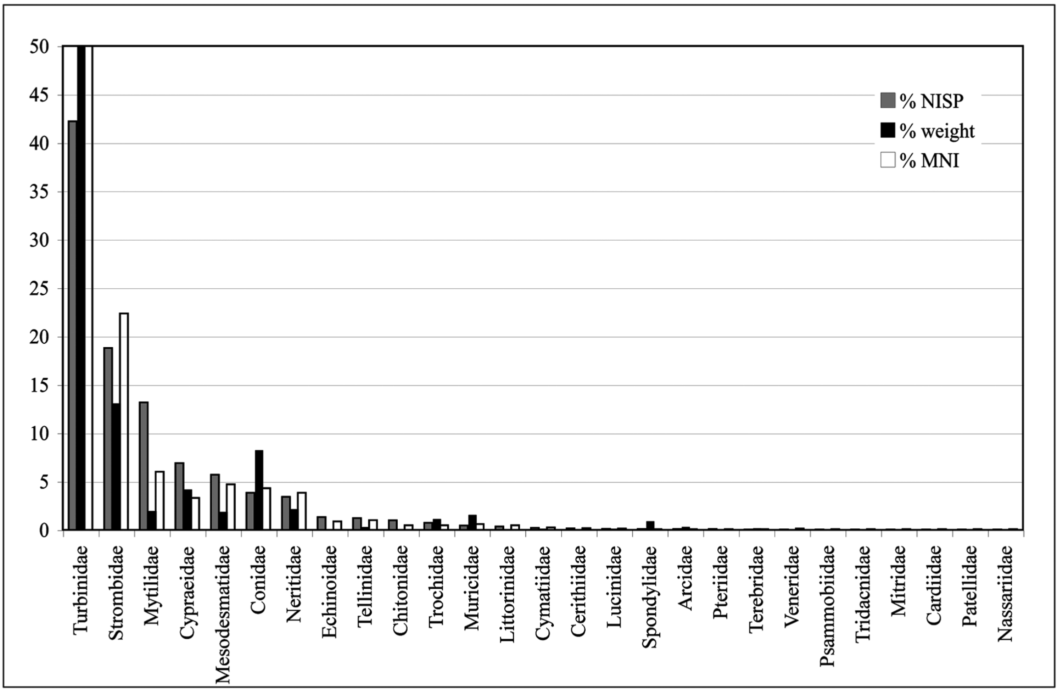

FIGURE 9. Mid-late Nayau shellfish taxa, listed by family.

masi contained the majority of small bones (mean anterior vertebral centra width 2.98 mm and mean estimated weight 118 g), representing small-bodied fishes. (I do not attribute this variation in the size of fishes to differences in recovery of fauna because I directed the excavation and screening of the study sites and used the same nested screens in each context [sieves with 1/2 inch (12.8 mm), 1/4 inch (6.4 mm), 1/8 inch (3.2 mm), and 1/16 inch (1.6 mm) mesh].) Na Masimasi also produced the broadest range in the size of fishes with vertebral centra measuring 0.61–20.2 mm, although the vast majority of fish vertebrae are small. Mid-late period sites on Nayau produced a smaller range in the

TABLE 5

Fish Vertebral Centrum Widths (mm) from Early and Mid-Late Period Occupations on the Study Islands

Provenience	*n*	Mean	Range	Standard Deviation	Mean Estimated Weight[a] (g)
Early Nayau	1,432	2.98	0.61–20.2	1.76	118
Early Aiwa	281	4.65	1.5–13.0	2.05	363
Mixed Aiwa	174	4.2	1.7–14.3	2	281
Mid-late Nayau	464	4.3	3–18.7	3.9	298
Mid-late Aiwa	165	4.85	2.04–13.33	1.9	404
Total	2,516	4.2	0.61–20.2	—	281

[a] Estimates of total body weight (g) are made using the allometric formula $\log Y = 2.53(\log X) + 0.872$, where Y is the body weight and X is the vertebral width, following Newsom and Wing (2004:71).

size of fishes exploited, a mean estimated weight of 298 g, and a mean vertebral centra size of 4.3. The fish remains from Aiwa exhibit a less-dramatic variation in size over time (the mean estimated weight is 363 g with a 4.65 mm centra width at the early period sites and 404 g and 4.85 mm in the mid-late period sites).

Ethnography

Over 50 fishing expeditions were documented to record information on modern marine-oriented subsistence activities. Eleven fishing expeditions were recorded on Lakeba, and seven expeditions were recorded on Aiwa Levu and Aiwa Lailai. A total of 37 hr of fishing was recorded (about 155 person-hours) on Lakeba. On Nayau, nine fishing trips, covering a total of 20 hr (1,140 person-hours), were formally documented.

Ethnographic investigations on the island of Lakeba in August 2007 confirmed that Lauans collect and consume virtually every fish that is caught by nets or hand lines in the inshore area. Shellfish are sometimes collected and consumed on the reef, but they form a very minor component of the catch and marine portion of the diet overall. These findings support conclusions derived from previous research on Nayau (O'Day et al. 2003, O'Day 2004, Jones 2007). The total number of fish taxa recorded in modern fishing expeditions is 112; 105 of these fishes are eaten, and only seven species are bycatch, which are not consumed (see Appendix). I recorded the numbers of modern taxa that are collected and eaten on each island; the results are as follows: Aiwa Levu, 24; Aiwa Lailai, 15; Lakeba, 49; Nayau, 94. (Obviously, these data describe only a portion of the taxa exploited and are limited by the fact that I recorded fishing and collection over the duration of my fieldwork rather than a lifetime of observation.) These data also suggest that the majority of fish taxa are collected with nets inshore (85.7% of the 112 fishes).

Lauan fishing expeditions that utilize nets inshore produce a broad cross section of the existing inshore species. On a single expedition the fishing group will exploit numerous areas that range in depth and substrate. They utilize their nets in various ways, for example, to corral the fish or to chase the fish into the nets. Net fishing is conducted at various times, day and night, and in every season. When and where people fish depends on the occasion that the fisherpeople are collecting for, the target taxa (if any), the moon phase, and the tidal phase, among other social issues. The important point is that net catches provide an extensive array of fish taxa that may be used to understand biodiversity of bony fishes inhabiting the inshore area.

ETHNOGRAPHIC INTERVIEWS. A number of important issues were brought up in ethnographic interviews with fisherpeople on Lakeba and Nayau (Table 6). Findings include information on a wide range of issues, such as the style of fishing particular to certain environments and villages, variations in the way men and women fish, the types of fishes preferred by Lauans, and shifts in the local availability of certain resources.

Traditional *vono* style fishing is the primary mode that people in the northern villages on Lakeba (Nasaqalau and Vakano) use to fish inshore; they state that this has been the case for many generations. The method produces thousands of small inshore fishes over the course of 2 to 3 days (especially rabbitfishes, or *Siganus* spp.; emperorfishes/Lethrinidae; and convict tangs). *Vono* is documented in detail in a short ethnographic film that I and other individuals involved in this research project helped to write and produce. (The fishing expedition documented in the film can be viewed on Google Video at http://video.google.com/videoplay?docid=6257583410432053434&q=vono+fiji&ei=q6eQSOPfAYSGqwPZtt2iCA.) In modern Fiji, this traditional fishing method is only practiced in the Lau Group on Lakeba. Like all inshore fishing in the region, this complex net method is organized and run entirely by women. Many Lauan women spend part of each day on the inshore reef, collecting marine resources. However, in each village there is a clear division between the "sea people" (the fisherpeople, *yavusa wai* or *kai wai*) and "land people" (primarily farmers, who rarely if ever fish, the *yavusa vanua*, or

TABLE 6

Shifts in Marine Resources as Recorded in Ethnographic Interviews on Lakeba, and Resources Specific to Various Villages

	Village		
Shift	Tubou	Nasaqalau	Vakano
Resources no longer available or in marked decline	Large-bodied parrotfishes, large mullet, mangrove crabs, giant clams (*Tridacna* spp.), strombids (*Strombus* spp.), spider shell (*Lambis lambis*), top shells (*Trochus niloticus*), Turbo (*Turbo* spp.), trumpet triton (*Charonia tritonis*)	Large-bodied mullets (*Mugil cephalus* and *Valamugil buchanani*), coral cod (*Cephalopholis* spp. and *Epinephelus* sp.), sea cucumbers (Holothuroidea)[a], mangrove mussels (*Modiolus agripetus*), bent nose clam (*Tellina palatum*), mangrove clam (*Gafrarium tumidum*), clams (*Periglypta sowerbyi* and *P. puerperal*), cockles (*Anadara cornea*), spider shell (*Lambis lambis*), threespot reef crab (*Carpilium maculates*), redeye crab (*Eriphia sebana*), slipper lobster (*Parribacus caledonicus*); painted rock lobster (*Panulirus versicolor*)	Bumphead parrotfish (*Bolbometopon muricatum*), large (>50 cm TL) sweetlips (*Plectorhinchus* spp., including *P. picus*), large eels (Muraenidae), midnight snapper (*Macolor macularis*), mullet (all local species), large barracuda (*Sphyraena* spp.), crabs, giant clams (*Tridacna* spp.), strombids (*Strombus* spp.), spider shell (*Lambis lambis*)
Other changes, including social	People claim that there are fewer large fish now (versus 10 years ago), and they can see that the sea level is rising, coral is dying, and the ocean is becoming warmer. These changes are noted both inshore and offshore.	More men are collecting in the inshore area now than they did in the past. In particular, men and boys will spend many hours each week with spears, small nets, and their hands collecting crabs, small fish, and occasionally shellfish in the mangroves between Nasaqalau and Vakano. People claim that there are fewer large fish inshore now (versus 10–20 years ago); they can see that the sea level is rising, coral is dying, and the ocean is warmer.	In general there are fewer large fish to be caught in the inshore area; the change is noted over the last 20 years. The chief and men of the village claim that spear fishing is still highly productive. People used locally handmade natural fiber nets and line until about 10 years ago when people shifted to using microfiber nets and line.
Marine resources and techniques known to be productive in each village	Mullet, herrings, crescentbanded grunters, and sea grapes (*Caulerpa racemosa*). All forms of fishing techniques are used here and many people have motorboats, more than in other villages in central Lau. People do more offshore trolling from Tubou and they travel to Aiwa frequently. They often catch large-bodied offshore fishes on the reefs far outside Tubou (fishes such as tuna, barracuda, trevally and jacks, wrasses, and sweetlips).	Coral cod (*Cephalopholis* spp.), turtles (Cheloniidae). All forms of fishing techniques are used here. However, women typically participate in *vono* expeditions (1–2 times each week) or fish alone or in small groups using spears, hooks, and handlines. Men sometimes throw a spear to hit a fish; this is especially common in the mangrove areas. Men also troll offshore and spearfish, both inshore (at night) and offshore (night or day). Nasaqalau is known for sharks and the practice of shark calling (done by female priests in one clan). This was last done in 1992 for a BBC film, but no sharks came. It was last practiced successfully in 1967. The mangroves are highly productive.	Mangrove crabs (*Scylla serrata* and *Cardisoma cardifex*), swimming crab (*Thalamita crenata*), sea urchins (*Tripneustes gratilla*), top shells (*Trochus niloticus*), Turbo (*Turbo* spp.), bent nose clam (*Tellina palatum*), mangrove clam (*Gafrarium tumidum*), clams (*Periglypta sowerbyi* and *P. puerperal*), cockles (*Anadara cornea*), pearlshell (*Pinctada martensi* and the large-bodied *Pinctada maxima*), coral cod (*Cephalopholis* spp.), turtles (Cheloniidae). People fish *vono* style and with spears. They preserve the fish by drying and smoking it on a *vesa*, or fish dryer. The mangroves are highly productive.

[a] Most of the sea cucumbers are exported from Lau to the markets on Viti Levu. People eat them occasionally on Lakeba and Nayau.

kai vanua). Women of the sea people clan are the keepers of traditional marine ecological knowledge (TEK). They hold a wealth of information about marine ecology and biota, and have intimate knowledge of the natural order as well as changes and fluctuations in the system. According to informants, the sea people have always been the fisherpeople of Lau, from the time of the first human occupation. They are the descendents of the first Lauan fishers and the people who collected the marine resources that occur in ancient archaeological sites. I hypothesize, although it would be difficult or impossible to prove, that women were the primary producers of inshore marine resources in prehistory, just as they are in the present.

Small inshore fish species make up the largest portion of all animal protein consumed by Lauans each day. For example, the convict tang (*A. triostegus triostegus*) is a favorite fish of Lakebans. It is small, measuring an average of only 18–22 cm in total length (TL). This fish is locally considered to be associated with the high chief of Lakeba and the Lau Islands, or king, the late Tui Lau, because he was very fond of this fish and commissioned *vono* expeditions whenever he was on Lakeba. People on Nayau also claim to love eating the convict tang (Jones 2009*a*). Interviews indicate that the majority of survey respondents on Nayau favor inshore reef species that are typically small-bodied in the modern environment ($\leq$35 cm in TL). The single most sought after fish among women I interviewed is a group referred to collectively as *kawakawa* (small groupers, including *Epinephelus merra* and *Cephalopholis* sp., the honeycomb and hind groupers). *Epinephelus merra* in Fiji measure 20 cm (TL) on average when caught, and *Cephalopholis* averages 24–40 cm in TL (Froese and Pauly 2006).

Most of those interviewed from Lakeba and Nayau stated that they have noticed a decline in the local availability of some fishes and invertebrates (Table 6). For instance, the villagers of Vakano and Nasaqalau on Lakeba complained that people from other villages frequently come to their inshore reefs to collect fish. This practice is becoming increasingly common as the marine resources in larger villages on Lakeba, such as Tubou, are in more obvious decline. Lauans, and especially the fisherpeople, are keenly aware of worldwide environmental shifts such as global warming, the heating of the oceans, and sea-level rise. The long-term sustainability of Lauan fishing practices is something that all the fisherpeople I interviewed on Lakeba mentioned, and in each village on Lakeba there are active representatives from the Fiji Ministry of Fisheries. This is not the case on Nayau, where there is comparatively little discussion of conservation and the effects of global warming; however, people are aware of changes in the marine environment. The long-term impacts of intensive marine harvesting, fishing, and collecting are a frequent subject of conversation among the village chiefs and fisherpeople.

Biological Surveys

Over 200 species of marine vertebrates (sharks, stingrays, sea snakes, bony fishes, and turtles) from over 50 families, and almost 200 species of macroinvertebrates, were observed around the study sites. The reefs of Aiwa Levu and Aiwa Lailai have the widest range and abundance of observed vertebrates and invertebrates (Table 7). The detailed results of this biological survey will be published in the future. Most of the identified fishes are relatively common in the waters of the tropical Pacific (Myers 1991) and belong to the most abundant coral reef families including the following: Acanthuridae, Chaetodontidae (butterflyfishes), Labridae (wrasses), Lethrinidae, Mullidae (goatfishes), damselfishes (Pomacentridae), Scaridae, Lutjanidae (snappers), and Serranidae. On average, the inshore scuba and snorkel surveys identified 41 fish species on Lakeba (per 1,000 m^2 area), 55 species on Nayau (per 500 m^2), 67 species on Aiwa Levu (per 500 m^2), and 66 species on Aiwa Lailai (per 500 m^2).

The presence of juvenile fishes in the inshore areas varies according to differences in the marine environments, including the tide, the moon phase, and the substrate. On the north side of Lakeba, villagers have planted extensive areas of mangrove trees. This ap-

TABLE 7

Summary of Marine Biological Survey Data from Lakeba, Nayau, Aiwa Levu, and Aiwa Lailai

Island	Survey Site	Survey Type, Transect Measurement	Total Fish	No. of Fish Species
Lakeba	Oru	Scuba, 200 m/1,000 m^2	988	54
Lakeba	Tubou	Snorkel, 200 m/1,000 m^2	711	37
Lakeba	Nasaqalau Mangrove	Walked, 200 m/1,000 m^2	37	2
Lakeba	Waciwaci	Snorkel, 200 m/1,000 m^2	807	33
Lakeba	Nukunuku Mangrove	Walked, 200 m/1,000 m^2	27	3
Lakeba	Vakano Mangrove	Walked, 200 m/1,000 m^2	210	16
Lakeba	Selesele Point	Forereef scuba, 18 m maximum depth	366	54
Lakeba	Vakano	Forereef scuba, 20 m maximum depth	339	54
Lakeba	Ucuiboagi Point	Forereef scuba, 26 m maximum depth	430	64
Lakeba	Nasaqalau	Forereef scuba, 20 m maximum depth	480	64
Lakeba	Oru	Forereef scuba, 20 m maximum depth	357	62
Aiwa Levu	Aiwa 1	Scuba, 100 m/500 m^2	938	76
Aiwa Levu	Aiwa 2	Scuba, 100 m/500 m^2	651	58
Aiwa Lailai	Aiwa LL1	Snorkel, 100 m/500 m^2	703	60
Aiwa Lailai	Aiwa LL2	Snorkel, 100 m/500 m^2	784	72
Nayau	Salia	Snorkel, 100 m/500 m^2	618	49
Nayau	Narocivo	Snorkel, 100 m/500 m^2	831	66
Nayau	Liku	Snorkel, 100 m/500 m^2	587	50

pears to have increased the local abundance of fishes on the reef flats. Juveniles of several species were frequently recorded in close proximity to the planted mangrove trees, and they are especially abundant around Aiwa Lailai and in the intertidal area of Aiwa Levu. Aiwa Levu's mangroves also act as nurseries for juvenile fishes. Around Nayau, the presence of young fishes appears to be highly dependent on the tide, but the inshore flats around all three of Nayau's villages boast high frequencies of juveniles in the families listed here.

The effect of harvesting invertebrates is clearly visible on most of Lakeba and Nayau's reef flats. Species of giant clam (*Tridacna* spp.) and large snails (e.g., *Trochus* spp.) are rarely encountered (note that when large-bodied invertebrates such as *Tridacna* and *Trochus* are encountered by Lauans they are immediately collected and often consumed right on the reef). In contrast, on Aiwa Levu and Aiwa Lailai, where regular harvesting is less common, several species that are rare on Lakeba flourish (*Tridacna* spp.). The majority of forereef dive sites had less than 5% coral cover, which is likely due to a recent bleaching event. Since records began, the first time the reefs of central Lau were affected by bleaching was in 2003 (Leon Zann, University of the South Pacific, pers. comm., 2006). (Apparently Lauan reefs were minimally affected or unaffected by the 1997/1998 El Niño–Southern Oscillation mass-bleaching event.)

On both Lakeba and Nayau the reefs generally exhibit a notable lack of gorgonians and neptheids (soft tree corals, finger soft corals, etc.). The environments evidence severe leather soft coral diebacks (*Sinularia*, *Sarcophyton*, and *Lobophytum* spp.). The scale and condition of the coral bleaching and death on Lakeba and Nayau is so severe that although local fishing pressures over the last 3,000 years have undoubtedly affected it, recent climatic shifts are likely to blame. Nevertheless, small coral recruits were documented and thus natural partial recovery of once larger colonies is beginning at all the study reefs. Despite the poor state of much of the coral on these islands, substantial populations of fishes were observed in pockets of healthy reef and in association with the recovering reef colonies, including large-bodied species of groupers, juvenile groupers and parrotfishes, wrasses, large-bodied parrotfishes, and a small number of sea turtles. Large-bodied fishes were relatively uncommon in the inshore areas and common but not abundant on the forereef of all the study sites. Reef sharks and jacks are most frequently observed around the inshore reefs of Aiwa. These animals were also documented off Nayau's north and south forereefs.

DISCUSSION

This research has produced important results, including descriptions of modern exploitation patterns, extant marine biodiversity, and the outcomes of inshore fishing expeditions. In addition, ethnoarchaeological studies have illuminated several long-term trends in marine resource exploitation and biodiversity. There appears to be relatively little variation in the types of marine vertebrate species exploited over time. The vertebrates are relatively diverse and do not show a marked decline in size according to the zooarchaeological data. However, both the invertebrate archaeological assemblages and modern invertebrate communities provide evidence for shifts in exploitation and availability of marine resources over time.

Archaeology

Laboratory analysis on archaeological bone and shell samples from Nayau and Aiwa has contributed to the understanding of the makeup and sizes of exploited marine taxa. Detailed analysis of over 24,000 fish bones and shellfish remains indicates that the indigenous inhabitants of the study areas intensively exploited relatively small-bodied inshore marine resources over the course of their 3,000-year history. However, to date, there is no solid zooarchaeological evidence suggesting a major decrease in the overall sizes of exploited fishes and invertebrates over time. Rather, the data from fish vertebral measurements suggest an increase in the sizes and weights of fishes exploited on Nayau from the early to mid-late time periods, and relatively little change on Aiwa Levu and Aiwa Lailai. On Nayau this bimodal distribution pattern in the Lapita-period site of Na Masimasi may be indicative of two distinct fishing technologies utilized contemporaneously, such as trolling (resulting in the capture of large-bodied fishes) and inshore net fishing (resulting in the small-bodied fishes).

The most obvious differences are in the taxa exploited and changes in the composition of the assemblages through time. There is little temporal variation in the overall numbers of fish taxa exploited, regardless of the NISP and calculated MNI. By comparing fish assemblages with measures of diversity and equitability, it becomes apparent that the taxa exploited remained relatively even over time, and diversity (H) was moderate to high. More variation is evident in the invertebrate assemblages, but the shifts are minor with the exception of the early exploitation of fighting conch (*Strombus gibberulus*) on Nayau at Na Masimasi. On Aiwa Levu and Aiwa Lailai, the invertebrate assemblages are consistently dominated by turban snails (*Turbo* spp.). The invertebrate pattern may be attributed to preference; that is, the first inhabitants of the islands selected choice invertebrates based on taste and/or ease of access to these items. For example, the inshore area by Na Masimasi is composed of coral reef on sand and limestone flats, exactly the habitat preferred by fighting conch. It should be noted that today both fighting conch and turban snails are relatively rare on Lakeba and slightly less rare on Nayau and the Aiwas (this is based on biological surveys and ethnographic data documented during fishing expeditions in the inshore area). Lauans claim that these taxa were more abundant 20–50 years ago. The change in prehistoric and modern availability could be due to a long history of intensive exploitation, resulting in overexploitation, or a combination of environmental and human-induced changes. However, in the absence of data supporting a species-size reduction in middens over time it is difficult to distinguish human impacts from the effects of natural disturbance on invertebrate populations or decreased shell bed density. Archaeologists have identified sites exhibiting reductions in shellfish abundance that are likely the result of terrestrial/agricultural development, including increased siltation into the marine environment (Kirch and Yen 1982, Spennemann 1987). Unfortunately, in most situations there is no simple explanation for the presence or absence of a marine species in a given habitat because this depends heavily on natural stochastic recruiting events (Sale 1980).

HABITAT. Between 80% and 95% of the identified fishes from all the study sites inhabit inshore coral reef environments (by measures of NISP and MNI). The vast majority of the identified invertebrates inhabit the intertidal reef, the splash zone above the high-tide line, tide pools, sand flats, and fringing reefs. Turban snails (Turbinidae), the most common invertebrate at all the sites, with the exception of Na Masimasi where fighting conchs are more frequent, inhabit coral reef habitats and rocky coral areas. *Turbo setosus*, the most frequently identified *Turbo* on Aiwa, is known to prefer exposed areas of coral reef and the sublittoral zone in shallow waters (it accounts for 40–60% of the invertebrate assemblages by measure of MNI and NISP). The identified bivalves can be found in shallow-water habitats, including silty or sandy inshore areas on fringing reefs (Kay 1979, Colin and Arneson 1995). Bivalves make up a small portion of all the zooarchaeological assemblages (<20% at any site).

In his analysis of archaeological marine resources from Lakeba, Best (1984:498) argued that there is little evidence of any noteworthy changes in the fish taxa exploited over a 3,000-year sequence of data. Best's conclusions are supported by the archaeological data in this study. One possible explanation for this phenomenon is that given fairly small and stable human population sizes over time, the Lauan data represent a relatively stable system of exploitation, where some of the traditional fishing methods utilized by Lauans and the animals exploited (e.g., convict tangs and rabbitfishes that are targeted in *vono* expeditions have short population-doubling times) are suited to long-term sustainability (also see Jennings and Polunin 1996). Although this may be true for some bony fishes, the exploitation and availability of particular shellfish species appears to have decreased through time.

A number of complex ecological processes may be related to the documented changes in fish and shellfish exploitation. These include, but are not limited to, variations in fishing technologies, shifting climatic conditions, recruitment, and changing predator-prey relations. Undoubtedly the marine biota of Lau experienced both natural and human-induced shifts across space and time; these phenomena are well documented throughout the Pacific islands (Allen 2006). Allen (2006) discussed new data from long-lived Pacific corals and general climate modeling for the central Pacific. She described climatic shifts in the region and areas of particular instability. The data suggest increased El Niño–Southern Oscillation (ENSO) variability from A.D. 1100 to 1400, with a shift from cool conditions after A.D. 1200 and a short warm period at about A.D. 1300 (Allen 2006:530). In Fiji the transition from the Little Climatic Optimum (LCO) (1250–700 B.P.) to the Little Ice Age (LIA) (700–200 B.P.) at around 700 B.P. was a period of frequent and intense ENSO activity, resulting in increased storminess, low-pressure systems, sea-level decline, and heightened sea temperatures (Nunn 2000, Hughes et al. 2003, Field 2004). Increased temperatures and ocean salinity are known to heavily impact coral reefs through bleaching and, ultimately, tremendous coral die-offs as seen in modern ENSO events (Hughes et al. 2003, Allen 2006). The high level of decline in marine productivity due to these natural climatic events is extreme and may outweigh the potential negative impacts that relatively small populations such as those occupying Aiwa and Nayau at any given time could have exerted upon their rich marine environments (Thomas makes a similar observation in his paper in this volume, regarding the potential marine impacts of small populations inhabiting atolls in Kiribati. However, this view and that of Allen stand in contrast to work by Pandolfi and colleagues [2003:957], who argue that their data trajectories of decline in fisheries worldwide through time are similar and that "All reefs were substantially degraded long before outbreaks of coral disease and bleaching," and therefore, human overfishing, along with associated land-based pollution and runoff, is the only reasonable explanation for the pre-1900 decline of worldwide coral reefs); additional faunal data from sites dating to the LCO-LIA transition and fine-grained radiocarbon dates are needed to further illuminate this issue.

In D'Arcy's (2006) recent book he discussed potential impacts of highly unpredictable annual and seasonal climatic variations on the lives of Pacific islanders inhabiting Remote Oceania. In terms of fishing patterns, biomass of fish taxa also changes annually and over longer-term periods, with variability visible in terms of individuals. "The fact that instability in individual species' numbers can occur alongside stability in the overall size of the ecosystem biomass suggests that there can be continuity in marine harvests for fisherfolk not rigidly tied to harvesting a few species only" (D'Arcy 2006:21). In a highly variable environment flexibility in terms of technologies, habitats exploited, and targeted catch appears to be a great advantage. In particular, net technologies are well suited to capture a broad spectrum of available inshore species. I argue that Lauan fisherpeople's flexibility and natural shifts may both account for the zooarchaeologically observed patterns in the Lau marine fauna. In addition, Lauans have long-standing elaborate systems of marine tenure and rules regarding the use of specific areas of the reef. They consider even minor shifts in marine variability and shift focus accordingly in ways that manage use and temporarily conserve particular resources. This may be achieved by declaring areas of the reef taboo or "off limits" for some time while local populations of marine resources are allowed to recover. Or a village elder may decide that a particular type of fish should not be captured over a given time period.

Ethnography

The inclusion of indigenous behaviors and knowledge is a unique and critical component of this project. Interactions between scientists and local communities are undoubtedly crucial to understanding and the long-term maintenance and stewardship of marine biological communities. Inshore fishing expeditions are coordinated and directed by elder women, who pass knowledge of how and where to fish on to the younger generations. I worked closely with these fisherwomen in an attempt to learn what marine resources are harvested and how the diversity of available fishes and invertebrates has changed. Archaeological fish bones indicate that Lau's first inhabitants intensively harvested relatively small inshore fishes, just as their descendants do today. There appears to be a direct correlation between the fish taxa that Lauans claim to prefer and those that are actually collected and consumed. The evolutionary perspective afforded by combining multiple perspectives has illuminated long-term trends in Lauan exploitation and preferences. It is possible that some of the Lauan traditional systems for marine exploitation and management allow for long-term sustainability (especially in the case of small-bodied inshore bony fishes), but others, such as the harvesting of shellfish, do not. Pandolfi et al. (2005) suggested that indicators of a healthy reef and successful management might include the presence of taxa such as parrotfishes, grazing sea urchins, sharks, turtles, large jacks, and groupers. These taxa are found on all the study reefs but infrequently on Lakeba and more frequently on Nayau and the Aiwas.

Biological Surveys

The results of the marine biological surveys in association with this project build on previous marine biological surveys from the Lau region by Wells (1977), Jennings and Polunin (1995, 1996), Vuki et al. (2000), Dulvy et al. (2004), Kuster et al. (2005, 2006), and Turner et al. (2007). These workers and others have noted that traditionally managed fisheries in Fiji have expanded to accommodate escalating demands for fish in emerging market economies (Jennings and Polunin 1995, 1996), and that indigenous or informal knowledge is extremely useful for marine biologists and ecologists in Fiji and the Pacific islands in general (Dulvy and Polunin 2004, Kuster et al. 2006, Middlebrook and Williamson 2006).

On each of the study islands the biological surveys revealed that there are patches of healthy, recovering reef associated with relatively large populations of diverse fish communities. However, the overall diversity and the numbers of fishes recorded varied depending on the island (Table 7). The data indicate that Aiwa and Nayau have more diverse and possibly more abundant marine communities. For example, the Lakeba surveys found relatively fewer total fishes and fewer fish species in larger survey areas (1,000 m^2) than the surveys on Nayau and Aiwa (500 m^2). The Aiwa reefs have some healthy colonies of soft tree corals and finger soft corals, which are lacking on Lakeba and in most areas on Nayau. Reef sharks and large-bodied fishes are also more abundant around Aiwa than the larger islands.

CONCLUSIONS

Using the past as a baseline for comparison with the present to explore change, the interview and fishing expedition data provide important information about the status of the coral reefs; methods and technologies of exploitation; changes in this environment; and presence, absence, or shifts in the local availability of particular resources. A wide range of species is regularly exploited, that is, a total of 112 taxa for all four islands. The biological surveys recorded over 200 species of fishes, and the archaeological bone identifications include over 50 fish taxa. Although there are many factors that influence the outcome of the summary data for each line of evidence, these measures do indicate an overlap in the available resources past and present, and continuity in the way that the marine fauna have been used throughout Lauan history. In the following section I discuss four key findings based on the data derived from the fieldwork and laboratory analyses. More research is needed to adequately address the complex issues raised, but I begin with the following observations and interpretations.

First, the data from central Lau suggest that the relative intensity of human exploitation (intensity is related to population size, land area and use, and the degree of agricultural development) will determine the current composition and biological diversity of marine communities. It appears that biodiversity does not vary as a function of physical factors alone. Although Lakeba should be the most diverse of the islands surveyed, due to the large size and the natural physical variation in the types of reefs, substrates, and land forms, Aiwa and Nayau appear to have more diversity in modern marine communities (according to catch diversity in Appendix and that observed in marine surveys [Table 7]). Lakeba has the highest overall human population for the study sites, and it likely has since the island was settled. However, by land area/m^2 and reef area Lakeba is currently less densely settled than Nayau. A detailed comparison of the faunal material from Lakeba, presented in Best (1984) (the comparison is hampered by the fact that Best's collection and identification methods differ from my own in fundamental ways. For example, Best did not use fine screens to collect faunal samples, shellfish was not collected using the methods he used for vertebrates, and he did not identify fishes using the same elements that I use, rather he relied only on so-called "special elements" for identification), and that from Nayau and Aiwa will determine if this pattern of diversity is apparent throughout the archaeological data. It is interesting that the diversity of the zooarchaeological samples of both bony fishes and shellfish is greater on Nayau than on Aiwa. Assuming that inshore catches represent a cross section of the available marine resources, this pattern may reflect greater diversity on Nayau in prehistory and a shift in contemporary times to a less-diverse marine environment. Alternatively, the data could be indicative of a broader exploitation pattern by the prehistoric occupants of Nayau versus that on Aiwa.

Second, human disturbance may have occurred more extensively and continuously on large islands, and therefore small islands may harbor species-rich communities. This finding is evidenced on the islands of Aiwa Levu and Aiwa Lailai and relates to the point already made. Lakeba has a larger human population, more advanced technologies and infrastructures (roads, cars, educational and medical compounds, an airport, a large pine tree farm, generators), and more development and runoff from agriculture than the other islands studied. Nayau, Aiwa Levu, and Aiwa Lailai are much less disturbed in modern times, but even in prehistory these environments appear to have had less impacts resulting from human occupation. It is likely that these smaller islands had continually smaller population densities and less-intensive exploitation over time (note that the size of the reef on Nayau is approximately the same size as the reef associated with Aiwa Levu and Aiwa Lailai). The diversity of fishes and invertebrates species exploited on Nayau and Aiwa is greater across prehistory; the reefs of these islands currently have more diverse biological communities than those of Lakeba.

Third, humans appear to have a selective effect on marine biodiversity as particular species are/were targeted according to local standards of ranking and preference. For example, people sometimes target large taxa, but they also target fishes with specific physical characteristics such as big eyes and red lips; this includes, for example, emperorfishes (O'Day 2004). It should be noted that optimization criteria derived from foraging theory do not entirely dictate cultural preference in this setting. In addition to exploiting large-bodied fishes with spears and while trolling (trolling and fishing outside the reef is a male activity; women fish in the inshore area), Lauan women target fishes in the inshore area (which are primarily small-bodied) and are motivated by characteristics that extend beyond the body size of particular animals (Tables 3–5 and Figures 2–9). This finding was apparent in the archaeological data (small-bodied fishes occur in the highest frequencies in all sites across time periods), and the small-bodied fighting conch was intensively exploited at Nayau's earliest known Lapita occupation site, Na Masimasi. The majority of the animal protein consumed each day by Lauans comes from the inshore area; therefore small fishes contribute the most animal protein to the diet and have since the earliest occupation of the islands examined in this study, according to the zooarchaeological data. (This statement needs to be evaluated by isotope analysis, which is forthcoming.) By determining local standards of preference and rank and examining social and environmental motivations for exploiting particular food items, we can better understand how humans make decisions about using their environment and its resources.

Fourth, vulnerable species are currently overexploited or locally extinct; even rare resources have withstood 3,000 years of human impacts and thus may have life history traits supporting resilience, making conservation efforts worthwhile (Jackson et al. 2001, Steadman 2006). In all of the archaeological sites, fish bones constitute the majority of the recovered fauna, suggesting a heavy reliance on the sea and relatively small inshore reef fish in particular. The bony fish families that contribute the most to zooarchaeological assemblages throughout the archaeological sequence by count (NISP) and the numbers of individuals (MNI) are Acanthuridae (tangs), Serranidae (groupers), Scaridae (parrotfishes), and Lethrinidae (emperorfishes). Modern subsistence systems also rely heavily on these families of fishes, and they form a majority of the modern fauna, according to the biological surveys. Invertebrates make up a less-important portion of the diet. The most commonly exploited archaeological invertebrates include species in the family Turbinidae (turban snails), which are now rare on Lakeba and Aiwa and becoming increasingly rare on Nayau; Strombidae (strombs); Conidae (cones); and Patellidae (limpets). My study did not note any locally extinct resources (species that occurred in the past but were absent in the modern community overall), but according to ethnographic and biological survey data, many large-bodied fishes and invertebrates appear to be in decline after three millennia of exploitation (groupers, parrotfishes, sweetlips, snappers, mullet, coconut crab, giant clam, strombids, trumpet triton). These species and those that are known to be locally productive on Lakeba, Nayau, and Aiwa would be excellent targets for conservation (see Table 6). For example, in the study area the local diversity of lethrinids, despite 3,000 years of intensive exploitation, is remarkable. There are 14 species of lethrinids documented in all of the Fiji Islands (World Wildlife Foundation 2003), and my research documented 10 species from ethnographic observations, six from the archaeological sites, and four in the modern marine surveys.

Convict tangs (*Acanthurus triostegus*) and rabbitfishes (*Siganus spinous*) are well suited to the types of exploitation practiced in the northern villages of Lakeba and on Nayau because they are less vulnerable than other species—their population doubling times are 1.4–4.4 years and less than 15 months, respectively (Froese and Pauly 2006). Apparently, a component of the Lauan traditional system for marine management, moving from various fishing grounds exploited by group fishing practices, allows for long-term sustainability of particular types of resources. These ecological practices and traditional ecological knowledge (TEK) may be used to guide the development of programs for sustainable use of marine resources in Fiji and elsewhere in the tropics. In fact, social attitudes toward marine resource management are critical to the success of management and conservation programs (Middlebrook and Williamson 2006, Turner et al. 2007).

Thomas Lovejoy, who coined the term biodiversity, claims that this is the single most important measure for evaluating the impacts of humans on the environment (Lovejoy 1997:10). To understand the extent of the human impact on marine ecosystems in Lau and the complicated relationships surrounding this issue, long-term research is needed. It is clear that modern surveys and interviews, as well as ethnographic documentation of fishing practices are all useful modes of determining the local reliance on and importance of marine resources. Each line of evidence contributes varied but overlapping information, which should be compared with the archaeological data.

Allen (2006) predicted that marine productivity declines due to heightened ENSO activity during the LCO-LIA shift around 700 B.P. had an obvious signature on marine zooarchaeological assemblages; that is, these climatic changes resulted in environmentally induced cultural change. On Viti Levu Field (2004) documented shifts to fortified settlements around A.D. 1300–1500 that were accompanied by a broadening diet breadth. The mid-late period archaeological data from Nayau and Aiwa exhibit minor shifts in the diversity of exploited taxa. A slightly greater diversity in bony fish exploitation occurred during the mid-late period occupations on Nayau, where a more diverse group of invertebrates was exploited over time. However, there is no evidence for intensive declines in marine productivity from the Lauan archaeological data. More obvious declines in invertebrates and large-bodied fishes appear in the modern data, rather than in the archaeological past. Perhaps the data illustrate both Lauan stability and flexibility in marine exploitation patterns, just as D'Arcy (2006:21) suggested for all the inhabitants of Remote Oceania, who have been subject to highly variable climatic shifts throughout their history.

The responsible management and conservation of marine ecosystems is critical for Fijians. In the remote Lauan archipelago, the entire population lives on the coast and relies heavily on marine resources for food and their livelihoods. Like coastal ecosystems worldwide, Fiji's marine biodiversity faces the growing threat of overfishing and impacts resulting from pollution, land development, climatic change, and coral bleaching. Compared with other areas of Fiji, the Lau Group is less well studied but exhibits great marine diversity as the result of smaller human populations, less development, partial isolation, little or no commercial fisheries, and lack of a tourist infrastructure. My multidisciplinary approach contributes to the understanding of Lauan biodiversity through three perspectives, archaeological, ethnographic, and biological. Together this information was used to better understand the marine environment and human interactions with it over the three millennia of human occupation on the study islands. Ultimately, I expect that an evolutionary perspective will facilitate the development of programs for sustainable use of marine resources in the study area and beyond.

Methodologically, this study indicates that each level of data (ethnographic, archaeological, and marine biological) produces different but overlapping results. A better understanding of environmental problems and solutions for dealing with them will come from multidisciplinary collaborations and the examination of biological complexity over the long term (Lovejoy 1997, Jackson et al. 2001, Briggs et al. 2006). Combining multiple approaches and methodologies will enhance understanding of the issues related to marine changes on local and global scales (Kronen and Bender 2007, Turner et al. 2007, Rick and Earlandson 2008). A multidisciplinary historical ecological approach holds much promise for the future of research in Fiji and in marine ecosystems worldwide.

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Appendix

Fish Species Collected in Modern Fishing Expeditions on the Islands of Aiwa Levu, Aiwa Lailai, Nayau, and Lakeba

Taxa: Scientific Name	Common Name	Aiwa Levu	Aiwa Lailai	Lakeba	Nayau
Carcharhinidae	Requiem sharks				
Carcharhinus spp.	Reef sharks	L[a]	L		L
Galeocerdo cuvier	Tiger shark	L			L
Dasyatidae	Stingrays				
Dasyatis kuhlii	Bluespot stingray				G
Muraenidae	Moray eels				
Gymnomuraena zebra	Zebra moray				G*
Gymnothorax favagineus	Blackblotched moray				S, G
G. meleagris	Guineafowl moray				G*
G. zonipectus	Bartail moray				S, G
Enchelynassa canina	Longfang moray				S, G
Enchelycore schismatorhynchus	Whitemargined moray				G*
Echidna nebulosa	Snowflake moray			G	S, G
Ophichthidae	Snake eels				
Myrichthys colubrinus	Harlequin snake eel			G*	G*
Elopidae	Ladyfishes				
Elops sp.	Ladyfish				G
Plotosidae	Eel catfishes				
Euristhmus lepturus	Longtailed catfish				G

Appendix (continued)

Taxa: Scientific Name	Common Name	Aiwa Levu	Aiwa Lailai	Lakeba	Nayau	
Clupeidae	Herrings					
Herklotsichthys quadrimaculatus	Bluestripe herring			G		
Batrachoididae	Toadfishes					
Chelonodon patoca	Mikspotted toadfish				S, G	
Exocoetidae	Flyingfishes					
Cypselurus sp.	Flyingfish				N, T	
Belonidae	Needlefishes					
Platybelone argalus platyura	Keeled needlefish			G	G	
Strongylura incisa	Reef needlefish				G	
Tylosurus crocodilus crocodilus	Hound needlefish				G	
Hemiramphidae	Halfbeaks					
Hyporhamphus acutus acutus	Halfbeak				N	
Holocentridae	Squirrelfishes, soldierfishes					
Myripristis sp.	Soldierfish	S	S, G	S, G	S, G	
Sargocentron spiniferum	Longjawed squirrelfish	S	G	S	S, G	
S. violaceum	Violet squirrelfish				S, G	
Platycephalidae	Flatheads					
Onigocia spinosa	Spiny flathead				S, G	
Scorpaenidae	Scorpionfishes				G*	
Serranidae	Groupers					
Cephalopholis argus	Peacock grouper (rockcod)	S	S		G, T	
C. sonnerati	Tomato hind				G, T	
Epinephelus merra	Honeycomb grouper	S, G, H	S, G	S, G	G	
E. lanceolatus	Giant grouper				S, T	
E. howlandi	Blacksaddle grouper			G		
E. polyphekadion	Marbled grouper			S, G	G, T	
E. tauvina	Reef cod	S				
Therapontidae	Grunters					
Terapon jarbua	Crescentbanded grunter			G	G	
Carangidae	Jacks, trevallys					
Alectis ciliaris	Pennantfish				S, G, T	
Caranx ignobilis	Giant trevally				S, G, T	
C. melampygus	Bluefin trevally	H, T	S	S, G	S, G, T	
Gerreidae	Mojarras					
Gerres oyena	Common silver-biddy			G		
Lutjanidae	Snappers					
Lutjanus spp.	Snappers				S, H, T	
Lutjanus gibbus	Paddletail				S, H, T	
Haemulidae	Sweetlips, grunts					
Plectorhinchus spp.	Sweetlips			S, H, T	S, H, T	
Nemipteridae	Threadfin bream					
Scolopsis bilineata	Twolined monocle bream	S			G	
Coryphaenidae	Dolphinfishes					
Coryphaena hippurus	Common dolphinfish			T	T	
Lethrinidae	Emperorfishes					
Gnathodentex aureolineatus	Yellowspot emperor		G		G	
Gymnocranius grandoculis	Bluelined largeeye bream	S			S, G	
Lethrinus conchyliatus	Redaxil emperor			G		
L. erythropterus	Orangefin emperor			S, G	G	
L. harak	Blackspot emperor			G	G	
L. miniatus	Trumpet emperor			G		
L. obsoletus	Yellowstripe emperor				G	
L. xanthochilus	Yellowlip emperor			G	G	
L. atkinsoni	Yellowbrown emperor				G	
Monotaxis grandoculis	Bigeye bream			S, G	G	G

Appendix (continued)

Taxa: Scientific Name	Common Name	Aiwa Levu	Aiwa Lailai	Lakeba	Nayau
Mullidae	Goatfishes				
Mulloidichthys flavolineatus	Yellowstripe goatfish	G			G
Mulloides vanicolensis	Yellowfin goatfish		G	G	
Parupeneus barberinoides	Half and half goatfish		G	G	G
P. cyclostomus	Yellowsaddle or Yellow goatfish				G
P. indicus	Indian goatfish			G	
P. macronemus	Longbarbel goatfish			G	
P. multifasciatus	Multibarred goatfish	S			G
P. trifasciatus	Goatfish	S			
P. pleurostigma	Sidespot goatfish			G	G
Kyphosidae	Sea chubs				
Kyphosus bigibbus	Gray sea chub				S, G
Ephippidae	Batfishes, spadefishes				
Platax teira	Longfin spadefish			G	
Chaetodontidae	Butterflyfishes	S	G	G	G
Chaetodon vagabundus	Vagabond butterflyfish			G	G
Pomacanthidae	Angelfishes				
Pygoplites diacanthus	Royal angelfish			S	G
Pomacentridae	Damselfishes				
Abudefduf septemfasciatus	Banded sergeant	S		S	
Labridae	Wrasses				
Anampses spp.	Wrasses				G
Bodianus vulpinus	Blackspot pigfish				S, G
Cheilinus undulatus	Doubleheaded Maori wrasse				S, G
Hologymnosus doliatus	Pastel ringwrasse			G	
Labrichthys unilineatus	Tubelip wrasse				G
Novaculichthys taeniurus	Carpet wrasse				S, G
Thalassoma spp.	Wrasses			G	G
Iniistius pavo	Peacock wrasse				S, G
Scaridae	Parrotfishes				
Calotomus carolinus	Carolines parrotfish			G	
Chlorurus microrhinos	Steephead parrotfish				S, G
C. sordidus	Bullethead parrotfish	S	S, G		
Scarus globiceps	Globehead parrotfish	S			
S. rubroviolaceus	Redlip parrotfish	S			G
S. prasiognathos	Dusky parrotfish				S, G
S. schlegeli	Yellowband parrotfish	G			
S. oviceps	Blue parrotfish	S, G	G		S, G
Mugilidae	Mullets				
Mugil cephalus	Flathead mullet			G	G
Valamugil buchanani	Bluetail mullet			G	G
Liza vaigiensis	Squaretail mullet				G
Sphyraenidae	Barracudas				
Sphyraena barracuda	Great barracuda			G	S, H, T
Sphyraena obtusata	Striped seapike				S, H, T
Blenniidae	Blennies				
Salaris sinuosus	Fringelip blenny			G	
Acanthuridae	Surgeonfishes				
Acanthurus lineatus	Blueband surgeonfish	S			G
A. guttatus	Whitespotted surgeonfish			G	G
A. nigricauda	Epaulette surgeonfish			S	
A. triostegus triostegus	Convict tang	G, S	G	S, G	G
Ctenochaetus striatus	Striped bristletooth	S	G	S	S, G
Naso lituratus	Orangespine unicornfish			G, S	S, G
N. unicornis	Bluespine unicornfish		S	G, S	S, G

Appendix (continued)

Taxa: Scientific Name	Common Name	Aiwa Levu	Aiwa Lailai	Lakeba	Nayau
Zanclidae	Moorish idol				
Zanclus cornutus	Moorish idol			G	G
Siganidae	Rabbitfishes				
Siganus argenteus	Forktail rabbitfish			G	G
S. spinus	Little spinefoot rabbitfish	S		G	G
Scombridae	Tunas, mackerels, bonito				
Scomberomorus spp.	Mackerel				T
Bothidae and Soleidae	Flounder and sole				S, G
Balistidae	Triggerfishes				S, G, H
Balistoides viridescens	Bluefinned triggerfish				S
Pseudobalistes fuscus	Yellowspot triggerfish				G
Melichthys niger	Ebony triggerfish				S, G
Ostraciidae	Trunkfishes				
Ostracion cubicus	Yellow boxfish			G*	G*
Lactoria diaphana	Roundbelly cowfish			G*	G*
Tetraodontidae	Puffers				
Arothron reticularis	Reticulated pufferfish				G
Arothron stellatus	Starry pufferfish			G	S, G
Triodon macropterus	Threetoothed puffer				S, G
Diodontidae	Porcupinefishes				
Chilomycterus reticulatus	Porcupinefish				S, G
Diodon hystrix	Porcupinefish			G	S, G
Istiophoridae	Billfish, marlin				T

Note: Only seven species are bycatch, which are not consumed; these are marked with an asterisk (*).

[a] Modes of collection: L, longline; G, gill net; S, spear; N, hand net; T, trolling; H, hand line.