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Subsistence harvest of coral reef resources in the outer islands of American Samoa: modern, historic and prehistoric catches

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Abstract
The outer islands of American Samoa provided an opportunity to examine a small-scale subsistence fishery from four perspectives: modern, historic and pre-historic harvests, and standing stocks. The per capita catch in 2002 was 71 kg/person of which 63 kg/person was consumed and the remainder sent to family members on the main island of Tutuila. The annual harvest (37.5 mt) consisted of the coastal pelagic bigeye scad *Selar crumenophthalmus* (31%), reef-associated fish (57%) and invertebrates (12%). Fishing effort was low (averaging only 2.7 fishers at any given time), but when this effort was expanded to an annual period, it amounted to 20,282 hours of fishing and an extraction of 1,400 kg of fish and invertebrates per kilometer of shoreline. The harvest yield of reef-associated fishes (2.3 mt/km^2/yr) was approximately 1-3% of standing stocks. Fish biomass on the reefs (2.6 mt/ha) was more closely aligned with literature values for remote and relatively unfished reefs (3.0 mt/ha) than fished reefs (1.1 mt/ha) in the central Pacific region. Additionally, most village elders interviewed (85%) felt that fishing now was good and similar to when they were younger. The current composition of fish harvested was also similar to that previously found in a nearby archeological excavation dated 1000-3000 years ago. These findings indicate that the harvest has been sustainable over the millennia, although some potential impacts to the coral reef ecosystem are noted, particularly the current scarcity of large fish.

Key words: fishing, subsistence, coral reef, American Samoa

1. Introduction

Fishing pressure on coral reefs is a major concern throughout the tropics due to its well-documented impacts on reef ecosystem structure and function (e.g., Russ, 1991; Jennings and Polunin, 1996; Russ and Alcala, 1998; Friedlander and DeMartini, 2002; Bellwood et al., 2004). Yet it is generally difficult to quantify harvests, particularly small-scale subsistence fisheries that operate continuously through the year, use a variety of gear types, catch multiple species, and have multiple landing sites. Additionally, historic and prehistoric catch data are rarely available.

The outer islands of American Samoa provide an opportunity to examine a subsistence fishery that is generally uncomplicated by other sources of fishing mortality (commercial or recreational fishing) or extensive anthropogenic stresses (destructive fishing practices, land-based pollution, tourism). Although subsistence fishing is declining on the main island (Tutuila) as lifestyles and economies become westernized (Craig et al., 1993; Ponwith, 1991; Saucerman, 1994; Coutures, 2003; Hill, 1978; Wass, 1980; Zeller et al., 2006), it continues to be an important activity in the outer islands where coral reef resources provide a significant contribution to the family diet.

The present study assessed the subsistence fishery on two of the outer islands, Ofu and Olosega, where we examined the subsistence fishery from four perspectives: modern, historic and prehistoric harvests, and standing stocks. Study objectives were to characterize the fishery in terms of resources harvested and compare this to the abundance of coral reef fishes in nearshore waters around the islands. Potential changes in the fishery over past decades were obtained through interviews with village elders, and a previous archeological excavation in the study area provided information on fish catches dated 1000-3000 years ago, the older date being when Polynesians first inhabited these islands (Nagaoka, 1993; Kirch and Hunt, 1993).

2. Methods

2.1. Study area and fishery

American Samoa (lat. 169-170^0 W, long. 14^0 S) consists of seven small islands in the South Pacific, with 96% of the territory's rapidly growing population of 65,500 dwelling on the main island of Tutuila (ASDOC, 2006). The outer islands of Ofu (7.3 km^2) and Olosega (5.3 km^2) lie 100 km east of Tutuila and are small volcanic islands connected by a short bridge (Fig. 1). Populations in the three villages there are small (505 people total) and declining (-1%/yr; ASDOC, 2005) as villagers move to Tutuila for jobs or schooling. Lifestyles in the outer islands remain somewhat more traditional than on Tutuila. The islands are serviced by small aircraft and a weekly supply boat.

Fringing coral reefs surround most of Ofu-Olosega, forming a single, continuous reef. Along southern shorelines, backreef moats (1-2 m deep at low tide) support a diverse assemblage of corals (Craig et al., 2001). Percent coral cover averaged 43% in the moats and 14% on the reef slopes at the 10-m depth in 2002 (Green, 2002). Two marine protected areas (MPAs) are located on Ofu's southern shoreline: Vaoto Marine Park (0.4 km^2, Sector 2 in Fig. 1) and the National Park of American Samoa (1.5 km^2, Sectors 3 and 4).

Fishing by villagers consisted primarily of shore-based activities by individuals or groups. The few operating boats were used only occasionally for nearshore fishing. Small catches of only offshore pelagic fish (primarily tuna) are not included as part of the nearshore harvest in this report. As is common in the South Pacific, men conducted most fishing activities but women participated in gleaning the reef (hand-picking invertebrates) and fish weir efforts.

2.2. Data collection

Data collection trips to Ofu-Olosega were taken monthly, each trip lasting about one week, from March 2002 to May 2003 (data were pro-rated to a 1-year period where appropriate). Field trip dates were determined opportunistically based on staff availability. The lengthy project period was selected to encompass potential seasonal changes in catch or effort. Four local villagers were trained to conduct scheduled surveys and creel interviews. Data sheets were reviewed with each assistant for confirmation or clarification.

2.3. Fishing effort

The number and location of fishers and gears used was recorded during four time strata: daytime fishing (0600-1859) and night-time fishing (1900-0559) for both weekdays and non-weekdays (Saturdays and holidays; Sundays were not sampled because fishing was generally prohibited then).

A 1-hr census of fishing effort was conducted at 2-hr intervals during each 8-16 hr field day regardless of weather. Each survey consisted of a one-way drive of the 9.5 km length of the island road system from Ofu Village to Olosega Village. The island shoreline was divided into 10 sectors (each 1.5-5.5 km) for fishery reporting (Fig. 1). Where the coastline could not be viewed from the road, observers walked to specific vantage points along the beach to scan for fishers. Two inaccessible sectors were not surveyed: the uninhabited east side of Olosega (Sector 6) and northwest side of Ofu (Sector 10). Consequently, the visible coastline amounted to 17.9 km (83%) of the 21.5 km of coastline around both islands. No data expansion was made for the inaccessible areas because fishers reported that relatively little fishing occurred there.

During each 1-hr census, a count of all active fishing gears was made. Fishing effort was expressed in units of "gear-hours" to allow expansions to unsampled time periods. The count of fishing gears was essentially equal to the count of people fishing, except as noted below. An estimate of annual fishing effort (by gear type) in each of the four time strata was determined by multiplying the average number gears observed during 1-hr surveys in a stratum by the total number of hours in that stratum. The values for all strata were summed to produce an annual estimate of effort. When fishers worked cooperatively to use a single gear, we recorded fishing effort in person-hours. This applied to three species: palolo polychaetes (*Palola viridis*), small newly recruited striped bristletooth surgeonfish (*Ctenochaetus striatus*), and bigeye scad ("*atule*", *Selar crumenophthalmus*). Student's t-tests were used

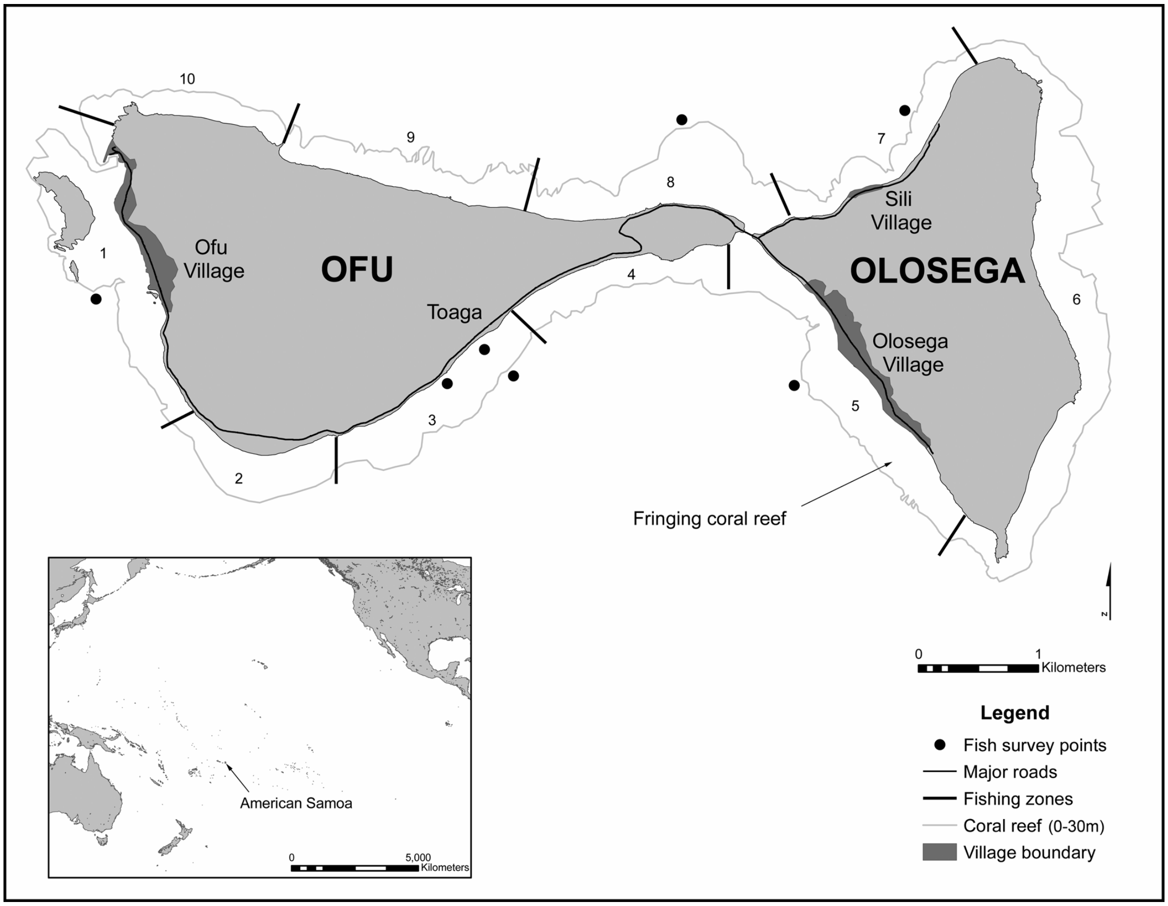

Fig. 1. Map of Ofu and Olosega islands, showing extent of coral reefs (approximately 0-30 m depth range), fish reporting sectors (1-10), fishery-independent in-water survey sites (black dots), and the archeological excavation site at Toaga on Ofu Island.

Table 1. Spatial distribution (ranked by gear frequency) of fishing effort on Ofu-Olosega islands during 472 surveys. See Figure 1 for locations.

Sector		Visible Coastline (km)	Count of gears observed (n)	%
1	Ofu Village	2.4	485	38.1
5	Olosega Village	3.1	288	22.6
8	Asaga	3.2	190	14.9
3-4	National Park	3.7	188	14.8
2	Vaoto Park	1.5	57	4.5
7	Sili Village	2.0	48	3.8
9	North Ofu	2.0	16	1.3
6	East Olosega	0	-	-
10	NW Ofu	0	-	-
		17.9	1272	100

to compare fishing effort during daytime versus nighttime hours, and during weekdays versus weekend/holidays.

2.4. Catch composition and catch per unit effort (cpue)

To determine catch composition and cpue for each gear type, we conducted creel surveys on an opportunistic basis and interviewed fishers who had been fishing at least one hour. During interviews, the number of fishers, location, time fished and catch weights were recorded (including sharks). Interviews were generally conducted in the Samoan language and Samoan names were used to identify taxa caught, consequently many fish names describe fish groups (e.g., fish families) rather than individual species. Fish were weighed by spring balances to the nearest 1 g for small fish or 100 g for large fish or groups of fish. Shellfish weights were converted to body weights using the following conversion factors: 21% for turban snails (n = 85 snails measured with and without shells), 25% for giant clams (n = 104), and 15% for sea urchins (visual estimate). Cpue for each gear type was calculated as the mean and standard error of a ratio (Cochran, 1997). For catch expansion purposes, cpue's were pooled into a single daytime stratum (i.e., weekdays and weekend/holidays combined) and, similarly, a single nighttime stratum, except day values were used in two instances where night data were lacking (boats, throw net).

2.5. Calculation of total catch

The catch in each time stratum was obtained by multiplying the average cpue per gear type by the expanded fishing effort in that stratum over a 1-yr period. The annual fish catch was calculated as the sum of catches during all time strata. Exceptions to this are that weir catches of bigeye scad and pulse catches of palolo polychaetes, newly recruited surgeonfish and newly recruited juvenile goatfish (*Mulloidichthys flavolineatus*) were calculated separately. For bigeye scad, all ten catches that occurred during the study period were monitored by our local assistants. A village typically divided each bigeye scad catch into about 60 piles of fish (one for each family). Total weight was estimated by expanding the average weight of 1-3 fish piles to the total number of piles. For palolo polychaetes, the total weight harvested was monitored during their brief period of availability (approximately a 2-hr period during each of two nights). For the other species, catch expansions were made only for the duration of their availability: surgeonfish recruits (8 days), and goatfish recruits (6 weeks).

2.6. Elder interviews

Most fishing was conducted by males, so we interviewed 20 elder males (mean age 58, range 43-72) from the three villages to gain insight on whether fishing conditions were better or worse than when they were younger, how often they fished, whether any of their catch was sold or shipped fish to family members elsewhere, the current status of other resources (palolo, bigeye scad, giant clams, turtles), amount of fishing in MPAs, and prevalence of destructive fishing practices on local reefs. Conversations were in Samoan and were freeform, after which the interviewer filled out 41 questions on the questionnaire used.

2.7. Fisheries-independent surveys

Reef fish were surveyed in March 2002 using scuba underwater visual surveys at five sites along the Ofu-Olosega reef slopes (10-m depth) and by snorkeling at two shallow sites (1.5-2 m depth) in the backreef moat along the southern shoreline of Ofu Island. At each site, 5 replicate transects (3 x 50 m) were conducted. Fish were surveyed by three sequential passes over each transect, with the first count being for large, mobile or diver-wary species, the second count was for medium-sized fish less disturbed by the diver, and the third count was for small, site-attached species. Fish size was estimated visually and later converted to biomass using standard weight (W)-length (L) relationships ($W = aL^b$) for each species; values for the constants (a, b) were obtained from FishBase (Froese and Pauley, 2003). For the purposes of our analyses, the biomass of a brief, mass recruitment event of small *Ctenochaetus striatus* was excluded from this dataset. One addition to this methodology was that, while the first pass along the 3 x 50 m transect was conducted, a wider transect (20 x 50 m) was also scanned at the same time for large species that are rare or diver wary.

2.8. Data limitations

Several sources of potential bias in this study include: (1) our use of local Samoan names for harvested fish resulted in lumping multiple species within single categories thus precluding assessments of individual species in many cases, (2) the underwater visual survey method restricted counts to only daytime active and non-cryptic species, (3) boat fishing was likely underestimated, and (4) the amount of reef fish sent to family members on other islands was estimated because the weekly supply boats were not consistently monitored. None of these limitations should greatly affect data analyses as presented.

3. Results

3.1. Fishing effort and catch rate

During 472 surveys of fishing effort, we observed 1,272 fishing gears or group fishing efforts. Our coverage of the fishery was lower at night than day (28% vs. 72% of surveys) but distributed equally over tidal conditions: 34%, 35% and 32% at high, medium and low tides, respectively. Actual number of hours surveyed compared to total annual hours in time strata were: weekdays (7.3% of 3,237 hrs in stratum), weeknights (4.6% of 2,427 hrs), weekend days (7.6% of 832 hrs) and weekend nights (6.0% of 1,016 hrs). The overall coverage was 6% of available hours. There was significantly more fishing during days than nights (3.1 vs. 2.0 gears/hr, $t = 3.98$, $P < 0.005$) and on weekends/holidays compared to weekdays (4.3 and 2.7 gears/hr, $t = 2.88$, $P < 0.005$).

Most subsistence fishing was a daily activity that was modest in scope when viewed on an hourly basis but substantial when totaled over an annual period. There were three categories of fishing effort. The first was the continuous daily fishing (except on Sundays). On average, 2.7 (± 0.15 se) villagers were observed fishing during a standardized 1-hr survey of the combined Ofu-Olosega islands, which equates to only 1 fisher per 7 km of shoreline at any one time. Nonetheless, this continued level of fishing adds up to 65 fishing hours per day or 20,282 hours per year on these small reefs.

Second, brief periods of fishing activity targeted seasonally available species. Palolo polychaetes are a Samoan delicacy that swarm late at night during one or two nights in October or November (Caspers, 1984) and are harvested with scoop nets (effort = 705 person-hours). In 2002 villagers also took advantage of large recruitment events of juvenile goatfish and striped bristletooth surgeonfish. The small goatfish (9.2 cm mean fork length, n = 58) were caught in traditional hand-woven baskets (875 person-hours), and the small surgeonfish (6.4 cm mean fork length, n = 97) were scooped up with various nets and window screening (80 person-hours).

Third, bigeye scad, a coastal pelagic carangid, were abundant in 2002 but we have treated them separately because they only occasionally occur in the study area and they are considered to be more a part of an external pelagic foodweb rather than reef-associated foodweb. Additionally, bigeye scad caught in weirs were not recorded during any of our standardized 472 surveys for fishing effort, but we did separately document all 10 harvest events that occurred during the study period. For much of 2002, large schools of these fish occupied the reef flats in front of the villages. Catching them involved a coordinated group effort as 50-100 villagers waded onto the reef flat and herded schools of the fish through a v-shaped weir (made of piled stones) into a large hand-woven mat (2,422 person-hrs).

3.2. Fishing location, gears, catch rate

Almost all fishing effort was shore-based, occurring in backreef moats, reef flats, and upper reef slopes, with only 5% of fishing occurring in deeper waters using boats. Most fishing (61%) occurred near the village sites (Table 1). The high effort in Ofu Village was due in part to the presence of a small boat harbor where villagers often fished. Only 20% of fishing effort occurred within the two Marine Protected Areas (where subsistence fishing is permitted): 15% in the National Park and 5% in Vaoto Marine Park.

Most catch and effort was made by four gears types (Fig. 2). Rod and reels caught bigeye scad, groupers, jacks and soldierfish. Spears caught parrotfish, groupers, surgeonfish, soldierfish, octopus and lobsters. Bigeye scad were caught by weir on the back reef (79%) and angling (21%). Gleaning involved hand-picking the reefs at low tide primarily for octopus, giant clams, and turban snails. Catch rates by gear type ranged from 0.7 to 4.8 kg/hour, with highest rates observed in the pulse fisheries for bigeye scad, palolo and juvenile recruits of goatfish and surgeonfish (Table 2).

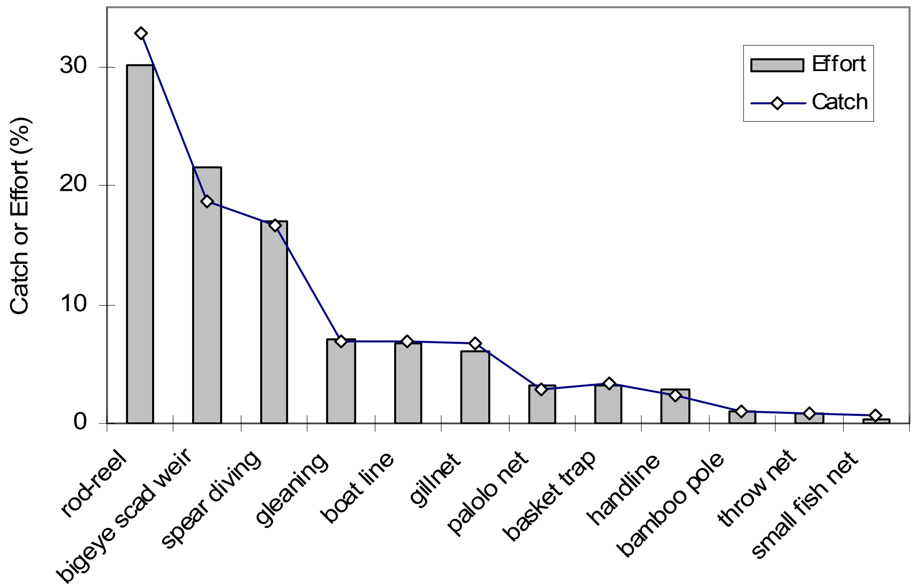

Fig. 2. Catch and effort by gear-type. Effort is presented as 'gear-hours' except as noted in text.

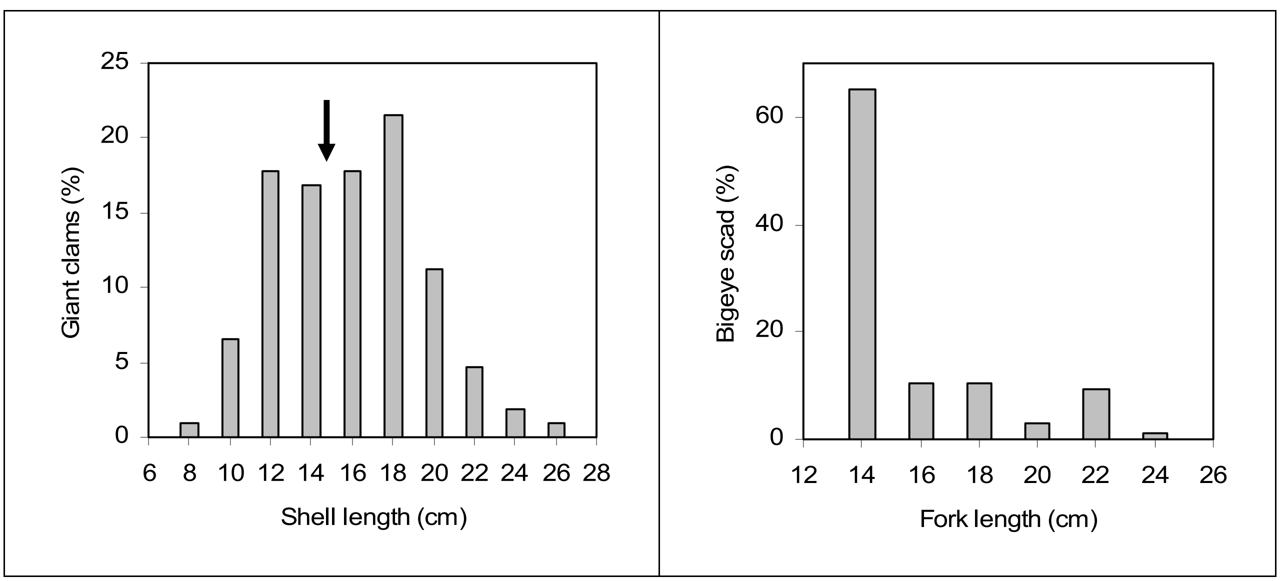

Fig. 3. Lengths of harvested giant clams (n = 107), mostly *Tridacna maxima*. The minimum legal size of 15.2 cm is indicated (arrow).

Fig. 4. Lengths of harvested bigeye scad, *Selar crumenophthalmus* (n = 95).

Table 2. Catch rates by gear type. See text for description of gear units. Abbreviations: CPUE (catch per unit effort), se (standard error).

Time	Gear	Creel interviews (n)	CPUE (kg/gear-hr)	CPUE (kg/person-hr)	(se)
Day					
	fish weir (for bigeye scad)	10		3.3	0.76
	netting (for juv. surgeonfish)[1]	4		1.8	0.92
	basket trap (for juv. goatfish)[2]	67	2.9		0.32
	gillnet	22	2.3		0.49
	rod & reel	112	1.5		0.18
	throw net	15	1.4		0.40
	free diving-spear	44	1.3		0.23
	handline	16	1.3		0.35
	gleaning[3]	63	1.2		0.13
	boat lines	15	1.1		0.27
	bamboo pole	20	0.7		0.16
Night					
	palolo polychaetes				
	-boat netting	6		4.8	0.70
	-shore-based netting	8		1.0	0.23
	free diving-spear	80	3.0		0.25
	handline	4	1.7		0.45
	bamboo pole	6	1.6		0.34
	rod & reel	81	1.2		0.14
	gillnet	4	0.9		0.23
	gleaning[3]	17	0.8		0.22

[1]Newly recruited *Ctenochaetus striatus*

[2]Newly recruited *Mulloidichthys flavolineatus*

[3]Weight without shells.

Catch composition, annual harvest, yield

We collected catch data from 594 fishers or fishing groups, who represented a combined fishing time of 4,660 hours and a catch of 4,182 kg (10% of the total harvest). The annual catch, 37.5 metric tons (82,584 lb), consisted of a diverse array of coral reef fishes and invertebrates, but bigeye scad dominated the catch (Table 3). Excluding bigeye scad, the reef-associated catch of 21.4 mt showed a more even harvest of fish and invertebrate taxa with most accounting for less than 10% of the catch. Major species taken were: parrotfish, goatfish (86% juvenile *Mulloidichthys flavolineatus*), jacks (mostly *Caranx melampygus*), groupers (mostly small honeycomb groupers, *Epinephelus merra*), snappers (46% *Lutjanus kasmira*), surgeonfish (51% *Ctenochaetus striatus*, 24% *Acanthurus lineatus*). Invertebrates (without shell weight) accounted for 17% of the annual harvest and consisted mostly of octopus (*Octopus cyanea*) and palolo polychaetes.

Most organisms harvested were small, averaging 0.2-1.2 kg (Table 3). When compared to size limits in territorial regulations, 3% of the spiny lobsters measured (n = 33, *Panulirus penicillatus*) were undersized (<8.2 cm carapace length), and 35% of the giant clams (n = 107, *Tridacna maxima*) were undersized (<15.2 cm shell length)(Fig. 3). Most of the approximately 65,000 bigeye scad caught were also small (Fig. 4), but some larger ones appeared to be sexually mature, with developing or spawned-out gonads.

The per capita harvest (including bigeye scad) was 71 kg/person (156 lb/person), but this calculation needs to account for the portion of the catch that was not consumed locally. Our observations indicated that about 20% of the catch from the bigeye scad weir and 10% of the general reef catch were sent to family members on Tutuila Island or sent as gifts to nearby Ta'u Island. Taking these into account, the per capita consumption of nearshore resources was approximately 63 kg/person or 1.2 kg per person per week. Note that this does not include consumption of occasional offshore pelagic fish or canned fish purchased at local stores. The value of the catch was approximately $206,000 (at $2.50/lb on Tutuila Island).

A reef fish yield of 2.3 mt/km^2/yr was obtained by dividing the total annual catch of reef-associated fish (21,386 kg, without bigeye scad or invertebrates) by all coral and hardbottom habitats encompassed within the 0-30 m depth zone around Ofu-Olosega (9.5 km^2; NOAA, 2005).

3.3. Historic and prehistoric perspectives

All 20 elder male villagers interviewed had been fishermen and most (80%) were still engaged in fishing activities. All felt that fishing now is similar to that when they were younger and that the current abundance of resources was generally good: fishing (85% of interviewees), palolo (100%), bigeye scad (95%), sea turtles (67%), giant clams (50%). Many sold fish to local villagers at least occasionally (60%), and all sent fish to family members on Tutuila Island at least occasionally. All mentioned that destructive fishing methods (dynamite, fish poisons) were commonly used 20-30 years ago, but none occurs now – it is prohibited by the village councils.

A previous archeological excavation in the study area at Toaga on the south coast of Ofu provided an opportunity to compare the modern harvest to prehistoric catches at the same location. In buried strata dated 1000-3000 years old, Nagaoka (1993) reported that 93% of identified bones (n = 9279) were of fish, the remainder being rats (4.1%), birds (1.5%), sea turtles (0.6%), and other (0.8%). The fish were nearly exclusively reef-associated groups as opposed to pelagic species like tuna (0.1%).

To compare modern catches (% biomass) and ancient catches (% fish bones), we excluded three items: (1) pufferfish spines from the archeological dataset to avoid over-emphasizing this taxa, (2) the small, newly recruited surgeonfish and goatfish in modern catches because their small bones would be less likely to be preserved, and (3) the modern bigeye scad catch because bigeye scad are sporadically available. The resulting comparison showed a significant similarity in catches (Fig. 5, r = 0.69, P <0.01). While a diverse assemblage of 25 fish families were represented in prehistoric and modern catches, the four most abundant fish taxa in the prehistoric site (surgeonfish, groupers, soldierfish, parrotfish) were still among the principal groups currently harvested (61% vs. 50% of catches, respectively). With the addition of jacks and snappers, the similarity rose to 70% vs. 80%, respectively. Invertebrate shells were also abundant at the archeological site -- 169 kg of shells comprised of over 50 species. Most shells (76%) consisted of turban snails (mainly *Turbo setosus*), trochus snails and giant clams, which are common in modern catches.

Table 3. Annual catch and composition of harvested fish (by family) and invertebrates (by species). Average weights of individuals within these taxa are also indicated (note that catch weights of newly recruited fish to the reef are included in the fish family categories).

Fish & invertebrates	Common name	Annual harvest (kg)	%	Catch without bigeye scad %	Fish & inverts. separately %	Avg. weight of individuals (n)	(kg)
Fish							
Carangidae	bigeye scad only	11,739	31.3		35.4	95	0.20
Mullidae	goatfish	2,898	7.7	11.2	8.7	163	0.30
Scaridae	parrotfish	2,852	7.6	11.1	8.6	639	0.58
Lutjanidae	snappers	2,609	6.9	10.1	7.9	783	0.31
Serranidae	groupers	2,605	6.9	10.1	7.9	1101	0.23
Carangidae[1]	jacks[1]	2,598	6.9	10.1	7.8	132	1.13
Acanthuridae	surgeonfish	1,926	5.1	7.5	5.8	1144	0.19
Holocentridae	soldierfish	1,758	4.7	6.8	5.3	1190	0.16
Lethrinidae	emperors	516	1.4	2.0	1.6	53	0.61
Carcharhinidae	sharks	495	1.3	1.9	1.5		
Scombridae	tuna	479	1.3	1.9	1.4		
Belonidae	needlefishes	454	1.2	1.8	1.4		
Mugilidae	mullet	418	1.1	1.6	1.3	88	0.61
Balistidae	triggerfishes	315	0.8	1.2	1.0	77	0.37
Muraenidae	moray eels	114	0.3	0.4	0.3		
Bothidae	flounder	106	0.3	0.4	0.3		
Labridae	wrasses	103	0.3	0.4	0.3		
Sphyraenidae	barracudas	89	0.2	0.3	0.3	31	0.39
Priacanthidae	bigeyes	50	0.1	0.2	0.2		
Polynemidae	threadfins	39	0.1	0.2	0.1		
Unidentified fish		963	2.6	3.7	2.9		
	Sub-totals	33,125	88.2	82.9	100		
New recruits to reef							
juvenile goatfish[2]						270	0.009
juvenile surgeonfish[3]						60	0.005
Invertebrates							
Octopus cyanea	octopus	2,192	5.8	8.5	49.7	236	1.17
Palola viridis	palolo	1,172	3.1	4.5	26.6		
Panulirus penicillatus	spiny lobster	573	1.5	2.2	13.0	186	0.47
Turbo spp.[4]	turban snail[4]	286	0.8	1.1	6.5	85	0.17
Tridacna spp.[4]	giant clam[4]	160	0.4	0.6	3.6	514	0.02
Diadema spp.[4]	sea urchin[4]	30	0.1	0.1	0.7		
	Sub-totals	4,414	11.8	17.1	100		
	Grand total	37,538	100	100			

[1]Carangids other than bigeye scad

[2]*Mulloidichthys flavolineatus* (2,517 kg total catch)

[3]*Ctenochaetus striatus* (243 kg total catch)

[4]Without shell

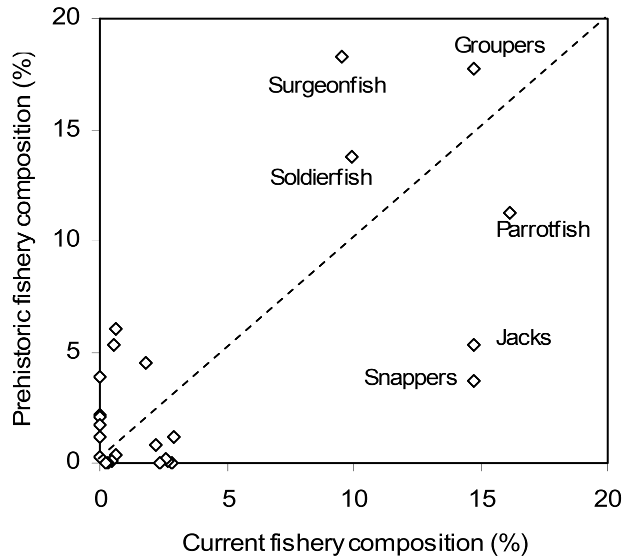

Fig. 5. Relative abundance of fish taxa in prehistoric and current harvests. The dashed line indicates equal values in both fisheries.

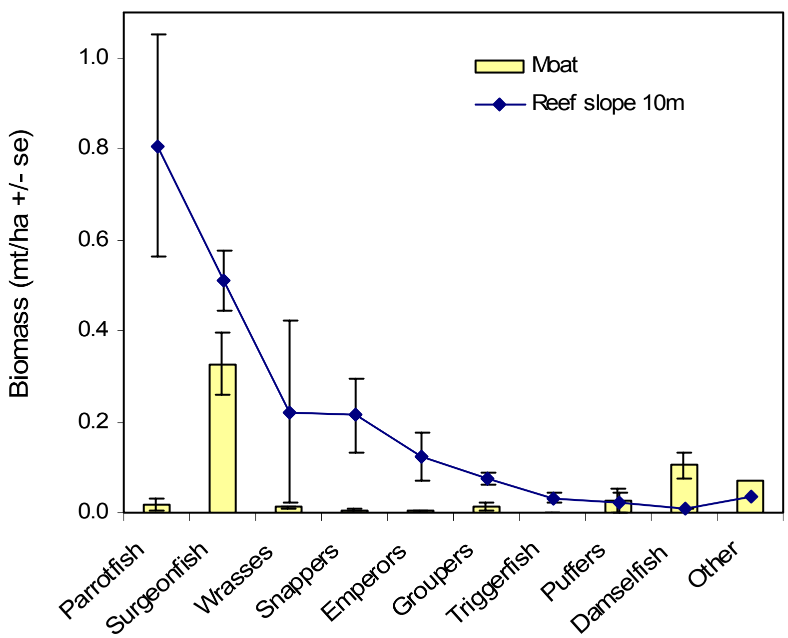

Fig. 6. Fish biomass on the reef slope (5 sites) and in a backreef moat (2 sites). Note: a single 210 cm nurse shark on the reef slope was not included in this figure.

3.4. Comparison to standing stocks of fish

Fisheries-independent surveys on the reef front at the 10-m depth documented 142 fish species with a total biomass of 2.6 mt/ha (± 0.71 se), predominantly parrotfish, surgeonfish, wrasses and snappers (Fig. 6). Fish biomass was lower in the backreef moat along the southern shoreline of Ofu (0.6 mt/ha ± 0.10 se).

Twenty-eight fish families were represented in either underwater surveys or harvest, with the dominant families shown in Fig. 7. At this taxonomic level, the harvest was correlated with fish abundance on the reef front at the 10-m depth ($r = 0.53$, $P < 0.01$) largely due to the abundances of surgeonfish and parrotfish, but it was not correlated to fish in the moat ($r = 0.25$, $P > 0.05$). Four fish taxa were targeted above their relative abundance on the reef: goatfish (mostly due to a large recruitment event of small juveniles harvested along shorelines), jacks (under-represented in scuba surveys but commonly caught by angling), and soldierfish (nocturnal fish not usually seen during daytime scuba surveys).

Conspicuously uncommon on the reef were large fish as indicated by the pooled lengths of all fish species, including sharks, sighted on the reef slope (Fig. 8). In this figure, fish <20 cm were excluded to avoid swamping the data with juveniles and naturally small species. While the sample size is not large (n = 5 sites with 25 replicate transects), the scarcity of large fish was equally pronounced in Green's (2002) larger dataset for Tutuila Island (Fig. 8). Green's combined data for Tutuila, Ofu and Olosega islands represent widespread coverage of the territory (22 reef slope sites, 76 replicate transects, and 25,485 fish observed), but only two fish >80 cm were seen on transect. Few large fish were seen in the larger 20 x 50 m transects: a single large humphead wrasse (150 cm) at Ofu and three large fish (60, 60, 70 cm) at Tutuila.

4. Discussion

4.1. The fishery

Several authors have provided comprehensive characterizations of subsistence fisheries in the Pacific islands (Dalzell et al., 1996; Ruddle, 1996), and their descriptions capture many aspects of the present study as well. The Ofu-Olosega fishery was small-scale (37.5 mt) and essentially unregulated. It contributed importantly to the diets of villagers -- the per capita catch was 71 kg/person of which 63 kg/person was consumed and the remainder was shipped to family members on the main island of Tutuila. There were no full-time fishermen. Fishing was a low but steady activity throughout the year with additional effort for seasonally available species. It was predominantly a shoreline fishery with occasional use of boats. Fishing gears used and species caught were diverse. Catch rates (0.7-4.8 kg/gear-hr) were similar to that reported in the literature, and the fish yield (2.3 mt/km^2/yr) was on the lower end of published records (Dalzell et al., 1996; Kuster et al., 2005). Even in these somewhat remote islands, the nature of the fishery has shifted from 'subsistence' to include the local sale of some fish or shipping some fish off-island. And as more employment opportunities have become locally available, the fishery even seems to be shifting from a subsistence necessity to a recreational activity. Store-bought foods are also available, which contributes to less reliance on fishing.

One interesting finding was how a seemingly casual but persistent level of fishing can exert a substantial pressure on nearshore fish and invertebrate resources. Although only 2.7 fishermen on average were observed fishing, this continued level of fishing adds up to 20,282 hours per year on these small reefs. One way to visualize this steady pressure is that it equates to one person fishing continuously day and night for 1.6 months along each kilometer of shoreline. The average removal of fish (excluding bigeye scad) and invertebrates was 1,400 kg per kilometer of shoreline (5,000 pounds/mile), so it is expected that the fishery has an effect on the composition and abundance of nearshore species.

The catch of bigeye scad was a major event in 2002, contributing almost one third of the harvest. There is little local knowledge about this species other than it is a coastal pelagic carangid whose presence is sporadic. Bigeye scad were not present in Ofu-Olosega for several years prior to, or after, 2002 (A. Malae, pers. comm.). When they do appear, they are vulnerable to fishing because they spend the daytime schooled-up in shallow waters on the reef flat. Villagers believe this is a gift to be taken while it lasts (and with refrigeration, it is now possible to take essentially all of them). We do not know whether bigeye scad were harvested as a 'windfall event' above and beyond regular harvest of reef fish, or whether catches of reef fish were correspondingly lower in 2002. Although this species is fast-growing and short-lived (Dalzell and Penaflor, 1989; Weng and Sibert, 2000), the population impact of this local fishing mortality is not known.

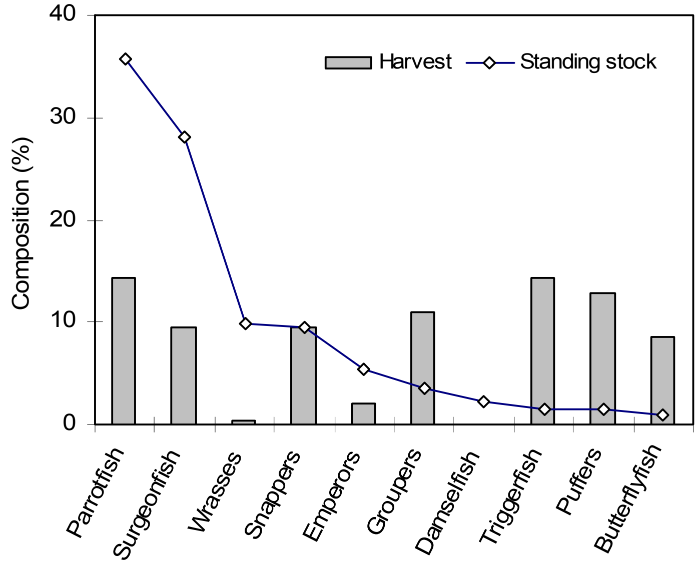

Fig. 7. Biomass comparison between fish abundance and harvest for the 10 most abundant fish families (excluding bigeye scad).

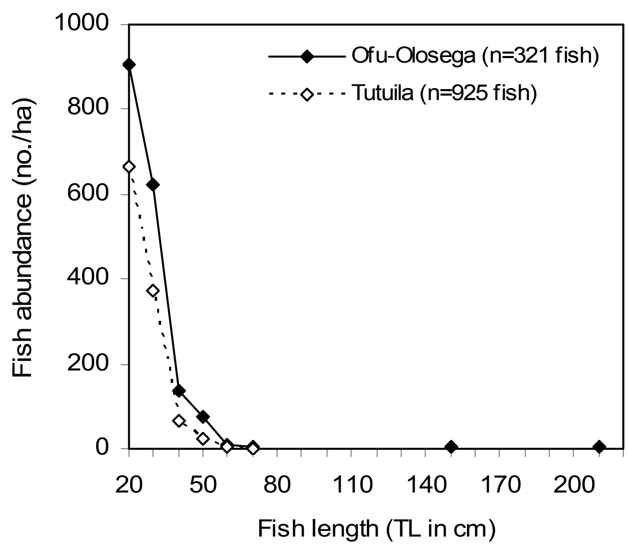

Fig. 8. Abundance by size class of large fish and sharks (>19 cm), species combined, on reef slopes in Ofu-Olosega and Tutuila, 2002.

Two other local management issues are giant clams and sea turtles. Green and Craig (1999) reported that giant clams have been heavily exploited in the Samoan archipelago. They are a delicacy, collected at almost any size encountered (35% were smaller than legally permitted) and there appear to be areas of local depletion. Hawksbill and green sea turtles occur in American Samoa in low numbers and they are listed as endangered or threatened species (Tuato'o-Bartley et al., 1993; NMFS and USFWS, 1998). Although only an occasional hawksbill turtle nests on local beaches, its eggs are still prized.

4.2. Sustainability

We evaluated the sustainability of subsistence fishery in Ofu-Olosega from several angles:

4.2.1. Comparison with historic and prehistoric catches

The clearest indication that the subsistence fishery in Ofu-Olosega has been harvested at a sustainable level is the similarity of current harvests to those in historic and prehistoric periods. Most village elders interviewed (85%) felt that fishing now was similar to when they were younger. This is in contrast to a similar survey conducted on Tutuila Island, where 70% of villagers felt that fishing had declined (Tuilagi and Green, 1995). For the prehistoric comparison, archeological data also indicate that the kinds of fish harvested 1000-3000 years ago (Nagaoka, 1993) were generally similar to those caught today. This supports the Dalzell's (1998) hypothesis that the early Polynesians that settled the South Pacific probably did not seriously impact the abundance or structure of reef fish communities because few fish species are restricted to shallow waters where most fishing occurs; however Dalzell notes that sedentary invertebrates may well have been depleted.

4.2.2. Harvest yield (fish catch per area)

The estimate of reef fish yield in Ofu-Olosega (2.3 mt/km^2/yr, excluding bigeye scad) is somewhat low compared to the range of Pacific island yields listed by Dalzell and Adams (1997): range 0.3-64 mt/km^2/yr, mean 7.7 mt/km^2/yr, n=46. Dalzell and Adams suggested that a range of 10-20 mt/km^2/year is potentially sustainable for the South Pacific region. Other more recent estimates of fish yield are similar to that reported in this study: 2.9-3.7 mt/km^2/yr in Fiji (Kuster et al., 2005) and 0.8 mt/km^2/yr in Hawaii (Friedlander and Parrish, 1997). Our estimate is, however, far lower than the value often cited in the literature for American Samoa 27 years ago (Wass, 1980): mean 26.6 mt/km^2/yr, range 15-44 mt/km^2/yr on Tutuila Island. The high end of this range is one of the highest yields reported in tropical waters worldwide, but this discrepancy with our results is largely based on differences in the definition used to describe the extent of marine area (i.e., depth zone) that supports the fishery. We chose the 0-30 m depth range, as is commonly done, because it is presumed that some fish harvested in shallow waters are recruited from populations deeper on the reef slope. Wass (1980) selected a smaller, shallower area restricted to where most fishing actually occurred (0-8 m), so his method would automatically calculate higher yields. However, for just this reason, Wass also provided a yield estimate of 4.7 mt/km^2/yr based on a deeper depth zone (0-37 m). That latter value is much closer to the present study, especially when it is noted that Wass included invertebrates and pelagic bigeye scad in his calculations whereas our Ofu-Olosega yield estimates do not.

Although a yield of 10-20 mt/km^2/yr has been presented as a theoretical potential for sustainable harvests in Pacific islands (Russ, 1991; Dalzell and Adams, 1997), we caution that it is still premature for managers to use this estimate as a yardstick to evaluate local harvest rates. Estimates of fish yield are readily susceptible to changes of 100% depending on the various ways researchers have defined their "catch per area", such as variations in the definition of "catch" (reef-associated fish only, or including invertebrates and coastal pelagic fish) and "area" (the area actually fished, or including adjacent waters to an arbitrary depth; and, including all habitats within a depth zone or coral reef habitats only). Also, most estimates of yield have been one-time calculations so it is not possible to assess whether they represent a sustainable harvest rate. It also seems reasonable to presume that, based on geographic, geomorphic, historic and other differences, the theoretical range of 10-20 mt/km^2/yr would not, of course, apply equally to all reefs. For reasons such as these, Adams et al. (1999) commented that "despite all the plans and guidelines for fisheries to be exploited 'sustainably', the current lack of knowledge about Pacific island marine resources is so profound that we have little idea what level of exploitation is actually 'sustainable', and under what conditions, for the vast majority of fisheries".

4.2.3. Harvest rate of standing stocks

The biomass of fish was low in the backreef moat (0.6 mt/ha) but higher on Ofu-Olosega reef slopes at the 10-m depth (2.6 mt/ha). These in-water estimates of fish abundance allow the calculation of the harvest as a percentage of the standing stock, but it is important to acknowledge several data limitations in this comparison: the sample size of our in-water surveys was small (n=7 sites, each with 5 replicate transects), only two depths were surveyed (2 and 10 m), and underwater visual surveys record only a portion of the fish fauna present (i.e., the diurnal, non-cryptic species). With these limitations in mind, the mean standing stock of reef-associated fish at the seven sites was 2.0 mt/ha and the extent of coral and hardbottom substrates around the islands in the 0-30 m depth zone was 9.5 km^2 (NOAA, 2005), thus the biomass of fish around Ofu-Olosega amounted to 1,900 mt of fish. The harvest of reef-associated fish (21.3 mt) was 1.1% of the standing stock. Brainard (in press) also surveyed fish biomass around Ofu-Olosega in 2002, 2004 and 2006, and obtained a mean biomass of 0.8 mt/ha. Although this was one third of our estimate, it would amount to a harvest rate of 2.8%. These low percentages support the view that the current harvest rate is low, although the fate of individual species in this fishery could be masked by analyzing data only to the level of species groups, as is commonly done in multispecies tropical studies.

4.2.4. Fish size

The fish caught were generally small, and few large fish were detected in nearshore waters on the reef slope. Regarding the first point, the small size of fish caught probably reflects that the juveniles of some species inhabit shallow waters and some fish caught there are naturally small (e.g., the commonly caught grouper *Epinephelus merra* grows only to 25 cm). Additionally, the brief harvests of palolo polychaetes and mass recruitment events of small, newly recruited surgeonfish and goatfish are not of concern here due to their extraordinary but temporary abundance and presumed high rate of natural mortality (Doherty et al., 2004). In other cases such as sessile giant clams, fishing pressure has probably reduced their size and abundance in shallow waters. However, the scarcity of large fish on the reef slope is at odds with the previous evidence that fishing pressure is low. Itano and Buckley (1988) surveyed these islands qualitatively 20 years ago and noted that "The presence of large, relatively unwary reef fish on the outer reef slope and relatively high densities of *Tridacna maxima* [giant clams] is evidence that these areas are seldom fished or visited by divers." In contrast, our surveys in 2002 documented few fish or sharks larger than 50 cm. We acknowledge that our relatively narrow dimensions used in our underwater surveys (3 x 50 m) would underestimate the abundance of large, diver-wary fish and sharks, but their near-absence points to fishing pressure. We think the underlying issue here is the small size of these reefs -- a fishing boat can circumnavigate both islands in only one hour, so intermittent fishing by boats might easily crop the larger fish. Alternatively, fishing pressure has caused surviving large fish to reside in deeper waters. In either case, a reduction in large fish can significantly impact the spawning capacity of coral reef fish populations (e.g., Palumbi, 2004; Birkeland and Dayton, 2006).

4.2.5. Comparison to other central Pacific islands

A final assessment of fishing pressure is to compare the biomass of fish on Ofu-Olosega reefs with those at other central Pacific islands. For this comparison, we selected published studies that documented all daytime-active, non-cryptic fish and shark families at 12 remote and relatively pristine or "lightly fished" islands and 12 "fished" islands from Hawaii, New Caledonia, American Samoa and the Line Islands (Fig. 9). Two of the fished islands were sampled in two different studies. The average biomass at the remote "lightly fished" islands was 3.0 mt/ha, a high value due to an abundance of large fish and apex predators (Friedlander and DeMartini, 2002; Stevenson et al. 2007). Fished reefs in the region had only one third the biomass (average 1.1 mt/ha). Ofu-Olosega scored midway in this comparison: 2.6 mt/ha in our survey, and a mean of 0.8 mt/ha in surveys by Brainard (in press). This indicates that the general biomass of fish there was moderate but affected by the low abundance of large fish. However, Ofu-Olosega scored considerably higher than the more heavily fished reefs on nearby Tutuila Island (0.9 mt/ha in this study, mean of 0.5 mt/ha in surveys by Brainard (in press)(Fig. 9). Reasons for the discrepancy between our data and those of Brainard (in press) are not known, except to note that the sighting of a single 210 cm nurse shark in our survey increased our biomass estimate by 26%.

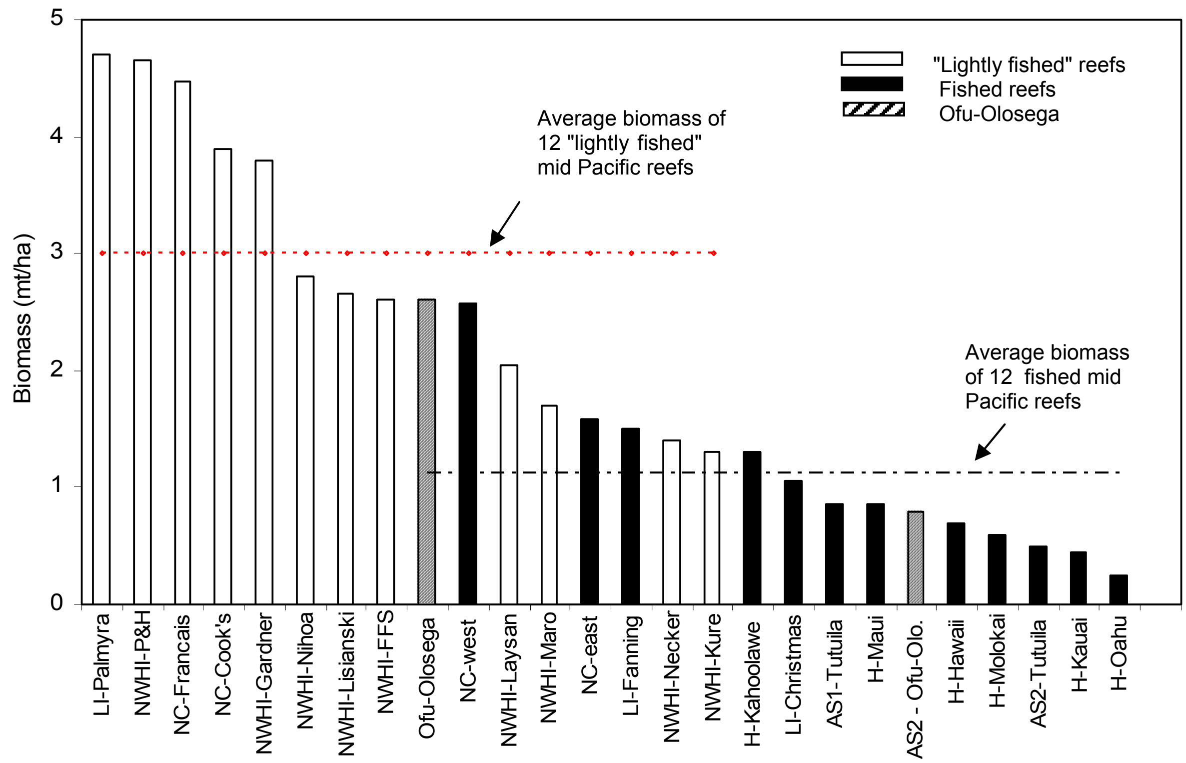

Fig. 9. Biomass of coral reef fishes on reef slopes at selected mid Pacific islands. Data sources: NWHI – Northwest Hawaiian Is. and H – Hawaiian Is. (Friedlander and DeMartini, 2002; A. Friedlander, pers. com.), LI – Line Is. (Stevenson et al., 2007), NC – New Caledonia (Letourneur et al., 2000), AS1 – American Samoa (Green 2002, with recalculated weights using the weight-length relationship $W = aL^b$), AS2 – American Samoa (Brainard, in press).

4.2.6. Summary

A variety of measures indicate that the subsistence fishery at Ofu-Olosega has been sustainable over the millennia. This situation is currently facilitated by the declining human population on these outer islands and the increasing socioeconomic opportunities for the islanders which translates into less reliance on fishing. At the same time, the fishery has not been without impact to the coral reef ecosystem, at least in modern times. A considerable biomass of fish and invertebrates is extracted from these small reefs (1,400 kg/km of shoreline), and the current scarcity of large fish and sharks in nearshore waters is a common indicator of fishing pressure.

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