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# Trends in Reef Fish Population and Associated Fishery after Three Millennia of Resource Utilization and a Century of Socio-Economic Changes in American Samoa

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*A series of social and economic changes in American Samoa brought about by westernization from United States occupation has resulted in an interesting interaction between the fishery and coral reef fish populations. Analysis of data from an extensive database and review of technical reports rarely accessed by the public yield a unique temporal pattern showing a significant decline in shoreline fishing effort and a non-significant decrease in boat-based effort, resulting in constant catch landings and catch-per-unit effort. Concurrent with the decline in fishing effort and constant catch landing was an increase in fish abundance and biomass for the targeted families. This fishing pressure release and recovery of the fish stock occurs in a period of rapid population growth, indicating non-dependence of the general population on fishing, reflecting the change in the social and economic dynamics within the territory. On a historical context, Samoans had relied and utilized marine resources for thousands of years. However, analysis showed present fish community composition, and catches showed significant similarity with prehistoric catches dating from 1000–3000 years ago, indicating that the marine resources were possibly utilized in a sustainable manner, and the recent socio-economic changes allowed recovery from prehistoric utilization.*

**Keywords** boat-based fishery, shoreline fishery, reef fish abundance, population density, fishing effort, catch landing

## 1. INTRODUCTION

Management of coral reef fisheries is difficult due to the complex nature of the ecosystem, the diversity of the fishery, and the nature of the culture utilizing the resource. Coral reef fisheries are usually multi-species fisheries with varying degrees of target preference, gear usage, and habitat utilization (i.e., reef flat, reef slope, and outer banks). These parameters are confounded with the complexity of reef fish populations, where each are characterized by varying niche, life-history strategy, habitat preference, and fish behavior. It is logistically impossible to manage coral reef fisheries using a management unit species approach since gathering biological data to model the population of a single

species takes a great deal of time and effort, which increases exponentially, given that there are often hundreds of species to manage. In order to understand the fishery and formulate an ecologically sound management strategy, a multidisciplinary approach should be considered, incorporating all factors that affect the fishery and fish populations. An ecosystem-based approach was proposed to manage multispecies assemblage by looking at trophic assignments (Hawhee, 2006), population metrics (Ault et al., 1998), community structure metrics and length-based statistics (Ault et al., 2005, 2006), and groups with similar life-history strategies (Lindeman et al., 2000).

The American Samoa archipelago is a small, isolated island system separated by deep ocean basins. American Samoa lies approximately 14°20' S and 170°44' W (Figure 1) and is comprised of one true coral atoll (Rose Atoll), one low island (Swains Island), and five small volcanic islands, with the largest of these, Tutuila, having a land area of only 142 km<sup>2</sup>. The volcanic

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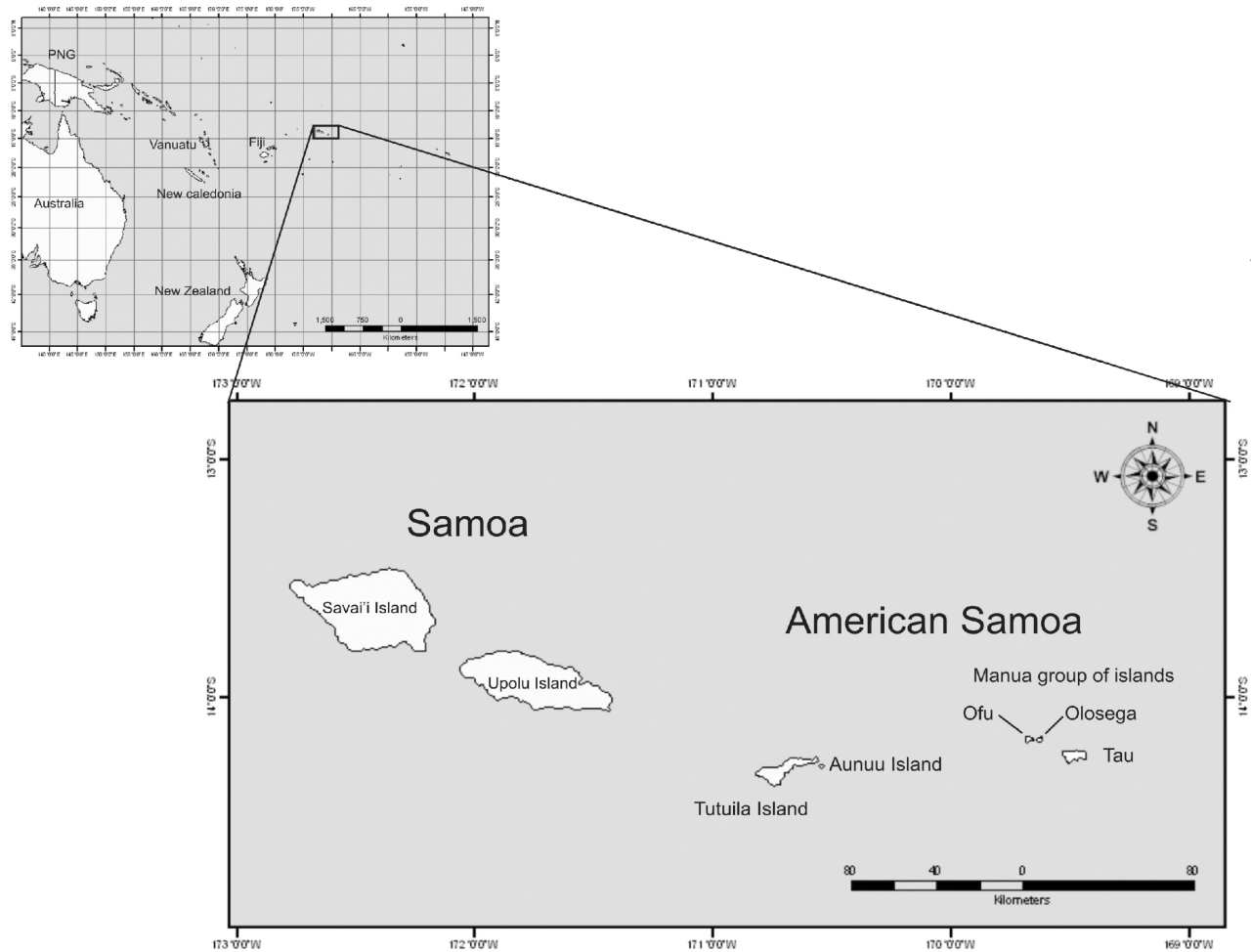


**Figure 1** Location map of Samoa.

islands of American Samoa generally have highly eroded slopes and limited flat land areas suitable for human habitation. The coral reefs surrounding the islands are limited in their development, characterized by narrow reef flats, and are often patchy and separated by volcanic pavements. Reef slopes are generally less steep on the south side than the north, except at the area of Larsen and Fagatele Bay, where the reef slope descends directly and steeply to the insular shelf. More developed coral reef areas dominate the south shore of Tutuila, while the north shore is dominated by volcanic pavements colonized with encrusting corals (NOAA NCCOS, 2005). The total coral reef area for Tutuila is estimated to be approximately 315 km<sup>2</sup> along the 100-m isobath (Brainard et al., 2008). The degree of isolation of the Samoan archipelago renders it to be largely self-seeding based on 30-day drogue data simulating a passive pelagic larval phase of coral reef fishes (Brainard et al., 2008). With the potential lack of outside sources of recruits for recovery, as well as the relatively limited area of coral reef habitat, the coral reef ecosystem is vulnerable to degradation brought about by rapid urbanization along the coast and over-exploitation due to a steep increase in human population growth.

The near-shore resources of American Samoa have been utilized for several millennia, ever since Polynesians have occupied the islands. Fishing in the shallow lagoon areas has been a daily activity for Pacific islanders using various fishing methods (Dalzell et al., 1996; Herdrich and Armstrong, 2008). The fishery resources have commonly been reported as over-exploited due to a rarity of apex and large fish species based on fishery-independent surveys such as underwater surveys (Green, 1996, 2002; Green et al., 2005; Craig and Green, 2005; Craig et al., 2005), reconstruction models (Zeller et al., 2006), ecological footprints (Newton et al., 2007), and qualitative observations (Tuilagi and Green, 1995). Introduction of SCUBA spearfishing in 1994, where the majority of fishermen were Tongans and Western Samoans (based on DMWR fishing permits issued), was believed to have greatly impacted the fish population and significantly reduced the large fish stocks (Page, 1998; Green, 2003). In contrast, 30 years of fisheries-dependent time-series data shows a different pattern, whereby the fishery has experienced varying levels of shifts and a general decrease in fishing pressure (Ponwith, 1991; McConnaughey, 1993; Saucerman, 1995a; Coutures, 2003; Brookins, 2006; Sabater, 2007).

Generalizations from simple indices about sustainability of coral reef fishery from a single variable (i.e., biomass, abundance, catch, CPUE, effort or population density alone) could be misleading without understanding the effect of social, cultural, economic, and ecological issues on these parameters in a particular area. There have been no previous attempts to merge the two independent data sets in order to objectively assess the status of the coral reef fish population and how it is affected by the fishery. The aim of this review is to provide an initial analysis of all available data from fishery-dependent and independent surveys, and to also examine historical, archaeological archives, and socio-economic surveys of the American Samoa population to provide a holistic and multidisciplinary approach in assessing the status of the reef fish population and coral reef fishery.

## 2. *CURRENT PERSPECTIVES ON FACTORS AFFECTING CORAL REEF FISH POPULATION AND FISHERY IN AMERICAN SAMOA*

Substitution of spatial data in the absence of a decent time-series baseline was done by Friedlander and DeMartini (2002), where a comparison of biomass and abundance was conducted between pristine and impacted coral reef areas. This spatial comparison has been used widely in a data-limited situation. This strategy was used by NOAA Pacific Island Fishery Science Center-Coral Reef Ecosystem Division (PIFSC-CRED) to analyze patterns in their Rapid Ecological Assessment (REA) surveys conducted every two years since 2002 at various Pacific island territories under the United States. Their REA surveys are comprised of several underwater survey techniques looking at various metrics of the reef fish community at different spatial scales (Brainard et al., 2008). Results highlighted spatial comparison in biomass and abundance of reef fishes from the different islands of American Samoa, where the lowest biomass was found in heavily populated high islands and the highest biomass found at low island (Swains) and atoll (Rose), which has few to no inhabitants. This inverse relationship between fish biomass and human population density is a common trend reported in other areas (Knowlton and Jackson, 2008), but often neglected is the fact that fishing effects are confounded by other ecological (natural habitat variations, limited juvenile fish habitats) and biological (variations in life histories, both natural and learned behavioral differences) factors influencing patterns in fish population metrics being measured (Link, 2002).

Numerous natural factors have also caused habitat degradation on the reefs of American Samoa, such as crown-of-thorns (COTs) outbreaks (Birkeland et al., 1987, 1994, 1996, 2004), hurricanes (Birkeland et al., 1996, 2004), and coral bleaching, but currently there are signs of gradual recovery (Green, 2002; Birkeland et al., 2004; Craig et al., 2005). Impacts of larger scale disturbances, like increased sea surface temperature brought about by global warming and extreme low tide events timed with low water circulation and wind movement, are poorly documented. On the other hand, local anthropogenic impacts due

to utilization of coral reef resources and land-based sources of impacts have been documented through three decades of fishery-dependent monitoring and targeted research. Upland development causes high sedimentation at nearby coral reef areas flowing through the streams. Fish habitat degradation through sedimentation was first raised by Saucerman (1995a, 1995b) as a possible cause of low fish catch in Tutuila. Closer scrutiny of the impacts of sedimentation was not done until 2005, when insignificant amounts of sediments were shown to reach the reef slope despite high sediment influx coming from the streams (Fenner et al., 2008). The sediments are either carried directly to greater depths (to the sand flat areas beyond the reef slope) through channels across the mouth of the stream or are spreading and settling on reef flats. This is the subject of ongoing investigations.

Rapid increase in human population density was identified as a major problem potentially impacting resources and the coral reef ecosystem of American Samoa (Craig, 1995; Governor's Task Force on Population Growth, 2000). It was assumed that this increase in human population caused over-exploitation of marine resources and degradation of coastal habitats. This assumption was used by Zeller et al. (2006, 2007) to project catch decline from a 50-year reconstruction of the fishery, concluding that the territory's fishery resources are currently overfished. Analysis of the ecological footprint of 49 island countries showed 55% of coral reef fisheries are unsustainable, nine of which (including American Samoa) are in a collapsed state (Newton et al., 2007). Spatial comparisons of abundance and biomass of reef fishes between the main island of Tutuila (where most of the population resides) and the rest of the island group (least populated) showed Tutuila having the least dense fish assemblage and lowest biomass (Brainard et al., 2008). This pattern was attributed to fishing pressure, high population density, coastal development, pollution, sedimentation in islands that have high population density. The relationship between population and status of the territory's marine resources was not quantitatively addressed until now.

Information from unpublished reports and unanalyzed data are presented and consolidated to determine the status of the coral reef fish population and coral reef fishery. Included are a series of analyses of various data from different studies and monitoring efforts presenting a new perspective to current views on the status of reef fish communities and reef-associated fishery in American Samoa. This will aid in identifying research priorities, directions, and formulation of management strategies.

## 3. *SUMMARY OF METHODS*

### 3.1. *Data Sources*

Table 1 shows the summary of the data and the sources it was derived from that were used in the analysis of fish populations, coral reef fishery, and sociological changes over three decades of monitoring in American Samoa. Quantitative assessment of

**Table 1** Summary of data and sources used in determining historical trend in fish population and coral reef fishery from monitoring in American Samoa. Ancillary data from specific studies and census data were used as co-variables in analyzing the temporal trends

| Data category                                           | Study                                                | Survey year   | Study details                                                                                                                                        |
|---------------------------------------------------------|------------------------------------------------------|---------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| Underwater visual census                                | Wass (1982)                                          | 1977–1979     | Belt transects (200 m <sup>2</sup> ) at 63 sites around Tutuila and offshore banks                                                                   |
|                                                         | Birkeland et al. (1996)                              | 1977–1995     | Belt transects (200 m <sup>2</sup> ) at 3 sites around Tutuila                                                                                       |
|                                                         | Green (1996)                                         | 1996          | Belt transects (150 m <sup>2</sup> ) at 18 sites in Tutuila and Manua                                                                                |
|                                                         | Green (2002)                                         | 2002          | Belt transects (150 m <sup>2</sup> ) at 18 sites in Tutuila and Manua                                                                                |
|                                                         | Birkeland et al. (2004)                              | 1985–2001     | Belt transects (200 m <sup>2</sup> ) at 3 sites around Tutuila                                                                                       |
|                                                         | Green et al. (2005)                                  | 1977–2004     | Belt transects ( m <sup>2</sup> ) at 3 sites around Tutuila                                                                                          |
|                                                         | Sabater and Tofaeono (2005)                          | 2005          | Belt transects (150 m <sup>2</sup> ) at 24 sites around Tutuila                                                                                      |
|                                                         | Sabater and Tofaeono (2006)                          | 2006          | Belt transects (150 m <sup>2</sup> ) at 24 sites around Tutuila                                                                                      |
| Fishery statistics                                      | Western Pacific Fishery Information Network database | 1984–present  | Boat-based data from intercept interview at the main docks; shore-based data from roving catch and effort data collection; done in Tutuila and Manua |
|                                                         | Wass (1980)                                          | 1977–1979     | Shore-based data from roving catch and effort data collection; done in Tutuila                                                                       |
|                                                         | Ponwith (1991)                                       | 1990          | Shore-based data from roving catch and effort data collection; done in Tutuila                                                                       |
|                                                         | McConnaughey (1993)                                  | 1992          | Shore-based data from roving catch and effort data collection; done in Tutuila                                                                       |
|                                                         | Saucerman (1995)                                     | 1991–1994     | Shore-based data from roving catch and effort data collection; done in Tutuila                                                                       |
|                                                         | Page (1998)                                          | 1996–1998     | Markey survey; done in Tutuila                                                                                                                       |
|                                                         | Coutures (2003)                                      | 2002          | Shore-based data from roving catch and effort data collection; done in Tutuila                                                                       |
|                                                         | Craig et al. (2008)                                  | 2002          | Shore-based data from roving catch and effort data collection; done in Manua                                                                         |
| Prehistoric archaeological data on fish bone assemblage | Nagaoka (1993)                                       | 1987 and 1989 | Data gather via dry screening of the earth layer in Toaga in Ofu island, American Samoa; specimen was counted and identified to fish family level    |
| Sociological information                                | Kilarski et al. (2006)                               | 2006          | Household interview of 425 individuals                                                                                                               |
| Human demographic data                                  | U.S. Census Bureau (1990)                            | 1981–1990     | Population census and household interview                                                                                                            |
|                                                         | U.S. Census Bureau (2000)                            | 1991–2000     | Population census and household interview                                                                                                            |
|                                                         | American Samoa Statistical Yearbook (2006)           | 1900–2000     | Population census and household interview                                                                                                            |

coral reef fishes in American Samoa began as early as 1977, when Wass (1982) conducted a study on the community structure of reef fishes at 63 sites around Tutuila. Since that time, several fishery-independent surveys using underwater visual census (UVC) techniques have been conducted by various local agencies and visiting researchers (Birkeland et al., 1987, 1994, 1996, 2003, 2004; Green, 1996, 2002). PIFSC-CRED began their bi-annual surveys around all islands of American Samoa in 2002. In 2005, annual monitoring of reef fish populations began under the Territorial Monitoring Program (TMP) (Whylen and Fenner, 2005) and the Key Reef Species Program (Sabater and Tofaeono, 2005, 2006, 2007) of the Department of Marine and Wildlife Resources (DMWR). Of these, as well as other studies that employed UVC, belt transects were predominantly used to document diurnal non-cryptic fish assemblages, although transect dimensions varied in length and width. Some programs targeted specific assemblages while others were more inclusive. For example, the TMP focuses on all diurnal reef fishes, while ignoring nocturnal and cryptic species; Page (1998) focused on parrotfishes; and the Key Reef Species Program monitors

only fish species that are targeted as a food source in American Samoa. Also, while some programs examined temporal trends in fish abundance and biomass (Green, 2002; Green et al., 2005; Brainard et al., 2008), others focused on spatial patterns (Wass, 1982; Green, 1996; Sabater and Tofaeono, 2006, 2007; Brainard et al., 2008).

Fishery-dependent monitoring documenting catch and effort from boat-based and shoreline fisheries has been conducted by DMWR. Monitoring of the shoreline fishery began in 1977 (Wass 1980, 1984) and was monitored intermittently from 1990 to 1996 (Ponwith, 1991; McConnaughey, 1993; Saucerman, 1995a, 1995b). More regular and structured data collection started in 2000 (Coutures, 2003) and has continued until the present. The shoreline coral reef fishery includes the following methods: rod and reel, thrownets, gleaning, bamboo role, gill nets, and spearfishing. Shoreline fishery documentation method involves roadside surveys that record participation (effort) on the first outward run and then catch interviews on the return run. The area covered by the survey varied over the years, expanding from the central section of the island to the outer villages as

roads developed. There has been a good estimate of effort since it was easy to detect fishermen from the shore and determine what fishing gear they were using. However, catch data has only been sparse, as very few interviews have been conducted due to low participation in the fishery. Thus, only effort data (expressed in annual fisher hours) were used for the temporal trend analysis in this review. Additional inshore fishery data is available from studies conducted on the island of Ofu by the National Parks Service of American Samoa (Craig et al., 2008).

The boat-based fishery is composed of the following methods: trolling, long lining, bottom fishing, spearfishing (snorkel and SCUBA, depending on the year), and mixed method of both trolling and bottom fishing. Data collected from the boat-based fishery is more extensive, with data having been collected from 1982 until the present. Data collectors monitor the main docks, where most of the fishing boats are moored, and determine if there are boats out fishing every shift. They then wait for the boats to return to port and conduct the survey. The surveys involved intercept interviews of fishermen whereby reef fishes caught are sub-sampled and recorded using local names, and their length and weight measurements taken. Fishery data from both fisheries are compiled and made available to the public through the Western Pacific Fishery Information Network (WPacFIN) database.

### 3.2. Data Analysis

The underwater visual census data used for the analysis was fish abundance of targeted families, since earlier studies did not have length estimates and therefore cannot generate a biomass value. There were some differences in the transect dimensions and number of sites between studies yielding two different transect area (150 m<sup>2</sup> and 200 m<sup>2</sup>). In order to make values comparable, all fish abundance data was converted to fish density by dividing the count estimates by its respective transect dimension and then expressed in individuals per hectare (Green et al., 2005).

Temporal analysis of the fishery-dependent data was done for both boat-based and shoreline fisheries. For the boat-based fisheries, we used bottomfish and spearfishing data only, since these are the ones potentially affecting coral reef fish stocks. The following expanded data was used for the analysis of annual catch landing (in total pounds), effort (expressed in number of trips and fisher hours), and catch-per-unit effort (CPUE; expressed in average pounds per fisher hours). The shoreline fishery trends used only the aggregate expanded effort data, since the catch data was not sufficient to draw conclusive results.

Multiple regression was used to determine significant trends over time for fish density, fishery parameters (catch landings, fishing effort, and CPUE), and human population (data from the U.S. Census Bureau, 1990, 2000). The data was square root transformed to minimize effects of extreme values. Pair-wise deletion was used to treat missing data, since the distribution of

missing cells within factors appeared random. Product-moment coefficients were compared to determine relationships between fish density, fishing parameters, and human population. Correlation analysis was used to compare trends in prehistoric catch, present fish density, present catch number and weight, and fish preference. All regression and correlation analyses were based on Sokal and Rohlf (1995) and performed using Statistica 8.0 (StatSoft Inc., 2007). Graphic representations of the data and trends were done using a two-dimension scatter plot. Fish density and catch landing data were analyzed at the family level and were standardized to a mean of zero and a standard deviation of one.

Exploratory data analysis was used to determine changes in fish community structure over time (Clarke and Warwick, 2001). The 20 dominant species listed by Wass (1982) from his 1977–1979 UVC study were used as a contemporary baseline for community structure and compared with data from Green (2002). To minimize effects of transect dimensions, absolute abundance data was standardized to its respective area. Abundance density was log-transformed to minimize the effect of extreme values and was tabulated into a species-by-site per-year matrix. Euclidean distance was used as a similarity coefficient to generate the similarity matrix from the log-transformed abundance data matrix. The similarity coefficient was plotted on a two-dimension axis using Multidimensional Scaling Analysis (MDSA) to determine similarity in species composition by year and habitat types, where closer points indicate similarity. The stress value indicates reliability of the plot to reflect true differences, where lower stress values indicate a good fit along two dimensions. An Analysis of Similarity (ANOSIM) was performed to parametrically test differences between factors (year and habitat type) influencing the distribution. Similarity of Percentage of Species Contribution (SIMPER) test was used to determine which species contribute to the similarity between factors. Changes in percentages and composition indicate shifts in community structure between years and habitats. This analysis was performed using PRIMER-E v.5.0 (Clarke and Gorley, 2001).

## 4. TEMPORAL CHANGE IN FISH POPULATION AND UTILIZATION

### 4.1. Pre-Historic, Historic, and Current Patterns of Fish Utilization

In order to understand the dynamics of the fish population in relation to the fishery, historical and cultural inputs should be considered in the interpretation of reef fish distribution patterns and temporal trends. This provides a better perspective on whether the culture had utilized their resources in a sustainable manner through traditional management and various taboo beliefs. On the other hand, this would also provide information on whether resource users had excessively utilized the resources

due to advancements in fishing technology and fish demand in the ever-growing human population. Samoans have traditionally managed and utilized a variety of fishing methods to gather marine resources (Hart, 1996). A unique opportunity to examine prehistoric patterns of utilization occurred when an archaeological dig at Toaga on the island of Ofu uncovered faunal remains from a midden site (Nagaoka, 1993). This find showed what fish assemblage was being utilized by Samoans at least 1000–3000 years ago (Kirch and Hunt, 1993). The faunal remains were dominated by fish, followed by non-fish (land vertebrates) and shellfish. The Toaga specimens were considered to be the largest archaeological fish bone assemblage in Western Polynesia. For this particular analysis, Diodontidae samples were removed due to identification bias but were also reported to be common from other midden finds (along with pufferfish) in Polynesian (Leach and Intoh, 1984; Kirch, 1988; Allen, 1992). Among the bones identified from the 1989 dig, Acanthuridae dominated the specimens recovered, followed by Serranidae, Scaridae, and Holocentridae. The 1987 dig showed Holocentridae had the most remains, followed by Acanthuridae, Serranidae, and Scaridae. Noteworthy was that a number of factors also affected the results, which includes sampling protocol, ecology, fishing techniques, social structure, and food preference.

Comparing proportional composition of reef fish families from the faunal remains (number of identified specimen, NISP), present day catch (total pounds), fish community structure (total abundance), and fish preference for food (number of respondents) provided an opportunity to determine how the pattern of reef fish utilization has changed between pre-historic and contemporary periods. Correlation analysis of percentage composition in the present fish community structure from underwater surveys by Green in Ofu (using abundance averaging between 1996 and 2002), with the percentage composition in the average NISP from the faunal remains (1987 and 1989), showed a significant positive correlation ( $r = 0.656$ ,  $t = 2.610$ ,  $p = 0.028$ ; Table 2). This indicates that the present reef fish assemblage may be similar to what was available in the fishery 1000–3000 years ago. Note that these fish families are also the dominant ones from the underwater surveys. NISP were also significantly positively correlated with the percentage composition in the present day catch landings (Craig et al., 2008), indicating simi-

larity in catch composition for the two periods despite advances in fishing technology. Recent preference interviews of Samoans showed strong preference for fishes from the family Acanthuridae, followed by Serranidae, Holocentridae, and Muraenidae (Kilarski et al., 2006). Correlations between present day preference with present reef fish abundance ( $r = 0.957$ ,  $t = 4.679$ ,  $p = 0.043$ ) showed the preference might be influenced by what was readily available in the fishery. Fish preference was also positively correlated with the NISP ( $r = 0.609$ ), indicating that this preference may have existed since prehistoric times.

The information from analyzing fishery-dependent, fishery-independent, archaeological, and socio-economic data gave a unique insight on what drives the fisheries and Samoan behavior toward the fishery. The perceived preference for fish from certain families was probably driven by what was readily available in the fishery and can be considered as arbitrary. Taking what is readily available can be viewed as non-selective (non-targeting). The similarity in catch composition between prehistoric and present times, and absence of shifts in utilization, indicates species group prevalence over the years, thus implying that Samoans may have utilized their reef fish resources in a sustainable manner.

Shift patterns in prey items (in this case, items utilized in the fishery) have been used as an indicator for changes in resource use due to unavailability of the resources brought about by over-exploitation or habitat conditions affecting the population. Analysis of shellfish archaeological specimen at Fatumafuti in Tutuila showed sustainable utilization of this resource over a period of 3000 years, based on consistency in proportion and composition from the different time strata and the patterns of habitat utilization from the results of agent-based model simulation generated for this assemblage (Morrisson and Addison, 2008). Reviews done by Dalzell (1998), looking at archaeological data from the different Polynesian areas in the Pacific, support our results that long-term subsistence fishing of reef fishes by Pacific islanders had no serious negative effect on abundance or structure of reef fish communities. Settlers of outer islands of Moturakau in the Southern Cook Islands had utilized small in-shore groupers, which were the key food source throughout the period of human settlement, resulting in minimal prey-switch patterns in the archaeofish remains (Allen, 2002). In contrast,

**Table 2** Correlation matrix of proportional contribution of the various reef fish families in the prehistoric catch, present reef fish assemblage, present catch numbers, and reef fish preference. Missing data was treated using pair-wise deletion since the missing values for each variable was randomly distributed. Significant results are in **boldface**

| % in Prehistoric composition | % in Prehistoric composition                                       |                                                                   |                                                                   |                      |
|------------------------------|--------------------------------------------------------------------|-------------------------------------------------------------------|-------------------------------------------------------------------|----------------------|
| % in Present assemblage      | $N = 11$ ; $r = 0.656$ ; $r^2 = 0.431$ ; $t = 2.610$ ; $p = 0.028$ | % in Present assemblage                                           |                                                                   |                      |
| % in Present catch numbers   | $N = 9$ ; $r = 0.844$ ; $r^2 = 0.711$ ; $t = 4.159$ ; $p = 0.004$  | $N = 9$ ; $r = 0.585$ ; $r^2 = 0.343$ ; $t = 1.910$ ; $p = 0.098$ | % in Present catch numbers                                        |                      |
| Preference interview         | $N = 6$ ; $r = 0.609$ ; $r^2 = 0.371$ ; $t = 1.536$ ; $p = 0.199$  | $N = 4$ ; $r = 0.957$ ; $r^2 = 0.916$ ; $t = 4.679$ ; $p = 0.043$ | $N = 4$ ; $r = 0.667$ ; $r^2 = 0.444$ ; $t = 1.266$ ; $p = 0.333$ | Preference interview |

the mainland site of Ureia had shown over-harvesting based on a resource-depletion model, where there was a decline in large-bodied inshore fish and increase in off-shore species, indicating prehistoric settlers fished further out to sea to get their protein source. A prey-switch pattern was seen in the archaeological data from subsistence harvest of large arc clams, where it shifted from large to small individuals and utilization of other gastropods. The shift was attributed to sea level rise and removal of mangroves that limited the habitat for arc clams, and not due to over-harvesting (Amesbury, 2007). Archaeological data have shown coral reef fishery resources have been utilized for several millennia and continued to be productive in the absence of other perturbations. Westernization of these island areas in the past centuries and effects of climate change limited the ability of the reefs to attain productivity similar to pre-colonial period. Nonetheless, archaeological data provides a deeper understanding of how different island cultures have utilized their resources and can serve as a useful guide for the interpretation of contemporary fishery and ecological data.

4.2. Variations in Fish Density Over Time

Reef fish populations in American Samoa showed a general but non-significant increase in abundance over the period of three decades (Figure 2). A significant increase, however, was seen in the family Scaridae ( $r = 0.869$ ,  $F_{(1,7)} = 21.57$ ,

$p = 0.002$ ). This general increasing trend was reported in several studies and may be attributed to recovery from various disturbances such as the large COTS outbreak in the early 1980s, hurricanes in the 1990s, and SCUBA spearfishing from 1994 to 2001 (Birkeland et al., 1994, 1996, 2003, 2004; Green et al., 1999; Green, 2002). The surveys conducted by Green (1996, 2002) on reefs at the four high islands showed 73% of the sites surveyed in 1996 had low biomass, but in 2002 only 32% resulted as low, and most had moderate fish biomass levels. Also reported was an increase in abundance and biomass for the major families of reef fishes over a period of six years. The only significant decline in abundance was from the family Pomacentridae, which was attributed to the decline in Dick’s damselfish (*Plectroglyphidodon dickii*) populations as a result of the loss of corals that the damselfish is associated with after the crown-of-thorn outbreak (Birkeland et al., 1996, 2003, 2004). Some fluctuations were also attributed to observer bias (Green et al., 2005). Short-term changes were attributed to differences in survey method used (Green et al., 1999), incidental sightings (schools of fish, particularly jacks, fusiliers, parrotfish, and surgeonfish), or recruitment pulses. On the other hand, long-term trends were more indicative of effects from factors such as impacts of historical fishing, natural disturbances (i.e., crown-of-thorn infestation, hurricanes, mass bleaching, and extreme low tide resulting in altered habitats), and habitat degradation (i.e., sedimentation and eutrophication) operating on a larger spatial and temporal scale.

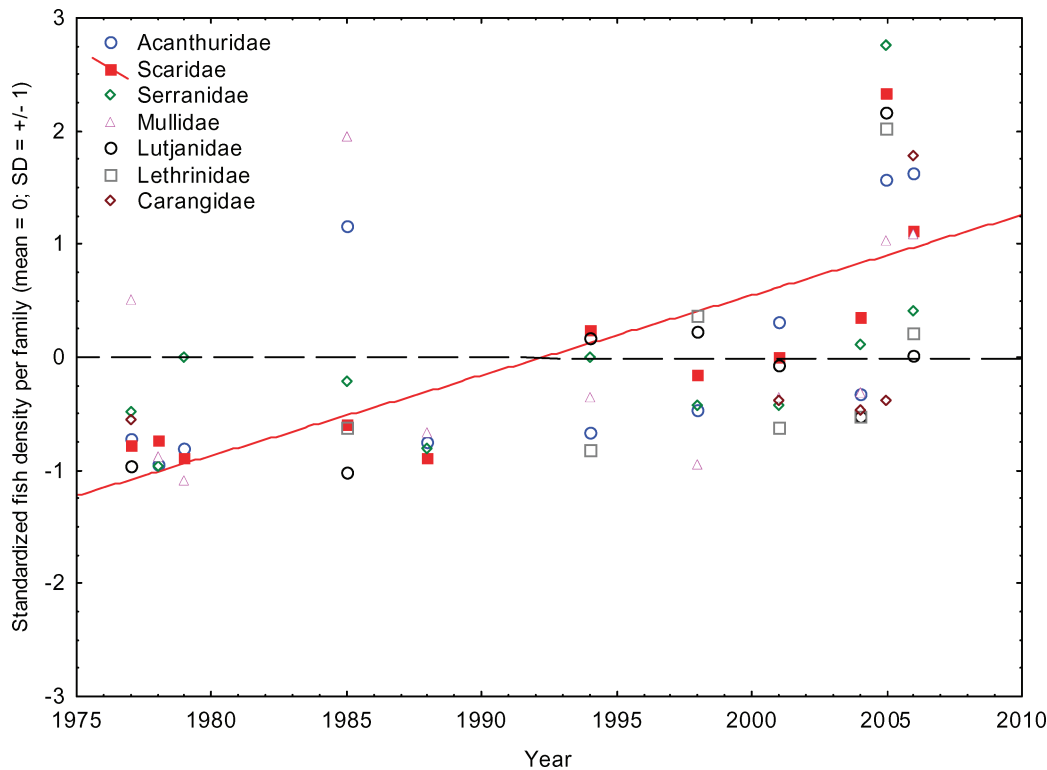


Figure 2 Fish density over time.

#### 4.3. Changes in Fish Community Structure Over Time

Earlier studies have shown a dominance of damselfish, surgeonfish, and parrotfish in the coral reef fish community for most sites around Tutuila (Wass, 1982). The bristletooth surgeon fish (*Ctenochaetus striatus*) was the single most common species found in underwater surveys (Green, 1996, 2002; Green et al., 2005; Whaylen and Fenner, 2005). This was confirmed as the most dominant species based on the index of relative dominance (Sabater and Tofaeono, 2007). Shifts in biomass dominance were seen on a family level where family Scaridae dominated biomass in the late 1970s (Wass, 1982), whereas recent data from the rapid ecological surveys by PIFSC-CRED showed Acanthuridae now dominates biomass (Brainard et al., 2008). This shift from Scaridae to Acanthuridae may be attributed to the occurrence of SCUBA spearfishing from 1994 to 2001, which targeted mostly parrotfish. However, our current analysis showed a significant increase in the parrotfish abundance over time (Figure 2), despite being heavily targeted by the SCUBA spearfishing. The SCUBA spearfishing technique increased fishing efficiency by 15 fold, leading to the removal of 35.3 mt from the standing stock estimated at 189 mt (Page, 1998). Despite increased fishing efficiency, the level of extraction was not beyond maximum sustainable yield (MSY) estimated to be at 53.9 mt. Nonetheless, DMWR banned such fishing techniques, which was considered unsustainable over longer time periods. It was also reported that the population of parrotfish had shown recovery, with an increase in biomass in 2002 from 1996 levels ever since the ban was put in place (Green, 2002; Green et al., 2005).

Multidimensional scaling analysis was used to graphically show changes in fish community structure between factors (years and habitat types). The stress value was 0.11, indicating that the distances between points were a good measure of actual dissimilarity (Clarke and Warwick, 2001). There was no significant change in the community structure of the dominant species between 1977 and 2002 (ANOSIM<sub>year</sub>: Global-R<sub>value</sub> = 0.111,  $p = 0.500$ ; Figure 3). A minor shift in species dominance occurred between these years when *Plectroglyphidodon dickii* became less dominant and parrotfishes were more represented in recent years (*Chlorurus japanensis*, *C. sordidus*, and *Scarus psittacus*). Results indicate minimal change in the community structure in terms of abundance of the dominant species despite natural and anthropogenic disturbances. Decreased dominance of *P. dickii* was attributed to impacts of COT infestation that significantly reduced live coral cover with which *P. dickii* is tightly associated (Birkeland et al., 1987, 1994, 1996; Green, 1997; Green et al., 1999). In contrast, areas that were not impacted by COTS still contain high numbers of *P. dickii* (Birkeland et al., 1996; Green, 1997).

Significant differences in fish community structure were found to occur between habitat types. Deep reefs differ slightly from reef fronts, and both habitats were significantly different from reef flats (ANOSIM<sub>habitat</sub>: Global-R<sub>value</sub> = 0.484,  $p = 0.001$ ; Figure 3, Table 3). Reef fronts and deep reefs were

numerically dominated by damselfishes, while reef flats were dominated by surgeon fishes. *Pomacentrus vaiuli*, *P. brachialis*, *Plectroglyphidodon dickii*, *P. lacrymatus*, *Chromis iomelas*, and *C. xanthurus* were shown to have a habitat preference for exposed seaward and outer slope areas (Sano et al., 1984; Allen, 1991; Masuda and Allen, 1993; Kuitert and Tono-zuka, 2001), possibly due to abundance of their food items such as benthic algae, benthic invertebrates, and zooplankton in these areas (Hiatt and Strasburg, 1960; Hobson and Chess, 1978; Sano et al., 1984; Thresher and Colin, 1986; Allen, 1991; Myers, 1991; Masuda and Allen, 1993). Although surgeonfish *Ctenochaetus striatus*, *Acanthurus lineatus*, and *A. nigrofasciatus* were relatively more abundant on reef flats, they were also commonly found on reef fronts and deep reefs. The white bar gregory (*Stegastes albifasciatus*) and five-stripe wrasse (*Thalassoma quinquevittatum*) had strong dominance only on reef flat, a pattern also found by other researchers (e.g., Myers, 1991; Lieske and Myers, 1994; Green et al., 1999), due to abundance of their food items such as benthic algae and benthic invertebrates, namely crabs, shrimps, and other zoobenthos (Belk, 1975; Randall et al., 1990).

#### 5. STATUS OF THE CORAL REEF FISHERY

The status of reef fishes in American Samoa has commonly been reported as over-exploited (Tuilagi and Green, 1995; Green, 1996, 2002; Craig and Green, 2005; Craig et al., 2005; Green et al., 2005; Whaylen and Fenner, 2005). However, these conclusions were based only on data from fishery-independent surveys. This is the first attempt to compare patterns and trends from fishery independent surveys with fishery-dependent data simultaneously. Using a multi-disciplinary approach and merging data from fishery-independent surveys and fishery-dependent monitoring provides a more holistic view of the actual impact of the fishery on reef fish populations. Below, we present time-series data looking into various parameters that may provide a better perspective on the status of the issue.

##### 5.1. Trends in Boat-Based and Shoreline Catch and Effort

Trends in overall commercial catch landings of coral reef fishes have been relatively constant over the past three decades, with the exception of an abrupt delayed increase in catch triggered by the booming bottomfish fishery starting 1981 (first dotted red box in Figure 4). After 1988, the coral reef-associated bottomfish catch started to decline due to a shift from bottom-fishing to the more profitable trolling fishery. Another abrupt increase was from 1994 to 2000 with the introduction of SCUBA spearfishing (second dotted red box in Figure 4), reaching a peak in 1997. The same trend occurred for boat-based fishing effort expressed in fisher-hours ( $r = -0.359$ ,  $r^2 = 0.129$ ,  $F = 2.52$ ,  $p = 0.131$ ) and number of trips ( $r = -0.054$ ,  $r^2 = 0.003$ ;  $F = 0.052$ ;  $p = 0.823$ ). Boat-based effort and CPUE trends showed a non-significant decrease over time. The effect of the

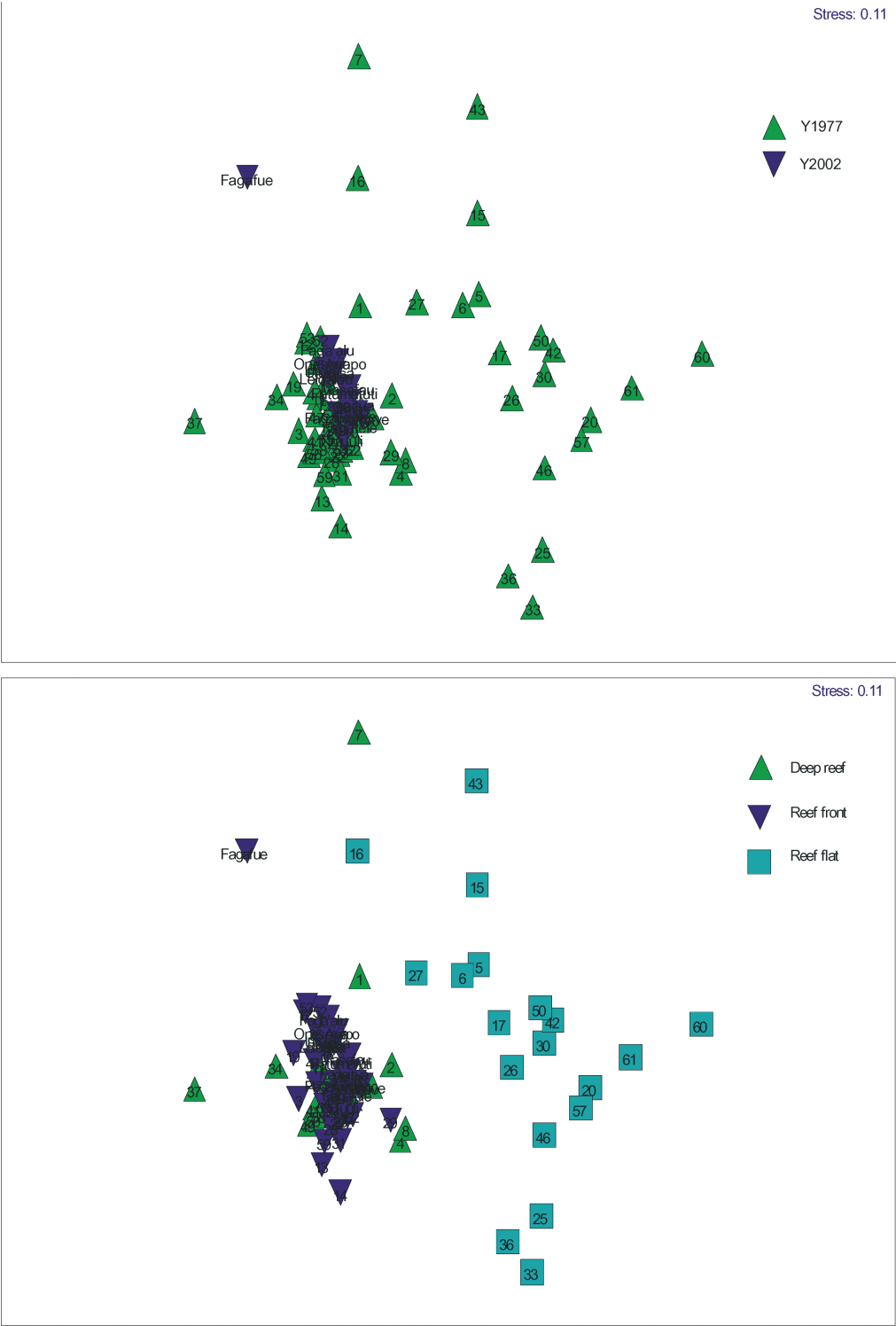


Figure 3 MDS of community structure.

abrupt increases in catch, effort, and CPUE were dampened by the decreases due to impacts of two successive hurricanes that hit American Samoa in 1990 and 1991 and others in 2004 and 2005 (solid red boxes). This devastated the artisanal fishing fleet and reduced the number of boats engaged in coral

reef fishing. Many fishermen decided to find other sources of income and abandoned fishing altogether. The fish communities were also affected by these large-scale disturbances (Green et al., 2005) but were showing signs of recovery (Birkeland et al., 2004).

**Table 3** Similarity of percentage species contribution analysis of the dominant reef species in American Samoa comparing between deep reefs, reef fronts, and reef flats to determine variations in dominant species by habitat type. (Legend key: Av.Sim = average of similarity coefficient; Sim/SD = similarity coefficient over standard deviation; Contrib% = percentage contribution; and Cum.% = cumulative percentages)

| A. Site similarity based on dominant species at deep reef habitat Average similarity: 59.83  |        |        |          |       |
|----------------------------------------------------------------------------------------------|--------|--------|----------|-------|
| Species                                                                                      | Av.Sim | Sim/SD | Contrib% | Cum.% |
| <i>Ctenochaetus striatus</i>                                                                 | 12.33  | 2.88   | 20.60    | 20.60 |
| <i>Pomacentrus vaiuli</i>                                                                    | 10.41  | 2.39   | 17.39    | 38.00 |
| <i>Pomacentrus brachialis</i>                                                                | 8.44   | 1.58   | 14.10    | 52.10 |
| <i>Plectroglyphidodon dickii</i>                                                             | 6.78   | 1.12   | 11.33    | 63.43 |
| <i>Acanthurus nigrofusus</i>                                                                 | 4.41   | 1.15   | 7.36     | 70.79 |
| <i>Chromis iomelas</i>                                                                       | 3.84   | 0.69   | 6.42     | 77.21 |
| <i>Chromis xanthura</i>                                                                      | 3.65   | 0.96   | 6.10     | 83.31 |
| <i>Plectroglyphidodon lacrymatus</i>                                                         | 3.00   | 0.74   | 5.01     | 88.32 |
| <i>Chlorurus sordidus</i>                                                                    | 2.52   | 1.08   | 4.21     | 92.53 |
| B. Site similarity based on dominant species at reef front habitat Average similarity: 63.49 |        |        |          |       |
| Species                                                                                      | Av.Sim | Sim/SD | Contrib% | Cum.% |
| <i>Ctenochaetus striatus</i>                                                                 | 13.94  | 4.33   | 21.96    | 21.96 |
| <i>Pomacentrus brachialis</i>                                                                | 12.00  | 2.58   | 18.90    | 40.86 |
| <i>Pomacentrus vaiuli</i>                                                                    | 6.57   | 1.55   | 10.35    | 51.21 |
| <i>Plectroglyphidodon lacrymatus</i>                                                         | 6.20   | 1.85   | 9.76     | 60.97 |
| <i>Plectroglyphidodon dickii</i>                                                             | 5.49   | 0.92   | 8.65     | 69.62 |
| <i>Acanthurus nigrofusus</i>                                                                 | 4.09   | 1.48   | 6.43     | 76.06 |
| <i>Chromis xanthura</i>                                                                      | 3.99   | 1.17   | 6.28     | 82.34 |
| <i>Chromis acares</i>                                                                        | 2.50   | 0.56   | 3.94     | 86.28 |
| <i>Chlorurus sordidus</i>                                                                    | 2.29   | 0.87   | 3.61     | 89.89 |
| <i>Chromis iomelas</i>                                                                       | 1.72   | 0.61   | 2.71     | 92.59 |
| C. Site similarity based on dominant species at reef flat habitat Average similarity: 51.59  |        |        |          |       |
| Species                                                                                      | Av.Sim | Sim/SD | Contrib% | Cum.% |
| <i>Stegastes albifasciatus</i>                                                               | 13.46  | 1.13   | 26.08    | 26.08 |
| <i>Ctenochaetus striatus</i>                                                                 | 10.87  | 1.07   | 21.07    | 47.15 |
| <i>Acanthurus lineatus</i>                                                                   | 9.53   | 1.12   | 18.46    | 65.62 |
| <i>Acanthurus nigrofusus</i>                                                                 | 8.50   | 1.12   | 16.47    | 82.09 |
| <i>Thalassoma quinquevittatum</i>                                                            | 5.93   | 0.73   | 11.50    | 93.59 |

Analyzing the temporal trend at family level showed a different pattern in contrast to the aggregated catch trend, where it showed a non-significant increase in catch of family Acanthuridae, Holocentridae, Kyphosidae, and Scaridae, and remained relatively constant for the rest of the major families (Figure 5). The increase in catch of Acanthuridae and Scaridae is largely, if not entirely, a consequence of SCUBA spearfishing, which can therefore be regarded as a temporary effect. Prior to SCUBA spearfishing, catch levels were moderate and dropped even lower due to hurricane impacts in early 1990, and present day catches are low due to low participation in the fishery. Trends in overall catch were driven by the trends in family Acanthuridae, Scaridae, Serranidae, Holocentridae, and Kyphosidae (Table 4). These were families that were targeted during the SCUBA

spearfishing period, as shown by the increase in catch from 1994 reaching a peak in 1997 or 1998 which declined thereafter.

A significant decrease was recorded in the shoreline effort over the past three decades ( $r = -0.849$ ,  $r^2 = 0.721$ ,  $F = 20.712$ ,  $p = 0.002$ ). Catch statistics for the shoreline fishery were not reported due to insufficient samples brought about by the low effort levels (Brookins, 2006). The survey design for the shoreline fishery documentation is sensitive to fishing effort, thus a fishery that is characterized by a low-fishing effort makes it difficult to interview fishermen for their catches. They were either gone on the return run or still out fishing. The decline in the shoreline and boat-based efforts were brought about by socio-economic changes from a subsistence to a cash-based system (Craig et al., 1993).

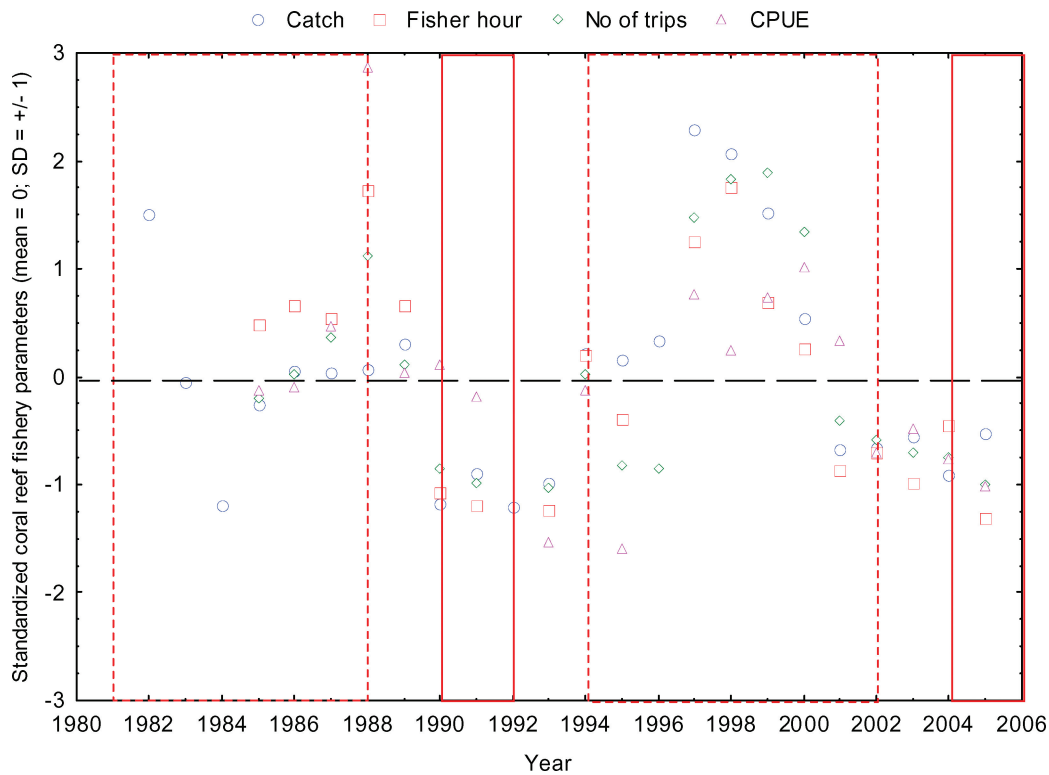


Figure 4 Fishery parameters over time.

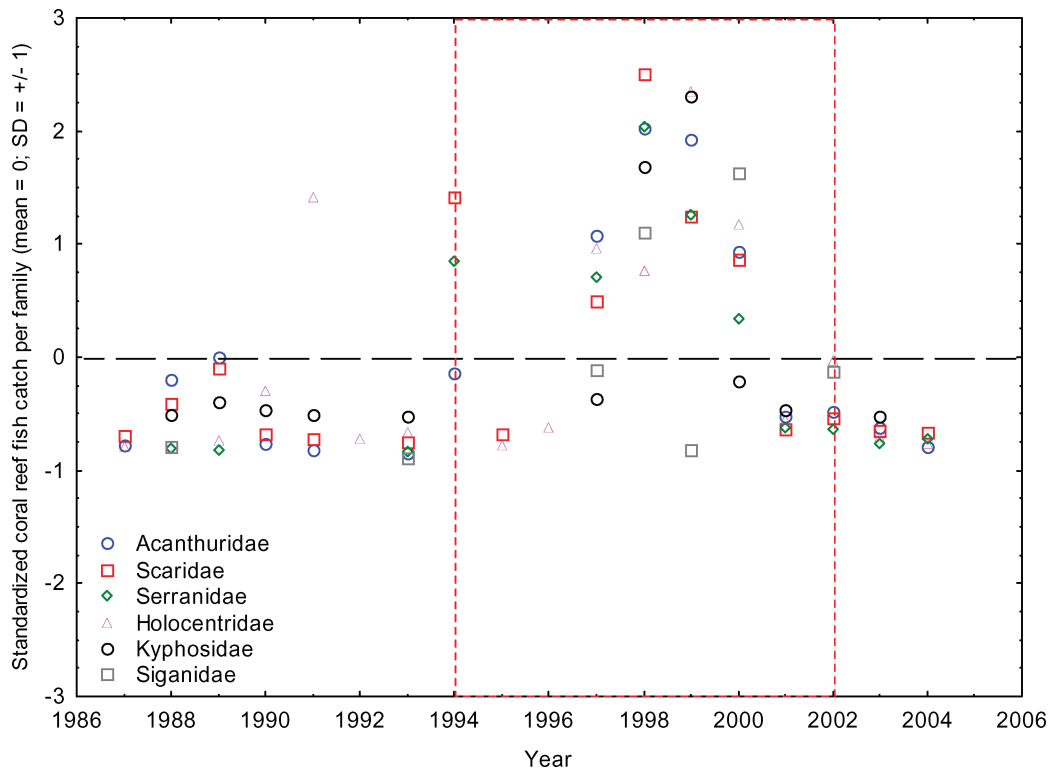


Figure 5 Family level catch over time.

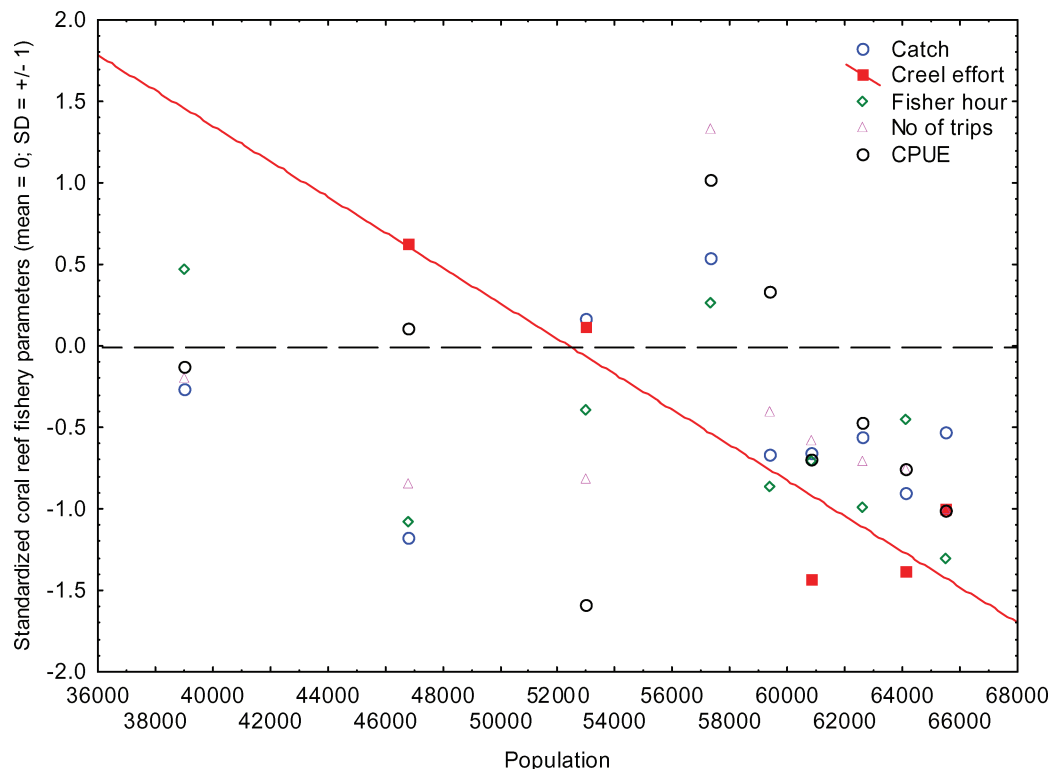
**Table 4** Multiple regression of fish density at family level with overall density for fish community and fishery dependent parameters to determine which family contributed to changes on the overall trends. Significant contributors are in **boldface**

| Parameter         | Dependent variable          | Independent variable        | N         | r           | r <sup>2</sup> | Fstatistic   | Pvalue       |
|-------------------|-----------------------------|-----------------------------|-----------|-------------|----------------|--------------|--------------|
| Fish community    | <b>Acanthuridae density</b> | <b>Overall fish density</b> | <b>7</b>  | <b>0.88</b> | <b>0.77</b>    | <b>16.69</b> | <b>0.009</b> |
|                   | Serranidae density          | Overall fish density        | 7         | 0.36        | 0.13           | 0.76         | 0.423        |
|                   | Scaridae density            | Overall fish density        | 7         | 0.19        | 0.04           | 0.19         | 0.684        |
| Fishery dependent | <b>Acanthuridae catch</b>   | <b>Overall catch</b>        | <b>15</b> | <b>0.91</b> | <b>0.83</b>    | <b>64.45</b> | <b>0.000</b> |
|                   | <b>Serranidae catch</b>     | <b>Overall catch</b>        | <b>12</b> | <b>0.84</b> | <b>0.70</b>    | <b>23.47</b> | <b>0.001</b> |
|                   | <b>Scaridae catch</b>       | <b>Overall catch</b>        | <b>16</b> | <b>0.79</b> | <b>0.62</b>    | <b>22.69</b> | <b>0.000</b> |
|                   | <b>Holocentridae catch</b>  | <b>Overall catch</b>        | <b>16</b> | <b>0.56</b> | <b>0.31</b>    | <b>6.43</b>  | <b>0.024</b> |
|                   | <b>Kyphosidae catch</b>     | <b>Overall catch</b>        | <b>11</b> | <b>0.64</b> | <b>0.41</b>    | <b>6.23</b>  | <b>0.034</b> |
|                   | Siganidae catch             | Overall catch               | 7         | 0.33        | 0.11           | 0.62         | 0.468        |

## 5.2. Consequence of Human Population Growth on Fishing Pressure

From a census conducted in 2000, 97% of the 57,291 individuals were found to reside in Tutuila, while only 2.4% are in Manua (ASDOC, 2006). There was a negative population growth in Manua after 1950. The population had almost quadrupled between 1900 (estimated at 5679 individuals) and 1950 and subsequently tripled to 68,200 individuals by 2007. Increases in human population density commonly leads to over-exploitation of natural resources. It may therefore be expected that, with the more recent increase in human population in American Samoa, fisheries resources may also be facing increased, and possible over exploitation. This, however, does not appear to be the

case, as, while the human population in American Samoa, particularly in Tutuila, has increased, fishing catch and effort has declined. Human population density has a negative correlation with all fishing parameters notably, a significant negative regression with shoreline fishing effort ( $r = -0.926$ ,  $r^2 = 0.857$ ,  $F = 17.943$ ,  $p = 0.024$ ; Figure 6). Despite the population of Polynesian heritage and the associated traditional and cultural importance of fishing, modernization has shifted the society toward a cash-based economy, where the majority of the population relies on paid employment. American Samoa have experienced a rapid rate of economic development compared to its neighboring islands. Economic statistics show American Samoa's gross domestic product value at \$203,125,300, whereas its island neighbors range from \$624,000 (Tokelau) to \$165,885,700

**Figure 6** Fishery parameters by population growth.

(Independent State of Samoa) (Dalzell et al., 1996). This higher economic status has enabled American Samoans to purchase food instead of fishing for their protein source (Ponwith, 1991; Craig et al., 1993; Saucerman, 1995a, 1995b; Coutures, 2003; Zeller et al., 2006). Such dietary changes and economic modernization have been documented throughout Pacific Island populations in the second half of the 20th century and is thought to be responsible for the increase in numbers of people that are overweight or obese (Ulijaszek, 2002; WHO, 2003). Kilarski et al. (2006) reported that American Samoans still consider fishing an important part of their culture and engage in fishing occasionally. However, the vast majority of the population does not engage in subsistence or commercial fishing activities, but fishes in more of a recreational manner. Fishery production data from 1989 to 1994, described in Dalzell et al. (1996), had shown American Samoa coastal subsistence and commercial fishery production were at 215 and 52 tons, respectively, generating a total nominal value of \$993,000. The production values were 13 times less than the neighbor island of Independent State of Samoa at 3281 and 208 tons for subsistence and commercial fishery, respectively, generating a total nominal value of \$5.4 million. Such a shift from a subsistence-based to a cash-based economy has been reported to occur as early as the mid 1900s (Schaffer, 2000).

Data from the U.S. Census Bureau (1990, 2000) shows an increase in the labor force in the past 10 years, with 52% of the population now employed and only 7% involved in pure subsistence activities. Thirty-five percent (35%) of the workforce is involved in the manufacturing industry, including work at the two canneries; 17% in education, health, and social service; and 9% in public administration. Only 3% of the population currently works in agriculture, forestry, fishing, hunting, and mining combined. There was also a steady increase in government employment from 2000 to 2004, as well as in the private sector, while employment at the canneries has decreased slightly every year starting in 2001. These social dynamics have led to a decrease in fishing effort in the past three decades, as reported by Ponwith (1991), McConnaughey (1993), Saucerman (1995a, 1995b), and Coutures (2003).

Subsistence fishing may still be well practiced in the Manua islands. Studies done by Craig et al. (2008) on the island of Ofu showed 1272 fishing gear deployments observed from 472 survey sweeps covering a 9.5-km sampling area. In contrast, the work of Coutures (2003) showed an observed 800 gear deployments observed from 463 sampling sweeps covering a 23.7-km sampling area. Both studies were conducted on the same time period and almost the same sampling protocols were used. It appears that greater shoreline fishing activities are occurring in the Manua island group than Tutuila, based on almost similar sampling effort and greater spatial coverage.

Taking all these into consideration, caution will have to be taken in using human population growth as a factor for modeling fishery and fish population interaction. A reconstruction of the coral reef fishery catches done by Zeller et al. (2006, 2007) showed a significant decline in per capita coral reef catch over a period of 50 years using human population as a driver to run the

simulation. This simulation failed to factor in the significant decline in the shoreline fishing effort as explicitly reported by the authors of the technical reports used as "reference data points" in the reconstruction. Also reported was an increase in imports of fish from neighboring Independent State of Samoa due to inability to supply the local demand for fish from local stock. From the local fish dealer standpoint, it is more economical to import fish from Samoa than pay contracted local fisherman, and has nothing to do with lack of supply. Craig et al. (1993) reported that the sizes of fish caught in the shoreline subsistence fishery was generally small and is confounded by the fact that most of the gears listed for this fishery are used on shallow reef areas dominated by small-sized fish. The American Samoa coral reef fishery was also shown to be on a collapsed state when looking at the ecological footprint (Newton et al., 2007). The calculations of the ecological footprint also used per-capita consumption based on the population level and does not incorporate effort levels.

The pattern of fishery utilization in American Samoa deviates from the norms of global fishery trends brought about by the unique economic and social circumstances that the territory has recently experienced. However, this situation should be viewed as temporary as the fate of the economy relies heavily on the two tuna canneries and subsidies from the federal government of the U.S. If economic conditions shift, people may revert back to the sea for a food source.

### 5.3. *Decrease in Fishing Mortality Enhances Reef Fish Density*

The decrease in boat-based and shoreline fishing effort in American Samoa may have enabled a slight increase in reef fish abundance and density due to the reduction of fishing mortality. More recent recovery of the coral communities in American Samoa after a series of major disturbances (Fenner et al., 2008) may have also contributed to the increase. Family Scaridae has shown a significant increase in abundance since 1988. This increase was probably due to increases in the dominant parrotfish species, namely *Chlorurus japanensis*, *Scarus rubroviolaceus*, *Chlorurus sordidus*, and *Scarus forsteni* (Sabater and Tofaeono, 2007). Interestingly, these species were also the dominant species in the catch during the period where SCUBA spearfishing was prevalent (Page, 1998). It appears that parrotfishes were resilient and are currently recovering from the impacts of the SCUBA spear fishery. Effort and catch declined greatly with the implementation of the SCUBA spearfishing ban in 2001, although catch and effort abruptly declined as early as 1998. This initial decline was due to the strict implementation of fishing licenses, which disallowed foreign nationals who made up the majority of the fishers involved in the SCUBA spearfishery, and allowed only American Samoans to participate (Ray Tulafono, personal communication). Thus, foreign nationals disproportionately contribute to fishing effort. Foreign nationals often fill in the niche in society that American Samoans vacate due to better employment opportunities and

social benefits, since foreigners are not entitled to the same benefits as U.S. nationals. These social displacements have also been reported from other Pacific island countries (Dalzell et al., 1996).

Regression analysis of abundance and density with different fisheries parameters showed a significant inverse relationship between abundance and density with boat-based number of fishing hours ( $r = -0.780$ ,  $r^2 = 0.608$ ,  $F = 7.772$ ,  $p = 0.038$ ). Family level regression between density and catch showed no apparent trend over time (low  $r$  and  $r^2$ ), indicating fishing might have no significant direct relationship on density of each family being targeted.

## 6. POSSIBLE IMPACTS FROM HABITAT DEGRADATION ON FISH POPULATIONS

Patterns showing a decrease in catch and CPUE along with an increased effort in the fishery and a consequent decline in abundance, biomass, and size at age of targeted fish are indicative of overfishing conditions (Saucerman 1995a, 1995b). Patterns and trends in catch, effort, and abundance density in the fishery and fish populations in American Samoa did not manifest these classic signs of overfishing. Sizes-at-age data for lined surgeonfish (*Acanthurus lineatus*), a major component of the coral reef catch, showed no signs of over-fishing (Craig et al., 1997). Given that the fishery metrics are showing minimal effect on the fish population, other factors therefore have to be considered in interpreting the patterns and trends in fish populations. There is evidence of two decades of both natural and man-made disturbances, which may have resulted in significant changes to the reef fish community around Tutuila and the other islands of American Samoa (Craig et al., 1995; Birkeland et al., 1996). Saucerman (1995a, 1995b) hypothesized that habitat degradation had a more active role in impacting the coral reef fish population. Estimation of sedimentation rates along the channel and reef flats are currently being conducted by DMWR using replicated transects of sediment traps from the stream mouth toward the reef slope. Work also needs to be done on the possible impacts of eutrophication of the coral reef ecosystem.

Sedimentation is considered a major disturbance that can alter the structural integrity of coral reefs. Sedimentation rates in Tutuila range from 9.75 g/cm<sup>2</sup>/day at stream mouths, 3.08 g/cm<sup>2</sup>/day at the reef slopes of embayment areas, to virtually absent (0.57 g/cm<sup>2</sup>/day) at the slopes of point areas (Fenner et al., 2008). Stream sediments may be deposited into deeper water through channels at the stream mouth or at shallow reef areas.

The reefs of American Samoa, particularly around the main island of Tutuila, also have very limited areas of shallow water habitat (e.g., reef flats, back reef pools, lagoons, seagrass beds, and mangroves), and significant portions of these habitats have been altered or destroyed in Tutuila through development. Reef flats are particularly vulnerable to degradation by trampling of gleaners and fishermen targeting octopus. Shallow habitat ar-

eas are known to be refugia for small fishes that still could not survive on reef slopes where larger predatory fish dwell (Holand et al., 1993; Nagelkerken et al., 2000; Adams and Ebersole, 2002; Dorenbosch et al., 2004; Heupel and Simpfendorfer, 2005; Pikitch et al., 2005; Dorenbosch et al., 2006; Freitas et al., 2006). The humphead wrasse (*Cheilinus undulatus*) is known to utilize the shallow nursery areas with low branching coral, with associated macro algae and seagrass beds as a juvenile rearing habitat (Tupper, 2007). Extensive mangrove areas were shown to enhance biomass of fishes in the Caribbean due to functional linkage between tropical coastal areas (Mumby et al., 2004). The Nu'uuli Pala Lagoon, at the main island of Tutuila, is an important juvenile and spawning habitat for some reef fishes like jack, mullets, emperors, rudderfish, black tip reef sharks, goatfish, surgeons, and groupers (Ponwith, 1992; Iose and McConnaughey, 1993). The mangrove area at the base of the lagoon is also a habitat for mullets, great barracuda (*Sphyraena barracuda*), and juvenile giant trevally (*Caranx ignobilis*) (Yamasaki et al., 1985). The Caribbean parrotfish (*Scarus guacamaia*) were shown to rely heavily on mangrove areas to complete their life cycle (Mumby et al., 2004). Further limiting availability of suitable juvenile habitat is likely to affect the abundance of certain species of reef fish that rely upon such habitat during their recruitment and juvenile life-history stages, ultimately affecting the number of adults that are found on the reefs. The impacts of all these different factors on the distribution patterns of reef fishes and how they relate to the fishery is the subject of ongoing investigation by the Department of Marine and Wildlife Resources. This review will hopefully result in refocusing research effort on the effects on habitat variations and degradation on fish population and encourage a more in-depth analysis of the existing fishery data.

## 7. CONCLUSION

Samoans have fished their reefs for approximately 3000 years. Archaeological and recent history information has indicated that Samoans may have utilized their marine resources without adversely affecting the population, thereby allowing for recovery. Additionally, fishing mortality has decreased in the past three decades due to social changes, thereby relieving pressure on reef fish populations allowing for potential recovery. The significant increase in human population over the past century in Tutuila has had no significant relationship with fishing pressure. The unique pattern of interaction between fish populations, the fishery, social dynamics, and human demographics in American Samoa can be considered as an exception rather than the rule. However, the ecological benefits derived from the economic and social prosperity being received by American Samoa may be temporary and could deteriorate once the territory becomes affected by future economic downturn, where denizens would revert back to the near-shore resources for nourishment. Finally, effects of habitat degradation on the reef fish population may be confounded with the effects of fishing, thus warranting

further investigation. Taking a multidisciplinary approach to understanding the patterns and trends provides a better and unique perspective in evaluating the status of reef fish population and its associated fishery.

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## REFERENCES

- Adams, A. J., and J. P. Ebersole. Use of back-reef and lagoon habitats by coral reef fishes. *Mar. Ecol. Prog. Ser.*, **228**: 213–226 (2002).
- Allen, G. R. *Damselfishes of the World*. Melle, Germany: Mergus Publishers (1991).
- Allen, M. S. Temporal variation in Polynesian fishing strategies: The Southern Cook Islands in regional perspective. *Asian Perspect.*, **31**: 183–204 (1992).
- Allen, M. S. Resolving long-term change in Polynesian marine fisheries. *Asian Perspect.*, **41**: 195–212 (2002).
- Amesbury, J. R. Mollusk collecting and environmental change during the Prehistoric Period in the Mariana Islands. *Coral Reefs*, **26**: 947–958 (2007).
- ASDOC (American Samoa Department of Commerce). *American Samoa Statistical Yearbook 2006*. American Samoa Government, Pago Pago, American Samoa (2006).
- Ault, J. S., J. A. Bohnsack, and G. A. Meester. A retrospective (1979–1996) multi-species assessment of coral reef fish stocks in the Florida Keys. *Fish. Bull.*, **96**: 395–414 (1998).
- Ault, J. S., S. G. Smith, and J. A. Bohnsack. Evaluation of average length as an estimator of exploitation status for the Florida coral-reef fish community. *ICES J. Mar. Sci.*, **62**: 417–423 (2005).
- Ault, J. S., S. G. Smith, J. A. Bohnsack, J. Luo, D. E. Harper, and D. B. McClellan. Building sustainable fisheries in Florida's coral reef ecosystem: Positive signs in the Dry Tortugas. *Bull. Mar. Sci.*, **78**: 633–654 (2006).
- Belk, M. S. Habitat partitioning in two tropical reef fishes, *Pomacentrus lividus* and *P. albobfasciatus*. *Copeia*, **4**: 603–607 (1975).
- Birkeland, C. E., A. L. Green, C. Mundy, and K. Miller. *Long-term Monitoring of Fagatele Bay National Marine Sanctuary and Tutuila Island (American Samoa) 1985 to 2001: Summary of Surveys Conducted in 1998 and 2001*. Report to National Oceanic and Atmospheric Administration. U.S. Department of Commerce, 158 pp. (2004).
- Birkeland, C. E., R. H. Randall, and S. Amesbury. *Coral and Reef-fish Assessment of the Fagatele Bay National Marine Sanctuary*. Report to National Oceanic and Atmospheric Administration. U.S. Department of Commerce, 126 pp. (1994).
- Birkeland, C.E., R. H. Randall, A. L. Green, B. D. Smith, and S. Wilkins. *Changes in the Coral Reef Communities of Fagatele Bay National Marine Sanctuary and Tutuila Island (American Samoa) Over the Last Two Decades*. Report to National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 223 pp. (1996).
- Birkeland, C. E., R. H. Randall, A. L. Green, B. D. Smith, and S. Wilkins. *Changes in the Coral Reef Communities of Fagatele Bay National Marine Sanctuary and Tutuila Island (American Samoa), 1982–1995*. Fagatele Bay National Marine Sanctuary Science Series No. 2003-1, American Samoa (2003).
- Birkeland, C. E., R. H. Randall, R. C. Wass, B. D. Smith, and S. Wilkins. *Biological Resources Assessment of the Fagatele Bay National Marine Sanctuary*. NOAA Technical Memorandum Series NOS/MEMD No. 3, 232 pp. (1987).
- Brainard, R., J. Asher, J. Gove, J. Helyer, J. Kenyon, F. Mancini, J. Miller, S. Myhre, M. Nadon, J. Rooney, R. Schroeder, E. Smith, B. Vargas-Angel, S. Vogt, P. Vroom, S. Balwani, S. Ferguson, R. Hoeke, M. Lammers, E. Lundblad, J. Maragos, R. Moffitt, M. Timmers, and O. Vetter. *Coral Reef Ecosystem Monitoring Report for American Samoa: 2002–2006*. Coral Reef Ecosystem Division, NOAA Special Report NMFS PIFSC, 504 pp. (2008).
- Brookins, K. American Samoa coral reef fishery. In: *Western Pacific Regional Fishery Management Council Briefing Agenda* (133rd Meeting of the Western Pacific Regional Fishery Management Council, June 12–15, 2006). WPRFMC, Honolulu, HI, 2 pp. (2006).
- Clarke, K. R. and R. M. Warwick. *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation*, 1st ed. Plymouth, UK: Plymouth Marine Laboratory, 144 pp. (2001).
- Clarke, K. R. and R. N. Gorley. PRIMER v5: User manual/tutorial. PRIMER-E, Plymouth, UK (2001).
- Coutures, E. *The Shoreline Fishery of American Samoa: Analysis of 1-Year Data and Implementation of a New Sampling Protocol*. Biological Report Series No. 102. Department of Marine and Wildlife Resources, American Samoa, 22 pp. (2003).
- Craig, P. C. Are tropical near-shore fisheries manageable in view of projected population increase? *Proceedings of the South Pacific Forum Fisheries Agency Regional Inshore Management Workshop*, New Caledonia, June 26–July 7, 1995 (1995).
- Craig, P. C., and A. L. Green. Overfished coral reefs in American Samoa: No quick fix. *Reef Encounter*, **33**: 21–22 (2005).
- Craig, P. C., A. L. Green, and F. Tuilagi. Subsistence harvest of coral reef resources in the outer islands of American Samoa: Modern, historic, and prehistoric catches. *Fish. Res.*, **89**: 230–240 (2008).
- Craig, P. C., A. L. Green, and S. Saucerman. Coral reef troubles in American Samoa. *S. Pac. Commission Newsletter*, **72**: 33–34 (1995).
- Craig, P. C., B. Ponwith, F. Aitaoto, and D. Hamm. The commercial, subsistence, and recreational fisheries of American Samoa. *Mar. Fish. Rev.*, **55**: 109–116 (1993).

- Craig, P. C., G. DiDonato, D. Fenner, and C. Hawkins. The State of Coral Reef Ecosystems of American Samoa. **In: *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005*** (J. Waddell, Ed., pp. 312–337). Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring and Assessments Biogeography Team. Silver Spring, MD (2005).
- Craig, P. C., J. H. Choat, L. M. Axe, and S. Saucerman. Population biology and harvest of the coral reef surgeonfish *Acanthurus lineatus* in American Samoa. *Fish. Bull.*, **95**: 680–693 (1997).
- Dalzell, P. D. The role of archaeological and cultural-historical records in long-range coastal fisheries resources management strategies and policies in the Pacific Islands. *Ocean Coast. Manage.*, **40**: 237–252 (1998).
- Dalzell, P. D., T. Adams, and N. Polunin. Coastal fisheries in the Pacific Islands. *Oceanogr. Mar. Biol.*, **33**: 395–531 (1996).
- Dorenbosch, M., M. C. van Riel, I. Nagelkerken, and G. van der Velde. The relationship of reef fish densities to the proximity of mangrove and seagrass nurseries. *Est. Coast. Shelf Sci.*, **60**: 37–48 (2004).
- Dorenbosch, M., M. G. G. Grol, I. Nagelkerken, and G. van der Velde. Seagrass beds and mangroves as potential nurseries for the threatened Indo-Pacific humphead wrasse, *Cheilinus undulatus* and Caribbean rainbow parrotfish, *Scarus guacamaia*. *Biol. Conserv.*, **129**: 277–282 (2006).
- Fenner, D., M. Speicher, S. Gulick, G. Aeby, S. C. Aletto, P. Anderson, B. Carroll, E. DiDonato, G. DiDonato, V. Farmer, J. Gove, P. Houk, E. Lundbland, M. Nadon, F. Riolo, M. Sabater, R. Schroeder, E. Smith, C. Tuitele, A. Tagarino, S. Vaitautolu, E. Vaoli, B. Vargas-Angel, and P. Vroom. The state of coral reef ecosystem of American Samoa. The State of Coral Reef Ecosystems of American Samoa. **In: *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005*** (J. Waddell, Ed., pp. 307–352). Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessments Biogeography Team. Silver Spring, MD (2008).
- Freitas, R. H. A., R. S. Rosa, S. H. Gruber, and B. M. Wetherbee. Early growth and juvenile population structure of lemon sharks *Negaprion brevirostris* in the Atol das Rocas Biological Reserve off northeast Brazil. *J. Fish Biol.*, **69**: 1319–1332 (2006).
- Friedlander, A. M., and E. E. De Martini. Contrast in density, size, and biomass of reef fishes between the northwestern and main Hawaiian islands: The effects of fishing down apex predators. *Mar. Ecol. Prog. Ser.*, **230**: 252–264 (2002).
- Governor's Task Force on Population Growth. *Impacts of Rapid Population Growth in American Samoa: A Call for Action*. American Samoa Government, Pago-Pago, American Samoa, 30 pp. (2000).
- Green, A. L. *Status of the Coral Reefs of the Samoan Archipelago*. Report to the Department of Marine and Wildlife Resources, American Samoa (1996).
- Green, A. L. American Samoa bans destructive SCUBA fishery: The role of monitoring in management. **In: *Monitoring Coral Reef Marine Protected Areas*** (C. Wilkinson, A. Green, J. Alamany, and S. Dionne, Eds., pp. 38–39). Australian Institute of Marine Science, Townsville, Qld., Australia (2003).
- Green, A. L. *An Assessment of the Status of the Coral Reef Resources and their Patterns of Use in the U.S. Pacific Islands*. Report for the Western Pacific Regional Fisheries Management Council, Honolulu, HI, 254 pp. (1997).
- Green, A. L. *Status of Coral Reefs on the Main Volcanic Islands of American Samoa: A Re-survey of Long-Term Monitoring Sites (Benthic Communities, Fish Communities, and Key Macroinvertebrates)*. Report to the Department of Marine and Wildlife Resources, Pago-Pago, American Samoa, 86 pp. (2002).
- Green, A. L., C. E. Birkeland, and R. H. Randall. Twenty years of disturbance and change in Fagatele Bay National Marine Sanctuary, American Samoa. *Pac. Sci.*, **53**: 376–400 (1999).
- Green, A. L., K. Miller, and C. Mundy. *Long-term Monitoring of Fagatele Bay National Marine Sanctuary, Tutuila Island, American Samoa: Results of Surveys Conducted in 2004, Including a Re-survey of the Historic Aua Transect*. Report to Department of Commerce, Pago-Pago, American Samoa, 96 pp. (2005).
- Hart, J. W. *Samoan Culture*, revised edition. Pago-Pago, American Samoa: Ati's Print Shop (1996).
- Hawhee, J. M. *Western Pacific Coral Reef Ecosystem Report*. Western Pacific Regional Fishery Management Council. Honolulu, HI, 77 pp. (2006).
- Herdrich, D., and K. Armstrong. *Historic Fishing Methods in American Samoa*. A report submitted to NOAA-Pacific Island Fishery Science Center, Honolulu, HI (2008).
- Heupel, C. A., and C. A. Simpfendorfer. Quantitative analysis of aggregation behavior in juvenile blacktip sharks. *Mar. Biol.*, **147**: 1239–1249 (2005).
- Hiatt, R. W., and D. W. Strasburg. Ecological relationships of the fish fauna on coral reefs of the Marshall Islands. *Ecol. Monogr.*, **30**: 65–127 (1960).
- Hobson, E. S., and J. R. Chess. Trophic relationships among fishes and plankton in the lagoon at Enewetak Atoll, Marshall Islands. *Fish. Bull.*, **76**: 133–153 (1978).
- Holland, K. N., B. M. Wetherbee, J. D. Peterson, and C. G. Lowe. Movements and distribution of hammerhead shark pups on their natal grounds. *Copeia*, **2**: 495–502 (1993).
- Iose, P. K., and I. McConnaughey. *Fishery Resources in Pala Lagoon*. Report to the Department of Marine and Wildlife Resources, Pago-Pago, American Samoa, 29 pp. (1993).
- Kilarski, S., D. Klaus, J. Lipscomb, K. Matsoukas, R. Newton, and A. Nugent. *Decision Support for Coral Reef Fisheries Management: Community Input as a Means of Informing Policy in American Samoa*. M.Sc. thesis, The Donald Bren School of Environmental Science and Management. University of California, Santa Barbara, 132 pp. (2006).
- Kirch, P., and T. Hunt. *The Toaga Site: Three Millennia of Polynesian Occupation in the Manua Islands, American Samoa*. University of California, Berkeley. No 51, 248 pp. (1993).
- Kirch, P. V. *Niuaotuputu: The Prehistory of a Polynesian Chieftdom*. Thomas Burke Memorial, Washington State Museum, Monograph No. 5. (1988).
- Knowlton, N., and J. B. C. Jackson. Shifting baselines, local impacts, and global climate change on coral reefs. *PLoS Biol.*, **6**: 215–221 (2008).
- Kuiter, R. H., and T. Tono-zuka. *Pictorial Guide to Indonesian Reef Fishes. Part 2. FusiliersflDragonets, CaesionidaeftCallionymidae*. Australia: Zoonetics, pp. 304–622 (2001).
- Leach, B. F., and M. Intoh. An archaeological fish bone assemblage from the Vitaria Site, Rurutu, Austral Islands. *J. Societe des Oceanistes*, **78**: 75–77 (1984).
- Lieske, E., and R. Myers. *Coral Reef Fishes: Indo-Pacific and Caribbean including the Red Sea*. Harper Collins, London (1994).

- Lindeman, K. C., R. Pugliese, G. T. Waugh, and J. S. Ault. Developmental patterns within a multispecies reef fishery: Management applications for essential fish habitats and protected areas. *Bull. Mar. Sci.*, **66**: 929–956 (2000).
- Link, J. S. Ecological considerations in Fisheries Management: When does it matter? *Fisheries*, **27**: 10–17 (2002).
- Masuda, H., and G. R. Allen. *Meeresfische der WeltflGroß-Indopazifische Region*. Tetra Verlag, Herrenteich, Melle, 528 pp. (1993).
- McConnaughey, J. *The Shoreline Fishery of American Samoa in FY 1992*. Biological Report Series No. 41. Department of Marine and Wildlife Resources, Pago-Pago, American Samoa (1993).
- Morrison, A. E., and D. J. Addison. Assessing the role of climate change and human predation on marine resources at the Fatu-mafuti site, Tutuila Island, American Samoa: An agent based model. *Archaeol. Ocean.*, **43**: 23–34 (2008).
- Mumby, P. J., A. J. Edwards, J. E. Arias-Gonzales, K. C. Lindeman, P. G. Blackwell, A. Gall, M. I. Górczyska, A. R. Harborne, C. L. Pescod, H. Renken, C. C. C. Wabnitz, and G. Llewellyn. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature*, **427**: 533–536 (2004).
- Myers, R. F. *Micronesian Reef Fishes, 2nd edition*. Barrigada, Guam: Coral Graphics (1991).
- Nagaoka, L. Chapter 13: Faunal assemblages from the Toaga site. **In:** *The To'aga Site: Three Millennia of Polynesian Occupation in the Manu'a Islands, American Samoa* (P. Kirch and T. Hunt, Eds., pp. 189–216). Contributions of the University of California, Berkeley No. 51, 248 pp. (1993).
- Nagelkerken, I., G. van der Velde, M. W. Gorissen, G. J. Meijer, T. van't Hof, and C. den Hartog. Importance of mangroves, seagrass beds, and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. *Est. Coast. Shelf. Sci.*, **51**: 31–44 (2000).
- Newton, K., I. M. Cote, G. M. Pilling, S. Jennings, and N. K. Dulvy. Current and future sustainability of island coral reef fisheries. *Curr. Biol.*, **17**: 655–658 (2007).
- NOAA National Centers for Coastal Ocean Science (NCCOS). *Atlas of the Shallow Water Benthic Habitats of American Samoa, Guam, and the Commonwealth of the Northern Marianas Islands*. NOAA Technical Memorandum NOS NCCOS 8, Biogeography Team. Silver Spring, MD, 126 pp. (2005).
- Page, M. *The Biology, Community Structure, Growth and Artisanal Catch of Parrotfishes of American Samoa*. Report to the Department of Marine and Wildlife Resources, American Samoa, 51 pp. (1998).
- Pikitch, E. K., D. D. Chapman, E. A. Babcock, and M. S. Shivji. Habitat use and demographic population structure of elasmobranchs at a Caribbean atoll (Glovers Reef, Belize). *Mar. Ecol. Prog. Ser.*, **302**: 187–197 (2005).
- Ponwith, B. J. *The Inshore Fishery of American Samoa: A 12-year Comparison*. Biological Report Series No. 22. Department of Marine and Wildlife Resources, American Samoa, 51 pp. (1991).
- Ponwith, B. J. *The Pala Lagoon Subsistence Fishery*. Biological Report Series No. 27. Department of Marine and Wildlife Resources, Pago-Pago, American Samoa, 28 pp. (1992).
- Randall, J. E., G. R. Allen, and R. C. Steene. *Fishes of the Great Barrier Reef and Coral Sea*. University of Hawaii Press, Honolulu, HI, 506 p. (1990).
- Sabater, M. G., and S. Tofaeono. *Spatial Variation in Biomass, Abundance, and Species Composition of Key Reef Species in American Samoa*. Biological Report Series No. 2005-1. Department of Marine and Wildlife Resources, Pago-Pago, American Samoa, 54 pp. (2005).
- Sabater, M. G. *Prehistoric, Historic, and Current Fish Utilization and the Consequence of Human Population Growth on Fish Density, Biomass and Community Composition in American Samoa*. Biological Report Series No. 2007-01. Department of Marine and Wildlife Resources, Pago-Pago, American Samoa, 31 pp. (2007).
- Sabater, M. G., and S. Tofaeono. *Spatial Variation in Biomass, Abundance, and Species Composition of Key Reef Species in American Samoa. Revised Edition*. Biological Report Series No. 2006-2. Department of Marine and Wildlife Resources, Pago-Pago, American Samoa, 58 pp. (2006).
- Sabater, M. G., and S. Tofaeono. Effects of scale and benthic composition on biomass and trophic group distribution of reef fishes in American Samoa. *Pac. Sci.*, **61**: 503–520 (2007).
- Sano, M., M. Shimizu, Y. Nose. *Food Habits of Teleostean Reef Fishes in Okinawa Island, Southern Japan*. University of Tokyo Press, Tokyo, Japan, 128 pp. (1984).
- Saucerman, S. *The Inshore Fishery of American Samoa, 1991 to 1994*. Biological Report No. 77. Department of Marine and Wildlife Resources, Pago Pago, American Samoa, 26 pp. (1995a).
- Saucerman, S. Assessing the Management Need of a Coral Reef Fishery in Decline. *Joint FFA/SPC Workshop on the Management of South Pacific Inshore Fisheries*. Noumea, New Caledonia, June 26–July 7, 1995 (1995b).
- Schaffer, J. R. *American Samoa: 100 Years Under the United States Flag*. Honolulu, HI: Island Heritage Publishing (2000).
- Sokal, R. R., and F. J. Rohlf. *Biometry: The Principles and Practice of Statistics in Biological Research, 3rd edition*. New York: W. H. Freeman and Company (1995).
- StatSoft Inc. STATISTICA (data analysis software), version 8.0. www.statsoft.com (2007).
- Thresher, R. E., and P. L. Colin. Trophic structure, diversity, and abundance of fishes of the deep reef (30–300 m) at Enewetak, Marshall Islands. *Bull. Mar. Sci.*, **38**: 253–272 (1986).
- Tuilagi, F., and A. L. Green. Community Perception of Changes in Coral Reef Fisheries in American Samoa. Joint FFA/SPC workshop on the management of South Pacific Inshore Fisheries. Noumea, New Caledonia, June 26–July 7, 14 pp. (1995).
- Tupper, M. Identification of nursery habitats for commercially valuable humphead wrasse *Cheilinus undulatus* and large groupers (Pisces: Serranidae) in Palau. *Mar. Ecol. Prog. Ser.*, **332**: 189–199 (2007).
- Ulijaszek, S. J. Modernization and the diet of adults on Rarotonga, the Cook Islands. *Ecol. Food Nutr.*, **41**: 203–228 (2002).
- U.S. Census Bureau. Census of Population. American Samoa Government. Department of Commerce, Pago-Pago, American Samoa (1990).
- U.S. Census Bureau. Census of Population. American Samoa Government. Department of Commerce, Pago-Pago, American Samoa (2000).
- Wass, R. C. The shoreline fishery of American Samoa, past and present. **In:** *Marine and Coastal Processes in the Pacific: Ecological Aspects of Coastal Zone Management* (J. Munro, Ed., pp. 51–83). Paris: United Nations Education, Scientific, and Cultural Organization (1980).

- Wass, R. C. *Characterization of Inshore Samoan Fish Communities*. Report to the Department of Marine and Wildlife Resources, Pago-Pago, American Samoa, 48 pp. (1982).
- Wass, R. C. *An Annotated Checklist of the Fishes of Samoa*. NOAA Technical Report SSRF-781, U.S. Department of Commerce, 43 pp. (1984).
- Whaylen, L., and D. Fenner. *Report of 2005 American Samoa Coral Reef Monitoring Program (ASCRMP)*. Report to the Department of Marine and Wildlife Resources, American Samoa, 40 pp. (2005).
- WHO (World Health Organization). Diet, food supply, and obesity in the Pacific. Regional Office for the Western Pacific (2003).
- Yamasaki, G., D. Itano, and R. Davis. *A Study of and Recommendations for the Management of the Mangrove and Lagoon Areas of Nu'uuli and Tafuna, American Samoa*. Biological Report Series No. 10. Department of Marine and Wildlife Resources, Pago-Pago, American Samoa (1985).
- Zeller, D., S. Booth, P. Craig, D. Pauly. Reconstruction of coral reef fisheries catches in American Samoa, 1950–2002. *Coral Reefs* **25**: 144–152 (2006).
- Zeller, D., S. Booth, G. Davis, D. Pauly. Re-estimation of small-scale fishery catches for U.S. flag-associated island areas in the Western Pacific: The last 50 years. *Fish. Bull.*, **105**: 266–277 (2007).