Coral Reef Fishery Ecosystem Assessment in American Samoa

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Western Pacific Regional Fishery Management Council
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CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

Factors that affect coral reef fishery ecosystems can be grouped into two categories: man-made and natural disturbances. Presumably, these factors interact with each other and their interactions probably compound their impacts. Jackson (1997) has made the most compelling historical analyses of various factors affecting a coral reef fishery ecosystem with the Caribbean as a case study, to date. He pointed out that overfishing especially of mega-vertebrates and coral reef degradation through sedimentation has completely altered the processes on Caribbean coral reefs long before scientific research started. The rapid growth of Jamaica when it became an English colony in the 17th century led to the overharvesting of marine turtles that used to number in the hundreds of millions. Mega-vertebrates (turtles, manatees, monk seals) were keystone species. Their decimation dramatically reduced, and qualitatively changed, grazing and predation on seagrasses and sponges. These significant changes led to the loss of production in adjacent ecosystems and changed the structure of food chains. Large herbivores and carnivores are now ecologically extinct on Caribbean coral reefs and seagrasses, where food chains are presently dominated by small fishes and invertebrates that specialize on chemically-defended prey.

Sedimentation due to deforestation and poor agricultural practices also contributed to the massive decline of Caribbean coral reefs (Cortes and Risk 1985, Rogers 1985, 1990, Tomascik and Sander 1985, 1987, Bak 1987, Jackson and others 1989, Guzman and others 1991). Jackson (1997) pointed out that extensive deforestation in Barbados already started in the 17th century to pave for sugar plantations. The vegetation of the island was also completely destroyed thrice by hurricanes (references in Lewis 1984) which perhaps led to significant runoff of sediments degrading coral reefs and seagrass beds and probably led to the decline of Acropora palmata. Recent historical events such as the loss and/or decline in the abundance of herbivores have also contributed to the reef decline. Corals had catastrophic mortality due to overgrowth by macroalgae. Macroalgae overgrew corals after the heavy mortality of the algal grazer Diadema sea urchin and, by the 20th century, this was exacerbated by the large decline of large herbivorous fishes.

The negative impacts of storms and hurricanes on coral reefs (references in Rogers and others 1991) are well documented. The damage on coral reefs due to the physical force of strong waves (also by tsunami) includes sand-blasting and abrasion of coral tissues, dislodging of fragments and/or whole colonies and smothering and/or burial with sand. Tsunami waves together with earthquakes can crack large massive coral colonies and coral limestone (personal observation in Tutuila). The physical impact of strong waves can alter benthos characteristics and sometimes lead to abundance of macroalgae (Rogers and others 1991). The impacts of cyclones have been similarly speculated to cause decline of coral reef fisheries catch in American Samoa (Zeller and others 2000). The decline in fish catch can be attributed to the loss of habitat (e.g., live branching coral). However, reef fish species vary in their habitat preference so the possibility of increase in abundance of some other species cannot be ruled out.

The main objectives of this report are (1) to establish historical trends in catch-per-unit effort (CPUE) and fish catch composition in American Samoa, and (2) to correlate these trends with known events as a very general way of inferring their impacts of these historical events on the coral reef fisheries. Previously, Sabater and Carroll (2009) analyzed the CPUE data for all gears combined and family-level fish catch analyses in American Samoa. They showed no apparent general trend in the CPUE data across the years. They also showed significant variability in the fish catch composition in the combined catch analyses for all the gears. The fish families that contributed to the catch composition differences among the years were the surgeonfishes, groupers, parrotfishes, soldierfishes and rudderfishes. In related studies, Birkeland and others (1997, 2004) and Green (2002) correlated trends in hard coral cover in the Fagatele Bay National Marine Sanctuary and Tutuila Island with the occurrence of crown-of-thorns infestation, cyclones and bleaching events. There were some indications that cyclone and bleaching events potentially decreased hard coral cover in Tutuila Island. However, the separate impacts of these natural disturbances could be not be discriminated. In Fagatele Bay, the decline in hard coral cover after bleaching was evident for those colonies situated on the reef flat presumably due to more intense sunlight and increased warming. Fenner (2004) reported 50 percent morality of staghorn corals in a lagoon in Tutuila Island during the bleaching events in 2001 and 2002. It could not be ascertained how the loss of these habitats after cyclone and bleaching events impacted coral reef fishes and fisheries in American Samoa.

In this study, the CPUE data for various fish families for each fishing gear (shore-based and boat-based) were analyzed. In addition, species group catch composition among the fishing years were analyzed. The historical patterns in CPUE and catch composition with known severe natural disturbances and the timing of changes in the fishing technology in American Samoa were correlated. Specifically, the impacts of the ban of the self-contained underwater breathing apparatus (SCUBA) spearfishing and the cyclones that hit American Samoa during the last 30 years: 1981 (Esau), 1987 (Tusi), 1990 (Ofa), 1991 (Val), 2004 (Heta) and 2005 (Olaf) (Craig 2009) were especially of interest. Tusi and Olaf caused heavy damage in Manua while Ofa and Val were hard on Tutuila. The tsunami that hit American Samoa on June 2009 was highly devastating, although the damage on the reef was minimal and mostly on the reef flat (Fenner, personal communication). There were no significant fish kills reported. (One fish was photographed floating and dead after the tsunami presumably due to the waves' physical impact.). There was a crown-of-thorns starfish infestation in 1978. In addition, there were coral bleaching events in 2001, 2002 and 2004. It is hypothesized that there would be changes in CPUE after banning SCUBA spearfishing and decline in CPUE after the cyclone and tsunami occurrence. In addition, it is also hypothesized that there will be significant changes in fish group catch composition around the occurrence of these severe natural disturbances.

2 Material and Methods

Annual CPUE data per fishing gear expressed as weight-per-unit-hour were calculated. The data analyzed and the trends generated were based from the creel survey program data under the Western Pacific Fishery Information Network (WestPacFin). The methods conducted by this fisheries-dependent program are described in Sabater and Carroll (2009) and briefly summarized here.

The creel survey program that monitors fisheries-dependent data in two categories (shore-based or shoreline and boat-based or offshore) has been conducted by the American Samoa Department of Marine and Wildlife Resources. In general, the fisheries can be grouped into subsistence (non-commercial) where a significant portion of the catch is kept for personal or family consumption and the commercial where most if not all of the catch is sold. Subsistence fishing does not involve use of boats (usually done from the shore or shore-based fishery) while commercial fishing might involve a boat (boat-based fishery) or also fishing from the shore.

The shore-based fishery monitoring started in 1977 (Wass 1980, 1984) was intermittent in the 1990's (Ponwith 1991, McConnaughey 1993, Saucerman 1995a, 1995b) and became more regular since 2000 (Coutures 2003). The fishing methods under a shore-based fishery include rod-and-reel, throw net, gleaning, bamboo pole, gill net and spear. At a given two-hour sampling period, the shore-based creel survey involves a roadside survey for fishing effort data and later a fishermen participation interview survey during the reverse direction for fish catch data. During the participation survey, a fisherman is interviewed using a standard set of questions and length and weight of fish are recorded. Fish are identified using Samoan names. The shore-based survey has only focused on the south side of Tutuila island and in the Manua.

The boat-based fishery monitoring started in 1982 and is more regular than the shore-based survey. The fishing methods under the boat-based fishery include trolling, longlining, bottomfishing, spearfishing (snorkel and SCUBA; however, SCUBA has been outlawed since 1992), and mixed bottomfishing and trolling. Creel survey data collectors intercept the boat at known docks. Fishermen are interviewed with a standard set of questions and a sub-sample of catch is taken for fish length and weight measurements. Like the shore-based survey, fish are identified by their Samoan names.

Three levels of analyses were conducted to infer the impact of severe natural disturbances on the coral reef fisheries in American Samoa: (1) trends in CPUE were roughly correlated with the occurrence of known disturbances in specific years; (2) analysis of variance of CPUE between years of SCUBA spearfishing and banned SCUBA spearfishing; and (3) multivariate analysis of species composition in relation to disturbances and changes in fishing technology.

Analysis of variance using general linear model was conducted on the annual CPUE between years with no scuba spearfishing ban and when the ban took effect in the highly fished groups (surgeonfish, parrotfish, miscellaneous reef fish, crustaceans and groupers). Species groupings used were the coral reef ecosystem management unit species (CREMUS) categories. Homogeneity of variances was analyzed using Levene's test. In cases of heterogeneity, a non-parameteric analysis of variance was conducted. All analyses were conducted using Statistica 6.1.

Fish catch compositions across the years were analyzed for spearfishing, rod and reef and shore-based spearfishing using multivariate data analyses. Species groupings used were the CREMUS categories. Data was transformed to log (x + 1) and used in cluster analyses (group linkage), multi-dimensional scaling and analysis of similarities (ANOSIM). Factors used as categories in ANOSIM were disturbance (presence or absence in each year) and scuba spearfishing ban (yes or no in each year). The significance of groupings in the analysis of similarity was tested using randomization procedures (999 permutations). All analyses were conducted using Primer 5.1.

3 Results and Discussion

Determining the impact of severe natural disturbances such as cyclones, hurricanes and tsunamis on fish stocks is difficult given the background noise in the variability of processes affecting natural populations. The timing of these events also confounds the impacts. In addition, these natural disturbances are also not amenable to experiments that make the analyses of their impacts more complicated. Natural populations fluctuate in number through time due to variabilities in the processes operating in the pre-recruitment, recruitment and post-recruitment stages of marine organisms. Therefore, inferring impacts entails looking at pattern congruence among fish stocks and/or significant changes relative to the whole temporal trend in CPUE and changes in fish composition.

The low fish biomass and low abundance of large fish in American Samoa have been mainly attributed to the impact of fishing. Williams and others (2010) showed a trend of low fish biomass with high population density among US territories and remote island reefs in the Pacific. This decline in fish biomass has been correlated with increased population in American Samoa since the 1990's (Waddell and others 2005). However, it has also been pointed out there has been a general trend of decrease in fishing effort (Sabater and Caroll 2009) and economics data from WestPacFin indicated declining price for fish, which suggests a decreasing demand (Figures 1 and 2).

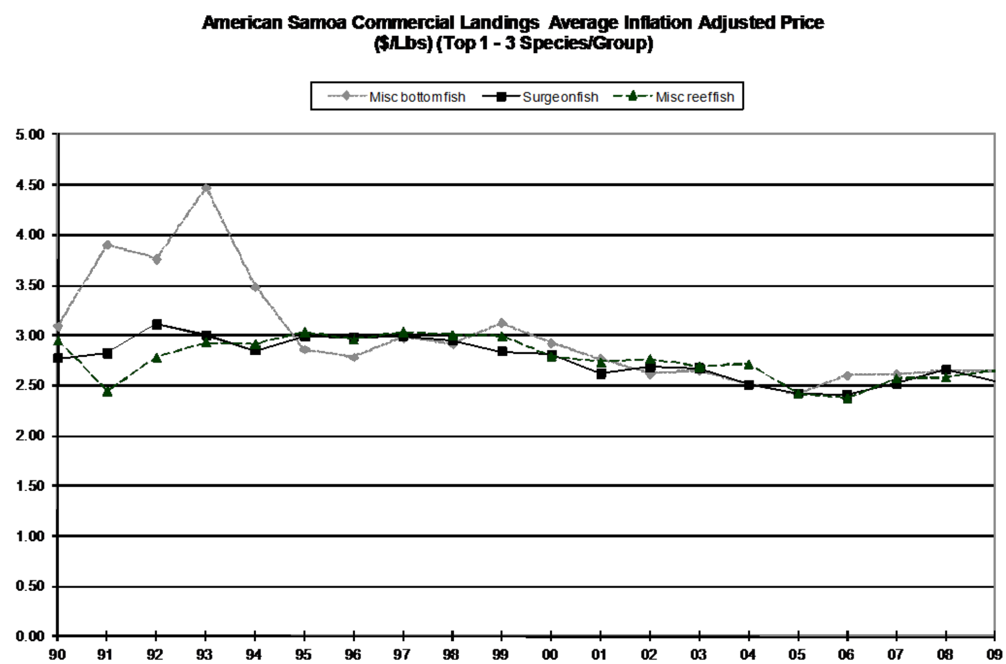

Figure 1. Inflation-adjusted fish prices for miscellaneous bottomfish, surgeonfish and miscellaneous reef fish in American Samoa.

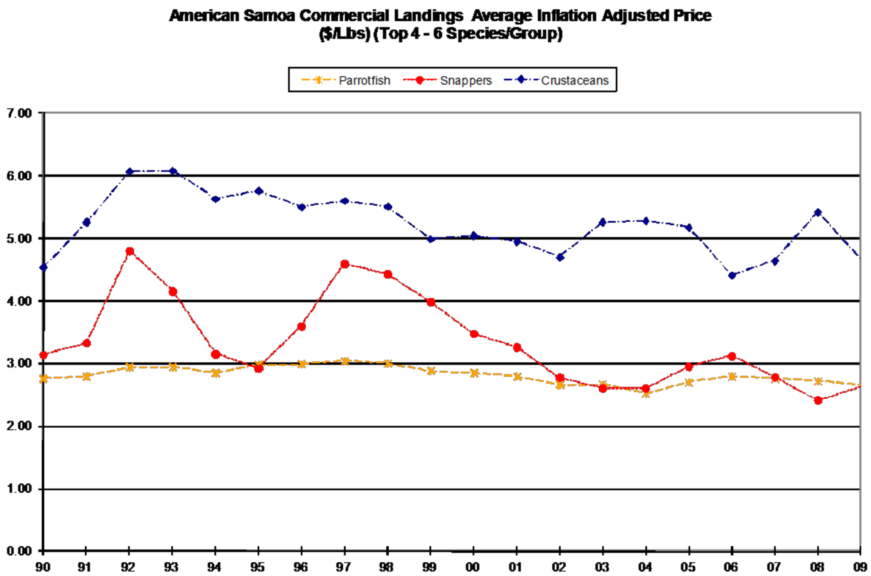

Figure 2. Inflation-adjusted fish prices for parrotfish, snappers and crustaceans in American Samoa.

These declining trends in fish prices over the last 19 years were statistically significant for the top fished groups based on regression analyses (miscellaneous bottomfish, $p < 0.001$; surgeonfish, $p < 0.0001$; miscellaneous reef fish, $p < 0.05$); parrotfish, $p < 0.01$; snappers , $p < 0.01$; crustaceans, $p < 0.05$).

There were highly similar temporal trends in the CPUE of various CREMUS (surgeonfish, parrotfish, miscellaneous reef fish, crustaceans, groupers and miscellaneous bottomfish) from 1986 to 2011 (Figures 3 and 4).

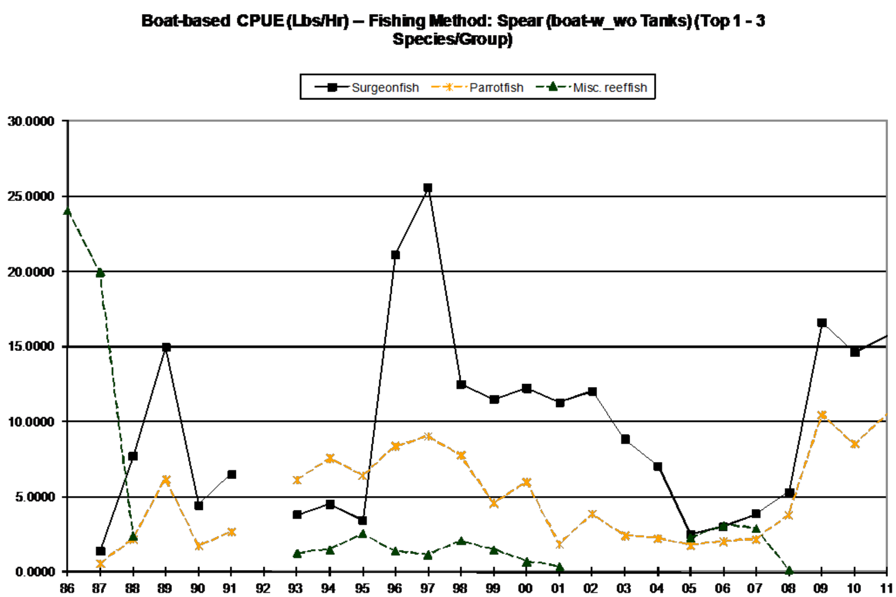

Figure 3. Trends in CPUE (lbs/hr) for surgeonfish, parrotfish and miscellaneous reef fish for commercial reef spear fishery (boat-based).

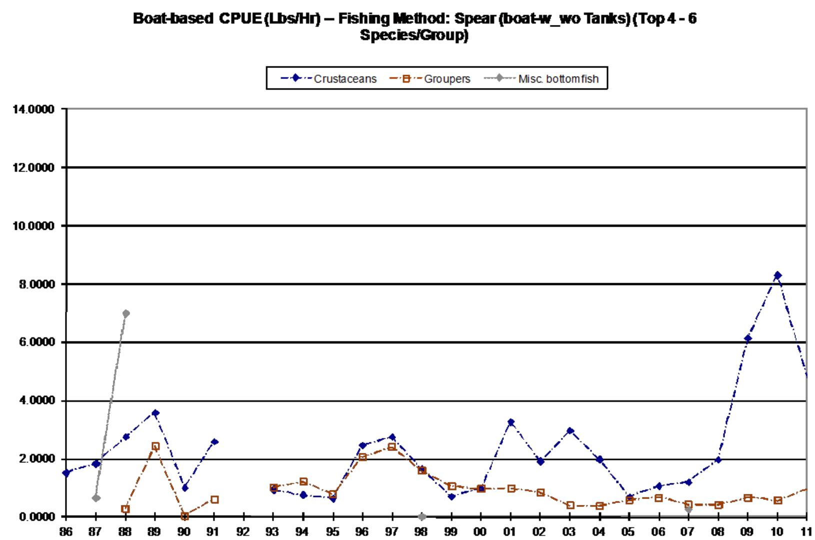

Figure 4. Trends in catch-per-unit (lbs/hr) for groupers, crustaceans and miscellaneous bottomfish from the commercial coral reef spear fishery.

Four of the six CREMUS groups had low CPUEs in 1987-1988 when cyclone Tusi hit American Samoa. Tusi was supposed to be particularly damaging to Manua (Craig 2009). All four CREMUS groups showed a decline in CPUE when the cyclone Ofa hit Tutuila hard in 1990. On the other hand, all of these groups showed an increase in CPUE in 1991 when cyclone Val hit Tutuila Island very hard. There were no declines in CPUE in 2009 during the tsunami that wiped out one village in Tutuila. However, there were declines in CPUE in 3 of the 4 CREMUS groups after 2009 (in 2010 and 2011). The patterns in CPUE differed for CREMUS collected through gleaning from 1990 to 2010 (Figure 5).

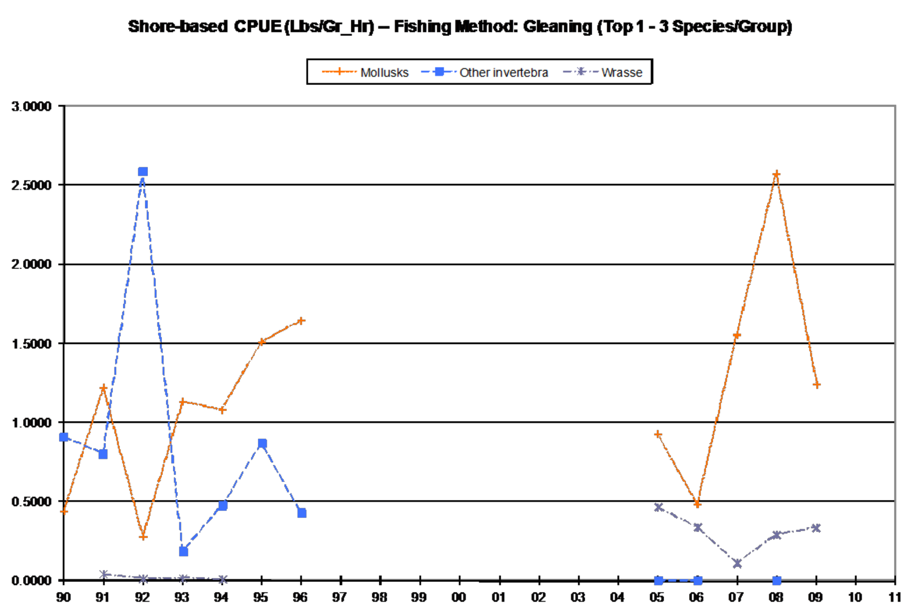

Figure 5. Trends in CPUE (lbs/hr) for mollusks and other invertebrates in gleaning. (The gap from 1997 to 2005 is due to non-collection of data).

There were low CPUEs in 1990 and 1991, but this seems to reflect more of a temporal variability especially when viewing the whole time series. However, there was a large drop in CPUE for mollusks in 2009 when a tsunami hit the island. Gleaning collects invertebrates and other CREMUS in the reef flat, which had more damage during the 2009 tsunami.

There were no apparent trends in the CPUE of groupers, jacks, atulai, mullet and other finfish based on data from bamboo pole fishing relative to known severe natural disturbances that occurred in American Samoa (Figure 6).

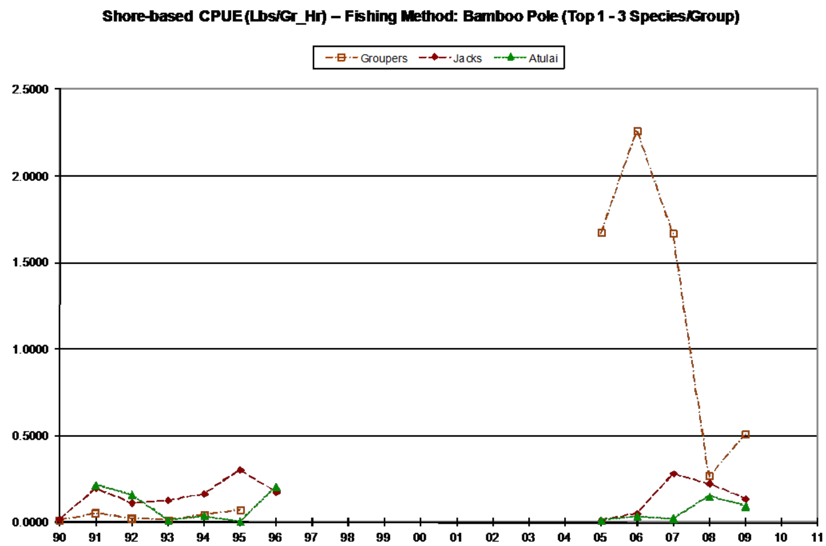

Figure 6. Trends in CPUE (lbs/hr) for groupers, jacks and atulai (big eye scad) from bamboo pole. (The gap from 1997 to 2004 is due to non-collection of data).

On the other hand, jacks, atulai, mullet and other finfish CPUE declined in 2009 (Figure 7).

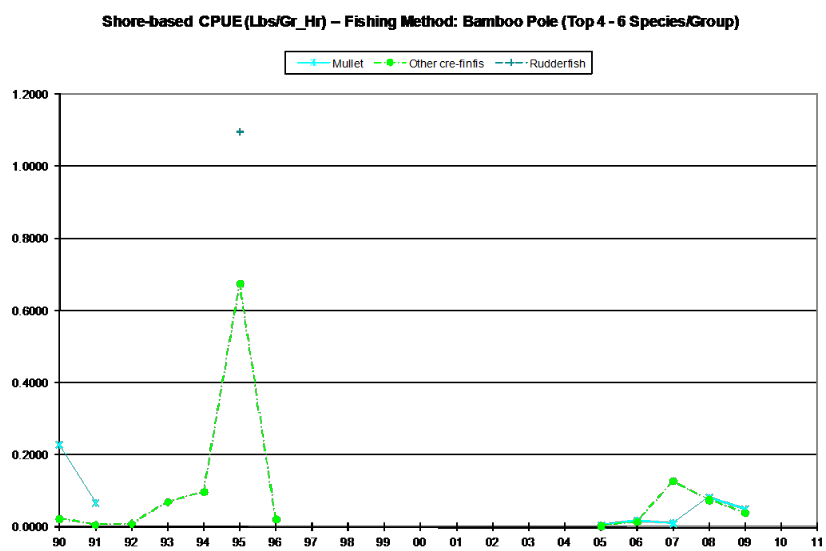

Figure 7. Trends in CPUE (lbs/hr) for mullet and other finfish from bamboo pole. (The gap from 1997 to 2004 is due to non-collection of data).

Like gleaning, bamboo pole operates in the shallow reefs. Only the CPUE of the groupers and the other finfish in the rod-and-reel have discernible patterns from 1990 to 2009. Both showed low CPUEs in 1990 when the cyclone Ofa hit the Territory (Figure 8).

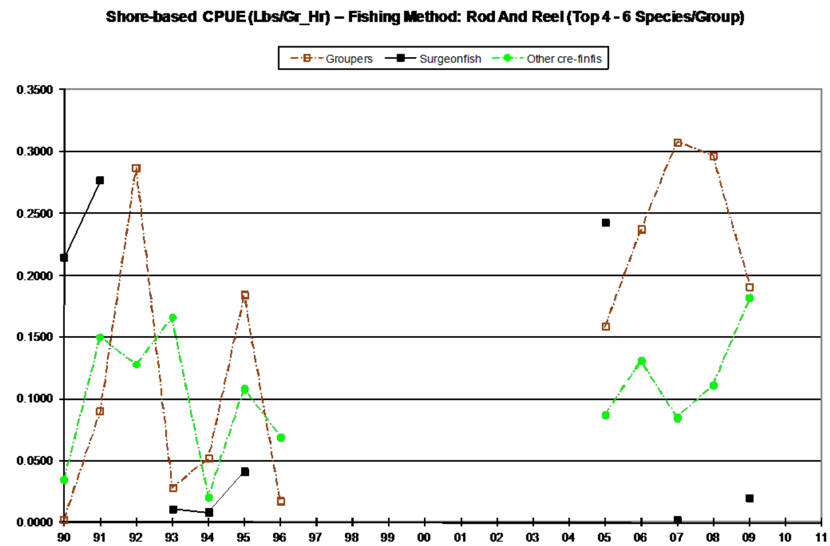

Figure 8. Trends in CPUE (lbs/hr) for groupers, surgeonfish and other finfish from rod-and-reel. (The gap from 1997 to 2004 is due to non-collection of data).

Groupers caught by rod-and-reel declined in catch in 2009. On the other hand, other CREMUS finfish increased in CPUE in the same year.

There were similar patterns in the CPUE trends for mollusks, surgeonfish, groupers, parrotfish and squirrelfish caught through shore-based spear snorkeling (Figures 9 and 10).

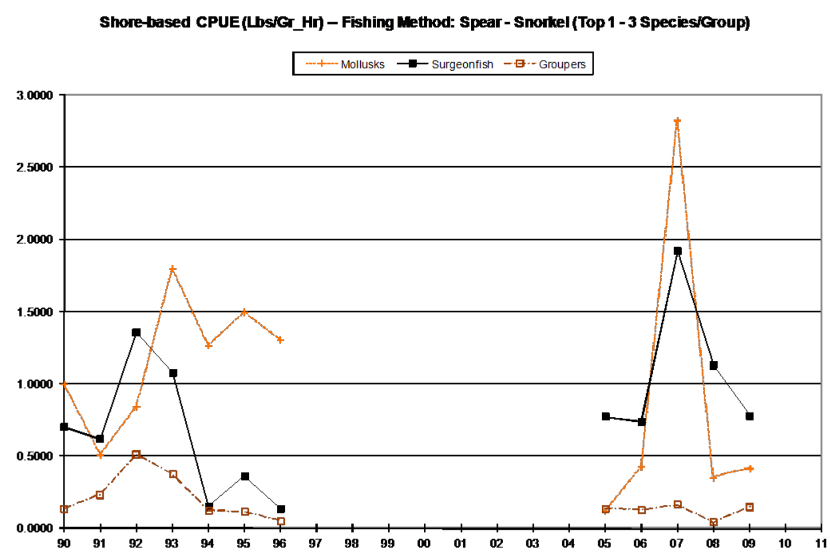

Figure 9. Trends in CPUE (lbs/hr) for mollusks, surgeonfish and groupers from shore-based spear-snorkeling. (The gap from 1997 to 2004 is due to non-collection of data).

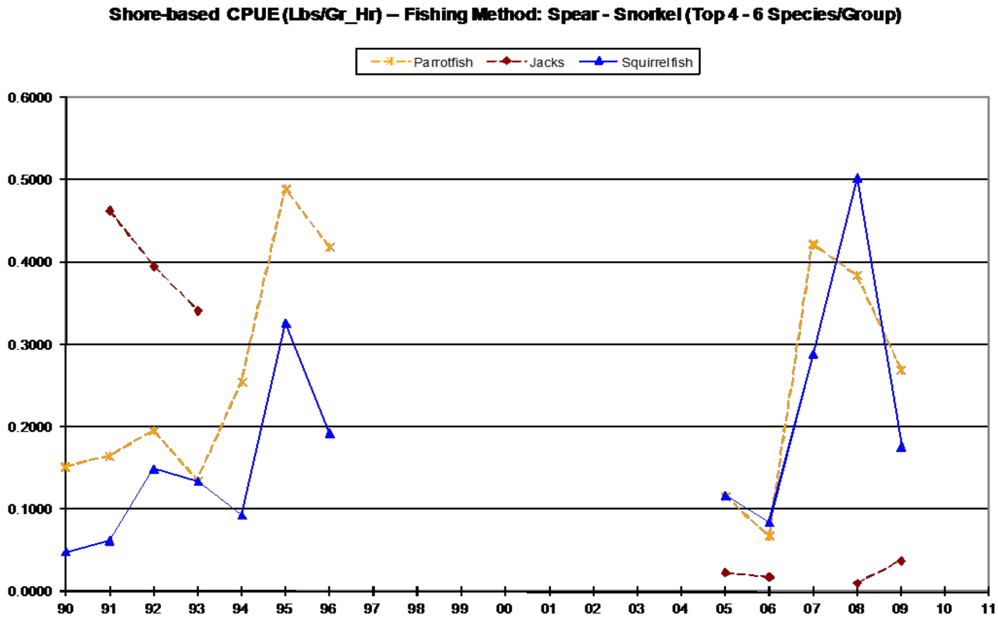

Figure 10. Trends in CPUE (lbs/hr) for parrotfish and squirelfish from shore-based spear-snorkeling. (The gap from 1997 to 2004 is due to non-collection of data).

All of these groups had low CPUEs as well in 1990 during cyclone Ofa and in 2009 during the tsunami. In the shore-based throw net fishing (Figures 11 and 12), there were similar trends of low CPUE in 1991 for mullet, surgeonfish, atulai, goatfish, jacks and other finfish. However, for the latter CREMUS groups only the mullets declined in CPUE in 2009.

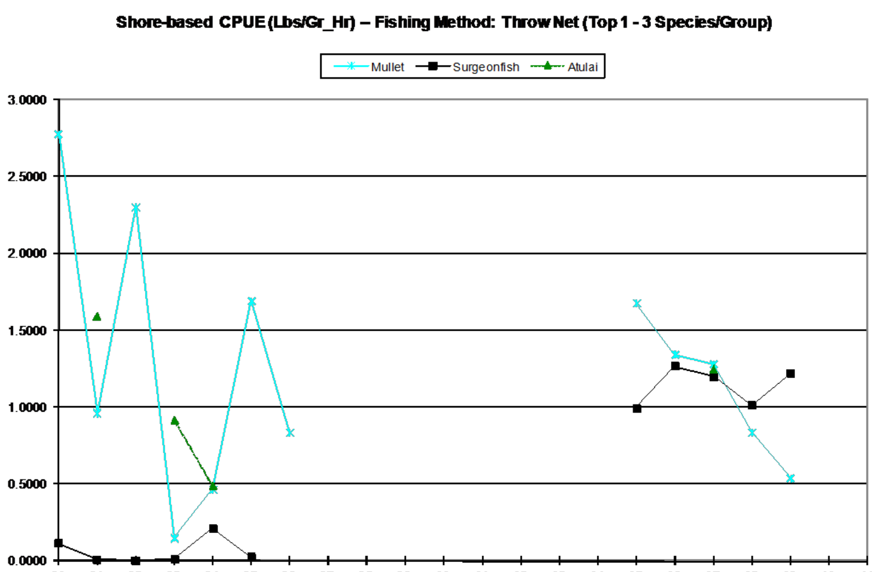

Figure 11. Trends in CPUE (lbs/hr) for mullet, surgeonfish and atulai from shore-based throw net. (The gap from 1997 to 2004 is due to non-collection of data).

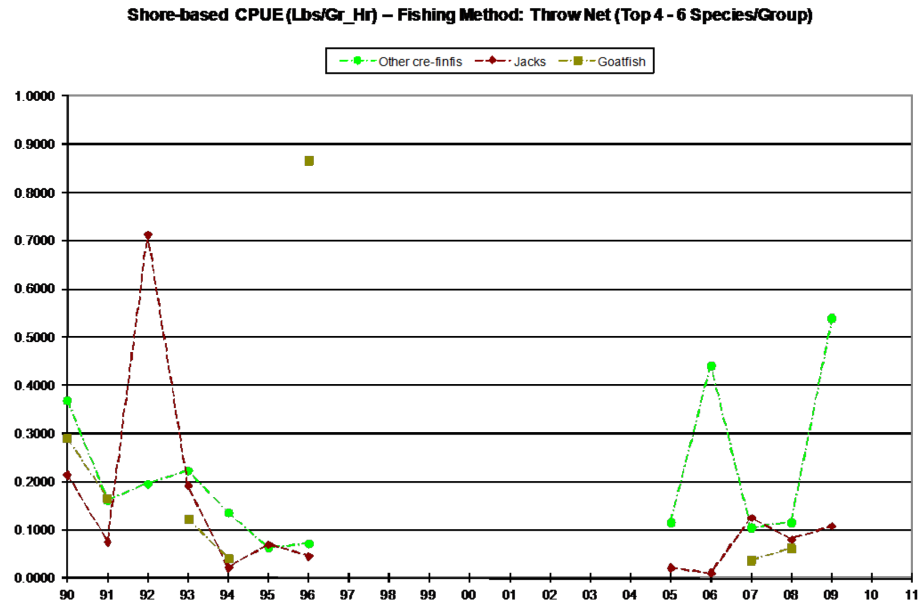

Figure 12. Trends in CPUE (lbs/hr) for various finfish, jacks and goatfish from shore-based throw net. (The gap from 1997 to 2004 is due to non-collection of data).

There were six years (cyclones in 1987, 1990, 1991, 2004, 2005; tsunami in 2009) with disturbance and 16 years with no disturbance in the data analyses for spearfishing. The analysis of similarity for catch in spearfishing between years with and without disturbance indicated significant differences in catch composition (global R = 0.38, p = 0.006). There was a 'weak' tendency for years with disturbance to group together based on cluster analysis and multidimensional scaling (Figures 13 and 14).

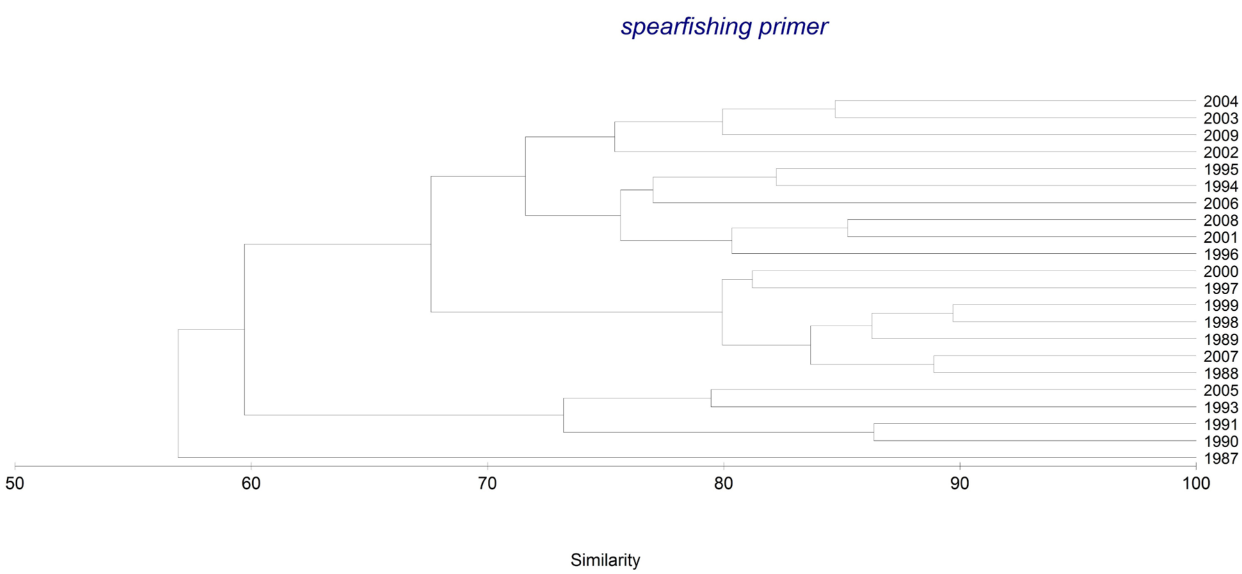

Figure 13. Cluster analyses of the catch composition in spearfishing (cyclone years: 1987, 1990, 1991, 2004 and 2005; tsunami: 2009).

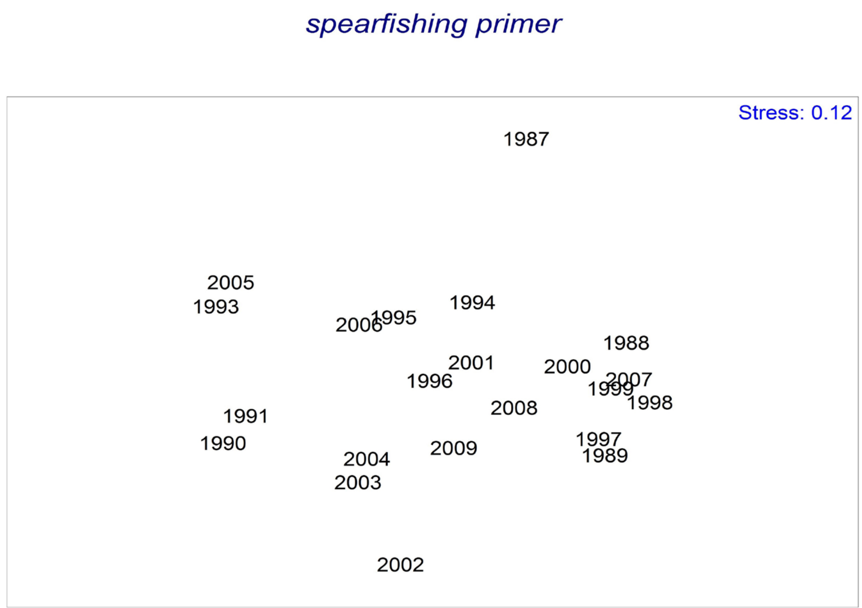

Figure 14. Multi-dimensional scaling analyses of the catch composition in spearfishing (cyclone years: 1987, 1990, 1991, 2004 and 2005; tsunami: 2009).

However, 1993 was also grouped with these 'cyclone' years although no cyclone was reported that year. The ban of scuba spearfishing has not altered the species composition in the catch of spearfishing (global R = 0.022, p = 0.34). This suggests that SCUBA spearfishing was not selective for some fish groups.

There were four years (cyclones in 1990, 1991, 2005; tsunami in 2009) with disturbance and eight years with no disturbance in the data analyses for shore-based spearfishing. The analysis of similarity for catch composition indicated no significant differences (global R = 0.04, p = 0.33). There was also no pattern of grouping based on disturbance from the cluster and multidimensional scaling analyses (Figures 15 and 16).

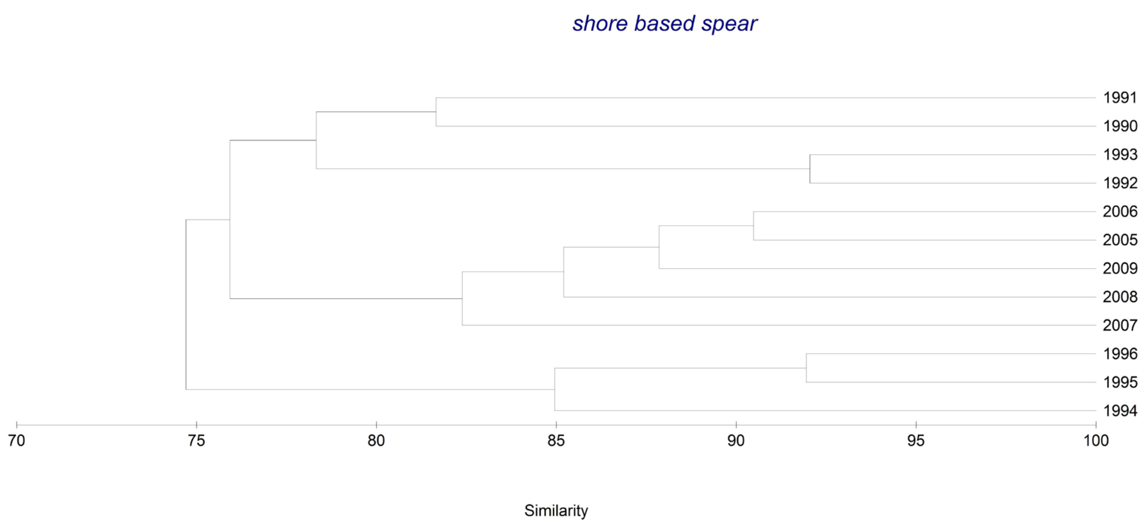

Figure 15. Cluster analyses of the catch composition in shore-based spearfishing (cyclone years: 1990, 1991 and 2005; tsunami: 2009).

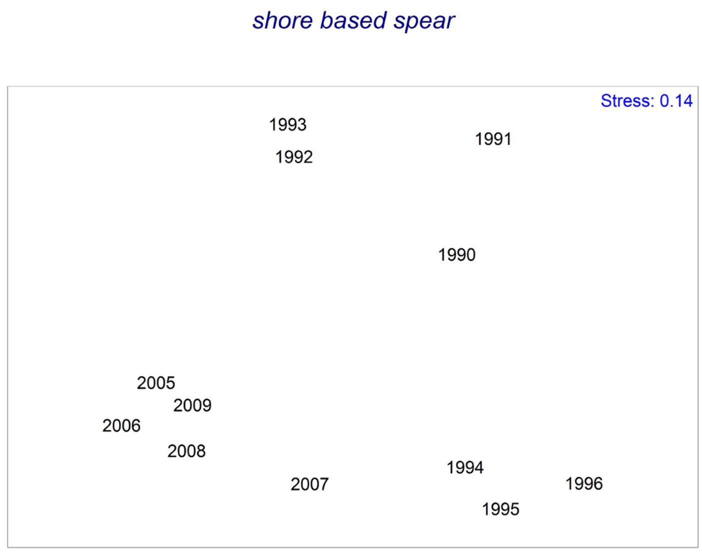

Figure 16. Multi-dimensional scaling analyses of the catch composition in shore-based spearfishing (cyclone years: 1990, 1991 and 2005; tsunami: 2009).

However, the analysis of similarity indicated significant differences in catch composition between years with and without scuba spearfishing (global R = 0.51, p = 0.05).

There were four years (cyclones in 1990, 1991, 2005; and tsunami in 2009) with disturbance and eight years with no disturbance in the data analyses for rod-and-reel. The analysis of similarity for catch in the rod-and-reel with disturbance as a factor indicated no significant difference in composition (global R = 0.04, p = 0.35). The absence of grouping for disturbance and non-disturbance years was also reflected in the cluster and multidimensional scaling analyses (Figures 17 and 18).

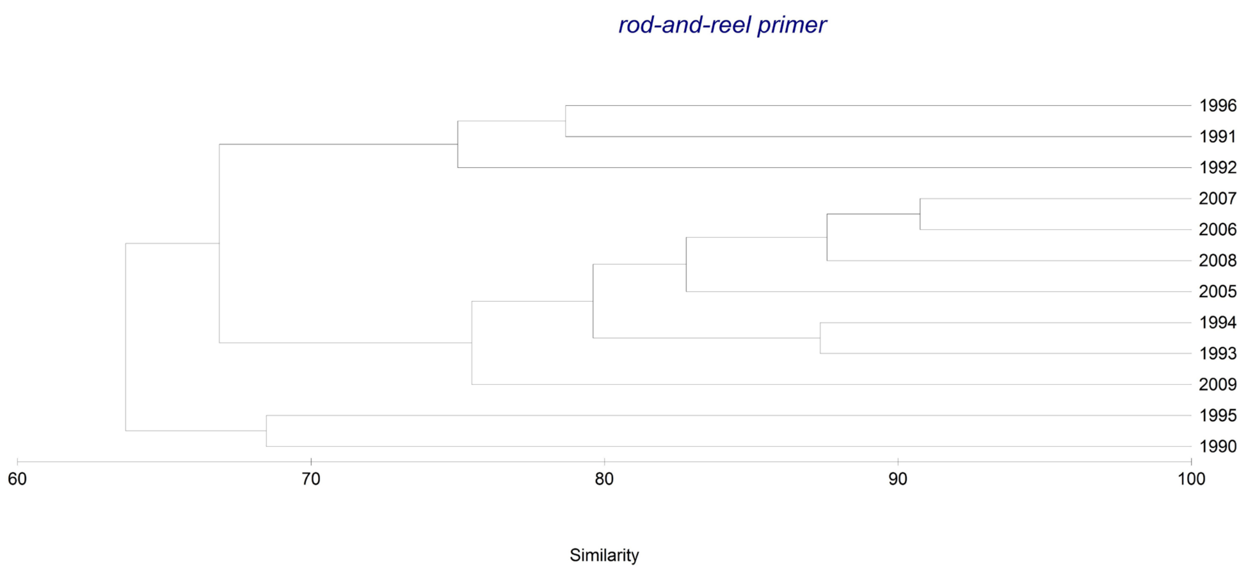

Figure 17. Cluster analyses of the catch composition in rod-and-reel (cyclone years: 1990, 1991 and 2005; tsunami: 2009).

Figure 18. Multi-dimensional scaling analyses of the catch composition in rod-and-reel (cyclone years: 1990, 1991 and 2005; tsunami: 2009).

There were 14 years and 11 years, with and without scuba spearfishing, respectively, on the analysis of the impact of scuba spearfishing. The general linear model analyses of variance indicated significant differences in the catch-per-unit-effort for surgeonfish, parrotfish, miscellaneous reef fish and crustaceans between scuba spearfishing and no scuba spearfishing years (Table 1).

Table 1. One-way analyses of variance for the annual CPUE of various fishing target groups with scuba spearfishing as factor.

	Df	SS	MS	F	p
surgeonfish	1	1128.44	1128.44	22.13	0.00
parrotfish	1	342.02	342.02	38.15	0.00
misc. reef fish	1	105.28	105.28	4.69	0.05
crustaceans	1	51.50	51.50	37.43	0.00

There were significantly higher CPUE during scuba spearfishing years for surgeonfish, parrotfish and miscellaneous reef fish. On the other hand, there was higher CPUE for crustaceans (mainly lobsters) after the ban on scuba spearfishing. The non-parametric analysis for CPUE in similar analysis for groupers indicated that CPUE was higher during the scuba spearfishing years (Table 2).

Table 2. Mann-Whitney U test for the impact of scuba spearfishing on the catch per unit effort in groupers.

	Rank Sum scubaspearfishing	Rank Sum no-scubaspearfishing	U	Z	p-level
groupers	178.00	98.00	32.00	2.09	0.04

4 Conclusion

In summary, the analysis of CPUE in spearfishing indicated higher CPUE using scuba for most fish groups except the crustaceans. This was expected since fishermen can stay in the water longer and go deeper making fishing more efficient. However, there are some ‘tenuous’ indications that CPUE declined in some cyclone years and during the year that a tsunami hit American Samoa (1990-1991 cyclones and tsunami in 2009). There was an exception of higher catch during the tsunami year. This concurrence suggests that these fish groups experienced a similar phenomenon. This concurrence could not be explained by natural processes such as recruitment variability nor similar changes in fish abundance since such processes most probably operate independently, especially among disparate species groups. Massive fish kills were also not observed during such events. It is hypothesized that these disturbances mostly impacted fishing behavior (less fishing activity and/or inclement weather adds for more effort for the same amount of fish or less) more than a decline in fish stocks. However, we cannot also rule out changes in fish behavior such as movement to deeper waters or other habitats due to these disturbances. There were also evidence that catch composition varied between disturbance and non-disturbance years. This also suggests disturbances affect some species groups differently. Decline in fish stocks can be ruled out as an alternative explanation since there were no massive fish kills recorded in these years. However, the other explanation is reduced catch due to fish movement. Although the latter cannot be ruled out, fish movement probably would be momentary and would not affect the CPUE on an annual basis.

The decline in CPUE has always been associated with decline in fish stocks. In fact, decline in CPUE has always been an ‘overfishing’ indicator. In reality, CPUE reflects a more complicated picture. It reflects the variability of fishing skills among fishermen and most probably changes in fish behavior. This report has pointed to some ‘tenuous’ evidence of negative impact of natural disturbances on coral reef fishery. On the other hand, there are some indications that the same disturbances have impacted the bottomfishing fishery, so there is some inverse relationship. The impact of severe natural disturbances on coral reef fisheries has always not been clear and will be difficult to show due to their timing and the background variability of processes affecting natural populations. However, this does not mean that they are not important factors. In contrast, the impact of these disturbances should be studied as they have implications on what can be said of the status of exploited stocks.

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