

Western Pacific Region Reef Fish Trends

*A Compendium of Ecological and Fishery Statistics for Reef
Fishes in American Samoa, Hawai'i and the Mariana Archipelago,
in Support of Annual Catch Limit (ACL) Implementation*

Prepared for
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October 4, 2010

Introduction

The Magnuson-Stevens Reauthorization Act (MSRA) of 2006 requires fishery management councils to submit fishery management plans for all fisheries under their authority that require conservation and management. These plans must “establish a mechanism for specifying annual catch limits (ACL)... at a level such that overfishing does not occur in the fishery, including measures to ensure accountability.” Ultimately these ACLs are policy decisions on the part of fishery management councils, but they should be “informed by risk analysis and cannot exceed the Acceptable Biological Catch (ABC)”, as set by the Scientific and Statistical Committee of each council (Witherell and Dalzell, 2008). For fisheries not currently experiencing overfishing, MSRA requires that ACLs are to be established by 2011.

The Western Pacific Region Fisheries Management Council (WPRFMC) is one of the eight fishery management councils reauthorized by the MSRA. WPRFMC creates policy recommendations for Exclusive Economic Zone (EEZ) waters in Hawai'i and the U.S. territories of the Commonwealth of the Northern Mariana Islands (CNMI), Guam, and American Samoa. All four of these areas support significant coral reef fisheries for which ACLs must be developed by 2011. The purpose of this technical report is to provide data and preliminary analysis of trends in these reef fisheries to facilitate the implementation of ACLs within the Western Pacific Region.

Methods

Study Regions

The region of study includes three archipelagos, namely American Samoa, the Hawaiian Archipelago and the Mariana Islands. The Hawaiian Archipelago is subdivided into the Main Hawaiian Islands (MHI) and the Northwestern Hawaiian Islands (NWHI). Stringent fishing restrictions have been implemented in NWHI (WPRFMC 2009a), with capture for scientific purposes. All fish caught for sustenance must be consumed in the NWHI.

The Mariana Archipelago, a continuous ecological unit, is politically divided into two separate entities: The Territory of Guam; and the Commonwealth of the Northern Mariana Islands (CNMI). Given this political reality, many of the analyses we applied at archipelagic scales were also applied separately to CNMI and Guam.

American Samoa consists of a southern archipelago, Tutuila, Manua Islands and Rose Atoll; and in the north of the US EEZ of Swains Island.

This document aims to analyze reef fish fisheries on both archipelagic and local scales with the term ‘local’ or ‘location’ used in reference to any scale smaller than archipelagic. For example, we treat Tutuila Island as a location in the American Samoa Archipelago and Guam Island as a location in the Mariana Archipelago. The term ‘area’ may refer to an archipelago or location, depending on the context.

Biomass Data

Biomass estimates for reef fish populations were provided by the National Marine Fisheries Service Pacific Islands Fisheries Science Center's (NMFS PIFSC) Coral Reef Ecosystem Division (CRED). As part of their Reef Assessment and Monitoring Program (RAMP), CRED conducts biological surveys on a biennial basis at 55 U.S. Pacific Islands, including the islands analyzed in this document (Williams, 2010). Since June 2007, the surveys have employed a stratified random sampling design within 0-30m hard-bottom habitats. The surveys aim to estimate a reef-fish density by species in three different hard-bottom habitat strata and then extrapolate archipelagic family biomass based on estimates of habitat area.

We requested RAMP biomass estimates for the following eleven coral reef fish families which typically account for the majority of reef fish catches: acanthuridae, carangidae, carcharhinidae, holocentridae, kyphosidae, labridae, lethrinidae, lutjanidae, mullidae, scaridae, and serranidae. The remaining families were combined under the category 'other biomass' such that there were a total of twelve categories (eleven families plus 'other'). (Note: In this document the term 'fish' will be used for all marine organisms that might be targeted in a fishery, i.e. 'fish' may include invertebrates such as crab, lobster, etc.)

In Guam, carangids, carcharhinids and kyphosids were not observed in the most recent RAMP surveys. All three families are known to exist in Guam and may even compose significant portions of the catch record, so we approximated their biomass using the corresponding estimated biomass density for nearest and most ecologically similar region, CNMI. We believe that using these proxies was justified because Guam and CNMI, while politically distinct, are contiguous parts of the same archipelago.

Catch Data

Hawai'i requires commercial fishermen to obtain a Commercial Marine License (CML) and requires all CML holders to submit a monthly logbook of catch data to the Hawai'i Division of Aquatic Resources (HDAR, 2010). The CML catch database extends from 1948 onwards but rigorous quality control procedures for logbook data were not applied until 1966 onwards so we have excluded data prior to that year. The Hawai'i data is reported by statistical grids, with which we were able to separate reef fish catches into those from federal and state waters

The NMFS PIFSC Western Pacific Fisheries Information Network (WPacFIN) boat-based and shore-based creel survey data were analyzed for American Samoa, Guam, and CNMI (Table 1). Creel surveys consist of detailed interviews with fishermen, and they aim to document the number and weight of the catch. The following section is taken from Hamm and Tao (2010), which details the creel survey methodology:

To be considered a 'complete and useable' interview [i.e. creel survey], the entire catch must be accounted for, either by direct

measurements and counts or by estimation procedures. Generally speaking and when possible, all fish are identified to the lowest taxonomic level within the capability of the surveyor collecting the interview and the number of individuals counted or estimated, individuals weighed and/or measured, and total weights collected or calculated based on samples collected.

Since this document aims to support the creation of ACLs for obligate reef-associated species, certain groups of fish included in the catch records were omitted from analysis. These included pelagic species, including all species in the families istiophoridae, scombridae, and xiiphiidae; the schooling carangids *Selar crumenophthalmus* and *Decapterus* spp.; deep-water bottomfish, notably the genera *Aprion*, *Etelis*, and *Pristipomoides*. Additionally, we decided to omit taxa that appeared in less than half of the catch record for a given archipelago on the basis that infrequently caught taxa were unlikely to have ACLs but rather would be incorporated into the ecosystem species category. The Hawaiian Archipelago catch record, for example, consisted of 44 years of data but only taxa that were caught in at least 22 years were included.

For the analyses presented here, the term ‘taxa’ (or ‘taxon’) refers to a designation used in the catch record for a given area. Sometimes catch records identified fish to the species level, but quite often fish were only identified to the genus or family level, creating the opportunity for overlapping designations. Thus, *Naso lituratus* and ‘miscellaneous *Naso* spp.’ are considered two separate taxa here, even though *N. lituratus* is subsumed by the *Naso* spp. label. Table 2 summarizes the number of species and families whose catch records were ultimately analyzed.

Catch data for all reef-associated species are organized by family and presented by archipelago in the attached appendices. With the exception of the Hawaiian logbook data, catch data for individual species are derived from raw samples of creel surveys; they may not represent a wholly unbiased sample of the population of reef-fish caught (Hamm and Tao, 2010). However, these data likely represent the best available information on catch, particularly on the species level, and may help illuminate general trends in reef-based fisheries.

Species Variability in Catch

To ascertain the level of variability in year-to-year species catch, coefficients of variation (or CV, equivalent to the standard deviation of catch divided by the mean catch) were calculated for the ten species with the highest aggregate catch in each archipelago. (In the Mariana Archipelago, catches from CNMI and Guam were evaluated separately.)

Exploited Biomass Estimates

NMFS PIFSC provided annual reef-fish catch by family for American Samoa, CNMI, Guam and Hawai’i in order to estimate the percentage of harvested biomass. These are essential expansions of the aforementioned creel survey data (Hamm, D.,

personal communication). Recent mean annual catch values were expressed as the percentage of biomass harvested per location/archipelago per family. Current RAMP surveys date from 2007 and only the mean catches for the most recent five years on record were used; namely American Samoa 2004-2008, Hawaiian Archipelago 2005-2009, and for the Mariana Archipelago 2005-2008. (The Mariana Archipelago mean catch was four years only because shore-based creel surveys in CNMI did not begin until 2005. Data from 2009 were not yet available.)

Regression analyses also were conducted with biomass as an independent variable and catch as its dependent variable to test for a relationship between catch and biomass on both local and archipelagic scales.

Family Variability in Catch

Variability in reef fish catch by family was analyzed in a manner similar to that used for species-level catch, except that we used expanded catch data, which were standardized for survey effort, rather than raw sample data.

Estimated Trophic Level Calculations

For each archipelago (and the Mariana states CNMI and Guam), the mean trophic score of the aforementioned eleven coral reef families was estimated using sample catch data. Catch data was used for this purpose because calculating family scores required the scores of their constituent species and we did not have species-level biomass data at the time of this analysis. Thus, fishes that were clearly identified to the species level in creel or logbook data were assigned trophic scores using values published from the WorldFish online database Fishbase.org (2000). Weighted family trophic scores were then calculated based on the relative abundance of each species in the family catch record for a given area. Where species information was not available for a given family, the trophic values for all species known to occur in that area were averaged.

Once family trophic scores had been derived, a single 'reef fish' trophic score for the population of all reef fishes (i.e. all families) in a given area was estimated by calculating the weighted average of the respective family trophic scores. 'Reef fish' scores were weighted using two separate measure of relative abundance: biomass data; and expanded catch data. (It was possible to use biomass data here because family-level data were available.) Overall, catch data was available for more families than was biomass data; however, only those eleven coral reef families common to both the catch and the biomass data were used to estimate 'reef fish' scores to enable comparisons between the two methodologies.

Catch in Local versus Federal Waters

We also conducted analyses of catch in local (State or Territory) versus Federal waters. For American Samoa and CNMI the closest available proxies were shore- and boat-based catch data, respectively (i.e. shore-based catch was used as a proxy for catch

in local waters and boat-based catch was used as a proxy for catch in federal waters). Guam also uses the 'boat' and 'shore' designations in its creel surveys, but in that case boat catch is further divided into local boat-based and federal boat-based catch. Hence, local catch in Guam is the sum of local boat-based and shore-based catch, whereas federal catch uses only federal-boat data. Hawai'i logbook data include the location of the catch, so federal and local catch are reported directly for that archipelago.

Results:

In two of three archipelagos (American Samoa and Mariana), the taxa were broadly distributed in terms of yearly catch frequency (Figs. 1 A-C). Only in the Hawaiian Archipelago (Fig. 1 D) were a clear majority of taxa found in every single year of the catch record (57 of 100 taxa), although American Samoa and Guam also had modes equivalent to their full records. In CNMI, there were more taxa that were caught in just five years (half the record) than there were taxa caught every single year. As previously mentioned, taxa found in less than half of the catch record for a given area were excluded from analysis therein.

In terms of catch record diversity, Guam had the most taxa analyzed and many more fish identified to the species level than any other region (Table 2). The Hawaiian Archipelago had the highest family richness. American Samoa and CNMI had similar numbers of families and taxa in their catch records. (Many fish in those areas were vaguely identified, usually only to the family level.)

CV values show significant variability in catch for the ten most abundant species (ranked by total catch weight) in each region (Table 3). In American Samoa and CNMI, CV over the past five years was > 0.5 (indicating that standard deviation was more than half of the mean) for eight of ten species, and in Guam seven of ten species were > 0.5 . American Samoa also had four species with $CV > 1$ in the past five years and seven species with $CV > 1$ over the total record. The Hawaiian Archipelago had lower species catch variability; only one species there had $CV > 0.5$ over the past five years (although a majority had $CV > 0.5$ over the whole record).

Catch variability was less pronounced when examining whole families, although values in American Samoa were still significant (Table 4). In that area, CV was > 0.5 for a majority of families for both the past five years and the whole record, and multiple families had $CV > 1$. The two other archipelagos typically had CV values < 0.5 .

Estimates of the percentage of biomass exploited were minor for most reef fish families at most locations (Table 5). Carangids, kyphosids and lethrinids tended to have the highest exploitation rates; they were the only families to have exploitation $> 50\%$ at some locations. Most other families had low to moderate exploitation rates, ranging from 22.5 % (mullids around Guam Island) to less than 1% (numerous other families in multiple locations).

By location, the percentage of exploited biomass for most families was highest in Guam, particularly when total Guam catches were compared with biomass estimates from Guam Island only. Eleven of the twelve fish categories—nine families and the ‘other’ category for miscellaneous reef fish—had their highest estimated exploitation rates around Guam. However, when Guam catch was compared with whole archipelagic biomass, the percentage exploited was significantly lower. Total carangid catch in Guam, for example, was nearly 160.3% of estimated biomass; however, it was only 7.9% of archipelagic biomass. In CNMI, exploitation rates for lethrinids (22.5%) and carangids (67.4%) were high in the area encompassing Rota to Farallon de Medinilla (FDM).

Exploitation in American Samoa was low for most families but at the island of Tutuila was moderate (> 10%) for carangids and kyphosids.

The Hawaiian Archipelago had uniformly low values, even when the NWHI were excluded. Only two families in MHI, Carangidae and Holocentridae, had harvest rates greater than 1%.

When total reef fish catch (all families) was compared against total biomass, the percentage exploited was typically less than 5% for most locations. Two locations in the Mariana Archipelago—Guam Island; and Guam Island and Banks—exceeded 5%. Guam Island had the highest total exploitation at 8.8%. Reef fish catch from Guam, however, was only 1.3% of archipelagic biomass.

When all twelve reef fish categories were used, regression analyses showed significant relationships between catch and biomass for Guam Island and Banks; and all locations in the American Samoa and Hawaiian Archipelagos (Table 6). The relationship was particularly strong in MHI (P-value < 0.01). When carangid, kyphosid and lethrinid biomasses were removed—on account of the difficulty of visually estimating the biomass of those families—all locations in all three archipelagos showed a significant relationship between these two parameters. The proportions of total catch and total biomass represented by each family are represented graphically in Figs. 3 A-I.

Estimates of family trophic score were fairly consistent between archipelagos (Table 7). Carcharhinids had the highest single family trophic score (4.23 in Hawai’i) and also the highest mean archipelagic score. Scarids had a score of 2.00 in all regions, the lowest individual and mean values for all families.

Overall ‘reef fish’ trophic scores were typically larger when calculated with expanded catch data than with biomass estimates (Table 8). The one exception was the Hawaiian Archipelago, but the difference between the two values there was small (0.09). American Samoa had the largest difference between the two methodologies (catch-based score was 0.8 greater than biomass-based score).

Expanded catch data appear to indicate a declining reef fish fishery in American Samoa, Guam and the NWHI (Figs. 2A, C, and E); and a mostly flat trend in CNMI, MHI and the Mariana Archipelago (Figs. 2B, D, and F). For the former three areas, recent

mean catches are lower than mean catch over the whole record, whereas they mostly comparable for the latter three areas. Information on local versus federal catch for species and families are provided in the attached appendices.

Discussion

Of particular significance to the task of creating ACLs are three general results: (1) highly variable catch in species with the highest overall catches; (2) low variability in catch for the most frequently caught families; and (3) moderate to low exploitation for most coral reef fish families in most areas.

Regarding the variability of species catch, it must first be reiterated that at the time of this analysis we were only able to acquire ‘raw’ species-level data, i.e. they were not standardized for survey effort; hence, they are inherently more variable than family-level data. Nonetheless, the high CV values in the predominantly caught reef fish species suggest that implementing species-level ACLs for coral reef fishes could prove exceedingly difficult. For instance, in CNMI the species with the highest total catch, *Lethrinus rubrioperuclatus*, had a CV of 0.9—the standard deviation of its catch is nearly equivalent to its mean catch—over the past five years. In American Samoa, *Lutjanus kasmira* had the highest overall catch. The standard deviation of its catch over the past five years actually exceeds the mean catch ($CV > 1$) over the same period. WPRFMC and NFMS are currently working to expand (standardize) species-level data by next year, which may reveal lower species CV values than presented here.

Lower variability in family catches may reflect the difficulty of identifying fish to the species level in creel surveys. During the surveys, fish that cannot be identified to the species level are assigned to a broader taxonomic grouping (Hamm and Tao, 2010), such as a genus or family. Observers differ in their fish identification ability, and presumably a less experienced observer will have more difficulty detecting the subtle morphological differences that separate some species. Thus, greater precision in family catch estimates should be expected. Since ACL monitoring will presumably rely heavily on fishery dependent data, family-level ACLs should be easier to implement than species-level ACLs.

However, given the low exploitation values for most reef fish families, even setting ACLs at the family level may prove excessive. Our analysis found that only four families in had > 20% of their biomass harvested in any area. One of these families, mullidae, had exploitation > 20% in only one area (Guam Island: 22.54%); the other three families—carangidae, kyphosidae, and lethrinidae—are either known or suspected to be underrepresented in visual surveys.

Jennings and Polunin (1995) concluded that underwater visual surveys grossly underestimated the amount of exploitable lethrinid biomass in Fiji, and Kulbicki (1988) suggested the same for *Lethrinus* spp. based on a poor relationship between observed density and catch per unit effort (CPUE). Watson et al. (2007a) found that *Kyphosus sydneyanus* kept greater distances from stereo-video cameras when SCUBA divers were

present, implying that SCUBA visual surveys would produce inaccurate population estimates for that species; similarly, Denny and Babcock (2004) observed *Pseudocaranx dentex* when using baited underwater cameras but did not observe the species in more than 16 SCUBA visual censuses in same areas. Kulbicki (1988), working in New Caledonia, did not record any carangids in more than 45 visual surveys, despite the presence of several tons worth in the catch record. If the RAMP surveys analyzed here underestimated biomass for these families, the corresponding estimates of percentage exploited would appear artificially high.

Underestimates in coral reef visual survey are also likely to occur when a given taxon has significant deep-water distributions, as is the case for carangids (Williams, 2010), because surveys are typically limited to safe diving depths. RAMP surveys are limited to 30 m, but Randall (2007) notes that *Caranx lugubris* is usually seen in more than 30 m of water, and that many other carangids occur well below depths of 100 m. *C. sexfasciatus* occurs in deep channels up to 96 m and *C. lugubris* is known up to 354 m (Honebrink, 2000). For several other species, there are ontological shifts in depth distribution, with adults preferring deeper waters (Meyers, 1991). Adult *Alectis ciliaris*, for example, usually occur at depths of 60 m or more, well beyond SCUBA survey depths. To further complicate matters, the vertical distribution of a given species may depend on the season, with some species schooling in deep waters during spawning seasons (Watson et al., 2007b). NMFS CRED continues to develop methodologies to account for deep water distributions below current survey depths (Williams, 2010), and the authors of this study advises additional exploitation rate analyses should recalibrated biomass estimates become available.

One final note regarding survey methodology as it relates to our exploitation estimates: It should be reiterated that NOAA CRED did not actually record carangids or kyphosids for the Guam region—apparently they were not seen there. Given that these families were both regularly caught in Guam from 2005-2008, we decided to crudely estimate their biomass there by using the average biomass density of those families over hard-bottom habitats in CNMI. A more refined methodology might produce significantly different biomass estimates, with the commensurate effect on estimates of the percentage exploited. It is somewhat telling that not a single kyphosid was seen in Guam visual surveys, yet the estimated annual kyphosid catch there was > 3,100 kg from 2005-2008.

Despite the aforementioned difficulties associated with estimating biomass for at least three of the twelve reef fish categories used, this analysis showed significant relationships between mean annual catch and estimated biomass for most areas. Furthermore, if carangids, kyphosids, and lethrinids are excluded from regression analyses, strong relationships between catch and estimated biomass emerge in areas where there previously were none. In CNMI, for example, removing these families caused P-values for Rota to FDM to drop from 0.85 to 0.003, and from 0.91 to 0.01 for Rota to the Northern Islands. On an archipelagic scale, P-values for the Marianas fell from 0.13 to 0.003. (P-values < 0.05 indicate statistical significance.) The apparent dependence of catch on biomass is intuitive and corroborates work by Kulbicki et al. (1994) where catch

(in this case, CPUE) had the highest correlation with biomass of all parameters analyzed in an experimental fishery in Oueva, New Caledonia.

With respect to overall 'reef fish' trophic scores, the fact that catch-based scores were consistently higher than biomass-based scores supports the premise that fishermen are targeting larger fish higher in the food chain. The only exception to this pattern was for the entire Hawaiian Archipelago, but that score may be skewed downward by limited catches in the NWHI, where high-trophic level fishes are present in great numbers. If significant fishing were still occurring in NWHI, the catch-based trophic score for the archipelago as a whole would likely be higher. After the Hawaiian Archipelago, the next highest biomass-based trophic scores were for the Mariana Archipelago and CNMI, respectively. Both of those regions include extensive island networks where fishing pressure is relatively light (WPRFMC, 2009b), resulting in larger biomasses of apex predators and thus higher trophic scores. In summary, estimated 'reef fish' trophic scores are in accord with the known ecological status of the areas in question, suggesting this metric may have some utility in monitoring the impact of ACLs —although clearly more work is needed to refine the methodology.

Fishery resources in the Western Pacific Region have frequently been reported as overexploited, often on the basis that apex predator abundance, size, or biomass are low in underwater surveys (Friedlander and Demartini, 2002; Craig et al., 2005). Taken as whole, this study suggests that coral reef fishery resources in the Western Pacific Region may not be overexploited, but rather, that localized depletion may be occurring in areas where fishing pressure is heavy. Fishing pressure can vary significantly between islands in the same archipelago. In MHI, for example, more than 63% of all reef fish landings from 2005-2009 occurred around the island O'ahu (Fig. 4), easily the most populated and urbanized island in the Hawaiian Archipelago.

There have been previous studies that documented low to moderate exploitation (Craig et al., 2008; see also Table 9) or declines in fishing mortality (Sabater and Carroll, 2009). Table 9 presents several other studies that found low to moderate fishing exploitation in the region, although most of these are not peer reviewed. Interestingly, it is not uncommon to record higher total mortality in un-fished areas than in paired fished areas (Langston et al., 2009; Longnecker et al., 2008c). Such results imply negative fishing mortality and are thus logically invalid; however, it is not illogical that total mortality for certain prey species would be higher in un-fished areas because fishing can remove top-predators that have the capacity to significantly structure reef communities (Babcock et al. 1999).

There are, however, several important caveats to the exploitation results presented here. Firstly, several areas in the Western Pacific Region have shown notable declines in their reef fisheries since monitoring began (Figs. 2 A and C). These declines could indicate reduced productivity (CPUE) in those areas; alternatively, they may simply be the result of reduced fishing effort over time, which has been documented in some parts of the region. In American Samoa, Sabater and Carroll (2009) noted generally low participation in reef fisheries, a non-significant decline in boat-based effort and a

significant decrease over the past three decades in shore-based fishing effort. Likewise, Saucerman (1995) noted a downward trend in reef fishing effort there in the early 1990s. These changes were attributed to shifting socioeconomic conditions—many American Samoans now have wage work—and natural disturbances, including several severe hurricanes, crown-of-thorns starfish outbreaks, and coral bleaching events. Nonetheless, the perception of most village elders, at least in the outer islands of Ofu and Olosega, is that fishing is good and similar to what it was in previous decades (Craig et al., 2008).

In Guam, effort has become restricted by reduced shoreline accessibility: Although there are 108 km² of coral reef area found within three miles of the island of Guam (Burdick et al., 2008), a personal communication from WPRFMC Guam Island Coordinator suggests that 50% of that coastal reef area is now inaccessible by land due to military and other restrictions and a further 25% of coral reef area has only very limited shoreline access. (Note that these reef areas may, however, be accessible by boat.) The impact on reef fishing is twofold: firstly, it creates large de-facto marine protected areas (MPAs) which may provide some replenishment for some coral reef species; secondly, it concentrates fishing into smaller areas potentially leading to localized depletion.

In Hawai'i, the number of recreational saltwater fishing days and anglers have declined significantly from 1991-2006 (Table 10); there are also fewer Hawai'i residents fishing. This may indicate less fishing pressure on MHI coral reefs, although more information on CPUE would be needed to confirm this. Meanwhile, fishing in the NWHI has halted following the area's declaration as a marine national monument.

In the Hawaiian Archipelago, another caveat to low exploitation is that this analysis only used commercial data when in fact recreational and subsistence catch is likely equal to or greater than inshore commercial fisheries (Friedlander et al., 2008). (For other archipelagos studied here, recreational and subsistence catch data are captured by creel surveys.) Subsequent to our initial analysis, we were able to obtain recreational catch data (NOAA NMFS Office of Science and Technology, 2010) for Hawai'i for eight of the eleven families that we analyzed. The inclusion of these data only significantly affected exploitation for carangids. In MHI, carangid exploitation increased from 3.07 % to 61.31%. However, in the greater Hawaiian Archipelago, exploitation for carangids was still very low (< 1%), probably on account of the large biomass of apex predators in NWHI (Friedlander and Demartini, 2002).

Additionally, our analysis did not include catch from the Hawaiian aquarium fishery, which is on the order of hundreds of thousands of fish per year in MHI (Friedlander et al., 2008).

One final shortcoming of this study is that patterns in fish size were not analyzed. Fish size can have a major influence on the reproductive potential of a given stock and thus its long-term ecological health (Berkeley et al. 2004; Scott et al. 2006). Thus, it is possible that while the percentage of biomass exploited for most families remains relatively low, mean fish size for some populations may have declined significantly due to fishing pressure. Friedlander and DeMartini (2002) found significant differences in

size, age structure and trophic guild between carangids, carcharhinids and other apex predators in the largely un-fished NWHI versus the heavily fished MHI. Had fish lengths been included in the catch data analyzed here, it might have been possible to estimate the size or age structures for some reef fish populations. Such an analysis could greatly augment the explanatory power of this study.

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Table 1. Summary of catch data analyzed for all areas studied.

Area	Collecting Agency	System	Timeframe
American Samoa	Department of Marine and Wildlife Resources	Boat-Based Survey	1986-2009
		Shore-Based Survey	1988-2009
CNMI	Division of Fish and Wildlife	Boat-Based Survey	2000-2009
		Shore-Based Survey	2005-2009
Guam	Division of Aquatic and Wildlife Resources	Boat-Based Survey	1982-2009
		Shore-Based Survey	1984-2009
Hawaiian Archipelago	Hawai'i Division of Aquatic Resources	Boat-Based Survey	1966-2009
		Shore-Based Survey	

Table 2. Taxonomic summary of catch record per archipelago/location.

Area	Number of Families Analyzed	Number of Taxa* Analyzed	Number of Identified Species
American Samoa	27	61	31
CNMI	24	68	36
Guam	39	183	173
Hawai'i	45	100	62

*Here 'taxa' refer to the lowest classification level available for a given fish. As previously mentioned, identification of fishes in creel surveys often depends on the ability of the surveyor, and many fishes in these data were not identified to the species level but rather only to the family or genus level. Hence, 'taxa' may refer to valid scientific names, genera that include multiple species, or whole families of fishes.

Table 3. Coefficient of variation (CV) for ten species with highest total catch in (A) American Samoa, (B) CNMI, (C) Guam, and (D) Hawaiian Archipelago.

(A) American Samoa

Species	Total Catch (kg)	Mean Catch (kg), Last Five Years	5-Year CV	Mean Catch (kg), Total Record	Total Record CV
<i>Lutjanus kasmira</i>	10,878.01	395.16	1.15	453.25	0.75
<i>Acanthurus lineatus</i>	9,708.60	362.07	0.85	422.11	1.10
<i>Lutjanus gibbus</i>	8,116.59	1010.49	1.12	338.19	1.76
<i>Variola louti</i>	6,145.64	199.40	0.49	256.07	0.68
<i>Lethrinus rubrioperculatus</i>	5,819.48	532.26	1.22	253.17	1.25
<i>Caranx lugubris</i>	4,298.56	195.36	0.51	179.11	0.68
<i>Lethrinus olivaceus</i>	4,281.84	379.04	0.91	194.63	1.14
<i>Lethrinus amboinensis</i>	2,641.95	309.73	1.37	176.13	1.35
<i>Ctenochaetus striatus</i>	2,514.55	6.33	0.32	157.16	1.33
<i>Cephalopholis sonnerati</i>	2,094.11	51.48	0.78	87.25	0.95

(B) CNMI

Species	Total Catch (kg)	Mean Catch (kg), Last Five Years	5-Year CV	Mean Catch (kg), Total Record	Total Record CV
<i>Lethrinus rubrioperculatus</i>	1,849.34	259.82	0.90	184.93	1.00
<i>Elagatis bipinnulata</i>	1,304.86	143.89	1.24	130.49	1.01
<i>Lethrinus harak</i>	506.25	100.47	0.55	50.63	1.27
<i>Naso lituratus</i>	203.31	27.35	0.51	20.33	0.67
<i>Lethrinus olivaceus</i>	174.64	15.56	1.86	17.46	1.08
<i>Variola louti</i>	125.05	22.60	0.59	12.51	1.13
<i>Lutjanus kasmira</i>	124.59	16.44	0.45	12.46	0.74
<i>Naso unicornis</i>	115.42	15.09	0.66	11.54	0.82
<i>Kyphosus cinerascens</i>	110.02	20.64	0.96	11.00	0.87
<i>Caranx lugubris</i>	106.95	11.12	0.26	10.70	1.26

(C) Guam

Species	Total Catch (kg)	Mean Catch (kg), Last Five Years	5-Year CV	Mean Catch (kg) , Total Record	Total Record CV
<i>Naso unicornis</i>	5,309.72	71.05	0.49	196.66	1.07
<i>Lethrinus rubrioperculatus</i>	4,945.41	85.93	0.68	176.62	1.66
<i>Sphyraena barracuda</i>	4,183.78	156.00	0.71	149.42	2.21
<i>Elagatis bipinnulatus</i>	3,579.29	88.87	0.57	127.83	1.04
<i>Epinephelus fasciatus</i>	1,612.06	33.05	0.04	57.57	1.84
<i>Hipposcarus longiceps</i>	1,598.44	9.46	0.92	63.94	1.04
<i>Mulloidichthys flavolineatus</i>	1,531.91	52.61	1.72	58.92	1.32
<i>Naso lituratus</i>	1,528.98	23.52	0.65	54.61	1.15
<i>Caranx melampygus</i>	1,448.54	64.75	0.27	51.73	1.92
<i>Cheilinus undulatus</i>	1,088.69	6.93	1.00	43.55	0.96

(D) Hawaiian Archipelago

Species	Total Catch (kg)	Mean Catch (kg), Last Five Years	5-Year CV	Mean Catch (kg) , Total Record	Total Record CV
<i>Lutjanus kasmira</i>	837,211.6	16,079.8	0.15	20,930.29	0.47
<i>Acanthurus dussumieri</i>	482,132.5	12,220.8	0.17	10,957.56	0.39
<i>Parupeneus chrysonemus</i>	363,978.7	1,769.0	0.20	8,272.24	0.54
<i>Naso unicornis</i>	335,442.6	9,306.9	0.20	7,623.69	0.39
<i>Mugil cephalus</i>	231,016.5	4,031.4	0.15	5,250.38	0.54
<i>Acanthurus triostegus</i>	220,865.3	5,102.9	0.11	5,019.67	0.27
<i>Caranx ignobilis</i>	219,058.4	7,981.8	0.46	7,553.74	0.55
<i>Sphyraena barracuda</i>	192,570.9	1,056.2	0.16	4,376.61	1.28
<i>Parupeneus porphyreus</i>	142,136.5	1,274.3	0.64	3,230.37	0.48
<i>Chanos chanos</i>	128,609.1	2,846.0	0.41	2,922.93	1.30

Table 4. Coefficient of variation (CV) for ten families with highest total catch in (A) American Samoa, (B) CNMI, (C) Guam, and (D) Hawaiian Archipelago.

(A) American Samoa

Family	Total Catch (kg)	Mean Catch (kg), 2004-2008	CV, Last Five Years	Mean Catch (kg), 1990-2008	CV, 1990-2008
Acanthuridae	140,431.8	4,303.64	0.55	7,391.15	0.75
Lutjanidae	136,885.5	5,993.36	0.60	7,204.50	0.44
Carangidae	71,020.0	2,851.18	0.57	3,737.89	0.85
Lethrinidae	66,211.4	3,123.73	0.67	3,484.81	0.59
Scaridae	54,503.6	1,367.00	0.52	2,868.61	1.05
Serranidae	53,195.0	2,404.27	0.25	2,799.74	0.29
Holocentridae	23,826.4	705.36	0.48	1,254.02	0.90
Mugilidae	19,483.6	1,185.36	0.43	1,025.45	1.81
Labridae	6,899.5	1,078.36	0.57	363.13	1.46
Kyphosidae	4,687.3	338.36	0.39	246.70	0.85

(B) CNMI

Family	Total Catch (kg), 2005-2008	Mean Catch (kg), 2005-2008	CV, 2005-2008
Lethrinidae	63,567.7	13,052.0	0.16
Carangidae	42,112.7	9,249.9	0.39
Acanthuridae	15,171.8	3,550.3	0.26
Scaridae	10,625.0	2,082.0	0.31
Mullidae	10,594.5	1,899.3	0.51
Serranidae	10,252.7	2,562.2	0.48
Lutjanidae	8,435.5	2,509.1	0.42
Mugilidae	5,230.9	1,307.7	0.40
Siganidae	4,954.5	1,237.4	0.43
Holocentridae	3,748.2	880.5	0.96

(C) Guam

Family	Total Catch (kg)	Mean Annual Catch (kg), 2004-2008	CV, 2004-2008	Mean Annual Catch (kg), 1985-2008	CV, 1985-2008
Acanthuridae	646,483.18	94,136.82	0.07	26,936.80	0.39
Carangidae	422,785.00	97,323.18	0.04	17,616.04	0.40
Lethrinidae	344,222.73	38,763.64	0.05	14,342.61	0.40
Scaridae	241,587.27	29,250.91	0.09	10,066.14	0.47
Mullidae	228,171.36	22,454.55	0.10	9,507.14	0.48
Siganidae	221,775.00	23,026.36	0.05	9,240.63	0.41
Lutjanidae	155,361.36	24,270.00	0.08	6,473.39	0.34
Serranidae	153,158.64	22,773.18	0.06	6,381.61	0.41
Mugilidae	115,619.09	6,478.18	0.09	4,817.46	0.71
Kyphosidae	108,013.18	16,495.45	0.11	4,500.55	0.56

(D) Hawaiian Archipelago

Family	Total Hawaiian Archipelago Catch (kg)	Mean Archipelagic Catch (kg), 2005-2009	CV, 2005-2009	Mean Archipelagic Catch (kg), 1966-2009	CV, 1966-2009
Carangidae	2,524,731.95	20,938.07	0.21	57,380.27	0.48
Acanthuridae	1,365,142.36	35,368.38	0.09	31,025.96	0.25
Mullidae	1,317,387.58	5,395.61	0.28	29,940.63	0.46
Lutjanidae	824,376.09	17,335.22	0.14	20,152.71	0.59
Holocentridae	698,720.70	18,759.28	0.33	15,880.02	0.37
Scaridae	513,408.24	17,993.57	0.20	11,668.37	0.55
Carcharhinidae	306,489.98	334.22	0.38	6,965.68	1.67
Albulidae	303,024.05	3,459.69	0.43	6,886.91	0.70
Sphyrnidae	285,459.01	1,982.63	0.30	6,487.70	0.87
Kyphosidae	252,570.18	10,682.90	0.34	5,740.23	0.50

Table 5. Percentage of exploited biomass for various catch and biomass permutations in American Samoa , Commonwealth of the Northern Mariana Islands (CNMI), Guam, and the Hawaiian Archipelago (MHI = Main Hawaiian Islands; NWHI = Northwestern Hawaiian Islands).

Catch Data	Biomass Data	Acanthuridae	Carangidae	Carcharhinidae	Holocentridae	Kyphosidae	Labridae
Am. Samoa (Tutuila Only)	Am. Samoa (Tutuila Only)	0.86	11.13	0.45	4.74	16.83	2.02
	Am. Samoa (Tutuila, Tau, Ofu, Olosega)	0.56	7.07	0.16	1.89	3.91	1.28
CNMI	Rota to FDM	0.72	67.43	0.44	1.57	6.45	0.75
	Rota to Northern Island	0.30	4.42	0.12	0.63	0.45	0.37
	Whole Mariana Archipelago	0.22	3.99	0.08	0.57	0.41	0.21
Guam	Guam Island	6.12	157.61	0.66	19.73	67.11	0.55
	Guam and Banks	4.24	104.89	0.44	8.57	44.66	0.36
	Whole Archipelago	1.01	7.92	0.11	0.72	3.58	0.16
Combined CNMI and Guam	Southern Banks to FDM	2.25	201.08	1.00	2.89	63.37	0.51
	Whole Archipelago	1.23	11.91	0.19	1.29	3.99	0.36
MHI	MHI	0.21	3.07	0.35	2.06	0.72	0.09
Hawaiian Archipelago	Hawaiian Archipelago	0.07	0.04	0.00	0.59	0.15	0.02

Catch Data	Biomass Data	Lethrinidae	Lutjanidae	Mullidae	Scaridae	Serranidae	Other	Total
Am. Samoa (Tutuila Only)	Am. Samoa (Tutuila Only)	7.35	9.60	1.32	0.50	5.53	1.45	1.90
	Am. Samoa (Tutuila, Tau, Ofu, Olosega)	5.26	4.54	1.03	0.33	2.50	1.08	1.25
CNMI	Rota to FDM	24.52	1.95	6.88	1.30	1.75	1.20	2.49
	Rota to Northern Islands	10.83	0.26	3.71	0.51	0.59	0.47	0.84
	Whole Mariana Archipelago	9.90	0.23	2.36	0.35	0.50	0.32	0.63
Guam	Guam Island	160.34	9.81	22.54	3.29	12.86	8.69	8.84
	Guam and Banks	75.94	6.05	13.13	2.18	7.23	5.18	5.66
	Whole Archipelago	5.36	0.50	4.66	0.66	0.95	1.46	1.30
Combined CNMI and Guam	Southern Banks to FDM	32.17	3.63	10.06	1.77	3.48	3.23	4.19
	Whole Archipelago	15.26	0.73	7.02	1.01	1.45	1.79	1.92
MHI	MHI	0.39	0.43	0.29	0.30	0.07	0.62	0.41
Hawaiian Archipelago	Hawaiian Archipelago	0.02	0.11	0.10	0.05	0.07	0.19	0.08

* = Carangids, kyphoids and carcharinids were not seen in Guam RAMP surveys. Biomass values for these families in were estimated using the corresponding family biomass (kg/ha) density from CNMI.

Table 6. Results from regression analyses comparing biomass versus catch. The acronym CKL refers to biomass of carangids, kyphosids and lethrinids—biomass is known or suspected to be underrepresented in underwater visual surveys for these families (see discussion). P-values < 0.05 indicate statistically significant relationships. $0.05 < P < 0.1$ was considered near significant. Note also that R^2 = correlation coefficient.

Catch Data	Biomass Data	R^2	P-Value	Relationship Between Biomass and Catch
Am. Samoa (Tutuila)	Am. Samoa (Tutuila)	0.43	0.02	Significant
	Am. Samoa (Tutuila) Minus CKL	0.47	0.04	Significant
	Am. Samoa (Tutuila, Tau, Ofu, and Olosega)	0.42	0.02	Significant
	Am. Samoa (Tutuila, Tau, Ofu, and Olosega) Minus CKL	0.46	0.04	Significant
CMNI	Rota to FDM	0.00	0.85	No Apparent Relationship
	Rota to FDM Minus CKL	0.58	0.01	Significant
	Rota to Northern Islands	0.003	0.91	No Apparent Relationship
	Rota to Northern Islands Minus CKL	0.59	0.01	Significant
Guam	Guam Island	0.33	0.05	Near Significant
	Guam Island Minus CKL	0.70	0.01	Significant
	Guam Island and Banks	0.36	0.04	Significant
	Guam and Banks Minus CKL	0.75	0.002	Significant
Mariana Archipelago	Mariana Archipelago	0.22	0.13	Not Significant
	Mariana Archipelago Minus CKL	0.74	0.003	Significant
MHI	MHI	0.52	0.01	Significant
	MHI Minus CKL	0.54	0.02	Significant
Hawaiian Archipelago	Hawaiian Archipelago	0.36	0.04	Significant
	Hawaiian Archipelago Minus CKL	0.46	0.04	Significant

Table 7. Estimated family trophic scores by archipelago/location, weighted by relative abundance in the catch record. Scores for the Mariana Archipelago were calculated by taking the weighted average of CNMI and Guam scores. Catch records in the NWHI were too few to accurately calculate trophic scores.

	Acanthuridae	Carangidae	Carcharhinidae	Holocentridae	Kyphosidae	Labridae
American Samoa	2.05	4.18	4.14 ¹	3.53	2.30 ²	3.60
CNMI	2.31	3.71	4.20 ¹	3.56 ¹	2.30 ²	3.91
Guam	2.27	4.06	4.06	3.57	2.19	3.84
Hawai'i	2.21	4.17	4.23 ¹	4.00	2.10 ¹	3.49
Mariana Archipelago	2.28	3.95	4.09	3.56	2.20	3.88

	Lethrinidae	Lutjanidae	Mullidae	Scaridae	Serranidae
American Samoa	3.75	3.64	3.30 ²	2.00 ³	4.17
CNMI	3.62	3.60	3.22	2.00 ³	3.54
Guam	3.58	3.93	3.39	2.00 ²	3.96
Hawai'i	3.19 ²	3.63	3.50	2.00	4.48 ²
Mariana Archipelago	3.61	3.83	3.34	2.00	3.82

¹No individual species data available so trophic score was calculated by averaging trophic score of species known to exist in Hawai'i.

² Only 1 species used in calculation, although for scaridae the value presented here is the clear mode of the family.

³No species data, but the value presented here is the clear mode of the family.

Table 8. ‘Reef fish’ (all families) trophic scores, calculated using family trophic scores from sample catch data (see table 7) and relative family abundances from either biomass or expanded catch data.

	Biomass	Catch
American Samoa	2.55	3.35
CNMI	3.06	3.40
Guam	2.95	3.25
MHI	2.64	3.01
Hawaiian Archipelago	3.12	3.03
Mariana Archipelago	3.09	3.30

Table 9. Moderate to low estimates of total (Z) and fishing (Z) mortality for various reef fish in the Western Pacific Region.

Species	Publication	Location of Study	Z	M	F	E
<i>Acanthurus lineatus</i>	Craig et al. 1997	Hawai'i	0.24	0.20	0.04	0.17
<i>Acanthurus trigostegus sanvicensis</i>	Longnecker et al., 2008b.	Hawai'i	0.68	0.54	0.15	0.21
<i>Caranx melampygus</i>	Chaloupka, M. (personal communication)	Hawai'i (O'ahu)	-	-	-	0.69
<i>Centropyge potteri</i>	Longnecker et al., 2008c	Hawai'i	0.39	0.31	0.08	0.21
<i>Chlorurus sordidus</i> (in an MPA)	McIlwain, 2009	Guam	0.52	0.52	0	0
<i>Chlorurus sordidus</i> (in fished areas)	McIlwain, 2009	Guam	0.62	0.52	0.10	0.17
<i>Ctenochaetus strigosus</i> (Females)	Langston et al., 2009	Hawai'i	0.56	0.53	0.03	0.05
<i>Ctenochaetus strigosus</i> (Males)	Langston et al., 2009	Hawai'i	0.68	0.44	0.24	0.35
<i>Lethrinus harak</i>	Taylor, 2009	Guam	0.57	0.29	0.28	0.49
<i>L. rubrioperculatus</i> (using length-conversions)	Trianni (personal communication)	CNMI	1.18	1.41	-	-
<i>L. rubrioperculatus</i> (using age-length)	Trianni (personal communication)	CNMI	1.07	1.54	-	-
<i>Parupeneus multifasciatus</i>	Longnecker et al., 2008c.	Hawai'i	0.30	0.44	-	-
<i>Naso unicornis</i>	Eble et al., 2009*	Hawai'i	0.07	-	-	-
<i>N. unicornis</i>	Eble et al., 2009*	Hawai'i	0.14	-	-	-

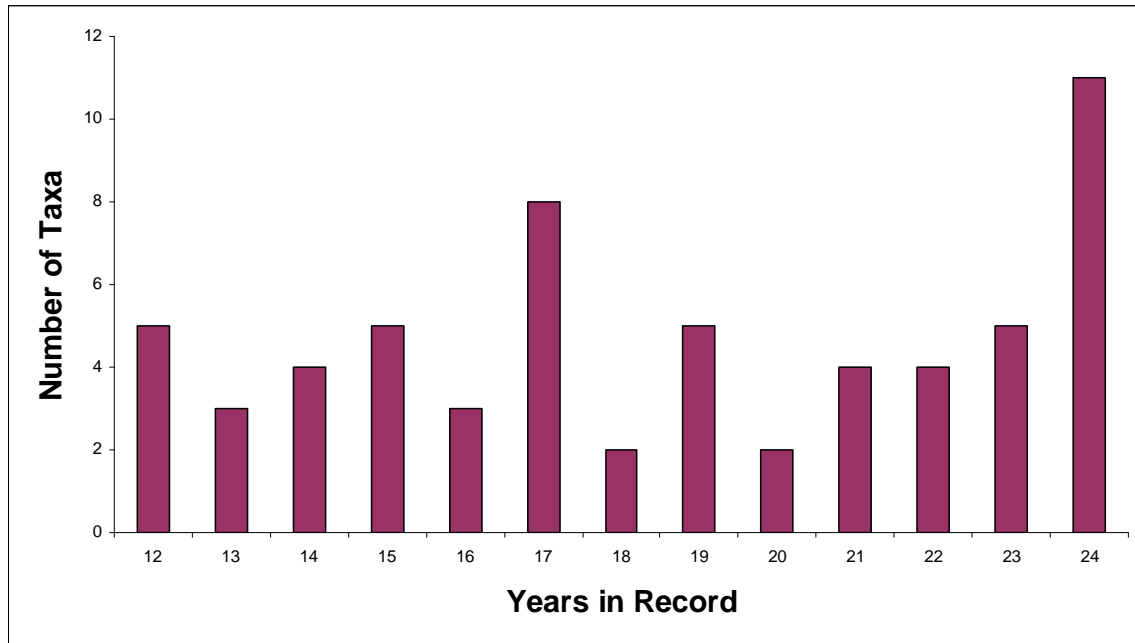
*Derived from Hoenig (1983).

Table 10. Recreational fishing statistics for Hawai'i. (Source: U.S. Fish and Wildlife, 1991-2006.)

Variable	1991	1996	2001	2006	Change from 1991-2006
Saltwater Anglers	192,000	244,000	144,000	154,000	-38,000
Saltwater Angling Days	2,189,000	2,901,000	2,567,000	1,411,000	-778,000
% of Resident Population that Fished	18%	14%	13%	9%	-9%

Fig. 1. Frequency of taxa in catch records.

A. American Samoa, Sample Creel Survey Data.



B. CNMI, Sample Creel Survey Data.

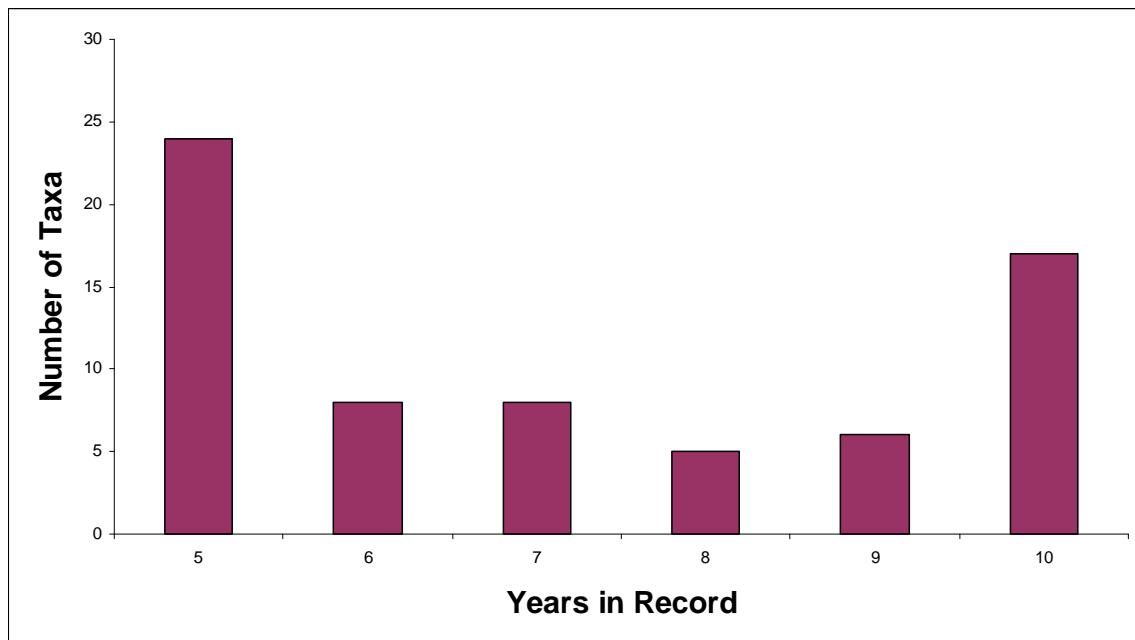
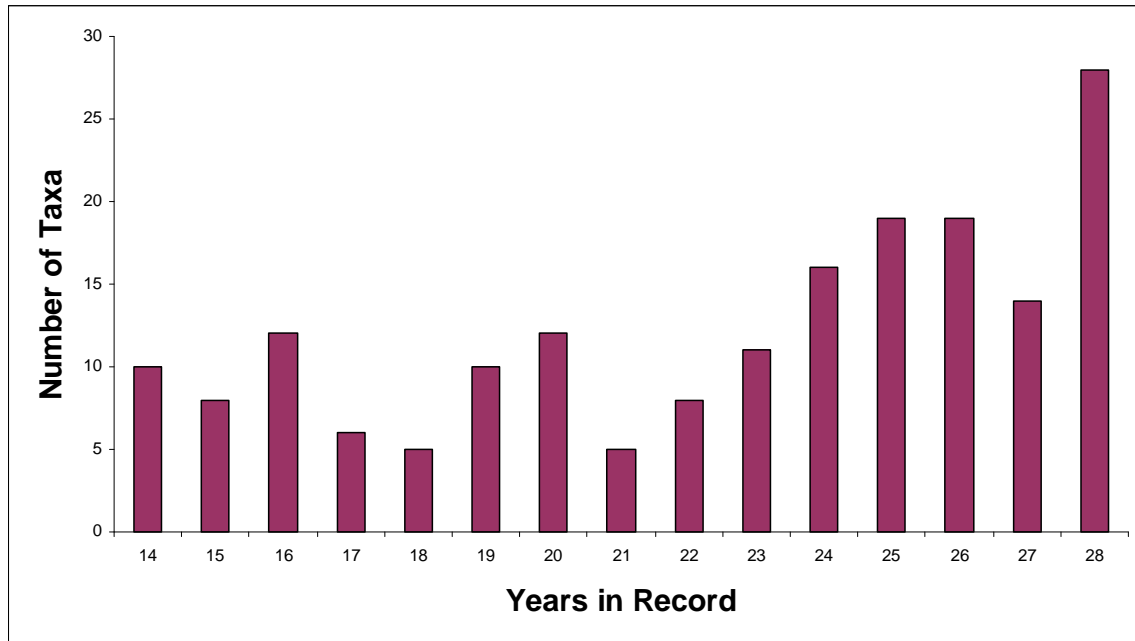


Fig. 1. Frequency of taxa in catch records.

C. Guam, Sample Creel Survey Data.



D. Hawaiian Archipelago, Logbook Data.

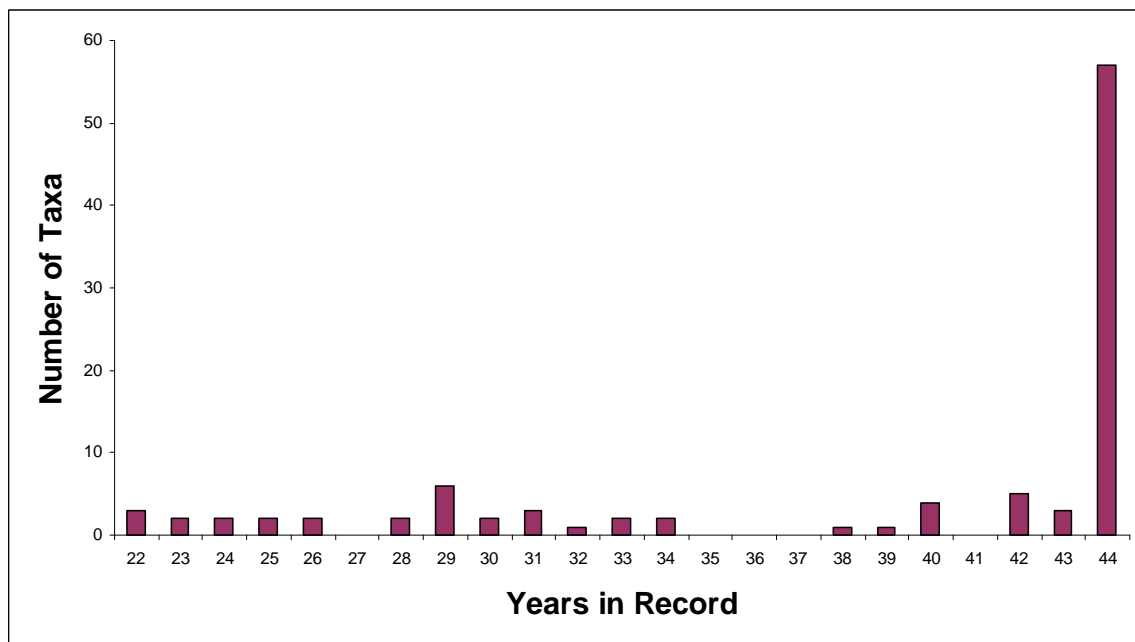
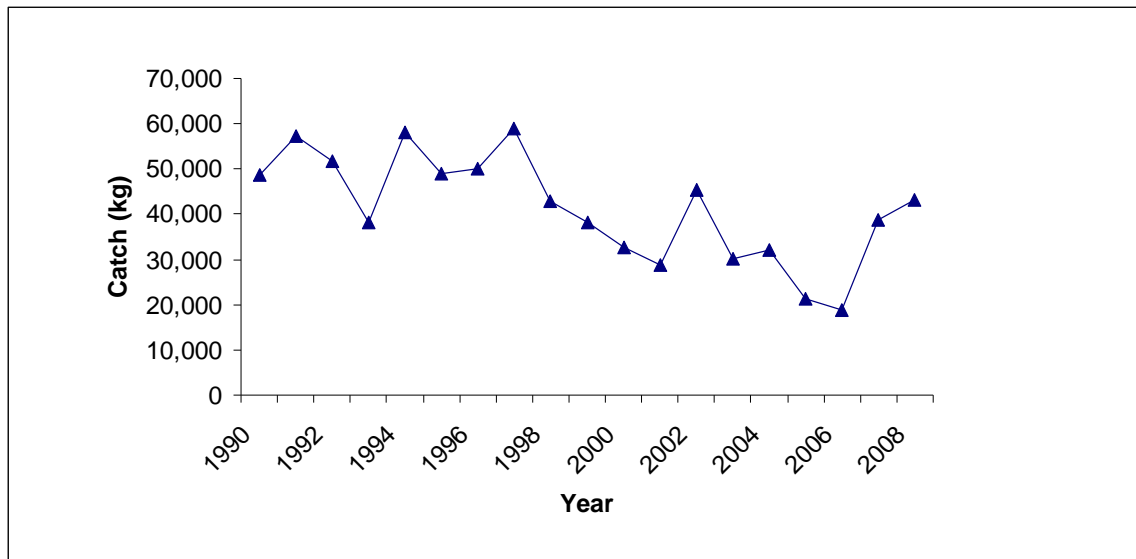


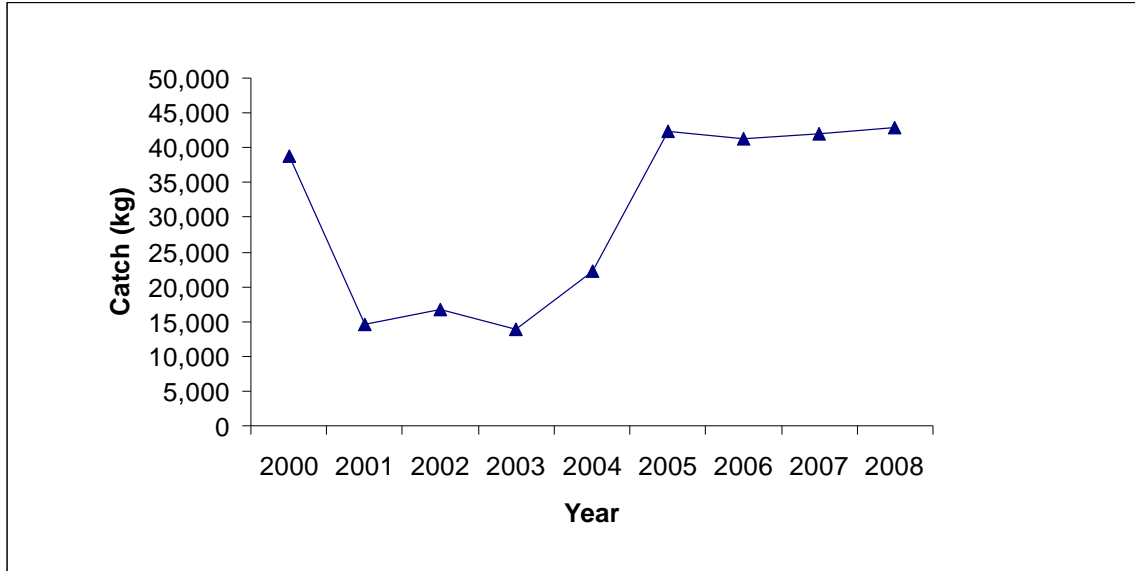
Fig. 2. Total reef fish catch (kg) by archipelago/location.

A. American Samoa. (Source: Expanded creel survey data.)



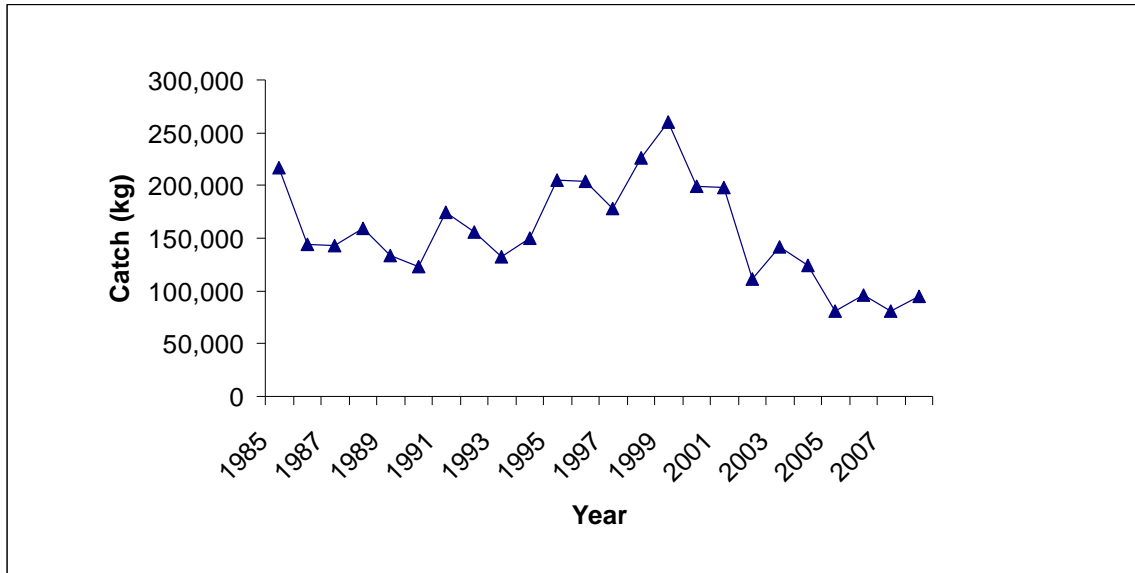
	2004-2008	1990-2008
Mean Catch (kg)	30,823.7	40,739.0
Standard Deviation	10,693.1	11,841.3
Confidence Value	9,372.8	5,324.4
Upper Bound CI	40,196.5	46,063.4
Lower Bound CI	21,451.0	35,414.6

B. CNMI. (Source: Expanded creel survey data.)



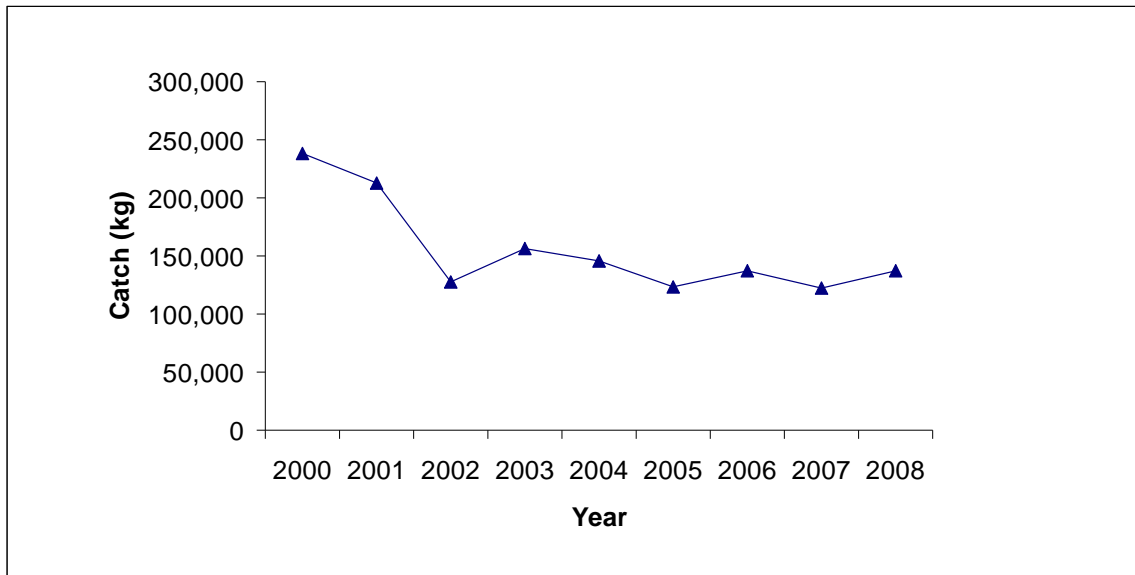
	2005-2008	2000-2008
Mean Catch (kg)	42,108.4	30,502.5
Standard Deviation	664.2	13,243.9
Confidence Value	650.9	8,652.5
Upper Bound CI	42,759.3	39,155.0
Lower Bound CI	41,457.5	21,850.0

C. Guam. (Source: Expanded creel survey data.)



	2005-2008	1985-2008
Mean Catch (kg)	88,017.3	155,532.3
Standard Deviation	8,361.8	48,114.9
Confidence Value	8,194.4	31,434.5
Upper Bound CI	96,211.7	186,966.7
Lower Bound CI	79,822.9	124,097.8

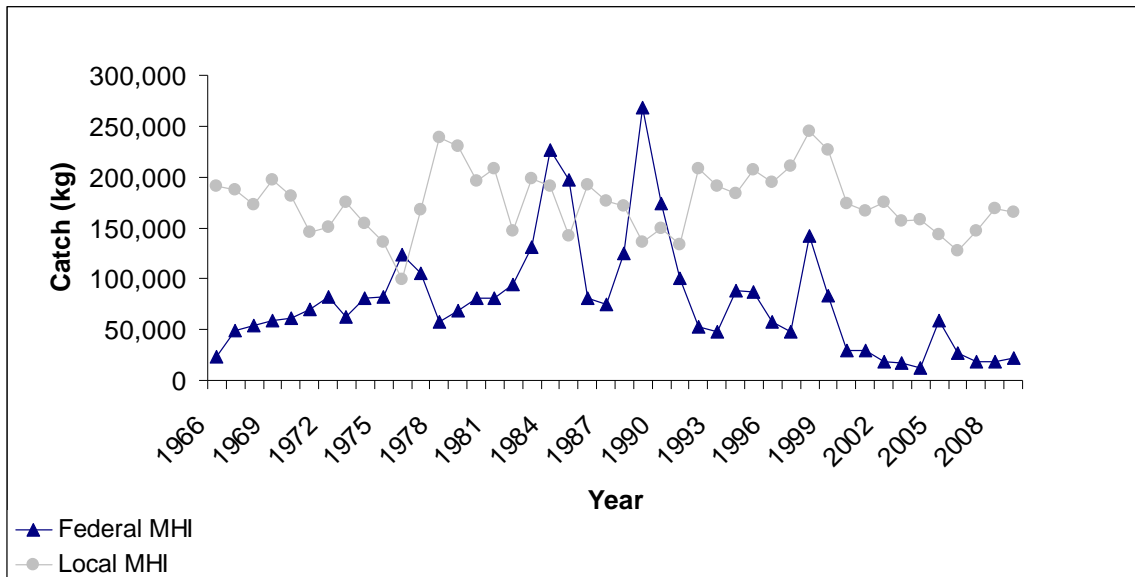
D. Combined Mariana Archipelago. (Source: Expanded creel survey data.)



	2005-2008	2000-2008
Mean Catch (kg)	130,125.7	155,726.2
Standard Deviation	8,308.5	41,555.3
Confidence Value	8,142.2	27,149.0
Upper Bound CI	138,267.9	182,875.1
Lower Bound CI	121,983.5	128,577.2

Note: CNMI shore-based surveys date from 2005 only.

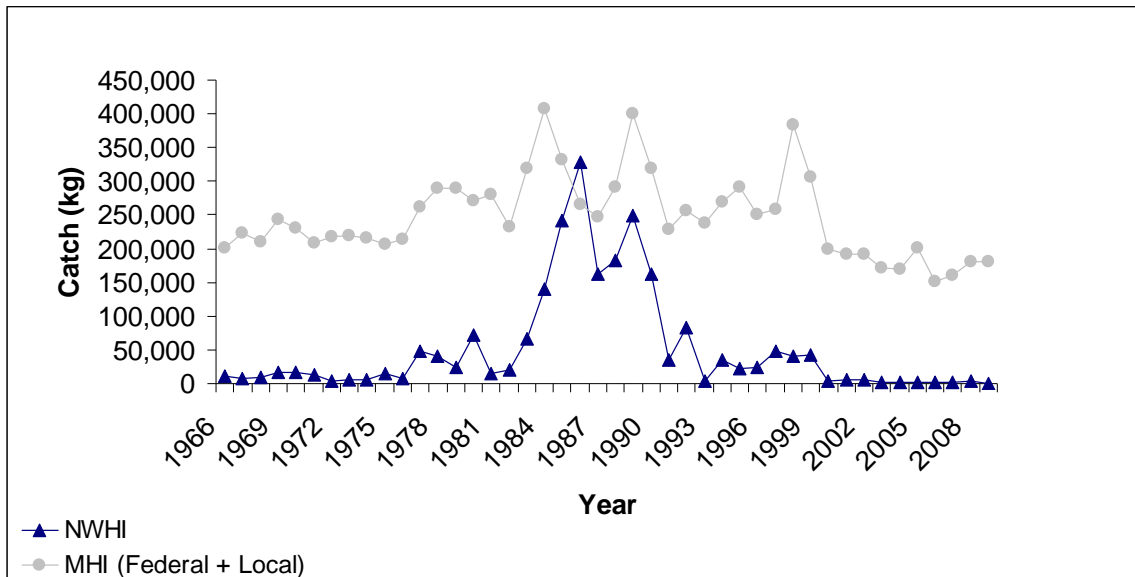
E. Main Hawaiian Islands (MHI). (Source: Commercial marine license logbook data.)



2005-2009	Federal MHI	Local MHI
Mean Catch (kg)	28,808	150,594
Standard Deviation	17,043	17,046
Confidence Value	14,939	14,941
Upper Bound CI	43,746	165,535
Lower Bound CI	13,869	135,653

Total Record (1966-2009)	Federal MHI	Local MHI
Mean Catch (kg)	78,836	175,469
Standard Deviation	55,565	31,317
Confidence Value	16,418	9,253
Upper Bound CI	95,254	184,723
Lower Bound CI	62,418	166,216

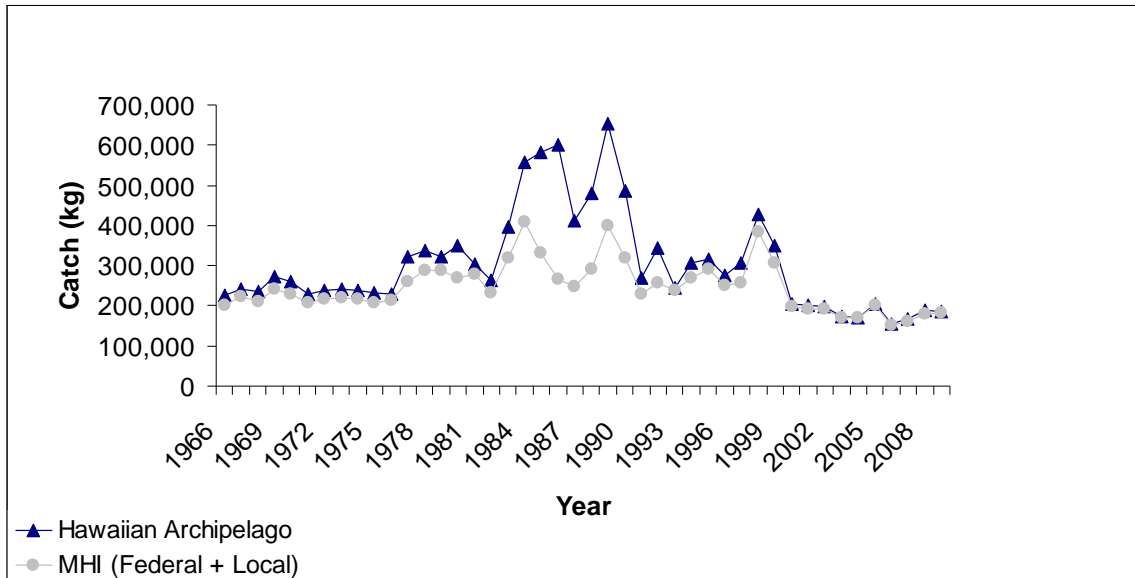
F. MHI versus NWHI. (Source: Commercial marine license logbook data.)



2005-2009	NWHI	MHI (Federal + Local)
Mean Catch (kg)	1,727	175,218
Standard Deviation	1,099	19,247
Confidence Value	963	16,870
Upper Bound CI	2,690	192,088
Lower Bound CI	763	158,348

Total Record (1966-2009)	NWHI	MHI (Federal + Local)
Mean Catch (kg)	50,502	247,155
Standard Deviation	77,028	60,634
Confidence Value	22,760	17,916
Upper Bound CI	73,262	265,071
Lower Bound CI	27,742	229,239

F. MHI versus Hawaiian Archipelago catches. (Source: Commercial marine license logbook data.)



Last Five Years	Hawaiian Archipelago	MHI (Federal + Local)
Mean Catch (kg)	180,404	175,218
Standard Deviation	18,943	19,247
Confidence Value	16,604	16,870
Upper Bound CI	197,008	192,088
Lower Bound CI	163,800	158,348

Total Record	Hawaiian Archipelago	MHI (Federal + Local)
Mean Catch (kg)	304,539	247,155
Standard Deviation	123,567	60,634
Confidence Value	36,511	17,916
Upper Bound CI	341,050	265,071
Lower Bound CI	268,028	229,239

Figure 3. Proportion of archipelagic/local biomass and catch for reef fish families using biomass from: (A) Tutuila; (B) Tutuila, Tau, Ofu, Olosega; (C) Rota to Farallon de Medinilla; (D) Rota to the Northern Islands; (E) Guam Island; (F) Guam Island and Banks; (G) Mariana Archipelago; (H) Main Hawaiian Islands (MHI); and (I) Hawaiian Archipelago.

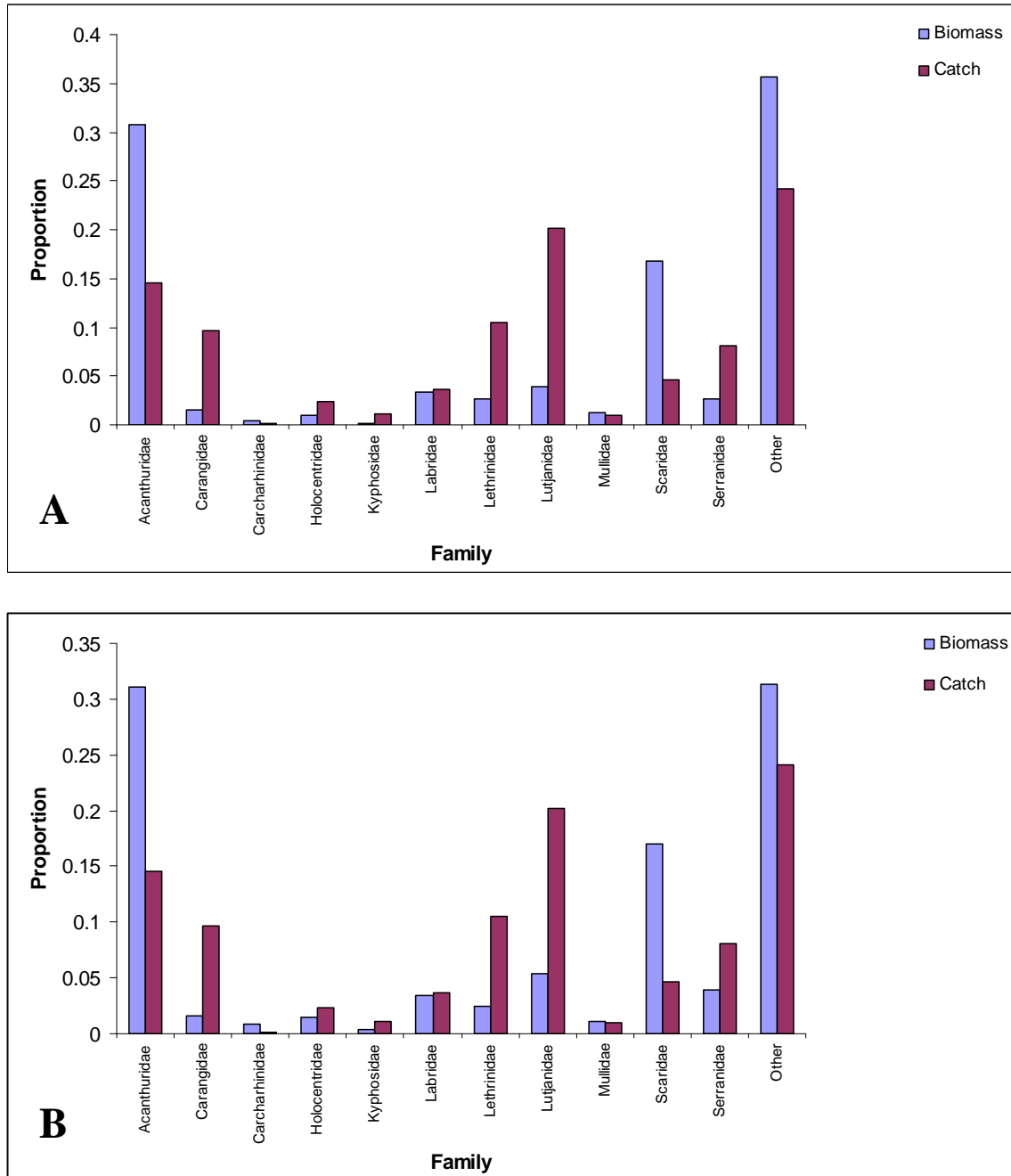


Figure 3. Proportion of archipelagic/local biomass or catch for reef fish families.

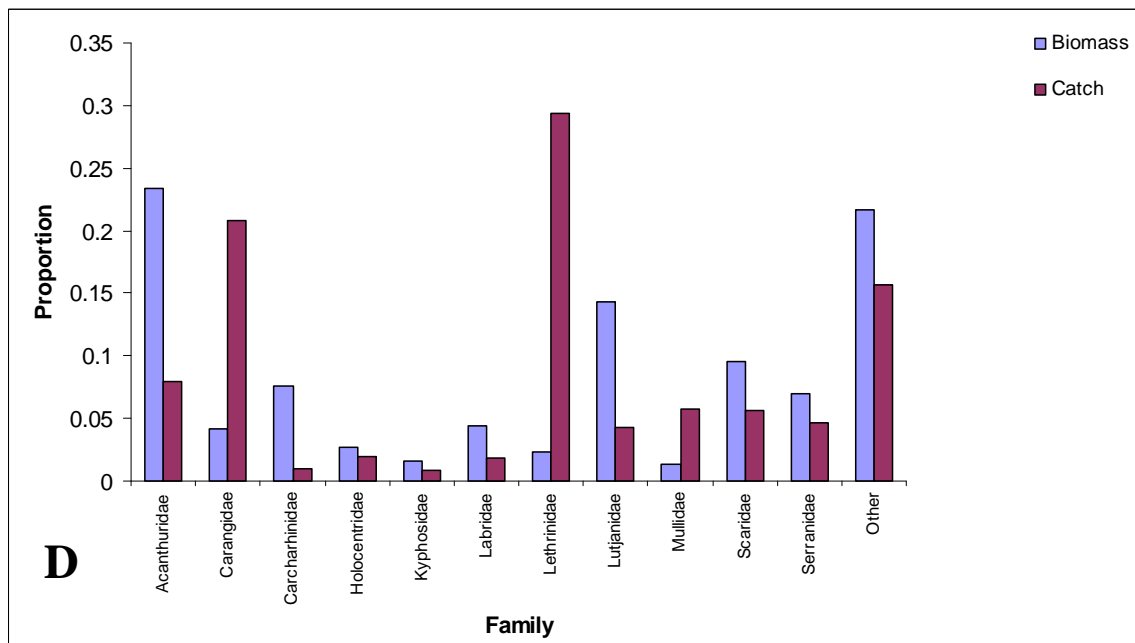
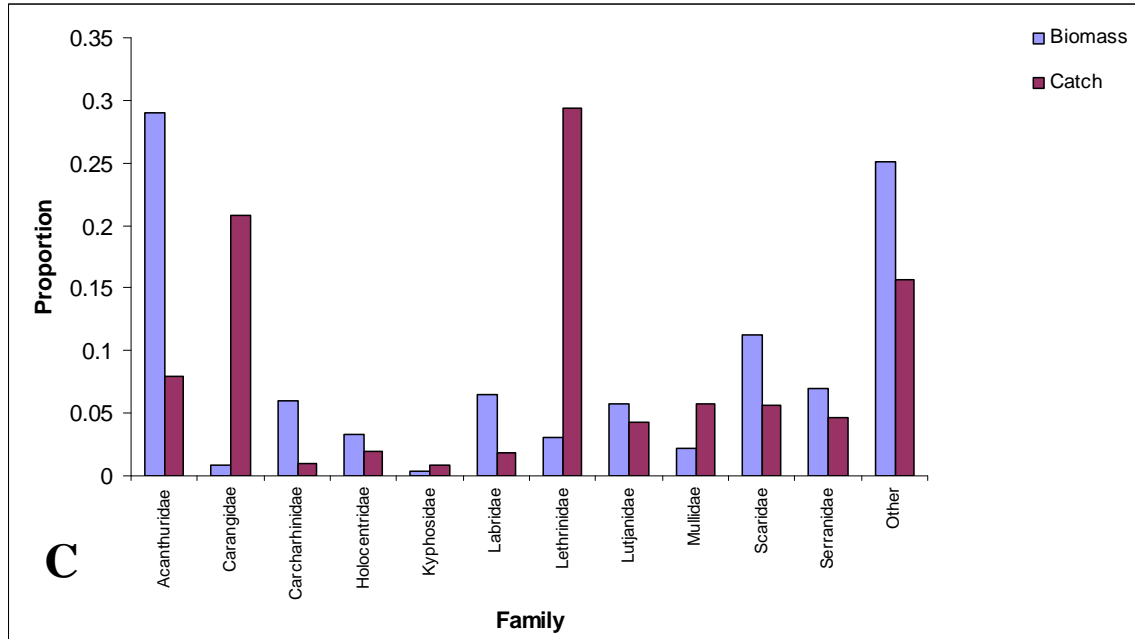


Figure 3. Proportion of regional biomass or catch for reef fish families.

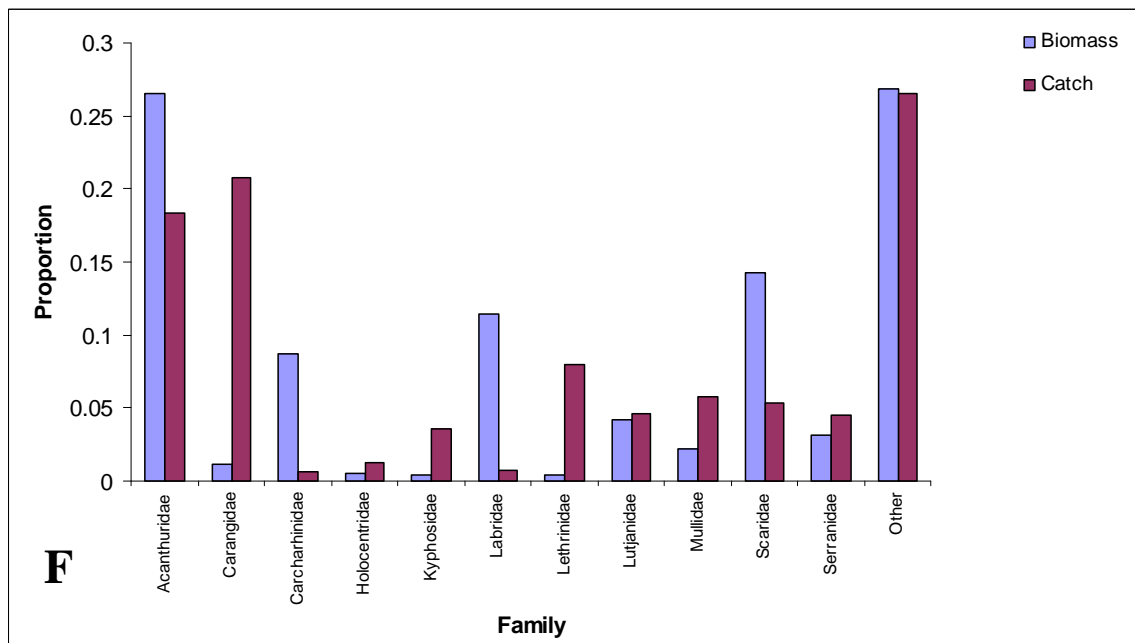
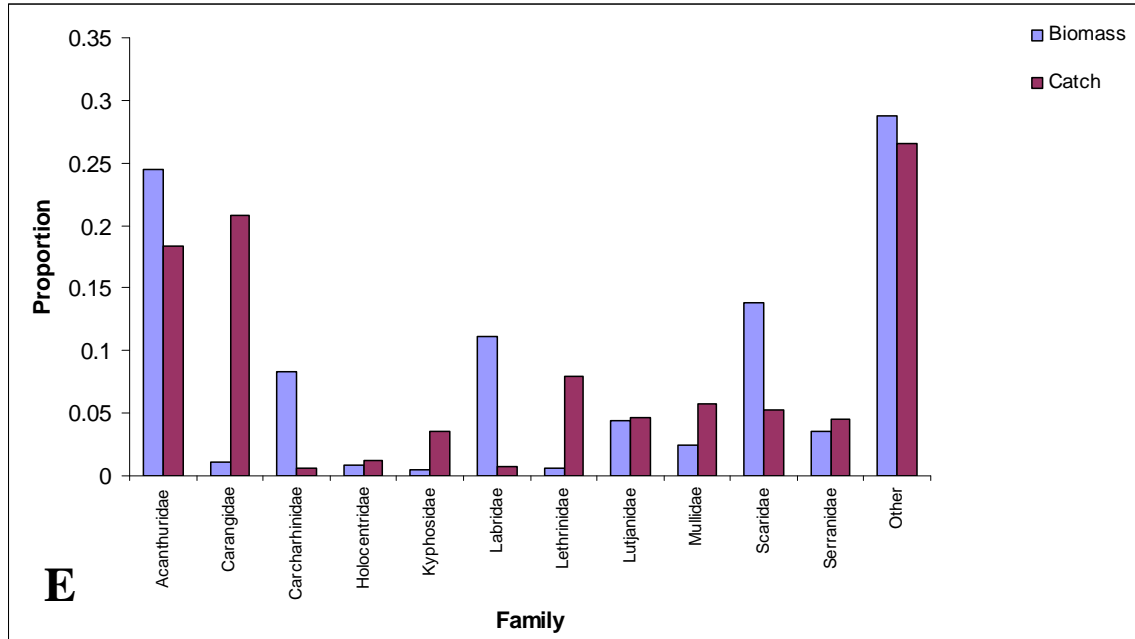
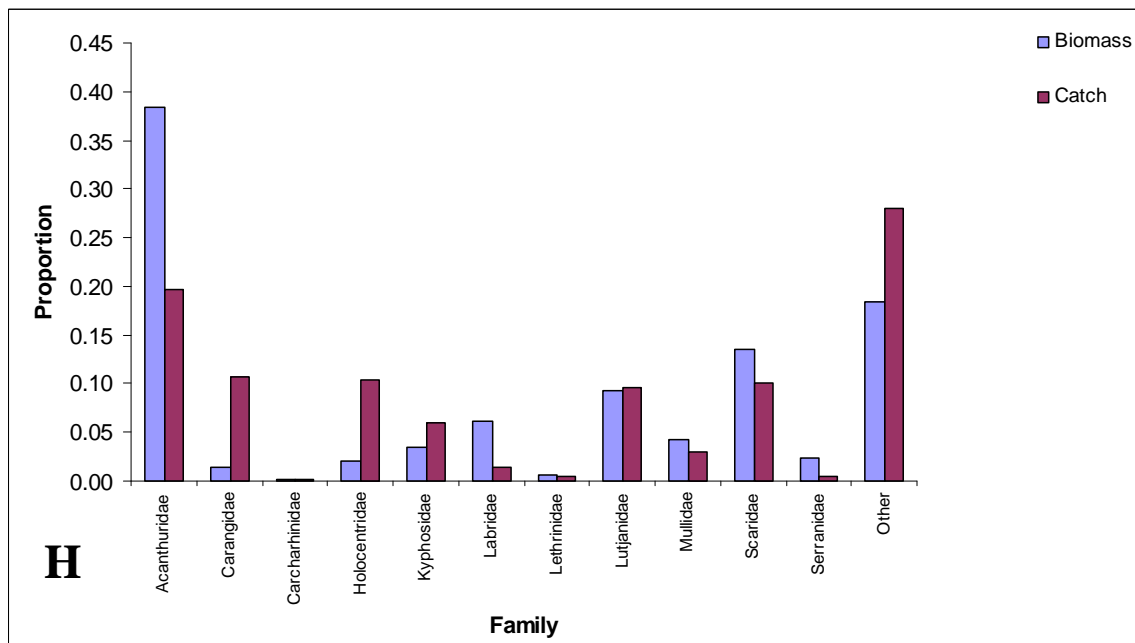
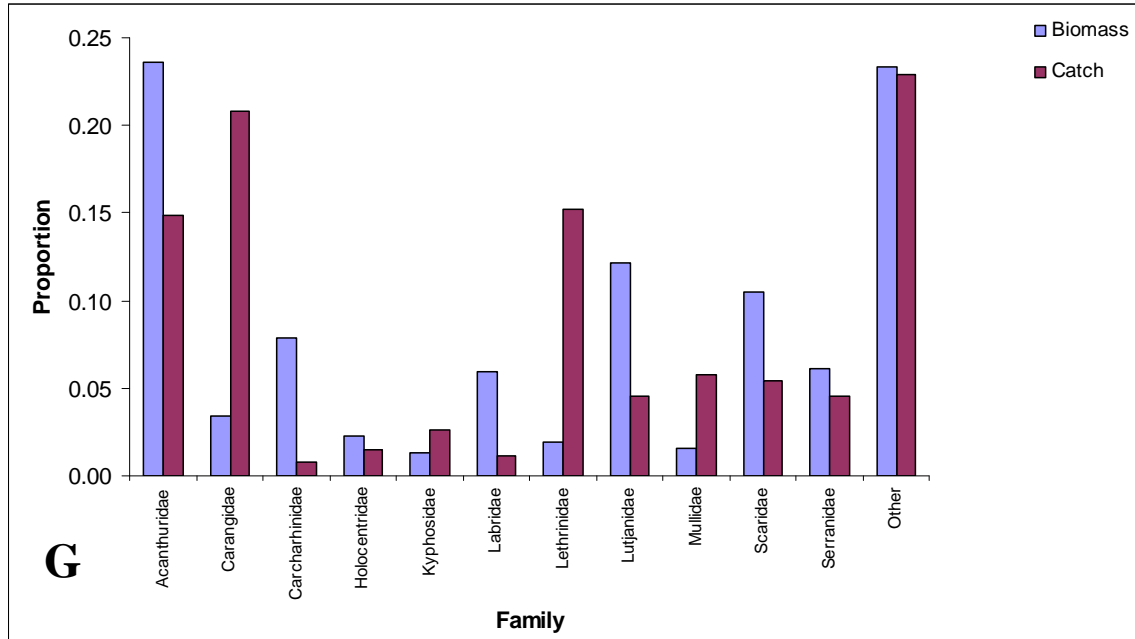


Figure 3. Proportion of regional biomass or catch for reef fish families.



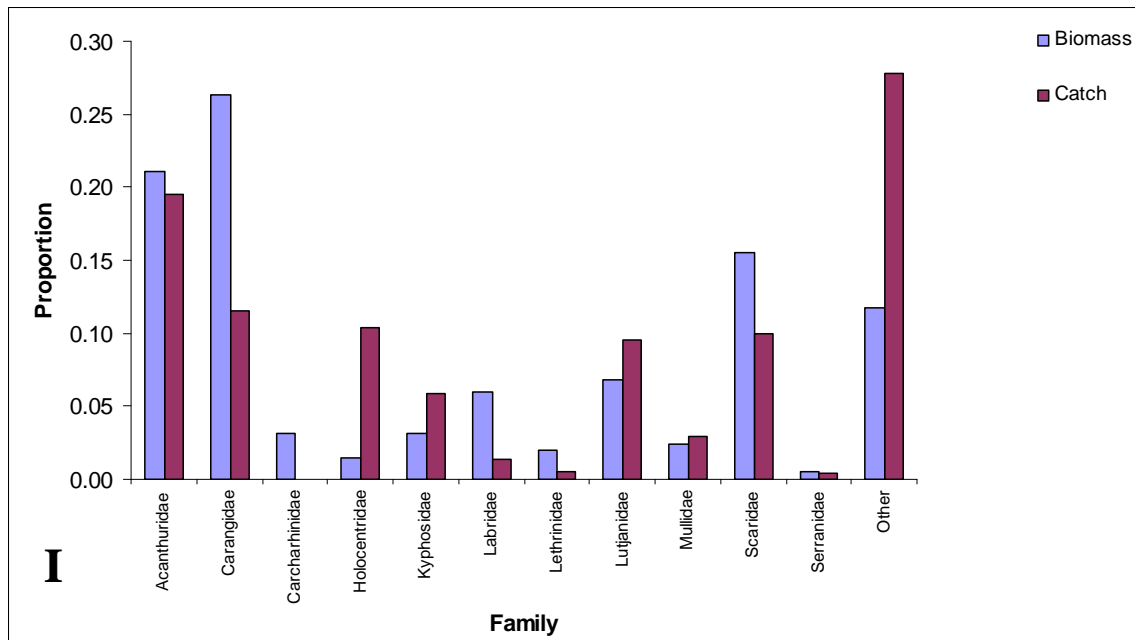


Figure 4. Graphical representation of the percentage of total reef fish caught in MHI (2005-2009) by island landed.

