

SPATIOTEMPORAL ANALYSIS OF LOBSTER TRAP CATCHES: IMPACTS OF TRAP FISHING ON COMMUNITY STRUCTURE

BY

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ABSTRACT

Commercial and research lobster trapping, targeting two species of lobster (*Panulirus marginatus* and *Scyllarides squammosus*), began in the Northwestern Hawaiian Islands in the mid 1970s. Commercial fishing effort peaked in 1986 at 1.3 million trap hauls. A corresponding site-specific, depth-stratified research-monitoring program began in 1986 with two sites, Necker Island and Maro Reef, visited annually. Two types of traps were used in the commercial and research fisheries, initially a 2x4-inch-mesh wire trap and later a 1x2-inch-mesh plastic trap. Research trapping was carried out in two depth strata: 18-37 m (shallow) and 38-91 m (deep). Both trap types are highly selective with target species comprising 90% and 73% of the research catch for wire and plastic traps, respectively. Changes in diversity and species abundance of the research trap catches from 1976-2003 are evaluated and discussed in terms of potential impacts due to fishing activity. The Simpson diversity index measured for the community, using plastic trap catch data, showed a significant increase over time for both depth strata at Necker Island, but a significant decline over time for the shallower depth stratum at Maro Reef. Significant increases in species richness for all sites as measured by Margalef's diversity index were strongly related to increases in trapping effort. Simpson's measure of evenness declined significantly over time for both depth strata at Maro Reef. Declines in abundance of both target species attributed to direct removal (harvest) occurred at Necker Island and for spiny lobster at Maro Reef. Declines in abundance for nontarget species were not observed. Increases in species abundance possibly attributed to competitive replacement were observed for slipper lobster at Maro Reef and for nontarget crab species at both study locations. Recent increases in whitetip reef shark abundance were observed for both Necker Island and Maro Reef, but they could not be explained in terms of fishery impacts.

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INTRODUCTION

Impacts of Fishing on the Ecosystem

High biodiversity is thought to provide stability to an ecosystem exposed to stress including anthropogenic disturbances such as pollution and fishing pressure (Jennings and Kaiser, 1998; McCann, 2000; Magurran, 2004; Kiessling, 2005), and the protection of ecosystems and their biodiversity is a goal of many resource management and conservation organizations. All fishing activities impact the ecosystem in some manner. The nature and extent of the impact varies with the fishery, gear used, and effort expended. Due to their extractive nature, fisheries, at the very least, directly reduce the available biomass of target species. Active gears such as trawls and dredges generally have larger impacts to the ecosystem than do passive gears such as traps or hooks (Alverson et al., 1994; Jennings and Kaiser, 1998). Trawls typically have low selectivity for target species with the discarded bycatch comprising as much as 90% of the total catch (Alverson et al., 1994). Active gear can also drastically alter the structure of the habitat, which can lead to changes in biodiversity, species composition, and productivity (Jennings and Kaiser, 1998). Passive gears, by contrast, generally have lower rates of bycatch and are less likely to directly alter the substratum (Alverson et al., 1994; Jennings and Kaiser, 1998). Not all fishing impacts are direct. With the complex interactions within any food web, direct alterations in abundance of any one species may indirectly cause changes in abundance of another dependent species by prey removal, prey release, competitive replacement, or scavenger enhancement.

Diversity measures are comprised of two components, richness and evenness, and various indices emphasize one or the other component differently. Fishing activities can impact either component. In some cases the impacts of fishing activities are restricted to changes in target species size and abundance, either with no observable change in community diversity or species richness (Watson et al., 1996), or with no change in richness but changes, including increases, in diversity due largely to changes in evenness (ICES, 1996; Rice, 2000; Bianchi et al., 2000). In other cases fishing activities have led to declines in richness and diversity through extirpation of target species (Randall and Heemstra, 1991; Jennings et al., 1995; Jennings and Polunin, 1997; Jennings and Kaiser, 1998; Hall, 1999; Gislason et al., 2000).

Northwestern Hawaiian Island Lobster Fishery

The Northwestern Hawaiian Islands (NWHI) is a series of islands, islets, banks, and reefs extending 1,500 nautical miles from Nihoa Island to Kure Atoll. Commercial and research lobster trapping in this region commenced concurrently in the mid-1970s. During the 1980s, the commercial trap fishery was one of Hawaii's most valuable demersal fisheries, valued at approximately \$6 million per year (Polovina, 1993). This fishery is a multispecies fishery and primarily targets Hawaiian spiny lobster (*Panulirus marginatus*) and common slipper lobster (*Scyllarides squammosus*). Commercial catch peaked in 1985, and effort peaked in 1986 (Fig. 1); however, the commercial fishery was

closed in 2000 due to an increasing lack of confidence in the population models used for management decisions. Research to advance the existing population models is presently underway (DiNardo and Wetherall, 1999).

The nature of the commercial fishery changed over time. When the fishery started in the mid-1970s, one to two vessels targeted Hawaiian spiny lobster in the NWHI each year bringing them back to port alive for the live-lobster market. Trips lasted about 10 days and coupled bottomfishing with lobster trapping with a total of less than 20 trips per year combined. Trapping effort was relatively low, circa 50-100 trap hauls per vessel-day totaling less than 20,000 hauls per year. The standard trap for the fishery was the two-chambered California lobster trap. This was a wire trap with a 2x4-inch mesh. In 1981, vessels began conducting trips dedicated solely to lobster trapping and processed the catch at sea, landing only frozen tails for an export market. The fleet size increased in the early 1980s to as many as 15 vessels fishing in a single year. Trapping effort on these trips increased markedly with trips frequently lasting 40-60 days and approximately 1,000 traps hauled per vessel-day. By the mid-1980s, the gear of choice changed from the wire California trap to a stackable molded plastic trap with a 1x2-inch mesh. This gear change allowed vessels to carry and fish more traps and also resulted in much higher slipper lobster catch rates.

Research trapping by NMFS used similar gear and techniques. Efforts in the late 1970s and early 1980s were largely exploratory in nature, spread thinly throughout the Archipelago. In 1986, a monitoring program was initiated whereby set sites around Necker Island and Maro Reef were visited annually using standardized gear and trapping techniques.

In this study, we analyzed the time series of NWHI lobster trap catches obtained on research cruises. Changes in diversity and species abundance were evaluated and discussed with particular emphasis on changes that can be associated with fishing activities.

METHODS

Field Operations

The National Oceanic and Atmospheric Administration (NOAA) Fisheries Honolulu Laboratory conducted fishery-independent lobster trapping operations in the NWHI since 1976. As in the commercial fishery, two types of traps were used during this time. Two-chambered California lobster traps with a 2x4-inch mesh were used from 1976 through 1991, and molded plastic traps with a 1x2-inch mesh were used from 1986 through the present. Plastic trap escape vents, required to be opened for the commercial fishery, remained closed on the research cruises allowing for greater catchability of small organisms including small individuals of the target species. During research operations, baited traps were set in the afternoon, soaked over night, and then hauled the next day. All organisms captured were identified to the lowest taxonomic level possible, generally the species level, with total counts of each taxon recorded for each trap. In 1986, the Honolulu Laboratory initiated a fixed-site, depth-stratified survey program. Selected sites

were sampled annually during early summer at two banks in the NWHI, Necker Island and Maro Reef, with the exception of 1989, when no survey was conducted, and 2003, when only Maro Reef sites were visited. Two depth strata were targeted. Ten strings of 8 traps were set in 18-37 m at each survey site and two to four strings of 20 traps were set in 38-91 m at sites where these depths occurred. At sites where the deeper water was not present, all trap strings were set within the shallower range. From 1986 to 1991, wire traps were used for the strings of 8 traps, and plastic traps were used for the strings of 20 traps. Starting in 1992, plastic traps were used for all sets.

Data Analysis

Raw data from the fishery-independent trap surveys conducted from 1976 to 2003 were summarized by species, year, bank, site, depth, and gear type. Some taxa (e.g., hermit crabs, moray eels, and sharks) were poorly identified on a few earlier research cruises (e.g., to the genus or family level only), particularly on the 1991 cruise. For the purpose of analysis in this study, individuals of those poorly identified taxa within any site strata (bank/site/depth) were allotted amongst the probable species based on the relative abundances of those component species within that strata recorded for other years. Data for specific trapping sites at each bank were pooled into four bank/depth bins for diversity and abundance analysis. These bins are: Necker Island 18-37 m, Necker Island 38-91 m, Maro Reef 18-37 m, and Maro Reef 38-91 m. Data were excluded for years when less than 50 traps were fished within a particular bin.

Simpson's diversity ($1/D$), Simpson's measure of evenness ($E_{1/D}$), and Margalef's diversity (a measure of richness) indices were calculated as follows for the four sampling bins.

Simpson's Diversity Index ($1/D$): $1/D = 1/\sum((n(n-1))/(N(N-1)))$

Simpson's Measure of Evenness: $E_{1/D} = (1/D)/S$

Margalef's Diversity Index: $D_{Mg} = (S-1)/\ln(N)$

where n = number of individuals of a particular species

N = total number of individuals of all species in the sample

and S = total number of species in the sample

Catch-per-unit-effort (CPUE), in terms of number per trap-haul, was calculated for species groups based on those species that comprised at least 1.0% of the catch in plastic lobster traps (spiny lobster, slipper lobster, hermit crabs, calappid crabs, portunid crabs, moray eels, and *Heniochus diphreutes*). Two additional groups, octopus and the whitetip reef shark, *Triaenodon obesus*, were added to the analysis for reasons explained in the discussion section. In order to compare patterns of species with very different catch rates, CPUE values for each species were indexed by their median value. Indexing results in a 1.0 value representing the "normal" catch rate, 0.5 being one half normal, 6.0 being six times normal, etc. The indexed CPUE values were then graphed together to compare abundance patterns. Linear regressions were applied to each series of diversity and indexed CPUE values using Microsoft Excel data analysis tools. Significant regressions at the 95% confidence level, positive or negative, were considered as evidence of possible fishing impact.

RESULTS AND DISCUSSION

Selectivity

Both wire and plastic lobster traps are highly selective gears for lobsters. Wire traps set between 1976 and 1991 on research cruises caught a total of 82 species (Table 1). Of these species, the two target species of lobster accounted for 90.5% of the catch by number. Plastic trap catches from 1986 to 2003 contained 258 species (Table 2) of which 73.1% were the two target species. For both gears the two target species were most abundant in the catches. Also, two species of *Dardanus* hermit crabs were next in abundance for both gears, with the moray eel (*Gymnothorax steindachneri*) within the top ten in both cases. Ridgeback slipper lobster (*Scyllarides haanii*), a large reef fish (*Melichthys niger*), and adults of three bottomfish species (*Pristipomoides filamentosus*, *Epinephelus quernus*, and *Pseudocaranx cheilio*), rounded out the top ten for the wire traps, whereas three sand-dwelling crabs (*Calappa calappa*, *Charybdis hawaiiensis*, and *Ranina ranina*), and two small reef-fish species (*Heniochus diphreutes* and *Pervagor pilosoma*) did so for the plastic traps. It is interesting to note that, with the exception of juveniles of *Epinephelus quernus*, bottomfish species were not caught with the plastic traps. This may be a result of these species avoiding the plastic traps, similar to the behavior of avoiding structure, including plastic traps, observed by Moffitt and Parrish (1996) for juvenile *Pristipomoides filamentosus*.

The smaller mesh size of the plastic traps was likely responsible for the greater number of species captured, most of which were small species. These traps were nearly equal to wire traps in their ability to catch spiny lobster, but were much better at catching slipper lobster (Table 3). Although the number of species caught in the plastic traps was much greater than in the wire traps, this gear was still highly selective. The top nine species comprised 90% of the catch by number (Table 2). Of the remaining species, 181 of them (70% of the 258 species total) were represented in the catch by 18 or less individuals, which means they averaged only one individual caught per year of research trapping compared to an average catch of 4,114 targeted lobsters per year.

Diversity

Because the traps used in the NWHI lobster fishery were highly selective for target species, they did not provide a very accurate measurement of the diversity of the reef community on the lobster fishing grounds. However, changes in diversity indices measured by these traps over time could indicate whether fishing activity may have altered the diversity of the benthic community. Because the wire and plastic traps had different catchability characteristics for most species, the results could not be pooled across trap types, therefore only plastic trap results are included below. Unfortunately, diversity indices are strongly influenced by sample size (Kaiser, 2003; Magurran, 2004), and the sampling effort in this study fluctuated (generally increased) over time. The indices used in this study were selected for their resistance to sample size influences.

Results of the linear regressions for diversity indices and species abundances over time are listed in Table 3. The Simpson diversity indices obtained for three of the four bank-depth bins displayed significant trends (Fig. 2). At Necker Island the observed diversity increased over time for both depth bins, whereas at Maro Reef a significant decline was observed for the shallower depth bin. Richness (Margalef's diversity index) and evenness components were evaluated separately and can help explain the observed changes in the diversity indices. Margalef's index was selected as the measure of richness for this paper because of its resistance to sample size bias (Margurran, 2004). Despite this resistance, evaluation of species richness over time for the four bins showed a significant increase in all cases, largely mirroring changes in trapping effort and probably not reflecting actual increases in species richness in the benthic community. Regressions of effort and Margalef's indices were significantly positive for all bins (Table 4). The relationship between richness and trapping effort over time for Necker Island 18-37 m is shown in Figure 3. Significant decreases in species evenness were observed for both depths at Maro Reef and are likely due to the large increase in slipper lobster abundance described below. Changes in evenness for Necker Island, on the other hand, were not significant. No significant increase in the evenness component with the fishing down of abundant target species as reported by ICES (1996) and Rice (2000) was observed in our study. In light of the changes in richness and evenness components of the diversity indices, it is likely that increases measured for Necker can be attributed to increases in the richness component as a result of increased sampling effort. For Maro Reef, decreases in the evenness component may have counteracted the observed increases in the species richness indices leading to a significant decline in diversity for the 18-37-m depth bin and no significant change in the 38-91-m bin.

Relative Abundance

Only lobsters showed a significant decline in abundance (Table 4). Spiny lobster CPUE values show significant declines as expected for three of the four sampling bins. The exception was the deeper (38-91 m) bin at Maro Reef, where spiny lobsters were never particularly abundant, and the observed declines in this bin were not significant. Changes in slipper lobster abundance showed a different pattern. Necker 18-37 m slipper lobster CPUE significantly declined in a similar manner to that of spiny lobster, whereas declines in the deeper bin were not significant. Slipper lobster abundance at Maro Reef, however, showed increases, significant at the shallower depths but not the deeper (Fig. 4). This increase in abundance is likely a case of competitive replacement in response to the drastic drop in spiny lobster abundance at the shallower depths at Maro Reef; slipper lobsters were able to outpace the decline in abundance expected from commercial harvest.

All other species groups examined showed either a positive trend or no significant trend in abundance over time. The nontargeted crustaceans groups, hermit crabs, calappid crabs, and portunid crabs, all showed a positive trend in CPUE in the shallow bin at Necker. These increases may be due to competitive replacement in response to declining lobster abundance. Hermit crabs showed no significant trend in the other

sampling bins, calappid abundance increased in the 38-91-m bin at Necker, and portunids increased in both depth bins at Maro. The only reef-fish species in the top 90% of the catch, *Heniochus diphreutes*, showed no significant linear trends in abundance for any sampling bin. In spite of this, their pattern of abundance is interesting (Fig. 5). These fish were caught as recently settled juveniles, and their abundance in the catch for any year may reflect year-class recruitment strength. As can be seen, abundance fluctuated markedly between years, most notably at Maro. Changes in abundance of the whitetip reef shark are presented in Figure 6. It was included in this paper due to its interesting pattern. As can be seen, abundance was low for most of the study period, but has increased markedly in the last few years at both Necker Island and Maro Reef. This increase is not likely related to fishing activity (e.g., competitive replacement or scavenger enhancement) and remains unexplained. Finally, octopus abundance was evaluated due to its potential as an important prey item for the endangered Hawaiian monk seal (*Monachus schauinslandi*). As can be seen in Table 3, octopus are a relatively rare item in our trap catches with only 83 individuals captured in the 1986-2003 study period. Furthermore, examination of research CPUE data shows no significant decline or increase in abundance over time.

CONCLUSION

In conclusion, lobster trapping activities have likely contributed to changes in abundance of a few species of the benthic community on the NWHI lobster fishing grounds, but do not appear to have resulted in major changes to the ecosystem. Significant declines in species abundance through direct removal (harvest) appear to be limited to the target species. Competitive replacement may have led to increases in abundance of several nontarget crab species and the targeted slipper lobster at Maro Reef. Direct damage to the benthic habitat by the traps has not been studied, but is not likely to be substantial due to the low relief, hard substrate that characterizes the fishing grounds (Parrish and Boland, 2004). Future researchers may be able to measure and document the resiliency of the lobster populations now that commercial fishing has stopped.

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Table 1. Species caught in wire traps, 1976-1991.

Species	#	%	Cum %	Species	#	%	Cum %
<i>Panulirus marginatus</i>	21749	81.6098	81.6098	<i>Aluterus scriptus</i>	7	0.0263	99.6510
<i>Scyllarides squamosus</i>	2368	8.8856	90.4953	<i>Calappa calappa</i>	5	0.0188	99.6698
<i>Dardanus gemmatus</i>	1034	3.8799	94.3752	<i>Gymnothorax albimarginatus</i>	5	0.0188	99.6886
<i>Dardanus brachyops</i>	374	1.4034	95.7786	<i>Chaetodon militaris</i>	5	0.0188	99.7073
<i>Gymnothorax steindachneri</i>	322	1.2083	96.9869	<i>Panulirus penicillatus</i>	4	0.0150	99.7223
<i>Pristipomoides filamentosus</i>	80	0.3002	97.2871	<i>Carpilius maculatus</i>	4	0.0150	99.7373
<i>Epinephelus quernus</i>	70	0.2627	97.5497	<i>Echinothrix calamaris</i>	4	0.0150	99.7523
<i>Scyllarides haanii</i>	68	0.2552	97.8049	<i>Gymnothorax berndti</i>	3	0.0113	99.7636
<i>Pseudocaranx dentex</i>	56	0.2101	98.0150	<i>Conger cinereus marginatus</i>	3	0.0113	99.7749
<i>Melichthys niger</i>	52	0.1951	98.2101	<i>Parupeneus porphyreus</i>	3	0.0113	99.7861
<i>Bodianus bilunulatus</i>	45	0.1689	98.3790	<i>Parupeneus insularis</i>	3	0.0113	99.7974
<i>Carcharhinus amblyrhynchos</i>	37	0.1388	98.5178	<i>Kyphosus bigibbus</i>	3	0.0113	99.8086
<i>Astopyga radiata</i>	31	0.1163	98.6341	<i>Heniochus diphreutes</i>	3	0.0113	99.8199
<i>Carpilius convexus</i>	30	0.1126	98.7467	<i>Luidia magnifica</i>	2	0.0075	99.8274
<i>Gymnothorax undulatus</i>	29	0.1088	98.8555	<i>Eucidaris metularia</i>	2	0.0075	99.8349
<i>Melichthys vidua</i>	25	0.0938	98.9493	<i>Sargocentron xantherythrum</i>	2	0.0075	99.8424
<i>Ranina ranina</i>	24	0.0901	99.0394	<i>Caranx ignobilis</i>	2	0.0075	99.8499
<i>Dardanus "purple leg"</i>	22	0.0826	99.1220	<i>Parupeneus chrysonemus</i>	2	0.0075	99.8574
<i>Dromidiopsis dormia</i>	22	0.0826	99.2045	<i>Acanthurus olivaceus</i>	2	0.0075	99.8649
<i>Dardanus sanguinocarpus</i>	19	0.0713	99.2758	<i>Sufflamen fraenatus</i>	2	0.0075	99.8724
<i>Parribacus antarcticus</i>	13	0.0488	99.3246	<i>Pervagor spilosoma</i>	2	0.0075	99.8799
<i>Dardanus megistros</i>	13	0.0488	99.3734	<i>Pherecardia striata</i>	1	0.0038	99.8837
<i>Seriola dumerili</i>	13	0.0488	99.4221	<i>Plesionika sp.</i>	1	0.0038	99.8874
<i>Triaenodon obesus</i>	11	0.0413	99.4634	<i>Parthenope contrarius</i>	1	0.0038	99.8912
<i>Octopus cyanea</i>	10	0.0375	99.5009	<i>Lissocarcinus laevis</i>	1	0.0038	99.8949
<i>Octopus sp.</i>	9	0.0338	99.5347	<i>Comus quercinus</i>	1	0.0038	99.8987
<i>Gymnothorax flavimarginatus</i>	8	0.0300	99.5647	<i>Comus vexillum</i>	1	0.0038	99.9024
<i>Sargocentron spiniferum</i>	8	0.0300	99.5947	<i>Leiaster leachi hawaiiensis</i>	1	0.0038	99.9062
<i>Bodianus sp</i>	8	0.0300	99.6248	<i>Linckia guildingi</i>	1	0.0038	99.9099

Table 1. Species caught in wire traps, 1976-1991(Con'td)

Species	#	%	Cum %	Species	#	%	Cum %
<i>Linckia multifora</i>	1	0.0038	99.9137	<i>Priacanthus alalaua</i>	1	0.0038	99.9587
Ophiuroidea	1	0.0038	99.9174	<i>Carangoides orthogrammus</i>	1	0.0038	99.9625
<i>Diadema paucispinum</i>	1	0.0038	99.9212	<i>Parupeneus pleurostigma</i>	1	0.0038	99.9662
<i>Opheodesoma spectabilis</i>	1	0.0038	99.9250	<i>Kyphosus vaigiensis</i>	1	0.0038	99.9700
<i>Bathycongrus</i> sp.	1	0.0038	99.9287	<i>Chaetodon fremblii</i>	1	0.0038	99.9737
<i>Conger oligoporus</i>	1	0.0038	99.9325	<i>Polydactylus sexfilis</i>	1	0.0038	99.9775
<i>Myrichthys magnificus</i>	1	0.0038	99.9362	<i>Thalassoma purpureum</i>	1	0.0038	99.9812
<i>Synodus capricornis</i>	1	0.0038	99.9400	<i>Thalassoma ballieui</i>	1	0.0038	99.9850
<i>Physiculus rhodopinnis</i>	1	0.0038	99.9437	<i>Coris ballieui</i>	1	0.0038	99.9887
<i>Scorpaenodes corallinus</i>	1	0.0038	99.9475	<i>Acanthurus blochii</i>	1	0.0038	99.9925
<i>Segastapistes ballieui</i>	1	0.0038	99.9512	<i>Thamnaconus garretti</i>	1	0.0038	99.9962
<i>Segastapistes galactacma</i>	1	0.0038	99.9550	<i>Sphoeroides pachygaster</i>	1	0.0038	100.0000

Table 2. Species caught in plastic traps, 1986-2003.

Species	#	%	Cum %	Species	#	%	Cum %
<i>Panulirus marginatus</i>	37277	36.79281	36.79281	<i>Panulirus penicillatus</i>	160	0.157922	96.7695
<i>Scyllarides squamosus</i>	36783	36.30522	73.09803	<i>Parupeneus multifasciatus</i>	156	0.153974	96.9235
<i>Dardanus gemmatus</i>	6297	6.215208	79.3132	<i>Segastapistes ballieui</i>	152	0.150026	97.0735
<i>Dardanus brachyops</i>	3816	3.766434	83.0797	<i>Thalamita auauensis</i>	143	0.141143	97.2147
<i>Calappa calappa</i>	2284	2.254333	85.3340	<i>Parthenope contrarius</i>	131	0.129298	97.3440
<i>Charybdis hawaiiensis</i>	1801	1.777607	87.1116	<i>Astopyga radiata</i>	123	0.121402	97.4654
<i>Gymnothorax steindachneri</i>	1363	1.345296	88.4569	<i>Chaetodon fremblii</i>	96	0.094753	97.5601
<i>Heniochus diphreutes</i>	1134	1.11927	89.5762	<i>Myrichthys magnificus</i>	91	0.089818	97.6499
<i>Ranina ranina</i>	550	0.542856	90.1190	<i>Gymnothorax albimarginatus</i>	86	0.084883	97.7348
<i>Pervagor spilosoma</i>	468	0.461921	90.5810	<i>Dendrochirus barberi</i>	84	0.082909	97.8177
<i>Sargocentron xantherythrum</i>	464	0.457973	91.0389	<i>Cirrhitops fasciatus</i>	79	0.077974	97.8957
<i>Carpilius convexus</i>	464	0.457973	91.4969	<i>Parupeneus insularis</i>	79	0.077974	97.9737
<i>Pseudanthias thompsoni</i>	458	0.452051	91.9490	<i>Homola dickinsoni</i>	78	0.076987	98.0507
<i>Scyllarides haanii</i>	458	0.452051	92.4010	<i>Carcharhinus amblyrhynchos</i>	65	0.064156	98.1148
<i>Parupeneus pleurostigma</i>	443	0.437246	92.8382	<i>Conger cinereus marginatus</i>	63	0.062182	98.1770
<i>Gymnothorax undulatus</i>	406	0.400726	93.2390	<i>Dardanus sanguinocarpus</i>	63	0.062182	98.2392
<i>Chaetodon miliaris</i>	350	0.345454	93.5844	<i>Luidia magnifica</i>	61	0.060208	98.2994
<i>Triacnodon obesus</i>	342	0.337558	93.9220	<i>Charybdis paucidentata</i>	59	0.058234	98.3576
<i>Canthigaster jactator</i>	330	0.325714	94.2477	<i>Nassarius hirtus</i>	57	0.05626	98.4139
<i>Aulostomus chinensis</i>	325	0.320779	94.5685	<i>Nassarius papillosus</i>	56	0.055273	98.4691
<i>Pherecardia striata</i>	312	0.307947	94.8764	<i>Octopus sp.</i>	55	0.054286	98.5234
<i>Dromidiopsis dormia</i>	259	0.255636	95.1321	<i>Torquigener sp.</i>	52	0.051325	98.5748
<i>Lutjanus kasmira</i>	247	0.243792	95.3759	<i>Gymnothorax flavimarginatus</i>	48	0.047377	98.6221
<i>Parribacrus antarcticus</i>	234	0.230961	95.6068	<i>Dardanus megistros</i>	48	0.047377	98.6695
<i>Calappa pokipoki</i>	220	0.217142	95.8240	<i>Apogon maculiferus</i>	45	0.044415	98.7139
<i>Dardanus "purple leg"</i>	218	0.215168	96.0391	<i>Gymnothorax berndti</i>	45	0.044415	98.7583
<i>Carpilius maculatus</i>	212	0.209246	96.2484	<i>Dairoides kusei</i>	36	0.035532	98.7939
<i>Lupocyclus quinquentatus</i>	202	0.199376	96.4477				
<i>Epinephelus quernus</i>	166	0.163844	96.6116				

Table 2. Species caught in plastic traps, 1986-2003 (Con'td)

Species	#	%	Cum %	Species	#	%	Cum %
<i>Luzonichthys earlei</i>	31	0.030597	98.8245	Ophiuroidea	13	0.012831	99.4364
<i>Pseudanthias bicolor</i>	31	0.030597	98.8551	<i>Progyron mus</i>	13	0.012831	99.4492
<i>Enoplometopus occidentalis</i>	31	0.030597	98.8857	<i>Fusinus michaelrogersi</i>	12	0.011844	99.4611
<i>Chromis ovalis</i>	30	0.02961	98.9153	<i>Nassarius gaudiosus</i>	12	0.011844	99.4729
<i>Gymnothorax melatremus</i>	30	0.02961	98.9449	<i>Lissocarcinus laevis</i>	12	0.011844	99.4848
<i>Fusinus sandvichensis</i>	30	0.02961	98.9745	<i>Plectroglyphidodon johnstonianus</i>	11	0.010857	99.4956
<i>Plesionika sp.</i>	30	0.02961	99.0041	<i>Parupeneus chrysonemus</i>	11	0.010857	99.5065
<i>Octopus cyanea</i>	27	0.026649	99.0308	<i>Synodus ulae</i>	11	0.010857	99.5174
<i>Priacanthus alalaua</i>	26	0.025662	99.0564	<i>Mithrodia fisheri</i>	11	0.010857	99.5282
Nudibranchia (includes at least 1 <i>Halgerda terramfuensis</i>)	26	0.025662	99.0821	<i>Trizopagurus strigatus</i>	11	0.010857	99.5391
<i>Canthigaster rivulata</i>	24	0.023688	99.1058	<i>Turbo sandwicensis</i>	10	0.00987	99.5489
<i>Thalamita picta</i>	24	0.023688	99.1295	<i>Justitia longimana</i>	10	0.00987	99.5588
<i>Bothus thompsoni</i>	22	0.021714	99.1512	<i>Heterocarpus ensifer</i>	10	0.00987	99.5687
<i>Vexillum pacificum</i>	20	0.01974	99.1709	<i>Sargocentron diadema</i>	9	0.008883	99.5776
<i>Cycloes granulose</i>	20	0.01974	99.1907	<i>Eucidaris metularia</i>	9	0.008883	99.5864
<i>Acanthurus olivaceus</i>	19	0.018753	99.2094	<i>Odontodactylus hawaiiensis</i>	9	0.008883	99.5953
<i>Thalassoma ballieui</i>	19	0.018753	99.2282	<i>Cirrhitus pinnulatus</i>	8	0.007896	99.6032
<i>Gymnothorax meleagris</i>	19	0.018753	99.2469	<i>Dascyllus albisella</i>	8	0.007896	99.6111
<i>Echinothrix calamaris</i>	19	0.018753	99.2657	<i>Chaetodon kleinii</i>	8	0.007896	99.6190
<i>Linckia multifora</i>	19	0.018753	99.2844	<i>Conger oligoporus</i>	8	0.007896	99.6269
<i>Thalamita admete</i>	19	0.018753	99.3032	<i>Bursa luteostoma</i>	8	0.007896	99.6348
<i>Linckia guildingi</i>	17	0.016779	99.3199	<i>Thalamita wakensis</i>	8	0.007896	99.6427
<i>Canthigaster coronata</i>	16	0.015792	99.3357	<i>Lahaina ovata</i>	8	0.007896	99.6506
<i>Cantherhines verecundus</i>	16	0.015792	99.3515	<i>Aniculus maximus</i>	8	0.007896	99.6585
<i>Nassarius splendidulus</i>	16	0.015792	99.3673	<i>Calotomus zonarcha</i>	7	0.006909	99.6654
<i>Scyllarus aurora</i>	16	0.015792	99.3831	<i>Priacanthus meeki</i>	7	0.006909	99.6723
<i>Gymnothorax eurostus</i>	15	0.014805	99.3979	<i>Gymnothorax nudivomer</i>	7	0.006909	99.6792
<i>Coris ballieui</i>	13	0.012831	99.4108	<i>Squalus mitsukurii</i>	7	0.006909	99.6861
<i>Myripristis chryseres</i>	13	0.012831	99.4236	<i>Huenia pacifica</i>	7	0.006909	99.6930

Table 2. Species caught in plastic traps, 1986-2003 (Con'td)

Species	#	%	Cum %	Species	#	%	Cum %
<i>Portunus sanguinolentis</i>	6	0.005922	99.6990	<i>Scorpaenodes corallinus</i>	3	0.002961	99.8184
<i>Melichthys niger</i>	5	0.004935	99.7039	<i>Rhinopias xenops</i>	3	0.002961	99.8214
<i>Centropyge potteri</i>	5	0.004935	99.7088	<i>Pristilepis oligolepis</i>	3	0.002961	99.8243
<i>Seriola dumerili</i>	5	0.004935	99.7138	<i>Physiculus rhodopinnis</i>	3	0.002961	99.8273
<i>Scorpaenodes littoralis</i>	5	0.004935	99.7187	<i>Antennarius commerson</i>	3	0.002961	99.8302
<i>Myripristis kuntze</i>	5	0.004935	99.7236	<i>Gymnothorax javanicus</i>	3	0.002961	99.8332
<i>Ariosoma marginatum</i>	5	0.004935	99.7286	<i>Bohadschia paradoxa</i>	3	0.002961	99.8362
<i>Pentaceros cumingi</i>	5	0.004935	99.7335	<i>Culcita novaeguineae</i>	3	0.002961	99.8391
<i>Chlorodiella laevisima</i>	5	0.004935	99.7384	<i>Mitrella bella</i>	3	0.002961	99.8421
<i>Paramola alcocki</i>	5	0.004935	99.7434	<i>Pinaxia versicolor</i>	3	0.002961	99.8450
<i>Calotomus carolinus</i>	4	0.003948	99.7473	<i>Drupa grossularia</i>	3	0.002961	99.8480
<i>Chromis hanui</i>	4	0.003948	99.7513	<i>Bursa rhodostoma</i>	3	0.002961	99.8510
<i>Chromis vanderbilti</i>	4	0.003948	99.7552	<i>Lophozymus dodone</i>	3	0.002961	99.8539
<i>Parupeneus porphyreus</i>	4	0.003948	99.7592	<i>Thalamita spinifera</i>	3	0.002961	99.8569
<i>Mulloidichthys vanicolensis</i>	4	0.003948	99.7631	<i>Scylla serrata</i>	3	0.002961	99.8598
<i>Mulloidichthys flavolineatus</i>	4	0.003948	99.7671	<i>Portunus pubescens</i>	3	0.002961	99.8628
<i>Segastapistes galactama</i>	4	0.003948	99.7710	<i>Daldorfia rathbuni</i>	3	0.002961	99.8658
<i>Iracundus signifier</i>	4	0.003948	99.7750	<i>Hyastenus sp.</i>	3	0.002961	99.8687
<i>Hippocampus sp.</i>	4	0.003948	99.7789	<i>Galathea spinosirostris</i>	3	0.002961	99.8717
<i>Bathycongrus sp.</i>	4	0.003948	99.7829	<i>Fungia scutaria</i>	3	0.002961	99.8746
Pyrosomata	4	0.003948	99.7868	<i>Canthigaster epilampra</i>	2	0.001974	99.8766
<i>Leiaster leachi hawaiiensis</i>	4	0.003948	99.7908	<i>Sufflamen fraenatus</i>	2	0.001974	99.8786
Atyidae (includes at least 1	4	0.003948	99.7947	<i>Bothus pantherinus</i>	2	0.001974	99.8806
<i>Haminoea curta</i>)	4	0.003948	99.7986	<i>Thalassoma purpureum</i>	2	0.001974	99.8825
<i>Bulla vernicosa</i>	4	0.003948	99.8026	<i>Oxycheilinus bimaculatus</i>	2	0.001974	99.8845
<i>Fusinus midwayensis</i>	4	0.003948	99.8065	<i>Cheilodactylus vittatus</i>	2	0.001974	99.8865
<i>Calcinus laurentae</i>	3	0.002961	99.8095	<i>Paracirrhites arcatus</i>	2	0.001974	99.8885
<i>Bothus mancus</i>	3	0.002961	99.8125	<i>Chaetodon multinctus</i>	2	0.001974	99.8904
<i>Apogon kallopterus</i>	3	0.002961	99.8154	<i>Sebastapistes coniora</i>	2	0.001974	99.8924
<i>Scorpaenopsis brevifrons</i>	3	0.002961					

Table 2. Species caught in plastic traps, 1986-2003 (Con'td)

Species	#	%	Cum %	Species	#	%	Cum %
<i>Scorpaenopsis diabolus</i>	2	0.001974	99.8944	<i>Scarus sp.</i>	1	0.000987	99.9447
<i>Pterois sphex</i>	2	0.001974	99.8964	<i>Coris venusta</i>	1	0.000987	99.9457
<i>Neoniphon sammara</i>	2	0.001974	99.8983	<i>Bodianus sp.</i>	1	0.000987	99.9467
<i>Sargocentron punctatissimum</i>	2	0.001974	99.9003	<i>Amblycirrhitus bimaculata</i>	1	0.000987	99.9477
<i>Sargocentron spiniferum</i>	2	0.001974	99.9023	<i>Apolemichthys arcuatus</i>	1	0.000987	99.9487
<i>Antennarius pictus</i>	2	0.001974	99.9043	<i>Forcipiger flavissimus</i>	1	0.000987	99.9497
<i>Synodus falcatus</i>	2	0.001974	99.9062	<i>Kyphosus vaigiensis</i>	1	0.000987	99.9506
<i>Synodus amaranthus</i>	2	0.001974	99.9082	<i>Kyphosus bigibbus</i>	1	0.000987	99.9516
<i>Enchelycore pardalis</i>	2	0.001974	99.9102	<i>Mulloidichthys pfluegeri</i>	1	0.000987	99.9526
<i>Opheodesoma spectabilis</i>	2	0.001974	99.9122	<i>Naucrates doctor</i>	1	0.000987	99.9536
<i>Stichopus horrens</i>	2	0.001974	99.9141	<i>Apogon erythrinus</i>	1	0.000987	99.9546
<i>Diadema paucispinum</i>	2	0.001974	99.9161	<i>Dacyloptena orientalis</i>	1	0.000987	99.9556
<i>Acanthaster planci</i>	2	0.001974	99.9181	<i>Caracanthus typicus</i>	1	0.000987	99.9566
<i>Pleurobranchus sp.</i>	2	0.001974	99.9201	<i>Neoniphon aurolineatus</i>	1	0.000987	99.9576
<i>Conus pertusus</i>	2	0.001974	99.9220	<i>Sargocentron tiere</i>	1	0.000987	99.9585
<i>Morula granulata</i>	2	0.001974	99.9240	<i>Brotula multibarata</i>	1	0.000987	99.9595
<i>Bursa rosa</i>	2	0.001974	99.9260	<i>Synodus capricornis</i>	1	0.000987	99.9605
<i>Strombus vomer hawaiiensis</i>	2	0.001974	99.9279	<i>Gymnothorax ypsilon</i>	1	0.000987	99.9615
<i>Lybia edmondsoni</i>	2	0.001974	99.9299	<i>Scuticaria okinawae</i>	1	0.000987	99.9625
<i>Etisus splendidus</i>	2	0.001974	99.9319	Pectinidae	1	0.000987	99.9635
<i>Actaea nodulosa</i>	2	0.001974	99.9339	<i>Aplysia sp.</i>	1	0.000987	99.9645
<i>Carpilodes ruber</i>	2	0.001974	99.9358	<i>Terebra thaamumi</i>	1	0.000987	99.9655
<i>Lyreidus tridentatus</i>	2	0.001974	99.9378	<i>Terebra chlorata</i>	1	0.000987	99.9664
<i>Diodon holocanthus</i>	1	0.000987	99.9388	<i>Terebra gouldi</i>	1	0.000987	99.9674
<i>Thamnaconus garretti</i>	1	0.000987	99.9398	<i>Conus textile</i>	1	0.000987	99.9684
<i>Acanthurus nigrofuscus</i>	1	0.000987	99.9408	<i>Conus pulicarius</i>	1	0.000987	99.9694
<i>Acanthurus triostegus sandvicensis</i>	1	0.000987	99.9418	<i>Conus abbreviatus</i>	1	0.000987	99.9704
Gobiidae	1	0.000987	99.9428	<i>Conus striatus</i>	1	0.000987	99.9714
<i>Exallias brevis</i>	1	0.000987	99.9437	<i>Latirus nodatus</i>	1	0.000987	99.9724

Table 2. Species caught in plastic traps, 1986-2003 (Con'td)

Species	#	%	Cum %
<i>Prodotia iostomus</i>	1	0.000987	99.9734
<i>Murex pele</i>	1	0.000987	99.9743
<i>Bursa granularis</i>	1	0.000987	99.9753
<i>Strombus heli</i>	1	0.000987	99.9763
<i>Cerithium sp.</i>	1	0.000987	99.9773
<i>Pseudosquilla oculata</i>	1	0.000987	99.9783
<i>Pilumnus sp</i>	1	0.000987	99.9793
<i>Pilodius areolatus</i>	1	0.000987	99.9803
<i>Pilodius flavus</i>	1	0.000987	99.9812
<i>Neolimera immigrans</i>	1	0.000987	99.9822
<i>Xanthias glabrous</i>	1	0.000987	99.9832
<i>Lophozymus pulchellus</i>	1	0.000987	99.9842
<i>Lophozymus intonsus</i>	1	0.000987	99.9852
<i>Percnon abbreviatum</i>	1	0.000987	99.9862
<i>Thalamita crenata</i>	1	0.000987	99.9872
<i>Thalamita coeruleipes</i>	1	0.000987	99.9882
<i>Thalamita kukenthali</i>	1	0.000987	99.9891
<i>Thalamita alcocki</i>	1	0.000987	99.9901
<i>Charybdis erythrodactyla</i>	1	0.000987	99.9911
<i>Portunus nipponensis</i>	1	0.000987	99.9921
<i>Osachila japonica</i>	1	0.000987	99.9931
<i>Lambrachaeus ramifer</i>	1	0.000987	99.9941
Leucosiidae	1	0.000987	99.9951
<i>Paromola japonica</i>	1	0.000987	99.9961
<i>Munida sp.</i>	1	0.000987	99.9970
<i>Saron marmoratus</i>	1	0.000987	99.9980
<i>Oplophorus gracilirostris</i>	1	0.000987	99.9990
Amphipoda	1	0.000987	100.0000

Table 3. Mean catch rates of spiny and slipper lobster by gear type (number of lobsters per trap haul).

	Mean CPUE 1986-88	
	Wire	Plastic
Spiny	2.62	2.64
Slipper	0.20	1.19

Table 4. Significant changes in diversity and major species abundance through time.

	Necker 18-37			Necker 38-91			Maro 18-37			Maro 38-91		
	slope	r squared	p	slope	r squared	p	slope	r squared	p	slope	r squared	p
Diversity Indices												
Simpson's Index 1/D	0.18	0.67	0.0002	0.34	0.67	0.0002	-0.078	0.38	0.01	0.026	0.02	0.61
Simpson's Evenness $E_{1/D}$	-0.002	0.18	0.11	0.0003	0.00	0.87	-0.006	0.73	0.00002	-0.014	0.62	0.0005
Margalef's Index	0.44	0.91	0.00000005	0.43	0.74	0.00004	0.164	0.40	0.008	0.240	0.60	0.0006
Effort vs Margalef's Index	0.003	0.74	0.00004	0.007	0.90	0.00000008	0.004	0.48	0.003	0.021	0.75	0.00003
Abundance Indices												
Spiny Lobster	-0.10	0.60	0.0004	-0.14	0.61	0.0004	-1.188	0.51	0.001	-0.207	0.18	0.09
Slipper Lobster	-0.06	0.37	0.01	-0.07	0.19	0.09	0.081	0.78	0.000002	0.044	0.22	0.06
Hermit Crabs	0.06	0.43	0.006	0.02	0.03	0.51	0.022	0.04	0.44	0.039	0.03	0.52
Calappid Crabs	0.24	0.64	0.0002	0.14	0.60	0.0004	0.021	0.03	0.49	0.071	0.23	0.05
Portunid Crabs	0.08	0.37	0.01	-0.35	0.09	0.26	0.064	0.31	0.02	0.077	0.35	0.01
<i>Heriochus</i>	0.04	0.00	0.84	-0.28	0.08	0.30	0.937	0.08	0.26	0.438	0.07	0.31
Moray Eels	-0.04	0.21	0.08	-0.01	0.01	0.69	-0.023	0.13	0.16	-0.015	0.01	0.73
Whitetip Reef Shark	0.48	0.54	0.001	0.10	0.45	0.005	0.232	0.37	0.009	-0.108	0.16	0.11
Octopus	-0.0001	0.08	0.29	-0.0003	0.10	0.26						

All Banks 10-20

All Banks 21-50

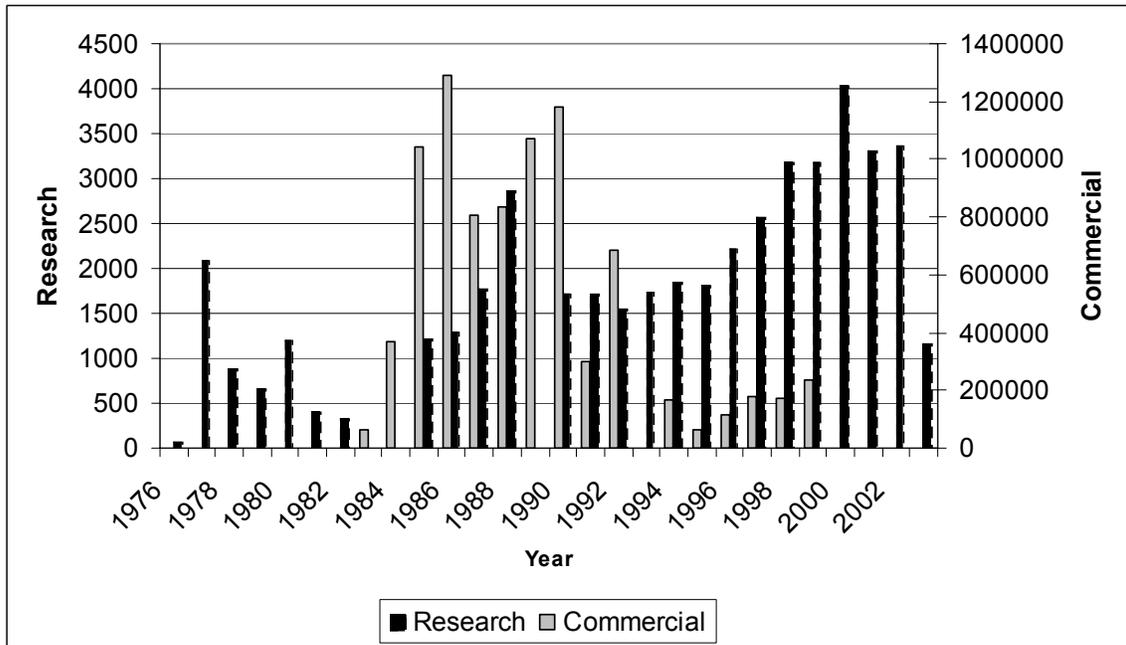


Figure 1. Commercial and research lobster trapping effort in trap hauls. (Commercial effort data is not available prior to the implementation of a Federal logbook system in mid-1983).

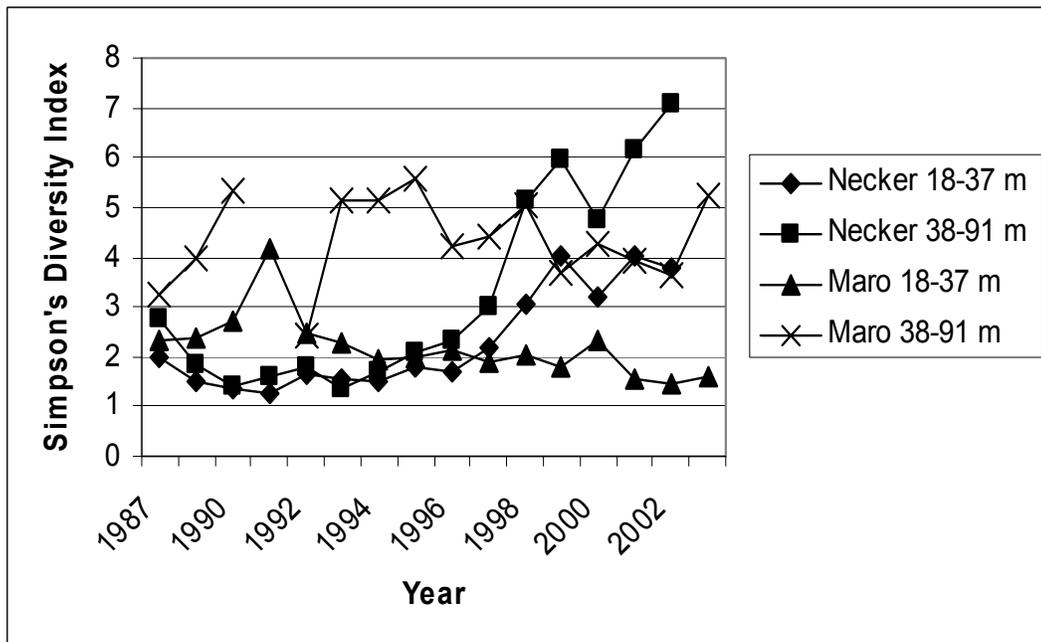


Figure 2. Diversity indices.

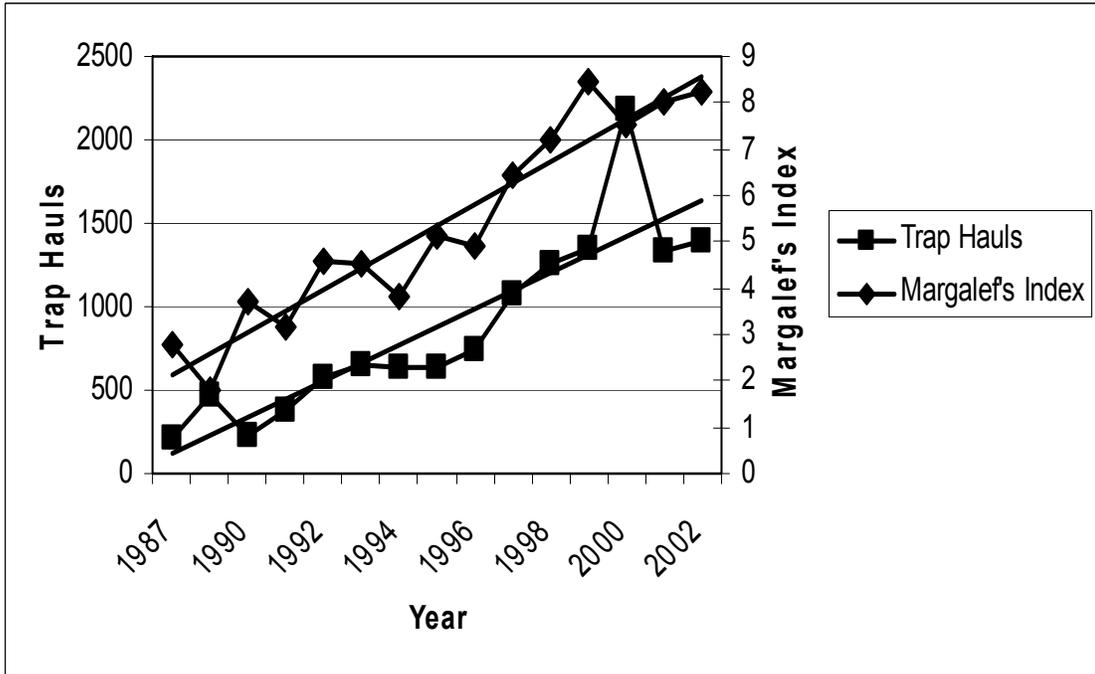


Figure 3. Species richness and trapping effort .

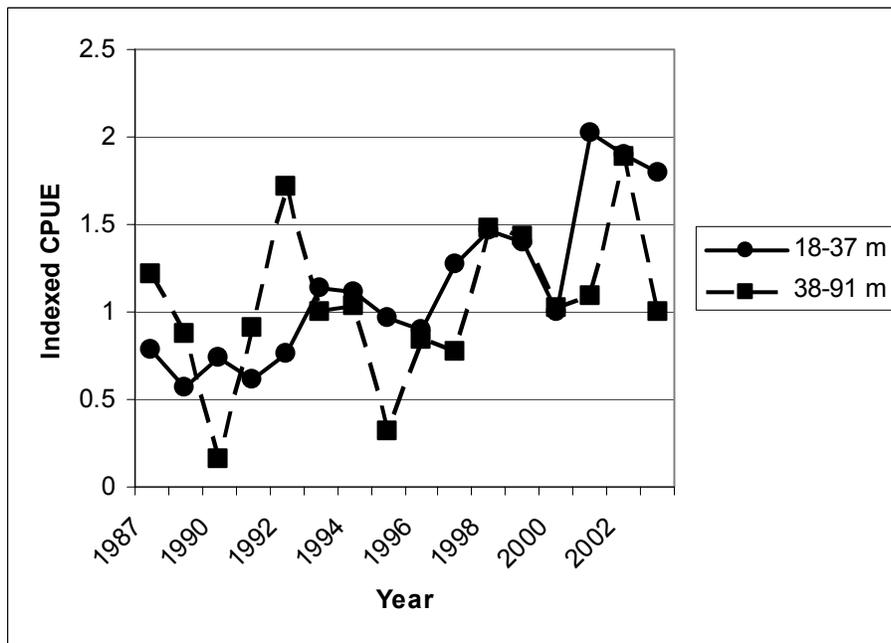


Figure 4. Indexed CPUE for slipper lobster at Maro Reef

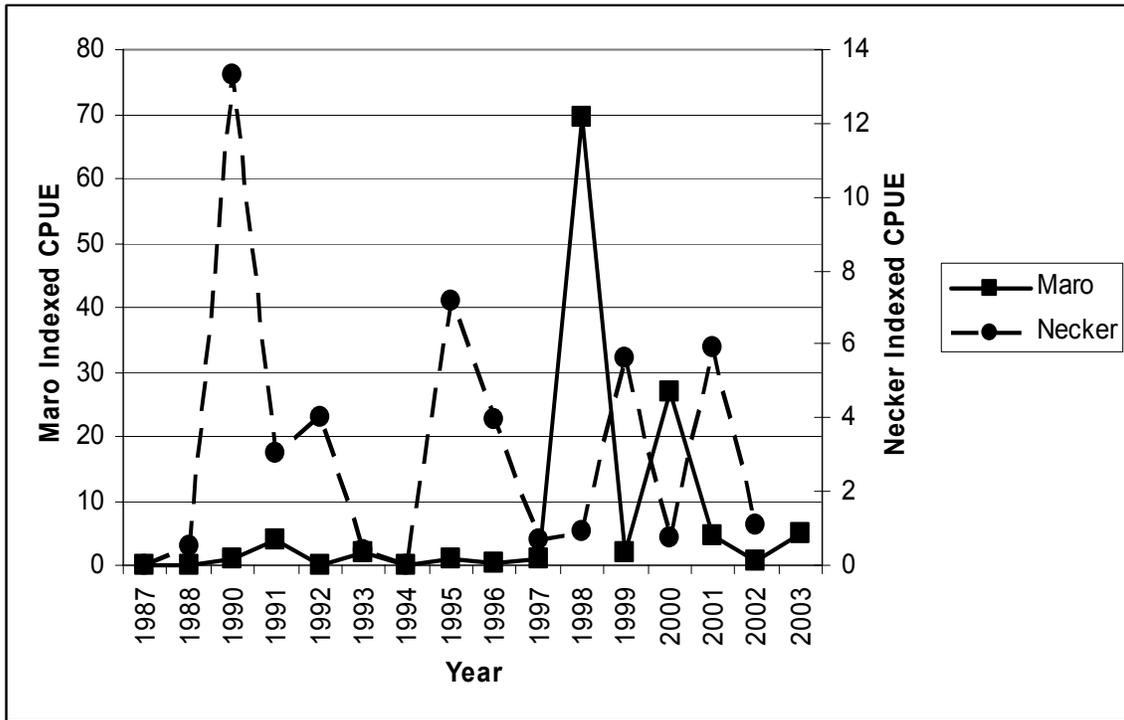


Figure 5. Indexed CPUE for *Heniochus dipheutes*.

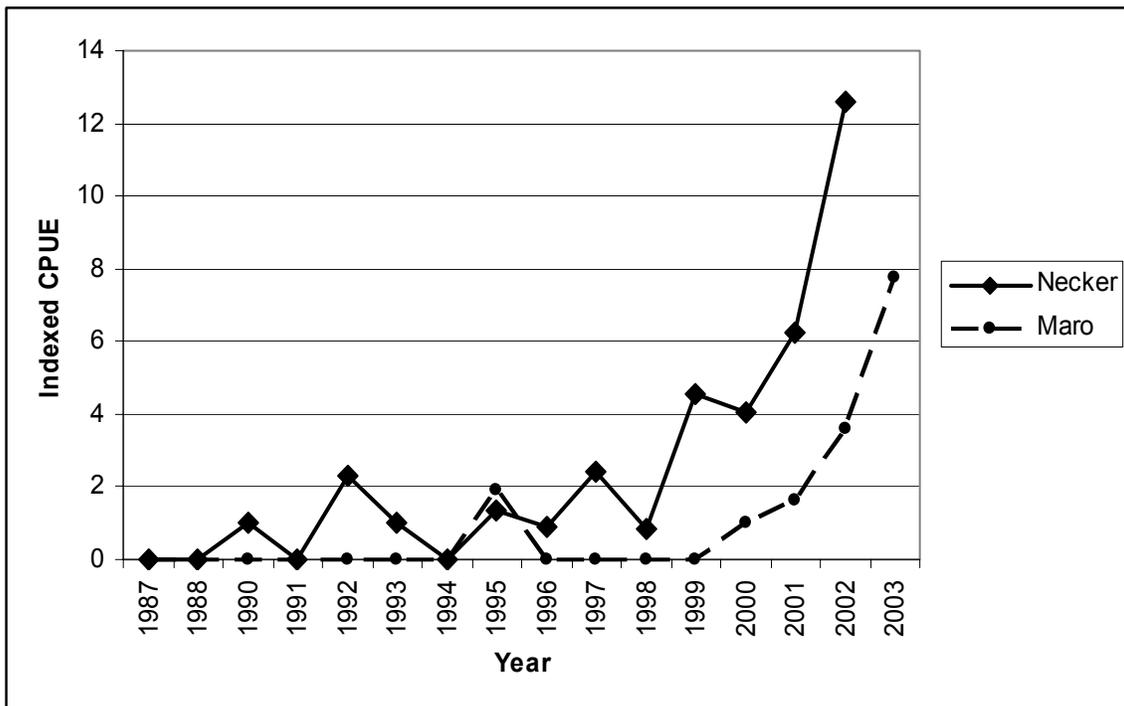


Figure 6. Indexed CPUE for whitetip reef shark.

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