Uncovering the Marine Biodiversity of Cocos Island, Costa Rica

by

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PROJECT DESCRIPTION

BACKGROUND

Tropical marine nearshore environments are among the most complex and biodiverse ecosystems on the planet, providing an estimated 100 million people with coastal protection, career opportunities and economic and natural resources (Hoegh-Goldberg 2005). The ecosystem goods and services provided by this environment contribute an estimated $375 billion to the global economy (Pandolfi *et al*. 2005). However, this habitat is threatened on a global scale, and is diminishing at an alarming rate as a result of anthropogenic impacts such as pollution, overfishing, habitat destruction, and global warming (Bellwood *et al*. 2004, Jackson *et al*. 2001, Knowlton 2001, Hughes *et al*. 2003, Myers and Worm 2003, Palmer *et al*. 2004, Roberts *et al*. 2002, Sadovy 2005, Wolanski and De'ath 2005). These impacts jeopardize resident biodiversity, and make it critical for scientists to increase their efforts to study and protect these important ecosystems.

Although scientists use many methods to study nearshore marine ecosystems, perhaps the most productive tool for *in-situ* research has been open-circuit SCUBA (Sale 1991). However, due to physiological and logistical limits of SCUBA technology as well as safety considerations, conventional SCUBA has a practical depth limit of about 50 m, and the vast majority of SCUBA-based research has focused on depths shallower than 30 m (Thresher and Colin 1986). Clear oligotrophic waters typical of tropical marine regions allow sufficient light for photosynthesis down to as much as 150 m, and robust marine communities of fishes and macro-invertebrates have been documented to this depth (Pyle 2000; unpubl. data). Thus, as much as 80% of the biodiverse nearshore marine environment remaining largely unexplored.

There is a tremendous potential for discovery at these relatively unexplored depths (>50 m). Recent efforts by scientists utilizing rebreathers to study this region have resulted in the discovery of 11 new species of fish for every hour spent surveying the deep region of nearshore ecosystems (Pyle 2000, unpubl. data). As a result it is estimated that deep reefs may harbor as many as 750-2000 undescribed species of fishes with the number of invertebrates likely to be much higher (Pyle 2000, unpubl. data). Thus the deep region of nearshore ecosystems represents one of the great unexplored ecosystems on the planet. Studying the extent of this ecosystem will provide information about species diversity, habitat utilization, and species assemblage structure, and will provide preliminary data on the connectivity between the shallow and deep nearshore habitats.

This project aimed to conduct an assessment of the biodiversity of fishes found at Cocos Island, Costa Rica, using SCUBA and the three-person submersible *Deep See*. The transition zone from 0-300 m was quantitatively and qualitatively surveyed to determine species richness at various depths (particularly below 30 m), and also to determine at what depth and how abruptly the nearshore fauna gives way to the species assemblages more characteristic of the subphotic zone. Additionally this project represented the first quantitative assessment of the fishes found at Cocos Island.

Geography

The Tropical Eastern Pacific (TEP) Biogeographic Region which is delimited by the Gulf of California southward to the northern boundary of Peru and includes five oceanic islands and archipelagos, including Cocos Island (Hastings 2000; see Figure 1). These islands and archipelagos contained within the TEP all originated from oceanic volcanoes and are geologically separate from the Americas (Allen and Robertson 1994). As a result long-distance larval dispersal provides the sole mechanism for establishing marine faunal communities at these isolated islands (Mora and Robertson 2005).

The TEP is isolated from the central and western Pacific by 4,000-7,000 km of deep-ocean. This vast stretch of deep water known as the Eastern Pacific Barrier (EPB) is the largest marine biogeographic barrier in the world (Ekman 1953). Additionally, the TEP is separated from the Tropical western Atlantic by the Central American land bridge that formed 3.5 million years ago (Jackson et al. 1996). These barriers severely limit or cease (in the case of the Central American land bridge) the flow of larvae between populations and result in the TEP being the most isolated marine biogeographic region in the world (Robertson et al. 2004).

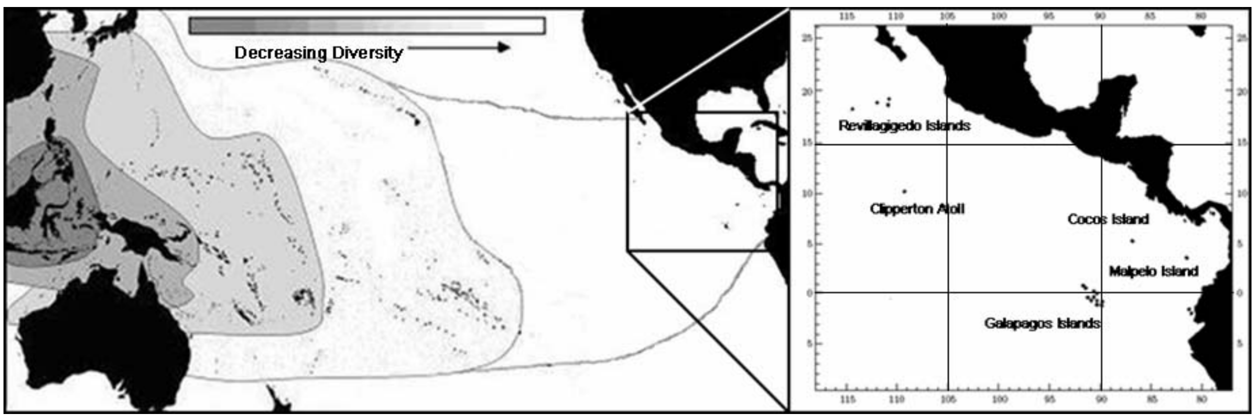

Figure 1. Map of the Tropical Eastern Pacific Biogeographic Region showing west-to-east decline in species diversity across the Pacific.

Diversity and Endemism

The diversity of marine fauna is highest in the Indo Australian Archipelago and decreases as one moves east across the Pacific Ocean (Randall 1998; see Figure 1). Thus the diversity of the nearshore fauna found in the TEP is relatively low compared to other locations in the Indo-Pacific. Geographic isolation and the complex oceanographic conditions that surround the region are the main factors influencing the region's low faunal diversity. This isolation however, contributes to the TEP having the highest endemism of nearshore fishes among any region in the world (Hastings and Robertson 2001). Of the 1195 shallow-water (< 100 m) fishes found in the TEP, 80% are endemic to the region (Robertson and Allen 2002).

The shallow water (<30 m) fish faunas of the TEP have been studied in detail over the past few decades and numerous reference materials have been published (Allen and Robertson 1994, Garrison 2000, Humann and Deloach 2004, Robertson and Allen 2002). However a majority of the observations and collections have focused on nearshore habitats shallower than 50 m (Allen and Robertson 1997, Hastings pers. comms.). Additionally new species continue to be discovered as a result of extensive collection efforts being made throughout the TEP and through the use of molecular techniques to distinguish East Pacific species from Central and Indo-Pacific species (Allen and Robertson 2002, Anderson and Baldwin 2000, Hastings 2001, McCosker and Long 1997).

The islands of the TEP are in the direct path of four major surface currents, the North Equatorial Countercurrent, the North Equatorial Current, the South Equatorial Current, and the Peru (Humboldt) Current (Dana 1975; See Figure 2). As a result the biogeographic patterns found in the TEP are unique and the distributions of species are influenced by the location of the island or archipelago in relation to the path of the surface currents. The region therefore exhibits two forms of endemism; 1) regional endemism where a

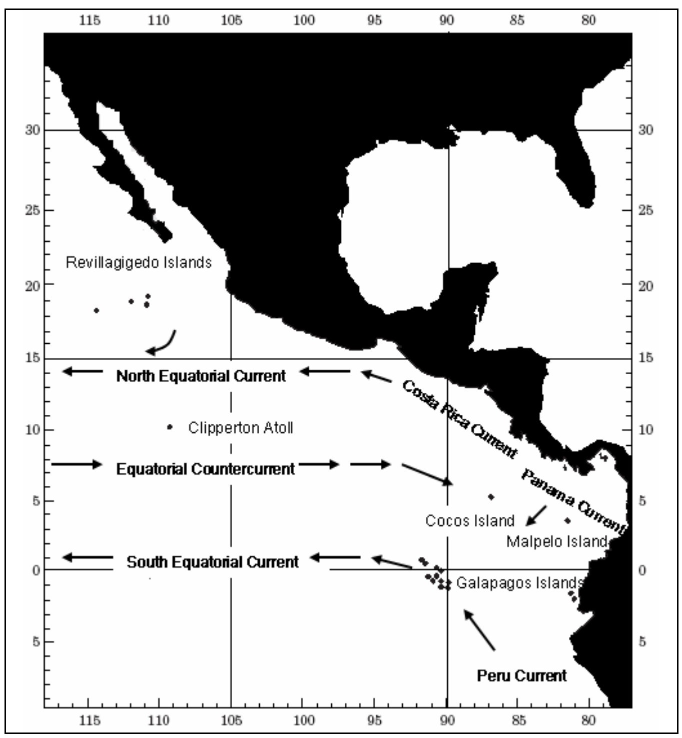

Figure 2. Map of the Tropical Eastern Pacific Biogeographic Region showing dominant current patterns.

species is only found in the TEP, and 2) insular endemism where individual islands or archipelagos within the TEP possess endemic species (Allen and Robertson 1994). The TEP also exhibits a strong relationship with the biota of the western Atlantic but the two regions share relatively few species in common as a result of independent evolution taking place over the past 3.5 million years with the development of the Panamanian land bridge (Rosenblatt 1967). The remainder of the fish species found in the TEP are comprised of Indo-West Pacific fauna (~7%) and trans-Pacific (6.5%) fauna.

Cocos Island is located approximately 480 km southwest of Cabo Blanco, Costa Rica at 5° 32´N, 86° 59´W (Figure 2). The island is roughly five miles by two miles and was formed through volcanic upheaval about two and half million years ago. Shallow-water shore fishes have been relatively well sampled as a result of the island being a popular recreational diving destination as well as been the focus of documentary films. Currently there are 260 nearshore species reported from Cocos Island, 27 of which are endemic (Garrison 2000). However recent exploratory dives using a submersible have resulted in the discovery of new species (identification pending taxonomic analysis) as well as the identification new records to the island and region (Baldwin pers. comms. Undersea Hunter pers. comms.).

PROJECT OBJECTIVES AND RESEARCH QUESTIONS

Accordingly the goal of this research project is to increase our understanding of the biodiversity and assemblage structure of nearshore fishes found at Cocos Island. This project focused on conducting a quantitative assessment of the fishes found at Cocos Island. This project also focused on identifying taxa and habitats (particularly depths in excess of 30 m) that have not been sampled previously.

Key objectives are to: (a) complete an assessment of the nearshore marine fishes found between 0-300 m at Cocos Island, Costa Rica; (b) Identify the fish faunal diversity and species abundance found at Cocos Island; (c) document any changes in the community structure between the shallow-reef (<50 m), deep-reef (50-150 m), and subphotic (150-300 m) communities; and (d) using the results from quantitative surveys, compare the data to the findings of previous surveys conducted on pristine and degraded reefs at other locations in the tropical Pacific. An additional goal was to develop survey methodologies that can be used for both submersible and diver assessment and monitoring activities.

By conducting qualitative and quantitative surveys of fishes at different isobaths (0-300 m) this research addressed the following research questions:

(1) What are the species of fishes inhabiting Cocos Island from 0-300 m and how are they distributed across different isobaths?

(2) What are the differences in faunal diversity between the shallow (<50 m), the deep (50-150 m) and the subphotic (150-300 m) ecosystems?

(3) Is there an abrupt change in the community structure of fishes between the shallow (<50 m), the deep (50-150 m) and the subphotic (150-300 m) ecosystems?

(4) How does the assemblage structure of Cocos Island compare to other locations in the tropical Pacific?

Previous Research Efforts to Survey Deep Nearshore Habitats

There is a tremendous potential for discovering new species found in tropical nearshore environments. Even with extensive surveys utilizing open-circuit SCUBA being conduced throughout the TEP, new species of fishes continue to be discovered (Allen and Robertson 2002, Anderson and Baldwin 2000, Hastings 2001, McCosker and Long 1997). However due to the limitations of conventional open-circuit SCUBA these surveys were restricted to habitats found in the upper 50 m. As a result the habitats found below 50 m represent one of the great unexplored ecosystems in the world.

Advances in technology primarily through the advent of Remotely Operated Vehicles (ROVs), submersibles, and rebreathers provide scientists with the ability to safely extend the range and duration of their research activities. Scientists taking advantage of these technologies in recent years to explore deep habitats of the Tropical Pacific have made many new discoveries (Allen and Randall 1996, Anderson and Baldwin 2000, Earle and Pyle 1997, Pyle, 1988, 1990, Pyle and Randall 1992, Randall and Pyle 2001).

In an earlier study conducted at Enewetak Atoll of the Marshall Islands, Thresher and Colin (1986) surveyed the fishes between 30-360 m using a 2-person submersible and found that the densities and number of species remained high throughout the euphotic zone. Scientists utilizing closed-circuit rebreathers have found similar density and diversity trends with depth at various sites throughout the Tropical Pacific including Fiji, Palau, Christmas Island, the Marshall Islands, and the Marquesas Islands (Pyle pers. comm.).

In 2002 a team of scientists conducted and assessment of fishes from 0-120 m at, “Fish Patch,” a dive site located just outside Suva Harbor in Fiji (Pyle pers. comm.). A total of 665 specimens, representing an estimated 144 species, were collected using rotenone at depths greater than 45 m. Preliminary taxonomic evaluation of the collections has yielded more than forty new species from the deep reefs alone. They also found

Table 1. Results of rebreather-diver collecting activity at different depths near “Fishes Patch”, Fiji Islands, 2002.

Depth (m)	Stations	Spp.[1]	N.sp.[1]	% New	Hrs.	NSPUE
0–15	2	74	0	0%	1.53	0
15–30	2	75	0	0%	1.62	0
30–45	1	28	0	0%	0.33	0
45–60	3	54	6	11%	1.67	3.6
60–75	2	31	9	29%	0.67	13.4
75–90	3	48	13	27%	1.3	10.0
90–105	4	55	21	38%	1.62	13.0
105–120	1	14	9	64%	0.33	27.0

[1]Spp.=total species; N.sp.=new species; numbers are not cumulative, becaus
some species were collected in more than one depth zone.
[2]New Species per Unit Effort (=hour of collecting time).

that the proportion of new species of fishes and the rate of discovery increased with depth (Table 1). The percentage of new species discovered ranged from 11%-64% (with as many as 27 new species discovered per hour) as the researchers sampled depths greater than 45 m.

Another interesting result from the Fiji project was that the number of species (species richness) recorded from the shallow reef (<45 m) reef was similar to that of the deep reef (>45 m). By plotting the results on a species accumulation curve (Figure 3), one can see that the number of deep reef species recorded per station (shown as square symbols) follows a similar trend to the plot of shallow water species recorded per station (shown as solid circles). Of note however is that the amount of effort (e.g. time spent at each site, the number of divers, and the amount of rotenone used) was much greater for the shallow stations compared to that of the deep stations. Additionally the plot of the number of species new to science (shown as triangles) shows a similar increasing trend. By extrapolating the number of new species discovered it is estimated that new species will account for 30% of the total number of known fishes identified from the site.

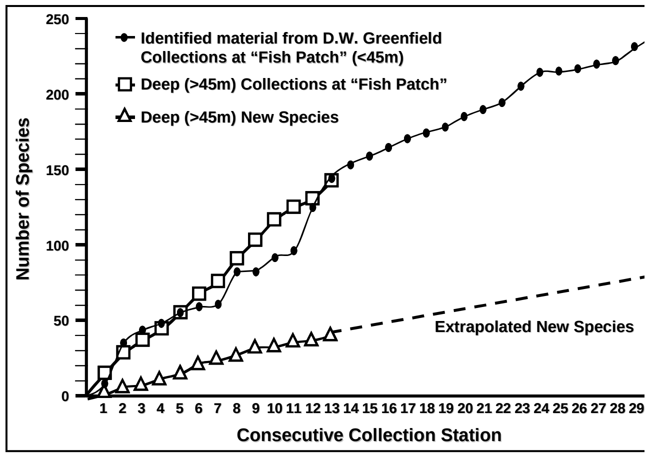

Figure 3. Species accumulation at "Fish Patch" Fiji Islands, 2002 – comparing deep and shallow collections.

Recent efforts by scientists utilizing rebreathers to study deep reefs around the Tropical Pacific have resulted in the discovery of 11 new species of fish for every hour spent surveying the deep reef (Pyle 2000, unpublished data). Based on these rates of discovery, the number of fishes awaiting discovery at depths between 50-150 m is estimated to be 750-2,000 species (Pyle 2000). An assessment of the deep habitats of the TEP will most likely yield results consistent with these previous studies.

With an estimated 30% of the world's tropical marine habitats found to be severely damaged (Wilkinson 2002) it has become increasingly difficult to examine marine ecosystems that are pristine and relatively free of anthropogenic influence. However over the past decades scientists have made concerted efforts to study locations that are remote and relatively free of anthropogenic influence. These remote sites provide scientists with an opportunity to observe how ecosystems function in the absence of humans and provide scientists with the ability to establish a natural baseline of ecosystem health. By comparing the abundance, trophic dynamics, and assemblage structure of fishes between pristine and degraded sites scientists can determine the magnitude of degradation and assess the potential for recovery. One key result from these studies is that ecosystems relatively free of human influence have considerably more large fishes (higher biomass) that are typically removed from ecosystems that are influenced by humans. In a study comparing the shallow-water (<20 m) density, size and biomass of fishes between the anthropogenically impacted Main Hawaiian Islands to the remote and relatively pristine Northwestern Hawaiian Islands, Friedlander and DeMartini (2002) found the biomass of fishes in the NWHI to be 260% greater than in the MHI. In a study conducted in the Line Islands researchers found similar differences in the fish biomass densities between pristine and degraded ecosystems (Sala et al. in prep).

APPROACH AND METHODS

Expedition and Survey Sites

This research project was conducted between May 17 and 29, 2006. Due to the geographic isolation of Cocos Island, research was conducted aboard the M/V *Sea Hunter*, a 36 m live-aboard diving vessel based in Costa Rica. The *Sea Hunter* is owned and operated by Undersea Hunter Group and is specifically built for long-range dive operations. Additionally, the *Sea Hunter* is outfitted with a 3-person submersible (*Deep See*) rated to 475 m and is capable of conducting dives for 6 hours (Figure 4). The submersible is unique in that the pilot and passengers are housed in a spherical acrylic compartment that provides them with unrestricted 360 degree view of the surrounding environment. The submersible is outfitted with a High-Definition digital video camera (Sony HDR-FX1) and a high-intensity-discharge lighting system. The digital video camera is mounted on an articulating pan mount arm to the front of the submersible that allows the operator to track organisms while the submersible remains stationary. Although there are plans to outfit the submersible with manipulating arms and equipment to collect specimens, all species identifications made during this project were based off of *in-situ* observations and from images recorded from the submersibles camera High-Definition camera.

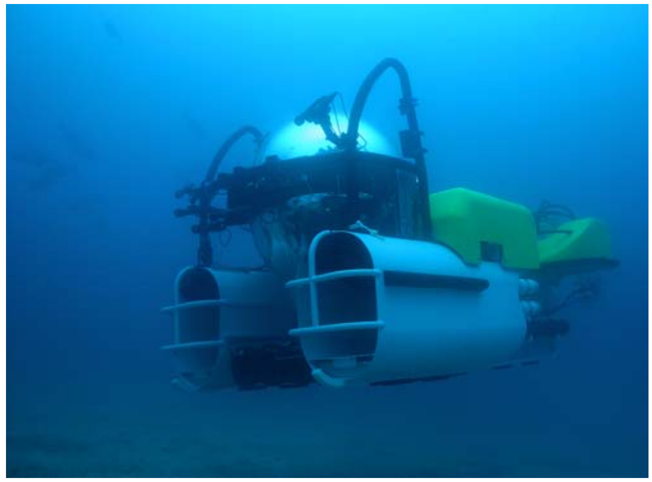

Figure 4. Picture of the 3-person submersible *DeepSee* used during this project.

A combination of technologies and survey methods were used to meet the research objectives of the project. Open-circuit SCUBA was utilized for surveys conducted shallower than 40 m and the three-person submersible *Deep See*, was used to complete surveys below 40 m. Thirty SCUBA dives and 3 submersible dives were completed during the survey period and a total of 33 hours were spent conducting underwater surveys. Scuba surveys were conducted at various sites around the island and submersible dives were restricted to the northern end of the island due to logistical and environmental restrictions (Figure 5). Water temperature ranged 18° – 28° C during the SCUBA surveys and 13° – 28°C during the Submersible surveys. The temperature differences can be attributed to the thermocline which was typically encountered at 30 m. Average underwater visibility ranged from 20-30 m and was directly impacted by the depth of the thermocline.

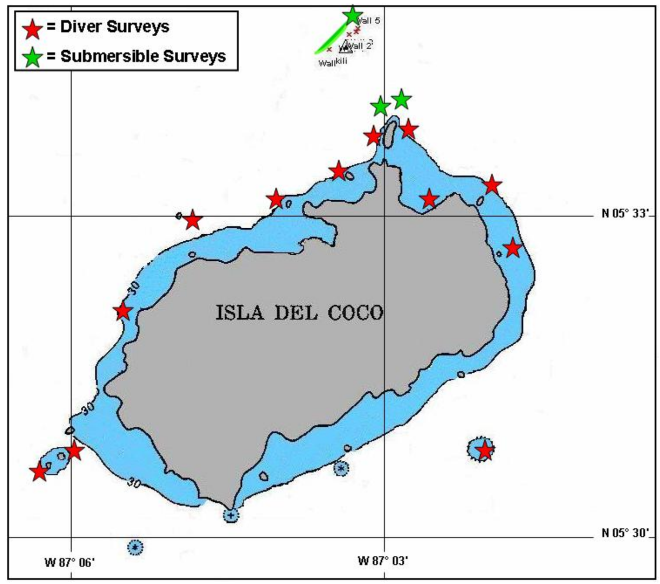

Figure 5. Map of Cocos Island showing the location of surveys completed using SCUBA and submersible technologies.

Survey Protocols

A modification of the Stationary Point Count (SPC) survey method developed by Bohnsack and Bannerot (1986) was used to estimate the abundance of fishes. The SPC method consists of tallying fishes that enter a column of water during a predetermined survey time. Because submersible and SCUBA technologies were incorporated into this project the SPC protocol had to be adjusted to facilitate the data collection process from the two platforms. In the original SPC design, a diver positions him/herself in the center of the

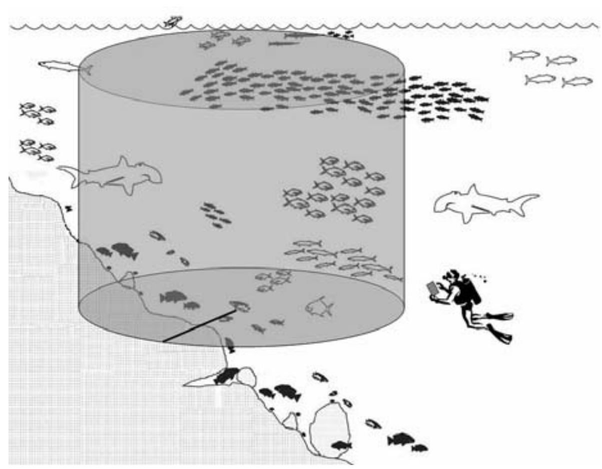

Figure 6. Diagram of the modified Stationary Point Count method used to conduct a quantitative assessment of fishes found at Cocos Island during this project.

column and rotates around the central axis tallying fishes that enter a column of water. Rotating around a central access is easily accomplished by free swimming divers but is not easily accomplished with a submersible. As a result SPCs were conducted by remaining stationary and making observations from the outside perimeter of the column of water (Figure 6). These adjustments facilitated the SPC method to be used during both diver and submersible surveys.

Noncryptic fishes estimated to be larger than 20 cm Total Length (TL) that entered a 5 m radius (78.5 m^2) column of water were tallied for an individual survey period of 5 min. Fishes were identified to species level and sizes were estimated to the nearest 5 cm TL. Individual dive schedules and corresponding transect length (e.g. the distance covered along a horizontal isobath) were influenced by no-decompression limits for the SCUBA surveys and by the logistical availability and presence of appropriate bathymetry for the submersible surveys. Scuba surveys (SPC and were typically 55 min in duration and the submersible surveys ranged from 75-140 min. Surveys were conducted from 10-300 m and individual surveys were assigned to 1 of 3 depth classes where: 1 = shallow-reef (<50m); 2 = deep-reef (50-150 m); and 3 = subphotic (150-300 m). A total of 75 SPC surveys were conducted at various sites at Cocos Island (45 shallow-reef, 15 deep-reef, and 15 subphotic).

Length estimates collected during the surveys were converted to weight using the allometric length-weight conversion equation $W=aL^b$, where weight (W) is in grams and L is total length in cm. The length-weight fitting parameters a (intercept) and b (exponent) were determined using web-based and published sources (Fishbase 2006). Efforts were made to use length-weight parameters from specimens originating from the TEP and values from congeners were used if length-weight parameters for a specific species were unavailable. Length-weight parameters did not exist for species observed in depths greater than 100 m and calculations of biomass density were not calculated for these depths.

Prior to conducting the research species lists were prepared utilizing taxonomic references and by viewing tapes previously recorded by the submersible *DeepSee*. During project period species lists were recorded during each dive to determine species richness for individual sites. These lists were then used to develop a checklist of total species richness for Cocos Island. Additionally, 3 trophic categories were assigned to all fishes observed during the surveys and included apex predators, lower-level carnivores, and herbivores. Assigned trophic categories were based on diet and feeding information found in the literature (Robertson and Allen 2002, Garrison 2000). Apex predators included only large fishes known to have a direct influence on the structure of the ecosystem and included the whitetip reef shark *Triaenodon obesus*, the carangids *Caranx melampygus, C. lugubris*, and *Seriola rivoliana*, and the snapper *Lutjanus novemfasciatus.*

RESULTS

Species Diversity and Community Structure

A total of 131 species representing 56 families were observed during the research expedition. All but nine fishes observed during surveys of the deep habitats (>150 m) could be identified to the species level and images of the unidentified species were recorded with the submersible's High-Definition camera to allow further analysis. Of the eight unidentified species three tentatively appear to be types scorpionfishes (family: Scorpaenidae) and further analysis and expert opinion will be required to make confirmation. However confirming the identification of species from images alone will be difficult to ascertain. Future efforts to collect specimens will provide invaluable taxonomic information and permit scientists to accurately describe the diversity of species found at Cocos Island.

The 15 most common taxa (>20 cm TL) observed during the shallow-reef (<40 m) surveys are listed in Table 2. The Pacific creolefish (*Paranthias colonus)* was the most commonly observed species with a mean number of 10.82 fish encountered during each survey. Lower-level carnivores were the most numerous (n=32.7), followed by apex predators (n=7.4) and herbivores (n= 3.1). The size of fishes observed during the surveys of all depths ranged from 20-350 cm TL with the prickly shark (*Echinorhinus cookei*) being the largest fish observed. Of the twelve size class categories used to tally fishes during the survey period, fishes estimated to be in the 20-30 cm TL size class were the most commonly observed.

Table 2. The 15 most commonly observed fishes at Cocos Island during the survey period. The trophic category, numerical density, and biomass density is given for each species.

Family	Taxon/ common name	Trophic Category	Mean number per station	Biomass Density (t/ha)
Serranidae	*Paranthias colonus* Pacific creolefish	Lower-level carnivore	10.82	0.15
Lutjanidae	*Lutjanus viridis* blue and gold snapper	Lower-level carnivore	5.31	0.10
Carangidae	*Caranx melampygus* blue trevally	Apex predator	5.07	1.49
Lutjanidae	*Lutjanus jordani* Jordan's snapper	Lower-level carnivore	3.80	0.07
Aulostomidae	*Aulostomus chinensis* Chinese trumpetfish	Lower-level carnivore	3.16	0.08
Hemigaleidae	*Triaenodon obesus* whitetip reef shark	Apex predator	2.29	6.20
Carangidae	*Elagatis bipinnulata* rainbow runner	Lower-level carnivore	1.91	0.11
Mullidae	*Mulloidichthys dentatus* Mexican goatfish	Lower-level carnivore	1.91	0.05
Serranidae	*Dermatolepis dermatolepis* leather bass	Lower-level carnivore	1.87	0.13
Haemulidae	*Anisotremus interruptus* burrito grunt	Lower-level carnivore	1.58	0.22
Labridae	*Bodianus diplotaenia* Mexican hogfish	Lower-level carnivore	1.36	0.10
Scaridae	*Scarus rubroviolaceus* bicolor parrotfish	Herbivore	1.16	0.10
Acanthuridae	*Acanthurus xanthopterus* yellowfin surgeonfish	Herbivore	1.07	0.09
Balistidae	*Sufflamen verres* orangeside triggerfish	Lower-level carnivore	1.02	0.03
Acanthuridae	*Prionurus laticlavius* razor surgeonfish	Herbivore	0.84	0.05

Species richness and the number of trophic groups represented decreased with depth (Figure 7, Table 3). The greatest decline in the number of species occurred at the transition from the euphotic to subphotic zone (100-300 m). Although the shallow-reef (<50 m) had the highest species diversity, the deep-reef (50-150 m) had the highest mean density of fishes (n=74) with a 32% increase in the mean number of fishes observed from 50-100 m. More than 60% of the fishes observed at depths between 50-100 m were comprised of shallow-water species (e.g. those encountered in shallow water <30 m). The proportion of shallow-water species abruptly decreased at depths greater than 100 m. Groupers (Serranidae) were the most specious (n=11) family observed, followed by Jacks (Carangidae, n=10), Triggerfishes (Balistidae, n=8), and Wrasses (Labridae, n=8).

Lower-level carnivores were the most commonly observed fishes across all depths (0-300 m). Four species of planktivores, which were included as lower-level carnivores, displayed unique distribution patterns that were not observed among any other species. The Pacific creolefish (*P. colonus*) was the most commonly observed fish on shallow-reef (<50m) surveys with a mean density of 10.82 observed per station. Although *P. colonus* was also observed during deep-reef (50-150 m) surveys it was replaced by the long-fin bigeye (*Cookeolus japonicus*) as the most commonly observed fish with a density of 53.71 observed per station. Two species of Anthias (Serranidae) were the most commonly observed species during surveys of the subphotic region (150-300 m). The thread-fin bass (*Pronotogrammus multifasciatus*) being the most common fish observed at depths between 180-220 and the rosey jewelfish (*Anthias noeli*) being the most commonly observed fish at depths between 220-300 m.

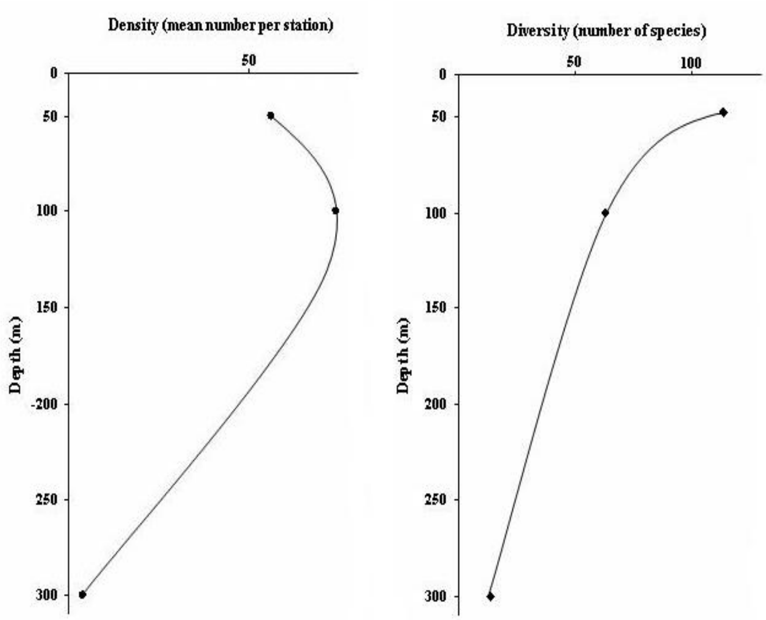

Figure 7. Depth profiles of the density and diversity of fishes observed at Cocos Island during the survey period.

Table 3. The depth zonation of the fish community found at Cocos Island.

Depth Range	Density (Mean number per station)	Diversity	Trophic Groups Represented
Shallow-reef (<50 m)	High (n=56)	High (n=115)	Carnivores, Planktivores, and Herbivores
Deep-reef (50-100 m)	High (n= 74)	Medium (n=63)	Planktivores and Carnivores
Subphotic (150-300 m)	Low (n=4)	Low (n=14)	Planktivores and Carnivores

Biomass Density

The grand mean biomass density of fishes at Cocos Island was 12.74 t ha^{-1} More than 65% of the total fish biomass at Cocos Island consisted of apex predators, primarily sharks and jacks. Lower-level carnivores accounted for 33% of the biomass and herbivores accounted for the remaining 2%. The whitetip reef shark (*Triaenodon obesus*) and blue trevally (*Caranx melampygus*) comprised 93% (7.69 t ha^{-1}) of the apex predator biomass and 60% of the total fish biomass. The whitetip reef shark (*T. obesus*) alone accounted for 75% (6.19 t ha^{-1}) of the apex predator biomass and occurred in densities of 2.29 sharks observed per shallow-reef (<40 m) survey. As for the herbivores, the bicolor parrotfish (*Scarus* rubroviolaceus) and the yellowfin surgeonfish (*Acanthurus xanthopterus*) comprised 73% (0.19 t ha^{-1}) of the total herbivore biomass and only 1.5% of the total fish biomass. Unlike the apex predator and herbivore trophic guilds, no single species of lower-level carnivore comprised a significant proportion of the guild's biomass. Although the Pacific creolefish was the most commonly observed fish overall with a mean density of 10.82 fish per station, it accounted for only 3.5% (0.15 t ha^{-1}) of the total biomass for lower-level carnivores. The burrito grunt (*Anisotremus interruptus*) comprised the largest proportion of biomass for lower-level carnivores but only contributed 5.2% (0.22 t ha^{-1}) of the total lower-level carnivore biomass.

Because this study represents the first effort to quantitatively survey the fishes of Cocos Island the results serve as a baseline of ecosystem health. Similar studies have been conducted at other sites throughout the tropical Pacific to assess the level of ecosystem degradation (Friedlander & DeMartini, 2002, Sala, et. in prep). By comparing the abundance, trophic dynamics and assemblage structure of fishes found at Cocos Island to these other sites one can make a preliminary assessment of the overall health of the ecosystem.

The grand mean biomass density of fishes inhabiting shallow-reefs (<50 m) at Cocos Island was 12.74 t ha^{-1} compared to 5.27 t ha^{-1} for Kingman Reef (Line Islands), 2.59 t ha^{-1} for Palmyra Atoll (Line Islands), 2.43 t ha^{-1} for the Northwestern Hawaiian Islands (NWHI), and 0.67 t ha^{-1} for the Main Hawaiian Islands (Figure 8, Table 4). Other tropical Pacific islands and reefs not influenced by humans display similar trophic distributions where apex predators comprise greater than 50% of the total fish biomass (Figure 8, Table 4). In contrast to these data, apex predators comprise only 3% of the total fish biomass in the populated MHI (Friedlander and DeMartini 2002).

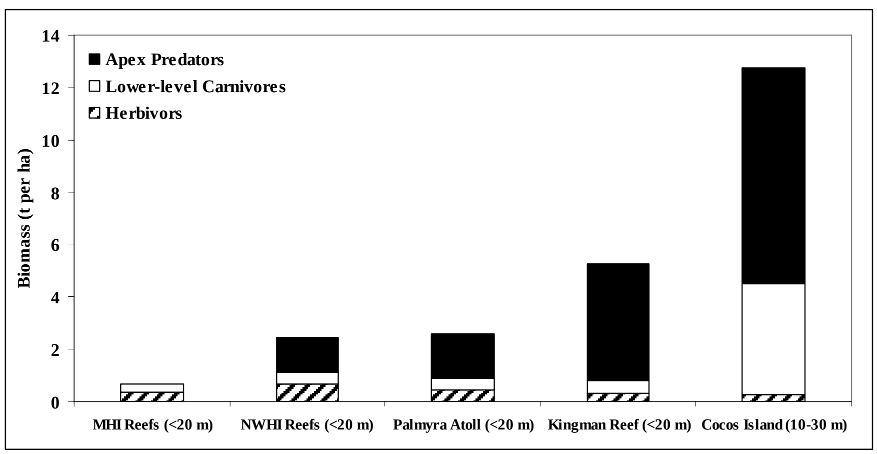

Figure 8. Ranked (from left to right, lowest to highest) total grand mean biomass and grand mean biomass by trophic level for all habitats surveyed in the Main Hawaiian Islands (MHI), Northwestern Hawaiian Islands (NWHI), Palmyra Atoll, Kingman Reef, and Cocos Island.

Table 4. Comparison of mean density and mean biomass of herbivores, lower-level carnivores, and apex predators on; shallow reefs of the Main Hawaiian Islands (MHI), banks and shallow reefs of the Northwestern Hawaiian Islands (NWHI), shallow reefs of Palmyra Atoll and Kingman Reef, and shallow-moderate depth reefs at Cocos Island, Costa Rica. The mean biomass values for apex predators were unavailable for the NWHI Banks.

Trophic Group	MHI (<20 m) (Friedlander and DeMartini 2002)	NWHI Banks (30-40 m) (Parrish and Boland 2004)	NWHI Reefs (<20 m) (Friedlander and DeMartini 2002)	Palmyra Atoll (<20 m) (Sala *et al.* in prep)	Kingman Reef (<20 m) (Sala *et al.* in prep)	Cocos Island (10-30 m)
Herbivores						
Mean Number (ha^{-1})	3979	580	4,633	3000	2000	506
Mean Biomass ($t\ ha^{-1}$)	0.37	0.09	0.68	0.43	0.33	0.26
Lower-level Carnivores						
Mean Number (ha^{-1})	5212	1,960	8,477	25,000	36,000	5,548
Mean Biomass ($t\ ha^{-1}$)	0.28	0.13	0.44	0.46	0.48	4.24
Apex Predators						
Mean Number (ha^{-1})	12	42	132	1500	2000	1064
Mean Biomass ($t\ ha^{-1}$)	0.02	--	1.31	1.70	4.46	8.25
All Trophic Groups						
Mean Biomass ($t\ ha^{-1}$)	0.67	--	2.43	2.59	5.27	12.75

DISCUSSION

Species Diversity and Community Structure

With 260 nearshore species known to inhabit Cocos Island the number of species observed during this project (n=131) was expected considering that survey efforts were focused on non-cryptic diurnal species larger than 20 cm TL. Extensive surveys of the shallow-reef (< 50 m) utilizing SCUBA were conducted at various sites around the island. A total of 30 dives and 45 Stationary Point Counts were conducted. Surveys of the deep-reef (50 – 150 m) and subphotic (150 – 300 m) were conducted utilizing the submersible *DeepSee.* A total of five hours was spent exploring the deep habitats and 30 Stationary Point Counts were conducted. However due to logistical and time constraints, submersible surveys were limited to the northern portion of the island.

This project was the first attempt at Cocos Island to look at assemblages of fishes across multiple depths. Consistent with other studies conducted in the tropical Pacific this study also found that the species diversity declined with depth, the density of fishes was highest in the euphotic zone decreasing abruptly at 100 m, and shallow-reef fishes (> 60%) could be found throughout the euphotic zone.

Biomass Density

The total mean biomass of fishes at Cocos Island was 242%-525% greater than other sites in the tropical Pacific that are also considered to be pristine and have minimal influence from humans. Although there is a difference in the mean biomass found between these pristine sites, the distribution of the biomass among trophic categories displays similar trends among the sites. At these sites apex predators comprise a considerable proportion (54-84%) of the total mean biomass. In contrast when comparing the total mean biomass of fishes at Cocos Island to the Main Hawaiian Islands (MHI), an archipelago heavily influenced by humans, there is a 1903% difference in biomass between the two locations. In the MHI, herbivores comprise 55% of the total mean biomass with apex predators comprising only 3% of the total mean fish biomass. The differences in biomass densities between pristine and human influenced sites can be attributed to the systematic removal of apex predators and other lower-level carnivores from the ecosystem (Friedlander and DeMartini 2002).

The removal of apex predators comprised primarily of commercially important species like Jacks (Carangidae), Sharks (Carcharhinidae and Hemigaleidae), Snappers (Lutjanidae), and Groupers (Serranidae) has been shown to have detrimental effects to the function of the marine ecosystem (Dulvy et al. 2004, Pandolfi *et al*. 2005, Pauly *et al*. 1998). Apex predators play an integral role in marine communities. These predators strongly influence ecosystem function by controlling and structuring the assemblage of fishes from the top down (Halpern et al. 2006, Mumby et al. 2006). By removing predators, species from lower trophic groups which typically have high turnover rates are uncontrolled. Left uncontrolled, the abundance of these species can fluctuate significantly, decreasing the stability and resilience of the ecosystem (Jackson et al. 2001, Bascompte et al. 2005, Baum and Myers 2004). Instability not only makes the ecosystem more susceptible to natural and human disturbances, it increases the likelihood of the ecosystem shifting to an alternate stable state (Bellwood et al. 2004, Done 1992, Hughes 1994, Knowlton 1992, 2001, Scheffer et al. 2001). Numerous examples of trophic cascades of marine ecosystems exist but the most well known is the collapse of coral reef ecosystems in the Caribbean as a result of overfishing and the mass mortality of the sea urchin (*Diadema antillarum*) from a species-specific pathogen Hay 1984, Hughes 1994, Jackson 1997, Lessios 1988, 1995).

Scalloped Hammerhead sharks are known to frequent seamounts and oceanic islands in large aggregations (Fishbase 2006). It is not clearly understood why this behavior occurs, but the sharks appear to congregate at Cocos Island to have ectoparasites removed by the Blacknosed Butterflyfish (*Johnrandallia nigrirostris*) and the King Anglefish (*Holacanthus passer*) which inhabit rocky reefs. Hammerhead sharks were commonly observed on all dives shallower that 100 m and were tallied on 5 SPC surveys (n=6). Even though scalloped hammerhead sharks are considered to be partially reef-associated (nearshore), the sharks tallied during quantitative surveys were not included in the biomass calculations due to their transit nature. However it should be noted that hammerhead sharks influence the structure of the ecosystem by providing a source of food (ectoparacites) and organic nutrients (urea and feces) to the environment surrounding Cocos Island.

Submersibles used in Research

Submersibles provide scientists with the ability to extend the range and duration of their research activities. Most of the submersibles used in a research setting require a tremendous amount of logistical support and are expensive to operate. As a result a majority of the research targets depths great than 300 m. Although some submersibles are cumbersome and have restricted visibility Submersible *DeepSee* provides an excellent platform for conducting scientific research activities. Having a 360° field of view proved to be extremely useful for making observations and for maneuvering the submersible. Occupants were able to observe organisms up/down slope from the submersible's position (>50 m away) which provides opportunities to make broad observations of the surrounding habitat.

The methods used to conduct surveys from submersibles are often restricted due to reduced peripheral visibility. However this was not the case with *DeepSee* and scientists were able to utilize the Stationary Point Count (SPC) method for quantifying fishes and assessing species diversity for both the submersible and diver surveys. The submersible's configuration provides its occupants with an unobstructed redundant view where each occupant has virtually the same field of view. In a research setting this enables scientists to work together to identify organisms in real time and to conduct surveys in tandem similar to the way in which belt transect surveys are conducted by divers in shallow water (Brock 1954, 1982).

A critical piece of equipment used during the submersible surveys was the High-Definition digital video camera mounted to the front of the submersible. The camera not only provided a mechanism to record vouchers of habitat and species it provided an opportunity to document species in their natural environment. Although there are plans to outfit the submersible with manipulator arms and specimen collection equipment (rotenone dispenser and collection tube) the camera provides the only means of documenting biogeographical range extensions and species that are potentially new discoveries. Since the submersible began exploring Cocos Island in the Fall of 2005 in operation off of the Live-a-Board dive boat M/V *Sea Hunter*, *DeepSee* has made numerous discoveries and contributions to science. The prickly shark (*Echinorhinus cookei*), a large deep-water species (Max: 400 cm TL, Compagno et al. 2005) previously known only to occur in the eastern Pacific from southern California to the Gulf of California, and from Costa Rica to Peru (Robertson and Allen 2002) was observed in one submersible dive in this study and has been observed and also documented on film by the crew on numerous dives (>200 m) and represents a new record for the island (Figure 9). Another new record for the island is the rosey jewelfish (*Anthias noeli*), recently described by Anderson and Baldwin (2000) from the Galapagos islands. It was the most abundant species of fish observed at depths between 200-300 m (Figure 9). Nine additional fishes observed during dives for this project have not been identified and require further collaborative analysis between experts. Because exploration of the deep habitats of the TEP has been limited, it is likely that these species represent new records.

Figure 9. Images of Prickly Shark (*Echinorhinus cookei*) top and Rosey Jewelfish (*Anthias noeli*) bottom taken from the submersible *DeepSee* at a depth of 290 m.

Evaluation of Survey Methods

The modified Stationary Point Count method proved to be effective for conducting a quantitative assessment of fishes greater than 20 cm TL at Cocos Island. However the original method described by Bohnsack and Bannerot (1986) was modified to allow surveys to be carried out during SCUBA and submersible dives. Specifically, the recommended radius of 7.5 m was reduced to 5 m and surveys were conducted from outside the survey area cylinder. Because surveys were conducted from outside the survey area cylinder the total distance that assessments had to be made was 10 m (e.g. the diameter of the cylinder). Although underwater visibilities of greater than 20 m were typically observed on all dives as a result of water clarity and the submersible's powerful lights, it was determined that estimating lengths of fishes would become increasingly difficult at distances greater than 10 m.

Additionally the SPC surveys provided a great deal of flexibility compared to other quantitative survey methods (e.g. the belt-transect method). Besides a data-slate and pencil used to tally fishes, no extraneous equipment (i.e. transect reels) was required, and surveys could be conducted in moderate surge and current. Unlike the belt transect method which is confined to a specific depth due to the use of a transect line the SPC surveys were not confined to a specific depth except for the time required to complete the individual survey thus allowing multiple depths to be surveyed during a single dive. The flexibility afforded by this method may be useful for conducting surveys of deep-habitats using advanced diving technologies (e.g. closed-circuit mixed-gas rebreathers) where dives to depths greater than 100 m have restricted bottom times due to decompression obligations. This study did not compare the results from the diver conducted surveys to the submersible conducted surveys future research comparing the two technologies are warranted

Contributions

This project represented the first quantitative assessment of reef fishes found between 0-300 m at Cocos Island, Costa Rica. The findings provide a preliminary baseline for this ecosystem. The preliminary findings of this project suggest that the marine ecosystems of Cocos Island are thriving and contain a robust community of fishes. Marine ecosystems that possess high densities of large predators are considered to be in the natural state and have the least amount of anthropogenic influence. With a mean biomass of apex predators of 8.25 Cocos Island has a mean apex predator biomass that is over six times greater than the Northwest Hawaiian Islands which is considered an example of a marine ecosystem in its natural state. As the results of this study are shared scientists and resource managers would have the first quantitative evidence that Cocos Island is one of the few remaining predator-dominated ecosystems in the world. Because the submersible provided an opportunity to assess regions not previously explored, there were species observed on the deep-reef that had not been previously documented for Cocos Island.

This project represented the first time this unique submersible design was used in a research capacity to make both qualitative and quantitative evaluations of deep-reef habitats (> 50 m). The project provided an evaluation of a modification of the Stationary Point Count method which was proven to be effective for both diver and submersible surveys. Efforts were also made to promote continued data collection by the submersible operators who continue to conduct dive operations at this site throughout the year. A survey tool was designed for the operators to continue to collect data that will be available to scientists conducting research on the Cocos Island ecosystem. The project established a collaborative effort between the owner of the submersible, the Scripps Institution of Oceanography and other scientists conducting research in the tropical Eastern Pacific.

Future Research

This project provided an initial assessment of the marine ecosystem at Cocos Island. It utilized a combination of SCUBA and submersible surveys. Findings from this study were based on data collection by a single scientist during a limited time frame. Although the diver conducted studies were well-distributed around the island and in different habitats, the submersible studies were restricted to the northern end of the island. There is a tremendous potential for increasing scientific knowledge of the Cocos Island marine ecosystem through future research. Suggestions for future research would include:

- Analysis of the video images from the submersible dives needs to be analyzed.
- More extensive surveys of the deep-reef habitats of Cocos Island need to be conducted using submersible and diving technologies.
- Documentation and collection of specimens to be used for taxonomic and identification purposes needs to be done in the deep-reef habitats using the submersible.
- A study to determine the effect of the submersible on the behavior of fishes should be conducted.
- Perform an evaluation of data from diver surveys versus submersible surveys in same location.
- An assessment of the invertebrates and marine algae in the Cocos Island ecosystem needs to be conducted.

Future of Cocos Island Conservation

Cocos Island represents a unique tropical marine ecosystem because of its biogeographic isolation and its limited anthropogenic impacts. Although Cocos Island was designated as a World Heritage site, efforts should be made to insure that conservation efforts continue in both the terrestrial and marine ecosystems. Because of Cocos Island's unique ecosystem it has become a desirable destination for divers from around the world. Currently only three liveabroad dive vessels operate in this region. Rangers patrol the surrounding waters and enforce fishing regulations. With fishing pressures increasing throughout the region it is critical that management and conservation agencies maintain a high level of vigilance.

Cocos Island is located in the TEP which is the most isolated marine biogeographic region in the world. Eighty percent of the nearshore fishes inhabiting the TEP are endemic to the region and Cocos Island alone contributes 27 endemic species (Garrison 2000, Robertson and Allen 2002). In recent efforts to develop conservation plans scientists have tried to identify priority areas based on species diversity and species endemism (Allen 2000, Bellwood and Hughes 2001, Hughes et al. 2002, Roberts et al. 2002). In a recent study Hughes et al. (2002) found that there is no concordance between centers of high species diversity and centers of high endemism in marine ecosystems. Regions with the greatest biodiversity contain species that tend to have broad geographic distributions, whereas regions that harbor a high percentage of endemic species are often isolated geographically like Cocos Island. This geographic isolation makes endemic marine species vulnerable to extinction. Because all of the tropical marine ecosystems globally are threatened from numerous anthropogenic impacts it is imperative that efforts are made to conserve the few remaining pristine ecosystems with high endemism.

Marine ecosystems that are dominated by apex predators are almost nonexistent due to the systematic removal of large predators from marine habitats. Based on the findings of this study Cocos Island is an exception and is one of the remaining few examples of an ecosystem in a natural state free of human influence. Because of the high biomass of apex predators which are composed of commercially important species like Jacks, sharks, groupers and snappers, both divers and fishermen are attracted to the region. It might be tempting for managers and politicians to think that in a region with so many predators a certain amount of fishing would have no impact. Yet few fisheries have been conducted sustainably whereas revenues received from ecotourism yield higher returns long term. Fortunately the Costa Rican government has supported increased ecotourism in its terrestrial areas and would be likely to support policies and management plans to protect the region's marine biodiversity.

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