

**AN ECOLOGICAL AND ECONOMIC BASELINE
FOR THE REVILLAGIGEDO ARCHIPELAGO
BIOSPHERE RESERVE, MEXICO**



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Ecological Assessment

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II. FUNDING AND SUPPORT

Grants

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Earth Friends

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Graduate Travel Funds, University of California San Diego

NSF IGERT Mini-Grant (SIO)

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Support

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CONANP

The Cortez Club

III. PUBLICATIONS & PRESENTATIONS

Presenter: Jason Murray

Medium: poster

Title: Conservation Values: An Ecological and Economic Baseline for the Revillagigedo Archipelago Biosphere Reserve, Mexico

Event: NSF IGERT Annual Meeting

Presenter: Pincelli Hull & Jason Murray

Medium: poster

Title: Conservation Values: An Ecological and Economic Baseline for the Revillagigedo Archipelago Biosphere Reserve, Mexico

Event: E.W. Scripps Associates Quarterly Meeting

Author: Octavio Aburto-Oropeza & Pincelli Hull

Medium: paper

Title: A spawning aggregation of the leather bass (*Dermatolepis dermatolepis*) in Revillagigedo Archipelago, Mexico

Status: In preparation

Author: Pincelli Hull, Katie Cramer, Kate Hanson, Octavio Aburto-Oropeza, Stuart Sandin

Medium: paper

Title: The relative effects of fishing and biogeography on community structure in the Mexican Eastern Pacific

Status: In preparation

Author: Octavio Aburto-Oropeza, Yulania Bedolla, Katie Cramer, Kate Hanson, Pincelli Hull, Jason Murray, Melissa Roth, Carlos Sánchez, Stuart Sandin, Fiona Tomas, Enric Sala

Medium: paper

Title: Expedition Notes: A marine baseline for the Revillagigedo Archipelago, Mexico

Status: In preparation

IV. NARRATIVE STATEMENT

1. Introduction

Marine ecosystems have been subject to unprecedented levels of anthropogenic disturbance over the past century. Today's oceans face formidable, chronic threats such as coastal development, overfishing, habitat alteration, pollution, and the introduction of exotic species (PEW Ocean Commission, 2003). Conservation and management programs seek to reverse the ecological declines associated with these threats. An essential first step for such management is the establishment of ecological and economic baselines against which any future variation in the system can be measured. At present, such time series or baselines are nonexistent for most marine systems (Jackson 1997, 2001; Dayton et al. 2000). Understanding anthropogenic impacts and predictions of future change are limited without a baseline, and rigorous evaluation of management actions is rendered impossible.

The Revillagigedo Archipelago is a group of four volcanic islands that lie approximately 400 miles southwest of Baja California (Figure 1). Although relatively unstudied, the marine ecosystems of the archipelago are known to be largely undisturbed and harbor abundant populations of sharks, rays, and large pelagic fish that attract recreational divers from around the world. Current evidence suggests that these islands- Socorro, Clarion, San Benedicto, and Isla Roca Partida- can provide essential information on the community structure and function of healthy marine ecosystems in the Eastern Tropical Pacific.

Human activity is largely absent from the Revillagigedo Islands due both to their isolation from the mainland and the use of Socorro as a military base. However, the islands support a small dive tourism industry. Tourism operations are based out of Cabo San Lucas and La Paz. An estimated 1,200 to 1,500 tourists visit the archipelago each year between November and May on approximately 70 to 80 diving cruises. There are no data about the catch of the almost entirely illegal sport fishery, which targets primarily billfish, tuna, groupers and snappers. The limited legal catch-and-release fishery pay fishing permit fees to Mexico, although none of these fees are currently allocated to the support of the marine reserve (CONANP, unpublished data).

The islands of the Revillagigedo Archipelago present a unique and invaluable opportunity for marine conservation and research in Mexico. The diversity and health of Revillagigedo Archipelago ecosystems have already attracted national and international notice; conservation efforts are underway to mitigate the threats to both the terrestrial and marine communities. Realizing the unique ecological resources of the archipelago, Mexico has taken steps in the last decade to ensure that the ecosystems are protected and improved. A Biosphere Reserve was established around the islands in 1994 (Ortega et al, 1995), and in 1996 the Comité Científico para la Conservación y Restauración del Archipiélago Revillagigedo was formed for the express purpose of protecting Revillagigedo. In 2002, Mexico declared a 12-mile area around the Revillagigedo Islands a no-take marine reserve.

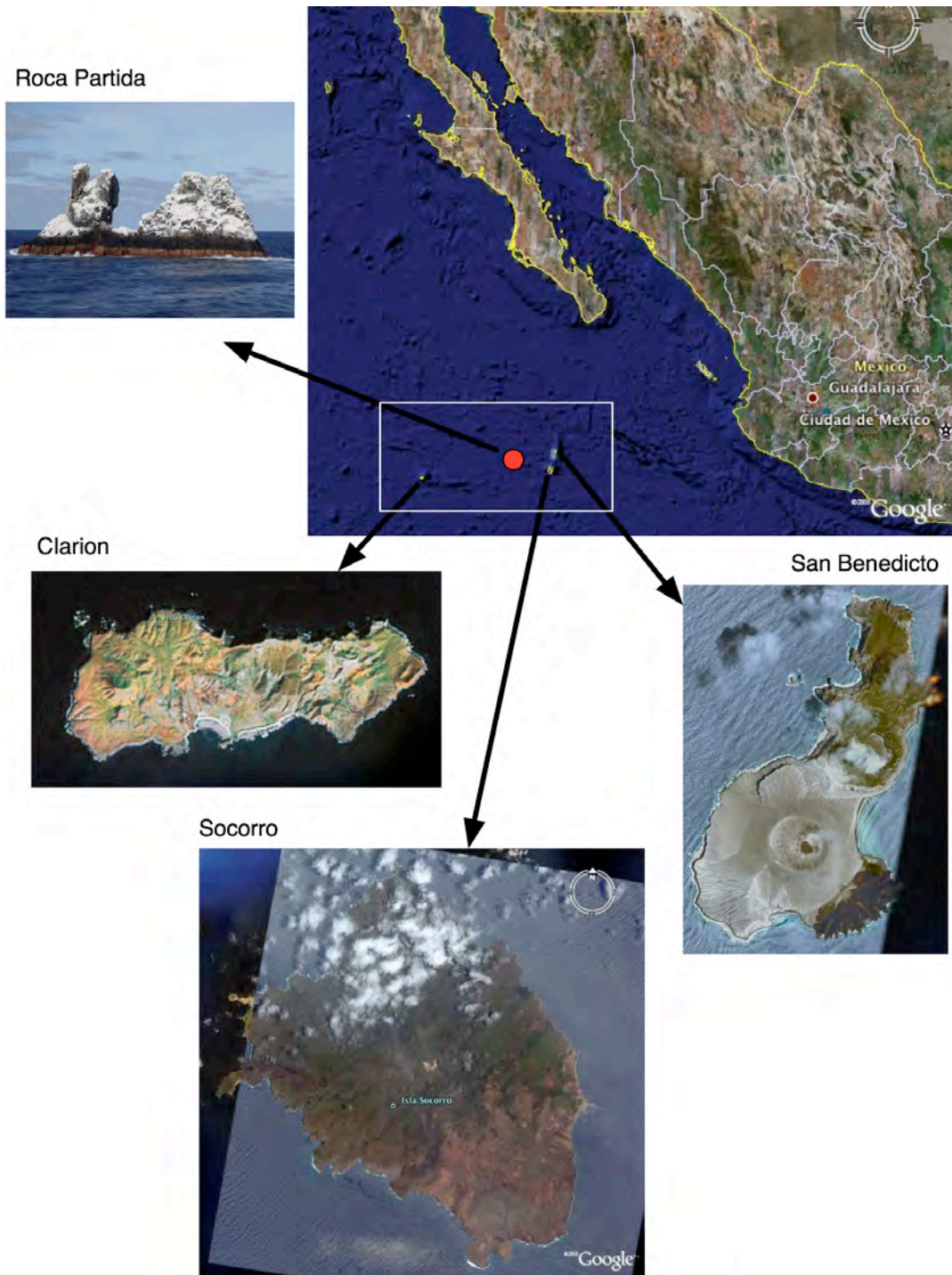


Figure 1.1. The islands of the Revillagigedo Archipelago, Mexico. Images obtained from Google Earth.

2. Project Objectives

The objective of the project was to establish an economic and ecological baseline for the marine system of the Revillagigedo Archipelago, México. The baseline provides the first quantitative data for the marine fish and macroinvertebrate communities, including information about distribution, abundance, biomass and value to the tourism trade. Comparisons between Revillagigedo and similar regions in the Gulf of California contrast the structure and the economic value of the relatively pristine Revillagigedo marine systems and relatively degraded Gulf systems. Combined, the economic and ecological data from this project could serve as a basis for the monitoring and research program proposed in the management strategy plan (Ortega et al., 1995) of the Biosphere Reserve.

3. Results

3.1. Marine Baseline

3.1.1 Introduction

Marine ecosystems include complex networks of organisms spanning expansive phylogenetic, morphological, and physiological spectra: from bacteria to plankton to pelagic sharks. Nevertheless, significant insight on the function, as a whole, of a particular ecosystem can be gained by focusing on species or groups of primary importance. In this study, we quantitatively examine three groups of organisms fundamental to the Revillagigedo ecosystem: macroalgae, macroinvertebrates, and benthic fishes. We also qualitatively examine large pelagic species such as mantas, sharks, and jacks. These groups span multiple trophic levels, from primary producers at the base of the food web to top carnivores.

The biological surveys that serve as the foundation of our marine baseline were performed on a series of cruises onboard the Nautilus Explorer (Feb-Mar 2006) during which we visited sites around all four islands of the archipelago (Figure 1). As the Nautilus Explorer is a dive tourism vessel, our sampling sites were restricted to areas chosen for recreational dives. Thus, our spatial coverage of those smaller of the four islands is more comprehensive than that of the larger. However, collaboration with a recreational dive vessel such as the Nautilus allowed us to sample the very areas frequented by divers, and to study the interactions between the divers and the biological environment (see Section 2.3). Furthermore, our analysis of community structure within given habitat types (i.e. boulder fields or seamounts) shows agreement between large and small islands, suggesting that differential sampling extent did not largely bias the resulting ecological patterns observed.

As the physical structure of a given habitat (relief, rugosity, availability of shelter or crevices) often influences the associated biological communities, we analyze community structure within particular habitats in addition to comparisons between habitat types. The habitats examined in this study include boulder fields (small and regular), vertical walls, lava flows, seamounts and flat reefs, and represent the full spectrum of habitat types found in Revillagigedo benthic communities. The island of Roca Partida is

treated as a distinct habitat type. As the neck of an old volcano, Roca Partida is a tiny island (less than 300 m in circumference) composed entirely of steep wall habitats. This, in combination with strong currents, allows for an entirely different community structure to flourish around the island.

Finally, the data on biological assemblage composition and structure obtained during this study for the Revillagigedo Archipelago were compared with similar data from the Sea of Cortez collected by SIO researchers and collaborators during the fall of 2005. The areas surveyed in the Sea of Cortez have experienced consistent and growing fishing pressure far exceeding that placed on Revillagigedo assemblages. By comparing these analogous data sets, we can begin to understand how the effects of island biogeography and protection from fishing pressure interact to structure offshore communities. Additionally, our data from Revillagigedo lend insight to how the marine communities of the Gulf of California may have been structured before being subject to intense fishing pressure.

3.1.2 Algae

Methods

Algal assemblages were surveyed by sampling along transects at 10 to 30 m depth, with transect length varying between 5 and 30 m. Presence/absence and relative abundance of algal species were estimated using quadrat surveys, recording all algal species in a 20 cm x 20 cm frame placed haphazardly at multiple points along the transect. Percent cover was estimated visually over the entire transect length, and included sponges, coral and other dominant substrate types. Regulations associated with the Revillagigedo Biosphere Reserve prohibited us from collecting algal samples for further taxonomic identification or biomass approximation, and algal transect surveys were conducted on only three of the four islands (Socorro, Clarion, and San Benedicto). The area surveyed comprised approximately the same area covered by the fish transects (see sections below).

Results

The algal communities found in the Revillagigedo Islands are in general very similar between sites. The main genera / species of algae found are reported below in Table 1.

Description of the sites visited

San Benedicto: The Canyon

The general algal seascape was quite homogeneous from 10 to 30 m depth. The rock was dominated (ca. 95% cover) by algal turf (1 – 2 cm height) and some coralline encrusting algae (rare); no large algae were present. The main turf-forming species were *Asparagopsis taxiformis* (Falkenbergia stage), *Polysiphonia* spp and *Cladophora* spp, as well as red coralline algae of the genera *Jania* and *Amphiroa*. The green algae *Neomeris vanbosseae* was also very abundant, though patchy in distribution. Several erect brown fleshy algae of the genera *Padina* and *Dictyota* were present, although the only erect

fleshy algae which achieved more than 2cm height was the red algae *Laurencia* cf. *pacifica*, which was typically between 5 and 10cm high.

Table 1.1 Dominate Marine Algae of the Subtidal Communities of Revillagigedo

CHLOROPHYTA	RODOPHYTA	PHAEOPHYTA
<i>Caulerpa racemosa</i>	<i>Amphiroa dimorpha</i>	<i>Dictyopteris spp</i>
<i>Cladophora spp</i>	<i>Amphiroa spp</i>	<i>Dictyota spp</i>
<i>Dictyosphaeria versluysii</i>	<i>Asparagopsis taxiformis</i>	<i>Lobophora variegata</i>
<i>Neomeris vanbosseae</i>	<i>Gelidiella spp</i>	<i>Padina spp</i>
	<i>Gracilaria spp</i>	<i>Ralfsia spp</i>
	<i>Hildenbrandia sp</i>	<i>Rosenvingea intricata</i>
	<i>Jania spp</i>	
	<i>Laurencia cf. pacifica</i>	
	<i>Lithophyllum spp</i>	
	<i>Lithothamnion spp</i>	
	<i>Peyssonnelia spp</i>	
	<i>Polysiphonia spp</i>	

San Benedicto: The Boiler

This site is characterized by a turf-dominated landscape, with some erect algae (not higher than 2 – 3 cm) and abundant sponges (*Aplysina* cf. *fistularis*). We also observed the presence of cyanobacteria mats. From 10 to 15 m the dominant species of algae were encrusting red algae of the genera *Peyssonnelia* and *Hildenbrandia* cf, turf algae of the genera *Gelidiella* and *Cladophora*, as well as the green algae *Dictyosphaeria versluysii*, the erect green algae *Caulerpa racemosa* and the erect brown algae *Dictyopteris* spp, which was often 10 – 15 cm tall.

Between 25 and 30 m, the main algae present were encrusting red coralline algae (*Lithophyllum* spp, *Lithothamnion* spp) as well as the brown encrusting algae *Ralfsia*, and turfs. The main erect algae found were erect coralline algae of the genera *Jania* and *Amphiroa*, turf-forming algae of the genera *Polysiphonia* and *Cladophora*, brown erect fleshy algae (*Padina* spp, *Dictyota* spp, *Dictyopteris* spp), and red fleshy algae of the genera *Laurencia*. Clumps of the green algae *Neomeris vanbosseae* were also abundant.

Socorro: Naval Base

Two different areas with distinct algal communities were observed in this area. On the one hand, there was an area along the edge of a lava flow which was a complete barren (0-15m depth) dominated by bare rock, barnacles, and some encrusting red coralline algae. Sea urchins (*Diadema mexicanum*) and small sea stars (*Acanthaster*, ca 3cm diameter) were very abundant. In addition, some patches were covered in cyanobacteria. The presence of cyanobacteria and of echinoderms could be indicative of a local influence of nutrients and organic matter. On the other hand, boulders at (5m) were dominated by erect algae and turf (e.g. *Dictyota* spp, *Padina* spp) (85%) alternating with some barrens (15%). Most of the time (75%) erect algae (*Dictyota* spp) covered

100% of the rock. The green algae *Nemoeris vanbosseae* and the erect red algae *Asparagopsis taxiformis* presented a very patchy distribution.

Socorro: Cabo Pierce

The general algal seascape was quite homogeneous. The rock was dominated (ca. 90% cover) by turf-forming algae (1 – 2 cm height), coralline encrusting algae (ca. 30%) and some red encrusting algae (*Peyssonelia* spp, ca 6%); some erect algae of the genera *Dictyota* were present (ca. 13%), although they were not very developed (ca. 1- 4 cm height). The main turf-forming species were *Asparagopsis taxiformis* (Falkenbergia stage) and *Polysiphonia*. The green algae *Neomeris vanbosseae* was present but rare. On the contrary, the sponge *Aplysina* cf. *fistularis* was fairly abundant (ranging from ca 15 to 65% cover).

Roca Partida

This site exhibited some peculiarities, which were not observed on the other sites examined, presenting the lowest diversity and abundance of algal species. Barnacles dominated the substrate down to 12-15 m, while high densities of the sea urchin *Diadema mexicanum* created barrens below that depth. Where urchins were absent, the landscape was characterized by a full dominance of encrusting brown (*Ralfsia* sp) and red (*Peyssonelia* spp and *Hildenbrandia* sp) algae and encrusting bryozoans (unknown species) on the shallow area (12 – 22 m depth). In deeper waters (ca. 24 m), turf-forming species (e.g. *Polysiphonia* sp) as well as some *Dictyosphaeria versluysii* were also found. No large macroalgae were present on this island within the depth range studied (ca. 10-30 m).

Discussion

The algal communities found in the Revillagigedo Islands sampled are characterized by turf-forming and encrusting algae, comprising very low biomass, but covering most of the substrate, except when high densities of the sea urchin *Diadema mexicanum* are present (e.g. Roca Partida and the site ‘Navy Base’ on Socorro). The species composition of the algal communities is very similar to those found on shallow rocky reefs in the Sea of Cortez (Tomas unpublished data), except for the absence of large macroalgae such as *Sargassum* spp. The lack of conspicuous macroalgae in the sampled sites may be due to several factors. On the one hand, the sampling took place at the beginning of spring, when algal development has not been fully achieved, which may explain why most of the erect fleshy algae (e.g. *Dictyota* spp, *Dictyopteris* sp, *Laurencia* cf. *pacifica*) were very small. The high abundance of herbivores in some sites (mostly sea urchins), may also be contributing to the maintenance of low-biomass turf-dominated algal communities, not allowing the development of large canopies. Although forest-forming algae such as *Macrocystis pyrifera* and *Sargassum* spp have been reported in this archipelago (Appendix 1) we did not record them on the sites sampled. One possibility is that the other studies were conducted in other areas / habitats. In any case, the hydrographic conditions of this archipelago, which is on the border between the oligotrophic North Equatorial current and the nutrient-rich California current (Lluch-Costa et al. 1995), would probably not allow the development of kelp forests, which do

not survive in warm nutrient-poor waters (Witman & Dayton 2000). In addition, Roca Partida, a unique site in comparison to the other islands studied as it is much smaller (ca 100 m long per 20 wide), isolated (Ortega et al. 1995), and consists mostly of exposed vertical walls from the shallows to the ocean floor, is generally not suitable for forest-forming macroalgae such as *Sargassum* spp or *Macrocystis pyrifera*, which need flat substrates to develop on (Witman & Dayton 2000).

3.1.3 Macroinvertebrates

Methods

For the purposes of this study, only benthic macroinvertebrates larger than 1 cm were surveyed. The groups included in these surveys were: Porifera (sponges), Cnidaria (hydroids, corals and sea fans), Mollusca (sea snails, clams and octopus), Crustacea (crabs and lobsters), Echinodermata (sea stars, sea urchins and sea cucumbers), and Urochordata (sea squirts). We surveyed four habitat types: big boulders (> 1m), small boulders (< 1m), walls and flat reefs. In each habitat we estimated the species richness, abundance and size structure of macroinvertebrates. SCUBA transects were conducted along isobaths at 10, 20, 30 and 40 m depth. Surveyed areas were 30 m long by 1 m wide at 10 and 20 m depths but shortened to 15 m x 1 m at 30 and 40 m depth to reduce diver bottom time. Every depth, habitat and site was surveyed by a minimum of 3 transects (Appendix 1). Total length of invertebrates was estimated to the nearest 2 cm with the help of a graduated PVC tube. Additionally, habitat characteristics and relative species distribution were noted on each transect.

Results

Species Richness

A total of 60 species of rocky benthic macroinvertebrates were recorded. Fifty-six species were counted within strip transects and four species were seen during supplemental dives conducted to identify rare species (Appendix 2). Corals and sea fans were the most species-rich groups with 23 species, followed by echinoderms with 7 species of sea cucumber, 5 species of sea urchin, and 3 species of sea stars (Figure 1.2). Within the >1cm macroinvertebrates, only the gastropod *Latirus socorrensis* has been declared as endemic to the Revillagigedo. However, distinct morphological characteristics in seven additional organisms indicate that they should be elevated to the level of endemic species (Carlos Sanchez, personal observations). This is true for the sponge *Aplysina* cf. *fistularis*, the mollusk *Spondylus* spp, and five sea fans (one *Eugorgia*, two *Pacifigorgia* and three *Muricea* species).

The total number of macroinvertebrate species sampled varied between islands as well as between habitat types. Forty-one species were recorded on Socorro, followed by San Benedicto with 36 species, Clarion with 33 species and Roca Partida with 26 species. Grouping by habitat type across islands, 40 species were recorded in vertical wall habitats, 32 in boulder fields and 31 in flat reefs. Groupings within trophic group across all species sampled, suspension feeders are the most specious group (32 spp), followed

by carnivores (16 spp), detritivores (6 spp) and herbivores (5 spp). The distribution of species richness per trophic group is similar in all habitats.

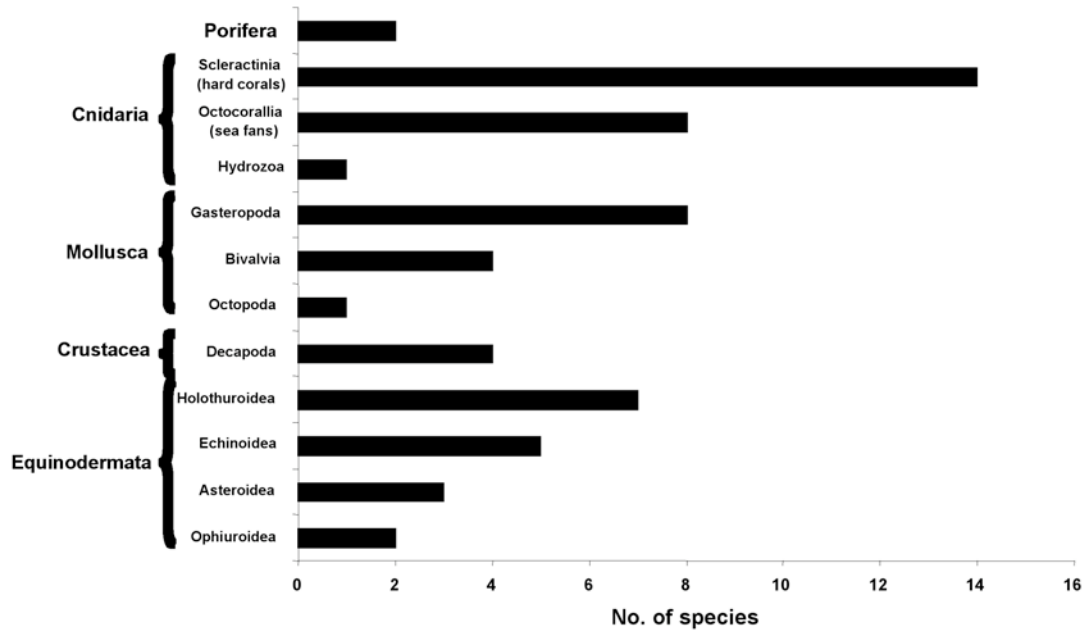


Figure 1.2. Number of macroinvertebrate species by Phylum.

Density

The sixteen species most common across the four islands represent 90% of all individuals recorded, with more than 50% of frequency of occurrence in all transects. These species are the sea urchins *Eucidaris thourarsii*, *Tripneustes depressus*, and *Diadema mexicanum*, the sponge *Aplysina* cf. *fistularis*, the cup coral *Tubastrea coccinea*, the hard corals *Pocillopora eydouxi*, *P. effusus*, *P. verrucosa*, *P. elegans*, *Porites lobata*, *Psammocora profundacella* and *Pavona gigantea*, the sea fan *Leptogorgia* sp., the sea cucumber *Isostichopus fuscus*, the clam *Spondylus* sp. and the endemic gastropod *Latirus socorrensis*. Although not listed above, the sea fan *Muricea apressa* and *Muricea* spp 1, are very common in Roca Partida especially at greater depths.

Roca Partida, the smallest of the four islands, had the highest number of individuals per square meter both when compared to the other islands (Figure 1.3a) and when compared to the other habitats (Figure 1.3b). The number of individuals per square meter on Roca Partida increased with depth (Figure 1.5). Following Roca Partida, vertical walls had the second greatest density of invertebrates, more than twice that of small boulder habitats (Figure 1.3b).

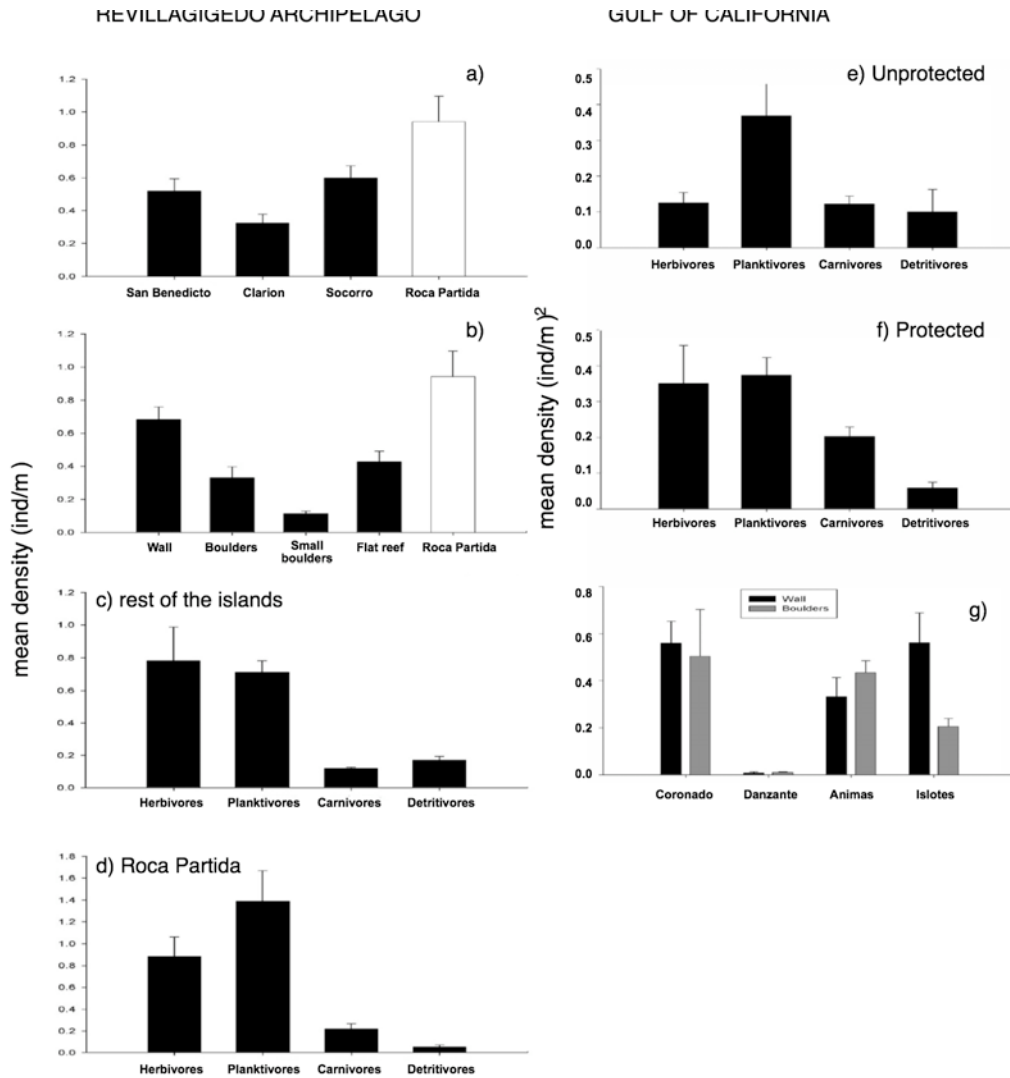


Figure 1.3. Density of macroinvertebrate species in Revillagigedo and the Gulf of California.

Trophic Structure

Planktivory and herbivory are clearly dominant feeding modes among invertebrate assemblages in the Revillagigedo Archipelago, these two groups comprise at least three times the density of carnivores and detritivores (Figure 1.3c and d). Herbivory and planktivory also dominate over carnivory and detritivory in the Gulf of Mexico, though the relative density of herbivorous invertebrates in comparison to planktivorous invertebrates is less than one in unprotected sites (Figure 1.3e) compared to a ratio close to one for protected sites and sites in Revillagigedo (Figure 1.3c,f). The density of trophic groups has a distinctive pattern between habitat types. Walls are dominated by planktivores and herbivores, and flat reefs by planktivores and detritivores. Density of individuals is most equitable between the four trophic groups in small boulder habitats.

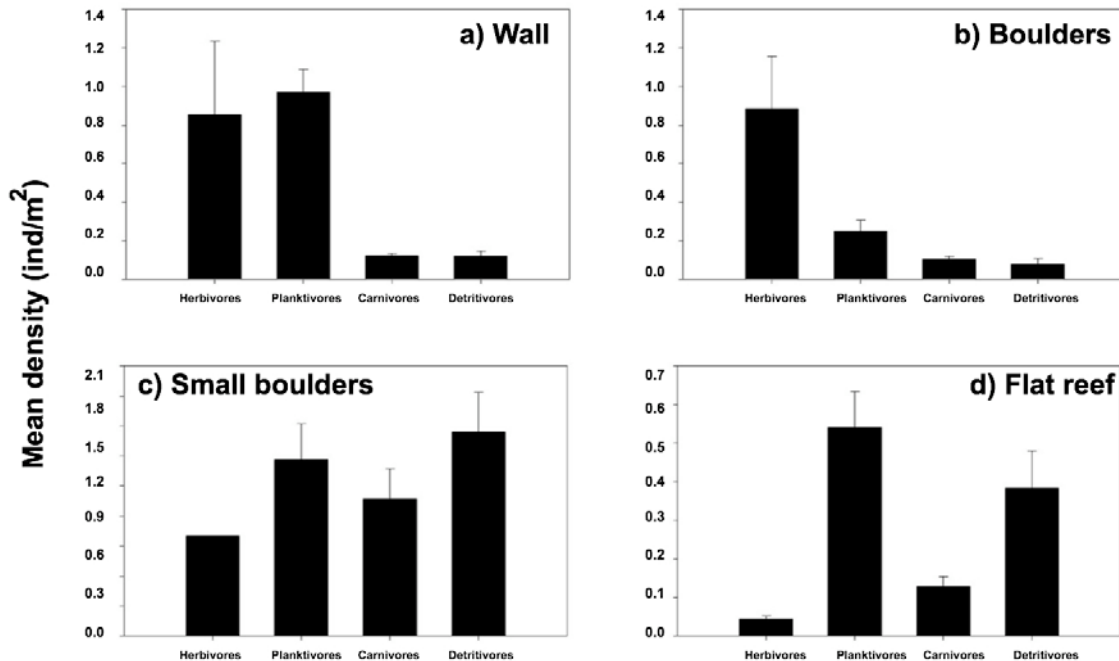


Figure 1.4. Density of macroinvertebrate species in Revillagigedo islands and habitats.

The distributions of trophic groups described above can be further elucidated by consideration for patterns of within-group species composition between sites and habitats. The most abundant planktivores (suspension feeders) on the four Revillagigedo islands were the sponge *Aplysina* cf. *fistularis* (not including Roca Partida), the cup coral *Tubastrea coccinea*, the hard corals *Pocillopora eydouxi* and *P. effusus*, the sea fan *Leptogorgia* spp and the oyster *Spondylus* spp. Carnivores were typified by the sea urchin *Eucidaris thouarsii*, the crown-of-thorn sea star *Acanthaster planci*, the lobster *Panulirus penicillatus* and the endemic gastropod *Latirus socorrensis*. The sea urchins *Diadema mexicanum* (except for Socorro) and *Tripneustes depressus* dominated the herbivores while the sea cucumbers *Isosticophus fuscus* and *Holothuria leucospidota* (excluding Roca Partida) dominated the detritivores.

The abundance of species within trophic groups in the Sea of Cortez was investigated to contrast with Revillagigedo. While the Sea of Cortez shares some of the dominant species of the Revillagigedo, also present among the most abundant planktivores (suspension feeders) were the hydroids (*Aglaophenia* spp. and *Lytocarpus nuttingi*), the sponges *Aplysina fistularis* and *A. gerardogreeni*, the cup coral *Tubastrea coccinea*, the sea fans *Muricea apressa* and *Leptogorgia rigida*, the hard coral *Porites panamensis* and the ascidian *Archidistoma pachecae*. Carnivores were dominated by the sea urchin *Hesperocidaris asteriscus*, the gastropods *Hexaples princeps*, *Conus* spp. and *Thais* sp, and the sea stars *Pentaceraster cumingi*, *Pharia pyramidatus* and *Phataria unifascialis*. Herbivores were predominantly composed of the sea urchins *Centrostephanus coronatum* and *Tripneustes depressus*, *Diadema mexicanum* and the sea

star *Phataria unifascialis*. Detritivores were poorly represented, though typified by the sea cucumbers *Isosticophus fuscus* and *Holothuria impatiens*.

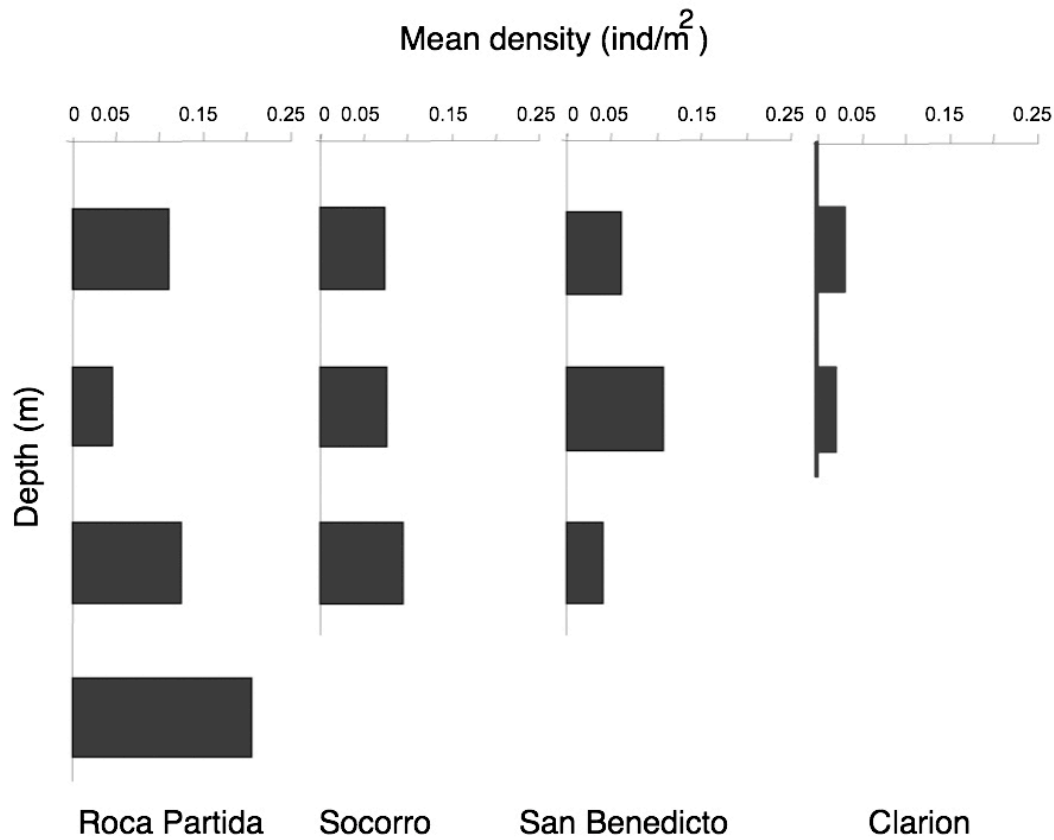


Figure 1.5. Density of macroinvertebrate species between islands and depth.

Size Frequency Distribution

The size distribution of trophic groups was comparable on all four islands. However, size distributions differed dramatically between different trophic groups. The majority of planktivores and carnivores were less than 15 cm in length, while the median length of herbivores and detritivores was greater than 15 cm with most individuals falling between 15 and 30 cm. The size range of planktivores (2-50 cm) was much larger than that of other groups. These patterns hold true across habitat types (Figure 1.6).

The size distribution of each trophic group in the protected and unprotected sites follows a similar pattern as in Revillagigedo. The distributions are skewed to the right, with trophic groups dominated by small individuals. Again, planktivores have individuals across a wide size spectra (2 – 40 cm), whereas the other three groups span a narrower span of size classes. In contrast to Revillagigedo, the majority of carnivorous and planktivorous invertebrates are smaller than 10 cm in length. Lengths between 5 and 20 cm typified both herbivores and detritivores.

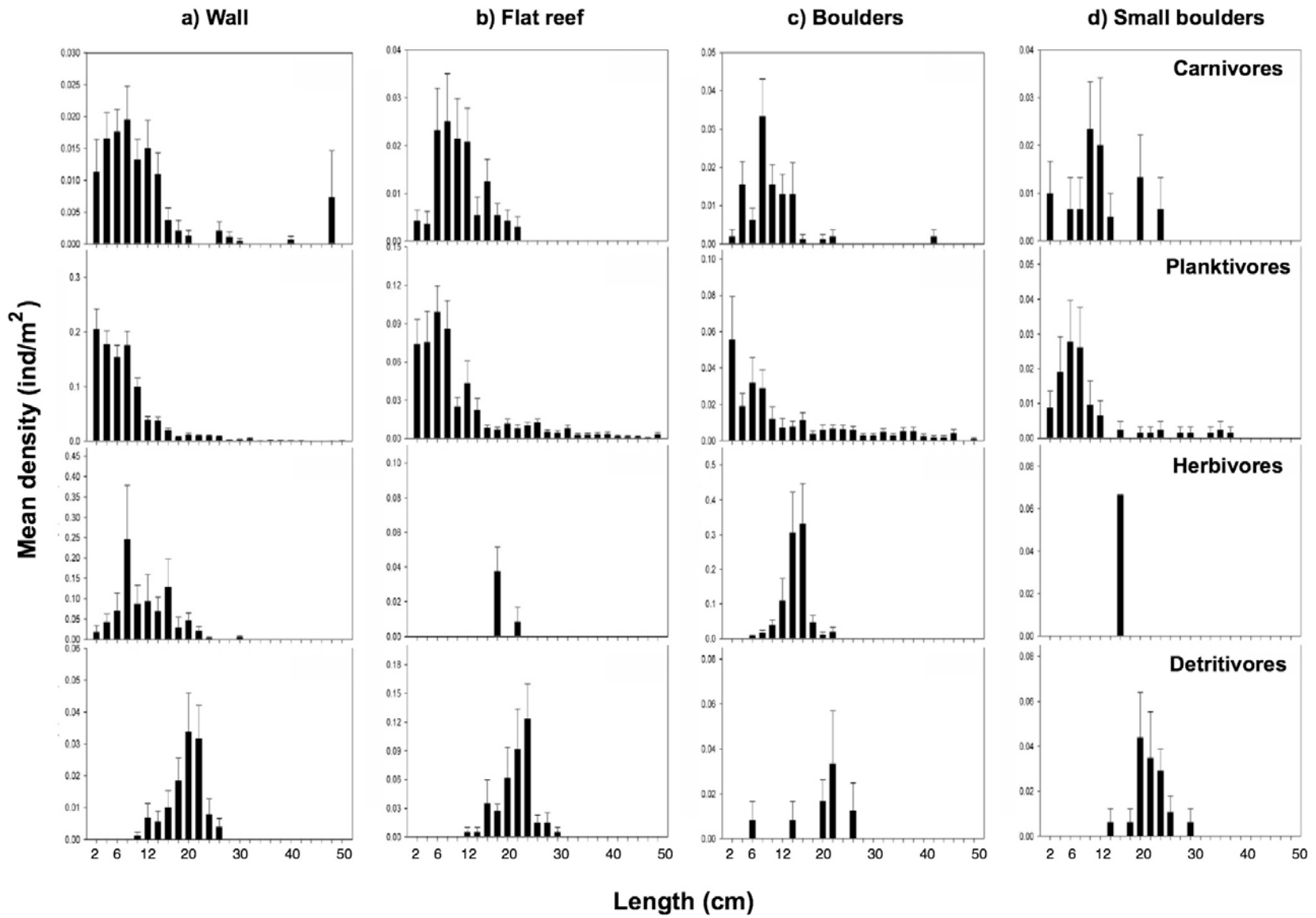


Figure 1.6. Macroinvertebrate length distribution by habitat.

Contrast with the Gulf of California: Species Specific Comparisons

Four species of lobster are present in the Mexican Pacific: *Panulirus interruptus*, *P. inflatus*, *P. gracilis* and *P. penicillatus*. The last three are tropical species with varying ecological requirements: *P. penicillatus* is an insular species (e.g. Revillagigedo) and *P. inflatus* is found in protected waters (e.g. Gulf of California). We recorded *P. penicillatus* in all four islands of Revillagigedo, especially in San Benedicto, Clarion and Socorro in densities between 0.1 – 0.5 ind/m². Although historical references indicate that lobsters used to be abundant in the Sea of Cortez, today it is rare to observe any rocky lobsters in the Gulf of California (e.g., maximum recorded strip transect density is 0.03 ind/m²). Fisherman in the Gulf place intense fishing pressure on lobster populations in a fishery that is entirely unregulated. In Revillagigedo the density of individuals over 32cm is two times greater than in the Gulf of California (both species have a maximum size greater than 40 cm) (Figure 1.7a). Lobster fecundity increases exponentially with size and larval survivorship is extremely low; therefore, lobsters in the Sea of Cortez may suffer from increased population fluctuations with negative impacts on the organisms that prey upon them.

The Crown-of-Thorn *Acanthaster planci* is an Indo-Pacific species of sea star that preys upon the polyps of benthic cnidarians. Its presence on the Revillagigedo Archipelago and the Gulf of California is highly associated with the hard corals, hydroids and sea fans on which it feeds. As seen in Figure 1.7b, *A. planci* has higher densities and sizes in Revillagigedo than in the Gulf of California. This is likely related to the higher density (coverage) of hard corals on the archipelago than in the Sea of Cortez.

The sea urchin *Tripneustes depressus* (Figure 1.7c) is very common both in Revillagigedo and Gulf of California; it prefers habitats consisting of big boulders and small boulders in shallow areas that range from 0 to 10 m depth. Predation on *T. depressus* has decreased precipitously in the Gulf of California due to widespread fishing pressure; unchecked by predation, this species has devastated large areas, leaving the boulders habitats without the three-dimension structure provided by algae. Three-dimensional structure provides critical nursery and adult habitat; a decrease in three-dimensional structure corresponds to an exponential decrease in total site biodiversity. The effect of predation is clear in the comparison of *T. depressus* in Revillagigedo and the Gulf of California. In Revillagigedo *T. depressus* is found in far lower densities than in the Gulf. The size distribution is skewed toward larger sizes in Revillagigedo, possibly as a result of size dependent mortality.

The sea cucumber *Isostichopus fuscus* is the sixth most abundant macroinvertebrate in Revillagigedo, dominating on the larger islands (Socorro, San Benedicto and Clarion). The mean density of the sea cucumber (Figure 1.7d) on the archipelago is almost three times greater than that reported for the Gulf of California with a broader size distribution. In the Gulf of California between 1989 and 1993 *I. fuscus* was very important commercially, and catches are reported to have reached 1750 tons in 1991 (Herrero-Pérezrul and Chávez-Ortiz, 2003). Demand was so high that the sea cucumber populations in Mexico, Costa Rica, and Ecuador began to show signs of overexploitation (Reyes-Bonilla y Herrero-Pérezrul, 2003) and this resulted in the shutdown of the fishery in 1994. Since 2003 the fishery was re-opened, but the values in the Gulf of California suggest that sea cucumber populations have not recovered and the fishery is still having a negative effect on the population densities.

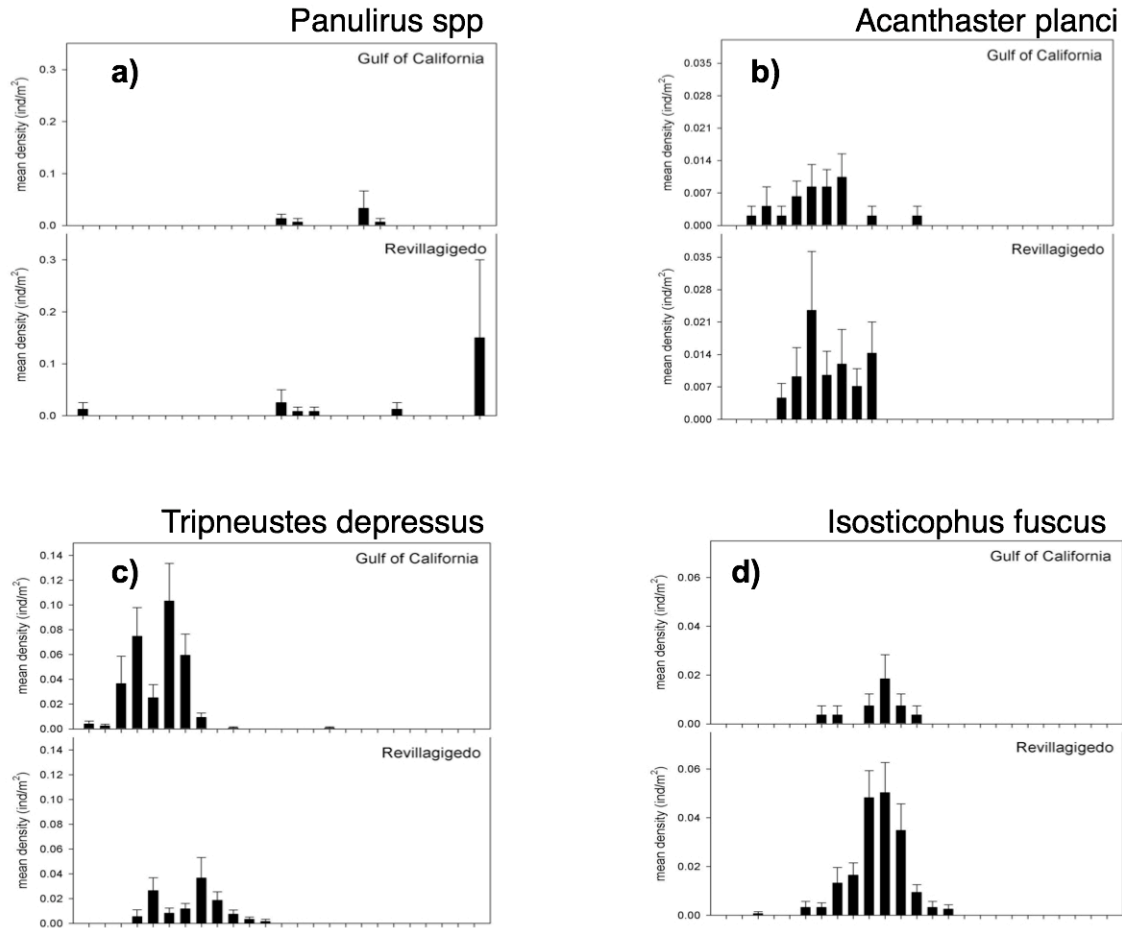


Figure 1.7. Comparison of macroinvertebrate species between Revillagigedo and the Gulf of California.

Discussion

This study is the first to provide a qualitative and quantitative description of the rocky reef macroinvertebrate (>1 cm) communities below 5 m water depth of the Revillagigedo Archipelago. To obtain this macroinvertebrate baseline, a community assessment of species richness, abundance, and spatial distribution was made with respect to island, habitat and trophic structure.

Observations from several expeditions to the Revillagigedo Archipelago yielded a total of ~250 species of macroinvertebrates (Bautista-Romero et al., 1994). These records belong to species found in various types of substrates (sand and rock), zones (intertidal and subtidal) and that were obtained through various sampling methods (collecting, quadrants, trawls). We estimate that half of the species can be found on rocky areas (~125 spp; intertidal and subtidal, infauna and epifauna). Therefore, the 60 species reported in this study are good descriptors of the non-cryptic macroinvertebrate community in rocky subtidal areas. However, because of the sampling methods (strip visual transects), rare or

infrequent species, or those species with cryptic behavior, were not recorded (e.g., snails, ophiurids).

Sponges, and to lesser extent sea fans, are conspicuous species on the archipelago. Sponges are present on all islands and at all depths with walls as their preferred habitat. Sea fans are common in some places and very abundant on some islands, especially in deep areas below 30 m depth and on flat reefs and walls. On Roca Partida, between 40 and 70 m depth, densities were especially high. Both taxa are practically absent from the Revillagigedo literature, and reports only mention the phyla without any scientific names (Mille-Pagaza et al., 2002). In the case of octocorals only genus levels are mentioned (Wells 1988; Verdi et. al., 1994). This indicates that *Aplysina* cf. *fistularis* (possibly endemic) and *Aplysina gerardogreeni* are the first records of these sponge species for Revillagigedo. This is also the case for the sea fans *Leptogorgia* sp. 1 (also reported for Manzanillo, Colima), *Muricea apresada*, *Muricea austera*, *Muricea* sp. 1, *Muricea* sp. 2, *Pacifigorgia* cf. *agassizii*, *Pacifigorgia* sp. 1, and *Eugorgia* sp.1. The last five species are likely new species and endemic to the archipelago (Sanchez-Ortiz, in prep).

The Revillagigedo Archipelago is the region of highest species richness of hard corals in the Mexican Pacific with 25 of the 34 species reported for the entire region. The majority of these species come from the Indo-Pacific, suggesting the archipelago can be considered a gateway to colonization of this fauna (Rodríguez, 2006). We recorded 14 species in the archipelago, and the most abundant and frequent in the first 15 m of depth in all the habitats were: *Pocillopora eydouxi*, *Pocillopora effusus*, *Pocillopora verrucosa*, *Pocillopora elegans*, *Porites lobata*, *Psammocora profundacella* and *Pavona gigantean*. Corals are found in shallow areas where visibility is good, although these areas are also characterized by intense wave action (typical of the coasts of Revillagigedo). These conditions favor the *Pocillopora eydouxi*, *Pocillopora effusus* and *Porites lobata* that were found to dominant in shallow water habitats. In other, more sheltered, regions of the Mexican Tropical Pacific (e.g Gulf of California, coasts of Nayarit, Colima, Guerrero and Oaxaca) this is not the case. Bautista-Romero et al. (1994) mention that most of the species of mollusks and crustaceans are reported for rocky and sandy intertidal areas. In our records the snail *Latirus socorrensis* stands out because it is one of the three endemic species of mollusks of the archipelago (Keen, 1971).

Among the macroinvertebrates with commercial importance on the archipelago are the octopus *Octopus bimaculatus*, the lobster *Panulirus penicillatus* and the sea cucumber *Isostichopus fuscus*. Species valued for their beauty, rarity, use for handcrafts, and as dye sources are the snail *Thais planospira*, the sea urchins *Eucidaris thouarsii* and *Tripneustes depressus*, sea stars *Acanthaster planci* and *Mithrodia Bradley*, and the corals *Pocillopora* spp. Only two species listed as endangered in the Mexican list (NOM-059-ECOL-2001) are the sea cucumber *I. fuscus* and the mother of pearl *Pinctada mazatlanica*.

The number species per habitat, as well as trophic level, showed a consistent pattern. The highest species richness and density of planktivores, carnivores and detritivores occur on wall habitats. Planktivores also can be found on dense flat reefs and herbivores characterize boulders. Compared to shallow areas and large and small boulders, vertical walls are the habitats with the most protection against physical disturbances and biological disturbances (predation disturbance caused by fish and sea urchins is low) (Whitman and Cooper, 1983). The shade offered by vertical walls is

advantageous for the settlement of photonegative larvae of cup coral and sea fans (Dean and Connel, 1987; Downes et al., 1998). Planktivores species on all islands dominate on vertical walls and flat reefs because they thrive in the plankton-rich currents.

Physical disturbance caused by wave actions and deep currents is higher in the open ocean and, therefore, in offshore islands (Connel and Keough, 1985). Strongest disturbances take place in areas where waves break, affecting shallow intertidal and subtidal communities. This disturbance decreases gradually as depth increases (Denny, 1995). High disturbance can lead to decreased species richness and density, with only the toughest species surviving in the marginal habitat. In Revillagigedo this disturbance can be seen from the surface down to 8-10 m depth. Although, we were unable to make surface surveys due to the intensity of the waves, we were able to see that the dominating organisms above 8 m were barnacles (*Megabalanus* spp.) and to a lesser extent the sea urchin *Echinometra oblonga*.

Species richness and abundance of sessile invertebrates (e.g. sea fans) increases at the depth of the thermocline due to one or both of two factors: 1) increased productivity, and 2) overlap of two biogeographic regions (Witman and Sebes, 1988). Water stratification in Revillagigedo generally forms between 30-40 m, while in the Gulf of California it forms between 20-30 m. Although this is evident in deep flat reef communities, it mainly occurs on vertical walls. On Roca Partida at 40 m depth we found the highest densities of sea fans (*Muricea apressa*, *Muricea* sp., *Muricea* cf. *austera* and *Pacifigorgia* sp.) and sponges (*Aplysina gerardogreeni*) in the entire archipelago, with 4-6 times the densities found in all other habitats, islands, and depths.

Species richness and density on the Revillagigedo Archipelago not only varies depending on type of habitat, but community structure and species composition is vertically heterogeneous. This may be caused by different factors like physical disturbances caused by wave action or deep currents that, down to 8-10 meters, make species richness and abundance decrease. Between 10-30 m species richness and abundance increase, however the 4-6 time increase occurs below the thermocline (>30-40m) where sessile species not present above that depth.

3.1.4 Fishes

Methods

Benthic fish baseline data was collected for four habitat types - boulders, lava, walls, and seamounts - and is considered representative of the assemblages of benthic fishes with the exception of the cryptic blennies and gobies which cannot be quantified adequately using a standard SCUBA strip transect. Although quantitative fish surveys are restricted to the previous mentioned habitats, data was collected on one occasion from a sand-gravel flat and on two separate occasions from the open ocean. However, only the most frequently found fishes in these habitats were recorded due to the limited time and effort we spent sampling there. In addition to SCUBA strip transects, we used semi-quantitative reports from recreational divers aboard the Nautilus of large pelagic fishes in order to obtain a minimum estimate of their current abundance. Both methods are described in more detail below.

Benthic Fish Survey Methods

Benthic fish assemblages were quantified using SCUBA strip transects, replicated per site and habitat (Appendix 4) in accordance with the methods used by Sala et al. (2002) within the Sea of Cortez. A standard transect size was 50 m long and 5 m wide for the large, mobile fishes and 2 m wide for the small, territorial fishes. Two paired observers counted and estimated the size of the reef fish found in the transect (the first counting large, mobile fishes and the second counting small territorial fishes). Fishes were identified to species, counted, and length estimated to within 5cm. Length-weight algorithms (obtained from Fish Base and literature searches) were used to convert the length and abundance of each fish species into a biomass estimate. Although the width of the transects remained constant, severe underwater conditions (including high swell and current) resulted in modified transects length or measurement at certain locations. When swell or current prevented the use of the standard 50meter transect tape, a 10minute swim was substituted (a 50 meter transects was established as lasting 10-minutes). On Roca Partida a separate modification to the standard transect was used; the distance between landmarks was measured and transects were swum landmark to landmark. Each site was described according to a set of environmental characteristics: ground type (wall, boulder, lava, and seamount), depth, and algal cover in order to investigate the issue of environmental covariates. In addition to the quantitative transects, short species richness surveys were swum at the end of each 50meter transect. Ten-minute species richness surveys were independently conducted as well and included in the species richness analysis. As many species are rare, this method allows for a more complete estimate of total species richness and allows for the sampling of large areas and inter-site comparisons.

Pelagic Fish Survey Methods

The observations of all scientists, crewmembers, and tourists onboard were compiled daily (and on occasion per dive) in order to increase the temporal and spatial coverage of the rare, but ecologically important, mega fauna. Divers were asked to report the animals that they ‘remembered seeing’ during each of the four dives of a given day. Reports were cross-correlated and are here reported in terms of the minimum possible abundance of each animal per site. The best possible diversity estimate and the minimum possible abundance of sharks, mantas, and schools of large pelagic fishes were obtained in this manner.

Results

Benthic Fish Communities

Species Richness

The Revillagigedo Archipelago supports a diverse assemblage of 279 recognized fish species (Robertson per. comm.), with many species restricted to one, or several, habitats and depth ranges. General marine habitats include: rocky reefs (with inter-bedded coral patch reefs), sand and gravel turf, boulders (large and small), lava flows, walls, seamounts, deep reefs (>30m), and the open ocean. Restricted to rocky reefs, lava flows, walls, and seamounts our total species richness estimate for the entire archipelago was only 122 fish species (Appendix 5). Figure 1.8 illustrates the division of species

richness by family; the most diverse six families of fish are the Carangidae (11-species), Labridae (10-species), Pomacentridae (9-species), Serranidae (8-species), Muraenidae (6-species), and Acanthuridae (6-species). The majority of families, however, are species poor, with 15 families represented by a single species.

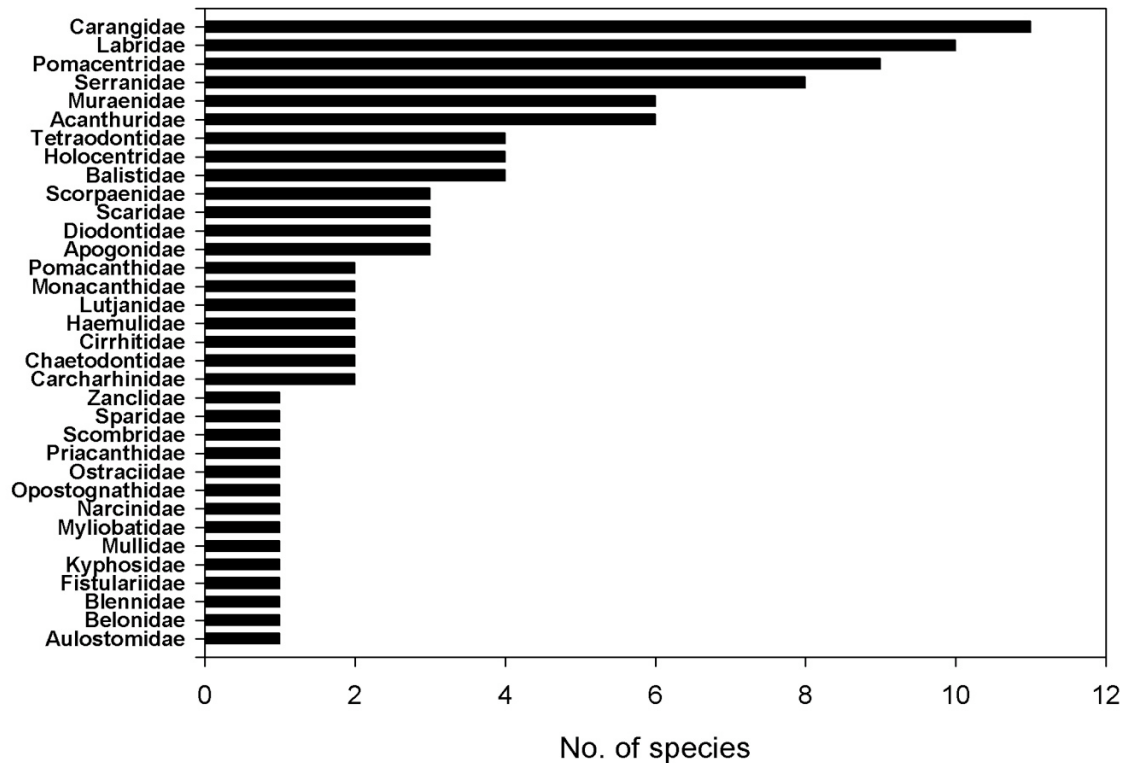


Figure 1.8. Number of fish species by family in Revillagigedo Archipelago.

Species richness by habitat was examined through the use of species accumulation curves (see Gotelli and Colwell 2001 for methods). Certain habitats (boulders) had far greater sampling than others (walls). By selecting a sample size equal to the area with the poorest sampling (7 transects) and randomly choosing that number of transects from each habitat type, habitats can be compared for total species richness without sampling bias (Figure 1.9). Boulders habitats are clearly the most speciose with 62 species after 7 transects followed by lava, seamounts, walls and Roca Partida walls with 54, 52, and 50, 48 species respectively. It is important to note that in no habitat does the species richness come to an asymptote, this means that additional sampling in any of the habitats will lead to an increased species richness estimate for that habitat. In contrast to 7-transects, after a single transect Roca Partida is by far the most species rich (Figure 1.9). This could be a result of either increased evenness or decreased patchiness of the Roca Partida fishes.

Further investigation into the pattern of species richness by habitat reveals that those families present in boulder habitats and missing from all other habitats are semi-cryptic species that lurk in the crevices present in boulder fields and, occasionally, in lava flows. Boulders habitats alone had species accounted for in the families Apogonidae and Holocentridae, both extremely shy, cryptic families. Similarly, only boulders fields and lava flows had species in the crevice-loving Blennidae, Priacanthidae, and Scopaeidae.

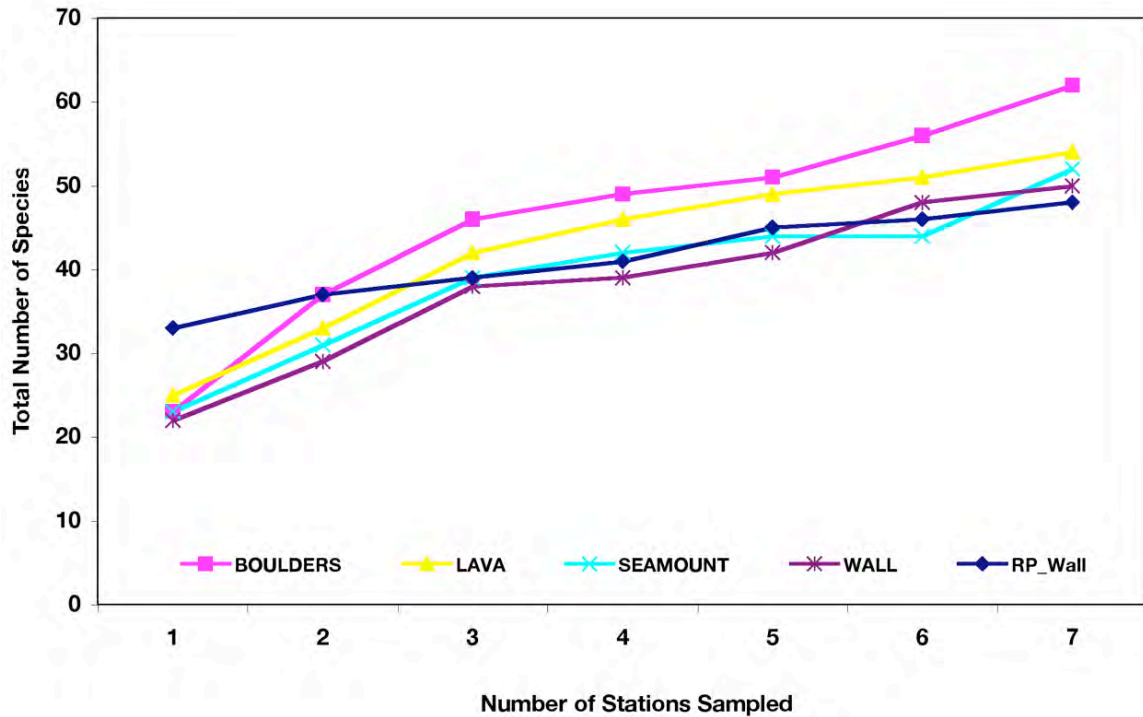


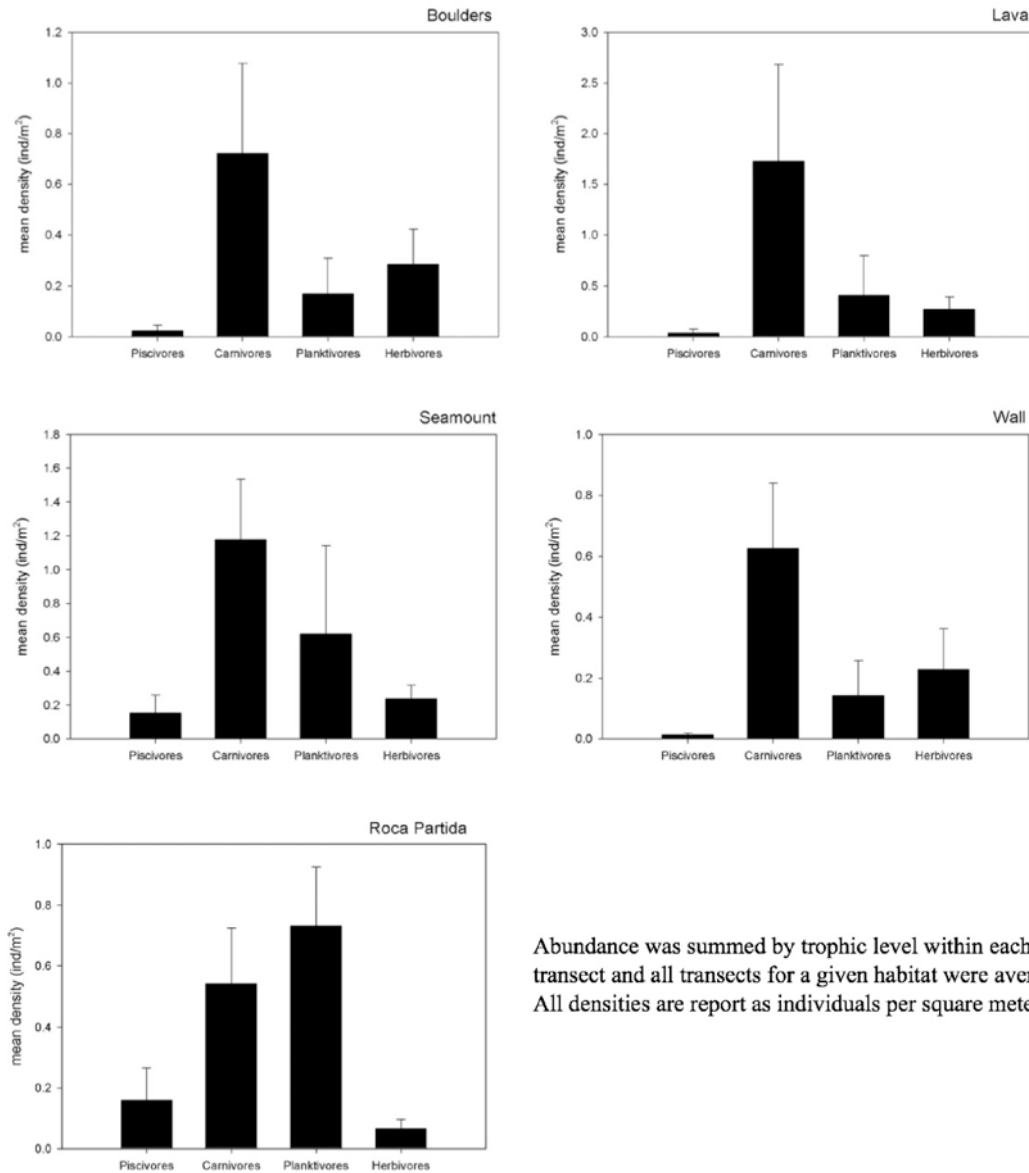
Figure 1.9. Benthic fish species accumulation curves by habitat.

Each trophic level was examined for cumulative species richness; carnivores (those species eating invertebrates but not other fishes) are by far the most species rich group with close to triple the number of species as all other trophic levels.

Species Abundance and Biomass

Species abundance patterns are fairly consistent across habitats, with the sole exception of Roca Partida (Figure 1.10). With the exclusion of Roca Partida, carnivores comprise the most abundant trophic level in all habitats with abundances ranging from 0.625 individuals/m² on walls to 1.72 individuals/m² on lava. Herbivore abundance is consistent across all habitats with a minimum density of 0.229 individuals/m² on walls to 0.286 individuals/m² on boulders (again excluding the Roca Partida habitat). When compared against all other habitats, seamounts, a habitat that is exposed to current, swell and pelagic organisms, had the highest densities of fishes in piscivores, carnivores, and planktivores. Only Roca Partida wall habitats, which are even more exposed than island-

sheltered seamounts, had slightly higher densities of piscivores and dramatically higher densities of planktivores than the seamounts.

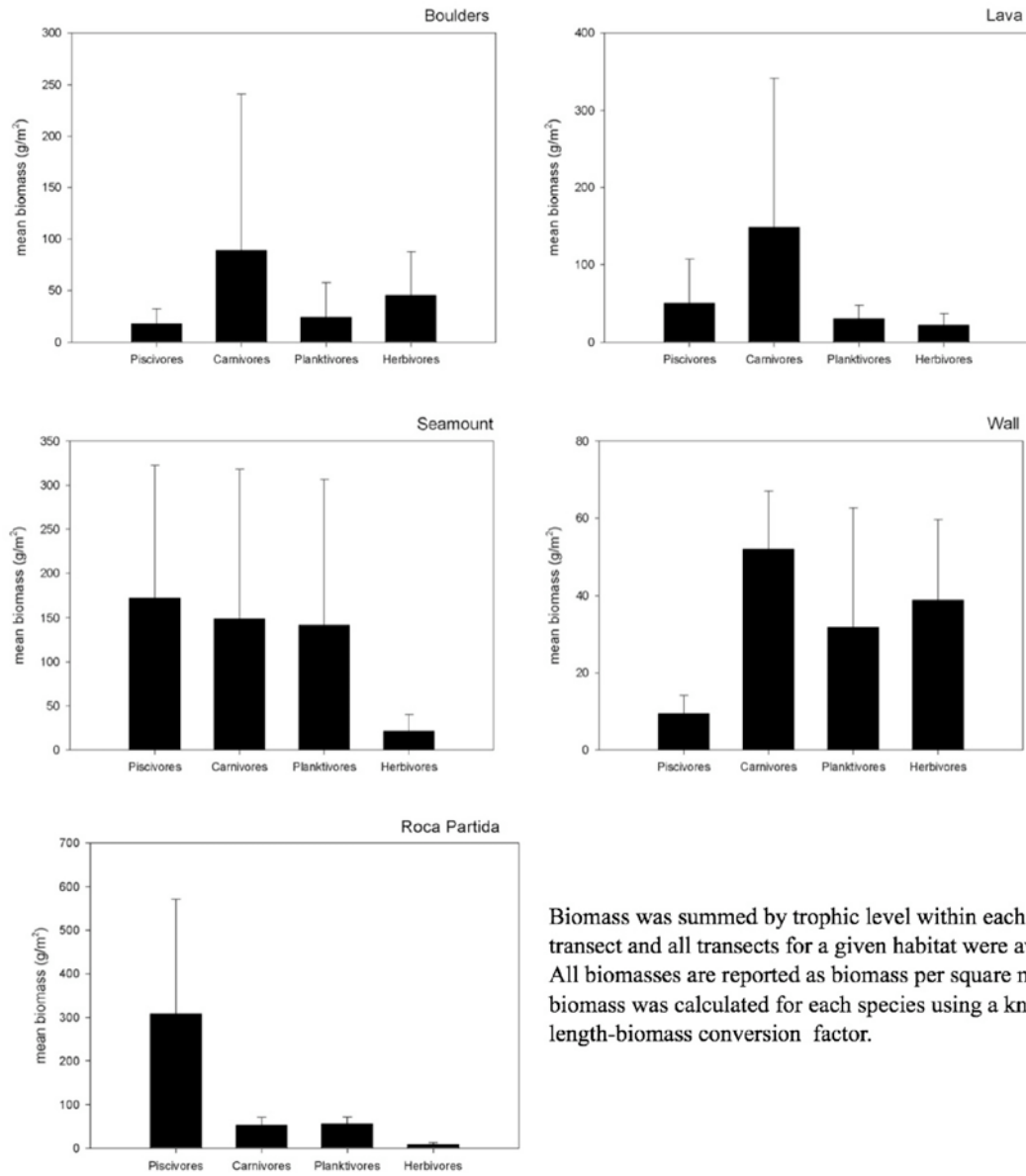


Abundance was summed by trophic level within each transect and all transects for a given habitat were averaged. All densities are report as individuals per square meter.

Figure 1.10. Abundance of benthic fishes by trophic level.

Biomass, as a reflection of the distribution of energy in a marine community, offers a far more critical, albeit complex, insight into ecosystem structure and function (Figure 1.11). Boulder habitats support a fish community with the same basic pattern of density and biomass distribution by trophic level. The relative contribution per trophic level is more equitable by biomass at 26% (herbivores), 14% (planktivores), 51% (carnivores), 10% (piscivores).

Piscivores are the least abundant fish in lava habitats but are second only to carnivores in biomass. In other words, top predators are rare but large. Trophic structure in lava habitats, as measured by relative biomass, varies considerably from boulder habitats with approximately a third of the relative herbivores biomass (9%) and double the relative piscivore biomass (20% piscivores).



Biomass was summed by trophic level within each transect and all transects for a given habitat were averaged. All biomasses are reported as biomass per square meter; biomass was calculated for each species using a known length-biomass conversion factor.

Figure 1.11. Biomass of benthic fishes by trophic level.

Seamounts, walls and Roca Partida wall habitats all have unusual trophic structures by biomass as well. As shown in Figure 1.11, walls have generally equal contributions from herbivores, planktivores, and carnivores, with relatively rare piscivores (7% by mass). This could be a result of the low overall biomass on walls; walls were found adjacent to either boulder fields or lava flows. The total biomass of non-piscivorous fishes found in boulder and lava habitats is 158.5 grams/m² and 200.5 grams/m² respectively. Walls, with an average of 122.8 grams/m² of non-piscivore, may not be as attractive to top predators as the other nearby habitats, thus accounting for the noted disparity between habitat types. Seamounts, in contrast, have approximately equal biomasses of piscivores, carnivores, and planktivores, with herbivores (the base of the food chain) contributing only 4.4% of the total biomass. Roca Partida is even more extreme with only 1.9% herbivores, and 13.1% planktivores by biomass. Although low when measured by percent contribution to total biomass, planktivores actually have a greater absolute biomass than is present in all habitats except seamounts. Roca Partida has a remarkable 72% of the total biomass in piscivores (almost entirely Carangidae), as such, it is the single greatest biomass reported in a rocky reef fish community.

Length Frequency Distribution

Figure 1.12 shows the length frequency distribution of fishes by trophic level for boulders, lava flows, seamounts, Roca Partida, and walls respectively. Size frequency distributions are discussed primarily for piscivores and carnivores (those trophic levels targeted by fishing within the Gulf of California).

The pattern in length distribution is not consistent across habitat types for piscivores and carnivores. Boulders, lava flows, and walls have an even distribution of piscivores across size classes and a strongly right skewed distribution of carnivores. Seamounts and Roca Partida have peak abundances of piscivores in the intermediate size classes; seamounts at 32.5 and 37.5 cm and 32.5 and 42.5 cm for Roca Partida. The peak abundance in carnivores for seamounts and Roca Partida was in the 7.5cm size class; i.e., the entire size distribution is less right skewed than it was for carnivores on boulders and lava fields.

It is interesting to note that the most abundant size class of planktivores is actually larger than the most abundant size class of carnivores in all habitats. Although a right-skewed size frequency distribution is often attributed to fishing pressure, this pattern between the two trophic levels could reflect several other factors as well. If piscivores preferentially predate upon the large carnivores over large planktivores, then the carnivores would show a stronger skew in population size than the planktivores. Alternatively, if mortality is elevated for some other reason (temperature excursions, food limitation, etc) for the larger size classes of carnivores, but doesn't affect the more pelagic-feeding planktivores, this pattern could result. Additionally, length frequency distribution can be affected by phylogenetic constraints that are not taken into account at present. Herbivores, like carnivores, have right-skewed populations for boulder fields and lava flows and slightly less skewed length distributions for Roca Partida, seamounts, and walls.

Although the piscivores do not show the strongly skewed length distribution typical of the fished piscivores in the Gulf (Aburto, unpublished analyses), it is notable that the mean size of the largest piscivore is only 30-40 cm. Top predators, whether

sharks, groupers, or even jacks, can be well over meter when fully grown. 30cm is within the maximum size range of some damselfish. Body size frequencies, like biomass distribution, provide only equivocal evidence for or against the presence of fishing. In order to untangle the relative influences of trophic interaction from environmental parameters, including fishing pressure, generalized linear models are being tested on benthic fish and invertebrate data from Revillagigedo and the Gulf of California.

Megafauna and Pelagic Fish Communities

Dive tourists travel to Revillagigedo for the charismatic mega-fauna, namely the sharks and the mantas. Large animals such as these are rare and the benthic reef fish transects were not sufficient to provide data as to the minimum abundance of megafauna at each site. Appendix 6 lists the locations, dates, and minimum species count for each species megafauna sighted by any diver on the boat. By collecting the accounts of all 20-divers on the boat, we report the minimum number of each species that is seen per dive boat of effort.

The giant manta, *Manta birostrus*, was observed on every island in Revillagigedo. This is the first confirmed sighting of a manta on Clarion. Although Appendix 6 lists all megafauna observations for each island and every site, it doesn't account days in which no megafauna were reported by of the divers. When this is accounted for, a different picture emerges. Mantas were sighted in one out of two days spent on Clarion (50%), two out of six days on Socorro (33%), seven of eight days on San Benedicto (87.5%), and three out of four days on Roca Partida (75%). For tourists traveling to Revillagigedo with the sole desire to interact with giant mantas, Roca Partida and San Benedicto are best suited.

Although it was unusual to encounter sharks within a SCUBA strip transect, they were commonly seen by researchers and tourists alike. Historic accounts of the Sea of Cortez describe the presence of abundant sharks and mantas. Systematic surveys of the Gulf fishes started in 1992, with a standardized sampling pattern initiated in 1998. From 1992-2006, these researchers have seen 17-sharks (Aburto, per. comm.). Fifteen hammer head sharks were seen on one occasion near a deep seamount (El Bajo, La Paz). During the 2005 surveys in the Gulf no sharks were seen within or in the vicinity of the SCUBA strip transects. No giant mantas have been seen by this team of researchers, although were reports in 2005 of manta sightings in the southern Sea of Cortez.

Discussion

This study is the first to provide a quantitative description of the benthic fishes of the Revillagigedo Archipelago. This baseline was obtained from a community assessment of species richness, abundance, and size on all four islands, in four different habitat types. Tourists travel to Revillagigedo with the primary desire to see giant mantas and sharks (see Section 3.2); from the semi-quantitative 'large pelagics' survey it is clear that not all islands are equal in this regard. San Benedicto and Roca Partida have far more mantas sighted per dive boat of effort than Socorro or Clarion. However, it is Socorro and Clarion that provide that habitat (and the diversity of habitats) that support the most species rich communities around Revillagigedo (boulder habitats primarily).

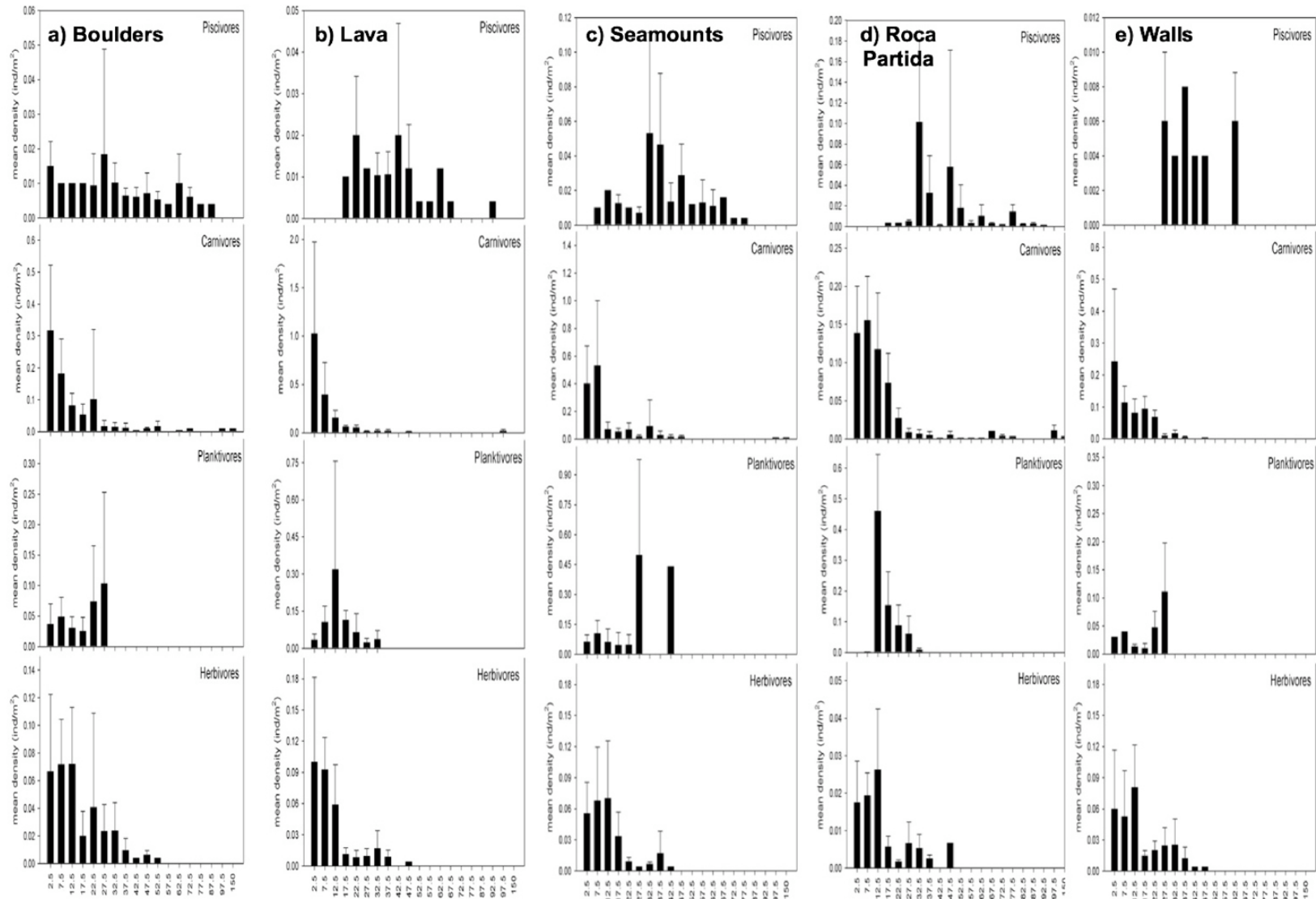


Figure 1.12. Benthic fish length distribution by habitat.

Along the coast of Baja, groupers and snappers are the most important top predators. Not only are there a limited number of species of groupers and snappers on Revillagigedo, they are present in low numbers. Most species of snapper and grouper in the Gulf recruit to the roots of mangroves (a critical habitat for their survivorship); however, there are no mangroves on Revillagigedo. All species of snapper and grouper recorded from the islands are known to recruit to either boulders or sea urchin spines. Juveniles of the Leatherbass grouper were observed on several occasions hiding within the spines of *Diadema mexicanum*. In the absence of other top predators, piscivores on the islands are almost entirely from Carangidae (the jack family), reaching an extreme on Roca Partida

The interaction of offshore island conditions and release from fishing pressure has a variable effect across habitats. Those habitats most favorable to the more pelagic jacks and the plankton feeding planktivores (Roca Partida wall habitats and seamounts) support the highest biomass of fishes. In these habitats the relative biomass structure is shifted, with 20-72% of the near-reef biomass composed of top predators. Similarly large abundances of piscivores are not noted in the more sheltered boulder, lava, and wall habitats. One might expect the snappers and groupers species that are present in those locations to increase in biomass (i.e., from competitive release from the multitude of snappers and groupers within the Gulf of California); however, this was not noted. This could be due to life history factors such as stage dependent mortality or habitat limitation or other selective pressures like predation by sharks. Predation by sharks can tentatively be ruled out from the length frequency distributions. If shark predation were suppressing the biomass of snappers and groupers in boulder, lava and wall habitats, a right-skewed distribution would be expected. This is not the case; piscivore length frequency distributions appear to be fairly normal or even. We tentatively propose that the species of large groupers (*Dermatolepis dermatolepis*, *Epinephelus labriformis*, *Epinephelus panamenis* primarily) and snappers (*Lutjanus viridis* and *Hoplopagrus guentherii*) are limited by their life histories from reaching the high densities (and mass) of related groupers and snappers in the Gulf.

Length frequency distribution in general is suggestive of a release from a size selective pressure (in this case, most likely fishing). However, all data (abundance, length distribution, biomass, habitat, depth and island) must be more fully analyzed both within the Gulf of California and Revillagigedo before conclusions can prudently be reached.

3.1.5 Conclusion: Marine Baseline

Our primary ecological objective, to set a marine baseline with “quantitative data for the marine fish and macroinvertebrate communities, including information about distribution, abundance, biomass and value to the tourism trade” was achieved and exceeded during our field research in the winter of 2006. We not only obtained quantitative data for the benthic fish and macroinvertebrate communities, but also were able to provide semi-quantitative data for marine algal communities, and to provide a minimum abundance of large pelagic fishes. Our baseline data spans the marine food web from algae to the top oceanic predators, though detailed quantitative information is restricted to macroinvertebrates and benthic fishes.

The second component of our principal objective was to make “comparisons between Revillagigedo and similar regions in the Gulf of California [and] contrast the structure ... of the relatively pristine Revillagigedo marine systems and relatively degraded Gulf systems”. Descriptive comparisons were made and show the following:

1. Exploited macroinvertebrate species within the sea of Cortez have a combination of decreased biomass, or a shifted length frequency distribution as compared to analogous species in Revillagigedo.
2. These differences (decreased biomass and skewed length frequency distributions) may reduce the resilience of Gulf ecosystems to disturbances
3. Piscivorous fishes have normal or even length frequency distributions and carnivorous fishes have a strongly right-skewed distribution in Revillagigedo. This is the opposite distribution pattern noted in the Gulf of California where piscivores are right skewed and carnivores are more normally distributed.
4. The relative patterns in piscivore and carnivore length distribution may be the result of a trophic cascade in the Gulf due to the presence of a higher predatory group, humans, selectively removing the largest piscivores thereby reducing the predatory pressure on the carnivores.
5. Island biogeographic effects cannot be ignored in Revillagigedo. In the absence of mangroves, snappers and groupers are a minor presence in many of the habitat types. These comparisons are being tested using general linear models to determine which trends are statistically significant and to elucidate the potential difference in structuring mechanisms in the two regions.

Inter-habitat and inter-island comparisons within Revillagigedo have provided critical insights into the structure and function of the marine ecosystems around the islands. Macroinvertebrates were found in high densities on wall communities, and in the highest total densities on Roca Partida (a continuous wall habitat). This is attributed to the exposure to currents (i.e., plankton food source for the planktivores) and protection from predation (i.e., invertivorous fish species are exposed to their piscivorous predators). Indeed, piscivores make up a significant proportion of the biomass in the exposed habitats (seamounts and Roca Partida) and carnivores have relative lower biomasses and strongly right-skewed length distributions. Additionally, urchin barrens are widespread on Roca Partida and algae and herbivorous fishes are extremely rare; the formation of urchin barrens as a result of predatory release is a well-known phenomena. Further comparisons and cascades are being identified through statistical analyses.

A marine baseline for the Revillagigedo Archipelago is now established for future studies to reference. Although this baseline provides a snapshot at one point in time of a proportion of the marine communities of the Revillagigedo Islands, it has already revealed interesting patterns within habitats, across trophic groups, between biogeographic regions.

3.2. Economic Baseline

3.2.1 Introduction

Human societies both impact and receive benefits from the natural systems they live within. Comprehensive understanding of a natural system therefore requires investigation of human interactions with the natural ecosystem. The economic baseline presented here identifies those industries and user groups which benefit from the conservation of healthy ecosystems within the Revillagigedo Biosphere Reserve. The baseline also identifies the potential for diver-fee based funding of reserve management.

Often, researchers wish to quantify benefits gained from an ecosystem or particular species in terms of a monetary value. Economists have developed techniques to quantify such values for non-traded goods and make inference about individual preferences using survey data and observed individual choices. Using these techniques, it is possible to estimate passive values – values that do not necessitate extraction and subsequent trade – for the ecosystem or species in question. In this study, we utilize surveys to study the legal direct users of the Revillagigedo Archipelago, the dive tourism industry and its consumers. We take the formation of the reserve by the Mexican government as a revealed social preference for protection of the marine community surrounding the islands. We take anecdotal evidence of poaching inside the reserve as an indication that further enforcement is desirable and we consider dive tourism and recreational fishing as the most likely sources of funding for increased enforcement. According to dive vessel owners and patrons, as well as SeaWatch, an independent non-governmental organization focused on the Sea of Cortez, enforcement of the reserve's no-take policy is inadequate and poaching is quite common. Funding the management of a marine protected area through diver fees is not a new concept but is arguably an underutilized source of funding (Tongson et al. 2003). For example, studies of Caribbean marine protected areas find that these entities have the potential to generate substantial additional revenue through user fees (Green et al. 2003).

Using publicly available data and personal communications with Captain Mike Lever of the Nautilus Explorer, we find baseline gross profits for dive tourism to be approximately \$500,000 per year¹. But this number is less important to policy makers than the amount of surplus they might extract from consumers and producers of dive tourism. Our study estimates extractable surplus and connects these values with specific mega-fauna residing in the reserve.

3.2.2 Stated Diver Preferences

Methods

Surveys created for this project (Appendix 7) are designed to estimate individual preferences, which drive consumer decisions regarding dive vacations, particularly how the presence of specific marine life affects these choices and the willingness-to-pay for conservation fees. Our survey design follows that of a contingent valuation survey: the

¹ Based on published price data, assuming all trips full on each boat and using rough cost of boat operation of \$4000/day-at-sea for both vessels.

valuation (or willingness-to-pay) questions are contingent upon two management scenarios. After answering diving related questions (such as number of dives, memorable encounters with marine life, etc) respondents are asked two valuation questions. First they are asked how large of a fee they would be willing to pay if they believed that the fee would be used to enforce protection of the Revillagigedo Biosphere Reserve. Then respondents are asked how their willingness-to-pay changes if they are uncertain about the uses of the funds.

The two valuation questions are asked in open-ended format, that is “What is the most you would be willing to pay ...” This is in contrast to the preferred closed-ended format. Closed-ended questions are binary choice questions of the form: “would you pay \$X ...” where X is varied over a range of values. This method is preferred over open-ended questions, which can introduce bias by encouraging strategic behavior. However, a large sampling size is required for close-ended questions. Thus, our limited sample population- 33 respondents- rendered an open-ended format more appropriate. We consider this initial small sample size as a pre-testing pilot study. Pre-testing provides a range of fee levels to use for closed-ended questions in surveys for future years and is shown to increase the statistical power of subsequent closed-ended questions (Hall et al. 2002, Hanemann et al. 1991). All surveys were administered to divers aboard the Nautilus Explorer during cruises in February and March of 2006. Our collaborator, Mike Lever, Captain of the Nautilus Explorer, has helped and will continue to help administer close-ended surveys to divers traveling to Revillagigedo Islands. Captain Lever is also the source of a detailed interview in which we validate our estimates with his own estimates of customers’ willingness-to-pay for conservation within the reserve.

Results and Discussion

Diver Fee

Twenty-six of the thirty-three administered surveys are included in the subsequent analysis. Seven surveys were omitted for non-numerical willingness-to-pay responses such as ‘anything’, ‘yes’, or ‘don’t know’ or a clear lack of understanding of multiple questions. On average, the recreational divers surveyed were willing to pay a fee of US\$85 towards conservation management in the reserve; the most frequent value reported was US\$100. Figure 2.1a is a histogram of the positive responses to a fee payment when that fee is fully dedicated to funding enforcement in the reserve.

Divers were also asked how much they would be willing to pay for an arbitrary fee that might not be used for enforcement or conservation. As expected, divers are willing to pay much less when fees do not go to conservation (Figure 2.1b).

The difference between the values reported for conservation fees versus arbitrary fees is of economic interest. Figure 2.1c gives a histogram of the individual differences in willingness to pay, i.e. the individual marginal value of conservation. That is to say, the values in Figure 2.1b represent willingness-to-pay for the trip to the Islands, a measure of current consumer surplus. Values are higher (Figure 2.1a) when conservation is the recipient of fees and so the difference between the two represents values over-and-above consumer surplus of the dive trip that are driven by existence values or other motives for conservation.

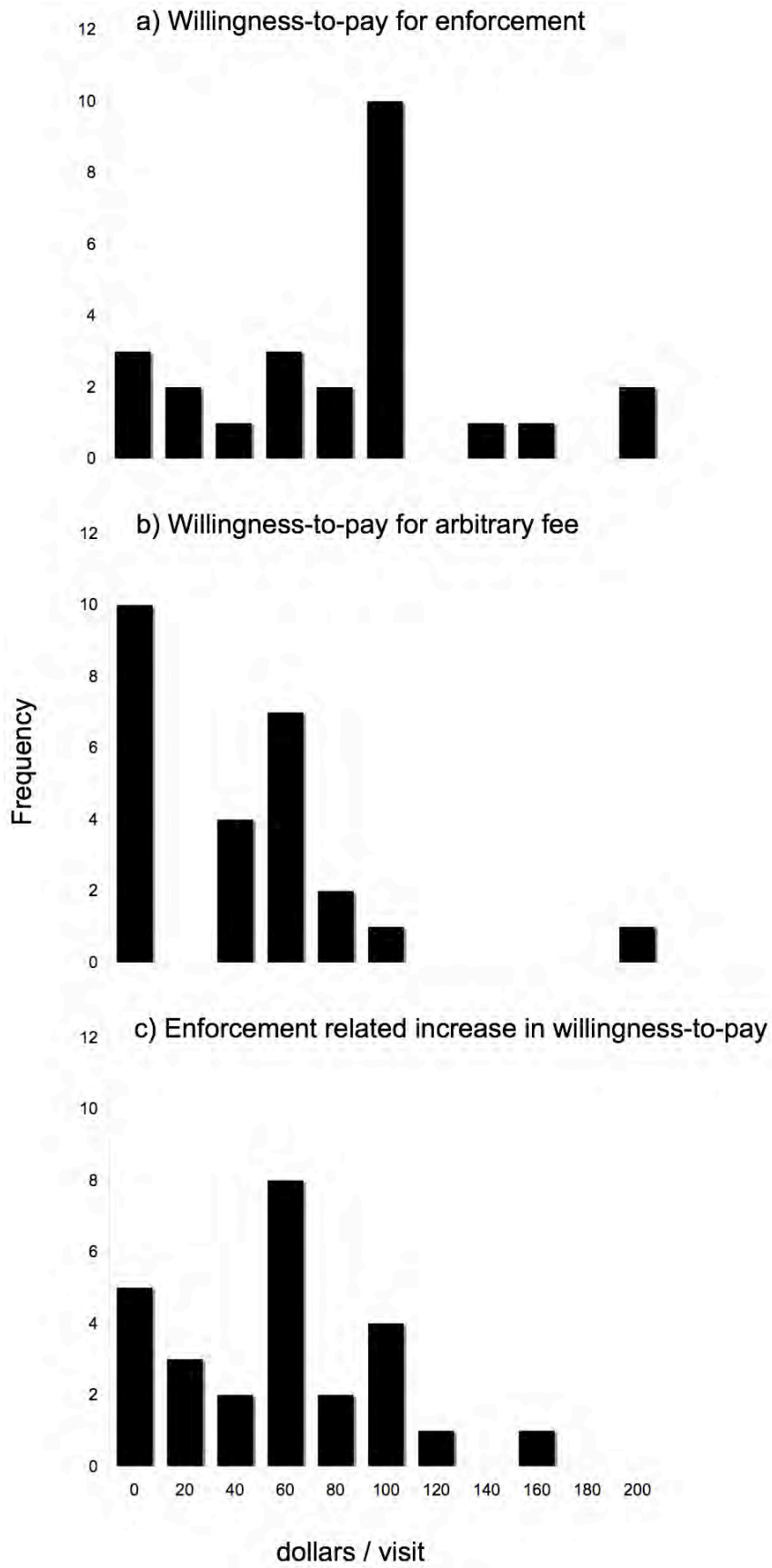


Figure 2.1. Willingness-to-pay diver surveys for enforcement.

We collected various diver descriptive statistics (see Appendix 7 for survey instrument) and attempted to correlate these with willingness-to-pay data. There is no significant relationship between self-reported likelihood of a return visit to Revillagigedo and elected diver fee. There is a positive but insignificant relationship between the likelihood of return and the difference (Figure 2.1c) between willingness-to-pay responses when fees are for conservation versus when the use of fees is unspecified. The high standard error of the regression coefficient is almost certainly due to the extremely small sample size and we plan to re-address this question as our sample size increases with future surveys. A one-tailed t-test strongly rejects the null hypothesis that the mean response of the underlying population is less than US\$60/visit ($p < 0.2$, 5% confidence level). For this and other reasons discussed below, we proceed assuming that imposing a fee of \$50/visit is unlikely to significantly decrease demand for dive trips to the Revillagigedo Archipelago. Not only does this assumption appear to be conservative given our data but the closest precedent for such a fee (Tongson et al 2004) was \$50/visit. Moreover, the captain of the Nautilus Explorer believes that \$50 would be an acceptable fee to the majority of his clients. Captain Lever has turned away many clients in the past year and believes that given sufficient marketing, there is demand for at least 20 sold-out dive trips Nautilus Explorer compared with the 11 that sold this past year. This final point suggests that if a small percentage of consumers are dissuaded from purchasing a trip to the islands by the proposed \$50 diver fee, excess demand is sufficiently large to replace those displaced divers.

Stated Preference for Marine Fauna

With total values estimated, it is important to determine which animals contribute most to diver valuations. The results here can be compared to the revealed preference data from our diver observations section. Divers were asked which animals were most important to their dive trip decisions. Diver responses in regards to preferences for specific marine fauna were scored into six categories in order to make this information comparable with observations on diver/habitat interactions. The results reveal clear preferences for specific marine fauna, particularly mantas and sharks. To the extent that tourists are to be a source of funding for protection of the ecosystem, the protection of mantas is critical.

Diver surveys suggest the potential for greater conservation revenue to be extracted from divers. This value appears to be most closely associated with mantas and sharks. This finding is confirmed in the following section. Divers claim to care about the marine community and appear to value it beyond tourism uses. The fact that divers care most about mega-fauna is not surprising but re-affirms that the protection of these species is a vital part of the protecting the ecosystem of Revillagigedo.

3.2.3 Diver/Habitat Interactions

As a complement to stated preference and valuation estimates obtained through surveys, in situ observations were made of diver behavior in the water. This set of observations served to (1) document dive environments experienced by dive tourists visiting the Revillagigedo Archipelago, (2) examine diver interactions with marine fauna (particularly with large, mobile pelagic fauna), and (3) provide an estimate of the relative

abundance of large, mobile pelagic species (sharks, mantas, jacks, etc.) not adequately sampled by the aforementioned fish transect protocol. This is the first study to our knowledge of examined recreational diver behavior.

Methods

Observations for this portion of the study were made over a series of 32 dives, with 1-4 tourist divers observed on each dive. Scan samples of both the dive environment and diver behavior were made every three minutes throughout the duration of the dive. All pelagic fish species within the visible dive environment (a 360° visual scan in the tourist diver location) were recorded, as was the corresponding diver behavior. For example, at observation interval 3 on dive number 20 the dive environment included one manta, a school of 100 chubs, and 3 small fish. During this interval, the two divers observed were photographing and reaching out towards the manta ray. Compilation of a series of such paired observations allowed objective estimates of the dive environment (i.e. snapshots of the dive landscape recorded by SIO/UCSD divers) to be paired with estimates of the subjective, interactive dive landscape (i.e. which portions of the total or 'objective' landscape did the divers notice, experience, or interact with.) Comparisons between these two sets of observations allowed us to estimate diver preferences by noting which species divers noticed, watched, and interacted with most often across the varied experiential landscapes.

Results

Divers spent the majority of their time scuba diving scanning the pelagic environment (Figure 2.2). More specifically, scanning the pelagic means divers were searching the portion of the water column where mantas and other large pelagics are likely to be seen. Almost 60% of diver time was spent scanning the water column, while divers investigated the benthos or bottom of the ocean only 9% of the time. Diver observations of or interactions with mantas comprised 13% of underwater time.

The various subjects of potential interaction (sharks, mantas, jacks, etc.) were not equally represented in the dive environment, as some species were encountered much more frequently than others. In order to evaluate diver preferences for particular species, this bias was removed by examining the proportion of time each diver spent interacting with a given species relative to the time that species was present in the dive environment (Figure 2.3a). Divers actively watched megafauna (mantas, sharks and dolphins) 75% of the time megafauna were present. In contrast, divers actively watched both large pelagic fish (leather bass and jacks) and benthic reef fish only 3% of the time they were present. Divers also exhibited preferences within these categories, giving greater attention to dolphins and mantas than to sharks and less still to large fishes (Figure 2.3b).

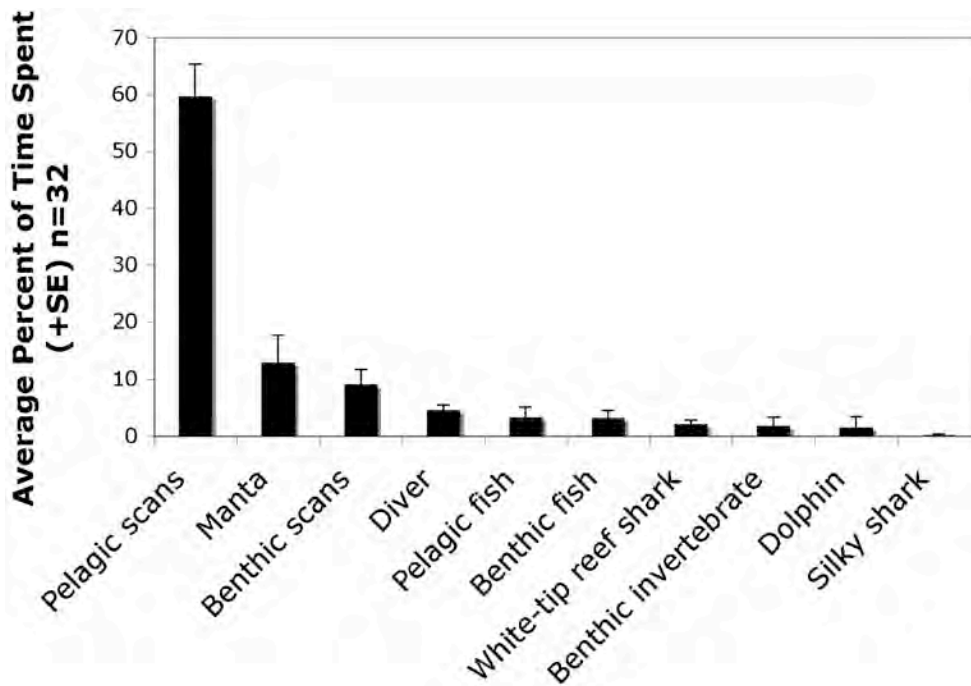


Figure 2.2. Distribution of activities comprising time spent underwater by recreational divers. Diver activities were scored as one of ten qualitative categories. The vertical bars depict the percentage of total dive time (over 32 dives) occupied by each activity. Error bars represent one standard error.

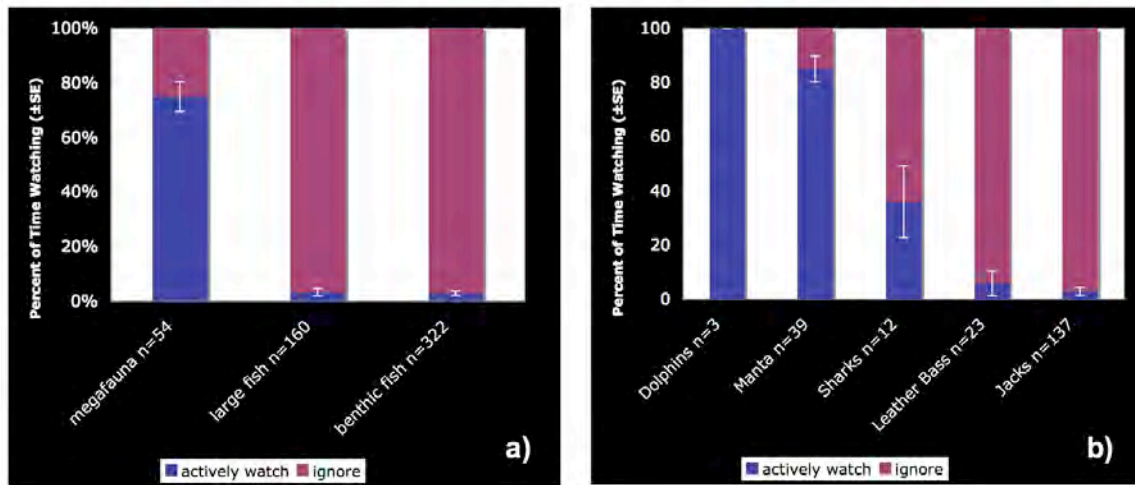


Figure 2.3. Group and species specific diver preferences as revealed by percentage of time recreational divers spent engaged in interaction: (a) proportion of time that megafauna, large fish, and benthic fish occupied diver activities relative to total time present (b) species specific expansion of relationships depicted in (a) . Error bars represent one standard error.

Discussion

To our knowledge, this is the first study to investigate diver preferences underwater. Dives experienced by recreational divers visiting the Revillagigedo Archipelago average depths of around 60 feet and frequent habitats such as vertical rock walls, boulder fields, and lava flows. Time spent underwater by recreational divers is dominated by activities focused on large pelagic megafauna, particularly dolphins, manta rays, and sharks. These species dominate diver attention when present, and the observed divers spent the vast majority of their time underwater scanning the habitats frequented by these species when absent. More specifically, as divers spent their time underwater searching for megafauna they often ignored or did not interact with smaller, less charismatic species when present. These results mirror those of self-reported diver preferences obtained through diver surveys, and suggest that a few organisms, primarily mantas and sharks, drive a disproportionate majority of recreational tourist interest in visiting the Revillagigedo Archipelago. These species, however, are also most likely to be threatened by illegal fishing and poaching activities. They are not only current targets of these activities but are long-lived and slow to reach reproductive maturity, decreasing the rate at which they can recover from population reductions. Therefore, management plans for the Revillagigedo Archipelago must take into account absolute protection of these species. While recreational and commercial harvesting of mantas and sharks are legally prohibited in the Revillagigedo Biosphere Reserve, illegal poaching does occur and is not prevented by mandates alone. Active enforcement of fishing restrictions and monitoring of illegal fishing activities within the reserve should be considered a vital priority in future management decisions for Revillagigedo.

3.2.4 Economic Conclusions

Both our stated preference and diver/habitat interaction observations indicate that most diver interest in the islands is driven by megafauna such as sharks and manta rays. We find that divers are willing to pay more for trips to the islands than they currently do; additional funding for enforcement could be obtained through a modest access fee to the reserve. Divers' willingness-to-pay dramatically increases when divers are convinced that fees are used only for conservation efforts. We find that these divers are most interested in the conservation of larger animals such as sharks, manta rays and dolphins. Anecdotal evidence suggests that enforcement is still a problem in the archipelago, such that revenue generated from diver fees could be well spent on conservation management if used to fund further enforcement. With a conservative estimate of a US\$50 per diver per trip fee we estimate that Revillagigedo Reserve could extract approximately US\$20,000 per year. If two more vessels are added to the dive tourism fleet, extracted fees more than double (Table 2.1).

Table 2.1 Estimated Current and Potential Extractable Fees

	Solmar V	Nautilus Explorer	Other Dive	Total Dive	Sport Fishing	Total
Current Trips	19	11	0	30	1	31
Extracted Surplus	\$9,500.00	\$5,500.00	\$0.00	\$15,000.00	\$0.00	\$15,000.00
Potential Fee ¹	19	11	0	30	1	31
Potential Extracted Surplus	\$19,000.00	\$11,000.00	\$0.00	\$30,000.00	\$0.00	\$30,000.00
Potential Trips I ²	19	11	30	60	1	61
Potential Extracted Surplus I	\$19,000.00	\$11,000.00	\$30,000.00	\$60,000.00	\$0.00	\$60,000.00
Potential Trips II ³	19	11	30	60	30	90
Potential Extracted Surplus II	\$19,000.00	\$11,000.00	\$30,000.00	\$60,000.00	\$150,000.00	\$210,000.00

According to Tim Eckstrom, owner of Royal Star Sportfishing, a San Diego, CA based sport fishing fleet, fees could reach up to two million dollars per year from a single sport fishing vessel making 30 trips to the islands per year (Table 2.1). Such a sport fishery would target tuna and wahoos exclusively (Eckstrom per. comm. 2006). According to our data these species are of little stated value and no revealed value to divers; however, strong caution is advised in this interpretation. Divers and dive operators tend to be less supportive of recreational fishing. Recently, dive-operators visiting Guadalupe Island for Great White cage diving, including our collaborator, Mike Lever have agreed not to allow any sport fishing on these trips (though the reserve does allow it) (Lever per. comm. 2006). The primary stated reason is the fear of damage to sharks from lost fishing gear. Any changes considered by the Mexican authorities hoping to gain revenue should consider potential conflicts between user groups. The divers are an established user group currently paying fees and potentially a source of greater revenues. Our results should not be interpreted to suggest that sport fishing is a viable or appropriate alternative to dive tourism.

It is worth noting in conclusion that our study does not quantify a potentially large portion of the economic value associated with Revillagigedo. Given that prohibitions on fishing were imposed by the Mexican government, there is a strong revealed preference on the part of the Mexican people as a whole for conservation of this ecosystem. It is likely that Mexican citizens have high existence values associated with animals inside the park as well as the system at large. This value, yet to be quantified, is important to consider for any changes to the management of the park. Even if increased diving and sport fishing can generate revenue for the park, it may be that the people of Mexico value the system in a more undisturbed state. If this is the case, then government funding or non-governmental donations will be the only feasible source of added funds to increase enforcement of no-fishing rules.

¹ Assumes a \$50 fee is imposed on all divers and does not decrease demand.

² Assumes that 2 more vessels can be accommodated by islands and sufficient demand exists to fill these vessels with fee as in [1], doubling number of vessel days per year, based on interview of Captain Mike Lever of the Nautilus Explorer.

³ Assumes that in addition to [1] and [2] a small sport fishery is allowed bringing in \$5000 per trip in access fees, based on interview with Captain Tim Eckstrom of Royal Star Sportfishing.

Ultimately it is the values held by Mexican citizens and policy makers that will and must determine conservation outcomes in the park. Our study offers information on what is there now and what potentials exist for conservation funding. We do not claim that management should or should not increase tourism. We show that there exists an apparent potential for growth in extractable surplus. And we show that this surplus is driven mainly by direct and indirect values associated with sharks and manta rays.

4. Project Significance

4.1 Scientific Significance

This study makes a key contribution towards understanding the structure marine food webs at the ecosystem level in the Mexican Pacific. It provides the first quantitative data for marine food webs in the Mexican Pacific, thereby allowing for a regional comparison of food web structure between the Sea of Cortez and offshore islands. Furthermore, it provides the first baseline data for the marine communities of the Revillagigedo Archipelago. Additionally, this study is the first attempt to value marine biodiversity in the Mexican Pacific from an economic perspective. The results of this study, with the synthesis of the ecological and economic data, will be aid in the evaluation of management actions in the biosphere reserve as well as the identification of conservation goals for rocky reefs in the Gulf of California and elsewhere.

4.2 Education and Outreach Significance

Education and outreach efforts were concentrated in 3-main areas: the education and training of participating students, presentations to the public, and scientific support of Mexican marine regulatory agencies.

This project provided an incredible educational opportunity for the second year graduate students in the Scripps Institution of Oceanography's Center for Marine Biodiversity and Conservation's (CMBC) graduate training program (supported by an NSF IGERT grant). Students were charged with the task of developing the interdisciplinary aspects of the research including the international collaborations, planning a field study in a remote location, and obtaining the additional funding needed to meet the goals of the projects. They learned critical scientific skills including proposal writing and underwater research techniques, and project management skills including the coordination and management of a large interdisciplinary, multi-institutional research project. This project allowed students to meet their second year requirement in the CMBC program of planning and conducting an interdisciplinary project. Additionally, Yuliana Rocio Bedolla-Guzmán, a master's student at UABCS, conducted her thesis research on the marine invertebrate communities of the Revillagigedo Archipelago.

A series of presentations covering topics from the natural history of the Revillagigedo Archipelago, to the structure of marine communities on the islands, to the state of the modern oceans were presented during each of the cruises on-board the Nautilus Explorer. On returning to San Diego, several presentations to the public have taken place with the largest presentation, a public lecture at the Birch Aquarium, planned for the winter of 2006.

However, on the Revillagigedo Archipelago, the most important group to educate are those responsible for the managing the islands. We worked closely with the Mexican council for Protected Areas Council (CONANP), a branch of the Mexican National Environmental Agency, throughout the course of the project. We had three meetings with the Biologist Carlos Narro, the first official director of Revillagigedo Biosphere Reserve, to discuss the benefits of our proposal for conservation strategies in the area. With the authorization of Carlos Narro, we established a collaboration-planning schedule in order to:

1. Carry out the surveys to set a baseline for the invertebrates and fish of Revillagigedo Archipelago.
2. Use this research opportunity to establish a collaboration agreement between tourist boats and the Biosphere reserve, which includes places in each trip for one or two researches every year.
3. Present the results of this research in a forum planned by CONANP, in order to show the opportunity costs of conservation efforts for Revillagigedo Archipelago.

The presentation of this report to CONANP will fulfill all the requirements of our permits from Natural Resources and Environmental Agency, Wildlife Department and National Fisheries Institute of Mexico and will be part of the official Revillagigedo reserve file.

5. Conclusions

Above all, our experiences in the Revillagigedo Archipelago have heightened our sense of the unique resources and singular beauties these islands harbor. The results of this study have provided ecological and economic data previously unavailable for the islands. From an ecological perspective, we find patterns of interest within Revillagigedo, which are further strengthened by comparison with analogous data from the Gulf of Mexico. From an economic perspective, we are able to identify current economic activities in the biosphere reserve and comment on their relative current and potential future contributions to both the reserve and the larger Mexican economy. Furthermore, this document marks the starting point of our efforts to publish the information contained herein and make it available to both professional and educational audiences as well as the general public. Also of significance are the cross-boarder collaborations this project made possible. In total 12 students and researchers and 2 faculty from the University of California, San Diego and Universidad Autónoma de Baja California Sur. La Paz, B.C.S. participated in the project. Furthermore, the strong foundations to what will likely prove to be continuing foundations have been built between the academic researchers, private economic stakeholders (Nautilus Explorer) and government regulatory agencies (CONANP).

5. Appendices

Appendix 1. Marine Algae of the Revillagigedo Archipelago

List compiled by:

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CHLOROPHYTA

Acetabularia parvula v. americana	Chlorodesmis mexicana
Blidingia marginata (Enteromorpha marginata)	Dictyosphaeria australis
Bryopsis galapagensis	Dictyosphaeria versluysii
Bryopsis pennata v. minor	Enteromorpha flexuosa
Caulerpa fastigiata	Enteromorpha flexuosa subs. paradoxa (Enteromorpha plumosa)
Caulerpa peltata (Caulerpa racemosa v. laetevirens)	Enteromorpha lingulata
Caulerpa racemosa	Enteromorpha muscoides (Enteromorpha clathrata)
Caulerpa racemosa v. occidentalis	Ernodesmis verticillata
Caulerpa sertularioides	Halimeda discoidea
Cladophora gracilis f. expansa	Halimeda opuntia
Cladophora inserta	Halimeda tuna
Cladophora perpusilla	Neomeris vanbosseae
Cladophoropsis membranacea	Ostreobium quekettii (Ostreobium reineckeii)
Codium decorticatum	Phaeophila engleri
Codium isabelae	Pilinia maritima f. pacifica
Codium longiramosum	Polyphysa parvula
Codium simulans	Pseudobryopsis hainanensis
Chaetomorpha antennina	Rhizoclonium riparium
Chaetomorpha exposita	Rhizoclonium riparium v. implexum (Rhizoclonium kochianum)
Chaetomorpha gracilis	Siphonocladus tropicus
Chlorodesmis caespitosa	Ulva lactuca
Chlorodesmis comosa	

RHODOPHYTA

- Colaconema daviesii* (*Acrochaetium daviesii*)
Acrochaetium eastwoodiae (*Rhodochorton eastwoodae*)
Acrochaetium pacificum (*Acrochaetium variabile*)
Agardhiella subulata (*A. tenera*)
Ahnfeltia plicata
Ahnfeltiopsis concinna
Ahnfeltiopsis gigartinoides
Ahnfeltiopsis serenei
Amphiroa beauvoisii (*A. crosslandii*), (*A. droueti*)
Amphiroa misakiensis (*Amphiroa dimorpha*)
Amphiroa misakiensis
Amphiroa rigida (*A. taylorii*)
Amphiroa valonioides (*A. annulata*)
Anotrichium tenue
Asparagopsis taxiformis (*A. sanfordiana*)
Asparagopsis taxiformis f. *amplissima* (*A. sanfordiana* f. *amplissima*)
Botryocladia pseudodichotoma
Callithamnion pacificum
Callithamnion paschale
Callithamnion soccoriense
Carpopeltis clarionensis
Centroceras clavulatum
Ceramium clarionense
Ceramium flaccidum (*C. gracillimum* v. *byssoides*)
Ceramium mazatlanense
Ceramium sinicola
Ceramium vagans (*C. vagabundum*)
Clarionema masonii
Colacodasya sinicola
Crouania attenuata
Cruoriella dubyi
Cryptonemia angustata
Cryptonemia taylorii
Champia parvula
Chondria clarionensis
Choreonema thuretii
Chroodactylon ornatum (*Asterocytis ramosa*)
Dasya sinicola v. *abyssicola*
Dasya stanfordiana
Dermonema virens (*Dermonema frapperi*)
Digenea simplex
Erythrocytis saccata
Erythrotrichia biseriata
Erythrotrichia carnea
Hydrolithon farinosum (*Fosliella farinosa*)
Galaxaura filamentosa
Galaxaura subfruticulosa
Gelidiella acerosa
Gelidiella adnata
Gelidiopsis tenuis
Gelidium okamurae
Gelidium pusillum
Gelidium sclerophyllum
Gracilaria crispata
Gracilaria tenuifolia
Gracilaria veleroe
Gracilaria gracilis (*Gracilaria verrucosa*), (*G. confervoides*)
Gracilariopsis rhodotricha
Grateloupia versicolor
Grateloupia versicolor v. *prostrata*
Griffithsia ovalis
Griffithsia pacifica
Gymnogongrus johnstonii
Gymnogongrus martinensis
Gymnogongrus sinicola
Gymnothamnion elegans
Halymenia actinophysa
Helminthocladia australis
Herposiphonia secunda (*Herposiphonia secunda* f. *tenella*), (*H. tenella*)
Hildenbrandia rubra
Pneophyllum conicum (*Hydrolithon conicum*)
Hydrolithon reinboldii
Hypnea cervicomis
Hypnea johnstonii
Hypnea musciformis v. *esperii* (*H. esperii*)
Hypnea pannosa
Hypnea spinella
Jania adhaerens
Jania mexicana
Jania tenella
Jantinella sinicola
Jantinella verruciformis
Kallymenia tenuifolia
Laurencia clarionensis
Laurencia decidua
Laurencia hancockii
Laurencia humilis
Laurencia pacifica
Laurencia papillosa v. *pacifica*
Laurencia richardsii
Osmundea sinicola (*Laurencia scrippsensis*)
Laurencia sinicola
Litholepis accola
Lithophyllum brachiatum
Spongites decipiens (*Lithophyllum decipiens*)
Lithophyllum divaricatum
Lithophyllum grumosum
Lithophyllum imitans
Lithophyllum lichenare
Lithophyllum margaritae (*Lithophyllum lithophylloides*)
Lithophyllum pustulatum (*Dermatolithon pustulatum* f. *ascripticum*), (*D. Lithoporella pacifica*
Lithothamnion australe
Lithothamnion indicum
Lithothamnion pacificum
Lithothamnion validum
Lomentaria baileyana
Lophosiphonia macra
Lophosiphonia mexicana
Melobesia marginata
Melobesia membranacea
Neogoniolithon trichotomum (*Lithophyllum trichotomum*)
Peyssonnelia calcea
Peyssonnelia clarionensis
Peyssonnelia rubra
Peyssonnelia rubra f. *orientalis*
Phyllophora clevelandi
Platythamnion pectinatum
Platythamnion pectinatum v. *laxum*
Plocamium cartilagineum (*P. coccineum* v. *pacificum*), (*P. pacificum*)
Polysiphonia beaudettei
Polysiphonia eastwoodae (*P. snyderae*)
Polysiphonia flaccidissima
Polysiphonia homioia
Polysiphonia scopulorum v. *villum*
Polysiphonia simplex
Polysiphonia sonorensis
Predaea masonii
Prionitis clarionensis (*Polyopes clarionensis*)
Pterocladia capillacea (*P. pyramidalis*)
Pterocladia musciformis
Pterosiphonia dendroidea
Sahlingia subintegra
Smithora naiadum (*Porphyra naiadum*)
Spongites fruticulosus (*Lithothamnion fruticulosum*)
Spyridia filamentosa
Stenogramme interrupta
Stylonema alsidii (*Goniotrichum alsidii*)
Wurdemannia miniata

PHAEOPHYTA

Aglaozonia canariensis	Macrocystis pyrifera
Colpomenia sinuosa	Neurocarpus delicatulus
Chnoospora minima (Chnoospora pacifica)	Padina concrescens
Dictyopteris delicatula	Padina crispata
Dictyota crenulata	Padina durvillaei
Dictyota dichotoma	Ralfsia californica
Dictyota divaricata	Ralfsia hancockii
Dictyota masonii	Ralfsia pacifica
Dictyota vivesii	Rosenvingea intricata
Ectocarpus acutus	Sargassum howellii
Masonophycus paradoxa	Sargassum liebmannii
Feldmannia indica (Giffordia duchassaingiana)	Sargassum palmeri
Feldmannia irregularis	Sphacelaria californica (S. hancockii)
Hincksia breviarticulata	Sphacelaria masonii
Hincksia mitchelliae	Sphacelaria mexicana
Lobophora variegata (Poccokiella variegata)	Sphacelaria rigidula (S. furcigera)