Figure 1. Aerial view Robinson Crusoe Island (from north to south). Photograph by Fabian Ramírez.

OCEANIC ISLANDS:

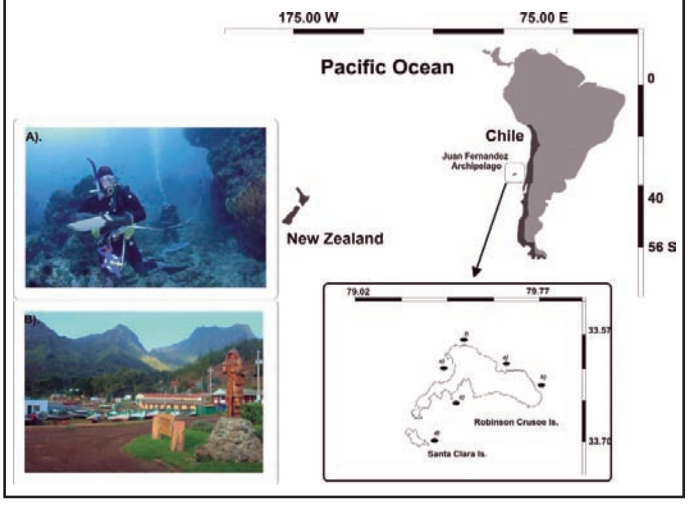
The Chilean Juan Fernández Archipelago. From Natural Observations to Management Challenges.

Early explorers to visit the Juan Fernández Archipelago in the 1700's found that lobsters were "in such abundance near the water's edge (of Isla Robinson Crusoe) that the boat-hooks often struck into them, in putting the boats to and from the shore" (Walter 1776) and were "found in such quantities that the fishermen have no other trouble to take them, than to strew a little meat upon the shore, and when they come to devour this bait, as they do in immense numbers, to turn them on their backs with a stick" (Molina 1808). We did not find such a plethora of the Islands' principal economic resource, the lobster.

We traveled to the Juan Fernández Archipelago in September 2007 to conduct research in subtidal habitats as part of our study for the Ph.D programme at the Victoria University of Wellington, funded by Education New Zealand Study abroad grant, and to undertake species collection for a global taxonomic review of ichthyofauna genres in collaboration with the fish research department at Te-Papa Museum New Zealand.

Oceanic Islands are those situated far from all continents and the Juan Fernández Archipelago fits perfectly into this category (Oliva & Castilla, 1987). Composed of three islands, the Juan Fernández Archipelago was discovered by the Portuguese sailor Joao Fernández in 1574. At that time, these Islands served as a source of provisions and a refuge for pirates. The Archipelago is the setting used by Daniel Defoe to write his best selling book named "Robinson Crusoe" inspired by the Scottish sailor, Alexander Selkirk who lived there for four years in solitude. Formerly named "más a tierra" (close from shore) and "más a fuera" (far from shore) now "Robinson Crusoe", "Santa Clara", along with "Alejandro Selkirk", coined for tourism, are located in the south Pacific (33° 37´S – 78° 51' W) 680 km off the port of San Antonio, Chile. These islands are of scientific interest for several different disciplines in biology and social sciences. These islands represent natural laboratories as they are an important source of speciation which taxonomically can be explained by the high degree of endemism for both terrestrial and marine groups (scientific studies, for example, have revealed 32, 67, 70, 15, 23, and 45 per cent of endemism for macroalgae, anthozoans, molluscs, decapods, crustaceans, echinoderms and reef fishes respectively Rozbaczylo & Castilla, 1987, Santelices, 1992; Pequeño & Lamilla, 2000). Biogeographic studies of Juan Fernández Archipelago have yielded a greater affinity with distant continents then

Figure 2. Map Showing Juan Fernández in respect to continental mainland Chile and New Zealand, the sampling sites (study sites a) Bahía Cumberland, b) El Frances, c) Los Chamelos, d) Punta Freddy, e) El Cernicalo, and f) Sal si puedes) are also represented. A) Depicting the sampling methods, and B) Bahía Cumberland and fisherman's boats. Photograph by Eduardo Sorensen and Alejandro Pérez-Matus.



neighboring South America, which has intrigued us as well as several other researchers (see Burridge et al., 2007). Formed by volcanic eruptions approximately 3.1 millions years ago, the Juan Fernández Archipelago resembles the Galapagos Islands with respect to the Equator coast.

As opposed to the terrestrial environment, which is facing several anthropogenic impacts through the introduction of invasive species, the marine realm, in particular the subtidal habitats of these Islands have been poorly studied. Moreover, few studies have described ecological interactions and their impacts that may drive species to co-exist in such isolated oceanic islands. However, important efforts have been made to determine geographical breaks, transitional areas, biogeographic patterns and most importantly, the fishery and biology of the Juan Fernández Lobster (*Jasus frontalis*) (reviewed by Arana, 2001). Taxonomic uniqueness and difficult access to these islands further limit insight into the ecology and biology of species that inhabit the islands. Our research trip represents a snapshot of the spatial distribution of marine subtidal species throughout Robinson Crusoe and Santa Clara Islands. These results and previous studies mayprovide the basis for models of future management and conservation strategies for subtidal habitats.

Major descriptions: Oceanographic and marine flora and fauna

One of the most prominent features of water circulation off continental Chile is the 300 to 400 Km of water mass called the Humboldt current, generated by the northward deflection of the West Wind Drift when it reaches the continent at approximately 45 º S. North of 40 º S and at 1000 km off the coast, two other water masses take over: the Subantarctic and the Subtropical currents. The latter warm mass (23-27 º C winter-summer temperature variation with salinities above the 34.5 0/00) flows southward over the northward cold water mass (10 to 18º C temperature variation with salinities of 32 to 34 0/00). This generates complex circulation and countercurrent regimes along the coastline, which are combined with strong southerly winds that generate a system of seasonally upwelled waters (Farina et al., 2005). In addition, oceanographic conditions off the northern coast of Chile are modified significantly during El Niño events (Camus, 1990; Thiel et al., 2007). Juan Fernández Archipelago, in turn, has surface temperatures above the 15º C with salinities of 34.3 0/00, and Subtropical water masses dominate over the Subantarctic ones in this region (Moraga & Argandoña, 2001).

As the Islands are characterized by steep slope, the rocky intertidal zone is considerably reduced (Figure 1). Therefore we concentrated our efforts in the sampling of the subtidal portions of the island by means of observational and photography-based data collection from several different sites throughout the archipelago. Our interest of study was principally related to community ecology describing abundance (biomass), size, density, and habitat type for key species of fish, shellfish, and algae from 2 to 35 m depth.

The subtidal habitat of the archipelago is characterized by rigid rock and volcanic boulder structures. Depending on the location of the site within the archipelago, topography is characterized by vertical walls, boulders or cobbles. Principally the “north-eastern” sites (Bahía Cumberland, El Frances, and Sal si Puedes; Figure 2 a, b, and c respectively) were highly eroded and were characterized by sand grains and small boulders. Big boulders, caves and vertical walls up to 40 m in depth principally characterize southern and more exposed sites (sites c and d, Figure 2).

Rocky reefs facilitate the settlement of some macroalgae and sessile invertebrate species. Different degrees of structural complexity found at the study sites form several microhabitats, which allow for differential organization of biotopes in small geographical areas. We found that benthic habitats are characterized by crustose algae that cover most of the deep portions of the volcanic rocks and bushy and erect brown macroalgae, predominantly the endemic *Padina fernandeziana*, *Dyctiota kunthii* and *Colpomenia sinuosa,* which form dense assemblages up to 20 m depth. Despite their abundance and dominance throughout the Chilean temperate coast, no kelp (Laminareales) was identified on the archipelago, possible due to the elevated seawater temperatures present in the island in respect to the continent. On the other hand, the introduced *Codium fragile* is abundant in almost all subtidal portions of protected bays we sighted. Another important component of the sea floor up to 35 meters depth is the cover of Vermetid gastropods throughout the archipelago; which can reach up 15 to 20 percent cover are characterize by mucus they generate for feeding.

All vertical walls of the islands are covered with colorful cnidarians and poriferans (Figure 3). Several zooanthids (*Parazoonthus juanfernandezi*) aggregate together and occur in vertical structures to trap their food. The sea cucumber (*Mertensiothuria platei*), a filter feeding macroinvertebrate is abundant at shallow depths and forms dense aggregations (4 individuals per m^2, approximately). Black corals (*Antipathes fernandezi*) are usually found deeper (Figure 4).

Figure 4. Black Coral. Photograph, Eduardo Sorensen.

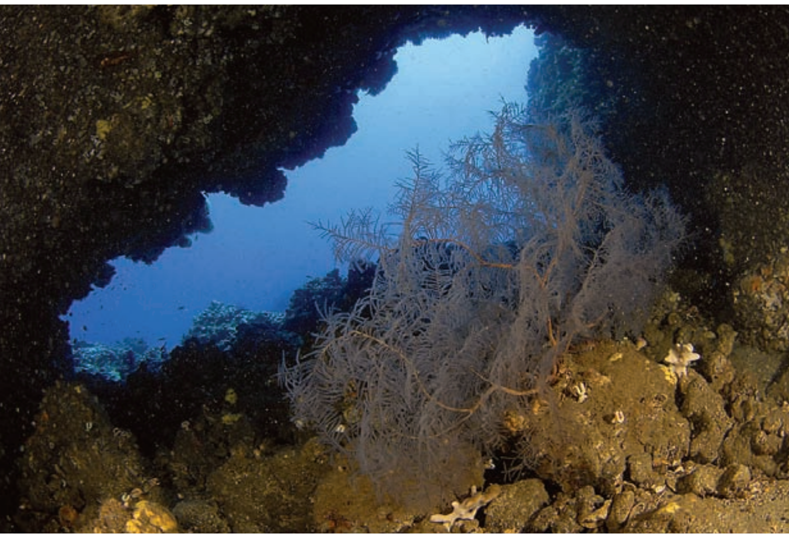


Figure 5. Sea urchin and Vermetid grastropods. Photograph, Eduardo Sorensen

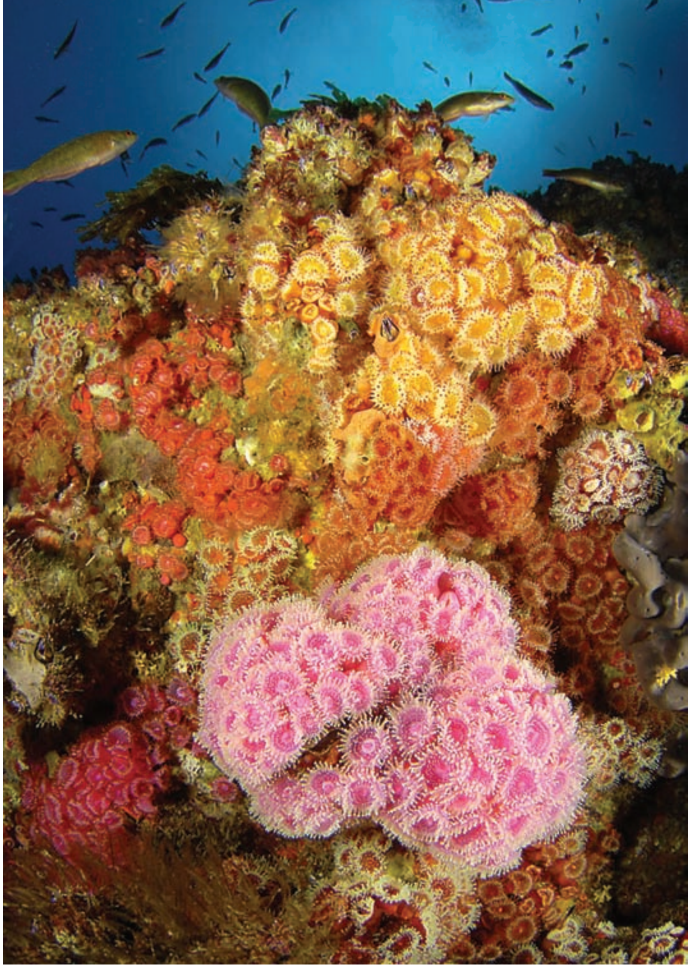


Figure 3. Diversity of cnidarians. Photograph by Eduardo Sorensen.

Mobile invertebrates are represented by the black sea urchin (*Centrostephanus rodgersii)*. High densities (around 5 individuals per m^2) of this echinoderm are predominantly found at sites protected from wave action. At these high densities urchins form "barrens", areas of substrate dominated by urchins and typically devoid of any macroalgae (Figure 5). We hypothesize that "urchin barrens", which alter environment and landscape, may generate profound impacts for a small island shelf as they may reduce potential habitat for the settlement of other benthic species such as lobsters.

Algae appear to change in abundance and coverage in the most exposed areas such as Santa Clara Island and Los Chamelos (sites c and d, Figure 2). Here the sea floor is steep with vertical walls and small seamounts fragmenting species composition. Shallow depths are typically characterized by turfing macroalgae such as the "ephemeral algae" *Enteromorpha intestinalis* and *Ulva* spp. Also present are: *Chaetomorpha* spp, and dense rhodophytes characterized principally by *Asparogopsis* sp., *Chantransia* spp, *Cryptonemia* sp., and *Ceramium rubrum*. Our observations at these sites represent similarities to the habitat characteristics found at some central to southern continental Chilean sites (personal observation, Pérez-Matus). At these exposed sites "loco" (*Concholepas concholepas*), the most important benthic resource of continental Chile, thrives with abundances of 3 to 4 individual per m^2, however there is no harvest permitted on the archipelago. The lobster (*Jasus frontalis)* was larger and more abundant in some patches and densely distributed at some sites characterized by caves and crevices such as in Chamelos and Punta Freddy (sites c and d, Figure 2). The starfish (*Astrotole platei*) is conspicuous and occurred in all study sites at low abundances.

Similarly, as percent cover of sessile flora and fauna vary among sites, the distribution of fish fauna represents a mosaic in terms of assembly formation and size distribution. Depth seems to be the only major factor that clearly stratifies the vertical distribution of fishes, an observation that is intrinsic to other populations and fish communities. We identified more than 25 species of fish; the most abundant are represented by wrasses (*Malapterus reticulatus* and *Pseudolabrus gayi*), which are spread throughout the study sites at shallow depths forming dense schools. Pelagic fishes as "pampanito" (*Scorpis chilensis*) and mackerels such as the transpacific *Trachurus murphyi* and *Pseudocaranx chilensis* are highly abundant in the southern study sites such as El Frances, where dense schools were observed (Figure 6). Other pelagic such as the kingfish (*Seriola lalandi*) and *Mola mola* cruise around the islands and were found at most survey sites. Benthic-pelagic fishes such as the serranid *Caprodon longimanus* were abundant at intermediate depth (10 to 20 m), forming aggregations of 25 to 30 individuals (Figure 7) particularly in protected bays such as El Cernicalo (site e, Figure 2). The benthic-territorial blenny *Scarthichthys variolatus* and the colorful "cabrilla de Juan Fernandez" *Hypoplectrus semicinctum* (endemic) were also conspicuous, occupying almost all of the cave structures at shallow depths (2 – 15 m). Gobies, roughies, and moray eels occupy almost all of lobsters' refuges. Herbivorous girellids (*Girella albostriata*) were usually found in schools of 20 individuals (unusual for temperate herbivores) and graze over vast macroalgal gardens primarily at southern sites.

Mammals are also represented on the islands. Nearly driven to extinction in the 60's by fur-trade companies; the endemic sea lion (*Archtocephalus phillipi*) is now recovering. Recent censuses performed on the archipelago estimate an approximate population of 300 000 individuals and from March to November these pinnipeds migrate to search for food. Whales are also sighted during spring and summer.

The data compiled in this study combined with historical fisheries catch data will create a database describing historical resource use and current biological community structure. Interviews with fishermen, community members, and ecologists provide local knowledge of community structure changes through time. This data is employed to model ecological relationships describing trophic interactions and the flow of energy and biomass through a biological community using STELLA and Ecopath software. These models are being used to test a series of scenarios of differing management schemes altering larval dispersal rates, fish immigration and emigration rates, fishery catch estimates, and marine reserve protection. This allows for simulation of differing protection measures, seasonal closures, minimum capture size, and extraction levels to determine effective management and conservation of species.

Management & Conservation: Applications for a Monospecific Fishery

The current lobster management plan used at the Juan Fernández Archipelago employs a seasonal closure (arbitrarily chosen) from May 15th until September 30th, a minimum cephalothorax harvest size of 11.5cm, and no capture of egg-carrying females. This minimum size limitation promotes the harvest of larger lobsters, thereby selecting for a smaller average size in the population. However, illegal harvest of undersized lobsters has been documented for consumption by fisherman and as bait for traps (Arana, 1987). The lobster fishery is considered to be mono-specific, however in the process several other species are targeted resulting in the harvest of nearly 300 pounds (136 kg) of fish a day for both bait and supply to the fresh

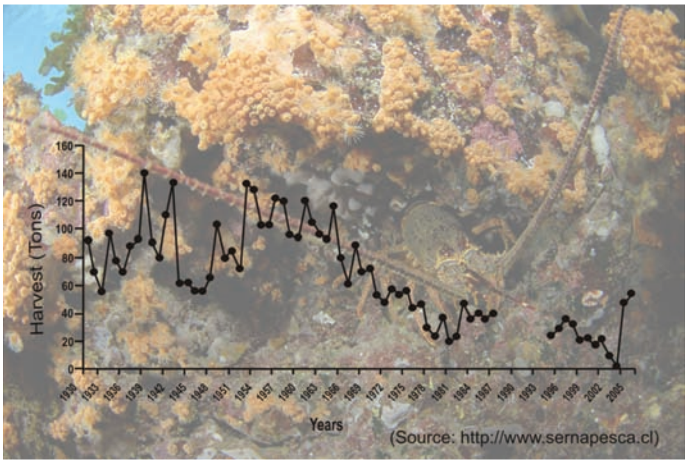


Figure 8. Total annual harvests of the Juan Fernandez's spiny lobster (*Jasus frontalis*). Including all the islands of the archipelago. Photograph by Eduardo Sorensen.

market (according to fishing community association of Juan Fernandez). The current lobster fishing effort is concentrated in the farthest areas of the archipelago in relation to the population centre and main port, Bahía Cumberland (site a, Figure 2). It is evident from harvest data (Figure 8) and anecdotal evidence from fishermen that despite current management regulations the lobster population has been severely depleted in most areas of the archipelago compared to pre-human inhabitation. For these reasons we presented information to the fishermen and community members of the Juan Fernández Archipelago about marine reserves (MRs) and marine protected areas (MPAs) and their potential benefits for the local lobster fishery and for species that are rare or face local extinction.

This presentation addressed the similarities of fish diversity between New Zealand and the Juan Fernández Archipelago irrespective of the long geographic distance that separate them. The dynamics of trophic interactions: how changing the abundance of one species may have dramatic effects on the abundances of other species with reference to the "loco"-mussels dynamic demonstrated at Las Cruces Marine Reserve in Chile (Castilla, 1999) were outlined. Benefits that MRs have demonstrated in many New Zealand locations for a closely related lobster species, *Jasus edwardsii* with regard to increased size and abundance inside MRs were presented. The conservation benefits of MRs for the selected and highly harvested lobster species are important as larger lobsters are targeted by the fishery. MRs as a potential source for larval export and emigrating juveniles and adults may also supplement adjacent populations, a process driven by density–dependence, commonly called the "spill-over" effect. Social and economic benefits of a MR for the archipelago could be dramatic, as the island currently is marketed as a dive destination and attracts tourism for its terrestrial national park. A marine reserve could provide an area of aquatic conservation that would attract naturalists, divers, conservationists and scientits helping to foster stewardship among the local community.

In reviewing studies performed on the archipelago we suspect that the Juan Fernández Islands are a fragile ecosystem with extinction and speciation rates occurring over short temporal scales. A highly complex process may take place in such small islands. We hypothesize that the Juan Fernández Archipelago represents a mosaic of biotas depicted by open (relying on recruits from other populations) for endemic species and closed populations (self-recruiting) acting as sources from adjacent areas (even the farthest ones). Without understanding the complete dynamics of community structure and how populations are connected in such a small isolated area, management strategies are uncertain up to date however important for a sustainable fishery to persist.

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Figure 6. Abundance of Pelagic fish species.
Photograph by Alejandro Pérez-Matus.

Figure 7. School of cabrilla (*Caprodon longimanus*).
Photograph by Alejandro Pérez-Matus.