INVENTORY, MONITORING AND IMPACT ASSESSMENT OF MARINE BIODIVERSITY IN THE SERI INDIAN TERRITORY, GULF OF CALIFORNIA, MEXICO

by

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A Jaqueline García Hernández

"*The Seri are gregarious, outgoing and aggressive, and have a sharp sense of humor…*"[1]

"*This vast expanse extends from Tiburón Island across the Canal de Infiernillo (Channel of little Hell) that separates from the mainland, and on northward up the coastline. Astronomical terms would be necessary to describe the abundance and numbers of living creatures that inhabit these waters*"[2]

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[1]R. S. Felger and M. B. Moser. 1985. People of the Desert and Sea. Ethnobotany of the Seri Indians. The University of Arizona Press, Tucson, AZ.

[2] Ray Cannon. January 27, 1956. Isla Tiburón billfish to the horizon. In G. S. Kira. 1999. The Unforgettable Sea of Cortez. Baja California´s Golden Age 1947-1977. The Life and Writings of Ray Cannon. Cortez Publications. Torrance, CA.

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ABSTRACT

The conservation of marine ecosystems is at least 20 years behind terrestrial and freshwater ecosystems due to the difficulties in studying and monitoring these dynamic and complex environments. Furthermore, marine environment receive less attention because human impacts are less visible in the sea, and oceans are viewed as global commons.

The purpose of the present dissertation is to contribute to the knowledge of marine conservation through the development of three components in natural resources management: inventory, monitoring, and assessment of impacts. I elaborate a multi-taxa inventory, identify key species to monitor, characterize one of the key species, and assess the impacts of the most important fishery in the community-based controlled marine area of the Seri Indians along the Sonoran desert coast of México.

A total 657 species of mollusks, echinoderms, sharks, rays, bony fish, sea turtles, sea snake, aquatic birds and marine mammals were recorded in the Seri territory through review of 30 scientific collections housed in museums and universities, literature, and field collections. The fish information was improved through the analysis of 151 traditional Seri names. Fifty species were identified for monitoring ecosystem health. They represent species with a legal status, rare, commercially important, taxa that dominate or characterize entire communities, common taxa, and species recognized in the Seri culture. The annual eelgrass (*Zostera marina atam*) was selected as a key species inside the Canal de Infiernillo in the Seri territory. Coverage of the eelgrass beds was estimated using aerial photographs, field mapping, and Seri traditional ecological

knowledge. The total extent of the eelgrass beds was approximately 6687 ha, which regrew in the same areas during the three-year study, maintaining the same general shapes and sizes. Twenty-six percent of the eelgrass beds overlap with the swimming crab (*Callinectes bellicosus*) fishing zones. Major impact on this fishery are caused by “ghost” fishing traps, which continue to capture crabs and animals and modify the substrate as they are moved around by currents and accumulate on the sea bottom. Efforts to standardize the use of traps will reduce these impacts on this fishery in the long term.

INTRODUCTION

Terrestrial, freshwater, and marine ecosystems have the same conservation problems: over-exploitation, habitat destruction and fragmentation, invasions of exotic species, pollution, and global climate change. However, the conservation of marine and coastal ecosystems is at least 20 years behind terrestrial conservation (Norse, 1993; Murphy and Duffus, 1996). This situation is mainly due to difficulties in studying and monitoring the dynamic and complex marine ecosystems (Ray and Grassle, 1991; Norse, 1993; Thorne-Miller, 1999). There is also a relaxed attitude toward marine conservation because human impacts are less visible in the sea (Vermeij, 1989; Thorne-Miller, 1999). In addition, marine conservationists tend not to take advantage of important sources of information, such as historical marine data—approximately 99% of this information has not been analyzed (Carlton, 1998)— and traditional or local ecological knowledge of coastal communities (Norse, 1993; Ruddle, 1994), in order to resolve management problems.

The purpose of my dissertation is to contribute to the knowledge of marine conservation through the development of three related components in natural resources management: inventory, monitoring, and assessment of impacts (IMA) (Nudds, 1999). In developing these components, I worked under the premises that conservation is a “crisis discipline” (Soulé, 1985) and an applied science. Therefore, the available information, resources, and traditional ecological knowledge and the people’s conservation concerns, were the main elements used to elaborate a multi-taxa inventory, identify key species to monitor, characterize one of the identified key species, and assess the impacts of the most important fishery in a defined and community-based controlled marine area. The purpose of this process is to obtain the necessary information to set baselines for monitoring programs and to recommend management guidelines.

The study was carried out in the marine territory of the Seri (or Comcáac) Indians, in the north-central portion of the Gulf of California, México. The Seri territory includes Isla Tiburón (1208 km^2, the largest island in México), a strip of coastal land, and the fishing rights around the island (Diario Oficial de la Federación, 1970, 1975; Bourillón-Moreno, 2002). The Mexican National Commission for the Knowledge and Use of Biodiversity (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, CONABIO) has listed this area as a terrestrial and marine priority region in México due to its high biodiversity (Arriaga-Cabrera et al., 1998, 2000). It is also listed in the Important Areas for Bird Conservation (Áreas de Importancia para la Conservación de las Aves, AICAS) due to the presence of threatened species such as the red-billed tropicbird (*Phaeton aethereus*), the blue-footed booby (*Sula nebouxii*), and the Craveri´s murrelet (*Synthliboramphus craveri*) (Arizmendi and Márquez, 1999).

Currently, there are a total of 670 Seri Indians (INEGI, 2000) living in two small fishing towns, Punta Chueca along side of Canal de Infiernillo and El Desemboque de los Seris located near the northern boundary of the territory. The Seri and their apparent ancestors have inhabited this region for the last 2000 years (Bowen, 1976); hence their knowledge of the local environment around them is profound (Malkin, 1962; Felger and Moser, 1985; Nabhan, 2000; Basurto-Guillermo, 2001; Bourillón-Moreno, 2002). Currently, the Seri way of life is not very different from the past, and they still depend on gathering desert plants, collecting shellfish, and fishing. In addition, they produce handicrafts for tourists, and recently they have been obtaining income from the sale of hunting permits (Medellín, 1998). The Seri territory has relatively well defined boundaries, legal ownership, and good access control [i.e. Canal de Infiernillo, see Basurto-Guillermo (2001) and Bourillón-Moreno, (2002)]. The long association with surrounding marine and desert biodiversity are key characteristics that facilitated the design of an inventory, monitoring, and assessment program in their territory. Another important element that contributed to the development of these three management components was the participation of the Seri community itself.

Inventory

The baseline component for sustainable management of natural resources is a biological inventory (Probst and Crow, 1991; O'Connell and Noss, 1992). However, the development of an inventory takes a considerable amount of time and resources as well as commitment from the users, owners, and government managers (Dallmeier, 1996; Dennis and Ruggiero 1996). In addition, marine areas have the problem of a reduced number of specialists (e.g. systematic biologists, managers), a low level of concern among the public, and many unique logistical difficulties (Norse, 1993; Haszprunar, 1998; Thorne-Miller 1999). Marine ecosystem management is usually focused on large regions (>200,000 km^2) (Sherman 1991), even though in practice, large-scale management strategies are difficult to apply due to lack of knowledge and weak international cooperation among other reasons. In addition, the sea is looked upon as a global commons (Norse, 1993).

All these factors contribute to the difficulty of developing marine inventory programs in small areas, with relatively low ecological impacts, and with small coastal communities depending on the natural resources. The Seri have a *de facto* co-management agreement with the Mexican Government (Basurto-Guillermo, 2001; Bourillón-Moreno, 2002). An inventory program is a strong tool for their natural resource management programs by giving the Seri community a greater amount of information that can be used when confronting federal or state government management authorities.

In the present study, I set the baseline information for an inventory by summarizing the available research collections in museums and universities, and literature records for seven major taxa (seagrasses, mollusks, echinoderms, fishes, marine reptiles, aquatic, and marine mammals). The collections-based inventory was enhanced with a series of field collections and observations from 1998 to 2000. The field inventory concentrated on seagrasses, fishes, and aquatic birds. In addition, I focused on the traditional ecological knowledge that Seri have of the fish fauna in their territory. This knowledge complemented the scientific knowledge and was included in the inventory. The final inventory provided the general patterns of taxonomic distribution and abundance, identified information gaps, and suggested key species to monitor. The key species were selected for the inventory on the basis of the following criteria: 1) species with a legal status, 2) endemic, rare, and alien species, 3) commercially important species, 4) taxa that dominate or characterize entire communities, 5) common taxa, and 6) species recognized by the public (Davis and Halvorson 1988).

Monitoring

Marine ecosystem monitoring is a difficult task due to the complexity of seas (Norse, 1993; Thorne-Miller, 1999). For example, the majority of marine species have different life stages (egg, larva, juvenile, adult) occupying different environments. Thus, a recommended approach is to use a taxon that provides much of the ecosystem's physical structure in order to monitor ecosystem health (Norse, 1993). It is assumed that if this taxon is disturbed or destroyed the diversity of the ecosystem will be diminished. Seagrasses are one of these taxa because they are recognized as the basis of one of the most productive marine ecosystems; they have significant ecological roles, and support complex communities and food webs (Short and Wyllie-Echeverria, 1996). In Canal de Infiernillo, annual eelgrass *Zostera marina atam* serves many critical ecological functions during nine months of the year. Hence it was the selected taxon to be characterized for the future monitoring program of the Canal.

The first step for monitoring eelgrass in Canal de Infiernillo was the mapping and characterization of the eelgrass beds. For the eelgrass distribution I used differential GPS (Global Positioning System) (error < 5 m), aerial photography and video, and traditional ecological knowledge. Seri can identify the different eelgrass areas inside the channel, including general characteristics such as eelgrass length. In addition, I used patch pattern, shoot density, depth, and distance from the coast for the eelgrass bed characterization. Eelgrass cover, shoot density, and biomass were used to estimate eelgrass total carbon production during full growth months (March and April).

Assessment of impacts

As part of the monitoring process, it is important to identify the human impacts on key taxa being monitored and on biodiversity (UNEP, 1995). Fisheries exploitation over the world has caused considerable impacts to target species and to the environments on which they depend. For example, Watling and Norse (1998) have estimated that trawling fisheries cover 150 times the land area that is clearcut every year, producing substantial damages to marine biodiversity. Besides overexploitation and habitat alteration, fishing activities cause damage by lost gear, which continues to catch fish while unattended (Norse, 1993; Thorne-Miller, 1999). In the Gulf of California, fisheries using shrimp trawlers, gillnets, long-liners, and spears are considered to be the most harmful to biodiversity (Knudson 1995, 1999; Brusca et al., in press). The swimming crab fishery, a fishery less than 15 years old, is beginning to impact the coastal environments. Therefore, the final section of the dissertation is an assessment of the possible impacts of the swimming crab (locally named "jaiba") (*Callinectes bellicosus*) fishery, which has been the main fishery in the Canal de Infiernillo since 1996. This last part of the research developed out of the Seri concern about physical damage to the eelgrass beds by the swimming crab trap, by-catch and ghost traps.

Explanation of the dissertation

The dissertation research deals with three baseline aspects of natural resources management in marine and coastal environments: inventory, monitoring, and impact assessment. The use of traditional ecological knowledge was incorporated into each of these aspects.

In Appendix A, I present the results of the marine species diversity inventory in the Seri territory (Gulf of California) and list of potential key species to monitor. The Seri traditional ecological knowledge was used to improve the inventory and to identify key species to monitor ecosystem health in a portion of their territory, Canal de Infiernillo. Appendix B is a detailed review of Seri traditional ecological knowledge used in the inventory; here I focus on the fish fauna. Appendix C is the characterization of eelgrass (*Zostera marina*) beds in the Canal de Infiernillo as a marine taxon selected for monitoring. In this paper, I also use the local knowledge to identify eelgrass areas in Canal de Infiernillo. In Appendix D, I assess the impacts of the main fishery in the Canal de Infiernillo, swimming crab (*Callinectes bellicosus*), on the eelgrass beds and the fish fauna. The focus on crab trap impacts resulted for concerns expressed by Seri fishermen. Each appendix has been formatted in the format style of the journal that it will be submitted.

Appendix A is the paper entitled "*Marine inventory and selection of monitoring species in the Seri Indian Territory, Gulf of California, México*" by Jorge Torre-Cosío, Luis Bourillón-Moreno, and Xavier Basurto-Guillermo. The role of the dissertation author in this paper was writing research and funding proposals, planning, coordinating and participating in the fieldwork, data collection in museums and universities, data analyses, and writing the final paper. Co-authors participated in writing funding proposals (L-BM), in fieldwork, discussing ideas, and revising manuscript drafts. Partial results of this appendix were presented as an oral presentation entitled "Biodiversity inventory for the co-management of the Seri Indian marine territory, Gulf of California" in the Fourth Conference on Research and Resource Management in the Southwestern Deserts. Meeting Resource Management Information Needs. May 15-17, 2002, Tucson, Arizona. An extended abstract will be published in the conference proceedings. The paper will be submitted to *Aquatic Conservation: Marine and Freshwater Ecosystems.*

Appendix B is the paper entitled "*Ethnoichthyology of the Seri Indians in the Gulf of California, México*" by Jorge Torre-Cosío and Lloyd T. Findley. The role of the dissertation author in this paper was collecting the traditional ecological knowledge of the fish fauna from the Seri community and the linguists S. Marlett and M. B. Moser (Summer Institute of Linguistics, SIL) through interviews, analyzing the data, and writing the final paper. Co-author provided information collected in the 1970s, discussing ideas, and revising a manuscript draft. An oral presentation of the partial results of this appendix were presented under the title "Seri ethnoichthyology: 2000 years of fish knowledge in the Gulf of California" in the 80th Annual Meeting of the American Society of Ichthyologists and Herpetologists hosted by Universidad Autónoma de Baja California Sur (UABCS). June 14-20, 2000, La Paz, Baja California Sur, México. The abstract was published in the meeting program. The paper will be submitted to the *Journal of Ethnobiology*.

Appendix C is the paper entitled "*Extent, stability, and distributional patterns of the annual eelgrass Zostera marina atam in the Canal de Infiernillo, Gulf of California, México*" by Jorge Torre-Cosío, Luis Bourillón-Moreno, Alf Meling-López, and Pedro Ramírez-Gracía. The role of the dissertation author in this paper was writing research and funding proposals, planning, coordinating and participating in fieldwork, analyzing the data and writing the final paper. Co-authors participated in writing funding proposals (LB-M), in some of the surveys (LB-M and PR-G), providing Seri traditional ecological knowledge of the eelgrass coverage (LB-M) and eelgrass phenology data (AM-L). They discussed ideas and revised manuscript drafts. Some of these results were presented in an oral presentation entitled "Distributional patterns of an annual eelgrass, *Zostera marina*, population in the Gulf of California" in the 5th International Seagrass Biology Workshop hosted by Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Baja California, México. October 7-11, 2002. The paper will be submitted to *Aquatic Botany*.

Appendix D is the paper entitled "*Impacts of the swimming crab (Callinectes bellicosus) fishery in the Canal de Infiernillo, Gulf of California, México*" by Jorge Torre-Cosío and Luis Bourillón-Moreno. The role of the dissertation author in this paper was writing research and funding proposals, planning, coordinating and participating in fieldwork, analyzing the data and writing the final paper. Co-author participated in the data collection, discussing ideas, and reviewing manuscript drafts. The paper will be submitted to *Fishery Bulletin*.

PRESENT STUDY

The methods, results, and conclusions of this study are presented in the papers appended to this dissertation. The following is a summary of the most important findings in these papers.

Appendix A. *Marine inventory and selection of monitoring species in the Seri Indian Territory, Gulf of California, México*. The Seri Indians have inhabited the Sonoran desert coast for the last 2000 years. Currently, they occupy a territory granted by the Mexican Government with a *de-facto* co-management arrangement. The development of a coastal and marine biodiversity inventory will provide to the Seri community a greater amount of information when the governmental management authorities confront them. However, inventories take a considerable amount of time and resources. An inventory of the marine Seri territory was developed using the available information in 30 collections in museums and universities, published and gray literature, collections in the field and from the fisheries of seven major taxa. In addition, the profound Seri traditional knowledge of the fish fauna was incorporated in the inventory. A total of 657 species were recorded, 210 mollusks, 62 echinoderms, 36 sharks and rays, 229 bony fish, 5 sea turtles, a sea snake, 106 aquatic birds, and 8 marine mammals. The final inventory provided the general patterns of taxonomic distribution and abundance and identified information gaps. We identified 50 species that should be monitored to assess changes in ecosystem health in this marine system. These species were selected based on their legal status, rareness, commercial importance, commonness, dominance or characterization of entire communities, and recognized in the Seri culture. The use of collection records and traditional ecological knowledge is recommended in setting baseline data in biologically important marine areas.

Appendix B. *Ethnoichthyology of the Seri Indians in the Gulf of California, México*. Subsistence of the Seri was traditionally and continues to be based mainly on fishing and shellfish gathering. Therefore, their knowledge of marine and coastal environments is profound. Formal and informal interviews were applied to obtain ichthyological information from 13 experienced Seri fishermen. We analyzed traditional fish nomenclature, gathering biological and ecological information for 113 ethnospecies related to 151 traditional names. The Seri identify 94 fishes at the level of species or genus in 68 families. They use conspicuous morphological, ecological, and behavioral characteristics to identify fish. Knowledge is more detailed for commercially important species, especially sharks, rays, grunts (family Haemulidae), snappers (Lutjanidae), mullets (Mugilidae), corvinas (Scianidae), and sea basses (Serranidae). The analyses showed that information about large species such as the totoaba (*Totoaba macdonaldi*), the goliath grouper (*Epinephelus itajara*), and the Gulf grouper (*Mycteroperca jordani*), which were important sources of food in the past, are disappearing because these species have been overfished. The Seri traditional ecological knowledge provides important insights into the Gulf´s fish fauna.

Appendix C. *Extent, stability, and distributional patterns of the annual eelgrass Zostera marina atam in the Canal de Infiernillo, Gulf of California, México.* We estimated and described the extent, stability, and distributional patterns of the annual eelgrass *Zostera marina atam* in Canal de Infiernillo, Gulf of California. These are the most extensive annual eelgrass beds in the Eastern Pacific, presenting distinctive biological characteristics (i.e. high seed production and germination, germination is triggered by changes in temperature). Total coverage of the eelgrass beds in the Canal was estimated using oblique and vertical aerial color photography and video from a blimp and a Cessna aircraft, from 1999 through 2001. Differential GPS (error < 5 m) was used to map eelgrass bed contours from an outboard motor boat, and inspection of beds was done from the boat or by diving in 1999 and 2000. Information on depth and eelgrass characteristics (e.g. continuous, patchy, short, tall) was collected to characterize the beds. In addition, traditional ecological knowledge of the Seri Indians was used to locate them. The total extent of the eelgrass beds inside the Canal was approximately 6687 ha. Eelgrass beds regrew in the same areas during the three-year study, maintaining the same shapes and sizes. Twelve percent (3642 ha) of the Canal's seabed surface area is covered by continuous eelgrass and 10% (3045 ha) by patchy eelgrass. Four general types of continuous eelgrass beds were observed in terms of their location, area, depth, and shoot density and length: (1) small (average 36 ha) isolated beds near estuary mouths with medium length (40-100 cm), (2) small (30 ha) beds along Isla Tiburón with medium shoot density (2516 m^{-2}) and length (40-100 cm), (3) medium (64 ha) beds occurring in the central portion of the Canal with the lowest shoot density (502 m^{-2}) and the largest shoot length (80-150 cm), and (4) large beds (221 ha) inside shallow and protected bays presenting the highest shoot density (3444 m^{-2}) and the shortest shoot length (16-29 cm). The large extent of eelgrass in the Canal is due to its large shallow area with particular current patterns and long eelgrass season in comparison to other areas in the Gulf of

California. Stability and distributional patterns of the beds appears to be due to the accumulation of large seed banks in specific areas of the Canal. Interaction of whirlpool currents, sand structures (bars, waves, and points), protected bays, and shallow waters keep the seeds in the same areas. The mapping of the eelgrass beds in this area is the first step towards long-term monitoring in the Seri territory.

Appendix D. *Impacts of the swimming crab (Callinectes bellicosus) fishery in the Canal de Infiernillo, Gulf of California, México*. This is the first study that describes and evaluates ecological impacts of the swimming crab (*Callinectes bellicosus*) fishery in the Gulf of California. The study area was Canal de Infiernillo that is part of the exclusive fishing zone of the Seri Indians. Data from 1998 through 2001 were used to assess the impacts of the fishery. First, we determined the area of overlap between the crab fishing zones and the annual eelgrass (*Zostera marina*) beds to estimate the mechanical disturbance of the fishing gear. We produced maps of the crab fishing zones and eelgrass beds using a differential GPS, aerial photographs and video, as well as information obtained by interviewing Seri fishermen. The eelgrass beds and the fishing crab zones cover 6687 ha and 5443 ha, respectively. Twenty-six percent of the eelgrass beds overlap with the trap zones. Next, we evaluated the effects of the fishing activities to obtain bait and the bycatch on invertebrates, sub-legal size swimming crabs, and fish by participating in commercial fishing trips. Crab buyers often provide bait for crab fishermen but on occasion fishermen catch their own, usually using hook and line as the most selective method. However, fishermen also use gillnets to fish faster, capturing and using 34 species as bait, some of them juveniles. Bycatch species are restricted to six invertebrate and six fish species. Finally, we described ghost (or lost) traps deteriorating conditions and their impacts on marine fauna through censuses during off-fishing season in the summer to estimate the number of ghost traps and examine their contents. Major impacts of the ghost traps are continuous fishing effects and modification of the substrate as they are moved around by currents and accumulate on the sea bottom. Efforts to regulate and standardize the use of crab traps will reduce the impacts of these traps on crab fishery in the long term.

Appendix E. This appendix is the inventory of the Seri territory and the adjacent area of Bahía Kino including species of mollusks, echinoderms, shark, rays and bony fish, marine reptiles, shore and sea birds, and marine mammals.

APPENDIX A

Marine inventory and selection of monitoring species in the Seri Indian Territory, Gulf of California, México

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ABSTRACT

The Seri Indians have inhabited the Sonoran desert coast for the last 2000 years. Currently, they occupy a territory granted by the Mexican Government with a *de-facto* co-management arrangement. The development of a coastal and marine biodiversity inventory will provide to the Seri community a greater amount of information when the governmental management authorities confront them. However, inventories take a considerable amount of time and resources. An inventory of the marine Seri territory was developed using the available information in 30 collections in museums and universities, published and gray literature, collections in the field and from the fisheries of seven major taxa. In addition, the profound Seri traditional ecological knowledge of the fish fauna was incorporated in the inventory. A total of 657 species were recorded, 210 mollusks, 62 echinoderms, 36 sharks and rays, 229 bony fish, 5 sea turtles, a sea snake, 106 aquatic birds, and 8 marine mammals. The final inventory provided the general patterns of taxonomic distribution and abundance and identified information gaps. We identified 50 species that should be monitored to assess changes in ecosystem health in a section of the marine Seri territory, Canal de Infiernillo. These species were selected based on their legal status, rareness, commercial importance, commonness, dominance or characterization of entire communities, and recognized in the Seri culture. The use of collection records and traditional ecological knowledge is recommended in setting baseline data in biologically important marine areas.
Keywords: collections, inventory, marine conservation, monitoring, key species, museums, Seri, traditional ecological knowledge

INTRODUCTION

Inventories and long term monitoring programs are two essential elements for the conservation and management of biodiversity (Noss, 1990; Probst and Crow 1991; Norse, 1993; Nielsen and West, 1994; UNEP, 1995). According to the UNEP (1995), inventories consist of surveying, sorting, cataloging, quantifying, and mapping any of the biotic and abiotic components of the biodiversity in a determined spatial scale. To develop a biodiversity inventory, extensive bibliographic research is conducted and it is complemented with the revision of the available information in maps, data bases, and collections in museums and universities (UNEP,1995; Dallmeier, 1996). In some cases when the available information is not sufficient, a rapid assessment of biodiversity is accomplished. The information compiled in the inventory provides baseline data of abundance and distribution about the biodiversity components on which it is focused (Probst and Crow, 1991; Pearson, 1995; Dennis and Ruggiero, 1996). The design of a monitoring program is based on the inventory, and the goal of the program is to develop a strategic framework to follow key variables (i.e. key species and abiotic factors) over time and make predictions to improve management decisions, increase management options, and assess changes in the monitored systems (UNEP, 1995).

Research on biodiversity inventories and monitoring programs has been more centered on terrestrial ecosystems than on marine (Norse, 1993). In addition to the difficulties entailed in any inventory and monitoring program, such as amount of available information, personnel capabilities, time, funds, and commitment (Dennis and Ruggiero, 1996); marine inventory programs have their unique complications. First, there is less concern for marine conservation among the publics and managers than for terrestrial conservation (Murphy and Duffus, 1996; Haszprunar, 1998). In general, marine areas present greater logistic constraints to sampling (e.g. three-dimensional environments) than terrestrial areas. There are also fewer specialists (Norse, 1993; Haszprunar, 1998; Thorne-Miller, 1999), even though there are more phyla in marine (28) ecosystems than in terrestrials (11) (Angel, 1996). Furthermore, the management of marine areas is mainly focused on large regions (>200,000 km^2) (Sherman, 1991), and the sea is viewed as a global commons (Norse, 1993).

Few biodiversity marine inventories and monitoring programs have been developed in established protected areas [(e.g. Channel Islands National Park, California (Davis *et al*., 1994)]. However, there are important marine areas under community-based managements, where the implementation of inventory and monitoring programs are needed. Such programs would provide them with tools to improve their management and give them potential for greater autonomy when confronted with governmental management authorities. The local knowledge that these communities have can be incorporated in management programs and translated into a Western scientific format. Another important source of information that is often ignored are the records from natural history collections in museums and universities (Nielsen and West, 1994; UNEP 1995; Mehrhoff, 1997; Boarman and Coe, 2000).

The Gulf of California is considered one of the most biodiverse and productive seas in the world, with at least 5966 species (Brusca *et al*., in press). This richness is due in part to the high diversity of environments: rocky, sand and mud shores and sea bottoms, wetlands (mangroves, seagrasses, and halophytes fields), and coral and rocky reefs (Thomson *et al*., 1979; Brusca, 1980; Brusca *et al.,* in press). A region in the Gulf that has a rich diversity of marine and coastal environments is the Seri (or Comcáac) territory in the Midriff islands region. The Seri are an indigenous group (670 people) living in two fishing towns, Punta Chueca and El Desemboque de los Seris (INEGI, 2000). The Mexican Government granted to the Seri a strip of coastal land, Isla Tiburón, and the exclusive fishing rights to the waters adjacent to the island to secure their survival (Diario Oficial de la Federación 1970, 1975). However, Mexican agencies still oversee fisheries practices. Therefore, the Seri have a *de-facto* co-management with the Mexican authorities (Basurto-Guillermo, 2001; Bourillón-Moreno, 2002). This ethnic group is characterized by their profound biological and ecological knowledge of their surrounding environment (Malkin, 1962; Felger and Moser, 1985; Nabhan, 2000; Basurto-Guillermo, 2001; Bourillón-Moreno, 2002; Torre-Cosío and Findley[3]). In addition, due to its high biodiversity the Seri region is listed in the Priority Terrestrial and Marine Regions of Mexico (Regiones Terrestres y Marinas Prioritarias de México, area numbers 17 and 15) by the Mexican National Commission for the Knowledge and Use of Biodiversity (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, CONABIO) (Arriaga-Cabrera *et al*., 1998, 2000). It is also listed in the Important Areas for Bird Conservation (Áreas de Importancia para la Conservación de las Aves, AICAS, area number 216) due to the presence of threatened species such as the red-billed tropicbird (*Phaeton aethereus*), the blue-footed booby (*Sula nebouxii*), and the Craveri´s murrelet

[3] See Appendix B of the dissertation for more details of the methods and results about Seri traditional ecological knowledge of the fish in their territory.

(*Synthliboramphus craveri*) (Arizmendi and Márquez, 1999). In the present study we developed a marine species inventory of the Seri territory with emphasis on the use of records in collections, literature, and traditional ecological knowledge. From the resulting inventory, we selected key species to monitor the ecosystem health of Canal de Infiernillo, a delimited portion of the territory. The list includes species that are under a legal protection status, rare, commercially important, common, dominate or characterizing entire communities, and important to the Seri community.

STUDY AREA

The Seri territory is located in the central portion of the Gulf of California on the Sonoran desert coast (28º45' - 29º30' and 112º00'- 112º30') (Fig. 1). This area is in the southern limit of the zoogeographic area known as Northern Gulf of California (Walker, 1960; Thomson, *et al*. 1979). The territory covers a coastal strip (913 km^2), the Isla Tiburón (1208 km^2), and approximately 250 km of coastline. This region is extremely arid and hot, with an annual precipitation between 100 to 250 mm (Sherwin, 1971; Meling-López and Ibarra-Obando, 1999). The hottest months are May and June with a maximum air temperature of 46ºC and surface seawater of 32ºC. In the winter months the temperature drops to 10ºC and 14ºC in the air and the water, respectively (Felger and Moser, 1985; Meling-López and Ibarra-Obando, 1999). In this desert region, no rivers or streams flow, freshwater flows on the land surface only during the rainy seasons (July-September and December-January). The average salinity of the seawater is 35ppt, but it can reach 40ppt in the negative estuaries or *esteros* [i.e. estuaries that have higher evaporation than precipitation or runoff (Brusca, 1980)].

The Seri marine territory can be divided in two areas according to its general oceanography. First is Canal de Infiernillo (297 km^2), located between Isla Tiburón and the mainland, with its northern limit at Bahía Sargento and the southern limit at Estero Santa Rosa. It is a shallow (average depth 5.5 m), long (41 km), and narrow (range 1.8-10 km wide) channel with estuarine characteristics. There are nine mangrove (*Rhizophora mangle*, *Laguncularia racemosa*, and *Avicenia germinans*) negative estuaries covering 30 km^2 and extensive annual eelgrass beds (*Zostera marina*) (67 km^2) (Torre *et al*.[4]). In addition, the submerged vegetation is composed of another species of seagrass (*Halodule wrightii*), ditch-grass (*Ruppia maritima*), and three commonly found algae: *Caulerpa* sp., *Padina durvillaei*, and *Sargassum* spp. Sand and mud cover the majority of the Canal bottom, however, there are a few rocky reefs, pebbled areas, and large areas (< 2 km^2) of mussel aggregations (mainly *Modiolus capax*) that function as hard substrate. The Canal has a characteristic current pattern produced by mixed semidiurnal tides, reaching a speed of 1 m/sec (Merifield *et al.* 1970; Maluf, 1983). When the tide is rising, water enters through both ends of the channel, producing two masses of water that meet in the middle. When the tides ebb, water flows out through the ends. These current patterns produce distinctive sand formations (bars, points, and waves) (Merefield *et al*., 1970).

The second zone includes the rest of the Isla Tiburón, which has oceanic characteristics. The waters west of the island reach 100 m of depth and off the southwest point of the island, Tiburón Basin reaches 200 m (Maluf, 1983). In contrast to the Canal de Infiernillo side, the coast of the rest of the island does not have estuaries, and the

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[4] See Appendix C of the dissertation for the results of the eelgrass mapping in the Canal de Infiernillo.

substrate is a mix of rocky habitats (i.e. rock outcrops, pebbles or cobbles, boulders, and rock platform) with few sandy beaches. Information on the submerged vegetation is limited. Felger and Moser (1985) report up to 200 algae species in the Seri region. This zone contains two important areas of upwelling and phytoplankton blooms: Bahía Agua Dulce and Bahía Kunkaak (Vonder Haar and Stone, 1973; Maluf 1983; Molina et al. 1997). Both are important fin whale (*Balaenoptera physalus*) feeding areas (Basurto-Guillermo *et al*., 1999). Due to its connectivity we include in the study the records collected on the continental side between Bahía Kunkaak and Bahía Kino even though there are not part of the Seri territory. This area has rocky shore, a long sand beach, and the large Estero La Cruz (75 km^2) in the southern limit (Grijalva-Chon *et al*., 1996).

METHODS

The inventory included six major taxa of marine animals, (1) mollusks, (2) echinoderms, (3) sharks, rays, and bony fishes, (4) sea turtles and sea snakes, (5) aquatic birds, and (6) marine mammals (Table 1). In addition to animals, we included the seagrass herbarium records from the Canal de Infiernillo due to the importance of this species in this marine community. The baseline inventory was developed using published and unpublished literature and through informal interviews and reviewing the field notes of eight experts who had been working in the area since the 1960s. We did an exhaustive search of records in catalogues and databases in the main collections with Gulf of California information in the USA and México (Table 2). The review in the collections was focused on records of all the included taxa excepting the marine reptiles and aquatic birds.

The fish species list was enhanced with Seri traditional ecological knowledge. We did formal and informal interviews with 13 Seri fishermen between 30 and 70 years old and a woman in her 50s. In the formal interviews we presented to them drawings, photographs and illustrated books about fish of the region (Thomson *et al*., 1979; Allen and Robertson, 1994; Fischer *et al*., 1995) and asked whether they believed each species was present or absent in their territory. During the interviews the consultants saw other fish species illustrated in the books but not present in the Seri territory. They expressed their lack of knowledge when the species was not recognized, even when the species had been recorded in the area. The informal interviews were conducted during visits to the fishing camps and while participating in fishing trips. We asked for the Seri name and general information using body parts such as shark jaws and fish heads, and fresh specimens available in the catch. In addition, we used the information compiled by three linguists and an ichthyologist working in the area since 1950s (Torre-Cosío and Findley[1]).

The Seri heavily use and have higher access control in the Canal de Infiernillo than in other areas of their territory (Basurto-Guillermo, 2001; Bourillón-Moreno, 2002). Therefore, we improved the baseline inventory of this area with a series of collections and observations from 1998 to 2000. Fifty-one collections were carried out to obtain mollusks, echinoderms, and fish, with emphasis on the last group. We used manual collection (11 occasions), hook and line (5), beach seine (3 x 1.2 m, mesh size 0.5 cm) (17), gillnets (mesh size 2.5 to 20 cm) (10), swimming crab traps (80 x 80 x 60 cm, hexagonal mesh 5.7 x 3.1 cm) (7), and on one occasion an ichthyocide (rotenone). The collections were on sand and mud bottoms, near eelgrass beds, and inside *esteros* mainly in winter (February-March) and summer months (June-August). In addition, we compiled lists of the fish species captured during 20 fishing trips with Seri fishermen between July 1999 and March 2000 that used gillnets (mesh size 2.5 to 10 cm) and crab traps. Censuses of sea turtles, aquatic birds, and marine mammals were made along both coasts of the Canal from a distance of 25-50 m from the shore in a small boat (7-m) in winter and summer months (1998-1999). The search was by naked eye and binoculars (7 x 10). All the gathered information was entered in a relational database (BIOTICA) designed by the Mexican National Commission for the Knowledge and Use of Biodiversity (CONABIO, www.conabio.gob.mx).

RESULTS AND DISCUSSION

Inventory

A total of 657 species of the selected marine animal species were recorded in the inventory: 210 mollusks, 62 echinoderms, 36 sharks and rays, 229 bony fish, 5 sea turtles, a sea snake, 106 aquatic birds, and 8 marine mammals (Table 3[5]). Adding Seri traditional ecological knowledge augmented the fish species list. Five families and 11 species of sharks and rays and 10 families and 18 species of bony fish were not recorded in the Western information sources, but they were included in the fish inventory. In addition, we confirmed the presence in the Canal de Infiernillo of two seagrass species (*Halodule wrightii* and *Zostera marina*) and the ditch-grass *Ruppia maritima* with the

[5] Species list is in the Appendix E of the dissertation.

University of Arizona Herbarium records, literature (Felger and Moser 1985; Meling-López and Ibarra-Obando, 1999) and field observations.

In the inventory, the mollusks were the group with the lowest percentage of species with respect to the reported number of species for the Gulf of California (10%) and the northern Gulf (21%) (Table 3). This is partially due to the absence of diversity studies of mollusks along the Mexican Pacific coast as stated by Reguero-Reza and García-Cubas (1993). The echinoderm species list has 24% of the species reported in the Gulf and 45% in the northern Gulf. Similar percentages are for the marine mammals, with 24% in the Gulf and 33% in the northern Gulf. The percentages were higher for the fish, reptiles, and birds because they are the groups more studied in the area (e.g. USFWS, 1965-2001; Felger *et al*., 1976; Cliffton *et al*., 1982; Henny and Anderson, 1979; Felger and Moser 1985; Grijalva-Chon et al., 1996; Russell and Monson, 1998; Cartron, 2000; Cartron and Molles, 2002; Castro-Longoria *et al*., 2002; Cartron *et al*., in press; Seminoff *et al*. in press) as is reported in other species diversity inventories (Stork, 1994).

We found that approximately 30% to 40% of the storage material in some museums and universities has not been sorted, catalogued, and identified. For example, there are mollusk specimens with no identification collected in the 1940s and fish material not sorted since the 1960s. In addition, it is common to observe misidentification and taxonomic problems (i.e. changes of families, genera, or species). Probably the most important fish collection for the Canal de Infiernillo was completely lost and discharged due to the lack of curatorial resources (Grijalva-Chon, J. M. pers. commun.). In the case of sea turtles, birds, and mammals, there are important field observations in unpublished reports. On the other hand, 65% of the 26 reviewed collections had published catalogs of their specimens (Luke, 1982, 1995; Vidal, 1991; Hendrickx, 1994) or are incorporating the information in databases available on the Internet (e.g. fish collections of Scripps Institution of Oceanography, Natural History Museum of Los Angeles County) or discs (e.g. Instituto Tecnológico y de Estudios Superiores de Monterrey-Campus Guaymas).

In the inventory database are compiled 2376 specimen records (i.e. a specimen record is a species collected, observed or reported in the literature with one or more individuals at a specific time and locality), 60% were from collections, 24% field observations, and 16% reported in literature. We did not capture marine reptiles in the database. Nevertheless, the presence of five sea turtles species (*Caretta caretta*, *Chelonia agassizii*, *Dermochelys coricea*, *Eretmochelys imbricata*, and *Lepidochelys olivacea*) and the yellowbelly sea snake (*Pelamis platurus*), the only sea snake reported in the Gulf of California, were confirmed through literature (Felger *et al*., 1976; Cliffton *et al*., 1982; Felger and Moser 1985; Seminoff *et al*. in press), field observations, and Seri traditional ecological knowledge.

The total number of georeferenced collection sites of the selected animal taxa was 353. The distributional patterns of the records show a skewed collecting effort to two accessible areas of the Seri territory and the adjacent area of Bahía Kino (Fig. 2). First is the southeast point of Isla Tiburón (Isla Turner and Ensenada del Perro), a protected area from winds, thus it is frequently used for anchorage and camping by fishermen, researchers, and tourists (Bourillón-Moreno and Basurto-Guillermo, 1998). Most of the expeditions of the University of Southern California´s Allan Hancock Foundation were in this area during the 1930s and 1940s. In addition, the Scripps Institution of Oceanography (SIO) and the University of California Los Angeles (UCLA), and the Universidad Nacional Autónoma de México (UNAM) made collections during the 1950s, 1960s and 1980s, respectively. In the case of the Bahía Kino area, the high number of collection sites is due to its proximity to the towns of Bahía Kino and Kino Nuevo [ca. 4000 people (INEGI, 2000)]. This area has been collected since the 1950s by different institutions (e.g., SIO, UCLA, UNAM), but mainly the University of Arizona (UA) in the 1960s and 1970s. The third area is the Canal de Infiernillo, where most of the records were obtained during the present study as well as from the UA fish records and publications about sea turtles and aquatic birds. There is an important gap of collecting effort in the oceanic Seri region in the west and north coast of Isla Tiburón and Bahía Kuunkak.

Species to monitor

From the inventory a list of species to monitor or indicators of the ecosystem health of the Canal de Infiernillo was developed. This area has relatively well defined boundaries. Furthermore it is the most heavily used area by the Seri community and also has the highest control fishing access (Basurto-Guillermo, 2001; Bourillón-Moreno, 2002). The selection of the species was based in the criteria developed by Davis and Halvorson (1988) for the Channel Islands National Park, California. The list includes: 1) species with a legal protection status, 2) endemic, rare, and alien species, 3) commercially important species, 4) taxa that dominate or characterize entire communities, 5) common taxa, and 6) species recognized by the public.

From the 23 coastal and marine species under a legal status according to the Mexican Official Norm for endangered, threatened, rare, and specially protected species (Diario Oficial de la Federación, 2002) in the Seri territory, 16 species are in the Canal de Infiernillo (Table 4). There are five species listed as endangered, five as threatened, and six under special protection. Birds have the most number of species with a legal status, eight species, followed by the five species of sea turtles. In addition, the Mazatlán pearl oyster (*Pinctada mazatlanica*), the brown sea cucumber (*Parastichopus fuscus*), and the sea lion (*Zalophus californianus*) are listed. The totoaba is the only marine fish listed in the Mexican Official Norm. This species supported an important fishery from 1920s to 1960s in the Seri territory (Bahre *et al*., 2000). Nevertheless, totoaba were distributed mainly outside of the Canal.

No endemic or alien species have been reported inside the Canal. However, it is important to point out the occasional records of the yellowbelly sea snake, which is from the Indo-Pacific Ocean (Fischer *et al*., 1995; Brusca *et al*., in press). The Seri consultants confirmed the rare presence of this species in Bahía Sargento. The occurrence of the sea snake has been related to the warmed waters during the El Niño years inside the Gulf of California. Felger and Moser (1985) reported the presence of the sea snake in the summer months according to their Seri consultants.

The main fisheries developed in the Canal are the pen shell (*Atrina maura*, *A. tuberculosa*, *A.* sp., and *Pinna rugosa*) and the swimming crab fishery (*Callinectes* *bellicosus*) producing approximately 70 mt and 350 mt each fishing season and valued at US $ 1.2 and US $ 3.5 million, respectively (Basurto-Guillermo, 2001; Bourillón-Moreno, 2002). Traditional knowledge of these species is profound, and Basurto-Guillermo (2001) states that the Seri fishermen have traditionally monitored the pen shell beds. In addition, there are the smaller scale fisheries of rays (*Dasyatis depterura, Rhinobatos* spp.), mullet (*Mugil* spp.), and corvinas (*Cynoscion* spp.).

We identified four important marine ecological communities in the Canal de Infiernillo, the mangrove *esteros*, the extensive eelgrass beds (Fig. 3), the areas covered by the algae *Caulerpa* sp., and the large aggregations of mussels. Information on the species related to these communities is poor. However, they are important substrates, reproductive, and nursery areas (Felger and Moser, 1985; Grijalva-Chon *et al*., 1992, 1996; Castro-Longoria *et al*., 2002). Basurto-Guillermo (2001) suggests that the mussel aggregations, the eelgrass and *Caulerpa* beds are natural refuges in terms of the reproduction and no-take areas for the pen shell fishery.

We identified 26 common species in all taxa in the Canal de Infiernillo according to literature, records in collections, local knowledge, and field observations. The pen shells and the mussels are common species in the mud and sand bottoms of the Canal. In addition, the snails of genus *Nassarius* and the species *Cerithidea mazatlanica* and *Cerithium stercusmuscarum* are commonly found in mud flats and *esteros* (Brusca, 1980), and the sea hare (*Aplysia californica*) is extremely common in the eelgrass beds (Felger *et al*., 1980). The pink-mouthed murex (*Phyllonotus erythrostoma*) and the Pacific turban (*Turbo fluctuosus*) are common bycatch of the swimming crab traps as is the orange star (*Echinaster tenuispina*) (Torre-Cosío and Bourillón-Moreno[6]). Another important echinoderm found in large aggregations (<1000 individuals) on sand near the eelgrass beds is the sand dollar *Encope grandis*. The fish group includes by their abundance, striped mullet (*Mugil cephalus*), spotted sand bass (*Paralabrax maculatofasciatus*), bullseye puffer (*Sphoeroides annulatus*), and stingrays of the genus *Urobatis*, which are found in all the environments of the Canal. In the *esteros* the mullet juveniles (*Mugil* spp.) and the goby *Quietula guaymasiae* are common species. In addition, the Gulf grunion (*Leuresthes sardina*) and the false grunion (*Colpichthys regis*) are abundant temporal residents in the *esteros* (Castro-Longoria *et al*., 2002). The Pacific green turtle (*Chelonia agassizii*) is the most common sea turtle in the Canal, where they spend the winter in dormancy at the edges of the eelgrass beds (Felger *et al*., 1976; Felger and Moser, 1985). Seri traditionally hunt sea turtles all year around. The common birds are the osprey (*Pandion haliaetus*) and the great blue heron (*Ardea herodias*), both residents, and willets (*Catoptrophorus semipalmatus*) [e.g. Russell and Monson (1998) observed 650 individuals in Estero Sargento on May, 1975] and black brants (*Branta bernicla nigricans*) in the winter months. The osprey population in the Canal is one of the largest in the Gulf of California (Henny and Anderson, 1979) and it has been described in the Canal as a high-inter annual variable population (Cartron, 2000; Cartron *et al*., in press). The U.S. Fish and Wildlife Service has been surveying winter waterfowl since the 1960s along the mainland Gulf of California and Baja California peninsula coasts by aerial censuses (USFWS, 1965-2001). The brant data for the Canal shows a steady

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[6] See Appendix D of the dissertation for the results of the swimming crab fishery impacts in the Canal de Infiernillo.

population of 5000 to 13000 individuals visiting the area each winter (Fig. 4). Large groups of brants (500-1000 individuals) are commonly observed in the eelgrass beds of Bahía Sargento. On the other hand, the total number of the other duck species has sharply decreased in the Canal (Fig. 5). The last common species identified for monitoring is the bottlenose dolphin (*Tursiops truncatus*). These form large aggregations (100 individuals) in the northern part of the Canal. What is probably a resident population has been identified in Bahía Kino (Ballance, 1990, 1992).

The eelgrass (*hatáam* in Seri language) has been an important resource for the Seri community since ancestral times. The Seri was the only culture in the world that consumed the eelgrass seeds as food and it was also used as medicine and to construct shelters and toys (Felger and Moser, 1973). Sea turtles (*mosni* is the general term, but the Seri have fourteen names for the different kinds of sea turtles) have been an important cultural resource for this indigenous group as is described in detail by Felger and Moser (1985). Sea turtles were at one time the main protein and fat sources for these people. In addition, the carapaces were used for storage, cooking, and transportation of their belongings. Sea turtle oil, important for medicine, was stored in sea turtle stomachs. The Seri recognized the abundance of the ospreys (*sipuj*) and identified an area on the east coast of Isla Tiburón, Valle de las aguilillas, and the coast of Bahía Sargento, as important nesting sites. The black brant (*xnois cacáaso*) is also an important species in the culture, and it is related to eelgrass harvesting (Felger and Moser, 1985). In addition, in the Seri folklore, the black brants fly to the Colorado River delta to transform into totoabas (Bahre *et al*., 2000).

The final list of species to monitor includes seven species of primary producers, which also are important producers of detritus in different seasons. For example, the eelgrass beds die-off during the summer months (Meling-López and Ibarra-Obando, 1999) producing large amounts of detritus. It is the same for the algae *Caulerpa* spp. that is substituted in the winter months by the eelgrass. Probably, most of the Canal de Infiernillo food web is based on detritus. There are species in each of the taxa treated in the inventory, including filter feeders (4 species), detritophagous (3 species), herbivorous (2 species), omnivorous (5 species), and carnivorous (25 species) (Table 5).

CONCLUSIONS

We developed two baseline components for the management of the natural resources in a community-based marine territory of an indigenous group of people, an inventory and a list of species to monitor, based in the available information in literature, records in collections, and traditional knowledge. However, both components are incomplete; the inventory is skewed to certain locations and taxa and the list of species to monitor has a high proportion of species of one trophic level (i.e. carnivores). In addition, it is necessary to develop and test specific monitoring protocols for each of the identified species.

Even though the information on collections and traditional ecological knowledge is not viewed as "systematically" obtained we strongly encourage their use. In most cases this information is only used by systematic biologists and anthropologists, but rarely used by natural resources managers. Nevertheless, these information sources are relatively accessible, and it is a way to involve the communities in the process of conservation and management of their own resources. It is important to point out that both sources of information are in peril, conditions of some of the collections are deteriorating due to lack of funding and proper management. And the traditional ecological knowledge is not passing along generations due to acculturation by external factors.

In the specific Seri case, currently, there are 15 young trained para-ecologists in basic Western science and traditional ecological knowledge (Nabhan, 2000). Two of the para-ecologists are carrying out the monitoring of one of the selected species, the swimming crab fishery. In addition, it is important to consider including the traditional monitoring by the Seri in the monitoring program.

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Table 1. Marine and coastal animal taxa included in the survey of natural history collections of the Seri territory.

Phylum	Class	Common name
Mollusca	Pelecypoda	clams
	Gastropoda	snails and sea hares
	Polyplacophora	chitons
	Cephalopoda	octopuses and squids
Echinodermata	Asteroidea	sea stars
	Ophiuroidea	brittle stars
	Echinoidea	urchins
	Holothuroidea	sea cucumbers
Chordata	Chondrichthyes	sharks and rays
	Actinopterygii	bony fishes
	Reptilia	sea turtles and sea snakes
	Aves	aquatic birds
	Mammalia	marine mammals

Table 2. Collections in USA and México reviewed. A record is a collected species with one or more individuals in a specific time and locality.

Collection	Records
Seagrasses	
UA, Herbarium	26
Mollusks	
LACM, Invertebrate Zoology	48
SIO, UCSD, Benthic Invertebrate Collection	167
UA, Dept. of Ecology and Evolutionary Biology, Invertebrate Collection	222
UNAM, ICMyL, Mazatlán Station, Invertebrate Reference Collection	16
Total number of records	453
Echinoderms	
UNAM, ICMyL, Systematic and Ecology of Echinoderms Laboratory	40
UNAM, ICMyL, Mazatlán Station, Invertebrate Reference Collection	1
LACM, Echinoderms Section	89
UCSD, SIO, Benthic Invertebrate Collection	12
UA, Dept. of Ecology and Evolutionary Biology, Invertebrate Collection	14
UCB, Museum of Paleontology, Invertebrate Collection	3
UH, Museum of Comparative Zoology, Dept. of Invertebrate Paleontology	3
USNM, Department of Invertebrate Zoology	10
Total number of records	172
Sharks, rays, and bony fishes	
UNAM, Institute of Biology, Dept. of Zoology, Fish Collection	190
CAS, Dept. of Ichthyology	90
LACM, Fish Section	117
UCSD, SIO, Fish Collection	76
UA, Dept. of Ecology and Evolutionary Biology, Fish Collection	107
UCLA, Fish Collection	58
USNM, Department of Zoology, Division of Fishes	2
ITESM-Campus Guaymas, Marine Vertebrate Collection	134
Total number of records	758
Aquatic birds	
UA, Dept. of Ecology and Evolutionary Biology, Bird Collection	3
UCB, Museum of Vertebrate Zoology	1
UK, Bird Collection	3
Total number of records	7
Marine mammals	
LACM, Mammals Section	2
USNM, Department of Zoology, Division of Mammals	1
UNAM, Dept. of Biology, Faculty of Sciences, Marine Mammals	2

Laboratory	
UNAM, Institute of Biology, Dept. of Zoology, Mammals Collection	9
ITESM-Campus Guaymas, Marine Vertebrate Collection	4
Total number of records	18
Reviewed collections without records	
San Diego Natural History Museum (SDNHM)	
Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE)	
ICMyL, Dept. of Malacology	
Universidad Autónoma de Baja California	

CAS = California Academy of Sciences, ICMyL = Instituto de Ciencias del Mar y Limnología, ITESM = Instituto Tecnológico y de Estudios Superiores de Monterrey, LACM = Natural History Museum of Los Angeles County, SIO = Scripps Institution of Oceanography, UA = University of Arizona, UCB = University of California at Berekeley, UCLA = University of California at Los Angeles, UCSD = University of California at San Diego, UH = University of Harvard, UK = University of Kansas, UNAM = Universidad Nacional Autónoma de México, USNM = National Museum of Natural History, Smithsonian Institution.

Table 3. Number of records, families, and species and percentage of species with respect to the reported number of species for the Gulf of California (GC) and Northern Gulf of California (NGC) by Brusca *et al*. (in press).

Phylum	No. records	Families	Species	%GC	%NGC
Mollusca	460	69	210	10	21
Pelecypoda	127	25	61	11	21
Gastropoda	299	39	135	9	21
Polyplacophora	30	4	12	21	32
Cephalopoda	4	1	2	10	33
Echinodermata	171	32	62	24	45
Asteroidea	58	9	13	-	-
Ophiuroidea	51	8	25	-	-
Echinoidea	51	10	15	-	-
Holothuroidea	11	5	9	-	-
Chordata	1718	112	369	33	68
Chondrichthyes	50	16	36	41	62
Actinopterygii	828	66	229	29	74
Reptilia	-	3	6	86	86
Aves	802	23	106	59	73
Mammalia	39	4	8	24	33

Table 4. Species with a special legal status in the Seri territory based in the Mexican Official Norm for endangered, threatened, rare, and specially protected species (Diario Oficial de la Federación, 2002).

Species	Common name	Status
Mollusca		
Pinctada mazatlanica	Mazatlan pearl oyster	special protection
Spondylus calcifer*	purple lip rock oyster	special protection
Echinoderms		
Parastichopus fuscus	brown sea cucumber	special protection
Marine reptiles		
Caretta caretta	loggerhead turtle	endangered
Chelonia agassizii	Eastern Pacific green turtle	endangered
Dermochelys coricea	leatherback turtle	endangered
Eretmochelys imbricata	hawksbill sea turtle	endangered
Lepidochelys olivacea	olive ridley turtle	endangered
Fish		
Totoaba macdonaldi*	totoaba	endangered
Aquatic birds		
Anas acuta	northern pintail	special protection
Anas Americana	American wigeon	special protection
Aythya affinis	lesser scaup	special protection
Egreta rufescens	redish egret	threatened
Ixobrychus exilis	least bittern	threatened
Larus heermanni	Heermann´s gull	threatened
Oceanodroma melania	black storm petrel	threatened
*Phaethon aethereus**	red-billed tropicbird	threatened
*Sterna antillarum**	least tern	special protection
Sterna elegans	elegan tern	threatened
Sula nebouxii*	blue-footed bobby	threatened
*Synthliboramphus craveri**	Craveri´s murrelet	threatened
Marine mammals		
*Balaenoptera physalus**	fin whale	special protection
Zalophus californianus	sea lion	special protection

* Species not recorded inside Canal de Infiernillo.

Table 5. List of selected species to monitor and their trophic level in Canal de Infiernillo, Gulf of California. C = carnivorous, D = detritophagous, F = filter, H = herbivorous, nd = no data, O = omnivorous, P = primary producer, TL = trophic level, S = saprophagous.

Species	TL*	Species	TL*
Plants		Fish	
Avicenia germinans	P	*Mugil* spp.	C, D
Caulerpa sp.	P	*Paralabrax maculatofasciatus*	C
Halodule wrightii	P	*Quietula guaymasiae*	C
Laguncularia racemosa	P	*Sphoeroides annulatus*	C
Rhizophora mangle	P	*Rhinobatos* spp.	C
Ruppia maritima	P	*Urobatis* spp.	C
Zostera marina	P	Marine reptiles	
Mollusks		*Caretta caretta*	C
Aplysia californica	H	*Chelonia agassizii*	O
Atrina spp.	F	*Dermochelys coricea*	C
Cerithidea mazatlanica	nd	*Eretmochelys imbricata*	C
Cerithium stercusmuscarum	C	*Lepidochelys olivacea*	C
Modiolus capax	F	*Pelamis platurus*	
Nassarius spp.	S	Aquatic birds	
Phyllonotus erythrostoma	nd	*Anas acuta*	O
Pinctada mazatlanica	F	*Anas americana*	O
Turbo fluctuosus	nd	*Ardea herodias*	O
Echinoderms		*Aythya affinis*	O
Echinaster tenuispina	C, S	*Branta bernicla nigricans*	H
Encope grandis	nd	*Catoptrophorus semipalmatus*	C
Parastichopus fuscus	D	*Egreta rufescens*	C
Crustaceans		*Ixobrychus exilis*	C
Callinectes bellicosus	C, D	*Larus heermanni*	C
Fish		*Oceanodroma melania*	C
Colpichthys regis	C	*Pandion haliaetus*	C
Cynoscion spp.	C	*Sterna elegans*	C
Dasyatis dipterura	C	Marine mammals	
Leuresthes sardina	C	*Tursiops truncatus*	C
		Zalophus californianus	C

*Information from Brusca (1980), Fischer *et al.* (1995), Seminoff *et al.*, 1997, Elphick *et al*. (2001)

Figure captions

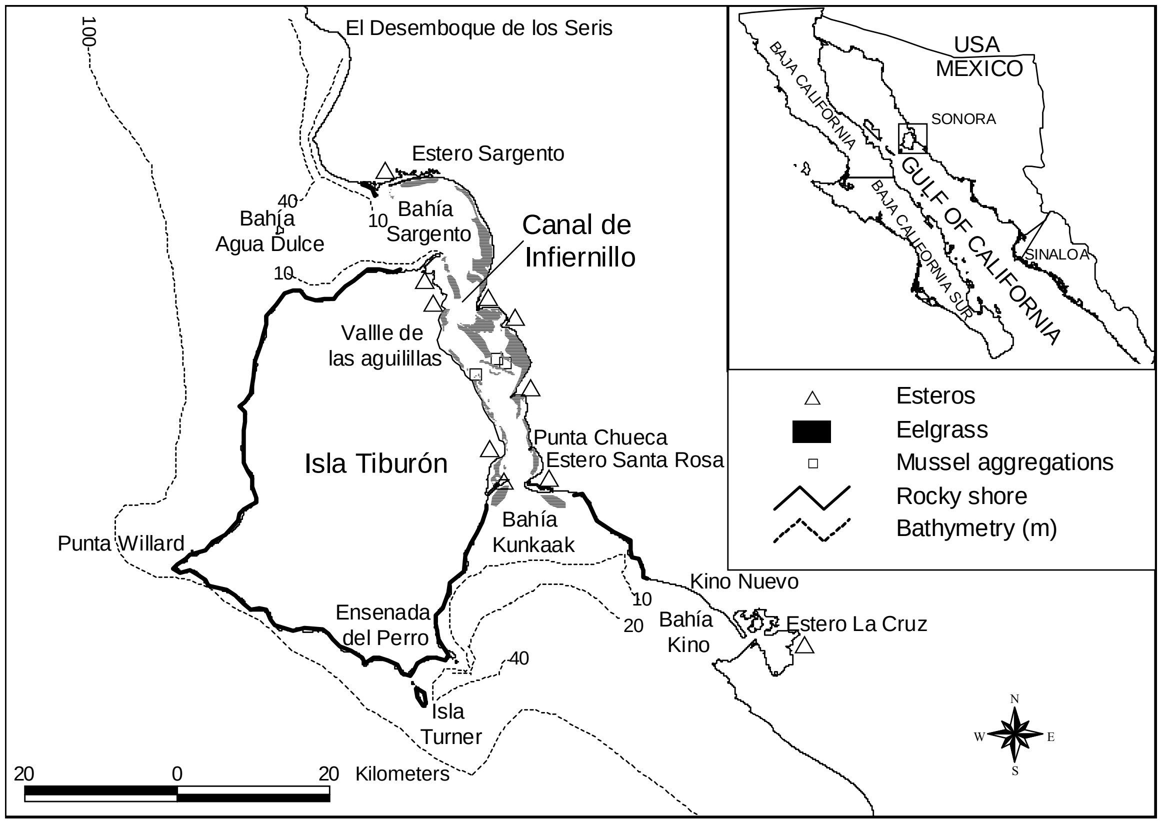
Figure 1. Study area, Seri territory.

Figure 2. Distribution of the records from collections, literature, and field observations of four taxa inside the Seri territory. In the bird map the rectangle show the area covered by the U.S. Fish and Wildlife Service winter waterfowls surveys (USFWS, 1965-2001).

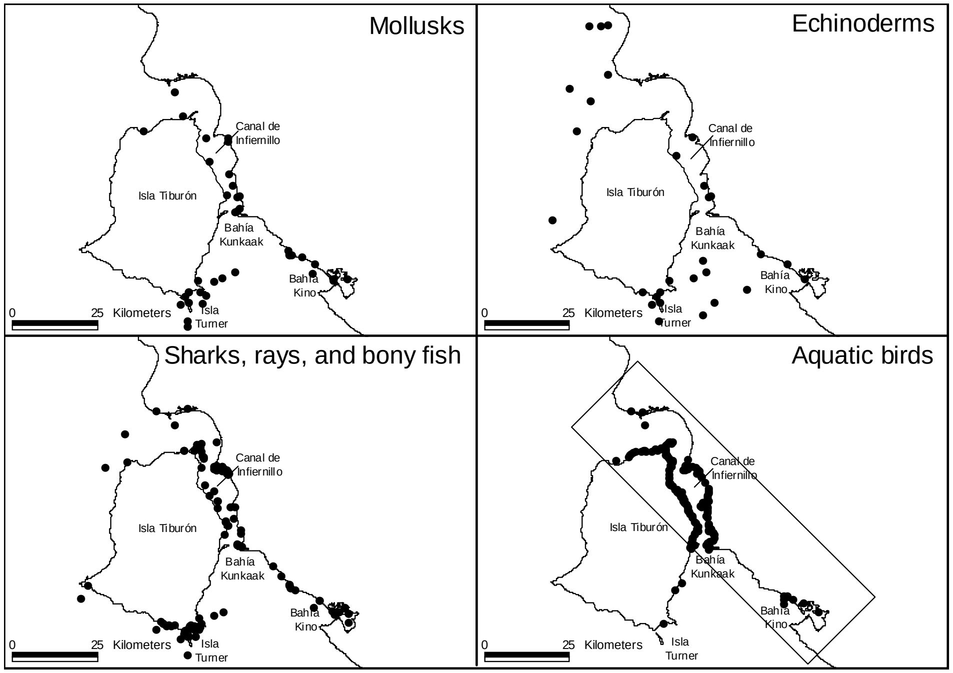
Figure 3. Diagram of the eelgrass community relations (modified and actualized from Felger and Moser, 1985).

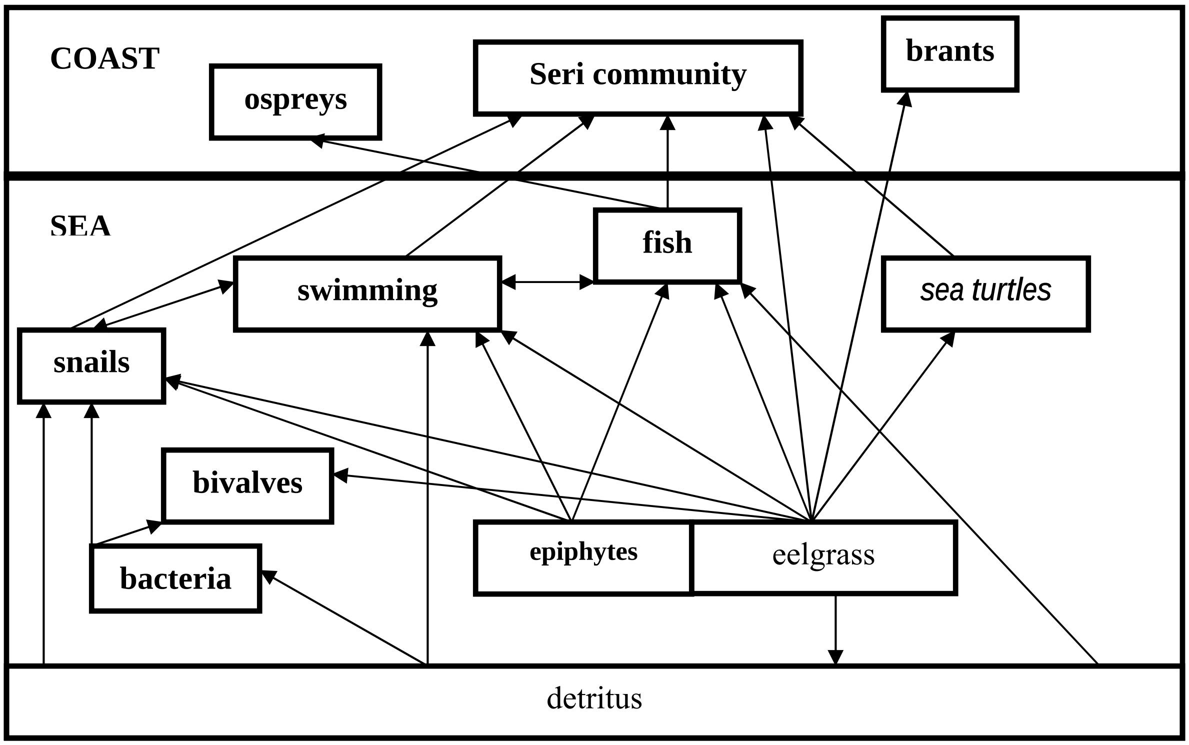
Figure 4. Numbers of black brants in Canal de Infiernillo from 1965 to 2001 (USFWS, 1965-2001)

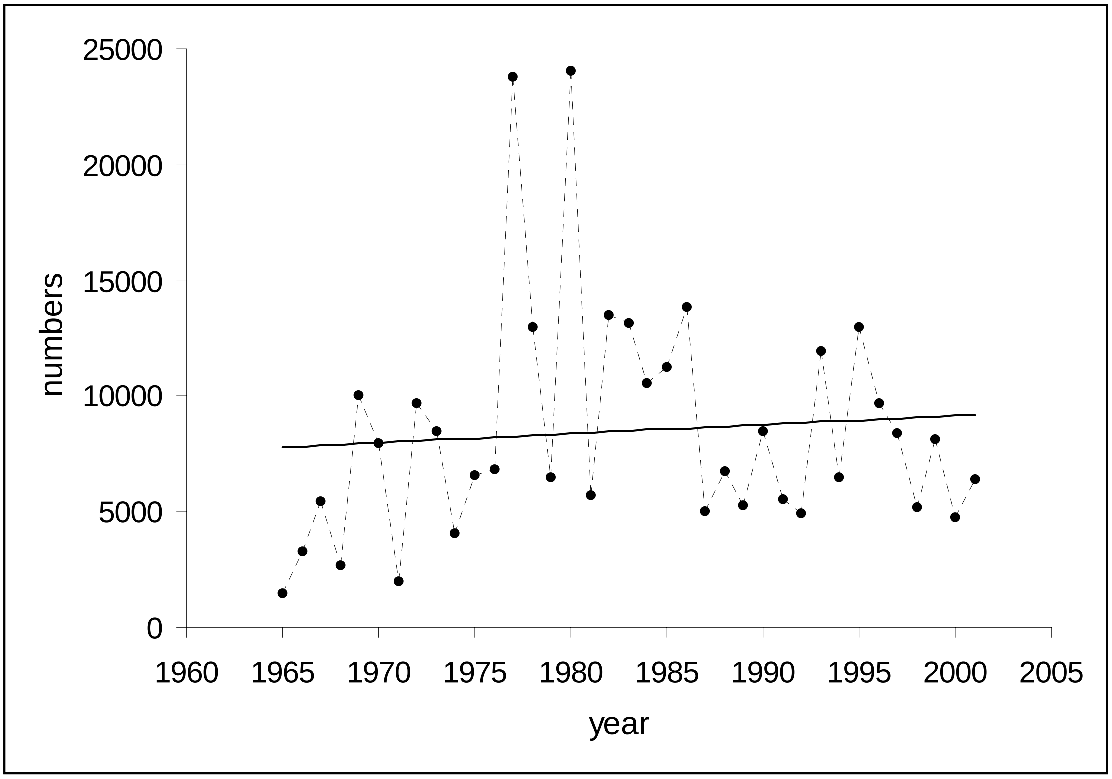
Figure 5. Number of ducks in Canal de Infiernillo from 1978 to 2000 (USFWS, 1965-2001).



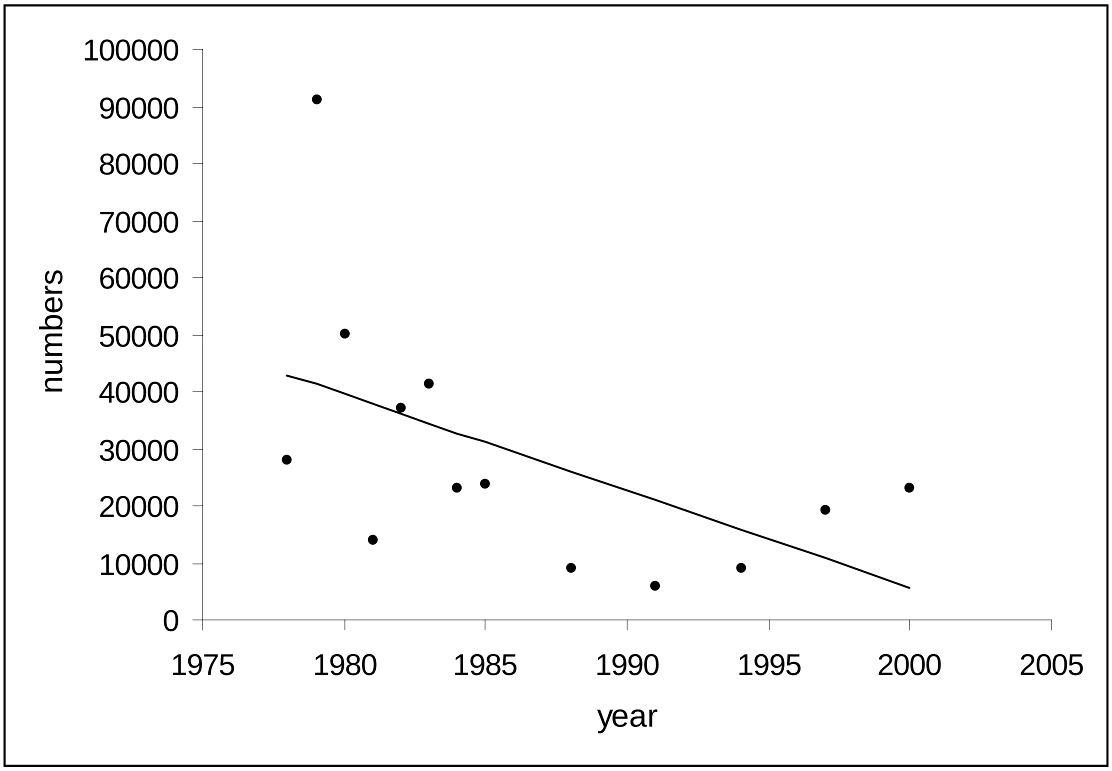
El Desemboque de los Seris
Estero Sargento
Bahía Sargento
Bahía Agua Dulce
Canal de Infiernillo
Vallle de las aguilillas
Isla Tiburón
Punta Chueca
Estero Santa Rosa
Bahía Kunkaak
Punta Willard
Ensenada del Perro
Isla Turner
Kino Nuevo
Bahía Kino
Estero La Cruz
100
40
10
20
20 0 20 Kilometers
USA
MEXICO
SONORA
BAJA CALIFORNIA
BAJA CALIFORNIA SUR
GULF OF CALIFORNIA
SINALOA
Esteros
Eelgrass
Mussel aggregations
Rocky shore
Bathymetry (m)
N
E
S
W


Mollusks
Echinoderms
Sharks, rays, and bony fish
Aquatic birds
Canal de Infiernillo
Isla Tiburón
Bahía Kunkaak
Bahía Kino
Isla Turner
0
25
Kilometers


COAST
ospreys
Seri community
brants
SEA
fish
swimming
sea turtles
snails
bivalves
epiphytes
eelgrass
bacteria
detritus



25000
20000
15000
10000
5000
0
numbers
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
year


100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
numbers
1975
1980
1985
1990
1995
2000
2005
year

APPENDIX B

ETHNOICHTHYOLOGY OF THE SERI INDIANS IN THE GULF OF CALIFORNIA, MEXICO

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ABSTRACT.- The Seri Indians and their apparent ancestors have been living on the central coast of Sonora and on Tiburon and San Esteban islands in the Gulf of California for approximately 2000 years. Traditional subsistence was and continues to be based mainly on fishing and shellfish gathering. Their knowledge of marine and coastal environments is profound. In the present study, we compiled ichthyological information gathered from 13 experienced Seri fishermen in two periods, 1970-1972 and 1999-2002. We also used the fish names compiled by the linguist Edward Moser during the 1950s-1970s. We focused our work on the analyses of traditional fish nomenclature, obtaining information on the biology and ecology of 113 ethnospecies related to 151 traditional names. The Seri recognize approximately 69 and 25 fish at the level of species and genus, respectively, in 68 families. They use conspicuous morphological, ecological, and behavioral characteristics to identify species. Knowledge is more detailed for commercially important species, especially sharks, rays, grunts (Haemulidae), snappers (Lutjanidae), mullets (Mugilidae), croakers (Scianidae), and sea basses (Serranidae). The Seri traditional ecological knowledge provides important insights into the Gulf´s ichthyofauna, but this knowledge bank is imperiled due to acculturation and overexploitation of the traditional natural resources.

INTRODUCTION

The Seri (Comcáac[7]) Indians lived along the central portion of the Sonoran coast, from Cabo Tepoca to Guaymas, and on Islas Tiburón and San Esteban (Fig. 1) before the Spanish contacts in the sixteenth century (Bahre 1980; Felger and Moser 1985; Sheridan 1999; Bowen 2000). Since then the Seri population and its territory were reduced by Spaniards and Mexicans (Felger and Moser 1985; Sheridan 1999) to only 180 people in 1920 (Bahre 1980). Today there are approximately 670 Seri (INEGI 2000) living in two small fishing towns, Punta Chueca and El Desemboque de los Seris. They still maintain their traditions and language (***Cmique iitom***), which is the only survivor of an extinct linguistic family of the Hokan stock (Marlett 2000). To secure the survivorship of this ethnic group, in 1970 and 1975 the Mexican Government granted to them a strip of coastal land, Isla Tiburón, and the exclusive fishing rights around the adjacent waters of this island (Diario Oficial de la Federación 1970, 1975; Bourillón-Moreno 2002).

The Seri way of life had been contrasted markedly to the other Indians of the southwestern USA and northwestern México by its nomadic and non-agriculturist culture (Rea 1981; Felger and Moser 1985). In the past they moved in small family groups establishing temporal camps mainly along the coast and surviving by eating desert plants, collecting shellfish, hunting, and fishing (Felger and Moser 1985; Sheridan 1996).

[7] Seri is the name by which they are most commonly known to outsiders. Their self-designation is, however, Comcáac (a plural noun). This name is pronounced (kōng-kŏk´) (using the pronunciation conventions of the American Heritage Dictionary).

Today, they still depend on these activities and on the production of handicrafts for tourists, such as their famous baskets (Moser 1973), necklaces, and ironwood figures (Johnston 1968; Felger and Moser 1985). They also sell hunting permits for a subspecies of bighorn sheep (*Ovis canadensis mexicana*), introduced to Isla Tiburón in the 1970s; in addition, they organize and participate as guides in the hunts (Medellín 1998). Nevertheless, fishing is still their main economic activity.

Before the use of new fishing technologies in the 1930s and 1940s, such as gillnets, hooks and lines, and dynamite (currently banned), the Seri used only spears and harpoons (Bahre 1967; Felger and Moser 1985; Sheridan 1996; Bahre et al. 2000). They harpooned sea turtles and large and abundant sharks, rays, and fish species such as mullets (*Mugil* spp.), sea basses (*Epinephelus* spp. and *Mycteroperca* spp.), snappers (*Lutjanus* spp.), and totoabas (*Totoaba macdonaldi*), among others (Malkin 1962; Felger et al. 1976; Felger and Moser 1985). Today, they only use the harpoon to capture large whiptail stingrays (*Dasyatis dipterura*). The Seri were adapted to the different fisheries developed in their territory (e.g., totoaba, shark, groupers, scallops, swimming crab) during the twentieth century, and their fame as excellent fishermen is well known by Americans and Mexicans.

The Seri and their ancestors have a 2000-year association with the Gulf of California (Bowen 1976). The sea has provided them with food, transportation, and refuge. This relationship has produced a precise and profound knowledge of marine biodiversity. For example, they are the only culture in the world that used eelgrass (*Zostera marina*) seeds as a food resource (Felger and Moser 1973). Their deep knowledge of sea turtle natural history is reflected in their classification, identifying 14 kinds of sea turtles—some of these forms probably now extinct—of the five species distributed in the Gulf (Felger et al. 1976; Cliffton et al. 1982; Felger and Moser 1985). The relation between the Seri and the sea can be summarized in the following oral tradition story compiled by Felger and Moser (1985):

> "The ***Hant Caai*** ('land maker') tested the man and the woman. He told the man to ride the horse but the man failed (he fell off). So ***Hant Caai*** told the man to paddle a balsa. This the man was able to do. He paddled out to sea and harpooned a sea turtle. Upon returning to land, the man found that he had no knife, so he split a stalk of reedgrass and used one of the sharp edges to butcher the turtle. These two tests showed the man was a capable fisherman, although incapable of working the land."

Ethnobiological fish research is scarce in comparison to other taxa (e.g. plants, birds). The works by Johannes (1981) in Palau, and Begossi and Figueiredo (1995), Paz and Begossi (1996), and Seixas and Begossi (2001) in Brazil are some of the most complete folk fish studies. In the Seri case, there are four sources of its fish traditional knowledge. First are the songs recorded by Coolidge and Coolidge (1939) about the natural history and uses of fish species and other marine animals (e.g., whale, sea turtle). In 1953 and 1955, Malkin (1962) compiled the knowledge of 42 fish species, including biological, ecological, and human use information. Felger and Moser (1985) briefly describe the information about some fish consumed by them. Finally, Bahre et al. (2000) reviewed the

Seri participation in the totoaba fishery (1930s-1960s) and their knowledge of this species. In the present study we compile the Seri traditional knowledge of the fish fauna in their territory through the analysis of 151 fish names associated with 113 ethnospecies or folk species. The Seri fish classification and biological, ecological, and behavioral information from the traditional nomenclature is examined.

METHODS

The procedure to obtain traditional knowledge of the fish fauna inside the Seri territory was through formal and informal interviews. Structured questionnaires were not applied in the formal interviews due to time constraints. In addition, the Seri have difficulty in narrowing their answers to specific questions as has been reported by Felger (2000) during his ethnobotanical work. Instead, we focused on the fish names and their meaning, and when consultants wanted or could, we allowed them to give mythological, biological, and ecological information. The formal interviews were done in two periods, 1970 to 1972 and 1999 to 2002. In the first period we presented drawings (e.g. Thomson and Eger 1966) and photographs of several species, and in the second period we used the best three illustrated books for the region, Thomson et al. (1979), Allen and Robertson (1994), and Fischer et al. (1995). Accurate pen-and-ink drawings and photographs characterize these books. In contrast to the 1970s interviews, when drawings were presented randomly, the latest interviews mainly followed the phylogenetic order by species of Allen and Robertson (1994).

During the interviews we let the consultants see other fish species illustrated in the books but not present in the Seri territory. Except for one occasion with respect to a drawing of an endemic mullet (*Mugil galapagensis*) from the Galapagos Islands, which three consultants believed was present in their territory; they correctly indicated when a species was not present in the area. In addition, when they did not recognize a species, even though it is present in the area, they expressed their lack of knowledge. Six experienced fishermen between 40 and 60 years old were interviewed, three from Punta Chueca and three from El Desemboque. One of consultants was interviewed in the first period and the rest five in the second period. Three of the interviewed Seri were present on one occasion, providing the opportunity to discuss among themselves, thus obtaining more accurate information.

The informal interviews were through visits to the fishing camps and in participatory fishing trips. We asked for the Seri name and general information using body parts as shark jaws and fish heads, and fresh specimens available in the catch. The information obtained in these interviews helped to corroborate the data from the formal interviews because the fishermen could directly handle specimens, observing colors, texture, shape, and size as they know the animals. We did informal interviews of ten fishermen between 30 and 70 years old and a woman in her 50s. Another important source of fish names was the information compiled by Edward and Mary B. Moser of the Summer Institute of Linguistics (SIL) during their studies of the Seri language. They lived among the Seri during the decades of the 50s through the 80s, obtaining extensive information of the language and culture of this indigenous group.

RESULTS AND DISCUSSION

The Seri have a rich oral tradition transmitted by story telling and songs (Coolidge and Coolidge 1939; Felger and Moser 1985). Fathers teach their sons about the natural history of marine life in daily fishing activities. For example, it is common to observe members of a family working on the same fishing team. In addition, music and song-poetry are important parts of their culture (Bowen and Moser 1970; Felger and Moser 1985; Astorga de Estrella et al. 1998, Vennum 2000). There are songs for the baby shark (unidentified species), the sardine (Clupeidae), the mullet (*Mugil* spp.), the totoaba (*Totoaba macdonaldi*) (Coolidge and Coolidge 1939), and the roosterfish (*Nematistius pectoralis*). However, as in other indigenous communities throughout the world, acculturation (Berlin 1992; Ruddle 1994) due to TV, now with satellite dish for example, has interfered with the historical transmission of traditional knowledge. In the specific Seri case, this is probably more accentuated in Punta Chueca than in El Desemboque due to the presence of electricity. This may in the future influence a cultural separation between the two communities.

Nabhan (2000) estimated that participation of the young Seri in traditional ceremonies and subsistence activities has been reduced 25%, even though they still retain the traditional species names. We observed that on some occasions the fish names are known but the consultants could not associate them to a specific species or family. For example, they recognized the name ***ziix inyácax*** as a “shark” without dorsal fin. Nevertheless, they did not identify it in the photographs and drawings presented to them. The same is true for three ray species, ***camáaina*** (the word comes from paddle),

hatajísijc (the name is also used for the saltbush *Atriplex canescens*), and ***zcapcoj*** (used for a small ray species); and nine bony fish, ***hant iconáil iisical̲***, ***hazni*** (probably a corvina, Scianidae), ***iicj***, ***iiz***, ***oot asáac*** ('son of the coyote'), ***tajísl*** (probably a sea chub, Kyphosidae), ***ziipxöl iso*** ['blue palo verde (*Cercidium floridum*) trout'], ***zixcám coopol*** ('black fish'), and ***zixcám coospoj caacoj quitjö*** ('large spotted fish with bile'). It is important to point out that all these names were compiled during the work by the Mosers and in the interviews in the 1970. Unfortunately, in the 1999-2002 interviews the consultants could not identify them, even though they knew the name.

Another factor affecting the diffusion of folk knowledge among the Seri is the growing scarcity of traditional marine food due to overexploitation. Therefore, there are no materials to teach the traditional knowledge. For example, in the past they identified seven ethnospecies of green turtle (*Chelonia mydas*), and in the 1980s fishermen captured only two of these ethnospecies (Cliffton et al. 1982). The same is true for the totoaba, the gulf grouper (*Mycteroperca jordani*), and the goliath grouper (*Epinephelus itajara*). These species are top predators in the rocky reef community, have large proportions (i.e., up to 100 kg for the totoaba and gulf grouper and 320 kg for the goliath grouper) (Thomson et al. 1979; Cisneros-Mata et al. 1995; Fischer et al. 1995), and were an important food resource for the Seri through their history. Malkin (1962) stated that these fishes were the main catch during his visits in the 1950s. The knowledge of these species is profound; the Seri distinguish several age classes (see Synonymies section below) as well they know about their migrations and seasonality (Malkin 1962; Bahre et al. 2000). However, due to heavy commercial and sport-fishing exploitation, their abundance has decreased considerably (Thomson et al. 1979; Cisneros-Mata et al.1995; Kira 1999; Bahre et al. 2000; Musick et al. 2000). Currently, all of them are listed as endangered (i.e., totoaba and goliath grouper) or vulnerable (i.e., gulf grouper) in national (Diario Oficial de la Federación 2002) and international laws (U.S. Fish and Wildlife Service 1988; Hilton-Taylor 2000; Musick et al. 2000). All the consultants confirmed the rarity of catching these species nowadays. For example, the last large totoaba school observed by the Seri was in the early 1960s (Bahre et al. 2000). Furthermore, non-commercial species have been disappearing without notice by Western scientists, but not for the Seri. The consultants indicated that a large flying fish (Exocoetidae) named ***xpatíinoj caacoj*** was common in the past, but is no longer present in their territory.

The Seri council of elders has realized the traditional knowledge loss problem. Therefore, efforts to prevent this loss are beginning to intensify. For example, recently formal training for 15 young Seri as para-ecologists was recently carried out, in which traditional knowledge and Western science were taught (Nabhan 2000). Furthermore, some families are now recording traditional knowledge on their own and spending time teaching sons and grandsons. However, overexploitation of the natural resources is not fully in the Seri hands.

Ethnotaxonomy.—The Seri have a hierarchical fish classification; first is the rank ***ziix*** (‘thing’) and the second rank is any living animal designated ***ziix ccam*** (‘thing that is alive’). Humans (***ziix quiisax***, ‘thing with soul’) are considered a parallel rank (Felger and Moser 1985). The third rank, are the three major groups recognized by the Seri and also by the ichthyologists. These are the sharks (***hacat***), the rays (***hacat cmaam***), and the bony fish (***zixcám*** or ***zixcam áa***). An archaic name for sharks is ***tohni****,* and for bony fish is ***ziix quipxási*** (‘thing with meat’). Dangerous sharks are called ***ziix anxö caiitim*** (‘harmful thing’), a name that is also applied to snakes.

The Seri know the close relation between sharks and rays, naming the rays ‘female shark’ (the meaning of ***cmaam*** is female). However, they also apply ***hacat cmaam*** as one of the four names for the whiptail stingray (*Dasyatis dipterura*) (Table 1). It was not possible to determine if ***hacat cmaam*** was used first exclusively for the whiptail stingray and then as a generic term or vice versa. The Seri considered the bony fish a different unrelated group from the sharks and rays as Malkin (1962) also recorded in his interviews. The last rank in the Seri taxonomy is the ethnospecies or terminal taxa (Berlin 1992), which are associated to any of the ichthyological families, genera, or species. Identification of the ethnospecies is based on the size, shape, color, number, and position of the different anatomical features (Table 2) as well as using biological (i.e. reproduction), ecological (i.e. habitat), and behavioral characteristics.

The Seri distinguish 14 shark ethnospecies included in eight families, identifying nine and five ethnospecies at species and genus levels, respectively. Eighteen names are used for the different shark ethnospecies, having synonymies for two genera (*Mustelus* spp. and *Sphyrna* spp.) and two species (*Galeocerdo cuvier* and *Rhincodon typus*). There are 11 ethnospecies of rays with 14 names to identify them in eight families. Except for the manta rays (Mobulidae), and the eagle (*Myliobatis* spp.), guitar (*Rhinobatos* spp.), and round sting rays (*Urobatis* spp.), all the ethnospecies are identified at the species level. The whiptail stingray is the only ray species with synonymies. Furthermore, there are two mythological rays. The first is ***cama***, described as a big ray with large sharp spines along the tail. This name is also used for the Velez ray (*Raja velezi*), and the consultants stated that the shape of this ray is similar to the mythological ray. The second mythological ray is called ***caaijoj***; it has a large fin on the head for grabbing prey.

The Seri do not associate the groups of fish-like eel as bony fish, such as the morays (Muraenidae) (Malkin 1962), snake eels (Ophichthidae), and garden eels (Congridae). They relate these groups with the terrestrial snakes. Paz and Begossi (1996) report that the fishermen in Gamboa (Brazil) also associate these three families with snakes. The Seri have different terms to designate morays and eels, using the generic term ***haajöc*** for any species of morays, and adding ***coil*** ('green') and ***coospoj*** ('spotted') to identify specific ethnospecies. The snake and conger eels are called ***xepe no coimaj*** ('snake in the sea'), which is also used for the true sea snake, *Pelamis platurus*. The word ***coospoj*** is added to ***xepe no coimaj*** to describe any spotted eel or the true sea snake.

Excluding the fish-like eel families, there are 86 ethnospecies of bony fishes in 49 families using 116 names. Approximately 53 ethnospecies are identified at the species level, and 17 and 12 at the genus and family level, respectively. There are 14 species, 3 genera, and 3 families with synonymies. Only two families have a generic term and specific names for some members of each family. These are the sardines (Clupeidae) and the sea chubs (Kyphosidae), named ***xiime*** and ***ims ctocnij***, respectively.

The consultants provided on three occasions a name that applies to different genera and families, probably due to their similar shapes. ***Queajc*** is used for jacks (*Caranx* spp.) and pompanos (*Trachinotus* spp.) both in the Carangidae family; ***caasquim*** for any member of three flounder families (Bothidae, Paralichthyidae, and Pleuronictidae). There is one case in which the name is applied to two families completely different in shape but with similar habitat. These are the pilotfish (*Naucrates ductor*, Carangidae) and the remora (Echeneidae) (***ziix ixz***), both are commensals of large sharks, rays and other fishes, sea turtles, and whales swimming near or attached (i.e., remora) to them (Allen and Robertson 1994; Fischer et al. 1995).

Synonymies.—The use of synonymies is a common practice by the Seri (Felger and Moser 1985). The fish synonymies are applied mainly to species that were and are relatively common in the Seri territory. There are 26 species with synonymies, seven have an old (archaic) and a recent (new) name, five use different names for the species life stages, two have names for their color varieties, and the rest have synonymies with no specific reason. The species with more synonymies are mainly those commercially important as the mullets with seven synonymies, the whiptail stingray, the finscale triggerfish (*Balistes polylepis*), the totoaba, and the goliath grouper with four synonymies each species, and the gulf grouper with three.

Felger and Moser (1985) reported that sometimes the Seri changed a plant name because it was associated with someone who died young. None of the consultants confirmed this kind of change for any of the fish names, however. It is important to point out that in early times there were six Seri bands speaking three mutually intelligible dialects (Moser 1963). Therefore perhaps some of the archaic names are retentions from the two extinct dialects. For example, ***tohni*** is the archaic generic term for shark used by the Seri people from San Esteban Island, extinct between 1880 and 1890 (Bowen 2000).

New names are more descriptive than archaic names (Felger and Moser 1985) as in the whale shark (*Rhincodon typus*), the whiptail stingray, the finscale triggerfish, the corvinas of the genus *Cynoscion*, the goliath grouper, and the gulf grouper.

The Seri use several names to identify the different development stages of the fish species (Malkin 1962) as is also described for the fishermen in the Atlantic forest coast of Brazil by Paz and Begossi (1996) and Seixas and Begossi (2001). The knowledge of the life-cycle stages is mainly in those species highly consumed or commercialized in the past or currently. This is the case for totoaba, goliath grouper, and mullet. The generic name for the totoaba is ***zixcám cacöla***. The small totoabas (in Spanish ***machorros*** or ***machorritos***) are ***pte cocái***, which today is the term for any fish school. The juvenile totoabas are ***zixcám coosotoj***, and the biggest animals are ***haznam***. The goliath grouper is called ***masni*** or ***l̲amz*** with two age classes recognized. The juvenile is called **olájö** and live in estuaries as the elder consultants affirm and as corroborated by Thomson et al. (1979). And the adult is named ***coláxö***.

In old times, the Seri harpooned mullets (*Mugil* spp.) or poisoned them using the crushed plant sand croton (*Croton californicus*) in the estuaries (Felger and Moser 1985). Today they generally use gillnets, although consultants claim that sometimes the ethnospecies ***hapásni canoj*** is also fished with hook and line. This ethnospecies is considered the fattest and with the best flavor. There are four other mullet ethnospecies, first is ***ziix coáfp áa***, an adult mullet with two age classes: ***xlolo***, described as a small mullet that does not stick the head above the surface of the water, and ***al̲o quicös*** is larger and sticks its head above the surface of the water. The other three mullet species are ***ziix***

coafp imóocp, ***ziix coafp queme***, and ***ziix coafp caxápotol***. In addition, the Seri differentiate two age classes for two less commercially important species. The juvenile needlefish (Belonidae) are named ***heemyoj*** and the adults ***quiisaxáacoj***. The milkfish *(Chanos chanis)* are called ***xojíjö,*** and the large organisms ***xojijöáacoj***. The age division of milkfish is also use by the Paluan fishermen as reported by Johannes (1981).

The Seri distinguish two color types of roosterfish (*Nematistius pectoralis*), ***ctooml*** and ***ctoomlíispoj***. The first name is used for any roosterfish and the second for a larger roosterfish with small dark spots over its body. The latter has not been reported in the literature. The leopard grouper (*Mycteroperca rosacea*) is another species with two color varieties; one is greenish to gray-brown and the other is golden yellow. The latter is present in 1% of the population (Thomson et al. 1979). The Seri know that both varieties are the same species, calling the greenish variety ***tatcö*** and the yellow one ***tatcö cmasol*** 'yellow ***tatcö***'. They also confirmed the rarity of the golden variety and specified that it is the "queen" or leader of the leopard grouper school.

Ethnobiology and ethnoecology.—Thirty-three percent (50 names) of the fish names were unanalyzable. These names are composed by a single word and are referred as linguistically primary names, which probably have considerable antiquity as is suggested by Felger and Moser (1985) and Berlin (1992) in their ethnobotanical and ethnobiological studies, respectively. The rest, 67% (101 names), are analyzable or a portion of them is translatable. The Seri names are descriptive, empathizing anatomical, biological, ecological, or behavioral characteristics of the species. None of the names is associated with commercial use or utilitarian information, which they are characteristics used to name fish in other cultures (Paz and Begossi 1996).

Morphological characteristics. Color is an important feature to identify ethnospecies been present in 30 fish names. The Seri use the conspicuous colors of the species as white (***cooxp***) (e.g. *Carcharodon carcharias*), yellow (***cmasol***) (e.g. *Rhinoptera steindachneri*), blue/green (***coil***) (e.g., *Gymnothorax castaneus*), red (***cheel***) (e.g., *Lutjanus colorado)*, or the light effect as brilliant (***czaahox***) (*Trichiurus lepturus*) and clear (***quiimj***) (*Albula* sp. A, leptocephalus larvae). Distinctive spots (***coospoj***) (e.g. *Triakis* semifasciata) or dark (***coopol***) marks (e.g. *Haemulon steindachneri*) are commonly referred in the names. In the case of the snook (*Centropomus spp*.) the dark lateral line is not literally in the name but it is implied. The name of spot tail grunt (*Orthostoechus maculicauda*) is the combination of the small white spots along the body and the now-rarely-practiced cultural tradition of face painting. Occasionally the name does not refer to the original color. For example, according to the consultants the ventral part of ***hacat inráil cheel*** (‘red-skinned shark’) changes to red after one or two hours of its capture. Others names are the combination of a color and large size (i.e., *Galeocerdo cuvier* and *Prionace glauca*) or shape (Opichthidae). In the case of the whale shark, the name combines the dark aspect of the animal when it is observed from a boat or coast and its calm swimming. A consultant indicated that the Seri from San Esteban Island sometimes swam near this peaceful shark.

The use of size contrast in the names is a common practice observed in 19 names. The majority of the names are related to the large (***aapa***, ***caacoj***, ***cacöla***) size of the fish (e.g. *Stereolepis gigas*) or a morphological feature (e.g., *Alopias* spp.). Diminutive terms are less applied, being present in the halfbeak (Hemiramphidae) name and in a totototoba age class. The shape of the body (e.g., *Achirus* spp.) or an anatomical feature (e.g., *Squatina californica*) is indicated in 17 names. It is common to compare the shape of a fish characteristic to other animal or thing. For example, the tail of the mako shark (*Isurus oxyrinchus*) is similar to the caudal fin of the dolphins (i.e., both caudal lobules are the same size) but in different position, thus the name is 'shark that looks like dolphin'. Some names indicate the conspicuous shape of the species anatomical feature as in the hammerhead sharks (*Sphyrna* spp.), both names are related to its uncommon head shape. Three species (*Negaprion* brevirostris, *Balistes polylepis* and *Parapsettus panamensis*) have flatness related names.

Other names use texture as the distinctive characteristic, for example the barred pargo (*Hoplopagrus guentherii*) is called 'thick skinned fish' for its strong scales, and in contrast is the 'soft skinned fish' applied to the corvinas (*Cynoscion* spp.). The consistency of the fish meat is also a feature present in the names as in the California pilchard (*Sardinops caeruleus*) and the merluccid hakes (*Merluccius* spp.). Another related meat characteristic is the fat content, for example two mullet names (***ziix coafp imóocp*** and ***ziix coafp quemen***) refer to the low fat condition of the ethnospecies and a third mullet (***hapásni canoj***) is one with the highest fat content as its name implies. Furthermore, the absence (*Mustelus* spp. and *Gymnura marmorata*) or presence (*Diodon holocanthus* and *Mugil* spp.) as well as the position (*Dasyatis dipterura* and *Coryphaena* *hippurus*) and number (*Menticirrhus* spp.) of anatomical features are also used in the names.

Non-morphological characteristics. Nineteen names are related to non-morphological features. Instead these are associated with food habits, behaviors, habitats, gender, reproduction, and the effects on humans. The Seri know that the main fish predators are fishes of other species, sea lions, and birds. For example, the bonefish (*Albula* sp. A) name is associated to the pelican's food habits. On the other hand, two fish species (*Leuresthes sardina* and *Trachionotus rhodopus*) are related as food that is not consumed by birds. According to Malkin (1962), the Seri think that the majority of the fishes are carnivorous, with the exception of the mullet that eats from the sea bottom. In addition, they associated the size of the food to the size of the predator (Malkin 1962). Food habit information was included only in a name of the tiger shark (*Galeocerdo cuvier*), called 'shark that eats sea lions' and is identified as a common species in San Esteban Island, which has an important sea lion colony in the Gulf of California (Zavala-Gonzáles and Melink 1997). A consultant specified that the lemon shark (*Negaprion brevirostris*) eats mullets in Canal de Infiernillo during the summer months; he called it ***hacat xica coafp quih quihit*** ('shark that eats mullets'). While participating in a mullet-fishing trip the senior author witnessed this food behavior. Foraging behavior is also present in a finscale triggerfish name as the one that 'arrives to its edge and then stands up with the face down. Other behaviors described in the names are the sound made by the species (Haemulidae), the swimming type (*Mugil* spp.), and the reaction in fishing activities (*Eucinostomus* spp.).

Habitat information is present in two names including sand (*Antennarius avalonis*) and rocky (Gobiesocidae) bottom. The consultants identified two types of substrate used by the spotted sand bass (*Paralabrax maculatofasciatus*), ***hant cooxp iti najóo*** '***najóo*** that lives on soft bottom' and ***hast ancoj ano najóo*** '***najóo*** that lives on rocky bottom'.

Three names (*Daysatis dipterura*, *Colpichthys regis*, *Etrumeus teres*) have gender information, even though the Seri do not mean to differentiate the sexes in these species. Nevertheless, they can differentiate the species gender by the presence of two "penises" or claspers in the shark and ray males as ichthyologist do. Malkin (1962) reports that the Seri distinguished the sex in 15 bony fishes species by their size (length and width) and color. More research is necessary to test these folk observations. A consultant specified that the sailfish (Istiophoridae) with small dorsal fin are females, called ***xpeezoj cmaam***. Reproductive information is present in a name of the gulf grunion (*Leuresthes sardina*), which is well known to the Seri for its distinctive spawning behavior. This species deposits its eggs in beach sand during winter and spring in the northern Gulf of California (Moffatt and Thomson 1975), as was confirmed by the senior author on the Canal de Infiernillo beaches.

Physical effects on humans are included in three names. First is the well-known electric ray *Narcine entemedor* that causes electric shocks when its vent is touched. In addition, the consultants identified the electric ray *Diplobatis ommata*; however they do not have a name for it. The second species recognized by its effects is a mullet (***ziix coafp caxápotol***) that produces hallucinations when it is consumed. The third species is the rainbow scorpionfish (*Scorpaena xyris*), named 'soup'. The Seri explained that the dorsal spine (***yacotni***) produces high fever when a person steps on it. The feeling is similar as when a person eats a hot soup. Another toxic species known by them is the bullseye puffer. For example, Felger and Moser (1985) report that on one occasion the Seri cooked the liver of this species with cinnamon, salt, and the shrub *Euphorbia* spp. to poison a man. According to Thomson et al. (1979), this species has a highly poisonous skin, viscera, and gonads, and they do not recommend its consumption. Nevertheless, it is commercialized due to its high quality meat. The only fish species that the Seri do not consume, which are considered taboo food, are the dolphin fish (Coryphaenidae) and the sailfish (Istiophoridae). In general, non-agriculturist cultures have few food taboos (Rea 1981).

Not all of the fish names are related to a natural history characteristic of the species. This is the case of the Pacific spadefish (*Chaetodipterus zonatus*) and the Cortez damselfish (*Stegastes rectifraenum*); their names are human kinship related. Others are associated to the coyote (*Canis latrans*) that is viewed as a stupid animal in the Seri culture. These are the bumphead parrotfish (*Scarus perrico*) and the soapfishes (*Rypticus* spp.) named the 'coyote of the sea' and ***'caanj*** (=Gulf grouper) of the coyote', respectively. Finally, the name for any pipefish species (Syngnathidae) is associated with a permanent fresh water place on the mainland.

CONCLUSIONS

The Seri are a non-agriculturist culture with a vast traditional knowledge of the desert and the marine resources as is reflected in the ethnobotanical work by Felger and

Moser (1985) and in our study. This extensive knowledge is the result of hundreds of years of observations to secure their survivorship by understanding the harsh coastal desert environment in which they live. Berlin (1992) pointed out that the Seri manifest the same intense interest in looking closely at nature as agrarian groups. Therefore, he concluded that the Seri are a counterexample of the hypothesis that agriculturist cultures will have deeper knowledge of their environment than hunters and gathers.

The higher levels of the Seri taxonomy are simple, dividing the fish in three general groups, sharks, rays, and bony fishes. On the other hand, they have specific knowledge of several fish species, identifying approximately 61% of them at the species level. Knowledge is more detailed for commercially important species as in other fishing communities (Paz and Begossi 1996). The Seri fishermen focus on sharks, rays, grunts (Haemulidae), snappers (Lutjanidae), mullets (Mugilidae), croakers (Scianidae), and sea basses (Serranidae). However, some of this knowledge is beginning to be useless for the new generations due to the scarcity of some of the large species (i.e., sharks, sea basses, and totoaba) by overexploitation; thus there is a rapid switch of target fishing species. For example, the merluza (Merluccidae) and the jawfish (Opistognathidea) are relatively young fisheries of less than five years old. In contrast, fisheries of large species such as the Gulf coney (*Epinephelus acanthistius*) or the Gulf grouper have almost disappeared. An important Seri culture characteristic is their adaptability to constant changes and pragmatism (Felger and Moser 1985), in addition to their cultural predisposition to observe nature in detail. These characteristics are producing detailed new traditional knowledge. Unfortunately, ancestral knowledge and ecologically important species (e.g., top predators) are in danger of being lost.

Currently, traditional ecological knowledge had been considered an important source of information for management about natural resources (e.g. Ruddle 1994; Nietschmann 1997; Kurien 1998; Berkes 1999). In the present study we analyzed the Seri fish nomenclature to obtain biological and ecological traditional information that provide important insights into the fish of the Gulf of California. Nevertheless, there is more work to do; it is necessary to test several of the folk observations (e.g., mullet classification, disappeared flying fish species) as Nabhan (2000) suggests, and to convert this information to management tools for the Seri and as examples in other fishing communities.

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Table 1. Seri fish names within three major groups.

Scientific name	Common name	Seri name	Literal translation and comments
Sharks			
Alopiidae			
Alopias spp.	thresher shark	***hacat yeesc cacösxaj***	'shark whose tip of tail (with which a soft sound is made) is long'
Carcharhinidae			
Carcharhinus leucas	bull shark	***hacat yax caacoj***	'big-bellied shark'
Carcharhinus spp.	requiem shark	***hacat ináil cheel***	'red-skinned shark'
Galeocerdo cuvier	tiger shark	***hacat coospoj caacoj***	'large spotted shark'
Galeocerdo cuvier	tiger shark	***hacat xapóo quih quihit***	'shark that eats sea lions'
Negaprion brevirostris	lemon shark	***hacat isxáp cpatj***	'flat-headed shark'
Prionace glauca	blue shark	***hacatíil***	big shark (where–iil is a suffix meaning literally 'blue', but generally associated with large size)
Heterodontidae			
Heterodontus spp.	horn shark	**queepoj**	unanalyzable name
Lamnidae			
Carcharodon carcharias	great white shark	***hacat cooxp***	'white shark'
Isurus oxyrinchus	shortfin mako	***hacat tacj cmis***	'shark that looks like dolphin'
Rhincodontidae			
Rhincodon typus	whale shark	**hant yapol cmis**	'thing that looks like a black place'
Rhincodon typus	whale shark	***ool***	unanalyzable name (archaic)
Sphyrnidae			
Sphyrna spp.	hammerhead shark	***hacat yeen iic iti coipj***	'shark whose face has something crossways'
Sphyrna spp.	hammerhead shark	***hasménelca quiip***	'the one carrying the lower part of the arrow shaft on the head'
Squatinidae			

Squatina californica	*Pacific angelshark*	***ziix mizj quisláizil***	‘thing with well-formed shoulders’
Triakidae			
Mustelus spp.	houndshark	***hacat imitáast***	‘shark without teeth’
Mustelus spp.	houndshark	***zeemj***	unanalyzable name
Triakis semifasciata	leopard shark	***hacat coospoj***	‘spotted shark’
Rays			
Dasyatidae			
Dasyatis dipterura	whiptail stingray	***hacat cmaam***	‘female shark’
Dasyatis dipterura	whiptail stingray	***quipcöáacoj***	‘large dune’
Dasyatis dipterura	whiptail stingray	***sapcö caacoj***	‘large ***sapcö***’ (archaic)
Dasyatis dipterura	whiptail stingray	***zaaj ano quitoj***	‘thing with eyes in the cave’
Gymnuridae			
Gymnura marmorata	California butterfly ray	***ziix imíipa***	‘thing without tail’
Mobulidae	manta ray	***cainécoj***	‘large (something)’
Myliobatidae			
Aetobatus narinari	spotted eagle ray	***hatip coospoj***	‘spotted ***hatip***’
Myliobatis spp.	eagle ray	***hatip***	unanalyzable name
Rhinoptera steindachneri	Pacific cownose ray	***hacat cmasol***	‘yellow shark’
Narcinidae			
Narcine entemedor	*electric ray*	***camátni***	‘thing that gives electric shock’
Rajidae			
Raja velezi	Velez ray	***cama***	unanalyzable name
Rhinobatidae			
Rhinobatos spp.	guitarfish	***coo***	unanalyzable name
Urolophidae			
Urobatis spp.	round stingray	***cotj***	unanalyzable name
Urobatis spp.	round stingray	***cotjíispoj***	‘spotted ***cotj***’
Bony fishes			
Acanthuridae			
Prionurus punctatus	yellowtail surgeonfish	***potáca camoz***	‘the one that thinks it is a ***taca***’
Achiridae			

Achirus spp.	American sole	***caasquim cpetij***	'round ***caasquim***'
Achirus spp.	American sole	***xomcahái***	unanalyzable name
Bothidae	lefteye flounder	***caasquim***	unanalyzable name
Albulidae			
Albula sp. A	bonefish	***tosnóom***	'thing that the pelican swallows'
leptocephalus larvae	bonefish larvae	***yax quiimj***	'whose stomach is clear'
Antennariidae			
Antennarius avalonis	roughjaw frogfish	***iicj ano mooxon***	'scorpion fish that lives in coarse sand'
Ariidae	sea catfish	***hacözj***	unanalyzable name
Atherinidae			
Colpichthys regis	*false grunion*	***quizi cmaam***	'female ***quizi***'
Leuresthes sardina	*Gulf grunion*	***caha***	the name means 'the one that spawns' or 'the one that travels in a group'
Leuresthes sardina	Gulf grunion	***slee imáai***	'what the heron does not catch (at night)'
Balistidae			
Balistes polylepis	finscale triggerfish	***taca***	unanalyzable name
Balistes polylepis	*finscale triggerfish*	***tis hatéen iixöp***	'mouth harpoon ?' (it was not possible to translate complete) (archaic)
Balistes polylepis	finscale triggerfish	***toozaj hant caap***	'arrives on its edge and then stands up' (archaic)
Balistes polylepis	finscale triggerfish	***ziix hant cpatj***	'flattened thing on the bottom'
Batrachoididae			
Porichthys spp.	toadfish	***sacö***	unanalyzable name
Belonidae	needlefish	**heemyoj**	unanalyzable name
Belonidae	needlefish	***quiisaxáacoj***	'big living thing'
Blennidae	combtooth blenny	***mojcoquépni***	unanalyzable name
Blennidae	combtooth blenny	***sloocöla***	unanalyzable name
Carangidae			
Caranx spp.	jacks	***queajc***	unanalyzable name
Naucrates ductor	pilotfish	***ziix ixz***	'pet of the thing'
Selene spp.	moonfish	***iizax***	'moon'

Seriola lalandi	*yellowtail amberjack*	***xpaasmoj***	unanalyzable name
Trachinotus rhodopus	gafftopsail pompano	***siic imám***	'thing that the bird does not swallow'
Trachinotus spp.	pompano	***queajc***	unanalyzable name
Centropomidae			
Centropomus spp.	snook	***tal cöhasítox***	'the one that has a stripe line made with a coal'
Chanidae			
Chanos chanos	milkfish	***xojíjö***	unanalyzable name
Chanos chanos	milkfish	*xojijöáacoj*	'large ***xojijö***'
Clupeidae	sardine	***xiime***	**unanalyzable name**
unidentified species	sardine	***xiime ctamcö***	'male ***xiime***'
Opisthonema libertate	Pacific thread herring	***cootpam***	unanalyzable name
Sardinops caeruleus	California pilchard	***xiime coiij***	'tubular sardine'
Sardinops caeruleus	California pilchard	***xiime coozlil***	'sticky sardine'
Congridae	garden eel	***xepe no coimaj***	'snake in the sea'
Coryphaenidae			
Coryphaena hippurus	common dolphinfish	***yazmíyat cöcafp***	'whose dorsal fin arrives to the tail'
Cynoglossidae			
Symphurus spp.	tongue fish	***caasquim ipl***	'***caasquim***'s tongue'
Diodontidae			
		cotxain hatécös	'thorny ***cotxain***'
Diodon holocanthus	*masked balloonfish*		
Echeneidae	remora	***ziix ixz***	'pet of the thing'
Elopidae			
Elops affinis	machete	***zixcám itámlc cmasol***	'fish with yellow temples'
Engraulidae	anchovy	***quizi***	unanalyzable name
Engraulidae	anchovy	***xiime itéencoj caaaj***	'wide mouthed ***xiime***'
Ephippidae			
Chaetodipterus zonatus	Pacific spadefish	***matcz***	'your younger sister'
Parapsettus panamensis	Panama spadefish	***xepe iti cpatj***	'the one that is flat on the sea'
Exocoetidae	flyingfish	***xpatíinoj***	unanalyzable name
unidentified species	flyingfish	***xpatíinoj caacoj***	'large ***xpatíinoj***'

Gerridae			
Eucinostomus spp.	mojarra	***tis quipox***	'the one that pulls out the harpoon point'
Gobiesocidae	clingfish	***hast iqui cpatj***	'the one that is flat against the rock'
Gobiidae	goby	***canáajöa***	unanalyzable name
Haemulidae			
Anisotremus interruptus	burrito grunt	***quecöl***	unanalyzable name
Haemulon flaviguttatum	***Cortez grunt***	***ipajö itóopol yazim cmasol***	'the base of the tail is dark and has yellow fin'
Haemulon steindachneri	latin grunt	***ipajö it coopol***	'the base of the tail is dark'
Orthopristis reddingi	*bronze-striped grunt*	***cootzi cöcooha***	'the one that cries like a pig'
Orthopristis reddingi	*bronze-striped grunt*	***hasotoj***	unanalyzable name
Orthostoechus maculicauda	*spotail grunt*	***hantíxp iti coahtolca***	'the one that puts on white face paint'
Xenistius californiensis	*salema*	***zixcám itoj caacöl***	'fish with big eyes'
Hemiramphidae	halfbeak	iifcoj cool	'the one whose noses are small'
Istiophoridae	sailfish	***xpeezoj***	unanalyzable name
Kyphosidae	sea chubs	**ims ctocnij**	'whose gills are ball-shaped'
Girella simplicidens	Gulf opaleye	***tjamoja***	unanalyzable name
Kiphosus analogus	striped sea chub	***tjamojíil***	'blue ***tjamoja***'
Lutjanidae			
Hoplopagrus guentherii	barred pargo	***hatoj***	unanalyzable name
Hoplopagrus guentherii	barred pargo	***zixcám inaíl quipcö***	'thick-skinned fish'
Lutjanus argentiventris	yellow snapper	***xnicatl***	unanalyzable name
Lutjanus colorado	colorado snapper	***xnicatl cheel***	'red ***xnicatl***'
Lutajnus peru	red snapper	***zixcám cheel***	'red fish'
Lutjanus peru	**red snapper**	***zixcám cquihjö***	'red fish'
Merlucciidae			
Merluccius spp.	merluccid hake	***zixcám imítac***	'fish without bones'

Mugilidae			
Mugil spp.	mullet	***al̲o quicös***	'spiny ***al̲o***'
Mugil spp.	mullet	***hapásni canoj***	'what is grilled and burns with a sizzle'
Mugil spp.	mullet	***xlolo***	unanalyzable name
Mugil spp.	mullet	***ziix coafp áa***	'true thing that jumps'
Mugil spp.	mullet	***ziix coapf imóocp***	'thing that jumps and does not grow up'
Mugil spp.	mullet	***ziix coafp queme***	'thing that jumps and is worn out'
Mugil spp.	mullet	***ziix coafp caxápotol***	'thing that jumps and makes you shake'
Muraenidae		***haajöc***	unanalyzable name
Gymnothorax castaneus	Panamic green moray	***haajöc coil***	'green ***haajöc***'
Muraena lentiginosa	jewel moray	***haajöc coospoj***	'spotted ***haajöc***'
Nematistiidae			
Nematistius pectoralis	roosterfish	***ctooml***	unanalyzable name
Nematistius pectoralis	roosterfish	***ctoomlíispoj***	'spotted ***ctoml***'
Ophichthidae		***xepe no coimaj***	'snake in the sea'
any spotted species in the family	snake eel	***xepe no coimaj coospoj***	'spotted sea snake'
Opistognathidae			
Ophistognathus spp.	jawfishes	***xlapaquíta***	unanalyzable name
Paralichthyidae	large-tooth flounder	***caasquim***	unanalyzable name
Pleuronectidae	righteye flounder	***caasquim***	unanalyzable name
Polyprionidae			
Stereolepis gigas	giant sea bass	***zixcám aapa***	'enormous fish'
Stereolepis gigas	giant sea bass	***zixcám caacoj***	'large fish'
Pomacanthidae			
Pomacanthus zonipectus	Cortez angelfish	***xpatáca***	unanalyzable name
Pomacentridae			
Abudefduf troschelii	Panamic sergeant major	***tajísipl***	the name includes the idea of "marks", but is otherwise unanalyzable
Stegastes rectifraenum	*Cortez damselfish*	***zaah aqueémot***	'sun´s brother-in-law (wife´s brother)'
Scaridae			
Scarus perrico	bumphead parrotfsih	***xepenóot***	'coyote of the sea'
Scianidae			
Atractoscion nobilis	white weakfish	***zixcám coil***	'blue fish'

Cynoscion spp.	corvina	***xpatajö***	unanalyzable name (archaic)
Cynoscion spp.	corvina	***zixcám ináil caitic***	'soft skinned fish'
Totoaba macdonaldi	totoaba	***haznám***	unanalyzable name
Totoaba macdonaldi	totoaba	***pte cocai***	'the one that follows the hook'
Totoaba macdonaldi	totoaba	***zixcám cacöla***	'large fish'
Totoaba macdonaldi	totoaba	***zixcám coosotoj***	'narrow fish'
Menticirrhus spp.	king croaker	***iifnalca czooxoj***	'four nostrils'
Scombridae			
Euthynnus lineatus	black skipjack tuna	***insóc***	unanalyzable name
Scomberomorus spp.	mackerels	***cpoot***	unanalyzable name
Thunnus albacares	yellowfin tuna	***yazopoj cöitoiilam***	unanalyzable name
Scorpaenidae			
Scorpaena mystes	*stone scorpionfish*	***mooxon***	unanalyzable name
Scorpaena xyris	*rainbow scorpionfish*	***xamátaj***	'soup'
Serranidae			
Epinephelus analogus	spotted grouper	***zixcám coospoj***	'spotted fish'
Epinephelus itajara	goliath grouper	***coláxö***	unanalyzable name (archaic)
Epinephelus itajara	goliath grouper	***l̠amz***	unanalyzable name (archaic)
Epinephelus itajara	goliath grouper	***masni***	unanalyzable name
Epinephelus itajara	goliath grouper	***olájö***	unanalyzable name
Mycteroperca jordani	Gulf grouper	***caanj***	unanalyzable name
Mycteroperca jordani	Gulf grouper	***caait***	unanalyzable name (archaic)
Mycteroperca jordani	Gulf grouper	***cquenj***	unanalyzable name (archaic)
Mycteroperca rosacea	leopard grouper	***tatcö***	unanalyzable name
Mycteroperca rosacea	golden grouper	***tatcö cmasol***	'yellow ***tatcö***'
Mycteroperca xenarcha	broomtail grouper	***zixcám itéen an coopol***	'whose inside of the mouth is black'
Paralabrax loro	parrot sand bass	***najóo caacoj***	'large ***najóo***'
Paralabrax loro	***parrot sand bass***	***itámlc cmasol***	'yellow cheek'
Paralabrax maculatofasciatus	spotted sand bass	***najóo***	unanalyzable name
Rypticus spp.	soapfishes	***oot icáanj***	'***caanj*** of the coyote'
Sparidae			
Calamus brachysomus	Pacific porgy	***itaastáacöl***	'whose teeth are large' or "big-toothed"

Syngnathidae		***hast hax cyaai***	'the one that goes to Pozo Peña'
Syngnathinae (subfamily)	pipefish		
Hippocampus ingens	Pacific seahorse	***heeesam***	unanalyzable name
Tetradontidae			
Sphoeroides annulatus	bullseye puffer	***cotxáin***	unanalyzable name (archaic)
Sphoeroides annulatus	bullseye puffer	***tzih***	unanalyzable name
Trichiuridae			
Trichiurus lepturus	*largehead hairtail*	***zixcám czaahox***	'bright fish'

Table 2. Seri fish anatomy.

Feature	Seri name	Literal translation and comments
anal fin	***yastíit***	anal fin
barbells	***itéems***	barbells
caudal fin	***ipajö***	caudal fin
dorsal fin	***yazim***	dorsal fin
dorsal fin (soft)	***yazim caitic***	'soft dorsal fin', refers to the soft ray portion of the dorsal fin
dorsal fin (shark)	***yacax***	any shark dorsal fin
eye	***zixcám ito***	'fish eye'
gill	***ims***	'filter'
gill rakers	***ims itac***	'filter bone'
gonad	***iist***	gonad
gonad (male)	***izcl***	used for male gonads
gonad (female)	***iixcám ano yaii***	'where are the fish things', used for female gonads
maxillary bone	***enm haxöl***	'metal clam', it is the expression used for 'spoon'
operculum	***iisj***	operculum
pectoral fin	***isel***	'shoulder join'
preoperculum	***itáaca***	'cheek'
scale	***inéezj***	used for scales on the fish
scale	***zixcám yeezj***	used for loose scales
spine (poison)	***yacotni yacótni***	refers to any poison spines as the scorpion fish

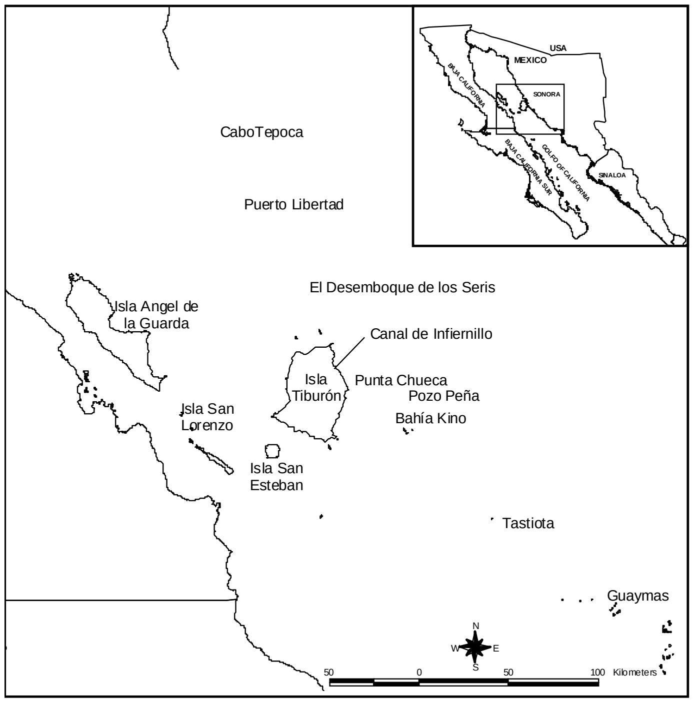

Figure 1. Map of the Seri region, Gulf of California, México.

APPENDIX C

Extent, stability, and distributional patterns of the annual eelgrass Zostera marina atam in the Canal de Infiernillo, Gulf of California, México

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Abstract

We estimated and described the extent, stability, and distributional patterns of the annual eelgrass, Zostera marina, in Canal de Infiernillo, Gulf of California. These are the most extensive annual eelgrass beds in the Eastern Pacific coast, presenting distinctive biological characteristics (i.e. high seed production and germination, and triggering germination by temperature changes). Total coverage of the eelgrass beds in the Canal de Infiernillo was calculated using oblique and vertical aerial color photography and video from a blimp and a Cessna airplane, from 1999 to 2001. Differential GPS (error < 5 m) units were used to map with computers eelgrass bed contours from an outboard motor skiff, and close inspection of beds was done from the boat or by diving in 1999 and 2000. Information on water depth and eelgrass characteristics (e.g. continuous or patchy beds, short or tall shoots) was collected to characterize the beds. In addition, traditional knowledge of the Seri Indians, native inhabitants of the area, was used to locate the eelgrass beds. The total extent of the eelgrass beds inside the Canal was approximately 6687 ha. Eelgrass beds regrew in the same areas during the three-year study, maintaining the same shapes and sizes. Twelve percent (3642 ha) of the Canal's undersea surface area is covered by continuous eelgrass and 10% (3045 ha) by patchy eelgrass. Four general types of continuous eelgrass beds were observed in terms of their location, area, depth, and shoot density and length: (1) small (average 36 ha) isolated beds near estuary mouths with medium length (40-100 cm), (2) small (30 ha) beds along Isla Tiburón with medium shoot density (2516 m^{-2}) and length (40-134 cm), (3) medium (64 ha) beds occurring in the central portion of the Canal with the lowest shoot density (502 m^{-2}) and the largest shoot length (80-150 cm), and (4) large beds (221 ha) inside shallow and protected bays presenting the highest shoot density (3444 m^{-2}) and the shortest shoot length (16-29 cm). The large extent of eelgrass in the Canal is because it is a shallow area presenting particular current patterns, and the long eelgrass life cycle in comparison to other areas in the Gulf of California. Stability and distributional patterns of the beds are caused by the accumulation of large seed banks in the sediments of specific areas of the Canal. Interaction of whirlpool currents, sand structures (bars, waves, and points on shore), protected bays, and shallow waters keep the seeds in the same areas. Mapping of the eelgrass beds in this area is the first step towards a long-term monitoring of the Seri Indian territory.

Keywords: eelgrass; Gulf of California; computerized mapping; monitoring; Seri; traditional knowledge

Introduction

Marine ecosystem monitoring is a difficult task due to the size and complexity of this environment (Norse, 1993; Thorne-Miller, 1999). Thus, a recommended approach is to use a taxon that provides much of the ecosystem's physical structure in order to monitor ecosystem health (Norse, 1993). It is assumed that if this key species is disturbed or destroyed, the biodiversity of the ecosystem will decrease. Seagrasses are key species because they form the basis of some of the most productive marine ecosystems on earth (Lee Long et al., 1996; Short and Wyllie-Echeverria 1996; Wood and Lavery, 2000). Seagrasses play significant ecological roles in supporting complex communities and food webs, stabilizing bottom sediments, improving water clarity, and removing and recycling nutrients from sediments and water (Dawes, 1981; Williams and Heck, 2000).

The first step for monitoring seagrasses is to obtain baseline information on the extent and distribution of the beds in a region (Lee Long et al., 1996). Along the North American Pacific coast, the eelgrass Zostera marina L. has been mapped in Alaska (e.g. Izembeck Lagoon) (Ward et al., 1997) and Washington (e.g. Padilla Bay) (Bulthuis, 1995; Norris et al., 1997) and coastal lagoons along the west coast of the Baja California peninsula (Ward et al. 2002). However, there are many eelgrass areas that have not been mapped (Ward et al., 1997) and which are probably being impacted by anthropogenic activities (Short and Wyllie-Echeverria, 1996). Such is the case of eelgrass beds at the southern limit of this species inside the Gulf of California. Santamaría-Gallegos (1996) reports cover and density reduction of eelgrass beds in Bahía Concepción on the Baja California peninsula caused by the action of shrimp bottom trawling. The same is probably occurring to the eelgrass beds on the Gulf's continental side in Sonora (e.g. Bahía Kino) and Sinaloa. The swimming crab (Callinectes bellicosus) fishery has an effect on the eelgrass beds in Canal de Infiernillo, Sonora (Torre-Cosío and Boruillón-Moreno[8]). However, eelgrass extent and distributional information has not been available for the area until now.

Eelgrass in the Gulf of California has particular physiological characteristics, belonging to an ecotype called atam—one of the five ecotypes described by Backman (1991) along the East Pacific Coast. While eelgrass germination on the North American Pacific coast is activated by low salinity (Phillips et al., 1983), germination in the Gulf ecotype is triggered by temperature changes (Felger and McRoy, 1975; McMillan, 1983; Phillips and Backman, 1983; Phillips et al., 1983; Meling-López and Ibarra-Obando, 1999; Santamaría-Gallegos et al., 2000). In addition, Gulf populations have 100% production of flowering shoots and the highest recorded seed germination (94%) in western North America (Phillips et al. 1983). These characteristics produce true annual populations inside the Gulf, which present life cycle spans that range from six to nine months (Felger and McRoy, 1975; Phillips and Backman, 1983; Phillips et al., 1983; Meling-López and Ibarra-Obando, 1999; Santamaría-Gallegos et al., 2000). Canal de Infiernillo presents the larger eelgrass life cycle, which can be summarized as follows, seeds germinate from late October to December due to low water temperatures (18-22ºC), rapid vegetative growth occurs during December and January (14-16ºC), and the reproductive phase starts in February (Phillips and Backman, 1983; Felger and Moser,

[8] See Appendix D of the dissertation for details of the swimming crab fishery impacts in the Canal.

1985; Meling-López and Ibarra-Obando, 1999; Santamaría-Gallegos et al., 2000; J. Torre-Cosío unpub. data). Then, in late April when temperature rises (22ºC), eelgrass begins to detach. May is when most of the massive die-off occurs (24-26ºC). In June and July eelgrass beds are reduced to small patches with broken blades and from July to mid-October (30-32ºC) they can become bare areas, with only seeds remaining in the sediment (Phillips and Backman, 1983; Felger and Moser, 1985; Meling-López and Ibarra-Obando, 1999; Santamaría-Gallegos et al., 2000; J. Torre-Cosío, unpub. data) (Fig. 1).

The Canal de Infiernillo has the most extensive eelgrass beds in western México (Felger and Lowe, 1976; Felger and Moser, 1985). They are grazed by sea turtles (Felger et al., 1980; Felger and Moser, 1985) and thousands of black brants (Branta bernicla nigricans) in winter (USFWS, 1965-2001; Felger and Moser, 1985; Kramer and Migoya, 1989). The eelgrass seeds were an important food resource for the local indigenous group Seri (or Comcáac) and their ancestors for thousands of years (Felger and Moser, 1985). They also used eelgrass for medicine, shelter, and to make toys (Felger and Moser, 1973, 1985). The most important fisheries in the Canal de Infiernillo today, swimming crab (Callinectes bellicosus) and pen shells (Atrina spp. and Pinna rugosa), have important relationships in terms of their ecology and fishery management with the eelgrass life cycle (Basurto-Guillermo, 2001; Bourillón-Moreno, 2002). Even though eelgrass is the main bio-structure in the Canal de Infiernillo and is easily distinguished from the air, there are no aerial coverage estimation and distributional information for this area. In this study, three years (1999-2001) of aerial and surface surveys, combined with Seri traditional ecological knowledge, were used to assess the extent and distribution of the Canal de Infiernillo continuous and patchy eelgrass beds. Due to the annual eelgrass pattern, selected beds were monitored to evaluate their stability to regrowth in the same area year to year. This study is the first step toward development of a long-term monitoring program of the eelgrass beds of the Canal de Infiernillo.

Study Area

Canal de Infiernillo (29º7'N, 112º13'W) is 29,753 ha of shallow (average depth 5.5 m), long (41 km), and narrow (range 1.8 - 10 km wide) channel located in the north-central portion of the Gulf of California (México), between the east coast of Isla Tiburón and mainland Sonora. Surface seawater temperatures range from 14ºC in winter to 32ºC in summer (Felger and Moser, 1985; Meling-López and Ibarra-Obando, 1999). In this desert region, no rivers or streams flow into the Canal, and freshwater only reaches the area during the rainy seasons (July-September and December-January) (Felger and Moser, 1985). The average salinity is 35ppt, but can reach 40ppt in the mangrove (Rhizophora mangle, Laguncularia racemosa, and Avicenia germinans) negative estuaries or esteros [i.e. estuaries that have higher evaporation than precipitation or runoff (Brusca 1980)] along the Canal.

The mixed semidiurnal tides produce characteristic tidal current patterns along the Canal de Infiernillo. When the tide is rising, water enters through both ends of the channel, producing two masses of water that meet in the middle. When the tides ebb, water flows out through both ends. These current patterns produce distinctive sand formations (bars, points, and waves) (Merifield et al., 1970).

Sand and mud cover the majority of Canal de Infiernillo's bottom. However, there are a few small rocky areas along the coasts. Another important hard substrate is the extensive areas (> 25 ha) of mussel aggregations (family Mytilidae). Besides eelgrass, ditch-grass Ruppia maritima and the seagrass Halodule wrigthii are part of the submergent marine vegetation. Life cycle information for these species is limited, however R. maritima is probably annual (R. S. Felger, personal comm., Drylands Institute) and H. wrigthii is perennial (McMillan and Phillips 1979). These other grasses occupy smaller areas than the eelgrass beds (J. Torre-Cosío, unpub. data). Ditch-grass is distributed inside the esteros or is intermixed with eelgrass, and H. wrigthii occurs mixed with eelgrass and ditch-grass (McMillan and Phillips, 1979; Felger et al. 1980, Felger and Moser, 1985) or in small single-species patches. Furthermore, there are up to 200 species of algae in the Seri region (Felger and Moser, 1985), Caulerpa sp, Padina durvillaei, and Sargassum spp. being the most abundant. Caulerpa sp. seems to take over the eelgrass areas during summer and fall months (Basurto-Guillermo, 2002; J. Torre-Cosío, unpub. data).

Materials and methods

Aerial surveys

Two techniques were used to obtain aerial information on eelgrass extent and stability over time, and distributional patterns. First, on March 3, 1999, vertical color video was filmed with a video camera (Sony 357) mounted in a 5.5 m by 2 m helium filled blimp, as was used by López-Blanco et al. (1998) to map Phillospadix spp. The blimp was elevated to 450-500 m above the ground and pulled by a boat (7 m long) with an outboard motor. A second boat was constantly under the video camera view obtaining geographic positions with a manual Garmin XL GPS unit every minute, along with depth and bottom type (algae, mussel areas, eelgrass, sand). The bottom type was identifiable from the boat due to the high transparency of the water. This survey only covered the central portion of Canal de Infiernillo and the eelgrass beds along Isla Tiburón coast. No zoom was used in the video. A series of digital images of areas approximately 300 x 220 m each were obtained from the video. Using these images, photo mosaics of the eelgrass beds were produced with approximately 20% image overlap. Then they were georeferenced with the positions taken by the second boat using the imaging analysis module of Arc View (version 3.2). To estimate eelgrass bed area, their outlines were drawn following the edge with the highest shoot density (i.e. darker contour) in Arc View.

The second aerial survey technique consisted of aerial photographs taken from a Cessna 182 airplane on November 27, 1999, March 18, April 22 and November 28, 2000, and March 13, 2001. The November flights coincided with the eelgrass reestablishment and fast growing season, and the March and April flights were during the peak biomass (full growth) of the eelgrass beds. Flights were conducted in two parts, first at an altitude of 2750 m and second at 1370 m, and in both cases the aircraft followed the channel coast. Oblique photographs (color slides) were taken with a SLR Canon T70 using a Phoenix 28-80 mm macro lens. A polarized filter was used to enhance the contrast between the eelgrass beds and the sandy bottom. In the 2750 m altitude flight, vertical photographs of selected areas in the Canal de Infiernillo were taken. The aircraft turned sideways until the right window, from where photos were taken, was approximately parallel to the ground to shoot photos at a vertical angle. On the March 2001 flight, an oblique digital video was taken with a Sony DCR-TRV510 camera. In addition, on June 28, 1998, when no eelgrass beds were present, an oblique video was taken with a Sony CCD-TR600 camera at an altitude of 1370 m. Photographs and videos always included a portion of the coast for further georeference. Flights were carried out during Beaufort scale of 0 or 1, between 7:30 am and 11:00 am, before afternoon winds began, and at low tide, no more than 5 days from the full or new moon.

A list of areas with continuous eelgrass beds was compiled for the Canal de Infiernillo. The presence or absence of these beds in the 1999-2000 and 2000-2001 seasons was noted. The 1999 information from the video taken from the blimp was incorporated into this list. The still photographs were classified according to the water clarity, eelgrass and sand contrast, and verticality. The best slides were scanned (600 dpi resolution) and georeferenced using the digitized continental coast maps (1:50,000 scale, INEGI) and the Isla Tiburón coastline was mapped using the differential GPS technique. The same procedure was used with images obtained from the blimp to estimate the eelgrass bed sizes in Arc View. Photographs were scanned and the outline of dense eelgrass areas were drawn.

Surface surveys

Transects in the Canal de Infiernillo were conducted on March 17, 18 and 27, April 13 and 14, December 21 and 30, 1999, and March 26, 2000, to locate and map eelgrass beds. The mapping procedure consisted of following the eelgrass bed edge from the surface with an outboard motor boat using polarized sunglasses and with the aid of an aqua scope. Differential GPS (error < 5 m) was used when making the maps. A Motorola GPS workhorse unit connected to a portable laptop computer obtained positions every second was taken aboard, and another GPS unit was stationed at Bahía Kino town as reference to correct the boat positions latter. The software Geolink (GeoResearch: Geolink version 4.1d and Postpoint version 3.3) was utilized to process and correct the data, and the final maps were managed in Arc View as were the aerial photographs. Every minute the water depth and the following eelgrass bed characteristics were recorded during the mapping process. The bed characteristics were estimated from boat observations as short (< 30 cm) or tall (> 30 cm), as continuous or patchy. Continuous eelgrass beds presented a compact arrangement of eelgrass shoots with little or no exposed sand patch area, and the patchy comprised sparse patches of grass with many continuous sand spaces. Mapping was carried out during sea conditions of Beaufort scale of 0 or 1 and good water visibility in order to see the bottom from the surface.

In addition to the eelgrass mapping, selected beds were closely inspected by snorkeling or diving on February 27 and 28, March 3, November 8, December 25, 1999, and March 27 and April 20, 2000. During the dives of March and April, 2000, four scattered samples of eelgrass $0.04 m^2$ each were taken in the central portion of the Canal (5 m), near Punta Palo Fierro (3-4 m), and Punta Hona (3 m). Shoot density and length was determined following the methodology of Meling-López and Ibarra-Obando (1999).

Seri traditional knowledge

Seri profound biological and ecological traditional knowledge has been well documented (Malkin, 1962; Felger and Moser, 1985; Nabhan, 2000; Basurto-Guillermo, 2001; Bourillón-Moreno, 2002; Torre-Cosío and Findley[9]). They can identify the precise location of individual eelgrass beds in the Canal de Infiernillo (Felger et al., 1980; Felger and Moser, 1985). Interviews about the Canal's eelgrass distribution were conducted with two Seri, 68 and 59 years old, recognized by the community as persons with profound traditional knowledge (one of them is a member of the elders' council of the tribe). As part of the interview methodology, black and white aerial photographs (1:75000-scale from 1994, INEGI) were used to aid in the identification of eelgrass areas. In addition, during the flights on June 28 and November 27, 1999, the two-interviewed Seri participated. Notes were kept of the areas pointed out by them from the air as eelgrass zones. Furthermore, during the eelgrass mapping from a boat a Seri guide was always present, helping to locate eelgrass beds based on his own knowledge.

Results

The total extent of eelgrass beds was 22% (6687 ha) of the Canal de Infiernillo area. Beds persisted in the same areas and maintained similar general shapes and areas from 1999 to 2001 (Fig. 2). The Seri consultants confirmed the reestablishment every year and the long-term stability of the beds with their oral history. Based on the characteristic of persistence, a composite map of the three years of data was produced showing the March and April bed sizes, when the eelgrass is fully-grown (Fig. 3).

[9] See Appendix B of the dissertation for details of fish traditional knowledge.

Twenty-six separate mapped beds formed the continuous eelgrass beds covering 12% (3642 ha) of the Canal the Infiernillo bottom. Two of them were partially mapped due to bad water clarity. These were the large beds south of Punta Arenas (ca. 544 ha) and along Bahía Sargento (ca. 1162 ha). The remaining 24 beds ranged from 4 ha to 243 ha, 67% with areas of less than 50 ha, 33% between 50 and 243 ha. In addition, 10% (3045 ha) of the Canal is covered by ten areas of patchy eelgrass along the coasts and in the central-north portion of the channel. The patchy eelgrass beds range from approximately 24 to 1057 ha, 80% above 100 ha. The limits of these areas were draw using aerial photographs, video and the Seri traditional knowledge. These areas contain short (20 cm) and tall (80 cm) eelgrass in compact areas (< 1 m^2). Presence of eelgrass outside the Canal, in the south mouth near the coast, was also identified (Fig. 3).

Continuous eelgrass beds were grouped in four areas according to their location in the Canal de Infiernillo, size, depth, and shoot density and length (Table 1). First are the isolated areas near estuary mouths and large sandbars such as the beds near Estero Sargento and Estero de Punta Perla, that cover 3% (107 ha) of the total continuous eelgrass areas (Fig 3). The eelgrass characteristics of these beds are similar to the ones along Isla Tiburón coast (11%, 394 ha), from Punta Coniic to Punta Tormenta. The third group of eelgrass beds is located between Punta Arenas and Punta Hona covering 24% (865 ha). These beds have the lowest shoot densities and tallest shoots in the Canal, with records of 150 cm long. Large areas of rippled sand and mussel substrate characterize this region; in the last substrate there is no growth of eelgrass. The last group of eelgrass beds grows inside large (3890-620 ha), shallow (1-6 m) protected bays (18%, 664 ha) such as south of Punta Hona, Punta Chueca, and Punta Xefe, having the highest shoot density and the shortest eelgrass of all the areas. No quantitative shoot density and length data were collected on the large bed along Bahía Sargento (44%, 1612 ha). However, by visual inspection, characteristics are found to be similar to the eelgrass along Isla Tiburón and the central portion of the Canal.

Discussion

The Canal de Infiernillo has the most extensive annual eelgrass beds in the East Pacific. However, there are other annual eelgrass populations along the continental coast of the Gulf of California, between Bahía Kino (28º 25'N) and Altata (24º20'N) (Felger and Lowe 1976; Felger and Moser, 1985; Ramírez-García and Lot, 1994). These eelgrass beds are along the coastline and inside estuaries, they are relatively small and difficult to detect. Information of their phenology and dynamics is unknown. Bahía Concepción (26º45'N) is the only area in the Baja California peninsula with eelgrass beds (Riosmena-Rodríguez and Sánchez-Lizaso, 1996; Santamaría-Gallegos, 2000). This area generally has similar characteristics to the Canal de Infiernillo: size (26,400 and 29,756 ha), shape (large 40 km and narrow 2-10 km), water temperature range (18º-32ºC), salinity (average 35ppm), annual rainfall (average between 100-250 mm), sea bottom (sand and mud), and tidal patterns. The main difference is depth, with Canal de Infiernillo (average 5.5 m) shallower than Bahía Concepción (average 17 m) (Santamaría-Gallegos, 1996). The Canal has two water entrances, which affects the flow out currents. The eelgrass season has a duration of six months in Bahía Concepción and up to nine months in the Canal. These three differences (depth, currents, and season length) are probably the main causes of the larger extent of the Canal eelgrass beds. Since they have more area in terms of depth, the seed dispersion by currents and the longer season, allows the colonization of more area.

In the present study we observed that eelgrass beds reestablish in the same areas maintaining similar general shapes and sizes year after. This pattern of permanency is the result of the interaction of four factors: seed production, seed dispersion mechanisms, currents, and bottom type. The eelgrass seed banks must be abundant due to the large seed production that characterizes the Canal eelgrass ecotype (Phillips et al. 1983). Studies by Phillips and Backman (1983) and Meling-López and Ibarra-Obando (1999) reported in average a minimum of 19 783 seeds m^{-2} and a maximum of 244 806 seeds m^{-2}. During three months (February-April) the ripe seeds are released in the production sites and accumulation in the sediments. McMillan (1983) suggested that the seeds probably do not germinate the next season after their production, instead they stay as part of the seed reserve, increasing the seed bank.

In the Canal de Infiernillo the major seed dispersion occurs during the months when eelgrass dies-off (April and May) and shoots have the highest number of mature seeds (Meling-López and Ibarra-Obando, 1999). A portion of the eelgrass shoots break off forming large floating rafts (Felger and Moser, 1985), being an important seed dispersion mechanism. Unknown portions of these shoots are moved out of the Canal during the ebb tides, and the rest drifts to the Canal´s beaches. On the other hand, when the north and south water masses encounter each other during rising of the tides, a nullifying effect between currents is produced in the central portion of the Canal, from

Punta Arenas to Punta Hona, slowing down the currents and forming whirlpools (Basurto-Guillermo, 2001). This contributes to the permanence of the detached shoots inside and in central areas of the Canal. Not all formed large eelgrass rafts are washed ashore, due to their weight some of them sink or are entangled with the unbroken remains of eelgrass on the bottom. In addition, some of the eelgrass dies and stays in place. Another factor that keeps the shoots and seeds in the same production areas is the algae Caulerpa spp. and other seaweeds, which occupy some of the same areas in fall and summer providing shield to the eelgrass dead shoots and seeds from currents. The particular current patterns in the Canal probably have accumulated dead shoots and algae through time in certain protected areas making sediments richer with organic matter than in areas probably more exposed to currents. Therefore, these areas are more suitable for reestablishment of eelgrass than others.

It is important to point out that beside the seed loss by the rafts floating out of the Canal and washed ashore, there is an unknown loss by consumption from sea turtles and waterfowl (Felger and Moser, 1985). In addition, the swimming crab Callinectes bellicosus is highly abundant in the area and supports an important fishery (Montemayor-López and Torre-Cosío, 2001; Bourillón-Moreno, 2002). This fishery probably has an impact on the seed bank by the interaction between the traps and the sediment (Torre-Cosío and Bourillón-Moreno, in prep.); or by consumption by crabs as has been reported for the blue crab (C. sapidus) in the west Atlantic (Fishman and Orth, 1996).

The accumulation of seeds and organic matter, current patterns, and water depth determine the distribution of continuous and patchy eelgrass beds. The continuous eelgrass beds are located in areas protected from the strong currents [ca. 1m/s (Merefield, 1971; Maluf, 1983)] as bays, sandbars, sand waves, and sand points, or among mussel aggregations, retaining shoots and seeds. Jacobs (1982) observed that the intertidal annual eelgrass in west Europe keep the same areas due to low seed movement from the production site by low currents. On the contrary, the patchy eelgrass areas in the Canal are more exposed to the currents, thus the probability to maintain a rich seed bank and organic matter is lower, producing a disperse distribution of shoots. The difference of shoot density and length inside the eelgrass is related to light availability as reported by Meling-López and Ibarra-Obando (1999). These authors state that in deep water light availability is lower, thus eelgrass is adapted to produce large shoots at the expense of the density as is observed in the eelgrass beds between Punta Arenas and Punta Hona. The opposite is found in beds inside shallow bays (e.g. Punta Hona) where the shoot density is high and the shoots are shorter.

The Canal de Infiernillo primary productivity has not been measured but it is clearly to be high due to its nine-mangrove esteros and eelgrass biomass produced every year. In addition, the north and south Canal mouths are close to areas of high phytoplankton concentrations (Bahía Agua Dulce and Bahía Kunkaak) (Vonder Haar and Stone, 1973; Molina et al. 1997). Meling-López and Ibarra-Obando (1999) reported that there is no significant difference between dry weight (DW) of above ground eelgrass biomass in the Canal shallow (2 m) and deep (5 m) beds. These authors estimated an average biomass from March and April (1997) of 425 g DW/m^{-2} (standard deviation 254.33). We estimated, using the information reported by these authors, that approximately the total dry weight biomass for the continuous eelgrass beds in a time during the maximum eelgrass growth months is 15 479 tons. Equivalent to 5882 tons of carbon using the 0.38 factor proposed by Ibarra-Obando (1985) for the proportion of carbon in a dry weight sample of eelgrass.

In this first estimation of the eelgrass beds extent and description in Canal de Infiernillo, we encountered three main methodological problems that need to be refined in any future evaluations. First, the blimp and aircraft were moved by air affecting the photographs and video verticality, thus their georeferencing. The mapping from the boat using differential GPS had an error with respect to the eelgrass edge; it was not always possible to be exactly over the edge. The third problem was that some of the continuous eelgrass areas have sections with patchy eelgrass inside, thus affecting the bed size estimation.

In conclusion, Canal de Infiernillo presents unique abiotic characteristics such as currents, sand structures (bars, points, and waves), protected bays, shallow waters, and sediments with high contents of organic matter that produce suitable areas for extensive annual eelgrass beds. These characteristics, in addition to the high production of seeds of this eelgrass ecotype and the proportion that survive the summer months buried in the sediment, make the reestablishment of eelgrass possible every year in the same areas with beds of similar shape and size. Measurement of the extent and distribution are the firsts steps toward a long-term monitoring program of this unique eelgrass population. We recommend monitoring using vertical aerial photographs between March and April at least every three years to detect possible cover changes. In addition, selected eelgrass beds must be surveyed for structure changes in shoot density and seed production.

Acknowledgements

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Table 1. General eelgrass bed characteristics in Canal de Infiernillo during the full growth months (March and April). Averages are followed by standard deviation in parenthesis.

Eelgrass bed location	Size (ha)	Bottom Depth range (m)	Shoot density (m^{-2})	Shoot length (cm)
Isolated (Punta Sargento and Punta Perla)	35.81 (17.35)	3-5	No data	40-100[a]
Along Tiburón Island (Punta Coniic to Punta Tormenta)	30.30 (34.93)	1-7	2516 (945.88)	40-100[a]
				134.40 (25.94) [b]
Punta Arenas to Punta Hona	64.24 (61.77) [c]	2-7	502.00 (223.98)	80.27 (20.8)
			657.91 (478.31)[d]	81.16 (8.39)[d]
Inside bays (south of Punta Chueca, Punta Hona and Punta Xefe)	221.22 (19.69)	1-6	3344.00 (904.16)	15.91 (2.35)
			3252.50 (365.32)[d]	23.96 (5.21)[d]
				28.79 (7.41)[b]

[a]No samples were collected, however their height were estimated.

[b]Data from March 1977 between Punta Palo Fierro to Punta Perla (Phillips and Backman, 1983).

[c]Does not include the large eelgrass bed of 544 ha, since its limits were not mapped with precision.

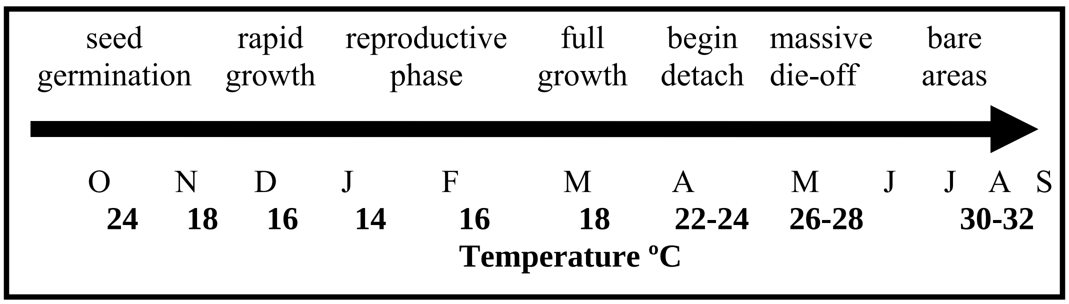
[d]Data from March and April 1997 at Punta Víboras and Punta Chueca, respectively (Meling-López and Ibarra-Obando, 2000).

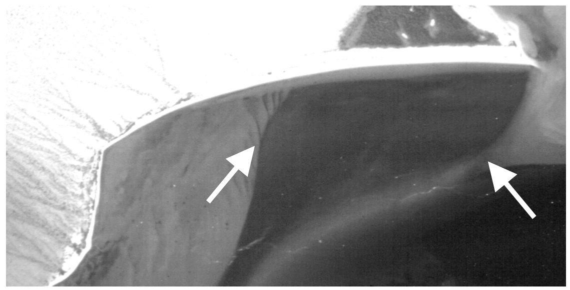
Figures captions

Fig. 1. Eelgrass life cycle in Canal de Infiernillo.

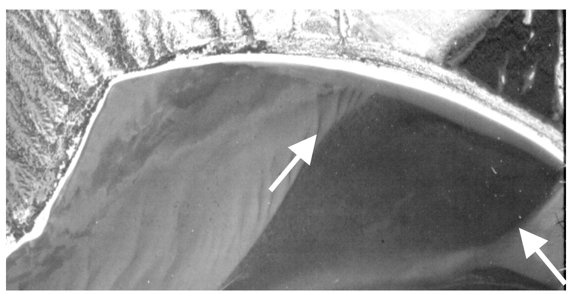
Fig. 2. Two examples of areas in Canal de Infiernillo where eelgrass regrew in the same areas and with similar general shape and extent every year. White arrows point characteristic features of the eelgrass beds.

Fig. 3. Composite map of the eelgrass beds from 1999 to 2001 in March and April in Canal de Infiernillo.

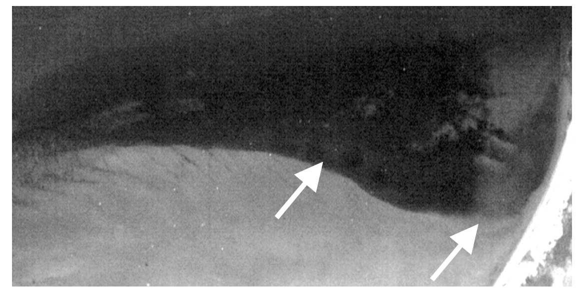

seed germination
rapid growth
reproductive phase
full growth
begin detach
massive die-off
bare areas
O N D J F M A M J J A S
24 18 16 14 16 18 22-24 26-28 30-32
Temperature ºC



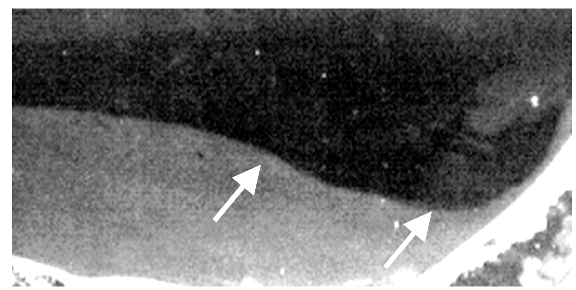
a



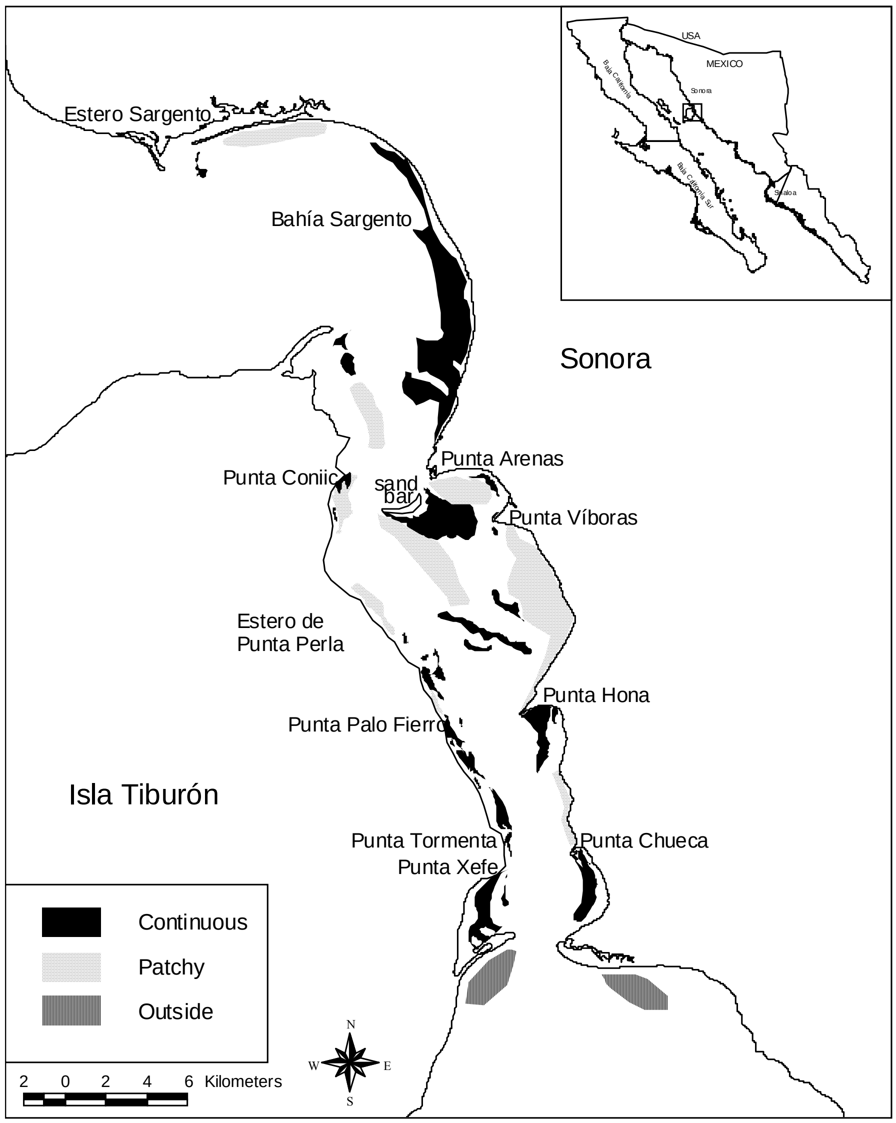
b



c



d



USA
MEXICO
Baja California
Sonora
Baja California Sur
Sinaloa
Estero Sargento
Bahía Sargento
Sonora
Punta Arenas
Punta Coniic
sand bar
Punta Víboras
Estero de Punta Perla
Punta Hona
Punta Palo Fierro
Isla Tiburón
Punta Tormenta
Punta Chueca
Punta Xefe
Continuous
Patchy
Outside
N
W
E
S
2 0 2 4 6 Kilometers

APPENDIX D

Impacts of the swimming crab (*Callinectes bellicosus*) fishery in the Canal de Infiernillo, Gulf of California, México

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Keywords: eelgrass, bait for crab traps, bycatch, Comcáac Indians, ghost fishing, Seri Indians, traps, *Zostera marina*

Abstract

This is the first study that describes and evaluates the swimming crab (*Callinectes bellicosus*) fishery ecological impacts in the Gulf of California. The study area was Canal de Infiernillo that is part of the exclusive fishing zone of the Seri Indians. Data from 1998 to 2001 were used to assess the impacts of the fishery. First, we determined the area of overlap between the crab fishing zones and the annual eelgrass (*Zostera marina*) beds to estimate the mechanical disturbance of the fishing gear. We produce maps of the crab fishing zones and eelgrass beds using a differential GPS, aerial photographs and video, and interviewing Seri fishermen. The eelgrass beds and the fishing crab zones cover 6687 ha and 5443 ha, respectively. Twenty-six percent of the eelgrass beds overlap with the trap zones. Next, we evaluated the effects of the fishing activities to obtain bait and the by-catch on invertebrates, sub-legal size swimming crabs, and fish by participating in commercial fishing trips. Crab buyers provide the bait, but on occasion fishermen catch their own, using hook and line as the most selective method. However, fishermen also use gillnets to fish faster capturing and using 34 species as bait, some of them juveniles. Bycatch species are restricted to six invertebrate and six fish species. Finally, we described ghost (or lost) traps deteriorating conditions and their impacts on marine fauna through censuses during off-fishing season in the summer to estimate the number of ghost traps and examine its contents. Major impacts of the ghost traps are continuous fishing effects and modification of the substrate as they move around and accumulate on the sea bottom. Efforts to standardize the use of crab traps will prevent the impacts on the same fishery in the long term.

Introduction

Fishing gear is a major anthropogenic disturbance that produces habitat destruction and fragmentation, along with overexploitation of target and non-target species and pollution in marine environments (Norse 1993, National Research Council 1995, Bohnsack and Ault 1996, Watling and Norse 1998). Traps or pots are fishing gear commonly used worldwide to capture gastropods, crustaceans, and fish. The little evaluation research to the trap ecological impacts has been mainly on ghost trapping (i.e., the continued capture of organisms by abandoned, discarded or lost fishing gear) of the lobster (Sheldon and Dow 1975, Pecci et al. 1978, Parrish and Kazama 1992) and crab fisheries (Breen 1987, Guillory 1993, Stevens 1996, Bullimore et al. 2001). In addition, studies of trap selectivity (Guillory 1998, Guillory and Hein 1998) and bycatch (Guillory 1993, Roosenburg et al. 1997, Guillory and Prejean 1998, Cole and Helser 2001) are mainly focused on the traps used to catch blue crabs (*Callinectes sapidus*) in the West Atlantic. Beside the listed fishing impacts other positive or negative trap effects include: 1) the direct physical trap impact on the sea bottom, 2) traps as substrate for colonization and refuge, and 3) the ghost (or lost) traps as trash affecting the marine and coastal landscapes. None of these trap impacts have been studied in the new and fast growing swimming crab fishery (*Callinectes* spp.) in the Gulf of California, México.

The blue crab fishery, one of the main fisheries in the United States (Rosenfield 1998), is having fluctuations due to overexploitation and habitat deterioration (Engel and Thayer 1998, Jordan 1998). This is producing a growing demand for crab products from other countries. Thus crab exports (*Callinectes* and *Portunus*) have increased mainly from Asia and Latin America to the United States (Johnson et al. 1998, Oesterling 1998). The American blue crab industry entrepreneurs are the principal investors in the establishment and fast development of crab fisheries in other countries (Oesterling 1998). For example, in 1995, crab products imported into the United States totaled 8840 mt, valued at US $74.6 million (Oesterling 1998). This year México was first in exports from Latin America, and second in the world, with 1500 mt of crabmeat valued at US $16 million. The crab fishery started in the Gulf of Mexico, and developed in the Gulf of California on a large scale in the mid 1980s (Molina-Ocampo 2000). The state of Sonora is the major producer in the Gulf of California, obtaining its maximum yield of hard shell crab in 1996 with approximately 8000 mt (Dario Oficial de la Federación 2000, Molina-Ocampo 2000).

Three species of swimming crab (locally called *jaiba*) are fished in the Gulf of California, *Callinectes arcuatus*, *C. bellicosus*, and *C. toxotes*. In Sonora, *C. bellicosus* is the main target species captured using modified “Chesapeake Bay type” traps, a rectangular (60 X 60 X 40 cm) design of hexagonal mesh (5.7 X 3.1 cm) of plastic-coated metallic wire. Traps have two or four entrance funnels, one cilindrical bait box, and one or two floors or compartments. Each trap is attached by rope to an individual buoy for its identification in the surface. The trap base has a steel re-bar frame as ballast to stay on the sea bottom. They are checked daily to retrieve the catch and re-baited. The total number of traps used along the coast of Sonora was around 30,000 in the fishing seasons 1999 to

2001[10]. Nevertheless, for the season 2002-2003 the government gave permits for the use of 70,420 traps in Sonora (El Vigía, 2002[11]).

Sonora is a leader in management regulations for this fishery in the Gulf of California, including: 1) fishing is allowed only from mid July through March; 2) a minimum size capture is recommended by the Government, for example between 1998 to 2001 the minimum carapace length was 5 cm; 3) traps are not allowed inside estuaries and in the Colorado River Delta; 4) two escape rings (5.3 cm) are obligatory in each trap; 5) no capture is permitted of egg-bearing females; 6) fishing using trawlers is prohibited; 7) a maximum of 70 traps is permitted per boat; and 8) traps must be removed from the water at the end of the fishing season (Diario Oficial de la Federación 2000, Molina-Ocampo 2001). In addition, the National Fishing Chart recommend an average annual capture per unit of effort (CPUE) of 0.2 kg/trap in the Gulf of California (Dario Oficial de la Federación 2000).

In the present study, we identify and examine the impacts of the swimming crab fishery along a small portion of the Sonora shore inside Canal de Infiernillo. This coastal region is the exclusive fishing zone of the Seri (or Comcáac) Indians, and is characterized by its high crab production. Bourillón-Moreno (2002) reports that in the fishing season 1999-2000, 173 mt of hard shell crab were obtained in one of the Canal's two fishing ports. In addition, this author states that this area is characterized by a large proportion (> 90%) and large size of male crabs (maximum reported carapace length of 88 mm)

[10] Molina-Ocampo, R. 2002. Personal común. Instituto Nacional de la Pesca (INP). Centro Regional de Investigación Pesquera (CRIP) de Guaymas, Calle 20 No. 605 sur, Guaymas, Sonora, C.P. 85450, México.
[11] El Vígia. Newspaper from Guaymas, Sonora. July 13, 2002. Front page.

compared to other fishing zones in Sonora. Based on their extensive traditional knowledge, the Seri fishers know that eelgrass (*Zostera marina*) is one of the main habitat that support crab and other fisheries in their territory. In recent years, Seri fishermen have voiced their concern about the effects of crab traps on eelgrass beds. The objectives of this study were to: 1) determine the area of overlap between the fishing crab zones and the annual eelgrass beds and to describe the trap physical effects on the eelgrass life cycle, 2) evaluate the impacts on the population of marine fauna due to the extraction of bait used for traps and the bycatch produced in the crab fishery, and 3) describe ghost trap evolving conditions over time after being lost on the bottom of the sea and their ecological positive or negative impacts.

Methods

<u>Study Area</u>

Canal de Infiernillo is a long (41 km), shallow (average depth 5.5 m) and narrow (range 1.8 – 10 km) channel located in the north-central portion of the Gulf of California. The Canal bottom is mainly sand and mud, and the only hard substrates are large zones (< 25 ha) of mussel aggregations (mainly *Modiolus capax*) and few small patches of rocky reefs along both coasts. There are nine mangrove (*Rhizophora mangle*, *Laguncularia racemosa*, and *Avicenia germinans*) negative estuaries or esteros [i.e., estuaries that have higher evaporation than precipitation or runoff (Brusca 1980)] and the submerged vegetation is composed of extensive annual (October to June) eelgrass beds (Felger and McRoy 1975, McMillan 1983, Phillips and Backman 1983, Meling-López and Ibarra-Obando 1999), another seagrass species (*Halodule* wrigthii), and the ditch-grass *Ruppia* *maritima*. In addition, Felger and Moser (1985) report that in the Seri region there are at least 200 algae specie of which *Caulerpa* sp., *Padina durvillaei* and *Sargassum* spp. are the most abundant in the Canal de Infiernillo.

The Seri have a total population of 670 people living in two small fishing towns, Punta Chueca and El Desemboque de los Seris, in the south and north portions of the Canal (Fig. 1), respectively. There are approximately 35 crab fishing boats (7-m fiberglass skiffs with 50-70 hp outboard motors, called locally *pangas*) in the area working throughout the complete nine-month fishing season; 18 boats in Punta Chueca and 17 in El Desemboque de los Seris. The number of traps used per boat is 70 to 120, even though the maximum legal number is 70 traps. Since 1996 this has been the main fishery in the Canal de Infiernillo (Bourillón-Moreno 2002).

<u>Trap zones and eelgrass beds</u>

Crab fishing zones and eelgrass beds were mapped to evaluate their degree of overlap and nature of interaction. Maps were produced using a differential GPS (error < 5 m) with the software Geolink (GeoResearch: Geolink version 4.1d and Postpoint version 3.3) and processed in Arc View (version 3.2). The mapping consisted of following the perimeter of a group of trap buoys in a boat. In the densest eelgrass beds the edge was seen from the surface with polarized lenses or an aqua scope. A Motorola GPS 8-channel workhorse receiver connected to a portable computer obtained boat positions every second, and another GPS unit was stationed in Bahía Kino as reference to correct the boat positions. Monthly trap mapping surveys were done during the fishing season of 1998-1999 and in August and September of 1999. In addition, 190 formal interviews were conducted with fishermen in order to complete trap zoning. Using a map of the area, fishermen were asked to point out the area where their traps were set. The interviews were done during two fishing seasons, 1999-2000 and 2000-2001.

Detailed eelgrass mapping using the differential GPS was carried out in March, April and December 1999 and March 2000. To complete the eelgrass mapping, aerial color photographs and video were taken from a platform in a 5.5-m helium filled blimp that was pulled 450-500 m above the sea surface in March 1999, and from a Cessna 182 aircraft in November 1999, March, April and November 2000, and March 2001(Torre-Cosío et al.[12]). Eelgrass beds were classified as continuous or patchy, the former being those presenting a compact arrangement of eelgrass shoots with little or no exposed sand patch area, and the second comprising sparse patches of grass with many continuous sand spaces. Mapping was done during sea conditions of Beaufort scale 0 or 1 and good water visibility in order to see the bottom in shallow waters. Traps zones and eelgrass beds composite maps were produced and then overlapped with Arc View to analyze and quantify their matching zones.

Bait and bycatch

Participation in 15 regular crab commercial fishing trips from July 1999 to March 2000 was conducted to record the bait used in the traps and the trap bycatch. Sampling was done in a fisherman's boat one to three times per month. We recorded type of fishing methods to catch bait, invertebrate and fish numbers per species as bait and bycatch,

[12] See Appendix C of the dissertation for more details of the eelgrass mapping methods and results.

standard length (1 mm precision) of each fish, total number of traps, and total weight of swimming crab fished per trip.

Since the fishing season of 1998-1999, the local non-profit conservation organization Comunidad y Biodiversidad A.C. (COBI) has been monitoring the swimming crab fishery in Canal de Infiernillo. The monitoring consists of the measurement of the carapace length (CL), and sex and sexual maturity determination of 100 to 120 crabs per boat arriving at one of the three landing ports (Punta Chueca, and the fishing camps El Egipto and El Sargento) (Bourillón-Moreno 2002). The sampling effort has not been equal through the seasons, however at least one boat every two weeks has been sampled, with the exception of July and October 1999 and 2000 for which data was not recorded. Another bias is that sampling from the seasons of 1998-1999 and 1999-2000 was concentrated on the central and south portions of the Canal (south of Punta Perla and Punta Arenas) while in the fishing season of 2000-2001 was focused to Bahía Sargento. Data of a total of 4223 (1998-1999), 1705 (1999-2000), and 13,104 (2000-2001) individuals were used to estimate the percentage of crab under the legal catch size (CL = 50 mm) that is fished as bycatch.

Ghost traps

Parallel boat transects along both coasts of Canal de Infiernillo were done to search for ghost traps. These transects were conducted at the end of two fishing seasons (1998-1999 and 1999-2000). Transects run approximately at 50 to 200 m from the coast to search for buoys with naked eye and binoculars (7 X 10). Surveys covered the same area from the southern entrance of the Canal to an imaginary line between Punta Perla and Punta

Arenas. The first census, June 16-18, 1999, had a longer duration due to the large number of lost traps found and bad weather conditions. The second census was carried out on May 27, 2000. Once a buoy was found on the surface, its geographic coordinates were recorded using a manual Garmin XL GPS unit. Once pulled on board, examination of the trap condition as percentage of external cover in each side of the trap by algae and sessile invertebrates (i.e., sponges, anemones, hydroids, and bryozoans) was done. Furthermore, incidental species captured and animals living outside the trap (i.e., mollusks, sea stars, crabs, and fishes) were registered. Number, sex, and sexual maturity of the swimming crabs were determined for the organisms trapped in the ghost traps. Large (> 10 cm) mollusks, crabs, and sea stars were identified to species level and an approximation of their abundances was estimated. The trapped fish species were identified and counted. Specimens were collected and preserved when identification was not possible in the field. All organisms trapped were set free and traps were marked with a colored plastic tag and returned to the water for later follow-up. To estimate the number of traps lost by fishermen per season, 20 informal interviews with fishermen were conducted from 1999-2001. Fishers were asked with how many traps they start the fishing season and how many they had by the end of it, and approximately how many traps they estimate to be lost during a season.

Results

Trap zones and eelgrass beds

The eelgrass annual life cycle (October-June) and the swimming crab fishing season (July-March) overlap in Canal de Infiernillo for six months, from October to March. The total area covered in the Canal by continuous and patchy eelgrass was estimated in 3642 ha and 3045 ha, respectively, and the total area used for trap fishing zones is 5443 ha (Fig. 1). During the three-year study, the eelgrass beds regrew in exactly the same areas, maintaining the same general shape and sizes of beds; and the fishermen placed their traps in the same swimming crab fishing grounds along the seasons. Twenty-six percent (964 ha) of the continuous eelgrass overlaps with the trap zones, and the same percentage (798 ha) is for the patchy eelgrass. The traps are set in the first four months of the fishing season (July-October) in areas of the sea floor where eelgrass will grow. During this time, only eelgrass seeds are buried in the sediments. In late October and November eelgrass starts to reestablish itself by germination. In this phase, eelgrass is short (< 15 cm) and sparse and fishermen cannot see the eelgrass beds from the surface. As a result, sometimes they place traps on top of eelgrass beds. From December to March, beds of continuous eelgrass are easily distinguishable from the surface. In these months, fishermen do not set traps on the beds because common practice has shown them that traps will get filled and covered with eelgrass, thus decreasing the number of crabs entering the trap and increasing the probability of losing it by entanglement with eelgrass. However, although fishermen avoid setting traps in beds of continuous eelgrass, they place them near the edge of the beds, sometimes as close as 5 m. This practice was observed during the mapping trips.

Bait and bycatch

Swimming crab buyers provide bait for the traps to the fishermen every day. The type of bait has changed over the years. In the early years of the fishery fishermen used frozen jumbo flying squid (*Dosidicus gigas*) and poultry leftovers. However, fishermen complain of the poultry as bait due to the putrefaction odor left in the water and the formation of a thin layer of animal oil on the water surface. Currently, the bait has been changed to frozen Pacific thread herring (*Opisthonema libertate*), Californian pilchard (*Sardinops caeruleus*), Pacific anchoveta (*Cetengraulis mysticetus*), black skipjack (*Euthynnus lineatus*), skipjack tuna (*Katsuwonus pelamis*), eastern Pacific bonito (*Sarda chiliensis*), or chub mackerel (*Scomber japonicus*). All this bait is imported from the Pacific coast of Baja California peninsula. However, sometimes crab buyers have problems to provide the bait, and some fishermen are independent and do not want to depend on the buyers for bait, therefore at times fishermen catch their own.

Fishermen use three fishing methods to obtain bait: hook and line, old crab traps, and small mesh size (2-6 cm) gillnets. Hook and line are mainly used to fish for spotted sand bass (*Paralabrax maculatofasciatus*). They need to catch one or two fish per trap, so for 70-120 traps, 140-240 fish have to be captured. Other fishermen place 5 to 10 used crab traps near rocky substrates or eelgrass, and checked them every day before crab fishing. Sometimes fish bycatch is also used as bait. Gillnets are placed in the afternoon near the crab fishing zones and checked in the morning before checking traps. In addition, fishermen commonly use gillnets as enclosure for fish schools (mainly mullets, *Mugil* spp.) in a fast manoeuvre of throwing a gillnet around the school. Combining the capture of these three methods, a total of 39 fish species in 24 families are fished (Table 1). The most commonly captured species are striped mullet (41%), spotted sand bass (24%), and bullseye puffer (12%). Hook and line and the traps are the most selective methods, capturing seven and six species, respectively, mainly spotted sand bass and bullseye puffer. The targeted species with these two methods is the spotted sand bass. Even though gillnets are preferred to capture mullet schools, another 33 species are fished, some of them in juvenile stage such as the carangid species. Fishermen use 36 species as bait with these three fishing methods, but 10 of them are separated because of their size, meat quality, and commercial demand for human consumption, and only three are discarded (Table 1). The round stingrays and scorpion fish, which are difficult to handle, are killed and discarded, and the seahorses are sometimes returned to bring good luck to the fisher. Another type of bait are the leftovers from the pen shell (*Atrina* spp. and *Pinna rugosa*) fishery, but this is an uncommon practice.

A total of 1184 traps were reviewed to check the bycatch in crab fishing trips. We identified six species, bullseye puffer (69%), spotted sand bass (24%), and round ray, seahorse, scorpion fish, and porgies (7%). An estimate of 0.28 and 0.15 fish individuals of bycatch are captured per trap and per kg of fished crab, respectively. The bullseye puffer is used as bait mostly at the beginning of the season. However, between November and January, when crab production decreases, this puffer becomes a commercially important species. In addition, six species of invertebrates were identified as bycatch, pink-mouthed murex (*Phyllonotus erythrostoma*), sea hare (*Aplysia californica*), Californian two-spotted octopus (*Octopus bimaculatus*), Hubb's octopus (*O. hubbsorum*), and sea stars (*Luidia phragma* and *Echinaster tenuispina*). Except for the octopus species that have market, the rest are discarded, most of the time alive. The bycatch of sub-legal crab (< 50 mm carapace length) was 10% in the fishing season 1998-1999, and reduced in 1999-2000 and 2000-2001 with 4% and 3%, respectively. The percentage of immature females sub-legal sizes has been decreasing, and the percentage of mature females has been increasing through time (Fig. 2).

Ghost traps

At the end of the fishing season 1998-1999, 227 ghost traps were counted. For the following season (1999-2000), numbers were considerably lower, only 27-traps. One month after the 1999 survey, 54-tagged traps in the census were found on the Punta Chueca beach completely clean and ready to be used by fishermen. Only two traps marked in 1999 were found in the 2000 survey. Ghost traps were distributed along all of the Canal de Infiernillo, with concentrations inside bays or the south side of sand points (i.e., Punta Tormenta, Punta Chueca, Punta Viboras, Punta Arenas, and Punta Perla) (Fig. 3). No surveys were carried out at the end of the fishing season 2000-2001, however a fisherman informed us that at least 200 traps were found south of Punta Perla. The counts of lost traps at the end of the fishing seasons are considered to be subestimations of the total number of traps lost during a fishing season. In many instances ropes break, and it is not possible to find the buoy from the surface. Fishermen reported that between 30% to 50% of their traps are lost during the season due to the breaking of ropes, buoys caught in floating sargassum (*Sargassum* spp.) or eelgrass mats, ropes being cut by outboard motor propellers, or by vandalism. They also explained that during the fast temperature drop (from 24 to 22-18ºC) between October and November a massive died off seaweed (e.g., *Caulerpa* spp.) occurs. This algae form mats that clough the traps mesh, blocking water current flow and forcing the traps to roll over the sea bottom, with a movement that wrap the rope and buoy around the trap making it invisible from the surface. Some of the buoys emerge to the surface after certain time or are moved to the shore. In addition, during the days of full and moon, when the tidal currents are the strongest it is more common that the rope is wrapped around the trap. Fishermen stated that half of their traps could be lost during this time and recuperated few days latter after the currents calm.

The ghost traps retrieved had variable conditions, 10% of the pulled ropes had only the steel bar frame ballast without the mesh part of the trap, and the remaining were complete. In addition, 16 % of the traps had highly corroded frame ballast. Accurate information on the time of the ghost traps in the water was unavailable. However, a pattern of colonization by algae and invertebrates in the external part of the traps was observed, which is the result of their time in the water since little cleaning maintenance is practiced. Forty-four percent of the traps were clean of algae or invertebrates, thus probably the traps had less than a complete fishing season in the water, and the other 56% had different coverage degrees (Fig. 3).

Forty-five percent and 51% of the inspected traps had in them macro-invertebrates and fish, respectively (Table 2 and Table 3). The swimming crab was the most abundant invertebrate, present in 21% of the traps. An average of 2.9 (SD ± 3.0) crabs per trap was estimated, 9% immature females, 17% mature females, and 74% males. Eight commercial fish species and 13 non-commercial species were identified inside ghost traps, spotted sand bass being the most common. In addition, it was frequent to find three species of blennies (*Hypsoblennius gentilies*, *H. jenkinsi*, *Exerpes asper*), seahorse, barred pipefish (*Hippocampus ingens*), and roughjaw frogfish (*Antennarius avalonis*) colonizing the rope of the trap together with moss animals (Bryozoa) and hydrozoa (family Plumulariidae), or among the eelgrass and sargassum caught on the rope. It is important to point out that 62% of the caught fish species have an affinity for rocky reef habitat and these species were present in traps with an external growth cover that was higher than 40%.

Discussion

Trap zones and eelgrass beds

Impacts on seagrass by fishing activities using mobile gear such as trawls and dredges had been reported elsewhere (Fonseca et al. 1984, Short and Wyllie-Echeverria 1996, Meyer et al. 1999, Ardizzone et al. 2000). However, information on the effects of passive gear on eelgrass has been largely unrecorded. Despite their ballast, traps in Canal de Infiernillo are continuously rolling or shuffling over in the sea bottom due to the strong tidal currents—1 m/sec (Merifield et al. 1970, Maluf 1983)—as was observed diving or from the boat. This observation contrasts with Parrish and Kazama (1992), which report that the lobster traps in Hawaii do not move from their setting place. The main difference is the trap weight; lobster traps have 10-kg lead ballast and a swimming crab trap only 2 kg ballast plus 3 kg of the plastic mesh. Trap movement is affecting the eelgrass in two ways: 1) damaging eelgrass during their reestablishment months (October and November) and 2) removing the buried eelgrass seeds. In addition, it is possible that ghost traps could be rolling over eelgrass beds. However, systematic quantification of these effects is necessary. Another possible ecological negative impact, observed and reported to us by fishermen, is the corrosion effect of the trap re-bar steel ballast frame on the eelgrass. The exact relationship between the eelgrass in the Canal de Infiernillo and the swimming crab life cycle is unknown. However, it can be inferred the recognized importance of seagrasses as habitat for the different life stages of blue crabs (*C. sapidus*) in Chesapeake Bay (Orth et al. 1996), and the demonstrated correlation between the loss of seagrass beds and the perceived decline of blue crab fishery (Engel and Thayer 1998).

<u>Bait and bycatch</u>

An indirect major impact produced by the crab fishery is the capture of marine fauna to bait traps. In this respect, fishermen can be divided in two types, those that use hook and line to fish for spotted sand bass, being 96% successful to fish this species, and fishermen that use gillnets to capture schools of striped mullet. The latter fishing method is non-selective, catching at least 33 fish species other than mullet, mainly juvenile specie. It is important to point out that Canal de Infiernillo is considered a nursery ground for several species due to its estuarine conditions (i.e., extensive eelgrass beds and mangrove esteros). A third important species for bait is the bullseye puffer that is captured as bycatch in the same crab traps. Puffers are also an important commercial species. The spotted sand bass, the striped mullet, and the bullseye puffer are common and abundant throughout the Gulf of California in sandy and estuarine habitats (Fischer et al., 1995; Thomson et al. 2000). Cartron and Molles (2002) reported that the striped mullet is the second most important prey for ospreys (*Pandion haliaetus*) in Canal de Infiernillo after needlefish (*Strongylura* spp. and/or *Tylosurus crocodilus*). The osprey population in the Canal is one of the biggest in the Gulf of California (Henny and Anderson 1979). However, in 1994, 1996, and 1997 osprey productivity of breeding pairs was extremely low probably due to a variation in food availability (Cartron 2000). More information is needed to estimate the impact of the mullet fishery for bait in osprey feeding habits. It is also necessary to study the use of alternative baits to replace the use of juvenile fish species that occur in the Canal.

The total number of boats working in the crab fishery at Punta Chueca is 18, from them 13 are owned by the private company that also provides frozen bait, thus reducing the days that fishermen need to go to fish bait on their own. There are only five boats independent from this company, owned by Seri fishermen, who prefer to fish for spotted sand bass using hook and line. Information about the reminder of the fleet, 17 boats from El Desemboque de los Seris that fish in the Bahía Sargento area, is unavailable.

Trap bycatch of fish species is a small problem in the swimming crab fishery in Canal de Infiernillo. Only six species abundant in Canal are captured, being the bullseye puffer and the spotted sand bass the most commonly trapped. The estimated ratios for number of bycatch species per trap of kilogram caught are lower than those reported by Alverson et al. (1994) for traps in other fisheries. In addition, the numbers of sub-legal catch size crabs have been decreasing from 10% to 3% between the seasons 1998-1999 to

2000-2001. This is probably in part the result of fishermen discarding small size crabs because they prefer large organisms, or because the request of crab buyers wanting only large crabs. Another explanation is that there are differences in recruitment among years, something that has been reported for the blue crab populations (Hines et al. 1987). We observed that the immature female crab numbers are lower every season, but the number of mature females crabs were higher. This is probably the result of a sampling error, because more samples were collected from the northern part of the Canal (Bahía Sargento) during the season of 2000-2001 than in the other two seasons (1998-1999 and 1999-2000). Based on the Seri traditional ecological knowledge, Bourillón-Moreno (2002) found that the northern part of the Canal is a zone of mature female crab concentrations and the central and south parts of the Canal are areas where male crabs concentrate. Field and experimental data of sexual segregation for this crab species (*C. bellicosus*) has not been collected. However, strong sexual segregation has been found in other species of *Callinectes* (Norse and Estevez 1977, Paul 1982, Villareal-Chávez 1992).

Ghost traps

A major ecological concern described for the ghost traps in other crustacean fisheries of the world is the amount of targeted species accidentally trapped, and not used for commercial proposes (Smolowitz 1978, Breen 1987, Stevens 1996, Guillory 1993). This is also a problem in the swimming crab fishery in the Canal de Infiernillo due to the high numbers of lost traps during each fishing season and their continuous effect of ghost fishing. We estimated that between 2500 and 3000 traps are used in the Canal, of them 750 to 1500 are lost in each fishing season. Therefore, if in average a ghost trap has 2.9

crabs as we estimated in the ghost traps censuses and the average weight of a commercial crab in the Canal is 0.26 kg, there is a loss of 0.56 to 1.1 t of crab product in the ghost trap. Nevertheless, a larger problem of these traps is the substrate modification, due to the permanency of ghost traps in the sea bottom. That change the substrate by: 1) deteriorating the benthic environments when continuously dragged by currents, 2) serve as refuge for species not common in the Canal de Infiernillo (i.e., rocky reef fish) when traps are covered by algae and colonized by sessile invertebrates transforming the trap in to a “small reef”, and 3) serve as sediment traps when buried in the sand, modifying the bathymetry. An important effect is the accumulation of lost traps in crab fishing zones. The senior author recorded that fishermen would not use one area (i.e., south Punta Hona) due to the high number of ghost traps in the bottom. One of the most important causes of the increase in numbers of ghost traps is that some fishermen purposely do not pull out their traps at the end of the fishing season, as was observed during 1998-1999. In the next fishing season, the numbers of ghost traps were reduced because the company that buys the crab production, and also owns the fishing equipment (boat, motor, bait, and traps), rewarded money to fishermen for each trap returned to the company at the end of the season. Another observed impact of the traps is that some traps are pushed by currents to be washed a shore, deteriorating the aesthetic values of the landscape. Approximately 135 were counted along the shore of the Canal de Infiernillo in June 1998.

Conclusions

The swimming crab fishery in the Gulf of California is an important economic resource and is a relatively new fishery, less than 15 years old. However, in the present study we detected four main ecological impacts of the fishery on the marine environments that may have impacts over the same fishery in the long term. Firstly is the disturbance of the sea bottom and the eelgrass beds, which are probably an important habitat for the swimming crab life cycle. Secondly, the indiscriminate use of fish species for trap bait, such as juveniles of species that are commercially important in their adult stage. Thirdly, the bycatch of sub-legal size crabs and the placement of traps in female aggregation zones. Fourthly, the accumulation of lost traps on the sea bottom is producing fishing ghost effects as well as creating artificial reefs attracting species uncommon in the Canal de Infiernillo. And finally, the accumulation of ghost traps affecting some fishing areas by not allowing the placement of more traps in those fishing areas.

The following are management recommendations to reduce the impacts of this fishing gear in Sonora, but valid for other parts of the Gulf of California where the fishery uses traps.

1) Even though most of the fishermen have a mental map of the continuous eelgrass beds when these are full grow, it is necessary to provide them with a detailed map of the all eelgrass zones (i.e., patchy areas). In addition, placement of traps on the eelgrass beds o near them should be prohibited.

2) Only frozen fish or squid bait should be allowed or any fishing for bait by hook and line only. The use of gillnets to fish for bait should be discouraged. There is a

need to experiment on new types of bait that take in consideration the attraction of the crabs to the trap but reducing the impacts in the environment.

3) The use of biodegradable panels or clips and hinged flats with a time-release mechanism has been recommended in other crab fisheries (Guillory 1993, Stevens 1996, Bullimore et al. 2001). However, this solution only reduces the ghost fishing effects, the parts of the traps will remain on the sea bottom modifying it. Therefore, Government and buyers need to keep the practice of rewarding fishermen for returning the traps used after each season. Another solution is that the fishermen own their traps, thus they will be responsible to pull them out of the water at the end of the fishing season.

4) It is necessary to standardize the use of traps among fishermen through workshops. Following the recommendations by Guillory (1993) for the blue crab fishery and adding others, the fishermen in the Canal de Infiernillo should: a) individualize their set of traps with numbers or colors, thus identification of lost traps will be possible; b) use the authorized number of traps and escape rings; c) give proper maintenance to the lines, buoys, and ballasts to reduce its lost; and d) use solid buoys, no plastic bottles because these can broke and sink.

5) A program organized by the buyers and the fishermen at the end of the fishing season to clean the water and the beach of ghost traps is highly recommended as well as recycling of traps.

6) A program of incentives for fishermen that follow the regulations need to be implemented. The incentives can be economic or acquisition of fishing equipment (traps, boat, motor).

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Table 1

Species captured using three fishing methods to obtain bait for the swimming crab fishery in Canal de Infiernillo during the fishing season 1999-2000. N = number of specimens; SL = average standard length; SD = standard deviation; C = human consumption, B = bait, and D = discarded; nd = no data.

				Fishing method								
				Trap			Gillnet			Line hook		
Scientific name	Common name	N	SL (SD)	C	B	D	C	B	D	C	B	D
Sharks												
Carcharhinidae												
Negaprion brevirostris	lemon shark	2	76.5 (0.7)[a]				X	X				
Rays												
Rhinobatidae												
Rhinobatos productus	shovelnose guitarfish	2	14.5 (3.5)[b]					X				
Dasyatidae												
Dasyatis dipterura	whiptail stingray	1	nd				X	X				
Urolophidae												
Urobatis halleri	Haller's round ray	12	19.7 (1.4)[b]		X	X		X	X			
Bony fishes												
Ariidae												
Ariopsis platypogon	cominate sea catfish	1	34.5								X	
Atherinidae												
Colpichthys Regis	false gruñón	13	19.0 (1.5)					X				
Balistidae												
Balistes polylepis	finescale triggerfish	8	nd		X			X			X	
Belonidae												
Tylosurus crocodilus	Mexican needlefish	2	80.5 (8.4)[a]					X				
Carangidae												
Hemicaranx leucurus	yellowfin jack	1	13.9					X				
Oligoplites altus	longjaw leatherjack	43	22.4 (2.4)					X				

Oligoplites refulgens	shortjaw leatherjack	1	16.8			
Selene brevoortii	Pacific lookdown	2	13.1 (0.4)		X	
Trachinotus kennedyi	blackblotch pompano	2	10.1 (1.2)		X	
Centropomidae						
Centropomus medius	blackfin snook	2	22.5 (2.1)		X	
Chanidae						
Chanos chanos	milkfish	9	23.8 (0.9)		X	
Ephippidae						
Chaetodipterus zonatus	Pacific spadefish	1	8.5		X	
Gerreidae						
Diapterus peruvianus	Peruvian mojarra	10	18.1 (0.5)	X	X	
Eucinostomus spp.	mojarra	6	nd		X	
Eugerres axillaris	black axillary mojarra	2	20.4 (0.8)	X	X	
Gerres cinereus	yellow fin mojarra	2	20.8 (10.8)		X	
Haemulidae						
Anisotremus davidsonii	sargo	10	22.7 (2.1)		X	
Haemulon sexfasiatum	greybar grunt	13	16.6 (3.0)		X	
Haemulon steindachneri	latin grunt	1	16.0			X
Haemulopsis nitidus	shining grunt	1	8.5			X
Orthopristis reddingi	bronze-striped grunt	5	17.8 (0.7)		X	
Kyphosidae						
Kyphosus analogus	Cortez Sea chub	13	17.9 (1.3)		X	
Lutjanidae						
Hoplopagrus guntheri	barred snapper	1	17.8		X	
Lutjanus colorado	colorado snapper	12	19.0 (2.3)	X	X	
Lutjanus argentiventris	yellow snapper	3	18.5 (0.5)	X	X	
Mugilidae						
Mugil cephalus	striped mullet	449	24.8 (1.7)		X	
Nematistiidae						
Nematistius pectoralis	roosterfish	18	17.3 (1.8)		X	
Scorpaenidae						

Scorpaena mystes	Pacific spotted scorpion fish	3	20.7 (6.0)			X			X			X
Scianidae												
Cynoscion parvipinnis	shortfin weakfish	13	29.6 (0.3)				X	X		X	X	
Umbrina wintersteeni	wintersteen drum	1	19.5					X				
Serranidae												
Mycteroperca rosacea	leopard grouper	1	26.0				X					
Paralabrax maculatofasciatus	spotted sand bass	268	17.2 (2.8)	X	X		X	X		X	X	
Sparidae												
Calamus brachysomus	Pacific porgy	61	16.2 (5.8)		X			X				
Syngnathidae												
Hippocampus ingens	Pacific seahorse	1	13.5[a]			X						
Tetraodontidae												
Sphoeroides annulatus	bullseye puffer	136	21.9 (2.5)	X	X		X	X				

[a]Total length; [b]Disc diameter

Table 2

Selected list of mollusks, crabs, and echinoderms inside ghost traps, combining the censuses at the end of the fishing seasons 1998-1999 and 1999-2000 in Canal de Infiernillo.

Scientific name	Common name	Abundance
Mollusks		
Aplysiidae		
Aplysia californica	sea hare	common
Mytilidae		
Modiolus spp.	mussels	common
Muricidae		
Phyllonotus erythrostoma	pink-mouthed murex	common
Octopodidae		
Octopus spp.	octopuses	common
Pectinidae		
Pecten spp.	scallops	uncommon
Pteriidae		
Pteria sterna	**western wing oyster**	common
Pinctada mazatlanica	Mazatlan pearl oyster	uncommon
Turbinidae		
Turbo fluctuosus	Pacific turban	common

Crabs		
Calappidae		
Hepatus lineatus	spotted box crab	uncommon
Majidae		
Stenocionops angusta	spidercarb	uncommon
Portunidae		
Callinectes bellicosus	swimming crab	abundant
Portunus spp.	crabs	uncommon
Sea stars		
Echinasteridae		
Echinaster tenuispina	orange star	common
Ophiocomidae		
Ophiocoma spp.	spiny brittle stars	abundant

Table 3

Fish species inside ghost traps, combining the censuses at the end of the fishing seasons 1998-1999 and 1999-2000 in Canal de Infiernillo.

Common name	Scientific name	Fish Percent	Comercial species	Percent trap cover[a]	Habitat[b]
Urolophidae					
Urobatis halleri	Haller's round ray	1	no	0-70	sand
Urobatis maculatus	spotted round ray	3	no	0-70	sand
Antennariidae					
Antennarius avalonis	*roughjaw frogfish*	< 1	no	90-100	rocky reef
Apogonidae					
Apogon spp.	cardinalfishes	1	no	90-100	rocky reef
Balistidae					
Balistes polylepis	*finescale triggerfish*	6	yes	0-100	sand-rocky reef
Engraulidae					
Anchoa spp.	*anchovies*	2	no	100	pelagic
Gobiidae					
Lythrypnus dalli	*bluebanded gobie*	< 1	no	90-100	rocky reef
Haemulidae					
Anisotremus davidsonii	*sargo*	< 1	yes	50	sand-rocky reef
Kyphosidae					
Girella simplicidens	*Gulf opal eye*	< 1	no	40	rocky reef
Lutjanidae					
Hoplopagrus guntheri	*barred snapper*	< 1	yes	50	rocky reef
Muraenidae					
Muraena argus	*white-spotted moray*	< 1	no	100	rocky reef
Paralichthyidae					
Paralichthys woolmani	*speckled flounder*	< 1	yes	0	estuarine
Scorpaenidae					

Scorpaena mystes	*stone scorpionfish*	2	no	0-80	rocky reef
Serranidae					
Alphestes immaculatus	Pacific mutton hamlet	< 1	no	40	rocky reef
Epinephelus analogus	spotted grouper	< 1	yes	40	rocky reef
Paralabrax maculatofasciatus	spotted sand bass	69	yes	0-100	sand
Sparidae					
Calamus brachysomus	*Pacific porgy*	3	yes	0-80	sand-rocky reef
Syngnathidae					
Hippocampus ingens	Pacific seahorse	< 1	no	50	rocky reef
Syngnathus auliscus	barred pipefish	3	no	50	estuarine
Tetraodontidae					
Sphoeroides annulatus	*bullseye puffer*	6	yes	0-40	sand

[a]Percent of trap external covered by algae and invertebrates.
[b] From Allen and Robertson 1994, Fischer et al. 1995, Thomson et al. 2000.

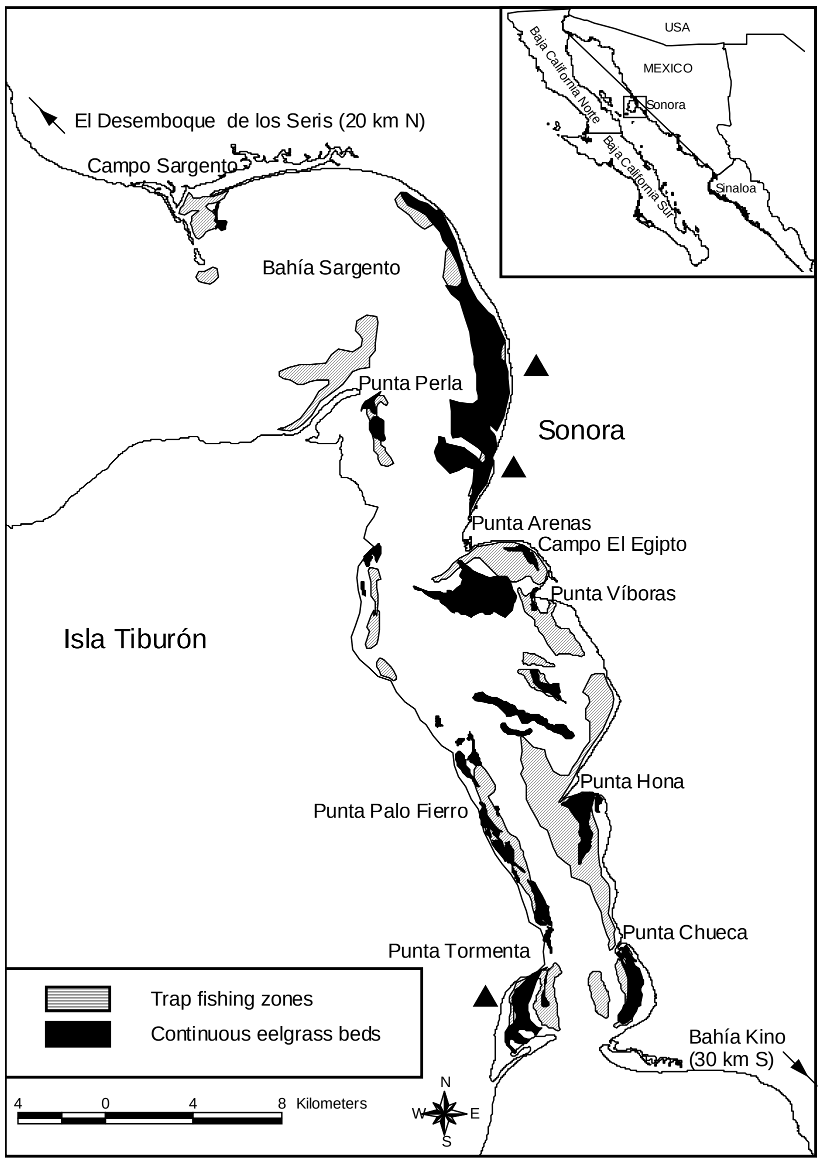
Figure captions

Figure 1. Composite map of eelgrass beds from 1999-2001 and swimming crab fishing zones 1998-2001. Black triangles near the coast are areas where below the eelgrass beds are trap zones.

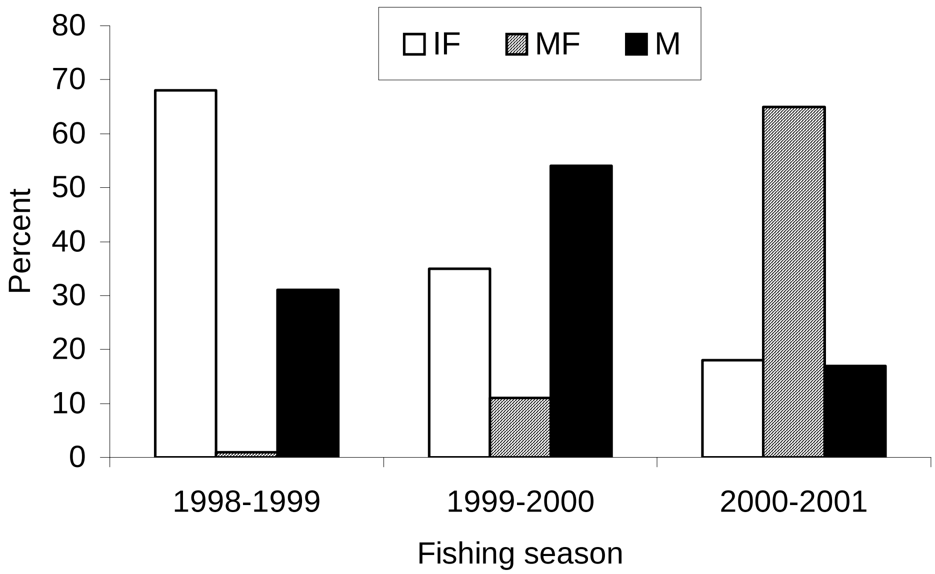
Figure 2. Percentages of the total swimming crab bycatch of immature females (IF), mature females (MF), and males (M) under the legal catch size (50 mm) in Canal de Infiernillo during three fishing seasons.

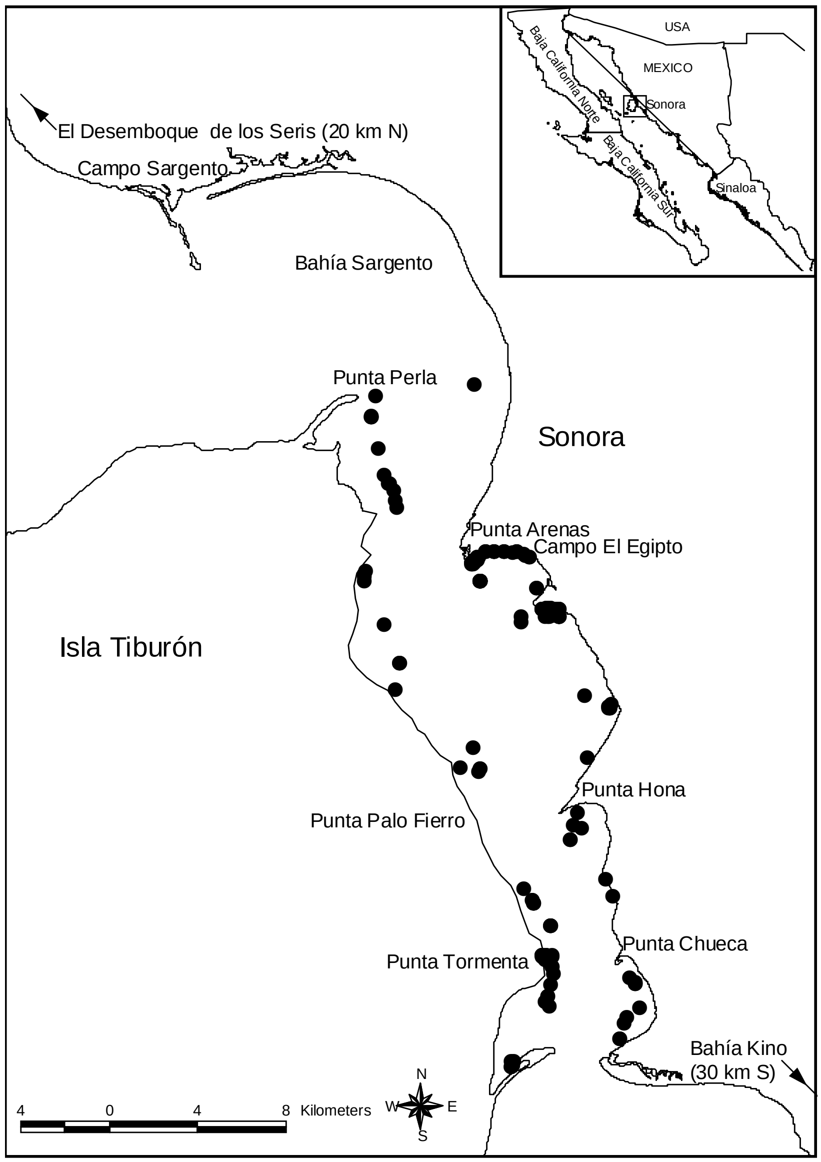
Figure 3. Location of concentration areas of ghost traps combining the censuses at the end of the fishing seasons 1998-1999 and 1999-2000 in Canal de Infiernillo, Bahía Sargento was not surveyed.

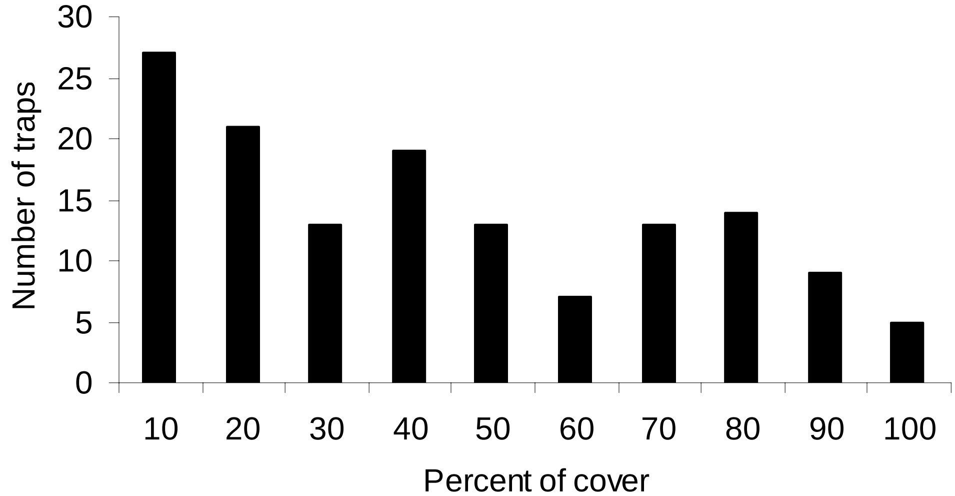
Figure 4. Percentages of external cover by algae and sessile invertebrates in ghost traps combined the seasons 1998-1999 and 1999-2000.



USA
MEXICO
Baja California Norte
Baja California Sur
Sonora
Sinaloa
El Desemboque de los Seris (20 km N)
Campo Sargento
Bahía Sargento
Punta Perla
Sonora
Punta Arenas
Campo El Egipto
Punta Víboras
Isla Tiburón
Punta Hona
Punta Palo Fierro
Punta Chueca
Punta Tormenta
Trap fishing zones
Continuous eelgrass beds
Bahía Kino
(30 km S)
4
0
4
8
Kilometers
N
W
E
S


IF
MF
M
Percent
80
70
60
50
40
30
20
10
0
1998-1999
1999-2000
2000-2001
Fishing season


USA
MEXICO
Baja California Norte
Sonora
Baja California Sur
Sinaloa
El Desemboque de los Seris (20 km N)
Campo Sargento
Bahía Sargento
Punta Perla
Sonora
Punta Arenas
Campo El Egipto
Isla Tiburón
Punta Hona
Punta Palo Fierro
Punta Chueca
Punta Tormenta
Bahía Kino
(30 km S)
N
W
E
S
4
0
4
8
Kilometers



30
25
20
15
10
5
0
Number of traps
10
20
30
40
50
60
70
80
90
100
Percent of cover

Apendix E

Inventory of the Seri territory

Species list of mollusks, echinoderms, sharks, rays and bony fish, marine reptiles, shore and sea birds, and marine mammals in the Seri territory (Canal de Infiernillo and Isla Tiburón) and Bahía Kino area. Records of the species were obtained from literature, collections in museums and universities, and field collections and censuses between 1998 and 2000[13]. The fish list was enhanced with the Seri traditional knowledge[14]. The system of classification for each major taxon is presented in the Table 1. Higher taxonomic categories are in phylogenetic order and the species/subspecies are listed alphabetically by genus, species, and subspecies.

Table 1. Taxa included in the marine species inventory of the Seri territory, Gulf of California. Common names and the system of classification of each taxa is presented.

Phylum	Class	Common name	System of classification
Mollusca	Pelecypoda	clams	Keen (1971)
	Gastropoda	snails	Keen (1971) and Fischer et al. (1995)
	Polyplacophora	chitons	Keen (1971)
	Cephalopoda	octopuses and squids	Keen (1971)
Echinodermata	Asteroidea	sea stars	Blake (1987) and Maluf (1988)
	Ophiuroidea	brittle stars	Maluf (1988)
	Echinoidea	urchins	Maluf (1988)
	Holothuroidea	sea cucumbers	Maluf (1988)
Chordata	Chondrichthyes	sharks and rays	Nelson (1994), Fischer et al. (1995), and Castro-Aguirre and Espinosa Pérez (1996)
	Actinopterygii	bony fish	Nelson (1994), Fischer et al. (1995), and Eschmeyer (1998)
	Reptilia	sea snakes and turtles	Flores-Villela (1993) and Fischer et al. (1995)
	Aves	aquatic birds	Peters (1934), Mayr and Cottrell (1979), AOU (1986), Howell and Webb (1995)
	Mammalia	marine mammals	Hershkovitz (1966) y Vidal et al. (1993)

[13] See Appendix A of the dissertation for more details of the methods and results of the inventory.
[14] See Appendix B of the dissertation for more details of the Seri traditional knowledge of the fish fauna in their territory.

Mollusks
Phylum Mollusca
Class Pelecypoda
Order Arcoida
Family Arcidae
Anadara concinna (Sowerby 1833)
Anadara nux (Sowerby 1833)
Arca mutabilis (Sowerby 1833)
Arca pacifica (Sowerby 1833)
Arcopsis solida (Sowerby 1833)
Barbatia alternata (Sowerby 1833)
Barbatia gradata (Broderip & Sowerby 1829)
Barbatia illota (Sowerby 1833)
Family Glycymerididae
Glycymeris multicostata (Sowerby 1833)
Order Mytiloida
Family Mytilidae
Brachidontes semilaevis (Menke 1849)
Lithophaga aristata (Dillwyn 1817)
Modiolus capax (Conrad 1837)
Family Pinnidae
Atrina maura Sowerby 1835
Atrina tuberculosa (Sowerby 1835)
Atrina sp.
Pinna rugosa Sowerby 1835
Order Myoida
Family Corbulidae
Corbula nasuta Sowerby 1833
Family Pholadidae
Pholas chiloensis Molina 1872
Order Pterioida
Family Pteridae
Pinctada mazatlanica (Hanley 1856)
Pteria sterna (Gould 1851)
Family Isognomonidae
Isognomon recognitus (Mabille 1895)
Family Ostreidae
Ostrea palmula Carpenter 1857
Family Pectinidae
Argopecten circularis (Sowerby 1835)
Lyropecten subnodosus (Sowerby 1835)
Pecten vogdesi Arnold 1906
Pinctada mazatlanica (Hanley 1856)
Family Spondylidae

Spondylus calcifer Carpenter 1857
Family Anomiidae
Anomia peruviana Orbigny 1846
Orden Verenoida
Family Crassatellidae
Crassinella pacifica (C. B. Adams 1852)
Family Carditidae
Cardita affinis Sowerby 1833
Cardita laticostata Sowerby 1833
Family Lucinidae
Codakia distinguenda (Tyron 1872)
Divalinga perparvula (Dall 1901)
Family Ungulidae
Felaniella sericata (Reeve 1850)
Family Chamidae
Chama mexicana Carpenter 1857
Pseudochama saavedrai Hertlein & Strong 1946
Family Cardiidae
Laevicardium elatum (Hertlein & Strong 1947
Trachycardium panamense (Sowerby 1833)
Trachycardium senticosum (Sowerby 1833)
Trigoniocardia biangulata (Broderip & Sowerby 1829)
Family Veneridae
Chione amathusia (Philippi 1844)
Chione californiensis (Broderip 1835)
Chione fluctifraga (Sowerby 1853)
Chione gnidia (Broderip & Sowerby 1829)
Chione subrugosa (Wood 1828)
Chione undatella (Sowerby 1835)
Dosinia dunkeri (Philippi 1844)
Megapitaria squalida (Sowerby 1835)
Periglypta multicostata (Sowerby 1835)
Pitar concinnus (Sowerby 1835)
Protothaca asperrina (Sowerby 1835)
Protothaca grata (Say 1831)
Family Petricolidae
Petricola parallela Pilsbry & Lowe 1932
Family Mactridae
Rangia mendica (Gould 1851)
Family Semelidae
Semele californica (Reeve 1853)
Family Tellinidae
Tellina mantaensis Pilsbry & Olsson 1943
Family Donacidae

Donax gracilis Hanley 1845
Donax punctatostriatus Hanley 1843
Family Solecurtidae
Tagelus affinis (C. B. Adams 1852)
Tagelus bourgeoisae Hertlein 1951
Tagelus violascens (Carpenter 1857)
Class Gastropoda
Order Archeogastropoda
Family Fissurellidae
Diodora alta (C. B. Adams 1852)
Diodora digueti (Mabille 1895)
Diodora inaequalis (Sowerby 1835)
Diodora saturnalis (Carpenter 1864)
Fissurella virescens Sowerby 1835
Lucapinella milleri Berry 1959
Family Acmaeidae
Collisella acutapex (Berry 1960)
Collisella atrata (Carpenter 1857)
Collisella stanfordiana (Berry 1957)
Collisella strigatella (Carpenter 1864)
Collisella strongiana (Hertlein 1958)
Collisella turveri (Hertlein y Strong 1951)
Patelloida semirubida (Dall 1914) [1]
Family Trochidae
Calliostoma eximium (Reeve 1843)
Calliostoma leanum (C. B. Adams 1852)
Calliostoma mcleani Shasky & Campbell 1864
Calliostoma palmeri Dall 1871
Solariella peramabilis Carpenter 1864
Homalopoma grippii (Dall 1911)
Family Liotiidae
Arene balboai (Strong & Hertlein 1939)
Arene fricki (Crosse 1865)
Family Turbinidae
Turbo fluctuosus Wood 1828
Family Phasianellidae
Tricolia substriata (Carpenter 1864)
Family Neritidae
Nerita funiculata Menke 1851
Nerita scabricosta Lamarck 1822
Theodoxus luteofasciatus Miller 1879
Tegula corteziana McLean 1970
Tegula eiseni Jordan 1936
Tegula globulus (Carpenter 1857)

Tegula mariana Dall 1919
Tegula rugosa (A. Adams 1853)
Order Mesogastropoda
Family Littorinidae
Littorina aberrans Philippi 1846
Littorina aspera Philippi 1846 [3]
Family Turritellidae
Turritella gonostomata Valenciennes 1832
Turritella lentiginosa Reeve 1849
Turritella leucostoma Valenciennes 1832
Turritella nodulosa King y Broderip 1832
Turritella radula Kiener 1844
Family Vermetidae
Vermetus indentatus (Carpenter 1857)
Family Cerithiidae
Cerithium maculosum Kiener 1841
Cerithium stercusmuscarum Valenciennes 1833
Liocerithium judithae Keen 1971
Family Potamididae
Cerithidea albonodosa Gould y Carpenter 1857
Cerithidea mazatlanica Carpenter 1857
Rhinocoryne humboldti (Valenciennes 1832)
Family Strombidae
Strombus galeatus Swainson 1823
Strombus gracilior Sowerby 1825
Strombus granulatus Swainson 1822
Family Hipponicidae
Hipponix pilosus (Deshayes 1832)
Hipponix serratus C. B. Adams 1852
Family Calyptraeidae
Crepidula arenata (Broderip 1834)
Crepidula incurva (Broderip 1834)
Crepidula excavata (Broderip 1834)
Crepidula incurva (Broderip 1834)
Crepidula onyx Sowerby 1824
Crepidula striolata Menke 1851
Crepidula uncata Menke 1847
Crucibulum spinosum (Sowerby 1824)
Family Naticidae
Natica chemnitzii Pfeiffer 1840
Natica othello Dall 1908
Polinices bifasciatus (Griffith & Pidgeon 1834)
Polinices intemeratus (Philippi 1853)
Polinices recluzianus (Deshayes 1839)

Polinices uber (Valenciennes 1832)
Family Triviidae
Trivia solandri (Sowerby 1832)
Family Ovulidae
Jenneria pustulata (Lightfoot 1786)
Simnia aequalis (Sowerby 1832)
Family Cassididae
Cassis coarctata Sowerby 1825
Family Cypraeidae
Cypraea annettae Dall 1909
Family Cymatiidae
Cymatium gibbosum (Broderip 1833)
Order Neogastropoda
Family Muricidae
Eupleura muriciformis (Broderip 1833)
Phyllonotus erythrostoma (Swainson 1831)
Pteropurpura erinaceoides (Valenciennes 1832)
Family Thaididae
Acanthina angelica I. Oldroyd 1918
Acanthina lugubris (Sowerby 1822)
Morula ferruginosa (Reeve 1846)
Morula lugubris (C. B. Adams 1852)
Neorapana muricata (Broderip 1832)
Neorapana tuberculata (Sowerby 1835)
Thais biseralis (Blainville 1832)
Thais speciosa (Valenciennes 1832)
Family Buccinidae
Cantharus elegans (Griffith & Pidgeon 1834)
Solenosteria macrospira Berry 1957
Solenosteria pallida (Broderip & Sowerby 1829)
Family Columbellidae
Anachis varia (Sowerby 1832)
Anachis coronata (Sowerby 1832)
Anachis hilli Pilsbry & Lowe 1932
Anachis pygmea (Sowerby 1832)
Columbella fuscata Sowerby 1832
Columbella strombiformis Lamarck 1822
Cosmiconcha palmeri (Dall 1913)
Cosmiconcha pergracilis (Dall 1913)
Mitrella guttata (Sowerby 1832)
Family Nassariidae
Nassarius angulicostis (Pilsbry & Lowe 1932)
Nassarius corpulentus (C. B. Adams 1852)
Nassarius insculpts (Carpenter 1864)

Nassarius iodes (Dall 1917)
Nassarius miser (Dall 1917)
Nassarius moestus (Hinds 1844)
Nassarius pagodus (Reeve 1844)
Nassarius taeniolatus (Philippi 1845)
Nassarius tiarula (Kiener 1844)
Nassarius versicolor (C. B. Adams 1852)
Family Fasciolariidae
Latirus praestantior Melvill 1892
Family Volutidae
Lyria cumingii (Broderip 1832)
Family Olividae
Agaronia testacea (Lamarck 1811)
Olivella dama (Wood 1828)
Olivia incrassata (Lightfoot 1786)
Olivia spicata (Roding 1798)
Family Mitridae
Mitra tristis Broderip 1839
Subcancilla erythrogramma (Tomlin 1931)
Family Cancellariidae
Cancellaria cassidiformis Sowerby 1832
Trigonostoma goniostoma (Sowerby 1832)
Family Conidae
Conus gradatus Wood 1828
Conus perplexus Sowerby 1857
Conus poormani Berry 1968
Conus regularis Sowerby 1833
Conus tornatus Sowerby 1833
Family Terebridae
Terebra armillata Hinds 1844
Terebra crenifera Deshayes 1859
Terebra intertincta Hinds 1844
Terebra larvaeformis Hinds 1844
Terebra lucana Dall 1908
Terebra panamensis Dall 1908
Terebra puncturosa Berry 1961
Terebra robusta Hinds 1844
Terebra specillata Hinds 1844
Terebra variegata Gray 1834
Family Turridae
Hormospira maculosa (Sowerby 1834)
Splendrillia bratcherae McLean & Poorman 1971

Order Cephalaspidea

Family Bullidae
Bulla gouldiana Pilsbry 1895
Family Atyidae
Haminoea virescens (Sowerby 1833)
Order Anaspidea
Family Aplysiidae
Aplysia californica Cooper 1863
Order Sacoglossa
Family Elysiidae
Tridachiella diomedea (Bergh 1894)
Order Gymnophila
Family Onchidiidae
Hoffmannola hansi Marcus & Marcus 1967
Class Polyplacophora
Order Chitonida
Family Chitonidae
Chiton virgulatus Sowerby 1840
Family_Acathochitonidae
Acanthochitona exquisita (Pilsbry 1893)
Family_Ischnochitonidae
Callistochiton gabbi Pilsbry 1893
Chaetopleura mixta (Dall 1919)
Lepidozona serrata (Carpenter 1864)
Radsiella guatemalensis (Thiele 1910)
Radsiella pentaloides (Gould 1846)
Radsiella tridentata Pilsbry 1893
Stenoplax conspicua (Carpenter MS) Pilsbry 1892
Stenoplax limaciformis (Sowerby 1832)
Stenoplax magdalenensis (Hinds 1845)
Family Lepidochitonidae
Nuttallina crossota Berry 1956
Class Cephalopoda
Order Octopoda
Family Octopodidae
Octopus bimaculatus Verrill 1883
Octopus hubbsorum Berry 1853

Echinoderms

Phylum Echinodermata
Class Asteroidea
Order Paxillosida
Family Luidiidae
Luidia phragma H. K. Clark 1910
Family Astropectinidae
Astropecten armatus Gray 1840
Tethyaster canaliculatus (A. H. Clark 1916)
Order Valvatida
Family Oreasteridae
Pentaceraster cumingi (Gray 1840)
Family Asterinidae
Asterina miniata (Brandt 1835)
Family Asterodiscididae
Amphiaster insignis Verrill 1868
Family Ophidiasteridae
Linckia columbiae Gray 1840
Pharia pyramidata (Gray 1840)
Phataria unifascialis (Gray 1840)
Order Spinulosida
Family Echinasteridae
Echinaster tenuispina (Verrill 1871)
Henricia aspera Fisher 1906
Order Forcipulatida
Family Heliasteridae
Heliaster kubinijii Xantus 1860
Family Asteriidae
Astrometis sertulifera (Xantus 1860)
Class Ophiuroidea
Order Phrynophiurida
Family Gorgonocephalidae
Astrocaneum spinosum (Lyman 1875)
Order Ophiurida
Family Amphiuridae
Amphiodia occidentalis (Lyman 1860)
Amphiodia periercta H. L. Clark 1911
Amphiodia violacea (Lutken 1856)
Amphipholis perplexa (Nielsen 1932) [2]
Amphipholis platydisca Nielsen 1932 [4]
Amphipholis pugetana (Lyman 1860) [2]
Amphipholis puntarenae (Lutken 1856) [1]
Amphipholis squamata Delle Chiaje 1828 [1]

Amphiura arcystata H. L. Clark 1911 [2]
Ophiophragmus marginatus (Lutken 1859) [1]
Family Ophiactidae
Hemipholis gracilis Verrill 1867 [1]
Ophiactis savignyi (Muller & Troschel 1842) [1]
Ophiactis simplex (Le Conte 1851) [4]
Family Ophiotrichidae
Ophiothrix spiculata Le Conte 1851 [9]
Family Ophiocomidae
Ophiocoma alexandri Lyman 1860 [2]
Ophiocoma aethiops Lutken 1859 [2]
Family Ophionereidae
Ophionereis annulata (Le Conte 1851) [4]
Ophionereis perplexa Ziesenhenne 1940 [1]
Family Ophiodermatidae
Ophioderma panamense Lutken 1859 [3]
Ophioderma variegatum Lutken 1856 [1]
Ophiopaepale diplax (Nielsen 1932) [2]
Ophiuroconis bispinosa Ziesenhenne 1937 [1]
Family Ophiuridae
Ophiolepis crassa Nielsen 1932 [1]
Ophiolepis variegata Lutken 1856 [2
Class Echinoidea
Order Cidaroida
Family Cidariidae
Eucidaris thouarsii (Valenciennes 1846) [3]
Hesperocidaris perplexa (H. L. Clark 1907) [2]
Order Diadematoida
Family Diadematidae
Astropyga pulvinata (Lamarck 1816) [7]
Centrostephanus coronatus (Verrill 1867) [3]
Order Arbacioida
Family Arbaciidae
Arbacia incisa (A. Agassiz 1863) [12]
Order Temnopleuroida
Family Toxopneustidae
Lytechinus pictus (Verrill 1867) [3]
Order Echinoida
Family Echinometridae
Echinometra vanbrunti A. Agassiz 1863 [5]
Order Clypeasteroida
Family Clypeasteridae
Clypeaster europacificus H. L. Clark 1914 [1]

Family Mellitidae
Encope grandis L. Agassiz 1841 [3]
Encope micropora A. Agassiz 1841 [2]
Order Holasteroida
Family Brissidae
Brissopsis pacifica (A. Agassiz 1898) [1]
Brissus obesus Verrill 1867 [1]
Family Loveniidae
Lovenia cordiformis A. Agassiz 1872 [4]
Family Schizasteridae
Agassizia scrobiculata Valenciennes 1846 [3]
Moira clotho Michelin 1855 [1]
Class Holothuroidea
Order Dendrochirotida
Family Sclerodactylidae
Athyone glasselli (Deichmann 1936) [1]
Family Cucumariidae
Pseudocnus californicus (Semper 1868) [1]
Thyonella mexicana (Deichmann 1941)
Order Aspidochirotida
Family Holothuriidae
Holothuria arenicola Semper 1868
Holothuria impatiens (Forsskål 1775)
Holothuria lubrica Selenka 1867
Holothuria rigida (Selenka 1867)
Family Stichopodidae
Isostichopus fuscus (Ludwing 1875)
Order Apodida
Family Chiridotidae
Chiridota aponocrita H. L. Clark 1920

Sharks and rays

Phylum Chordata
Class Chondrichthyes
Order Chimaeriformes
Family Chimaeridae
Hydrolagus colliei (Lay & Bennett 1849) [1]
Order Heterodontiformes
Family Heterodontidae
Heterodontus francisci (Girard 1855) [1]
Order Orectolobiformes
Family Rhincodontidae
Rhincodon typus Smith 1828
Order Charcarhiniformes
Family Scyliorhinidae
Cephaloscyllium ventriosum (Garman 1880) [1]
Family Triakidae
Mustelus lunulatus Jordan & Gilbert 1882
Mustelus californicus Gill 1864
Triakis semifasciata Girard 1855
Family Carcharhinidae
Carcharhinus leucas (Müller & Henle, 1839)
Carcharhinus porosus (Ranzani 1839)
Carcharhinus spp.
Galeocerdo cuvier (Péron & Lesueur 1822)
Negaprion brevirostris (Poey 1868)
Prionace glauca *(Linnaeus 1758)*
Rhizoprionodon longurio (Jordan & Gilbert 1882)
Family Sphyrnidae
Sphyrna zygaena (Linnaeus 1758)
Sphyrna spp.
Order Lamniformes
Family Lamnidae
Carcharodon carcharias (Linnaeus 1758)
Isurus oxyrinchus Rafinesque 1810
Order Squatiniformes
Family Squatinidae
Squatina californica Ayres 1859
Order Rajiformes
Family Narcinidae
Diplobatis ommata (Jordan & Gilbert 1890) [1]
Narcinae entemedor Jordan & Starks en Jordan 1895 [1]
Family Rhinobatidae
Rhinobatos leucorhynchus (Günther 1866) [1]

Rhinobatos productus (Ayres 1854) [4]
Zapteryx exasperata (Jordan & Gilbert 1880) [1]
Family Rajidae
Raja velezi Chirichigno 1973
Family Dasyatidae
Dasyatis dipterura (Jordan & Gilbert, 1880) [6]
Family Urolophidae
Urobatis concentricus (Osborn & Nichols 1916) [1]
Urobatis halleri Cooper 1863 [8]
Urobatis maculates (Garman 1913) [8]
Urobatis chilensis (Günther 1871) [1]
Urotrygon nana Miyake y McEachran 1988 [1]
Urotrygon rogersi (Jordan & Starks en Jordan 1895) [1]
Family Gymnuridae
Gymnura marmorata (Cooper 1864) [3]
Family Myliobatidae
Aetobatus narinari *(Euphrasen, 1790)*
Myliobatis californica Gill 1865 [2]
Rhinoptera steindachneri *Evermann & Jenkins, 1891*

Bony fish

Class Actinopterygii
Order Elopiformes
Family Elopidae
Elops affinis Regan 1909
Order Albuliformes
Family Albulidae
Albula sp.
Order Anguilliformes
Family Muraenidae
Gymnothorax castaneus (Jordan & Gilbert 1883)
Gymnothorax dovii (Günther 1870)
Muraena argus (Steindachner 1870)
Muraena lentiginosa Jenyns 1842
Family Ophichthidae
Myrichthys tigrinus Girard 1859
Myrichthys xysturus (Jordan & Gilbert 1882)
Myrophis vafer Jordan & Gilbert 1882
Ophichthus triserialis (Kaup 1856)
Family Congridae
Ariosoma gilberti (I. Ogilby 1898)

Order Clupeiformes
Family Engraulidae
Anchoa helleri (Hubbs 1921)
Anchoa ischana (Jordan & Gilbert 1882)
Anchoa lucida (Jordan & Gilbert, 1882)
Anchoa mundeoloides (Breder 1928)
Anchovia macrolepidota (Kner 1863)
Family Clupeidae
Etrumeus teres (DeKay 1842)
Harengula thrissina (Jordan & Gilbert 1882)
Opisthonema libertate (Günther 1867)
Sardinops caeruleus (Girard 1856)
Order Gonorhynchiformes
Family Chanidae
Chanos chanos (Forsskål, 1775)
Order Siluriformes
Family Ariidae
Arius platypogon Günther 1864
Bagre panamensis (Gill 1863)
Bagre pinnimaculatus (Steindachner 1877)
Order Aulopiformes
Family Synodontidae
Synodus lucioceps (Ayres 1855) [3]
Synodus scituliceps (Jordan & Gilbert 1881) [2]
Order Ophidiiformes
Family Ophidiidae
Ophidion galeoides (Gilbert 1890) [1]
Order Gadiformes
Family Macrouridae
Caelorinchus scaphopsis (Gilbert 1890) [1]
Family Merlucciidae
Merlucciius spp.
Order Batrachoidiformes
Family Batrachoididae
Porichthys spp.
Order Lophiiformes
Family Antennariidae
Antennarius avalonis Jordan & Starks 1907 [3]
Order Mugiliformes
Family Mugilidae
Mugil cephalus Linnaeus 1758 [19]
Mugil curema Valenciennes in Cuvier & Valenciennnes 1836 [6]
Mugil hospes Jordan & Cuvier 1895

Order Atheriniformes
Family Atherinidae
Atherinops affinis (Ayres 1860) [5]
Colpichthys regis (Jenkins & Evermann 1888)
Leuresthes sardina (Jenkins & Evermann 1889)
Order Beloniformes
Family Belonidae
Strongylura exilis (Girard 1854)
Tylosurus crocodiles *(Péron & Lesueur, 1821)*
Family Hemiramphidae
Hyporhamphus rosae (Jordan & Gilbert 1880)
Hyporhamphus unifasciatus *(Ranzani 1842)*
Order Gasterosteiformes
Family Syngnathidae
Cosmocampus arctus (Jenkins & Evermann 1889)
Hippocampus ingens Girard 1858
Syngnathus auliscus (Swain 1882)
Order Scorpaeniformes
Family Scorpaenidae
Scorpaena guttata Girard 1854
Scorpaena mystes Jordan & Starks 1895
Scorpaena sonorae Jenkins & Evermann 1888
Scorpaena xyris (Jordan & Gilbert) 1882
Family Triglidae
Bellator gymnostethus (Gilbert 1891)
Prionotus albirostris Jordan & Bollman 1889
Prionotus stephanophrys Lockington 1881
Order Perciformes
Family Centropomidae
Centropomus medius Günther 1864
Family Serranidae
Cephalopholis panamensis (Steindachner 1877)
Diplectrum labarum Rosenblatt & Johnson 1974
Diplectrum pacificum Meek & Hildebrand 1925
Diplectrum sciuris Gilbert 1892
Epinephelus analogus Gill 1863
Epinephelus itajara (Lichtenstein 1822)
Epinephelus labriformis (Jenyns 1840)
Mycteroperca jordani (Jenkins & Evermann 1889)
Mycteroperca rosacea (Streets 1877)
Mycteroperca prionura Rosenblatt & Zahuranec 1967
Mycteroperca xenarcha Jordan 1888
Paralabrax auroguttatus Walford 1936
Paralabrax loro Walford 1936

Paralabrax maculatofasciatus (Steindachner 1868)
Rypticus bicolor Valenciennes 1846
Rypticus nigripinnis Gill 1861
Serranus psittacinus Valenciennes 1846
Family Polyprionidae
Stereolepis gigas Ayres 1859
Family Opistognathidae
Opistognathus rhomaleus Jordan & Gilbert 1881
Family Priacanthidae
Pristigenys serrula (Gilbert 1891)
Family Apogonidae
Apogon atricaudus Jordan & McGregor 1898
Apogon retrosella (Gill 1863)
Family Malacanthidae
Caulolatilus affinis Gill 1865
Caulolatilus princeps (Jenyns 1842)
Family Nematistiidae
Nematistius pectoralis Gill 1862
Family Echeneidae
Remora remora (Linnaeus 1758)
Family Coryphaenidae
Coryphaena hippurus Linnaeus 1758
Family Carangidae
Caranx caballus Günther 1868
Caranx caninus Günther 1867
Caranx melampygus Cuvier en Cuvier & Valenciennes 1833
Caranx otrynter Jordan & Gilbert 1883
Caranx vinctus Jordan & Gilbert 1882
Chloroscombrus orqueta *Jordan & Gilbert 1883*
He*micarax leucurus* (Günther 1864)
Naucrates doctor (Linnaeus 1758)
Oligoplites altus (Günther 1868)
Oligoplites refulgens Gilbert & Starks 1904
Oligoplites saurus (Bloch & Schneider 1801
Oligoplites sp.
Selar crumenophthalmus (Bloch 1793)
Selene brevoortii *(Gill 1863)*
Seriola lalandi Valenciennes 1833
Trachinotus kennedyi Steindachner 1876
Trachinotus paitensis Cuvier en Cuvier & Valenciennes 1832
Trachinotus rhodopus Gill 1863
Family Lutjanidae
Hoplopagrus guentheri Gill 1862
Lutjanus aratus (Günther 1864)

Lutjanus argentiventris (Peters 1869)
Lutjanus colorado Jordan & Gilbert 1882
Lutjanus guttatus (Steindachner 1869)
Lutjanus peru *(Nichols & Murphy 1922)*

Family Gerreidae

Diapterus peruvianus (Cuvier) in Cuvier & Valenciennes 1830
Eucinostomus argenteus Baird & Girard in Baird 1855
Eucinostomus currani Zahuranec in Yañez 1980
Eucinostomus entomelas Zahuranec in Yañez 1980
Eucinostomus gracilis (Gill 1862)
Gerres cinereus Eigenmann 1891

Family Haemulidae

Anisotremus davidsonii (Steindachner 1875)
Anisotremus interruptus (Gill 1863)
Haemulon flaviguttatum Gill 1862 [8]
Haemulon maculicauda (Gill 1862) [3]
Haemulon sexfasciatus Gill 1862 [8]
Haemulon steindachneri (Jordan & Gilbert 1882)
Haemulopsis elongatus (Steindachner 1879)
Haemulopsis leuciscus (Günther 1864)
Microlepidotus inornatus Gill 1862
Orthopristis chalceus (Günther 1864)
Orthopristis reddingi Jordan & Richardson in Jordan 1895
Pomadasys macracanthus (Günther 1864)
Pomadasys panamensis (Steindachner 1876)
Xenistius californiensis (Steindachner 1876)

Family Sparidae

Calamus brachysomus (Lockington 1880)

Family Sciaenidae

Atractoscion nobilis (Ayres 1860)
Bairdella icistia (Jordan & Gilbert 1881)
Cynoscion parvipinnis Ayres 1861
Cynoscion reticulatus (Günther 1864)
Cynoscion sp.
Menticirrhus undulatus (Girard 1854)
Menticirrhus panamensis (Steindachner 1877)
Micropogonias ectenes (Jordan & Gilbert 1881)
Pareques viola (Gilbert) in Jordan & Evermann 1898
Totoaba macdonaldi (Gilbert 1890)
Umbrina roncador Jordan & Gilbert 1882
Umbrina wintersteeni Walker & Radford 1992
Umbrina xanti Gill 1862

Family Mullidae

Mulloidichthys dentatus (Gill 1862)

Pseudupeneus grandisquamis (Gill 1862)
Family Pomacanthidae
Pomacanthus zonipectus (Gill 1863)
Family Kyphosidae
Girella simplicidens Osburn & Nichols 1916
Hermosilla azurea Jenkins y Evermann 1889
Kyphosus analogus (Gill 1863)
Family Pomacentridae
Abudefduf troschelii (Gill 1862)
Chromis limbaughi Greenfield & Woods 1980
Stegastes rectifraenum (Gill 1862)
Family Labridae
Bodianus diplotaenia (Gill 1862)
Decodon melasma Gomon 1974
Halichoeres nicholsi (Jordan & Gilbert 1882)
Halichoeres semicinctus (Ayres 1859)
Thalassoma lucasanum (Gill 1863)
Family Scaridae
Scarus perrico Jordan & Gilbert 1882
Family Tripterygiidae
Crocodilichthys gracilis Allen & Robertson 1991
Family Dactyloscopidae
Dactylagnus mundus Gill 1863
Dactyloscopus pectoralis Gill 1861
Myxodagnus opercularis Gill 1861
Family Labrisomidae
Exerpes asper (Jenkins & Evermann 1889)
Labrisomus multiporosus Hubbs 1953
Labrisomus xanti (Gill 1860)
Paraclinus altivelis (Lockington 1881)
Paraclinus sini Hubbs 1952
Starksia cremnobates (Gilbert 1890)
Xenomedea rhodopyga Rosenblatt & Taylor 1971
Family Clinidae
Malacoctenus gigas Springer 1959
Malacoctenus hubbsi Springer 1959
Malacoctenus zonifer (Jordan & Gilbert 1882)
Family Chaenopsidae
Acanthemblemaria crockeri Beebe & Tee-Van 1938
Chaenopsis alepidota (Gilbert 1890)
Coralliozetus micropes (Beebe & Tee-Van 1938)
Coralliozetus rosenblatti Stephens 1963
Emblemaria hypacanthus (Jenkins & Evermann 1889)
Protemblemaria bicirris (Hildebrand 1946)

Stathmonotus sinuscalifornici (Chabanaud 1942)
Family Blenniidae
Hypsoblennius gentilis (Girard 1854)
Hypsoblennius jenkinsi (Jordan & Evermann 1896)
Family Gobiesocidae
Gobiesox papillifer Gilbert 1890
Gobiesox pinniger Gilbert 1890
Gobiesox schultzi Briggs 1951
Pherallodiscus funebris (Gilbert 1890)
Tomicodon boehlkei Briggs 1955
Tomicodon humeralis (Gilbert 1890)
Family Gobiidae
Aruma histrio (Jordan 1884)
Barbulifer pantherinus (Pellegrin 1901)
Bathygobius ramosus Ginsburg 1947
Chriolepis zebra Ginsburg 1938
Clevelandia ios Jordan & Gilbert 1882
Coryphopterus urospilus Ginsburg 1938
Ctenogobius sagittula (Günther 1861)
Elacatinus puncticulatus (Ginsburg 1938)
Evermannia zosterura (Jordan & Gilbert 1882)
Gillichthys mirabilis Cooper 1863
Gobionellus sp.
Gobiosoma chiquita (Jenkins & Evermann 1889
Ilypnus gilberti (Eigenmann & Eigenmann 1889)
Lythrypnus dalli (Gilbert 1861)
Quietula guaymasiae (Jenkins & Evermann 1889)
Quietula y-cauda (Jenkins & Evermann 1889)
Family Ephippidae
Chaetodipterus zonatus (Girard 1858)
Parapsettus panamensis (Steindachner 1875)
Family Luvaridae
Luvarus imperialis Rafinesque 1810
Family Acanthuridae
Prionurus punctatus Gill 1862
Family Sphyraenidae
Sphyraena ensis Jordan & Gilbert 1882
Family Trichiuridae
Trichiurus nitens Linnaeus 1758
Family Scombridae
Euthynnus lineatus Kishinouye 1920
Scomber japonicus Houttuyn 1782
Scomberomorus concolor (Lockington 1879)
Scomberomorus sierra Jordan & Starks 1895

Thunnus albacares *Bonnaterre 1788*

Family Istiophoridae

Makaira spp.

Order Pleuronectiformes

Family Bothidae

Bothus leopardinus (Günther 1862)

Family Paralichthyidae

Cyclopsetta querna Jordan & Bollman 1890

Citharichthys gilberti Jenkins & Evermann 1889

Etropus crossotus Jordan & Gilbert 1882

Paralichthys aestuarius Gilbert & Scofield 1898

Paralichthys californicus (Ayres 1859)

Paralichthys woolmani Jordan & Williams en Gilbert 1897

Syacium ovale Günther 1864

Xystreurys liolepis Jordan & Gilbert 1880

Family Pleuronectidae

Hypsopsetta guttulata (Girard 1856)

Pleuronichthys ocellatus Starks & Thompson 1910

Pleuronichthys verticalis Jordan & Gilbert 1880

Family Achiridae

Achirus mazatlanus (Steindachner 1880)

Family Cynoglossidae

Symphurus atramentatus Jordan & Bollman 1890

Symphurus fasciolaris Gilbert 1892

Symphurus melanurus H. W. Clark 1936

Symphurus williamsi Jordan & Cuvier 1895

Order Tetraodontiformes

Family Balistidae

Balistes polylepis Steindachner 1876

Family Tetraodontidae

Sphoeroides annulatus (Jenyns 1842)

Sphoeroides lispus Walker & Bussing 1996

Family Diodontidae

Diodon holacanthus Linnaeus 1758

Marine reptiles

Class Reptilia

Order Testudines

Family Cheloniidae

Caretta caretta (Linnaeus 1758)

Chelonia agassizii Bocourt 1868

Eretmochelys imbricata (Linnaeus 1766)

Lepidochelys olivacea (Eschscholtz 1829)

Family Dermochelyidae

Dermochelys coriacea (Vandelli 1761)
Order Squamata
Family Hydrophiidae
Pelamis platurus (Linnaeus 1766)

Aquatic birds
Class Aves
Order Gaviiformes
Family Gaviidae
Gavia immer (Brunnich 1764)
Gavia pacifica (Lawrence 1858)
Gavia stellata (Pontoppidan 1763)
Order Podicipediformes
Family Podicipedidae
Podiceps auritus (Linnaeus 1758)
Podiceps nigricollis Brehm 1831
Podilymbus podiceps (Linnaesus 1758)
Order Procellariiformes
Family Hydrobatidae
Oceanodroma melania (Bonaparte 1854)
Family Procellariidae
Fulmarus glacialis (Linnaeus 1761)
Puffinus grisseus (Gmelin 1789)
Order Pelecaniformes
Family Phaethontidae
Phaethon aethereus Linnaeus 1758
Family Sulidae
Sula leucogaster (Boddaert 1783)
Sula nebouxii Milne-Edwards 1882
Family Pelecanidae
Pelecanus erythrorhynchos Gmelin 1789
Pelecanus occidentalis Linnaeus 1766
Family Phalacrocoracidae
Phalacrocorax auritus (Lesson 1831)
Phalacrocorax brasilianus (Gmelin 1789)
Phalacrocorax penicillatus (Brandt 1837)
Family Anhingidae
Anhinga anhinga (Linnaeus 1766)
Family Fregatidae
Fregata magnificens Mathews 1789
Order Ciconiiformes
Family Ardeidae
Ardea herodias Linnaeus 1758
Botaurus lentiginosus (Rackett 1813)

Bubulcus ibis (Linnaeus 1758)
Butorides virescens (Linnaeus 1758)
Egretta alba (Linnaeus 1758)
Egretta caerulea (Linnaeus 1758)
Egretta rufescens (Gmelin 1789)
Egretta thula (Molina 1782)
Egretta tricolor (P. L. S. Muller 1776)
Ixobrychus exilis (Gmelin 1789)
Nycticorax nycticorax (Linnaeus 1758)
Nycticorax violaceus (Linnaeus 1758)
Family Threskiornithidae
Ajaia ajaja (Linnaeus 1758)
Eudocimus albus (Linnaeus 1758)
Plegadis chihi (Vieillot 1817)
Order Anseriniformes
Family Anatidae
Anas acuta acuta Linnaeus 1758
Anas americana Gmelin 1789
Anas clypeata Linnaeus 1758
Anas crecca Linnaeus 1758
Anas cyanoptera Vieillot 1816
Anas strepera Linnaeus 1758
Anser albifrons (Scopoli 1769)
Aythya affinis (Eyton 1838)
Aythya americana (Eyton 1838)
Aythya collaris (Donovan 1809)
Aythya valisineria (Wilson 1814)
Branta bernicla (Linnaeus 1758)
Bucephala albeola (Linnaeus 1758)
Bucephala clangula (Linnaeus 1758)
Clangula hyemalis (Linnaeus 1758)
Melanitta perspicillata (Linnaeus 1758)
Mergus serrator Linnaeus 1758
Oxyura jamaicensis Gmelin 1789
Order Falconiformes
Family Accipitridae
Pandion haliaetus (Linnaeus 1758)
Order Gruiformes
Family Rallidae
Fulica americana Gmelin 1789
Rallus limicola Vieillot 1819
Rallus longirostris Boddaert 1783
Family Gruidae
Grus canadensis (Linnaeus 1758)

Order Charadriiformes

Family Charadriidae

Charadrius alexandrinus Linnaeus 1758
Charadrius semipalmatus Bonaparte 1825
Charadrius wilsonia Ord 1814
Pluvialis squatarola (Linnaeus 1758)
Charadrius vociferus Linnaeus 1758

Family Haematopodidae

Haematopus palliatus Temminck 1820

Family Recurvirostridae

Himantopus mexicanus (Muller 1776)
Recurvirostra americana Gmelin 1789

Family Scolopacidae

Actitis macularia (Linnaeus 1766)
Aphriza virgata (Gmelin 1789)
Arenaria interpres (Linnaeus 1758)
Arenaria melanocephala (Vigors 1829)
Calidris alba (Pallas 1764)
Calidris alpina (Linnaeus 1758)
Calidris canutos (Linnaeus 1758)
Calidris mauri (Canabis 1857)
Calidris minutilla (Vieillot 1819)
Catoptrophorus semipalmatus (Gmelin 1789)
Gallinago gallinago (Linnaeus 1758)
Limnodromus griseus (Gmelin 1789)
Limnodromus scolopaceus (Say 1823)
Limosa fedoa (Linnaeus 1758)
Numenius americanus Bechstein 1812
Numenius phaeopus Linnaeus 1758
Phalaropus tricolor (Vieillot 1819)
Tringa flavipes (Gmelin 1789)
Tringa melanoleuca (Gmelin 1789)
Tringa solitaria Wilson 1813

Family Laridae

Chlidonias niger (Linnaeus 1758)
Larus argentatus Pontoppidan 1763
Larus atricilla Linnaeus 1758
Larus californicus Lawrence 1854
Larus delawarensis Ord 1815
Larus glaucescens Naumann 1840
Larus heermanni Cassin 1852
Larus livens Dwight 1919
Larus philadelphia (Ord 1815)
Larus pipixcan Wagler 1831

Stercorarius pomarinus (Temminck 1815)
Sterna antillarum Lesson 1847
Sterna caspia Pallas 1770
Sterna elegans Gambel 1849
Sterna forsteri Nuttall 1834
Sterna hirundo Linnaeus 1758
Sterna maxima Boddaert 1783
Sterna nilotica Gmelin 1789
Family Alcidae
Endomychura craveri (Salvadori 1865)
Order Coraciiformes
Family Alcedinidae
Ceryle alcyon (Linnaeus 1758)
Chloroceryle americana (Gmelin 1788)

Marine mammals
Class Mammalia
Order Cetacea
Family Delphinidae
Delphinus spp.
Globicephala macrorhynchus Gray 1846
Pseudorca crassidens (Owen 1846)
Tursiops truncatus (Montagu 1821)
Order Carnívora
Family Otariidae
Zalophus californianus (Lesson 1828)
Family Eschrichthidae
Eschrichtius robustus (Lilljeborg, 1861)
Family Balaenopteriidae
Balaenoptera edeni Anderson 1878
Balaenoptera physalus Linnaeus 1758

REFERENCES

Alverson, D. L., M. H. Freeberg, S. A. Murawski, and J. G. Pope. 1994. A global assessment of fisheries bycatch and discards. FAO Fisheries Tech. Paper 339:1-233.

Allen, G. R., and D. R. Robertson 1994. Fishes of the Tropical Eastern Pacific. University of Hawaii Press.

American Ornithologists Union (AOU). 1983. Check-list of North American Birds. Allen Press, Inc.

Angel, M. V. 1996. Ocean diversity. Pp. 228-243 in Oceanography. An Illustrated Guide. C. P. Summerhayes and S. A. Thorpe (eds.). John Wiley & Sons.

Ardizzone, G. D., P. Tucci, A. Somaschini, and A. Belluscio. 2000. Is bottom trawling partly responsible for the regresion of *Posidonia oceanica* meadows in the Mediterranean Sea? Pp. 37-46 in The effects of fishing on non-target species and habitats. M. J. Kaiser and S. J. Groot (eds.). Blackwell Science, Inc.

Arizmendi, M. C., and L. Márquez 1999. Áreas de Importancia para la Conservación de las Aves en México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), México.

Arriaga, L., J. M. Espinoza, C. Aguilar, E. Martínez, L. Gómez, and E. Loa 2000. Regiones terrestres prioritarias de México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), México.

Arriaga, L., E. Vázquez, J. González, R. Jiménez, E. Muñoz, and V. Aguilar 1998. Regiones Marinas Prioritarias de México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), México.

Astorga de Estrella, M. L., M. B. Moser, and E. F. Naval. 1998. Las canciones seris: una vision general. Pp. 499-526 in Cuarto Encuentro Internacional de Lingüística en el Noroeste. Z. Estrada Fernández, M. Figueroa Esteva, G. López Cruz, and A. Acosta (eds.). UNISON, Hermosillo, Sonora, México.

Backman, T. W. H. 1991. Genotypic and phenotypic variability of *Zostera marina* on the west coast of North America. Canadian Journal of Botany 69:1361-1371.

Bahre, C. J. 1967. The reduction of Seri Indian range and residence in the State of Sonora, Mexico (1536-present). Unpublished Ph. D. dissertation. Department of Geography, University of Arizona, Tucson.

Bahre, C. J.1980. Historic Seri residence, range, and sociopolitical structure. The Kiva 45:197-209.

Bahre, C. J., L. Bourillón, and J. Torre. 2000. The Seri and commercial totoaba fishing (1930-1965). Journal of the Southwest 42:559-575.

Ballance, L. T. 1990. Residence patterns, group organization, and surfacing associations of bottlenose dolphin in Kino Bay, Gulf of California, Mexico. Pp. 267-283 in The Bottlenose Dolphin. S. L. Leatherwood and R. R. Reeves (eds.). Academic Press, Inc.

Ballance, L. T. 1992. Habitat use patterns and ranges of the bottlenose dolphin in the Gulf of California, Mexico. Marine Mammal Science 8:262-274.

Basurto-Guillermo, X. 2001. Community-based conservation of the callo de hacha fishery by the Comcáac indiands, Sonora, México. Unpublished M. Sc. Thesis. School of Renewable Natural Resources, University of Arizona.

Basurto-Guillermo, X., T. Pfister, and J. U. Ramírez. 1999. Photo-identification of fin whales (*Balaenoptera physalus*) in the Bahía de Kino, Sonora area: a preliminary report. XXIV International Meeting for the Study of Marine Mammals. Mexican Society for the Study of Marine Mammals, April 18-22, Mazatlán, Sinaloa, México.

Begossi, A., and J. Lima de Figuereido. 1995. Ethnoicthyology of southern coastal fishermen: cases from Búzos Island and Sepetiba Bay (Brazil). Bulletin of Marine Science 56:710-716.

Berkes, F. 1999. Sacred Ecology. Traditional Ecological Knowledge and Resource Management. Taylos & Francis.

Berlin, B. 1992. Ethnobiological Classification. Princeton University Press.

Blake, D. A. 1987. A classification and phylogeny of post-Paleozoic sea stars (Asteroidea: Echinodermata). Journal of Natural History 21:481-528.

Bohnsack, J. A., and J. S. Ault. 1996. Management strategies to conserve marine biodiversity. Oceanography 9:73-82

Boarman, W. I., and S. J. Coe. 2000. Finding value in pre-existing data sets. Conservation in practice 1:32-24.

Bourillón-Moreno, L., and X. Basurto-Guillermo. 1998. Recomendaciones para el Manejo de la Actividad Humana en la Región de las Grandes Islas del Golfo de California. Executive Report to World Wildlife Fund for the Nature (WWF) by Comunidad y Biodiversidad A.C. (COBI), Guaymas, Sonora, México.

Bourillón-Moreno, L. 2002. Exclusive fishing zone as a strategy for managing fishery resources by the Seri indians, Gulf of California, Mexico. Unpublished Ph. D. Dissertation. School of Renewable Natural Resources, University of Arizona.

Bowen, T. 1976. Seri prehistory. The archeology of the central coast of Sonora, Mexico. Anthropological Papers of The University of Arizona 27:1-120.

Bowen, T. 2000. Unknown Island. Seri Indians, Europeans, and San Esteban Island in the Gulf of California. University of New Mexico Press.

Bowen, T., and E. W. Moser. 1970. Material and functional aspects of Seri instrumental music. The Kiva 35:178-200.

Breen, P. A. 1987. Mortality of dungeness crabs caused by lost traps in the Fraser River estuary, British Colombia. North American Journal of Fisheries and Management 3:429-435.

Brusca, R. C. 1980. Common Intertidal Invertebrates of the Gulf of California. The University of Arizona Press.

Brusca, R. C., L. T. Findley, P. A. Hastings, M. E. Hendrickx, J. Torre-Cosío, and A. M. van der Heiden. In press. Macrofaunal biodiversity in the Gulf of California (Sea of Cortez). In Biodiversity, Ecosystems and Conservation in Northern Mexico. J.-L. E. Cartron and G. Ceballos (eds). Oxford University Press.

Bullimore, B. A., P. B. Newman, M. J. Kaiser, S. E. Gilbert, and K. M. Lock. 2001. A study of catches in a fleet of "ghost fishing" pots. Fishery Bulletin 99:246-253.

Bulthuis, D. A. 1995. Distribution of seagrasses in north Puget Sound estuary: Padilla Bay, WA. Aquatic Botany 50:99-105.

Carlton, J. T. 1998. Apostrophe to the Ocean. Conservation Biology 12:1165-1167.

Cartron, J. E. 2000. Status and productivity of ospreys along the eastern coast of the Gulf of California: 1992-1997. Journal of Field Ornithology 7:298-309.

Cartron, J. E., and J. M. C. Molles. In press. Osprey diet along the eastern side of the Gulf of California, Mexico. Western North American Naturalist.

Cartron, J.-L. E., S. A. Sommer, and D. Kilpatrick. In press. Ecology and population status of ospreys in coastal Sonora. In Biodiversity, Ecosystems and Conservation in Northern Mexico. J.-L. E. Cartron and G. Ceballos (eds.). Oxford University Press.

Castro-Aguirre, J. L. And H. Espinosa-Pérez. 1996. Catálogo sistemático de las rayas y especies afines de México. Listados Faunísticos de México. Vol. VII. UNAM, Instituto de Biología.

Castro-Longoria, R., J. M. Grijalva-Chon, and J. F. Sánchez-Osuna. 2002. La comunidad ictiológica de la laguna costera El Saregento, Sonora, México. Ciencias Marinas.

Cisneros-Mata, M. A., G. Montemator-López, and M. Román-Rodríguez. 1995. Life history and conservation of *Totoaba macdonaldi*. Conservation Biology 9:806-814.

Cliffton, K., D. O. Cornejo, and R. S. Felger. 1982. Sea turtles of the Pacific coast of Mexico. Pp. 199-210 in Biological Conservation of Sea Turtles. K. Bjorndal (ed.). Smithsonian Institution Press.

Cole, R. V., and T. E. Helser. 2001. Effect of three bycatch reduction devices on diamondback terrapin *Malaclemys terrapin* capture and blue crab *Callinectes sapidus* harvest in Delaware Bay. North American Journal of Fisheries Management 3:825-833.

Coolidge, D., and M. R. Coolidge. 1939. The Last of the Seris. E. P. Dutton & Co., Inc.

Dallmeier, F. 1996. 15. Biodiversity inventories and monitoring: essential elements for integrating conservation principles with resource development projects. Pp. 221-223 in Biodiversity in Managed Landscapes. Theory and Practice. R. C. Szaro and D. W. Johnston (eds.). Oxford University Press.

Davis, G. E., K. R. Faulkner, and W. L. Halvolson. 1994. Ecological monitoring in Channel Islands National Park, California. In The Fourth California Islands Symposium: Update on the Status of Resources. Santa Barbara Museum of Natural History. W. L. Halvorson and G. J. Maender (eds.).

Davis, G. E., and W. L. Halvorson (eds.). 1988. Inventory and monitoring of natural resources in Channel Islands National Park California. National Park Service, Channel Islands National Park, Ventura, CA., U. S. Department of Commerce, National Technical Information Service.

Dawes, C. J. 1981. Marine Botany. John Wiley & Sons.

Dennis, J. G., and M. A. Ruggiero. 1996. Biodiversity inventory: building an inventory at scales from local to global. Pp. 149-156 in Biodiversity in Managed Landscapes. Theory and Practice. R. C. Szaro and D. W. Johnston (eds.). Oxford University Press.

Diario Oficial de la Federación. 1970. Decreto por el que se concede como donación de ejido al poblado denominado El Desemboque y su anexo Punta Chueca, Municipio de Pitiquito, Estado de Sonora, una superficie de 91,322 ha. de agostadero. November 28, 1970. México.

Diario Oficial de la Federación. 1975. Decreto por el que se declara que única y exclusivamente los miembros de la tribu Seri y los de la Sociedad Cooperativa de Producción Pesquera S. C. L., podrán realizar actos de pesca en las aguas de los esteros y bahías, situados en el Golfo de California y de los litorales que forman la Isla del Tiburón localizada en el Mar de Cortés. February 11, 1975. México.

Diario Oficial de la Federación. 2000. Carta Nacional Pesquera (National Fishing Chart). SAGARPA, INP, México.

Diario Oficial de la Federación. 2002. Norma Oficial Mexicana NOM-059-ECOL-2001. Protección ambiental-especies nativas de México de flora y fauna silvestres categorías de riesgo y especificaciones para su inclusión, exclusión o cambio lista de especies en riesgo. March 6, 2002. México.

Engel, D. W., and G. W. Thayer. 1998. Effects of habitat alteration on blue crabs. Journal of Shellfish Research 17:579-585.

Elphick, C., J. J. B. Dunning, and D. A. Sibley 2001. The Sibley Guide to Bird Life and Behavior. National Audubon Society, Alfred A. Knopf.

Eschmeyer, W. N. 1998. Catalog of Fishes. California Academy of Sciences.

Felger, R. S. 2000. The Seris and the guy who cuts the tops off plants. Journal of the Southwest 42:521-543.

Felger, R. S., K. Cliftton, and P. J. Regal. 1976. Winter dormancy in sea turtles: independent discovery and exploitation in the Gulf of California by two local cultures. Science 191:283-285.

Felger, R. S., and C. H. Lowe. 1976. The island and coastal vegetation and flora of the northern part of the Gulf of California. Contribution in Science, Natural History Museum of Los Angeles County 285:1-58.

Felger, R. S., McRoy, C. P. 1975. Seagrass as potential food plants. Pp. 62-74 in Seedbearing Halophytes as Food Plants. G. F. Somers (ed.). University of Delaware.

Felger, R. S., and M. B. Moser. 1973. Eelgrass (*Zostera marina* L.) in the Gulf of California: discovery of its nutritional value by the Seri Indians. Science 181:355-356.

Felger, R. S., and M. B. Moser 1985. People of the Desert and Sea. Ethnobotany of the Seri Indians. The University of Arizona Press.

Felger, R. S., M. B. Moser, and E. W. Moser. 1980. Seagrasses in Seri Indian culture. Pp. 260-276 in Handbook of Seagrass Biology: An Ecosystem Perspective. R. C. Phillips and C. P. McRoy (eds.). Garland STPM Press.

Fischer, W., F. Krupp, W. Schneider, C. Sommer, K. E. Carpenter, and V. H. Niem. 1995. Guía FAO para la Identificación de Especies para los Fines de la Pesca. Pacífico Centro-Oriental. Vols. I to III. Roma, FAO.

Fishman, J. R., Orth. R. J. 1996. Effects of predation on *Zostera marina* L. seed abundance. Journal of Experimental Marine Biology and Ecology 198:11-26.

Flores-Villela, O. 1993. Herpetofauna Mexicana. Carnegie Museum of Natural History, Special Publication 17:1-73.

Fonseca, M. S., G. W. Thayer, and A. J. Chester. 1984. Impact of scallop harvesting on eelgrass (*Zostera marina*) meadows: implications for management. North American Journal of Fisheries Management 4:286-293.

Grijalva-Chon, J. M., R. Castro-Longoria, and A. Bustamante-Mongue. 1992. Distribución, abundancia y diversidad de larvas de peces en la laguna costera Santa Rosa, Sonora, México. Ciencias Marinas 18:153-169.

Grijalva-Chon, J. M., S. Nuñez-Quevedo, and R. Castro-Longoria. 1996. Ictiofauna de la laguna costera La Cruz, Sonora, México. Ciencias Marinas 22:129-150.

Guillory, V. 1993. Ghost fishing by blue traps. North American Journal of Fisheries Management 13:459-466.

Guillory, V. 1998. Blue crab, *Callinectes bellicosus*, retention rates in different trap meshes. U. S. National Marine Fisheries Service, Marine Fisheries Review 60:35-37.

Guillory, V., and S. Hein. 1998. A review and evaluation of escape rings in blue crabs traps. Journal of Shellfish Research 17:551-559.

Guillory, V., and P. Prejean. 1998. Effect of a terrapin excluder device on blue crab, *Callinectes sapidus*, trap catches. U. S. National Marine Fisheries Service, Marine Fisheries Review. 60:38-39.

Haszprunar, G. 1998. Marine biodiversity - thoughts on the subjects and their investigators. Pp. 43-52 in Biodiversity. A Challenge for Development Research and Policy. W. Barthlott and M. Winiger (eds.). Springer.

Hendrickx, M. E. 1994. Catálogo de moluscos pelecypodos, gasterópodos y poliplacóforos. Colección de Referencia, Estación Mazatlán, ICML, UNAM. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO) and Insituto de Ciencias del Mar y Limnologia (ICMyL), UNAM, México.

Henny, C. J., and D. W. Anderson. 1979. Osprey distribution, abundance, and status in western North America: III. The Baja California and the Gulf of California population. Bulletin of Southern California Academy of Sciences 78:89-106.

Hershkovitz, P. 1966. Catalog of living whales. United States National Museum Bulletin 216:1-259.

Hilton-Taylor, C. 2000. 2000 IUCN Red List of Threatened Species. IUCN, Gland, Switzerland and Cambridge, UK.

Hines, A. H., R.N. Lipcius, and A. M. Haddon.1987. Population dynamics and habitat partitioning by size, sex, and molt stage of blue crabs *Callinectes sapidus* in a subestuary of central Chesapeake Bay. Marine Ecology Progress Series 36:55-64.

Howell, S. N. G., and S. Webb. 1995. A Guide of the Birds of Mexico and North Central America. Oxford University Press.

INEGI (Instituto Nacional de Estadística Geografía e Informática). 2000. Sonora. Resultados definitivos tabulados básicos, México.

Ibarra-Obando, S. E. 1985. Introducción al método de marcado para medir la producción en pastos marinos. Universidad Autónoma de Baja California, Ensenada.

Jacobs, R. P. W. M. 1982. Reproductive strategies of two seagrass species (*Zostera marina* and *Z. noltii*) along west European coast. Pp. 150-155 in Studies on Aquatic Vascular Plants. J. J. Symoens, S. S. Hooper, S. S., and P. Compere (eds.). Royal Botanical Society of Belgium.

Johannes, R. E. 1981. Words of the Lagoon: Fishing and Marine Lore in the Palau District of Micronesia. University of California Press.

Johnston, B. 1968. Seri ironwood carving. The Kiva 33:156-166.

Johnson, J. A., Jr., D. P. Green, and R. E. Martin. 1998. Industry perspectives: the hard blue crab fishery - Atlantic and Gulf. Journal of Shellfish Research 17:371-374.

Jordan, S. J. 1998. Introduction. Journal of Shellfish Research 17:369-370.

Keen, A. M. 1971. Sea Shells of Tropical West America. Marine mollusks from Baja California and Peru. Standord University Press.

Kira, G. 1999. The Unforgettable Sea of Cortez. Baja California Golden Age 1947-1977. The Life and Writings of ray Cannon. Cortez Publications.

Knudson, T. 1995. A Dying Sea. The Sacramento Bee. December 10-13, 1995.

Knudson, T. 1999. Return to Dying Sea. The Sacramento Bee. July 4-6, 1999.

Kurien, J. 1998. Traditional ecological knowledge and ecosystem sustainability: new meaning to asian coastal proverbs. Ecological Applications 8:2-5.

Kramer, G. W., Migoya, R. 1989. The Pacific coast of Mexico. Pp. 507-528 in Habitat Management for Migrating and Wintering Waterfowl in North America. L. M. Smith, T. L. Peterson, and R. M. Kaminski (eds.). Texas Tech University Press.

Lee Long, W. J., L. J. McKenzie, M. A. Rasheed, and R.G. Coles. 1996. Monitoring seagrasses in tropical port and harbours. Pp. 345-350 in Seagrass Biology: Proceedings of an International Workshop. J. Kuo, R. C. Phillips, D. I. Walker, and H. Kirkman (eds.). Faculty of Sceinces. The University of Western Australia.

López-Blanco, J., P. Ramírez-García, and A. Lot. 1998. Local distribution of seagrasses (*Phyllospadix* spp.) by means of processing infrared and color imagery obtained with a tethered blimp to the north of Ensenada, Mexico. Fifth International Conference Remote Sensing for Marine and Coastal Environments, San Diego, 5-7 October.

Luke, S. R. 1982. Catalog of the Invertebrates Collections. Echinodermata. Reference Series. Scripps Institution of Oceanography.

Luke, S. R. 1995. Catalog of the Benthic Invertebrate Collections. Mollusca. Reference Series. Scrips Institution of Oceanography.

Malkin, B. 1962. Seri etnozoology. Occasional Papers of the Idaho State College Museum 7:58.

Maluf, L. Y. 1983. The physical oceanography. Pp. 26-45 in Island Biogeography in the Sea of Cortez. T. J. Case and M. L. Cody (eds.). University of California Press.

Maluf, L. Y. 1988. Composition and distribution of the Central Eastern Pacific echinoderms. Technical Reports of the Natural History Museum of Los Angeles County 2:1-242.

Marlett, S. A. 2000. Why the Seri language is important and interesting. Journal of the Southwest 42:611-633.

Mayr, E. and G. W. Cottrell. 1979. Check-list of Birds of the World. Vol. I. Museum of Comparative Zoology.

McMillan, C. 1983. Seed germination for an annual form of *Zostera marina* from the Sea of Cortez, Mexico. Aquatic Botany 16:105-110.

McMillan, C., and R. C. Phillips. 1979. *Halodule wrightii* Aschers. in the Sea of Cortez, Mexico. Aquatic Botany 6:393-396.

Medellín, R. A. 1998. True international collaboration: now or never. Conservation Biology 12:939-940.

Mehrhoff, L. J. 1997. Museums, research collections, and the biodiversity challenge. Pp. 447-465 in Biodiversity II. Understanding and Protecting our Biological Resources. M. L. Reaka-Kudla, D. E. Wilson, and E. O. Wilson (eds.). Joseph Henry Press.

Meling-López, A. E., and S. E. Ibarra-Obando. 1999. Annual life cycles of two *Zostera marina* L. populations in the Gulf of Calfiornia: contrasts in seasonality and reproductive effort. Aquatic Botany 65:59-69.

Merifield, P. M., J. E. Marzolf, and D. L. Lamar. 1970. Marine sand waves in El Infiernillo Channel, Gulf of California. Office of Naval Research, Dept. of Defense. Final Report Contract No. 00014-69-C-0210.

Meyer, D. L., M. S. Fonseca, P. L. Murphey, J. R. H. Michael, M. M. Byerly, M. W. LaCroix, P. E. Whitfield, and G. W. Thayer. 1999. Effects of live-bait shrimp trawling on seagrass beds and fish bycatch in Tampa Bay, Florida. Fishery Bulletin 97:193-199.

Moffat, N. M. and D. A. Thomson. 1975. Taxonomic status of the gulf grunion (*Leuresthes sardina*) and its relationship to the California grunion (*L. tenuis*). Transactions of the San Diego Society of Natural History 18:75-84.

Molina-Ocampo, R. E. 2000. La pesquería de jaiba (*Callinectes bellicosus*) en el estado de Sonora, México. Pp. 329-348 in Sustentabilidad y Pesca Responsable en México: Evaluación y Manejo. SEMARNAP-INP, México D.F.

Molina-Ocampo, R. E. 2001. Normatividad vigente para la unidad funcional de manejo jaiba en la región de Bahía Kino y Canal de Infiernillo, Sonora. Pp. 49-53 in Unidad Funcional de Manejo de Jaiba Verde. Descripción de los Aspectos Biológicos, Económicos, Sociales y de Manejo Pesquero de Jaiba Verde (*Callinectes bellicosus*) en Bahía Kino y Canal de Infiernillo, Sonora. G. Montemayor-López and J. Torre-Cosío (eds.). Conservation International-México, Gulf of California Bioregion Program, Guaymas, Sonora, México.

Molina, R. E., F. A. Manrique, and J. García. 1997. Nota sobre un florecimiento de *Stenophanopyxis palmeriana* (grenville) Grunow (Bacillariophyceae) en la Bahía Kunkaak, Golfo de California. Hidrobiología 7:84-86.

Montemayor-López, G., and J. Torre-Cosío (eds.). 2001. Unidad Funcional de Manejo de Jaiba Verde. Descripción de los Aspectos Biológicos, Económicos, Sociales y de Manejo Pesquero de Jaiba Verde (*Callinectes bellicosus*) en Bahía Kino y Canal de Infiernillo, Sonora. Conservation International-México, Gulf of California Bioregion Program, Guaymas, Sonora, México

Moser, E. W. 1963. Seri bands. The Kiva 28:14-27. [Spanish version available on-line at http://www.sil.org/mexico/seri/A004-BandasSeris-SEI.htm].

Moser, E. W. 1973. Seri basketry. The Kiva 38:105-140.

Musick, J. A. and 17 other authors. 2000. Marine, estuarine, and diadromous fish stocks at risk of extinction in North America (exclusive of Pacific salmoids). Fisheries 25:6-30.

Murphy, D. D., and D. A. Duffus. 1996. Conservation biology and marine biodiversity. Conservation Biology 10:311-312.

Nabhan, G. P. 2000. Interspecific relationships affecting endangered species recognized by O'odham and Comcáac cultures. Ecological Applications 10:1288-1295.

National Research Council.1995. Understanding marine biodiversity. National Academy Press.

Nelson, J. S. 1994. Fishes of the World. John Wiley & Sons, Inc.

Nielsen, E. S., and J. G. West. 1994. Biodiversity research and biological collections: transfer of information. Pp. 101-121 in Systematics and Conservation Evaluation. P. L. Forey, C. J. Humphries, and R. I. Vane-Wright (eds.). The Systematics Association by Clarendon Press.

Nietschmann, B. 1997. Protecting indigenous coral reef and sea territories, Miskito coast, Raan, Nicaragua. Pp. 193-224 in Conservation Through Cultural Survival. Indigenous People and Protected Areas. S. Stevens (ed.). Island Press.

Norse, E. A. 1993. Global Marine Biological Diversity. Island Press.

Norse, E. A., and M. Estevez. 1977. Studies on portunid crabs from the eastern Pacific. I. Zonation along enviornmental stress gradients from the coast of Colombia. Marine Biology 40:365-373.

Norris, J. G., S. Wyllie-Echeverria, S., A. B. T. Mumford, and T. Turner. 1997. Estimating basal area coverage of subtidal seagrass beds using underwater videography. Aquatic Botany 58:269-287.

Noss, R. F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4:355-363.

Nudds, T. D. 1999. Adaptive management and the conservation of biodiversity. Pages 179-193 in Practical approaches to the conservation of biological diversity. R. K. Baydack and J. B. Haufler (eds.). Island Press.

O'Connell, M. A., and R. F. Noss. 1992. Private land management for biodiversity conservation. Environmental Management 16:435-450.

Oesterling, M. J. 1998. "Blue" crab resources in other countries: implications for the U.S. industry. Journal of Shellfish Research 17:375-368.

Orth, R. J., J. Van Montfrans, R. N. Lipcius, and K. S. Metcalf. 1996. Utilization of seagrass habitat by the blue crab, *Callinectes sapidus* Rathbun, in Chesapeake Bay: a review. Pp. 213-244 in Seagrass Biology: Proceedings of an International Workshop. J. Kuo, R. C. Phillips, D. I. Walker, and H. Kirman (eds.). The University of Western Australia.

Parrish, F. A., and T. K. Kazama. 1992. Evaluation of ghost fishing in the Hawaiian lobster fishery. Fishery Bulletin 4:720-725.

Paul, R. K. G. 1982. Abundance, breeding and growth of *Callinectes arcuatus* Ordway and *Callinectes toxotes* Ordway (Decapoda, Brachyura, Portunidae) in a lagoon system on the Mexican Pacific coast. Estuarine, Coastal and Shelf Science 14:13-26.

Paz, V. A., and A. Begossi. 1996. Ethnoichthyology of Gamboa fishermen of Sepetiba Bay, Brazil. Journal of Ethnobiology 16:157-168.

Pearson, D. L. 1995. 7. Selecting indicator taxa for the quantitative assessment of biodiversity. Pp. 75-79 in Biodiversity. Measurement and Estimation. D. L. Hawksworth (ed.). Chapman & Hall and The Royal Society.

Pecci, K. J., R. A. Cooper, C. D. Newell, R. A. Clifford, and R. J. Smolowitz. 1978. Ghost fishing of vented and unvented lobster, *Homarus americanus* traps. U. S. National Marine Fisheries Service. Marine Fisheries Review 40:9-24.

Peters, J. L. 1934. Check-list of the Birds of the World. Vol. II. Museum of Comparative Zoology.

Phillips, R. C., and T. W. Backman. 1983. Phenology and reproductive biology of eelgrass (*Zostera marina* L.) at Bahia Kino, Sea of Cortez, Mexico. Aquatic Botany 17:85-90.

Phillips, R. C., W. S. Grant, and C. P. McRoy. 1983. Reproductive strategies of eelgrass (*Zostera marina* L.). Aquatic Botany 16:1-20.

Probst, J. R., and T. R. Crow. 1991. Integrating biological diversity and resource management. Journal of Forestry 89:12-17.

Ramírez-García, P., and A. Lot. 1994. La distribución del manglar y de los "pastos marinos" en el Golfo de California, México. Anales del Instituto de Biología de la Universidad Nacional Autónoma de México, Serie Botánica 65:63-72.

Ray, G. C., and J. F. Grassle. 1991. Marine biological diversity. BioScience 41:453-457.

Rea, A. M. 1981. Resource utilization and food taboos of Sonoran Desert peoples. Journal of Ethnobiology 1:69-83.

Reguero Reza, M., and A. García-Cubas. 1993. Estado actual de la investigación sobre diversidad de moluscos en México. Revista de la Sociedad Mexicana de Historia Natural XLIV:191-207.

Riosmena-Rodríguez, R., and J. L. Sánchez-Lizaso. 1996. The southern distributional limit of *Zostera marina* L. and *Phyllospadix torreyi* Watson for northwestern México. Oceanides 11:45-48

Rosenfield, A. 1998. Preface. Journal of Shellfish Research 17:367.

Roosenburg, W. M., W. Cresko, M. Modesitte, and M. B. Robbins. 1997. Diamondback terrapin (*Malaclemys terrapin*) mortality in crab pots. Conservation Biology 11:1166-1172.

Ruddle, K. 1994. Local knowledge in the folk management of fisheries and coastal marine environments. Pp.161-206 in Folk Management in the World´s Fisheries Lessons for Modern Fisheries Management. Christopher L. Dyer and Jame R. McGoodwin (eds.). University of Colorado Press.

Russell, S. M., and G. Monson 1998. The Birds of Sonora. The University of Arizona Press.

Santamaría-Gallegos, N. A. 1996. Ciclo de crecimiento y fenología de la fanerogama *Zostera marina* L. en Punta Arena, Bahía Concepción, B. C. S., México. Unpublished M. Sc. Thesis. Centro Interdisciplinario de Ciencias Marinas, Instituto Politécnico Nacional, La Paz, Baja California Sur.

Santamaría-Gallegos, N. A., J. L. Sánchez-Lizaso, and E. F. Félix-Pico. 2000. Phenology and growth cycle of annual subtidal eelgrass in a subtropical locality. Aquatic Botany 66:329-339.

Seminoff, J. A., W. J. Nichols, A. Resendiz, and L. Brooks. In press. Ocurrence of hawksbill turtles, *Eretmochelys imbricata*, near Baja California, México. Pacific Science.

Seminoff, J. A., W. J. Nichols, and A. Resendiz. 1997. Diet composition of the black sea turtle, *Chelonia mydas agassizii*. Proceedings of the Seventeeth Annual Sea Turtle Symposium. S P. Epperly and J. Braun (compilers). NOAA Technical Report NMFS-SEFSC-415:89-91.

Sexias, C., and A. Begossi. 2001. Ethnozoology of fishing communities from Ilha Grande (Atlantic forest coast, Brazil). Journal of Ethnobiology 21:107-135.

Sheldon, W. W., and R. L. Dow. 1975. Trap contribution to losses in the American lobster fishery. Fishery Bulletin 73:449-451

Sheridan, T. E. 1996. The Comcáac (Seris) people of the desert and sea. Pp. 187-211 in Paths of Life. American Indians of the Southwest and Northwestern Mexico, T. E. Sheridan and N. J. Parezo (eds.). The University of Arizona Press.

Sheridan, T. E. 1999. Empire of Sand. The Seri Indians and the Struggle for Spanish Sonora, 1645-1803. The University of Arizona Press.

Sherman, K. 1991. The large marine ecosystem concept: research and management strategy for living marine resources. Ecological Applications 1:349-360.

Sherwin, R. W., Jr. 1971. Coastal landforms and vegetation associations of the straits of Infiernillo, Sonora, Mexico: a pole ward habitat for mangroves. Unpublished M. Sc. Thesis. Department of Geography and Area Development, University of Arizona.

Short, F. T., and S. Wyllie-Echeverria. 1996. Natural and human-induced disturbance of seagrasses. Environmental Conservation 23:17-27.

Smolowitz, R. J. 1978. Trap design and ghost fishing: an overview. U. S. National Marine Fisheries Service, Marine Fisheries Review 40:2-8.

Soulé, M. E. 1985. What is conservation biology? BioScience 35:727-734.

Stevens, B. G. 1996. Crab bycatch in pot fisheries: causes and solutions. Pp. 151-158 in Solving Bycatch: Considerations for Today and Tomorrow. Alaska Sea Grant Program Report 96-03. University of Alaska.

Stork, N. E. 1994. Inventories of biodiversity: more tha a question of numbers. Pp. 81-100 in Systematics and Conservation Evolution. P. L. Forey, C. J. Humphries, and R. I. Vane-Wright (eds.). Claredon Press.

Thomson, D. A. and W. H. Eger. 1966. Guide of the families of the common fishes of the Gulf of California. Gulf of California Field Guides Series 2. The University of Arizona.

Thomson, D. A., L. T. Findley, and A. N. Kerstitch 1979. Reef fishes of the Sea of Cortez. The Rocky-shore Fishes of the Gulf of California. The University of Arizona.

Thomson, D. A., L. T. Findley, and A. N. Kerstitch. 2000. Reef fishes of the Sea of Cortez. The Rocky-shore Fishes of the Gulf of California. Revised edition. University of Texas Press.

Thorne-Miller, B. 1999. The Living Ocean. Understanding and Protecting Marine Biodiversity. Island Press.

UNEP (United Nations Environment Programme). 1995. Global Biodiversity Assessment. Cambridge University Press.

U. S. Fish and Wildlife Service. 1965-2001. Winter waterfowl survey, Mexico. Annual reports written by various authors, Washington (D.C.), Portland (OR).

U. S. Fish and Wildlife Service. 1988. Endangered Species Act of 1973. As Amended through the 100th Congress. U. S. Department of Interior.

Vennum, T., Jr. 2000. Locating the Seri on the musical map of indian North America. Journal of the Southwest 42:635-760.

Vermeij, G. T. 1989. Saving the Sea: what we know and what we need to know. Conservation Biology 3:240-241.

Vidal, O. 1991. Catalog of osteological collections of aquatic mammals from México. NOAA Technical Report NMFS 97:1-36.

Vidal, O., L. T. Findley, and S. Leatherwood. 1993. Annotated checklist of the marine mammals of the Gulf of California. Proceedings of the San Diego Society of Natural History 28:1-16.

Villareal-Chávez, G.1992. Algunos Aspectos de la Biología de *Callinectes arcuatus* (Crustacea: Decapoda: Portunidae) en el Delta del Río Colorado, México. Proceedings of the San Diego Society of Natural History 10:1-4.

Vonder Haar, S. P., and R. O. Stone. 1973. Oceanographic analysis of orbital photographs of the Upper Gulf of California. Photogrammetria 29:45-61.

Walker, B. W. 1960. The distribution and affinities of the marine fish fauna of the Gulf of California. Systematic Zoology 9:123-133.

Ward, D. H., C. J. Markon, and D. C. Douglas, D. C. 1997. Distribution and stability of eelgrass beds at Izembek lagoon, Alaska. Aquatic Botany 58:229-240.

Ward, D. H., A. Morton, T. L. Tibiths, S. E. Ibarra-Obando, and D. Douglas. 2002. Recent trends in eelgrass, *Zostera marina*, distribution and abundance along the west coast of Baja California, México. 5th International Seagrass Biology Workshop. October 7-11, 2002, CICESE, Ensenada, Baja California.

Watling, L., and E. A. Norse. 1998. Disturbance of the seabed by mobile fishing gear: a comparison to forest clearcutting. Conservation Biology 12:1180-1197

Williams, S. L., and J. K. L. Heck. 2000. Seagrass community ecology. Pp. 317-331 in Marine Community Ecology. M. D. Bertness, S. D. Gaines, and M. E. Hay. (eds.). Sinauer Associates, Inc.

Wood, N., and P. Lavery. 2000. Monitoring seagrass ecosystem health - the role of perception in defining health and indicators. Ecosisyem Health 6:134-148.

Zavala- Gonzáles, A. and E. Mellick. 1997. Entaglement of California sea lions, *Zalophus californianus californianus*, in fishing gear in the central-northern part of the Gulf of California, Mexico. Fishery Bulletin 95:180-184.