MANAGEMENT AND CONSERVATION OF BENTHIC RESOURCES HARVESTED BY SMALL-SCALE HOOKAH DIVERS IN THE NORTHERN GULF OF CALIFORNIA, MEXICO: THE BLACK MUREX SNAIL FISHERY

By

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who loved life, music, and seafood.
I wish you were here.

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Abstract

I conducted a management assessment for the conservation of benthic resources harvested by small-scale hookah divers in the northern Gulf of California (NG), Mexico, and analyzed the reproductive ecology of the black murex snail.

Open access to the fisheries, combined with national and international market pressure, fishing methods, and the timing of fishing activities have caused an evident decline in production, the use of new fishing zones, and a shift of fishing effort towards deeper areas. However, the organization of the diving sector and its initiatives to establish forms of regulation provide an opportunity to alleviate this situation. I conclude that co-management has the potential to be an effective management system for the benthic resources of the NG, a system that could be facilitated by the sedentary and semi-sedentary nature of these resources. An informal type of co-management arena is already in place with the possibility of being formalized and solidified.

Introduction

The history of the northern Gulf of California (NG), Mexico, cannot be defined without speaking of fishing traditions. Considered to be one of the most productive marine ecosystems in the world, this region has supplied the Mexican, United States, and Asian markets with abundant fishing resources throughout the 20th century.

Since the beginning of the century, three coastal fishing communities have become established in the NG: San Felipe, Baja California; and in Sonora, El Golfo de Santa Clara and Puerto Peñasco. Through the years, these communities have utilized the tremendous richness of their coastal fishing resources in varying ways according to the availability of resources and in response to market demands. Particularly in the past two decades, there have been dramatic turnovers of resources exploited (i.e., changes in targeted species). Similarly, as exploitation has grown, the total number of species harvested has increased steadily.

Due to the overall biological and cultural importance of the northern Gulf of California and Colorado River delta ecosystems (Programa de Manejo Reserva de la Biosfera Alto Golfo de California y Delta del Río Colorado 1995), as well as Mexico's political and environmental agendas linked to the North American Free Trade Agreement (NAFTA) in the early 1990's (McGuire and Valdez-Gardea 1997), the Mexican Government declared this region a Biosphere Reserve in June of 1993 (Diario Oficial de la Federación, June 10 1993).

There are three primary users of the marine area of this Reserve: 1) the large-scale industrial fishing sector, which uses trawler boats to fish shrimp and, more recently, a variety of bony fish and elasmobranchs; 2) the small-scale or artisanal fishery sector, which uses small, fiberglass vessels with an outboard motor called *pangas*; 3) the tourism sector, engaged mainly in sport fishing activities. In terms of the number of people that directly and/or indirectly participate in fishing activities, small-scale fisheries are by far the most prevalent fisheries in the region and throughout the Gulf of California. Small-scale fisheries in the Gulf contribute approximately 20% of national fisheries production, and recent studies estimate that as many as 30,000 fishermen work in the Gulf of California (Conservation International 1998). In addition, approximately 150,000 jobs are generated indirectly from small-scale fishery activities (Conservation International 1998). In the three main communities of the NG, the small-scale fishing fleet totals approximately 700 *pangas*. This fleet exploits over 70 species of fish, mollusks, and crustaceans on a regular basis (Cudney-Bueno and Turk-Boyer 1998). Approximately 40% of this harvest is exported to the U.S. and the Asian markets primarily in California, Korea, China, and Japan (Cudney-Bueno and Turk-Boyer 1998). In spite of this importance, small-scale fisheries within the Reserve are poorly understood and their management has been insufficient and unsuccessful. The tremendous diversity of fishing activities taking place within the Reserve, the cultural differences between communities, and the vast dimensions of the Reserve make it a difficult area to manage. This is intensified by the lack of sufficient resources for implementing and enforcing management decisions, inadequate or lack of knowledge about the ecology of species exploited, and the insufficient efforts to actively involve fishing communities in management decision-making and implementation.

The blame for fishery management inefficiencies and/or failures cannot be easily addressed and it is certainly not unique to Mexico. In many places throughout the world, the inherent management complexity of marine fisheries translates to increasing utilization and often misuse of marine resources. In 1995, the Food and Agriculture Organization (FAO) reported that "69% of the world's fisheries were either fully to heavily exploited, overexploited, depleted… and therefore are in need of urgent conservation and management measures" (United Nations Food and Agriculture Organization 1995).

Management of small-scale fisheries certainly represents a challenge and has become of increasing concern as fishery managers and governments have realized the social and economic importance of this economic sector. For historical and logistical reasons, small-scale fisheries have been largely neglected in the formulation of fisheries policies (McGoodwin 1990). The small capital commitment, relatively low-levels of production per capita, and the fact that small-scale fishers produce primarily for household subsistence, community food needs, and local markets (McGoodwin 1990), have certainly played a part in this historical neglect. However, 94% of the world's fishers (more than 100 million people) are small-scale operators, and they produce about 45% of the total world fish catch (McGoodwin 1990). Small-scale fisheries are particularly important in developing countries, providing the bulk of the domestic day-to-day food for many communities and numerous employment opportunities. Aguero (cited in Castilla and Fernández 1998) estimated that as many as 10 million people are directly engaged in fishing activities in Latin America, and ~90% of them are small-scale fishers.

Most of the resources available and therefore harvested by this sector are pelagic or benthic species confined to inshore areas. However, as resources have become increasingly scarce and technology improved (e.g., better motors and vessels), venturing into offshore waters seems to become less of an issue or obstacle to small-scale fishers. Certainly, resources targeted by small-scale fisheries are not immune to overexploitation (Castilla and Fernández 1998). Small-scale fisheries are some of the world's most spatially extensive economic activities, and spatial and open access dimensions determine the root of many of the problems of the world's fisheries (Meaden and Do Chi 1996).

Management of small-scale fisheries could be facilitated if efforts were focused on identifiable fishing sectors and distinctive fishing zones (Cudney-Bueno and Turk-Boyer 1998). By working with zones, the difficulty of dealing with the dynamic nature of small-scale fisheries can be reduced as fishing zones may remain as tangible units for management through time. The different types of users that fish in each zone can be identified and possibly involved in management processes for a specific zone. Also, by working with specific users or sectors, more focused and reliable management proposals can be obtained for the fishery or fisheries undertaken (Cudney-Bueno and Turk-Boyer 1998). Also, nourishing the ecological knowledge of the fishers and the already existing sense of pride of the sector should facilitate management. By actively involving the sector in the establishment of management systems for its fishing resources, established regulations should have more credibility among users and the willingness and incentives to respect them may increase (Wilson et al. 1994, Pinkerton 1994, Christie et al. 1994, White et al. 1994).

One distinguishable small-scale fishing sector in the NG is the hookah diving sector of Puerto Peñasco, Sonora. Hookah fishing involves diving for benthic resources using a compressor on the boat that supplies air for divers through long hoses. Commercial divers in the NG have been harvesting benthic sessile and semi-sessile resources since the early 1970's, particularly rock scallop (*Spondylus calcifer*), octopus (*Octopus bimaculatus*), and snails (*Hexaplex (Muricanthus) nigritus*, and *Phyllonotus erythrostomus*). These diving fisheries activities exemplify the rapid exploitation and diversification of resources that have characterized small-scale fisheries in the NG during the last 20 years. Advances in technology, particularly the development of underwater breathing devices, have allowed fishers to harvest resources that were formerly either inaccessible or extremely difficult to exploit on a grand scale.

The goal of this thesis was to assess management possibilities for the conservation of benthic resources that are being exploited by small-scale hookah fishers in the northern Gulf of California, and propose management strategies based on this assessment. Most of my research focused on an in-depth analysis of the black murex snail (*Hexaplex (Muricanthus) nigritus*) fishery, which I used as a case study to address the various issues surrounding harvesting and managing benthic resources in the region.

In order to assess and propose management possibilities for benthic diving fisheries in the NG, I developed a management assessment that covered the following specific research objectives:

1) Assess the main features of hookah diving fisheries in the NG.
2) Assess the main features of the murex snail fishery in the NG.
3) Increase knowledge on the reproductive ecology of black murex.
4) Understand the existent forms of management and the role of the main factors influencing management of diving fisheries in the NG.
5) Identify and understand the main problems and challenges inherent to managing diving fisheries in the NG.
6) Identify fishers' opinions and proposals regarding management and conservation of benthic fisheries in general and murex in particular, and propose management strategies.

This thesis is organized into 6 chapters, each chapter addressing one of the six objectives above.

In Chapter 1, I assess the characteristics of the hookah diving sector, its structure, and the use of benthic resources. I also provide an historical overview of the development of hookah fisheries in the NG. Chapter 2 gives an in-depth analysis of the murex fishery. Chapter 3 describes aspects of the reproductive ecology of black murex and the methods I used for that specific part of my research. Chapter 4 analyzes the existing management framework surrounding small-scale benthic fisheries, specifically black murex. Chapter 5 discusses the issues I considered to be the main problems and challenges to the successful management and conservation of benthic diving fisheries in the NG. Finally, in Chapter 6, I describe and discuss fishers' perceptions and proposals for the management of exploited benthic resources and conclude with a final assessment of management recommendations.

I developed this thesis as a result of the initiative of Puerto Peñasco divers to better manage the black murex snail fishery. It represents the continuation of a field research project I coordinated for the Intercultural Center for the Study of Deserts and Oceans (CEDO) in Puerto Peñasco, between June 1996 and June 1998 and funded by the David and Lucile Packard Foundation. This project had the objectives of assessing small-scale fishing activities of the three main fishing communities of the NG and obtaining perceptions and proposals from fishers concerning management of their fisheries and the Biosphere Reserve. During this project, I worked particularly closely with the divers, who expressed an interest in participating in management efforts.

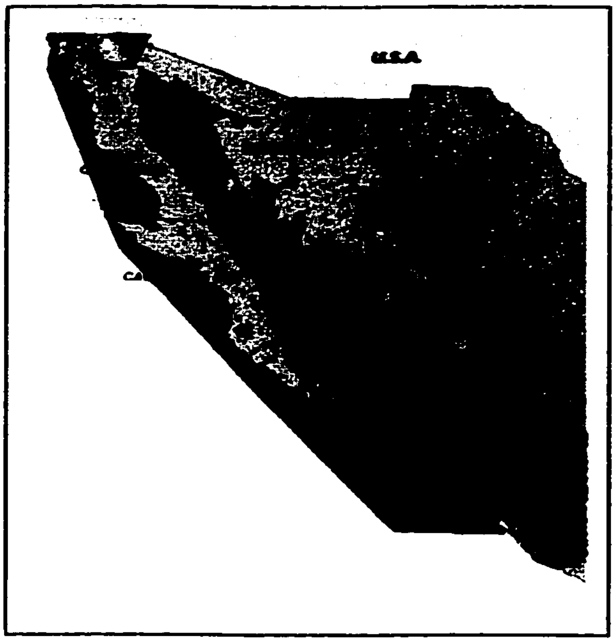
Setting: Natural History and Political Ecology of Fishing in the Northern Gulf of California

Natural History

The Gulf of California is a unique body of water with physical and biological characteristics that make it one of the most productive seas in the world. It supports the highest production of fishery resources in Mexico (Arvizu-Martínez 1987).

The Gulf is located in the northwest region of Mexico, between the 18 and 35 degrees of northern latitude. It is a marine basin bordering the states of Sonora, Sinaloa, and Nayarit on the east side, and the Baja California Peninsula on the west. An imaginary line between Cabo San Lucas, Baja California Sur, and Cabo Corrientes, in the state of Jalisco traces its southern limit (Figure 1).

Figure 1. Geographical location of the Gulf of California, Mexico.



Sources: INEGI, Instituto Nacional de Ecología, Southwest Fisheries Center San Diego, UIB, CECARENA ITESM Campus Guaymas.

The Gulf of California extends approximately 1400 kilometers, and its maximum width is 210 km (Bourillón et al. 1988). This width gradually decreases northward until reaching the mouth of the Colorado River. Much of the region around the northern Gulf consists of low-lying coastal plains, with mud and salt flats bearing sediments from the Colorado River (Brusca 1973).

On the west side, the Gulf's coast is characterized by high mountains and pre- to mid-Cretaceous igneous and metamorphic rocks of the Baja California Peninsula (Brusca 1973). On the east, the coast is dominated by the sedimentary and volcanic blankets of the coastal plains of Sonora and Sinaloa which are mostly covered by broad alluvial fans and deltas of sand and gravel (Brusca 1973).

The Baja California Peninsula is characterized by the absence of rivers. The east coast of the Gulf, however, is more flat and has a number of rivers that reach the coast from the Sierra Madre Occidental mountain range.

Because of its geographic orientation, subtropical latitudinal position, and marked variation in the ocean bottom relief, the Gulf of California has unique oceanographic characteristics and distributions of flora and fauna. The northern portion is distinguished from other regions of the Gulf in many ways. It is characterized by having large quantities of sediments of continental origin transported by the Colorado River. These sediment deposits are in some places up to 5 km deep (Bourillón et al. 1988). The ocean bottom is dominated by shallow waters, with slopes rarely exceeding 0.5% from the coastline to a 15 m depth (Thomson et al. 1969). Approximately 80% of the area is dominated by depths of less than 50 m, the Wagner Basin being the steepest and deepest depression of the region (Figure 2).

The NG has some of the largest tidal fluctuations found anywhere in the world, with approximately 6 to 10 m of vertical displacement (18 to 30 ft). These massive vertical displacements, coupled with the low inclination of the ocean bottom, generate enormous intertidal zones up to 5 km in width.

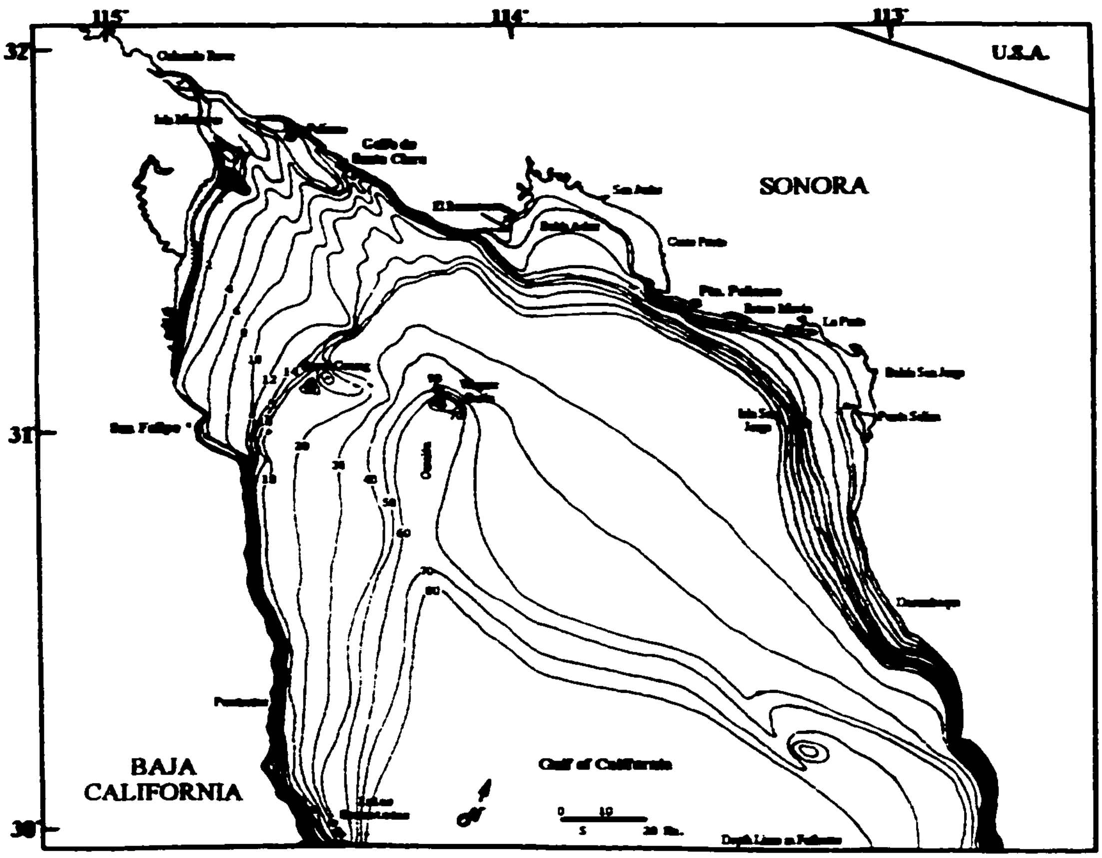
The intense diurnal and semi-diurnal tide cycles of the NG generate currents with speeds of 0.21 m/sec throughout the coast of Sonora and 0.89 m/sec in Baja California (Programa de Manejo Reserva de la Biosfera Alto Golfo de California y Delta del Río Colorado 1995). Water circulation is complex and the tides and currents give this circulation a rotation pattern distinct to other regions of the Gulf. This circulation allows constant mixing and re-suspension of sediments and nutrients resulting in a very productive environment.

There is a large seasonal temperature fluctuation in the NG. At Puerto Peñasco, this annual fluctuation may exceed 11° C. Onshore water temperatures at Puerto Peñasco may reach 30 to 32° C (88 to 91° F) in the summer, and may drop to 10-11° C (50 to 52° F) in the winter (Brusca 1973).

Salinity in the NG is 1-2% higher than that of same latitude areas in the Pacific Ocean (Roden and Groves 1959). In the lower parts of the Colorado River delta and the intertidal regions, surface salinity is close to 36.5‰ in the winter and more than 38.5‰ in the summer (Alvarez-Borrego and Galindo-Bect 1974).

The combination of these characteristics make the NG act as a biological barrier, excluding many species found in the southern Gulf and allowing the presence of endemics or of species that depend on the unique characteristics of the NG during some part of their life cycle.

Figure 2. Bathymetric map of the northern Gulf of California, Mexico.



Sources: McGuire and Greenberg 1993, Cudney-Bueno and Turk-Boyer 1998.

Development of Small-Scale Fisheries

In order to begin understanding the present status of fisheries in the NG, one must go back to a very different time: the outbreak of the Mexican Revolution in the early 20th Century. Although small-scale fishing has been carried out in the Gulf of California for hundreds of years, its foundation as a commercial industry can be traced back to this period.

During the Revolution, the brief administration of Francisco Madero dismantled franchises which had secured federal permits from President Porfirio Diaz' administration to harvest fishery resources within productive coastal waters (McGoodwin 1987). Madero declared all of Mexico's waters as free and open to all subsistence fishing, and the name *pescador libre* (free fisherman) was given to independent fishers (McGoodwin 1987), a term which is still used today.

After the Revolution, however, the federal government declared that its fisheries regulations were above those of states, municipalities, towns, or anyone else, although rights to subsistence fishing were still tacitly allowed to remain "free" (McGoodwin 1987). This clear intervention of the government over the regulation of Mexico's fisheries would set the tone for fishery management in the years to come.

The Northern Gulf of California fishing communities, as known today, were just beginning to be formed. During the 1920's, a huge demand for totoaba (*Totoaba macdonaldi*) developed. Totoaba is a large sea bass cherished by the Asian market for its swim bladder or *buche*. Fishers primarily from southern Sonora and Sinaloa ventured up to the arid and harsh lands of the NG to harvest this fish during its spawning migration route to the Colorado River delta (Munro 1994). Having extremely rich and productive waters amidst the Colorado River delta compensated the harsh living conditions of the region. Soon thereafter, the communities of San Felipe in the state of Baja California, and El Golfo de Santa Clara and Puerto Peñasco in the state of Sonora were formed and began to grow.

After the passage of Article 27 of the Mexican Constitution in 1933, the government claimed all rights to commercial exploitation of resources within inshore waters (McGoodwin 1987). This same year, the *Ley General de Cooperativas* (General Law of Cooperatives) was passed (Diario Oficial de la Federación 1933), and with it the beginning of an era of cooperatives. The government bought out private companies operating in coastal inshore waters and established some of Mexico's first cooperatives (McGoodwin 1987). It also integrated local cooperatives and packing plants into a government owned system to produce fishery resources, primarily shrimp, for export purposes (McGoodwin 1987).

Cooperatives not only offered access to credits for equipment and guaranteed fishing permits and access to fishing grounds, but also reduced the uncertainties of fishing. Most cooperatives, in theory, are based on a share system in which all participants share a portion of the profit, even if the profit is not large (McCay 1980). These advantages enabled cooperatives to recruit many rural fishers (McGoodwin 1987, Greenberg 1995).

While the complex structure of small-scale or in-shore fisheries was beginning to take form, another extremely important issue was about to take place at the end of the

1930's, which would dramatically change the course of fishing in the Gulf of California. A U.S. based company, *La Compañía Panamericana*, began trawling operations in the Gulf of California to export shrimp to the U.S. (Nava 1994). A short time later, Japanese boats began harvesting shrimp and eventually dominated the market (Greenberg 1995). President Cárdenas, as part of his expropriation politics, managed to expel these fishing fleets at the beginning of World War II and an opportunity opened for Mexico to develop an offshore fishing fleet (Greenberg 1995). By the 1960's Mexico's offshore shrimp trawling sector had become the nation's most important fishing sector, politically and economically (McGoodwin 1987).

During the thirties and forties, in addition to fishing for shrimp and totoaba, a shark fishery had developed for the production of vitamin A from shark liver oil. This fishery was especially important in the NG. Nevertheless, at the end of the forties and during the fifties, the demand for shark liver dropped due to the development of synthetic vitamin A. In this same period, the shrimp fishery began to grow exponentially in San Felipe, Puerto Peñasco, and El Golfo de Santa Clara. Up until the late 1980's, shrimp provided the main source of income for the fishing sector in these communities and was the catalyst for their growth. Even today, most of the fishing organizations are established primarily for the shrimp market.

In addition to causing an increase and industrialization of the large-scale or off-shore fishing fleet (fishing with trawler boats), shrimp fishing also stimulated the growth of the small-scale fishing sector which, as mentioned before, uses *pangas* as fishing vessels (Greenberg and Vélez-Ibáñez 1993). This sector is characterized by a much lower capital investment than that employed by the offshore industrial sector, as well as by its versatility in the employment of gear types and species targeted.

During President Echeverría's administration (1970-1976), government policies encouraged the expansion of this sector. Small-scale fishing cooperatives were formed, and by the late 1980's, Puerto Peñasco alone had 120 registered pangas, 80 of which were operated by cooperatives and 40 by private owners (Greenberg and Vélez-Ibáñez 1993).

During the 1970's, the selling price of shrimp increased significantly and a large portion of the population of San Felipe and Puerto Peñasco, formerly dedicated to other activities like tourism, began fishing for shrimp. At the same time, there was an influx of people from inland Mexico to these communities where shrimp was abundant. In essence, a new "gold rush" was taking place, but this time it was "pink gold" or "*oro rosado*", as shrimp is known locally.

The Gulf of California was experiencing a booming harvest of its fishery resources, as the government moved rapidly to maximize production by giving numerous credits and consolidating fishing infrastructure (Greenberg 1995). With this boom also came the necessary establishment of institutions such as the *Secretaría de Pesca* SEPESCA (Fishing Ministry) to enforce newly defined regulations.

Trawler and panga fleets grew markedly in the 1970's, despite warnings as early as 1971 of a possible crisis resulting from overexploitation (Vásquez León and McGuire 1993, Chávez and Lluch 1971). Although total shrimp production continued to climb, catch per unit of effort (CPUE) was falling, making shrimp fishing less and less profitable. Although the country was benefiting through increased overall production, each new boat or *panga* added to the fleet meant increased competition among fishers. While competition for resource exploitation had always existed between sectors (large-scale and small-scale sectors), conflicts arising from competition within sectors began to grow as resources were divided among many users.

At the end of the eighties and beginning of the 1990's, shrimp catches began to fall drastically in the NG. Shrimp fishers suffered consistent reductions of up to 50% in their production (Hoyos 1991). Production diminished to the point of financial collapse for the shrimp industry. Banks took possession of boats, cooperatives closed, and local people began searching for other work. In Puerto Peñasco alone, the active trawling fleet was reduced from 220 to 100 boats (Cudney-Bueno and Turk-Boyer 1998). Besides the obvious consequences this downfall brought to the local economies, it provoked more diversification of the fishing activities of small-scale fishers. Species that were sporadic target catches or that were never commercialized, such as *chano* or gulf croaker (*Micropogonias* spp.), suddenly became actively fished and represented important alternative fisheries to shrimp.

Besides this economic crisis, other recent issues had provoked an increasing interest for environmentalists and the Mexican Government to conserve the resources of the NG. In 1985, scientists working in the region discovered some of the first complete and fresh specimens of the *vaquita*, or Gulf of California harbor porpoise (*Phocoena sinus*) (Brownell et al. 1987). This small porpoise was first discovered and described by scientists in 1958 based on a skull specimen (Norris and McFarland 1958). The vaquita is endemic to the NG and extremely rare. Its "rediscovery" immediately caught the attention of the environmental community. The vaquita was being caught incidentally in trawling and gill nets, especially large nets used for sharks and to illegally fish for totoaba (Vidal 1995), which had been permanently banned from fishing since 1975 (Programa de Manejo Reserva de la Biosfera Alto Golfo de California y Delta del Río Colorado 1995). Although different theories had been proposed to explain why the *vaquita* was endangered, including habitat alteration by the lack of Colorado River water, the incidental mortality in nets was considered by most scientists as the most immediate threat to the survival of this species (Vidal 1995).

Creation of the Biosphere Reserve

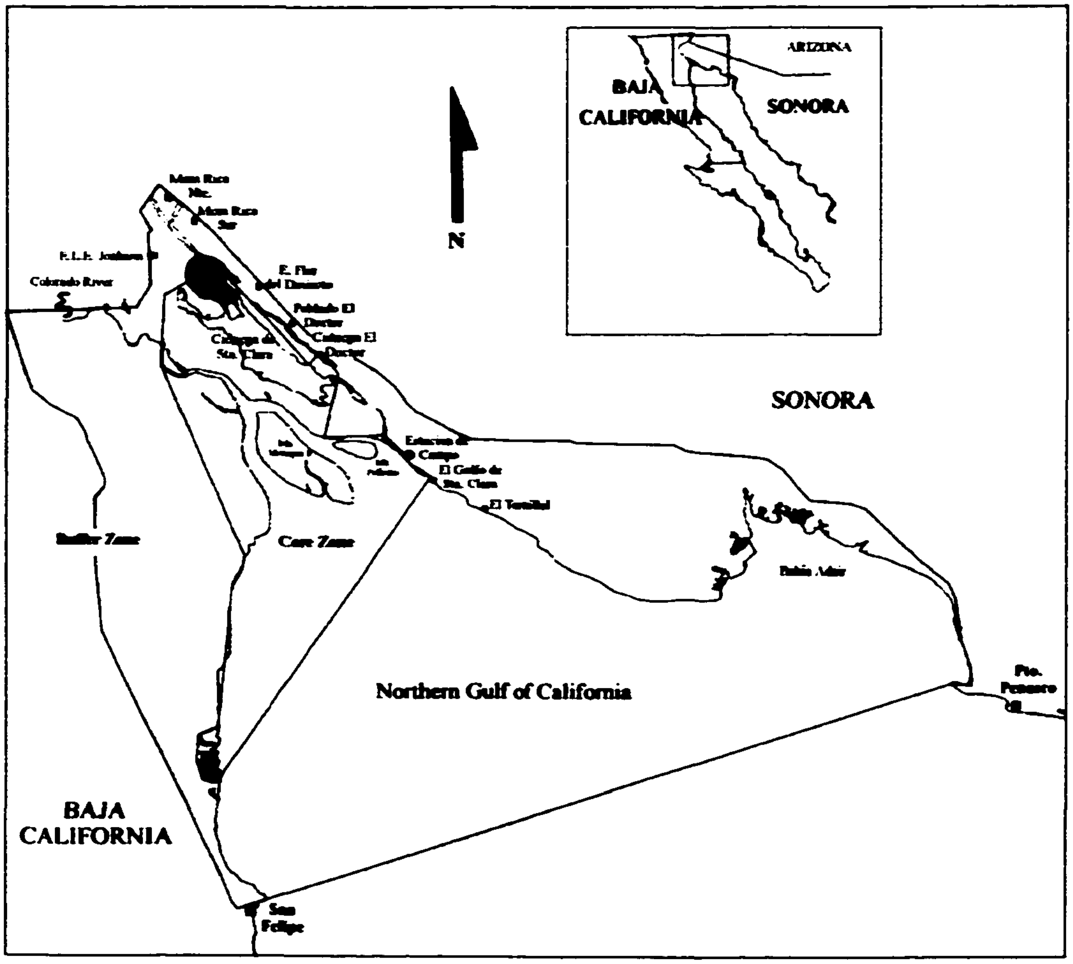
By the beginning of the 1990's, the NG was evidently experiencing an economic and ecological crisis (McGuire and Greenberg 1993). In August 1990, a workshop was carried out bringing together people and institutions to form a preliminary action plan dedicated to conserve the area (Programa de Manejo Reserva de la Biosfera Alto Golfo de California y Delta del Río Colorado 1995). In June 1992, as a result of the Workshop for the Identification of Marine Areas with Conservation Priorities organized by SEDUE (*Secretaría de Desarrollo Urbano y Ecología*) and World Wildlife Fund, the NG was considered as the third marine priority area in the country. In February 1993, Wetlands for the Americas called for the establishment of the Colorado River Delta as an international reserve of the *Programa Red Hemisférica de Aves Playeras* (Programa de Manejo Reserva de la Biosfera Alto Golfo y Delta del Río Colorado 1995). In March

1993, a proposal to declare the Upper Gulf of California and Colorado River Delta as a biosphere reserve was presented to the Federal Government both by NGO's and government officials. The decree was passed only three months later, establishing the Upper Gulf and Colorado River Delta Biosphere Reserve. Except for traditional practices by the Cucapah indigenous people living on the delta and clam hand-picking by local residents, this reserve was to prohibit all commercial fisheries within a *Zona Núcleo* (Core Zone) and increase regulations for most fisheries within a *Zona de Amortiguamiento* (buffer zone) (Figure 3).

One motive for establishing the Reserve was to show Mexico's concern over environmental issues, in compliance with the North American Free Trade Agreement (NAFTA) (McGuire and Valdez-Gardea 1997). In addition, Mexico required to undertake a multifaceted program of structural adjustment, including the privatization of Mexico's fisheries, as part of President Salina's neoliberalism politics (McGuire and Valdez-Gardea 1997). Ironically for the Reserve, fishers obtained new *pangas* and other fishing equipment through a new program of Salinas' administration, PRONASOL (*Programa Nacional de Solidaridad*). This program provided rural assistance but with the aim of increasing production through the creation of small enterprises or *Grupos Solidarios* (Solidarity Groups). PRONASOL itself would be a non-working partner in each of these groups and would share the profits (McGuire and Valdez-Gardea 1997).

Small-scale fisheries in the NG today are very different from what they were ten or twenty years ago. The number of people dedicated to small-scale fishing has grown, and their fishing activities are more diversified and dynamic, covering a wider territory in-shore as well as off-shore (Cudney-Bueno and Turk-Boyer 1998). This increase in resource use has fueled territorial and access conflicts within communities, between communities, and between the large-scale and small-scale sectors (Cudney-Bueno 1997).

Figure 3. Zonation of the Upper Gulf of California and Colorado River Delta Biosphere Reserve.



Source: José Campoy, Director Upper Gulf of California and Colorado River Delta Biosphere Reserve.

Although the original concept of the Biosphere Reserve was geared toward heavily restricting the fishing industry while finding new working alternatives for local people, the aftermath of its declaration shows a different management picture. The Management Program, finalized in 1995, was the first formal management program of any protected area in Mexico (personal communication, José Campoy, Director of Upper Gulf Biosphere Reserve, February 2000). It is a flexible program that fosters fishing activities within the Buffer Zone with certain restrictions that are set primarily on the large-scale fishing sector. It also recognizes the need to involve the communities in management decision making and implementation, a need which has been fostered by the Reserve's recently constituted management team.

Methods

The management assessment was carried out in seven steps:

1) Build rapport with the diving sector.
2) Extensive literature search and development of problem statement and framework of the project.
3) Assure fishing sector was positively receptive of the project.
4) Intensive ethnographic and ecological field research.
5) Preliminary analysis of results.
6) Sharing preliminary results with the fishing sector.
7) Final analysis and recommendations.

I conducted ethnographic and ecological field research in the fishing town of Puerto Peñasco, Sonora, from March to August 1999. Before beginning fieldwork, I conducted an extensive search and review of literature. This literature included existent biological information of the species harvested by divers and/or of similar species, ecological information about the intertidal and subtidal ecosystems of the NG, examples of similar studies carried out in other regions and those that addressed the costs, benefits, and challenges of establishing diverse fishery management practices. I also obtained hard copy and digital maps of the coastline, which were later used for mapping fishing activities and to serve as a means to enhance participation of fishers. Maps and the use of Geographic Information Systems (GIS) are known to be important tools to facilitate management decision-making processes in coastal as well as terrestrial systems (Norse

1993, Agardy 1997). In this project, I used maps to record the approximate fishing site when interviewing fishers on the beach, to discuss the distribution of effort for other diving fisheries (e.g., octopus, clams, rock scallop), and to discuss historical patterns of distribution of effort for the murex fishery. In addition, they served as important means to involve divers in management decision-making processes.

Before the utilization of the maps, I conducted a reconnaissance flight with an experienced diver to identify fishing zones, discuss possible changes in area use throughout the years, locate rocky substrates and possible rock scallop beds, and to add to the maps and photographs names given by fishers to important reference features on the coastline. Photos and video of the coastline were also taken on another flight to compliment this information. These materials also facilitated communication with the sector during group meetings or personal interviews to ultimately assess management possibilities.

Once I had developed the framework of my project, I organized a meeting with the diving sector to present the project and assure that the divers were receptive, interested, and willing to collaborate from its beginnings.

By mid May, when the snail season usually begins, I began intensive ecological and ethnographic work, remaining in the community until the snail season ended in mid August.

All ethnographic research was based on participant observation. Participant observation is considered the foundation of cultural anthropology (Bernard 1995). This method involves building rapport in the community, getting close enough to the people so that they feel sufficiently comfortable with the researcher's presence in order to share reliable information about their lives. In this particular case, it involved me participating and helping in their day-to-day activities (e.g. diving with them, helping clean their boats) and participating in gatherings when I was invited (e.g. social gatherings, cooperative meetings). Much of this rapport had already been established during my previous work with the sector. Participant observation also involves the researcher stepping back every day from cultural immersion to "intellectualize what has been learned, put it into perspective, and write about it convincingly" (Bernard 1995).

I gathered most of the information by interviewing key experts or "informants". These key people were selected because they had much knowledge regarding the particular issues I needed to assess, and because they comprehended the information I needed and were willing to share it with me. Since I had previous experience working with the sector, I knew and had worked with most of the key people I relied on for this research.

I interviewed fishers, buyers, management officials, and researchers as individuals or in small groups of 2-4 people. From September to November, I pre-analyzed the information and organized it into categories or "topic blocks", facilitating the identification of gaps in the information or important issues I hadn't previously considered which required further study. After this, I returned to the community in January 2000 and targeted specific informants with questions according to their area of expertise. I also organized a final meeting with the fishing sector and presented the results of my preliminary analysis, particularly results on the reproductive ecology of black murex.

My fieldwork stressed participation, interacting with the fishing sector to learn from and with them about their use of benthic resources and their main concerns or issues regarding management of these resources. Results were regularly presented to the fishing sector through small group meetings and at an individual level in order to obtain their feedback and facilitate their involvement. Since local users have an intimate relationship with their natural resources, their management perspectives may differ from those of an outside researcher. By constantly exchanging information, I reduced the possibilities of biasing the results towards my own perspectives. Participatory research has proven to be an efficient way to mobilize community discussion, planning, and resource management actions (Rocheleau 1991, Maine et al. 1996). Furthermore, by actively involving the local community in the research and decision-making process, regulations that may result from this process can have more credibility among users and the willingness to respect them should increase (Wilson et al. 1994).

Following is a detailed description of the methods I used to assess the objectives of the management assessment.

1) Assess the main features of hookah diving fisheries in the NG.

For this objective, I addressed 5 different topics: historical development of hookah fisheries in the NG, structure of the fishing sector, fishing methods, fishing cycle and species harvested, and processing and commercialization.

I conducted most of this work through direct observation (especially to assess fishing methods), and informal and unstructured interviewing of key informants.

An informal interview is characterized by a complete absence of control and structure (Bernard 1995). In essence, I remembered and recorded in a field journal or recorded in situ the conversations I held during the day. Unstructured interviews, on the other hand, are based on a thought-out plan of questions or aspects for which certain information needs to be obtained, but the interviewer's control over the responses of the informant is minimal. The purpose of these interviews is for the informant to express ideas openly in his/her own terms and pace (Bernard 1995).

Besides interviews, to assess the fishing cycle and species harvested I also relied on previous field experience and on a diary maintained by one of the divers I had worked with the most. In January 1998, this experienced and well respected diver expressed an interest in recording his fishing activities both for personal economic interests (e.g. to compare fluctuations in production throughout the months or years) as well as to help me better understand what hookah fishing is like in the NG. Fostering that interest, I developed a simple structured diary on which he has recorded, since February 1998, the fishing zones, species targeted, production, total time of immersion, and the reasons why he and his partners did not fish on a particular day. Not only has he recorded the information necessary for the structure I provided, but also extra observations like unusual species he saw on a particular day, natural history of species targeted or particular difficulties he has on a fishing day. Prior to reporting this information I obtained his permission to do so.

2) Assess the main features of the murex snail fishery in the NG.

For this objective, I also assessed five topics: history of murex harvesting, fishing methods, historical use of fishing zones, fishing effort and production, and processing and commercialization.

Information was obtained through direct observation and informal and unstructured interviewing of key informants. I used large grid maps (grids = $1km^2$) to facilitate interviews addressing historical use of fishing zones.

To assess fishing effort, I visited the *panga* landing site every morning to see if anyone had gone out to fish. If any diver had gone to fish, I would return at noon and wait for their arrival. Once on the beach I would ask the divers three essential questions: the approximate production of snail they had caught (kg), the approximate fishing area and its depth. I would also take note on other species harvested. These questions were asked in the form of a conversation, trying to be as non-obtrusive as possible. If, of course, the conversation led to other relevant issues, I would expand on it as long as the divers were the ones interested in continuing the conversation.

In addition to beach interviews, the main buyer of snail in Peñasco provided me with his notes on production. His records included information on the total catch brought in by each diver/*panga* as well as the total yield after the snail had been cooked and removed from the shell. Since all Peñasco divers sell their catch to this buyer, these notes offered me a detailed account of fluctuations in daily production and helped me reach the best estimate of total production. Unfortunately, official landings do not give an accurate account of true production. By combining my beach interviews with the buyer's notes I was also able to estimate total production for each fishing zone. I limited these quantitative estimates for the period comprising June 5 – July 12 (38 days), essentially the time in which this buyer received snail. Snail fishing before and after this period is minimal and my data for these marginal periods is based on beach interviews of fishermen.

3) Increase knowledge on the reproductive ecology of black murex.

In Chapter 4 I give a detailed description of the methods used to assess specific questions for this objective.

4) Understand the existing forms of management and the role of the main factors influencing management of diving fisheries in the NG.

For this objective I addressed four topics: management role and objectives of the central government, legal framework, community management, and the role of nature. The first two topics were assessed entirely through literature research (government web pages, primary and secondary literature) and interviews with key government officials. For community management, I relied on interviews of key informants and personal observations, identifying forms of management, official (institutionalized) and non-official that exist at a community level (e.g. forms of access control to the fishery, local sanctions, institutional arrangements within the community). To assess the role of nature, I compared fluctuations in fishing effort with natural factors such as winds, tides, and currents. Since my fieldwork was limited to the murex season, I also relied on previous fieldwork, interviews with key fishers, and the diver's diary to obtain an understanding of nature's role in managing diving fisheries throughout the year.

5) Identify and understand the main problems and challenges inherent to managing diving fisheries in the NG.

For this objective, I drew on my results of the previous four objectives and discussed the issues that I considered were major obstacles to successfully manage diving fisheries in the region.

6) Identify fishers' opinions and proposals regarding management and conservation of benthic fisheries in general and murex in particular, and propose management strategies.

As mentioned before, from May to August I accumulated information regarding management opinions and proposals of fishers through interviews with individual fishers as well as through small group meetings. I organized this information into categories that facilitated the identification of gaps in the data or issues that required further study. I also pre-analyzed the rest of the information gathered for the other objectives and came up with a set of management measures that I considered could have an application in the region. I then developed a list of management questions and returned to the community in January, where I held a focus group meeting with 15 divers. The purpose of this meeting was to follow up on the results of the project, obtain more feedback from fishers, and discuss management possibilities. Focus group meetings produce ethnographically rich data because they give good insight as to why people feel as they do about a particular issue (Bernard 1995). Furthermore, cross-referencing and group consensus ensure the validity of the information gathered (Harrington 1997) and can increase the credibility of the decision making process.

At the meeting, I presented the preliminary results of my research, particularly results on the reproductive ecology and known status of the black murex. After this presentation, the meeting led to a discussion of the results and a series of proposals from the fishers. I was careful not to lead the discussion, trying to act only as facilitator. Throughout the first part of the discussion, I asked open-ended questions and never gave my opinion as to what management strategies I thought should be taken into consideration. After fishers had discussed their proposals, I proceeded to analyze the feasibility of any of the management possibilities that divers had not talked about and that I considered should be discussed.

After the meeting, I analyzed the new or expanded information I had gathered. Finally, I assessed the feasibility of possible management strategies and produced a series of recommendations based on fishers' opinions and proposals and on an understanding of all other research objectives I had assessed.

Chapter 1
Small-Scale Hookah Diving Fisheries: An Overview

Historical Development of Hookah Fisheries

Benthic sessile and semi-sessile marine resources have been harvested for millennia for human consumption as well as for ornamental and religious purposes. Throughout Latin America, shells served as raw material for various artifacts (e.g., hooks, awls, spoons, needles, shovels, and instruments), a wide variety of personal ornaments, and for inlay and mosaic (Donkin 1998). Whether taking deep breaths, collecting in shallow waters, or devising ingenious methods to remain underwater as long as possible, fishers have managed to defy the water barrier and make use of its resources by being immersed in it in some way or another.

Donkin (1998) states that the extraordinary interest in shells is best exemplified by the massive spiny oysters or rock scallops, *Spondylus* spp., which were widely traded throughout much of the American continent. Archeological evidence, combined with early Spanish reports, indicates that the upper classes of all the major civilizations of the New World at the time of the Spanish conquest, and several others that had declined by then, went to great lengths to obtain these shells (Donkin 1998).

In the Gulf of California, one of the first, if not the first major commercial fishery was the pearl fishery. In fact, pearls from *Pinctada mazatlanica* and *Pteria sterna* were among the main reasons why Spaniards ventured into the Gulf of California. The first expedition into the Gulf of California was organized by Hernán Cortés and led by Diego Hurtado de Mendoza in 1532. This expedition landed in the Bahía de la Santa Cruz, (La

Paz) in the Baja California peninsula (Cariño 1996). Rumors quickly spread about the discovery of beautiful pearls and bountiful pearl beds. Soon, various pearling expeditions were undertaken, using black slaves from the mainland as well as local Indians. Pearls were harvested at this time from up to 20 fathoms deep (~40 m) (Obregón, ca. 1564 cited in Donkin 1998).

By the early 1700's, Father Eusebio Kino observed that "in all the coast, and especially in the adjacent islands, there are so many pearl fisheries that they can be counted by the thousands" (cited in Donkin 1998). By the end of the Jesuit period (late 1700's), the pearl banks had been greatly depleted, making their harvest unprofitable (Donkin 1998).

After the boom of the pearl industry it appears that diving fisheries in the Gulf of California greatly diminished and did not resurrect as major commercial fisheries until the second half of the 20th Century with the development of aqualung and underwater breathing devises.

The development of small-scale hookah diving fisheries in the northern Gulf of California is relatively recent. Its beginnings can be traced back to the late 1960's and the early 1970's in the fishing town of Bahía de Kino, Sonora. The islands offshore from Bahía de Kino, known as the Midriff islands, supported a rich ecosystem ideal for the harvest of benthic resources such as lobster (*Panulirus* spp.), octopus (*Octopus* spp.), lion's paw scallop (*Lyropecten subnodosus*), rock scallop (*Spondylus* spp.), and pen shells (*Pinna rugosa* and *Atrina maura*). Bahía de Kino, being the gateway to the Midriff island region, acted as a magnet for the development of diving fisheries and became one of the source points for the expansion of this activity throughout middle and northern Sonora.

Diving activities in those days occurred mainly from May to August, during the annual season closure of shrimp. Since the shrimp fishery was particularly profitable, many divers actively participated in the shrimp fishery throughout most of the year. Once the season ended, about 9 trawler boats were used as mother ships, traveling around the islands and along the Baja California coast line searching for good diving grounds. These boats would pull 4-7 *pangas*, and each *panga* was equipped with a hookah system usually employed by two divers at a time.

By the late 1970's, diving trips, whether based from mother ships or camps on islands and the mainland, were exploiting benthic resources throughout the northern reaches of the Gulf of California. Elder fishers state that diving in the northern Gulf came as a result of a decrease in the scallop beds of the Midriff region and in light of the rich rock scallop beds and shallow waters of the northern Gulf. Although many of the species harvested in the Midriff region were not found or were found in small quantities in the NG (particularly lobster, lion's paw scallop, and pen shells), rock scallop beds were immensely rich and could provide sufficient income for fishers through a complete fishing year cycle. In addition, the NG was particularly attractive to divers because of its shallow waters, which reduced the possibilities of suffering from decompression problems. One veteran diver recalls the first time he arrived to the NG "… the year was 1979. I could not believe my eyes when I saw the amount of rock scallops we could harvest so close to shore! We would camp on San Jorge island or on San Francisquito and work a 1 km stretch off the mainland and around San Jorge. The buyer would remain in San Francisquito to receive the product. There was so much scallop close to shore that sometimes we would even play around by fishing without the compressor and taking deep breaths. I remember that two divers in one *panga* could easily collect up to 150 kg of scallop muscle in one day. Those were the good days for rock scallop."

From these trips, divers soon settled permanently in Puerto Peñasco and by the beginning of the 1980's most of the divers who fish in the NG were already living in this port. However, this is not to say that long diving trips aboard boats stopped. Divers continued fishing in the Midriff region, particularly around the islands of Tiburón, Patos, San Esteban, Angel de La Guarda, and San Pedro Mártir. In addition, the northern most archipelago in the Gulf of California, an area known as the "Islas Encantadas" (Enchanted Islands), began to be used intensely around this time. This area was used both by divers from Puerto Peñasco and Bahía de Kino, Sonora, as well as by divers from San Felipe, Puertecitos, and Bahía de los Angeles, Baja California.

Throughout the eighties, diving activities in the NG were focused on the harvest of rock scallop and octopus, with rock scallop being by far the most important resource in terms of capital gains and its year-round availability. Although other species were harvested as well, these were minimal in comparison. Essentially, rock scallop was the key element that attracted locals to become hookah divers and remain as such. After shrimp, rock scallop was and has been one of the most profitable marine resources in the region, its price often exceeding that of shrimp.

By the late eighties and beginning of the 90's, divers were experiencing sharp declines in their catch, with certain patches of the scallop beds apparently suffering from overexploitation. This situation, added to economic pressure and outside demand for other species, forced the divers to diversify their catch. For instance, sea cucumber (*Isostichopus fuscus*), a species that was never considered as having any commercial value, began to be harvested intensely for the Asian market. By 1994, the Mexican Government listed this species as endangered (Diario Oficial de la Federación May 16, 1994) in light of the intense fishing pressure it was subject to throughout the Gulf of California. Fishers in Peñasco mention that both the amount and sizes of *I. Fuscus* around San Jorge island and El Borrascoso have never been the same since the 1994 season. That same year was also the last year when fishing trips aboard mother ships were carried out since they were no longer profitable. Mexico's Agency for the Environment, Natural Resources and Fisheries (SEMARNAP) prohibited the use of mother ships for hookah-diving purposes.

While rock scallops were the initial catalyst for the development of hookah fisheries in the NG, snails, particularly black murex (*Hexaplex* (*Muricanthus*) *nigritus*) and pink murex (*Phyllonotus erythrostomus*) became the primary target for the second growth stage of this activity. Hookah divers in the NG have harvested four different species of snail since the late 1970's: Pacific melongena (*Melongena patula*), giant Eastern Pacific conch (*Strombus galeatus*), black murex, and pink murex. Until the 1990's, however, their harvest had been a small endeavor since their demand was exclusively local. It was not until 1992, with the interest of Korean buyers, that murex snails began to be harvested in an industrial manner by divers from Puerto Peñasco. This demand, and the massive aggregations of snail close to shore provoked an influx of new divers. In one year, 1993, the number of divers had doubled with fishers who alternated their traditional fishing practices (e.g. gillnetting, long lining) with that of diving during the summer. Year-round divers, which I will refer to as "traditional divers", name these seasonal divers *caracoleros* ("snailers").

Today, the hookah fishery is more diverse than in its beginnings. Apparent decrease in production, as well as demand and economic pressure from national and international markets have forced a diversification of this activity. Some traditional divers have even begun to fish with gillnets or crab traps during one or two months out of the year. Using hookah equipment, divers harvest at least 18 species of invertebrates and 8 species of fish (Table 1). Of these, 3 species provide approximately 80% of the divers' income: rock scallop, octopus, and black murex.

Table 1. Species harvested by hookah divers of Puerto Peñasco, Sonora, Mexico.

Common Name Spanish	Common Name English	Species	Family	Degree of Harvest
Almeja amarilla	Giant Pacific egg cockle	*Laevicardium elatum*	Cardiidae	Uncommon
Almeja catarina	Pacific calico scallop	*Argopecten ventricosus*	Pectinidae	Common
Mano de león	Pacific lion's paw	*Lyropecten subnodosus*	Pectinidae	Uncommon
Almeja voladora	Vogde's scallop	*Pecten vogdesi*	Pectinidae	Uncommon
Callo de riñón	Tuberculate pen shell	*Atrina tuberculosa*	Pinnidae	Uncommon
Callo de hacha	Rugose pen shell	*Pinna rugosa*	Pinnidae	Uncommon
Callo de madreperla	Mazatlan pearl oyster	*Pinctada mazatlanica*	Pteriidae	Common
Callo de árbol	Western wing oyster	*Pteria sterna*	Pteriidae	Uncommon
Callo de escarlopa	Rock scallop	*Spondylus calcifer*	Spondylidae	Common
Callo mechudo	Pacific thorny oyster	*Spondylus princeps*	Spondylidae	Uncommon
Almeja blanca	Dunker's dosinia	*Dosinia dunkeri*	Veneridae	Common
Almeja chocolata	Callista clam	*Megapitaria sp.*	Veneridae	Uncommon
Caracol burro	Pacific melongena	*Melongena patula*	Melongidae	Uncommon
Caracol chino negro	Black murex	*Hexaplex (Muricanthus) nigritus*	Muricidae	Common
Caracol chino rosa	Pink murex	*Phyllonotus erythrostomus*	Muricidae	Common
Caracol de uña	Giat Eastern Pacific conch	*Strombus galeatus*	Strombidae	Uncommon
Pulpo	California two-spotted octopus	*Octopus bimaculatus*	Octopodidae	Common
Pepino de mar	Giant sea cucumber	*Isostichopus fuscus*	Stichopodidae	Uncommon
Caballito de mar	Pacific seahorse	*Hippocampus ingens*	Syngnathidae	Uncommon
Lenguado	Cortez halibut	*Paralichthys aestuarius*	Bothidae	Uncommon
Baya	Gulf grouper	*Mycteroperca jordani*	Serranidae	Uncommon
Cabrilla sardinera	Leopard grouper	*Mycteroperca rosacea*	Serranidae	Uncommon
Pinta	Spotted cabrilla	*Epinephelus analogus*	Serranidae	Uncommon
Pargo coconaco	Barred pargo	*Hoplopagrus guntheri*	Lutjanidae	Common
Pargo amarillo	Yellow snapper	*Lutjanus argentiventris*	Lutjanidae	Uncommon
Cochito	Finescale triggerfish	*Balistes polylepis*	Balistidae	Uncommon

Current Structure of Fishing Sector

Puerto Peñasco currently has 21 traditional divers. In addition, at least 13 seasonal divers harvested snail during the 1999 season. However, judging from fishermen's accounts, the total number of functioning compressors in the town, as well as from data on past fishing effort (see López-Reyes 1992), the number of seasonal divers can surpass that of traditional divers during the summer. Resource availability and the buyers' interests in incorporating new or seasonal fishermen and their willingness to finance these divers - mainly with credit for gas, food, ice, and diving equipment - define fluctuation in the numbers of seasonal divers.

Since the number of divers fluctuates dramatically, possibly the best index of fishing effort is the number of compressors (one compressor/*panga*) that are used for diving purposes in Peñasco. There are at least 26 compressors that are in working condition and could potentially be used for diving. Five of these were not in use during the 1999 season. Of the remaining 21, 12 are used year-round. This estimate does not include compressors that may be brought in by divers from other fishing communities of the Gulf.

All traditional divers are organized into three cooperatives, and most seasonal divers are free fishermen who do not form part of any cooperative. Regardless of the structure and role of these cooperatives, divers as a whole are united because of the type of work they do. There is a strong sense of pride among them for the simple fact that they are divers. As a result, they are readily recognized as a unique fishing sector. During town hall meetings or any time they arrive in port from fishing, they are usually found together. Other fishers in the community refer to them as *Los Buzos* "The Divers", and not as fishermen.

There are at least 20 buyers based in Peñasco who buy products from divers throughout the year. Of these, 13 have shops in the fish market, selling mainly to the local public, and 7 are larger buyers usually with the capacity of selling outside of Peñasco and even exporting. This number, however, does not include numerous restaurants and small food locales which many times buy directly from the fishermen.

Fishing Methods

The basic equipment used for hookah diving consists of a *panga* with an outboard motor and a rudimentary but ingenuous hookah breathing system. This system is usually composed of a modified paint spraying machine used as an air compressor and engine, a modified beer keg used as an air reserve receptacle, usually two and never more than three 50-100 m air hoses, and air regulators adapted from normal scuba diving equipment (Figure 4) . Sometimes, feminine tampons are used as air filters to reduce contamination from the motor's exhaust gases. However, since the filter reduces the intake of air, most divers prefer not to use one.

Besides the basic breathing equipment, the diver always carries a mask, snorkel, and a weight belt. The amount of weights used varies according to the preference of each diver, the depth at which they are fishing, and, most of all, whether the diver is walking on the bottom (with tennis shoes, old shoes, or neoprene boots) or swimming with fins. The fact that a diver swims or walks will in turn depend on the type of resource harvested, currents, or simply the preference of each diver. In general terms, more experienced divers with good physical condition usually rely on swimming, whereas less experienced and seasonal divers walk on the bottom.

Figure 4. Modified paint spraying machine used as the main breathing device by hookah divers in Puerto Peñasco, Sonora, Mexico (Photo by Richard Cudney-Bueno).

Since hookah fishing is, for the most part, a fishery that relies on collection of benthic resources, harvest is carried out mainly with the protection of cotton gloves. The utensils used to facilitate harvest are secondary since they will vary according to the resource fished. Among these are knives, hooks for octopus and fish, scallop picks (*pico callero*), scallop bags (*bolsas calleras*), and snail bags (*bolsas caracoleras*).

As with other small-scale fisheries in the region, three people usually participate in a fishing trip: a motorman, known as *popero* or *cabo de vida*, and two divers. However, depending on the current and the fishing depth, the number of divers will vary between one and three per *panga*. In general, strong currents and deep waters limit the number of divers that may fish.

Although the motorman almost never dives or is the least experienced diver, the life of the divers as well as the efficiency of the fishing day are determined by him. The motorman keeps the *panga* on course following the trail of bubbles left by each diver. He constantly supervises to make sure that the passage of air is not being obstructed and that the compressor is working adequately. He is also on the constant lookout of any signal that the divers might be giving him (by pulling the hose or surfacing), as well as of any potential danger in the water like other boats navigating nearby. He receives the product into the *panga* and participates in the sharpening of knives and pre-processing of the product.

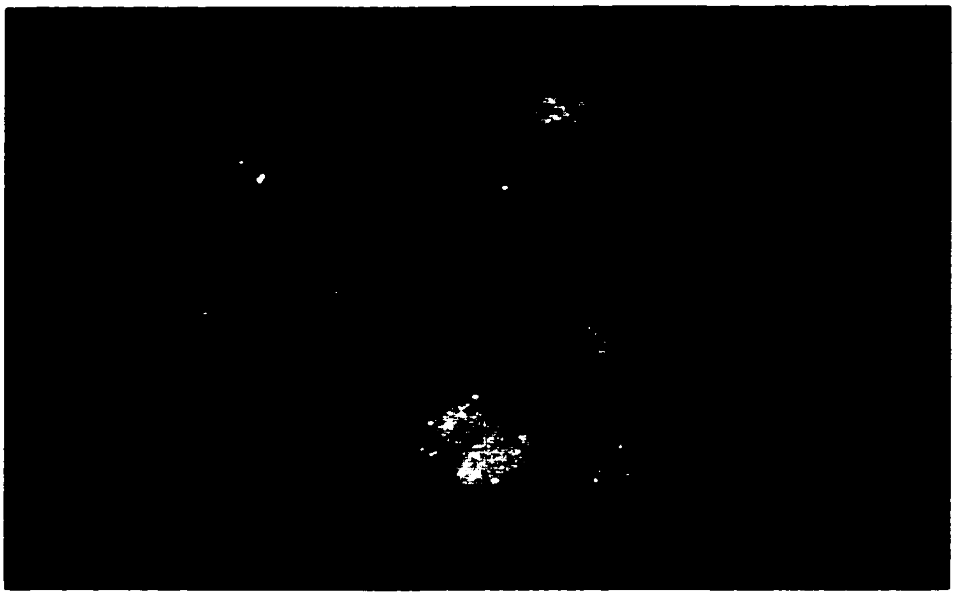
Divers, on the other hand, usually define the days and zones to fish, as well as the best time to leave and come back from a fishing trip. Besides fishing, divers also participate in the pre-processing, transportation, and selling of the capture.

Fishing Cycle and Species Harvested

Hookah fishing is carried out year round, but fishing effort and species harvested vary considerably depending mainly on resource availability, market demand, and weather conditions. It is difficult to establish what species divers are targeting during their fishing trips since they will usually harvest different species, sometimes in relatively distinct zones and employing different fishing methods within the same day. Diving is a very different fishing practice compared to other fisheries (e.g., net fisheries, long lining) in that the fisherman is able to constantly see underwater and decide what he wants or does not want to harvest. However, most of the fishing trips are planned in accordance with the tides and the availability of a particular resource or resources found at a specific time and zone.

Fishing activities are characterized by a year round harvest of *callo* with intermittent seasons of heavy harvest of other resources (Table 2). Divers refer to all bivalve mollusks with a large adductor muscle as *callo*. There are at least six species of bivalves harvested in the region that are commercialized as *callo* (Table 1). However, of these, the bulk of the production is rock scallop, *Spondylus calcifer* (Figure 5).

Figure 5. Rock scallop muscles harvested in the northern Gulf of California, Mexico (Photo by Richard Cudney-Bueno).



During the colder months, most of the fishing effort is concentrated on targeting *callo*, octopus, and fish. At this time, the muscle of rock scallop and of most other bivalves comprising *callo* is heavier (thicker), and easier to clean than in other months. This makes *callo* harvesting particularly attractive at this time since production is maximized. This marked increase and decrease in weight is apparently related to the reproductive stage at which the bivalve is found. The adductor muscle is a major site for nutrient reserves and gonadal increase during gametogenesis occurs at the expense of the adductor muscle (Mackie 1984). Hence, during reproduction the muscle is reduced as it is utilized as an energy source.

Table 2. Harvest cycle of the main resources targeted by hookah divers of Puerto Peñasco, Sonora, Mexico.

Resource Harvested	Total Months of Harvest	Principal Months of Harvest
Callo (Rock scallop and others)	January-December	September-March
Clams	April-October	June-September
Calico scallops	May-October	June-August
Murex Snail	May-August	June-July
Octopus	December-May	February-April
Fish	September-March	January-February

During these cold months, most of the *callo* is harvested while searching for octopus and fish amongst stretches of patchy reefs composed of rocks and conglomerates of shells and sediments known locally as *tepetates*. Production of octopus is dominated by one species, the California two-spotted octopus (*Octopus bimaculatus*), although another unconfirmed species appears to be harvested occasionally, possibly Hubb's octopus (*Octopus hubbsorum*). Large octopuses are found close to shore from December to May. Although some divers begin harvesting octopus in December, most of the fishing effort is concentrated between February and April, when octopuses are more abundant and apparently larger. This period also coincides with reproduction of *O. bimaculatus*. The length of the reproductive period of this species has been poorly studied in the region, however it is evident that harvesting takes place during egg laying, brooding stages, and most likely mating. It is common to find captured female octopuses with eggs in the oviduct as well as eggs attached to the suckers as the female protects the cluster when the diver pulls her out of the rock. Females brood the eggs immediately after laying, ventilating, cleaning, and protecting the cluster of embryos throughout their development. Prior to laying and during this maternal care taking, females cease to eat (Arnold 1984, Roper et al. 1995) and will push away normal prey species and strange objects (Arnold 1984, and personal observations). After hatching, females continue exhibiting this brooding behavior (Arnold 1984), become extremely emaciated and flaccid, and eventually die (Arnold 1984, and personal observation). This period of starvation facilitates harvest since octopuses are easier to find and become somewhat torpid.

Fish are caught during these cold months, both as secondary species (when conducting trips to harvest octopus and *callo*) as well as target species in specific rocky outcroppings and areas known to be good fishing grounds primarily for snappers and groupers. When searching for octopus and *callo*, divers will usually harvest small flounder (*Paralichthys aestuarius*) by stabbing them against the ground with the same knife they are using to cut open rock scallops. The amount of flounder caught is minimal, averaging approximately 4-5.0 kg/day. Other fish, like triggerfish (*Balistes polylepis*), groupers (leopard grouper, *Mycteroperca rosacea*, spotted cabrilla, *Epinephelus analogus*, gulf grouper, *Mycteroperca jordani*), and snappers (barred pargo, *Hoplopagrus guntheri*, dog snapper, *Lutjanus novemfasciatus*, yellow snapper, *Lutjanus argentiventris*) are also caught occasionally with a long hook when targeting *callo* and octopus. However, specimens are usually small since *callo* is generally found on exposed flat terrain. Larger specimens are found in areas surrounding rocky outcroppings and more rugged terrain. Fishing trips with the specific intent of harvesting larger groupers and snappers with hooks will take place primarily in January and February. Some of these trips can be very productive, bringing in ~70-100 kg of well-paid fish in one day.

As water temperatures begin to rise and octopus is found in smaller quantities, some divers will temporarily switch to fish with nets targeting different elasmobranchs, primarily guitarfish (*Rhinobatus productus*) and sting rays (*Dasyatis brevis* and *Gymnura marmorata*). Others will continue harvesting *callo* and other bivalves like clams (*Dosinia dunkeri*, *Megapitaria sp.*), while others will stop all fishing activities until late April, when the snail season usually begins. In essence, there is a period of approximately 1 month of transition during which a variety of species are targeted until the divers focus almost exclusively on murex snails.

Snail harvest will usually begin in May and continue through August, targeting two species of snail: black murex (*Hexaplex* (*Muricanthus*) *nigritus*) and pink murex (*Phyllonotus erythrostomus*). A detailed description of this fishery is given in the following chapter.

Giant white clams (*Dosinia dunkeri*), callista clams (*Megapitaria* sp.), and scallops (Pacific calico scallops, *Argopecten ventricosus*, and Vogde's scallop, *Pecten vogdesi*) are often caught during snail season. Strong currents and the unpredictable southern summer winds reduce the amount of days effective for snail harvesting since this fishery requires calm water and adequate visibility. During these difficult days, most divers will harvest clams and scallops close to shore on the outskirts of Puerto Peñasco. Divers have harvested these clams for many years, but their demand has grown in recent years with the steady increase of tourism coming to Puerto Peñasco.

In 1999, scallops offered a major economic alternative for divers. Some fishermen, especially younger ones, even spent more time harvesting scallops than snail, in part because it is easier to harvest this resource. On a good fishing day, divers were bringing in between 800 and 1000 kg/*panga*, and on normal days production usually averaged between 300-400 kg/*panga* (these weights are for the whole organisms, including shells, not for the scallops themselves that would comprise a small fraction of this total).

Another resource that this summer offered a new alternative to traditional diving activities was blue crab (*Callinectes* spp.), which is fished with traps. Since 1993, a major fishery for blue crab has rapidly developed throughout the Gulf of California. This year, divers participated in this activity for the first time and the largest buyer and processor of Peñasco resources harvested by divers interrupted the commercialization of snail and scallops in order to process blue crab. Divers who were able to work for a *patrón* who had permits for crab tried their luck in this endeavor. However, after about a month of fishing, they were all diving again. Apparently, a lack of experience with this type of fishing method forced them to revert to their traditional practices.

By mid August, the diving fleet is reduced to practically half the size it was during the snail season. Seasonal divers, those who only harvest snail during the summer, return to their gillnet and long line fishery practices or continue to fish blue crab with traps. Throughout September and October, divers harvest *callo* and occasionally clams and fish. Sea cucumber, *Isostichopus fuscus*, may also be harvested but, because of its protected status, its exploitation in the NG is minimal and to a certain degree clandestine.

During November, depending on whether the production of *callo* is adequate or not, some divers will revert to fishing for corvinas (*Cynoscion* spp.), and mullet (*Mugil cephalus*) with gillnets close to shore. Production of *Callo* as well as of snappers and groupers dominates the month of December, and by January most divers are again targeting octopus in addition to *callo* and fish (Table 2).

Processing and Commercialization

Following is a brief description of the processing and commercialization procedures of *callo*, octopus, and scallops. For snail, I give a thorough description of this subject in the following chapter.

Callo

Aboard the panga, *callo* is pre-processed by removing all organs and tissue adhered to the adductor muscle. The muscle is rinsed with seawater and is put in an ice chest with ice. When arriving to port, the product may be sold one of two ways. If the divers are owners of their panga, they will usually sell it to a buyer they trust, often times someone considered to be a friend as well. In essence, the efficiency of a price negotiation greatly relies in the ties existing between the buyer and the fisherman. These buyers, who are usually owners of a fish shop in the market, or of a restaurant, play a crucial role in the lives of fishermen. Not only do they buy their products, but also many times help them economically on a personal level. For instance, one diver had an urgent case of appendicitis and had to be treated immediately. The buyer lent most of the money for the operation and the diver was slowly paying it back with no interest.

If divers work for a *patrón* owner of *pangas*, they deliver the catch directly to him and are paid a set amount per kilogram of product delivered.

In spite of its high quality, the commercialization of *callo* is difficult since there are not any large scale buyers. It is also difficult to export it to the United States because of its hard consistency and strong taste. People in the United States are used to the soft consistency and taste of the East Coast bay scallops. However, buyers from Peñasco will occasionally travel to Phoenix and Los Angeles to sell it to rich customers from the Latino and Asian market at very high prices, up to $285.00 pesos/kg (~$30.00 dollars).

The bulk of *callo* harvested by Puerto Peñasco divers is commercialized nationally, mainly within the port of Puerto Peñasco and San Luis Río Colorado, in Sonora, Mexicali and Tijuana, in Baja California, and the border of Chihuahua. Most of the commercialization outside of Peñasco is carried out during Lent, when the demand for fishery products increases at a national level due to traditional religious believes. At other times, practically all of the production is sold locally.

Although there aren't large-scale buyers for *callo*, its demand and availability are annual and its selling price is always high. For these reasons, divers consider *callo* to be their most precious resource. Its beach price will vary between $75-85.00 pesos/kg

(~8.00-9.00 dollars), and it is sold locally to tourists between $100-130.00 pesos/kg (~9.5-14.0 dollars).

Octopus

Octopus is sold whole but eviscerated. The diver removes the internal organs moments after it is caught. Once eviscerated, it is kept on ice and commercialized locally and in Mexicali, Tijuana, and San Luis Río Colorado. Its beach price varies between $18.00-25.00 pesos/kg (~$2.0-2.5 dollars). The first buyer will sell it to a second buyer at between $25.00-30.00 pesos/kg (~$2.5-3.0 dollars).

Pacific Calico and Vogde's Scallops

These small scallops began to be harvested in 1997 as local buyers obtained permits for their commercialization. Calico and Vogde's scallops have always represented a major part of the shrimp trawling bycatch but were usually discarded or a small amount was consumed locally. In 1997, buyers began purchasing scallops from the trawler boats, processing them locally and exporting them since they are very similar to the bay scallops found in the East Coast of the United States. As expected, divers also wanted a share in this business since large scallop beds were accessible to them in shallow waters, areas prohibited by law to be used for trawling purposes. In 1999, divers began harvesting scallops on a regular basis. However, they cannot compete with the production brought in by trawler boats. Because of this, their sale price has to be much higher. Buyers, of course, will rather buy larger productions at a cheaper price, which restricts divers' ability to harvest scallops until the end of the shrimp season, usually late April. Adding trawling and hookah diving activities, these scallops are being harvested practically on a year-round basis, with essentially a month and a half of interruption (mid August-late September).

Divers may sell the scallops whole or clean (just the adductor muscle). Selling them clean will render more profits, \$30.0 pesos/kg/meat (~\$3.0 dollars) vs. \$3.0 pesos/kg/whole (~\$0.3 dollars), but cleaning scallops is time consuming and may interrupt preparations for the next fishing trip. Most of the time, divers sell their scallops whole to one of two buyers who hire workers to clean the product. About 60-80 whole scallops are needed to produce a kilo of scallop muscle. Clean scallops are then sold in ice locally, along the border of Sonora and Baja California, and in Guadalajara, Jalisco. Some of this production may be exported as well, although exportation is more restricted to the larger productions obtained during shrimp trawling activities. When shrimp trawlers harvest scallops, a buyer can obtain one metric ton (MT) of clean muscle in one day (~70,000 scallops). One buyer even brought about 60 people (including whole families) from Guerrero Negro, Baja California, to clean scallops. They work faster and have more experience than local residents.

Pacific calico scallops are similar in shape, color and size to the Atlantic calico scallop sold in the U.S. This species is misleadingly sold in the U.S. as the "Mexican bay scallop" (Dore 1991).

Chapter 2
The Murex Snail Fishery

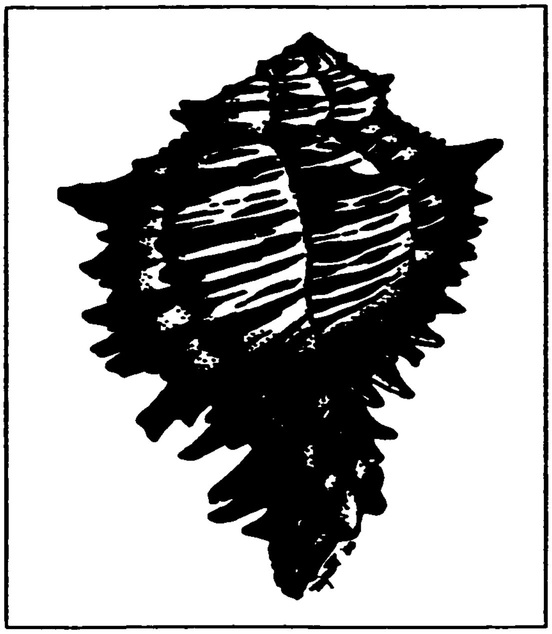


Figure 6. Black murex snail, *Hexaplex (Muricanthus) nigritus.*(source: CEDO)

History of Murex Harvesting

Snail harvesting in Mexico goes back to prehispanic times. For instance, it is known that the Caribbean conch snail (*Strombus gigas*) and the wide-foot purpura (*Purpura pansa*) had been exploited for hundreds of years prior to the arrival of the Spaniards (Donkin 1998). In the Gulf of California, numerous shell middens along its coast attest to a common utilization of snails and other mollusks by different native tribes (e.g. Cochimí, Guaycuras, O'odham, Hohokam, Yaquis). Snails and other mollusks not only provided a good source of protein, but were also used for important ornamental purposes, as instruments, and for the production of dyes. They were also a major component of religious and traditional rituals. In the NG, as part of the passage to manhood, Papago people conducted annual pilgrimages to Bahía Adair, north of Puerto Peñasco, to harvest salt and shells from its coast.

Enormous mounds of black murex shells (Figure 6) close to Bahía Adair suggest that this snail could have been one of the main resources targeted by native people visiting or living on the surroundings of Puerto Peñasco, ca. 200 BC (Martínez-Ramírez and Oliver 1999, personal observation). Likewise, shell middens of pink murex in southern Sonora and Sinaloa also suggest that native people in that region of the Gulf targeted this species. However, the lack of technology to remain underwater for long periods of time must have restricted their harvest to areas close to shore and within shallow waters.

Elder fishermen and other folk from Puerto Peñasco mention that around the 1960's murex snails were harvested along the shoreline of Bahía San Jorge, south of Puerto Peñasco, to sell it to buyers for the production of buttons. People would walk along the shoreline during low tide and find massive aggregations of black murex exposed or in just two-three feet of water. Snails were left to dry by hanging them or leaving them exposed on the beach. Once dead, the whole organism was pulled out of the shell, leaving the shell intact.

As mentioned before, traditional divers from Puerto Peñasco have harvested snail with hookah equipment since the late 1970's. However, until the 1990's, most of this production was small and restricted to local consumption. In the summer of 1992, with the interest of Korean buyers, murex snails began to be harvested in an industrial manner. In that year, snail production in Puerto Peñasco, strictly black and pink murex, doubled the production of all species of snail ever registered for the entire state of Sonora (López-Reyes 1992). Murex snails were not only found in great quantities close to shore, but they were also found during the summer months when rock scallop yield is much smaller. Besides emerging as a great alternative fishery for the divers, it also produced an influx of new fishermen since summer months, known locally as "*los meses del piojillo*" (the months of the louse), have traditionally been considered bad months for fishing. Shrimp fishing is outlawed during these months. In addition, the excruciating heat and the lack of fishery resources found in large quantities has always made the summer an unpleasant time to fish. Essentially, Murex snails offered an opportunity to harvest a resource in large quantities by being immersed in refreshing shallow waters. This way, fishers who had never practiced hookah fishing before began learning this task in relatively easy shallow waters. In some occasions, diving was not necessary, as people would walk along Bahía La Cholla during low tide and tie buoys to exposed snail aggregations. As the tide rose, they would return with a *panga* and harvest the aggregation snorkeling or walking in waist deep water. Even local teachers and other people with an academic profession participated in this harvest.

Divers and buyers mention that in 1992 and 1993, it was common for four *pangas* to harvest from the same aggregation of snails, and these aggregations could provide 3-4 MT of live snail. The amount and size of aggregations made it easy for divers to find them rapidly and also allowed them to conduct two different fishing trips within the same day. A shrimp trawler boat served as mother ship and all divers would land their catch on the boat, landing up to ~ 40 MT in three days of active fishing (López-Reyes 1992). This intense harvesting only lasted three years, at which time the main buyer opted to stop buying snail since it no longer became a high profit business. Buyers state that the resource evidently became harder to obtain. In addition, Asia was experiencing one of its worst economic crisis. This crisis affected fisheries world-wide, lowering the demand for fishery resources destined to the Asian market.

From 1995 to 1999, murex snails have continued to be harvested and the departure of this main buyer actually seems to have provoked an increase in the number of smaller buyers. However, contrary to the early 1990's when practically all snail was sold to the Asian market, today most of it is sold locally and within Mexico's northern border states. Exportation requires a constant supply of large quantities of snail, a requirement that today is seldom met.

Fishing Methods

It is important to state that fishing methods will vary according to the preference of the diver as well as the time and place he is fishing. For instance, diving in strong currents will require a different strategy than in calm waters. In general terms, however, this fishery requires a constant underwater search for breeding aggregations of murex. Contrary to other fisheries like *callo* and octopus in which divers know that the resource is found spread out along *tepetates* or rocky reefs, in the snail fishery a diver may search for hours without finding an aggregation, or he may find an aggregation as soon as he enters the water. This fishery relies as much on chance as it does on knowledge of the habitat in which snails may be found.

Since snails are searched for along the edges of *tepetates* and rocky reefs, traditional divers usually swim and carry with them a net bag and knife for *callo*, harvesting any *callos* of adequate size that they may find on their way. Seasonal and inexperienced divers walk on the bottom loaded with weights and do not harvest *callo*. Once a snail aggregation is found, the diver signals the motorman by pulling the breathing hose or surfaces. A "snail bag" (*bolsa caracolera*), made of a bicycle rim and pieces of old shrimp trawler nets, is tied with a long rope to the hose. Once tied, the motorman pulls the hose again so the diver knows it is ready. The bags are filled as fast as possible to avoid letting other divers arrive at the same spot. Besides the fact that another diver could take part of his find, the presence of other divers close-by complicates the operation since the hoses may easily become entangled. Once a bag is filled, the diver ties it to the loose rope and pulls on it to let the motorman know it is filled. This procedure is repeated until no more bags are needed. Divers then continue searching until the *panga* is filled or until they wish to call the day off.

A typical fishing trip will last 4-6 hours, of which the divers will remain immersed most of the time, occasionally surfacing to communicate with the motorman, to be pulled to a better fishing site if closeby, or to board the *panga* if they wish to go to another fishing site farther away. Depending on the condition of the compressor and the hoses, divers sometimes need to surface constantly to fix problems of air intake.

The depths at which they fish will vary considerably, from waist deep water to ~ 40 m. Most divers have experienced some type of decompression-related problem, and

Puerto Peñasco does not offer any adequate facilities to treat such problems. The nearest recompression chamber in Mexico is 10 hours away by bus.

The risk of suffering the bends increases during snail season due to warmer waters and the doubling in the number of participating divers. Warmer water temperatures allow fishers to remain underwater comfortably for longer periods of time. Although most divers realize the risks of their activities, economically they cannot afford to follow diving standards strictly since this would considerably restrict the quantity of their catch.

Historical Use of Fishing Zones

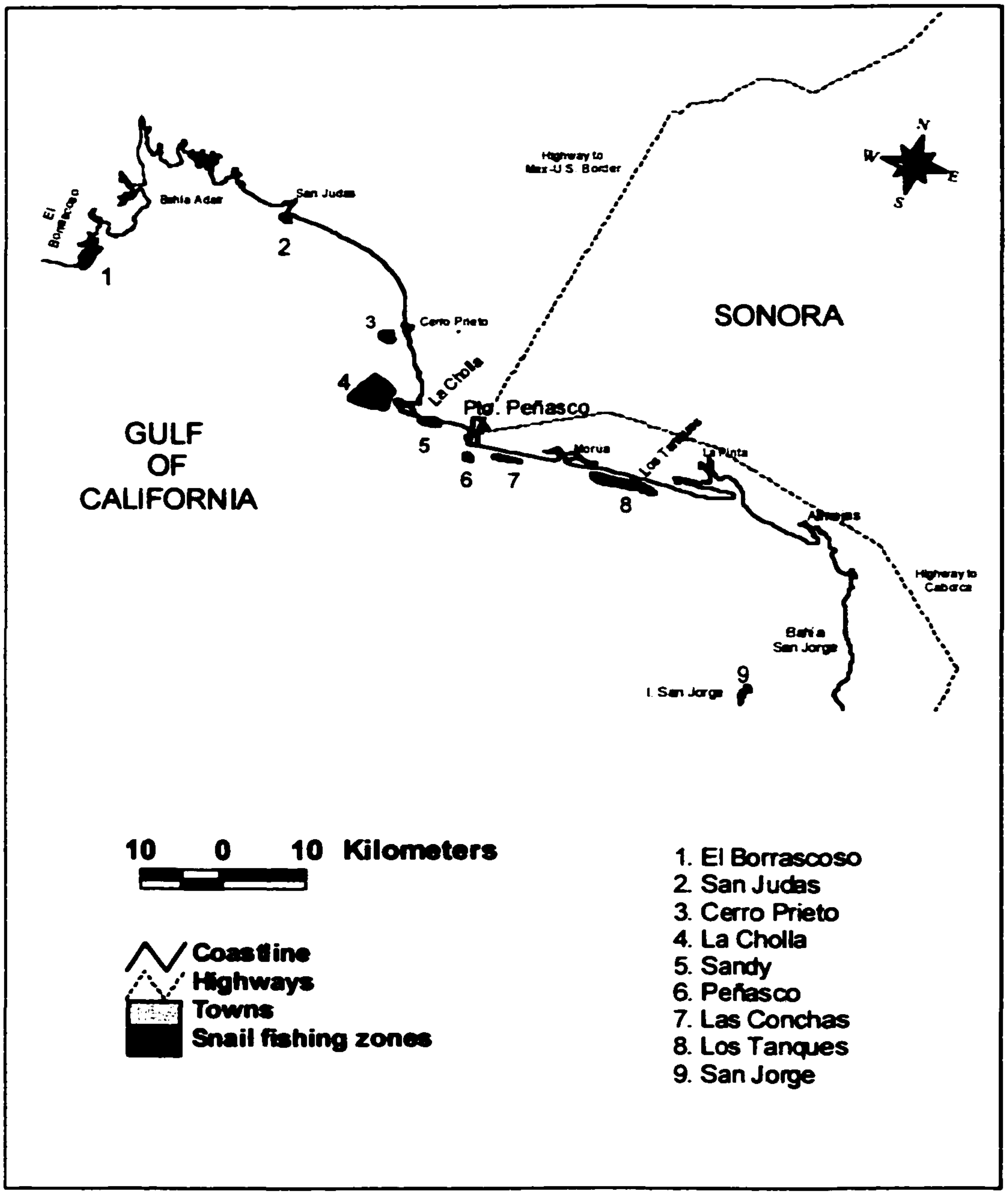
There has been a marked variation in the zones used to harvest snails since the fishery formally began in 1992. In that year, all fishing was carried out in shallow waters in front of Punta Pelícano and Bahía La Cholla, an area known by divers as "La Cholla" (Figure 7). La Cholla has always provided divers with large productions of not only snail, but *callo* and octopus as well. It is still the most heavily used area, because it is both productive and also close to port.

By the following season in 1993, most of the fishing effort apparently shifted to "El Borrascoso" and "San Judas" (Figure 7) as it became harder to find large aggregations in La Cholla. However, La Cholla still remained a prime fishing ground. Throughout 1994 and 1995, La Cholla, El Borrascoso, and San Judas were still providing abundant harvests and were the only zones needed for snail fishing. In some places, you practically did not need to dive as the aggregations were found at waist depth or less.

After 1995, the use of other zones expanded, utilizing, in addition to the previous three, "Las Conchas", "Los Tanques", and "Isla San Jorge" (Figure 7). Essentially, these and the previous three were the same zones used in 1999, although in 1999 two new areas were explored and used, "Sandy" and "Peñasco". However, divers state that, except for Sandy Beach and Peñasco, it has become increasingly difficult to find large aggregations within these zones and effort has shifted towards deeper waters or areas farther from port. In other words, although practically the same zones have been used since 1995, within them there has been an increasing need to search farther away from port.

By the time I concluded my summer fieldwork in 1999, divers were seriously considering venturing to "La Salinita" next season, even farther north than El Borrascoso. La Salinita is the last large stretch of shallow rocky reef and *tepetate* before arriving at the mouth of the Colorado River. Trawler boats that in previous years had been fishing close to the area reported to the divers that large amounts of snail were trawled as bycatch when targeting shrimp. This area is far from Peñasco (~ 50 km), and is surrounded by murky waters and strong currents.

Figure 7. Location of current snail fishing zones used by small-scale hookah divers of Puerto Peñasco, Sonora, Mexico.



Georeferenced coastline provided by UIB-CECARENA, ITESM Campus Guaymas

Fishing Effort and Production

A total of 139 panga trips were carried out from June 5 to July 12, 1999, bringing in an estimated 74,425 kg of murex snail (whole): 71,038 kg of black murex and 3,387 kg of pink murex (Table 3). CPUE (catch per unit of effort) for the period comprising June 5-July 12 was 535.4 kg/*panga*/day.

Most of the fishing effort was concentrated in La Cholla (64%), followed by El Borrascoso (13%), San Jorge (7%), Peñasco (6%), San Judas (3%), Sandy (3%), Las Conchas (2%), and Los Tanques (2%) (Table 3). Production by zone followed a similar trend. The largest production came from La Cholla (50 % of total production), followed by El Borrascoso (28.5%), San Jorge (10.5%), Peñasco (4 %), Los Tanques (2.5%), San Judas (2%), Sandy (2%), and Las Conchas (0.5%) (Table 3). Approximately 80% of the production was obtained within the Buffer Zone of the Biosphere Reserve and the rest outside the Reserve.

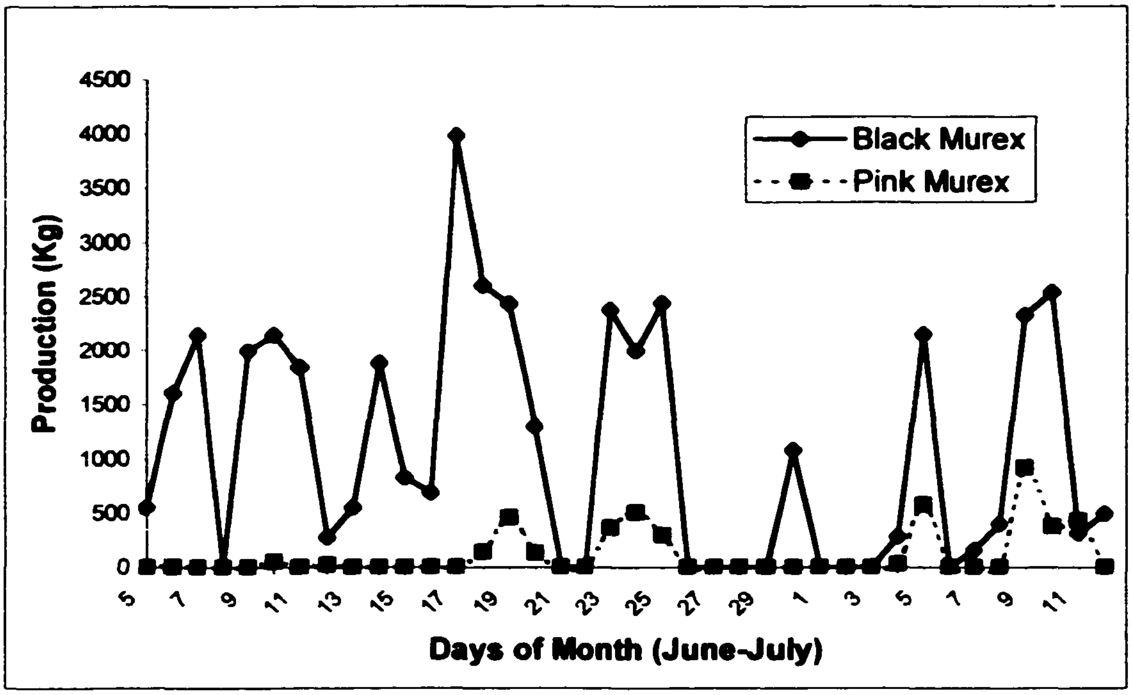
Table 3. Distribution of fishing effort and production by zone for the murex fishery, June 5-July 12, 1999 in Puerto Peñasco, Sonora, Mexico.

Fishing Zone	Effort (# of panga trips)	% Effort	Production (kg whole snail)	% Production
La Cholla	89	64	37,212	50
El Borrascoso	18	13	21,211	28.5
San Jorge	10	7	7,814	10.5
Peñasco	8	6	2977	4.0
San Judas	4	3	1480	2.0
Sandy	4	3	1497	2.0
Las Conchas	3	2	374	0.5
Los Tanques	3	2	1860	2.5
TOTAL	139	100	74,425	100

Fluctuation in daily production of black murex was characterized by spurts of increased production, usually lasting 2-3 days, followed by sharp decreases in catch and periods of no fishing activity (Figure 8). These decreases or interruptions in fishing activity were determined primarily by the intensity of the winds and currents. The highest production registered for one day was 3,981 kg on June 17, and most of the production concentrated throughout the second half of June (Figure 8). Production of pink murex, on the other hand, tended to increase as the season progressed but always remained minimal in comparison to that of black murex since it is not in high demand and it is harder to process (Figure 8). Pink murex is smaller, has a harder shell, and requires a longer time to cook.

It is important to mention that, although most of the snail harvesting ended on July 12 when the main buyer switched to buying blue crab, four *pangas* continued harvesting snail until the first week of August. Likewise, an unknown number of fishing trips were conducted between May 25, when the first *panga* went to fish, and June 5, when I began registering fishing effort on a daily basis. However, judging from interviews with fishermen at the beginning of the season, these trips were minimal (~ 6 *panga* trips total) due to the presence of winds and a lack of large-scale buyers.

Figure 8. Fluctuation of snail production in Puerto Peñasco, Sonora, Mexico, June 5 - July 12 1999.



Processing and Commercialization

Processing and commercialization of snail will vary throughout the season depending on the amount of snail and buyers available, and the proximity of the fishing area to port. There are 7 snail buyers in Peñasco. At the beginning of the season, when only small-scale buyers are receiving snail – predominantly black murex - divers will usually sell it without a shell. Breaking the shell is a lengthy, tiresome and dangerous endeavor. Each snail is broken one by one with a sledgehammer, usually in fishers' homes or close to camp when conducting long fishing trips to El Borrascoso or San Jorge (Figure 9). In the process, thin chips of shell shoot out, commonly cutting the fishermen or entering the eyes if not careful. However, when fishermen have harvested large quantities of snail, their profits are higher if sold without a shell since the price for whole snail is considerably lower than broken snail, \$2.80 pesos/kg whole black murex (~ \$0.30 dollars) vs. \$24.00 pesos/kg broken (~ \$2.5 dollars). On the other hand, when production is low, they are better off selling live snails since the weight of the shell compensates for the low production. Practically all pink murex is sold with shell, at \$1.80 pesos/kg (~ \$0.20 dls).

Figure 9. Divers breaking black murex shells to sell the meat in Puerto Peñasco, Sonora, Mexico (Photo by Richard Cudney-Bueno).

Another reason to break the shell, regardless of the production level, is the buyers' demand. At the beginning of the season, most buyers will only receive broken snail since they don't have the time nor the staff and facilities to break it and cook it. Thus, at this time the entire production of snail is sold locally and raw. Only the muscle of the snail's foot is sold. All other organs and the operculum or "cover" of the foot are discarded.

As the season progresses, the number of divers participating in the fishery increases and with it so does the production of snail. One large-scale buyer dominates the market at this time and mostly receives live snail. Snail is cooked in large 400 kg capacity containers with salted water. Black murex is cooked for 10 min while pink murex requires at least 20 min. After this, the operculum is easily detached from the foot, the entire organism is taken out of the shell, and all organs are removed. Approximately 30 people, men, women, and children participate in this process. Once removed, operculums are left to dry and all muscles are rinsed in fresh water to be transported to another processing plant in Peñasco, where they are rinsed once more, frozen, and packaged.

Between 1.5 and 2 tons of snail meat is needed for it to become economically attractive for a large-scale buyer to sell his product outside of Peñasco. This is equivalent to approximately 8 metric tons of live snail, a quantity that is never produced in one day. However, buyers mention that snails are very resilient, lasting two days out of the water without being processed. This need to produce a certain amount in order to allow buyers to sell their product exerts pressure on fishers to increase harvest, especially when the buyer has lent them money to conduct long fishing trips to El Borrascoso or San Jorge. Since these areas are far away from Peñasco, fishers need to establish camp for 2-4 nights and bring to port all their catch without shells. The quality of this meat, since it is kept on ice for some days, is different to that of snail that is cooked fresh, and therefore is usually destined for the local market and is rarely exported. Commonly, divers will not return to Peñasco until they have harvested a certain amount of meat previously specified by the buyer.

Buyers and divers mention that snail meat yield varies considerably according to the fishing area. The best snail in terms of the amount of meat obtained in relation to live weight is the snail from La Cholla, giving an approximate 14% yield. Although snails from La Cholla are not as large as those from San Judas and El Borrascoso, their shell is apparently thinner, cleaner, and with less calcareous deposits. Snail from El Borrascoso and San Judas give between 10-11% yield, San Jorge 10%, and those from Los Tanques and Las Conchas 7-9%. Besides being smaller snails, their shell is thick and covered with external calcareous deposits. The yield for pink murex is more consistent regardless of the fishing zone, usually being ~ 8%. These differences in yields not only influence where divers will fish and how much they will be paid, but also the ties and relationships between the diver and the buyer. Buyers prefer not to buy black murex from Los Tanques and Las Conchas or pink murex from any area because of their low yield. However, when currents are strong or no aggregations of black murex are found throughout a fishing day, divers sometimes have no choice but to fish in Los Tanques and Las Conchas or to harvest any pink murex aggregation they may have found. Buyers feel a certain commitment to receive this product because fishermen may switch to other buyers who will receive their catch and continue working for them. A price negotiation will take place, and although an agreement is reached, usually both parties will not be pleased with the results.

Snail meat is sold throughout Mexico's northern border cities, including Tijuana, Ensenada, and Mexicali in Baja California Norte, San Luis Río Colorado, in Sonora, throughout the border of Chihuahua, and in Guadalajara, Jalisco. It is used mainly in cocktails and for soups in the many Chinese restaurants found along the border. All fresh snail remains within Mexico, while much of the cooked snail reaches the U.S., specifically Los Angeles, California, where there is a strong demand from the Asian market. Los Angeles also acts as the distribution source of snail and other fishery resources from the northern Gulf (e.g., gulf coney, flounder, scallops) to other cities within the U.S. and to Korea and Japan.

Dried operculums, on the other hand, are sold to two buyers who distribute them in India and China for the production of incense. The price paid for these operculums to local snail buyers in Peñasco is high compared to the meat (~ $15.00 dls/kg). On many occasions operculums bring more profit than the sale of meat. They can even be considered the only reason why snails are bought from fishers when production is low since meat may not bring any profits at all under those conditions. Fishers are generally unaware that the operculums are sold at such a high price. Certainly, the money they receive per kilo of snail caught does not reflect a true value for what a whole snail is worth since they are essentially only being paid for the meat. Buyers who commercialize the operculums as well as those who do not, pay divers practically the same amount. Local buyers, in turn, are not knowledgeable about how much their product, regardless of what it is, may be sold for once it crosses the border or even once it leaves the state. In fact, this lack of knowledge and therefore control of sales overseas may go to the extreme of not even knowing how their products are being used. It was only recently that local buyers were told about the production of incense, and rumors still abound about other uses such as aphrodisiac pills.

Chapter 3
Reproductive Ecology of the Black Murex Snail, *Hexaplex (Muricanthus) nigritus*

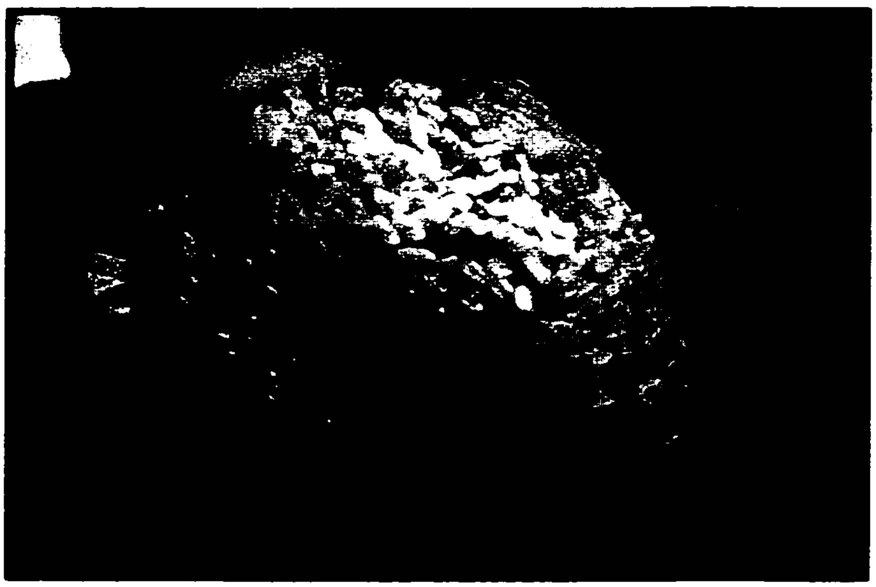
Introduction

An essential component of any fishery management regime involves understanding the basic life history of the resources harvested and how certain aspects of this life history influence fishing methods and practices. Of primary concern is understanding the reproductive ecology of species that form breeding aggregations, since aggregations will usually be targeted and sought by fishermen in order to maximize production. This is especially true for species with limited mobility (Cudney-Bueno and Turk-Boyer 1998, Caddy 1989). The black murex snail clearly exemplifies this issue. Like other gastropods (e.g., *Phyllonotus erythrostomus*), the black murex is known to form breeding aggregations (Barber 1961, Cudney-Bueno and Turk-Boyer 1998), at which time it is heavily targeted for harvest (López-Reyes 1992, Cudney-Bueno and Turk- Boyer 1998).

The black murex is a muricid prosobranch gastropod. The Muricidae constitute one of the best known and most distinctive families of mollusks and exhibit many remarkable feeding and reproductive adaptations (Radwin and D'Attilio 1976). Like other mollusks, they are extremely diverse, having successfully occupied many different types of marine habitats (Tompa et al. 1984). They are predators that occupy important niches in many food webs. They also take on economic importance wherever shell-fisheries exist (Radwin and D'Attilio 1976).

The black murex is believed to be endemic to the Gulf of California (Poutiers 1995). Adults are found mainly in sub-tidal waters up to 90 m deep, where they live primarily on sand and gravel bottoms (Poutiers 1995) and prey upon different species of clams and mussels (Brusca 1973). Apparently, the first and one of the only descriptions ever given of the reproductive habits of this species was that of Barber (1961), who observed spawning in the northern Gulf of California in early August and suggested a communal event including deposition of egg capsules on conspecific shells (Figure 10).

Figure 10. Black murex snail covered with egg capsules laid by a conspecific snail (Photo by Richard Cudney-Bueno).



Muricids are typical of higher prosobranch snails in that their embryos are enclosed within elaborate and structurally complex egg capsules for varying portions of their development before emerging as either planktonic larvae or juvenile snails (Rawlings 1995). D'Asaro (1991), based on morphological analysis of capsules obtained from one egg mass of *H. nigritus*, suggested that embryos hatch as planktotrophic veliger larvae. However, actual hatching of capsules has never been documented and confusion still prevails in this matter (see López-Reyes 1992).

Despite its economic and ecological importance, limited studies have been carried out regarding basic natural history of this species and its role in the ecosystems of the northern Gulf of California. Although Muricids constitute one of the best known and most distinctive families of mollusks, the vast majority of work on muricid reproduction has focused on a few species, and extrapolation to other species involves considerable risk (Radwin and D'Attilio 1976).

In this chapter I intend to increase our understanding of the reproductive ecology and habits of the black murex snail in the northern Gulf of California. I directed my research to answer questions I believed to be essential for management and conservation of this species.

Methods

I conducted fieldwork in Puerto Peñasco, Sonora from May to August 1999. Most of the research was based on direct observations and sampling of snails in their natural environment, sampling fishermen's daily catches, and maintaining individual snails in aquariums. Consulting key fishers and incorporating their knowledge also expanded data gathering.

To sample fishers' catches, three large buckets were used to scoop snails randomly from the *panga*. This was done in port as soon as divers had arrived from a day's fishing trip as well as on the *panga* when accompanying them to fish. Selection of fishers was based on the area where they had fished and the amount of snails caught. Only divers who had fished in one of the areas under study were considered for sampling to avoid mixing snails from different zones. When at port, fishermen were asked to provide the approximate location and depth at which the snails were found. When on the panga, I took depth and bottom temperature readings and used a Global Positioning System (GPS) to calculate the position. I obtained all samples used for the analysis from five of the nine general fishing zones described in Chapter 2: La Cholla, Cerro Prieto, Sandy Beach, Los Tanques, and San Jorge. A total of 9 samples/days were analyzed, comprising 372 snails (Table 4 and Figure 11). Weather conditions and the availability of aggregations as the fishing season progressed determined the available days and areas for obtaining samples. A more detailed description of the temporal and spatial research design is given later.

Table 4. Black murex snail sample days and sites in the northern Gulf of California, Mexico.

Sampling Day	Sampling Site	Depth (meters)	# Of Snails
06/06/99	La Cholla	16.0	35
06/07/99	Cerro Prieto	7.0	42
06/11/99	Sandy	10.0	40
06/14/99	Los Tanques	4.0	31
06/23/99	La Cholla	16.5	36
07/05/99	La Cholla	5.0	32
07/10/99	La Cholla	7.5	28
07/14/99	Los Tanques	6.5	97
07/20/99	Isla San Jorge	30.0	31
Total	--------	--------	372

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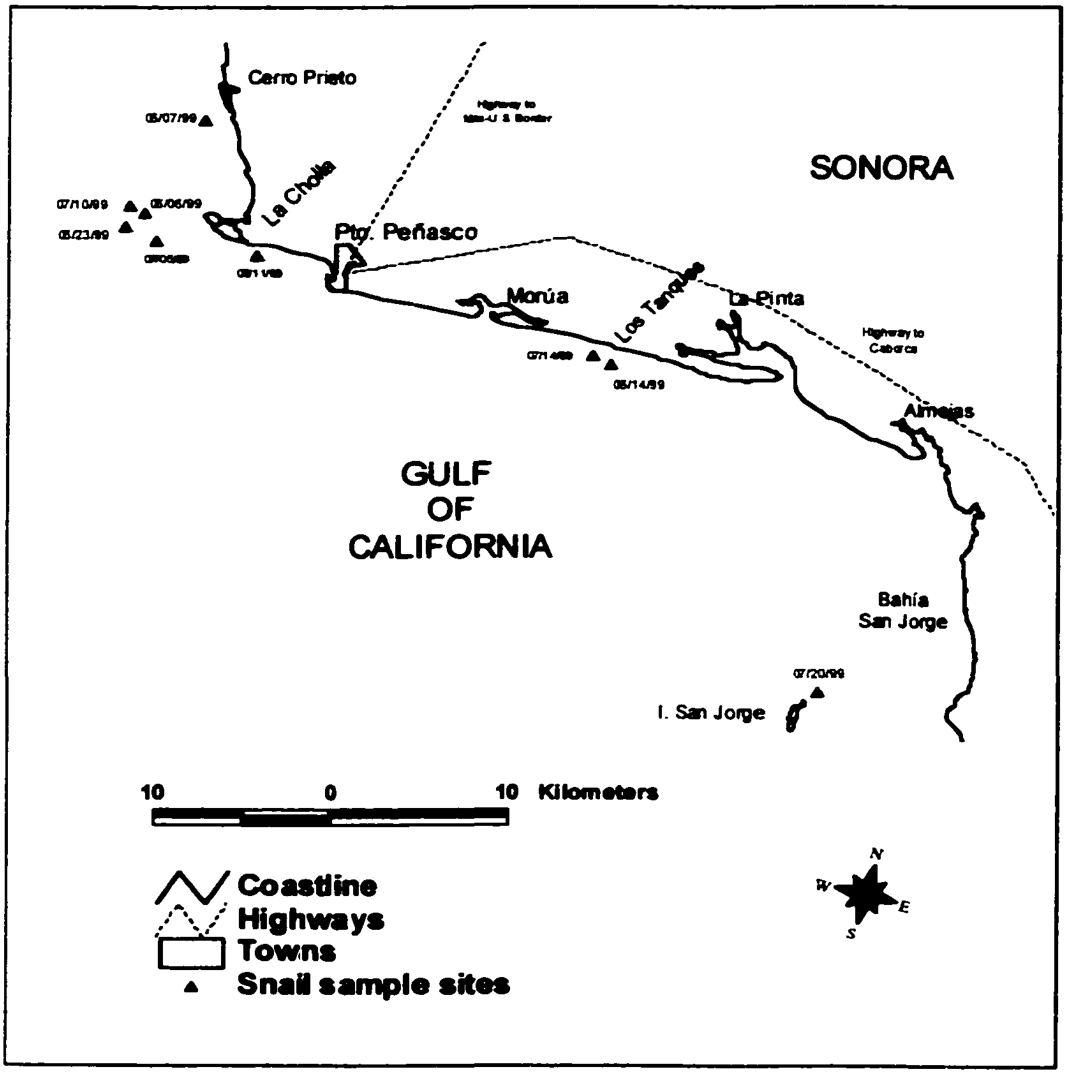
07/10/99	La Cholla	7.5	28
07/14/99	Los Tanques	6.5	97
07/20/99	Isla San Jorge	30.0	31
Total	-------	-------	372

Figure 11. Location of black murex snail sampling sites in the northern Gulf of California, Mexico.



Georeferenced coastline provided by UIB-CECARENA, ITESM Campus Guaymas.

The closeness of the fishing grounds to port (no more than 40 min travel under normal conditions) and the resilience of the snails made it possible to obtain and study live individuals. Buckets with snails were filled with sea water and transported to a wet laboratory for analysis at the Intercultural Center for the Study of Deserts and Oceans

(CEDO), located five minutes away from port, where I placed snails in aquariums. I filled four 20-gal and two 50-gal aquariums with sea water obtained from the inter-tidal zone during high tides at 1m below the surface. I maintained water temperature between 28.0-29.0°C by monitoring the temperature daily and introducing sealed plastic bottles with frozen water to allow a gradual decrease in temperature when needed.

I measured salinity daily with a Specific Gravity Meter, assuring levels between 37 and 38 ‰. To help reduce evaporation and maintain desired salinity levels, I used glass covers.

I filled the bottoms of aquariums with a 3.5 cm layer of inter-tidal sand and shell gravel, and used a gravel filter for all aquariums. Power heads were used to improve circulation and filtration in the larger aquariums.

For the most part, I relied on aquariums only for temporary storage of snails as they were being analyzed individually. Once data were recorded, I returned the snails to the ocean. However, I maintained 47 snails throughout the summer to observe snail behavior and egg case development.

I assessed three general topics. The following is a detailed description of the methods, questions assessed, and types of analyses used.

Reproductive Behavior

- Formation of Breeding Aggregations

Because the study area is heavily fished during breeding season, it is practically impossible to follow individual snails before, during, and after they form breeding aggregations or to assess changes within an aggregation through time. My data gathering therefore relied on fishers' knowledge and direct observations with scuba gear when accompanying divers on their fishing trips.

- Sex Distribution of Breeding Aggregations

I took a sample from fishers' catches on two occasions, June 23 ($n = 36$ snails) and July 5 ($n = 32$). Both samples were obtained from aggregations within the fishing zone of La Cholla. Males were distinguished from females through identification of the penis. Percentage of males and females was calculated for each sample and both samples were tested for marginal homogeneity using a Pearson χ^2 test.

- Egg Laying

In order to describe the egg laying process, I maintained 47 snails for observation from mid June to mid August in the aquariums. During this time I fed them live clams (*Chione* sp.) and mussels (*Mytilus* sp.).

I recorded data on the behavior of the snails throughout these two months. When egg laying occurred successfully, I recorded the laying time and counted the total number of egg capsules laid. I defined successful egg laying as a snail laying >10 consecutive capsules with ≤ 24 hr interruption between each capsule laid.

In addition to describing the egg laying process, I assessed two other questions:

1. Is there any relationship between sex and the presence or absence of egg capsules on the snails?

2. Are egg capsules laid on substrates other than snails?

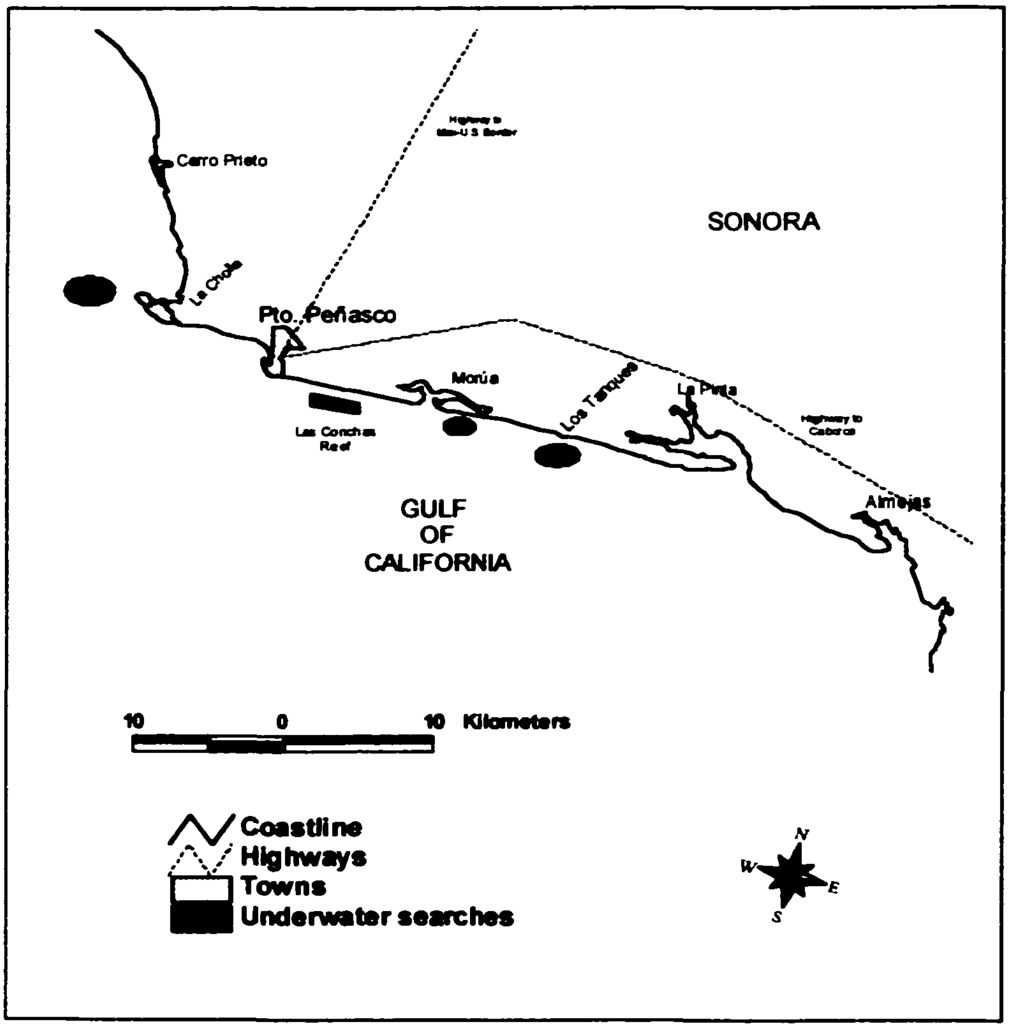
For the first question, the same snails that were used to assess sex distribution of breeding aggregations were analyzed by registering the presence and absence of egg capsules on male and female snails (only clusters of >10 capsules were considered for capsule presence). I calculated percentage of presence/absence of capsules for males and females and tested both sexes for marginal homogeneity with a Pearson χ^2 test.

To help assess if capsules were laid on substrates other than individual snails, I carried out ten dives throughout the breeding season in areas known to be potential habitat for snail aggregations (Figure 12). I limited search times on each dive to ~ 60 min due to air and safety constraints with the scuba gear. I conducted four of these dives in collaboration with fishers, following the diver's path and maintaining a constant lookout for egg cases. Once aggregations were found, I searched the perimeters of the aggregations and the surrounding areas <10 m away from the aggregation.

For dives not assisted by fishers, I followed the border lines of the second and third rocky reef of Las Conchas, where breeding aggregations were found at the beginning of the fishing season (Figure 12).

In addition to underwater searches, I consulted key fishers regarding past and/or present experiences of finding egg cases on substrates other than snails and asked them to define the areas and types of substrate where these were observed.

Figure 12. Underwater search sites for black murex egg cases in the northern Gulf of California, Mexico.



Georeferenced coastline provided by UIB-CECARENA, ITESM Campus Guaymas.

\- Egg Hatching

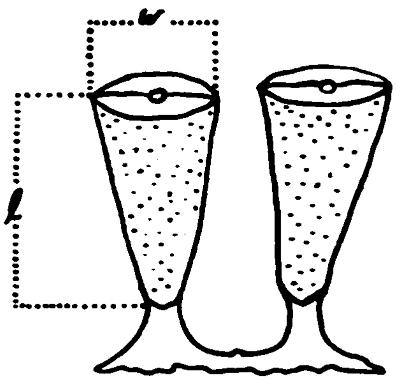
Incubation Time

I monitored egg cases laid in the aquariums throughout their development until individual capsules began hatching. I recorded the incubation time, defined as days of incubation from the first day a snail began laying an egg mass to the first hatching day.

Hatching Stage and Reproductive Output

To determine the developmental stage at which offspring hatch from the capsules and the relationship between reproductive output and the size of capsules, I collected 80 individual ready-to-hatch capsules from the random samples of snails taken from fishers' catches between June and July. All capsules used for the analysis came from La Cholla and Los Tanques. I introduced each capsule to individual small jars with 10 ml of aquarium water and measured their length and width (Figure 13). Capsule length was defined as the greatest dimension, i.e. the distance between the basal membrane and the apical plate with an escape aperture. Width was the greatest dimension at right angles to length. Morphological and measurement terminology was based on D'Asaro (1970) and D'Asaro (1986).

Figure 13. Length and width measurements
of black murex snail egg capsules.



Water level and the capsules were monitored daily until hatching, at which time they were cut open from the base and carefully pressed with thin forceps until the remainder of the capsule's contents was in the water. Once empty, I removed the capsule and stirred the water to allow a random distribution of the embryos through the water column. I proceeded to immediately introduce a 1 ml pipette and suctioned a 1 ml sample from the middle of the jar. I then introduced the sample to a 4 cm in diameter gridded petri dish (grids = 0.5 cm^2) and fixed this solution with a drop of 10% formalin-seawater mixture. I observed the dish under a 10x dissecting microscope and used a tally counter, using the grid as a guide, to count each individual offspring. Finally, I used a 1:10 conversion to calculate the number of offspring contained in each capsule.

I used these counts to determine the number of embryos found in an individual capsule and the relationship between capsule size and reproductive output. Linear regression of the log-transformed data was used to test the null hypothesis that there is no relationship between capsule size and reproductive output.

Geographic Variation of Reproductive and Non Reproductive Characteristics

- Geographic Variation of Capsule Maturity

Two questions were raised and assessed regarding geographic variation of capsule maturity:

1. Are there any significant differences in the maturity of capsules between different fishing zones fished within the same time period?
2. Are there any significant differences in the maturity of capsules between two breeding aggregations found within a fishing zone the same day?

To answer the first question, I took samples from divers' catches at the beginning and end of the fishing season. The first set of samples was comprised of snails with capsules obtained from La Cholla (n = 24), Cerro Prieto (n = 17), Sandy Beach (n = 24), and Los Tanques (n = 21) between June 6 and 14. The second set included samples from La Cholla (n = 19), Los Tanques (n = 62), and San Jorge (n = 24), collected between July 7 and 20.

I counted, removed, and registered all capsules as hatched or not hatched. Once the capsules were removed, I measured each snail (total length TL) with a 20-cm caliper and weighed them with a 2-kg spring scale. Snails without capsules were only measured and weighed, registering the absence of capsules for other analysis (see "Egg Laying" and "Temporal Variation in Number of Capsules Laid").

I calculated a proportion of hatched capsules PHC (hatched capsules/total # of capsules) for each snail with capsules. To discern differences between zones for the two sample periods, I logit-transformed the proportions [$\log_{10}$ (Y/1-Y)] to improve homogeneity of variance (Brown, Levene, and O'Briens tests, $P > 0.05$) and analyzed them using 1-way ANOVA. I performed a Tukey's multiple comparison test to determine pairwise relationships.

To discern if there were any significant differences in the maturity of capsules between two breeding aggregations found within a fishing zone on the same day, I obtained samples randomly from two small aggregations in Los Tanques on July 14 (n = 20 and n = 32 snails with capsules). The aggregations were separated by ~ 50 m on the same depth (6.3 m) and were comprised of ~ 50 and 70 snails, respectively. I calculated a PHC and applied logit transformations. I used a Students t-test to assess differences in the PHC of both aggregations.

- Capsule Size Variation

I collected capsules from the random samples of snails taken from fisher's catches of La Cholla and Los Tanques between June and July (La Cholla n = 57 capsules, Los Tanques n = 85). I measured each capsule's length and width. To assess differences in capsule lengths between both zones, I log-transformed the data and analyzed it by using a Students t-test.

- Snail Length and Weight Variation

To discern variation in snail length and weight between fishing zones, I compared all snails sampled for each zone (with and without capsules) between June and July (Los Tanques n = 128, La Cholla n = 131, Cerro Prieto n = 42, San Jorge n = 31, Sandy n = 40). I log-transformed the data (ln Y) and analyzed it using a 1-way ANOVA and Tukey's test.

Temporal Variation of Reproductive and Non Reproductive Characteristics

- Capsule Maturity Variation Through Time

I assessed temporal variation in the maturity of capsules for La Cholla and Los Tanques. I compared the PHC between each sample period: La Cholla, June 6 (n = 24), June 23 (n = 19), and July 5 (n = 19), and Los Tanques, June 14 (n = 21), and July 14 (n = 61).

I used a 1-way ANOVA and Tukey's test to analyze the data of La Cholla and a Students t-test for Los Tanques. I applied a logit-transformation to all data.

- Temporal Variation of Egg Capsule Presence on Snails

I assessed temporal variation in the percentage of snails containing capsules for La Cholla and Los Tanques. For each site, I tested the percentages for marginal homogeneity with a Pearson χ^2 test: La Cholla, June 6 (n = 35), June 23 (n = 36), and July 10 (n = 28), Los Tanques, June 14 (n = 31), and July 14 (n = 97).

- Temporal Variation in Number of Capsules Laid

To assess if there was any significant variation in the number of capsules laid on snails through time, I compared the mean number of capsules/snail for La Cholla (three sample periods, June 6 n = 24, June 23 n = 19, and July 10 n = 19) and Los Tanques (two sample periods, June 14 n = 21, and July 14 n = 61). I analyzed La Cholla samples with a 1-way ANOVA and Tukey's test and Los Tanques with a Students t-test after applying a square root transformation to all data.

Results

Reproductive Behavior

- Formation of Breeding Aggregations

May 25 was the first day divers went to harvest snails. On that day they landed 500 kg from aggregations found in Las Conchas reef. At this time, it was evident that the egg-laying process had already begun since recently laid egg cases were present on most of the snails. Although sample gathering and field observations were constrained to the snail fishing season (end of May-mid August), interviews with divers before and during the fishing season indicated that signs of aggregation formation began to be seen by late March by fishers diving for octopus and rock scallop in La Cholla. At this time, when found, individual snails were separated by short distances and were usually all headed in the same direction. Most divers stated that the mere fact of finding many snails within a same location is an indication that aggregations are beginning to be formed, as it is difficult to find individual snails at any other time of the year. Divers mentioned that, when found, snails are usually buried during the colder months. They "come out" to feed close to or on *tepetates* when the water temperature begins to rise. This is followed by the formation of breeding aggregations, usually on substrates comprised mainly of large granule sand, pieces of broken shells, and calcareous algae close to the *tepetates*.

Commonly, at the end of the season divers brought back snails that were feeding on different bivalves, mainly *Chione* sp. and *Megapitaria* sp. These snails, already dispersed, would be gathered individually for personal consumption when searching for calico scallops. However, practically no snail obtained from aggregations had any indication of feeding on bivalves. Likewise, snails maintained in the aquariums were offered live clams and mussels, but these were only eaten after the snails had been aggregated or after egg laying had occurred. Following feeding, snails kept in aquariums would usually bury themselves in the gravel.

- Sex Distribution of Breeding Aggregations

The percentages of male and female snails was 56%:44% respectively for the first sample period (n = 36), and 50%:50% for the second sample period (n = 32). The percentage of male and female of both samples combined was 53%:47%. No significant differences were found when comparing sex distributions of both sample periods ($\chi^2 = 0.21$, $P = 0.646$).

- Egg Laying

Ten egg cases were laid successfully by nine snails. The number of capsules laid varied considerably, from 27 to 337 ($\bar{x}$ =137, 95% CI = 66, 208). The number of capsules laid per day by individual snails varied considerably as well, from 5 to 87 capsules/day ($\bar{x}$ = 20, 95% CI = 10, 41 after log transformation) (Table 5).

Eight of the egg cases were laid on the glass surface of the aquariums, and two on top of other snails. At least 9 other laying attempts were made. However, these were not considered since the number of capsules laid was below 10.

Table 5. Distribution of clutch sizes and clutch-laying times for 10 black murex snails maintained in aquariums.

Snail TL (mm)	Snail Weight (g)	Total #of Capsules Laid/Clutch	Days Laying	# of Capsules Laid/Day
127.2	340	261	8	33
120.8	290	117	6	20
118.3	330	337	14	24
110.2	290	69	3	23
110.2	290	186	9	21
122.8	310	27	6	5
141.5	440	63	10	6
146.0	500	62	7	9
146.0	500	87	1	87
120.4	340	161	2	81

When diving, I found only two egg cases laid on substrates other than snails. Both of these were attached to small loose granite rocks. Fishers mentioned that egg cases are seen on other substrates, especially on the rocky outcrops of the northern point of San Jorge Island. However, they always stated that the number of egg cases that are not found on snails is minimal compared to those that are found on snails. Among the other substrates mentioned were steel cables lost from trawler boats, large shells of clams and other snails, and the surface areas where snails aggregate.

When analyzing the two samples from La Cholla collected on June 26 and July 5 (n = 68 combined), both male and female snails carried egg cases. I did not find a significant relationship between sex and the presence or absence of egg capsules (χ^2 = 0.022, P = 0.881). The percentage of male and female snails with egg cases was 63.89% and 65.63% respectively.

- Egg Hatching

Incubation Time

Incubation time for snails held in aquariums ranged from 18 to 31 days ($\bar{x}$ = 23, 95% CI = 19, 27).

Hatching Stage and Reproductive Output

All capsules released active veliger larvae. The longest period veligers were maintained alive was 10 days, and there was no indication of metamorphosis to settled larvae within that time period.

A significant relationship was found between capsule size and number of larvae present in the capsule ($F_{1,60}$ = 123.44, P<0.0001 after log transformation, simple linear regression). The number of larvae in capsules tended to increase with an increase in capsule length. I estimated that a 1mm increase in capsule length results in a 19.9% increase in the number of larvae (95% CI = 16.1%, 23.9%).

The number of larvae/capsule for capsules collected in La Cholla and Los Tanques (combined, n = 62) varied considerably, from 990 (CL = 14.46 mm) to 20,189 (CL = 21.84 mm). The mean number of larvae was 4,287 (95% CI = 3606, 5096).

Geographic Variation of Reproductive and Non Reproductive Characteristics

- Geographic Variation of Capsule Maturity

The distribution of proportion of hatched capsules (PHCs) for each fishing zone and sampling day is shown in Table 6. There is evidence to suggest that there are differences in the PHC between samples obtained from different fishing zones within the same time period. At the beginning of the fishing season, I found significant differences between samples taken from La Cholla, Sandy Beach, Los Tanques, and Cerro Prieto ($F_{3,82} = 4.42$, $P = 0.006$ 1-way ANOVA after logit transformation). These differences were evident when comparing La Cholla and Cerro Prieto, the later having a higher PHC than the former. However, no significance was found when I conducted any other comparison of collection sites (Tukey-Kramer's multiple comparison test).

Table 6. Distribution of the proportion of hatched capsules obtained for each fishing zone and sampling day in the northern Gulf of California, Mexico.

Fishing Zone/Date	Hatched Capsules	Non Hatched Capsules	Total # of Capsules	Proportion of Hatched Capsules
Cholla/June 6	432	6092	6524	0.0662
Cholla/June 23	726	5852	6578	0.1104
Cholla/July 5	6073	7426	13499	0.4499
Cholla/July 10	1481	3083	4564	0.3245
Sandy/June 11	1563	9636	11199	0.1396
Tanques/June 14	1703	6177	7880	0.2161
Tanques/July 14	14115	13396	27511	0.5131
Cerro Prieto/June 7	2499	4775	7274	0.3436
San Jorge/July 20	2395	7529	9924	0.2413
Total	**30987**	**63966**	**94953**	-------

I found significant differences when comparing the PHC of samples from La Cholla, Los Tanques, and San Jorge at the end of the season ($F_{2,101} = 8.03$, $P = 0.0006$ 1-way ANOVA after logit transformation). The PHC of San Jorge was lower than that of Los Tanques, but I did not find any significant difference when comparing other sites (Tukey-Kramer's test).

There is strong evidence to suggest that the PHC of both aggregations sampled from Los Tanques on July 14 was significantly different (t = 3.33, two-sided P = 0.0016 from a two sample t-test).

- Capsule Size Variation

Capsules collected from La Cholla (n = 57) and Los Tanques (n=85) showed significant differences in their lengths (t = 9.865, two-sided P<0.0001 from a two-sample t-test after log transformation) and widths (t = 5.56, two-sided P<0.0001 from a two-sample t-test). The mean length of capsules from La Cholla was 17.13 mm (95% CI = 16.41, 17.85 mm) and their mean width was 6.71 (95% CI = 6.34, 7.08 mm). For Los Tanques, the mean length of capsules was 13.6 mm (95% CI = 13.24, 13.96 mm) and their mean width was 5.49 mm (95% CI = 5.23, 5.74 mm).

- Snail Length and Weight Variation

There is strong evidence to suggest that the TL of snails sampled differs markedly between one fishing zone and another ($F_{4,367}$ = 156.46, P<0.0001; 1-way ANOVA after log transformation). Snails with highest TL were those from Cerro Prieto ($\bar{x}$ = 151.57 mm, 95% CI = 147.15, 156.13), followed by La Cholla ($\bar{x}$ = 136.31, 95% CI = 134.04, 138.61), San Jorge ($\bar{x}$ = 122.43, 95% CI = 118.87, 126.11), Sandy Beach ($\bar{x}$ = 113.76, 95% CI = 110.66, 116.94), and Los Tanques ($\bar{x}$ = 109.41, 95% CI = 107.77, 111.08) (Table 7). Differences in TL were significant between all zones except when comparing Sandy Beach and Los Tanques (Tukey-Kramer's test).

I found a similar pattern when comparing the weights of snails, these being significantly different between samples from the five zones ($F_{4,364}$ = 124.16, P<0.0001; 1-way ANOVA after log transformation). Again, heaviest snails where those from Cerro Prieto, followed by La Cholla, San Jorge, Los Tanques, and Sandy Beach (Table 7). As with TL, weights were significantly different between all zones except when comparing Sandy Beach and Los Tanques (Tukey-Kramer's test).

Table 7. Differences in lengths and weights of black murex snails obtained from five fishing zones in the northern Gulf of California, Mexico.

Sample Site	n (length)	Mean Length (mm) (95% CI)	n (weight)	Mean Weight (g) (95% CI)
Cerro Prieto	42	151.57 (147.15, 156.13)	42	616.58 (561.3, 677.3)
Cholla	131	136.31 (134.04, 138.61)	131	448.0 (425.72, 471.34)
San Jorge	31	122.43 (118.87, 126.11)	28	338.1 (307.81, 371.42)
Sandy	40	113.76 (110.66, 116.94)	40	243.25 (225.0, 262.93)
Tanques	128	109.41 (107.77, 111.08)	128	263.53 (252.0, 275.55)

Temporal Variation of Reproductive and Non Reproductive Characteristics

- Capsule Maturity Variation Through Time

The proportion of hatched capsules (PHC) of samples from La Cholla tended to increase through time (F = 9.30, P = 0.0003; 1-way ANOVA after logit transformation) (Table 6). However, only the PHC of snails from June 6 was significantly different of that from July 10 (Tukey-Kramer's test).

For the analysis of Los Tanques, I found a significant difference between the PHC of June 14 and July 14, with a higher PHC for July 14 (t = -3.107, two-sided P = 0.0026 from a two sample t-test after logit transformation).

- Temporal Variation of Egg Capsule Presence on Snails

No significant differences were found when comparing percentage of snails containing egg cases in the four sample periods of La Cholla ($\chi^2 = 2.34$, $P = 0.31$). I obtained similar results for Los Tanques ($\chi^2 = 2.58$, $P = 0.107$).

- Temporal Variation in Number of Capsules Laid

No significant differences were found when comparing the mean number of capsules/snail for the three sample periods of La Cholla ($F_{2,57} = 1.7$, $P = 0.191$; 1-way ANOVA after square root transformation). For this zone, the mean number of capsules on individual snails was 285 (n = 62, 95% CI = 228, 342). Similarly, differences were not significant for the two sample periods compared from Los Tanques (t = -0.894, two-sided P = 0.373 from a two sample t-test after square root transformation). The mean number of capsules on individual snails was 421 (n = 82, 95% CI = 355, 487).

Discussion

Considering fishers' accounts and the fact that the first catch of the season in May 25 included snails gathered from fully formed aggregations with recently laid egg cases, it is likely that the initial stages of the formation of breeding aggregations took place between mid-March and mid-April.

The similarity of sex distributions and the generally equal ratio of male to female snails suggests that breeding takes place within aggregations and not prior to their formation. If, in fact, aggregations were forming at the end of March, internal fertilization and the formation of egg masses within the snail most likely proceeds relatively quickly, since the majority of snails harvested at the beginning of the season were already covered with egg capsules.

Several non-spawning females and males are also reported for aggregations of *Murex fulvescens* studied in northwest Florida (D'Asaro 1986). Although I did not gather any data to assess if all females were or were not spawning, it is possible that *H. nigritus* behaves similarly as *M. fulvescens* in this matter.

There are three possible explanations as to why no significant differences were found between the number of capsules laid through time or the percentage of snails with egg capsules. First, small sample sizes may have played an important factor, especially when comparing number of capsules for the samples of La Cholla. Second, all egg cases may have been laid on different aggregations early in their formation and no or minimal additional laying occurred throughout the remainder of the season within a particular aggregation. However, this seems unlikely for various reasons, primarily the existing variation in the proportions of hatched capsules on individual snails within a sample. It was common to find snails with most of their capsules hatched and others with the majority of the capsules recently laid. Individual snails commonly had a section or sections of hatched capsules and others of recently laid capsules. These sections could usually be identified at a glance by a variation in color and structure of the capsules, certain sections having longer and wider capsules than others. These variations suggest not only that individual snails are reproducing at different times within an aggregation, but that more than one female snail may lay an egg case on one snail at different times. Similarly, individual snails may lay eggs on more than one occasion, possibly on different snails. Spight (1979) reported that the muricid snail *Thais emarginata*, in the presence of the competitor *Thais lamellosa* with which it shares the food supply, undergoes repeated small clutch size spawns to take advantage of the food supply and produce as many offspring as nearby *T. lamellosa*.

The third and most plausible explanation is that aggregations do not remain static throughout the reproductive season, rather they keep growing throughout the season but reproduction begins to take place early in their formation. As the season progresses, new snails are recruited into the aggregation, and old ones begin leaving some time after copulation and egg-laying. D'Asaro (1986) reports that mature individuals of *M. fulvescens* gather in protected areas and begin spawning almost simultaneously, while late arrivals add capsules on the periphery, on the shells of other spawners or on previously deposited capsules. This explanation seems consistent with fishers' observations and their fishing methods. At the beginning of the season, fishermen usually follow the direction of the anterior canal of individual snails to lead them towards the aggregation. By the end of the season, divers rely on the opposite direction to lead them towards the aggregation the snails have left.

It is unclear what behavior snails exhibit after dispersing from aggregations, but results suggest that they feed on bivalves while remaining close to or on *tepetates* and then bury themselves in the sand after feeding. Tompa et al. (1984) suggest that some snails that become gregarious at breeding times will undergo starvation during this period. This seems consistent with the fact that snails obtained from aggregations were never seen eating any clams or mussels while those obtained after dispersion usually were engaged in feeding behavior. Similarly, snails in aquariums exhibited aggressive feeding behavior after breeding and laying eggs.

It is evident that capsules hatch both when snails are aggregated as well as when they are dispersing. When conducting underwater observations, the proportion of hatched capsules from some aggregated snails could be as high as 1 (all capsules hatched) while some dispersed snails presented unhatched capsules. However, most of the dispersed snails with egg cases observed underwater, as well as those brought back to port by divers when collecting scallops, had practically all their capsules hatched, suggesting that most of the hatching takes place within the aggregations.

The location of reproductive sources is known to be an important factor determining the distribution and settlement of planktonic veliger larvae (Stoner et al. 1998). In this case, aggregations could play a crucial role in the settlement process by being located on or close to settlement and feeding habitat. In most of the cases, the metamorphic and settlement cue appears to arise from a more or less specific plant or animal on which adults of the metamorphosing species feed (Hadfield 1978, Disalvo and Carriker 1994). For instance, recently settled larvae of the Chilean muricid gastropod

Loco (*Concholepas concholepas*) are usually associated with barnacles, on which they later prey (Disalvo and Carriker 1994). Although descriptive and preliminary, my results show that larvae observed in the laboratory remained in a veliger stage as long as ten days without giving any indication of metamorphosing into a settlement stage. The duration of a veliger stage is highly variable among gastropod species (Hyman 1967). This duration also varies within a species according to the environmental conditions in which the larvae are found. For example, some species delay metamorphosis for long periods of time in the absence of the appropriate settlement cues (Hadfield 1978, Scheltema 1986). Castilla and Cancino (1976) reported larvae of *C. concholepas* growing for a period of about three months. Long planktonic veliger larvae periods may have significant consequences over the dispersal range of the species, as for most sedentary or semi-sedentary marine invertebrates, the larval stage is the most important mode of dispersal (Olson 1985, Scheltema 1986). Future studies should address comprehensive analysis of both pre- and post-settlement processes.

Results show conclusive evidence that egg cases are laid on substrates other than snails. However, it is also evident that the amount of egg cases laid on other substrates is minimal compared to those laid on snails. Muricid snails are usually found on or close to sandy and muddy habitats, and egg-laying on each other's shells may have evolved as a strategy to cope with insufficient or lack of hard substrates for egg case attachment. D'Asaro (1986), studying prosobranch egg capsules in the Gulf of Mexico in a barrier island with little exposed native rock, suggested that prosobranchs requiring unfouled, solid substrata for oviposition have limited choices. Thus, they aggregate to spawn on available substrata, often in multispecific populations, including exuviae of arthropods, plastic and aluminum debris, and on the shells of other spawners. Similarly, Tompa et al. (1984) state that snails living on soft substrates either construct their holdfast from a few empty capsules or take advantage of any available firm surface for deposition. Small stones, larger selected stones, sea grass, living shells of their congeners or their own shells may be used for egg case deposits. Carrying egg cases could also enhance the spread of offspring as the snails disperse from aggregations.

It is impossible to conclude how many capsules a snail usually lays during one reproductive season since only ten female snails successfully reproduced and laid eggs in the laboratory. Again, egg clutch size is highly variable among gastropods (Hyman 1967, Spight 1979). Incubation time in the laboratory, however, was found to be similar to other muricid gastropods (see Tompa et al. 1984, Disalvo and Carriker 1994,).

The fact that the number of larvae tends to increase with larger capsules may also reflect a relationship between the size of the organism and reproductive output. Capsules from los Tanques were significantly smaller than those from La Cholla, and both weight and length of snails from Los Tanques were markedly smaller than those of La Cholla. Similarly, smaller individuals in the aquariums appeared to lay smaller capsules than larger ones. This suggests that capsule size is related to snail size (larger snails = larger capsules), and therefore, the larger an individual snail is, the higher its reproductive output. However, it is possible that smaller individuals could lay a larger number of capsules. A relationship between size or age and reproductive output has been found not only in gastropods, but other mollusks as well (see Spight 1979, Dame 1996). Smaller individuals seem to put more effort into somatic growth and older individuals put more effort into reproduction (Dame 1996). However, younger individuals as a group may contribute as many or more offspring because their numbers are usually greater than those of larger individuals in the population (Dame 1996). Overall, however, results suggest that the reproductive output of this species is very high.

The evident differences in lengths and weights of snails from the different zones could be attributed to two factors. It is known that size variation within gastropods of the same age classes is common and usually related to diet quality and habitat characteristics. For instance, maximum size of abalone is determined by local food availability, both the quantity and species composition (Breen 1980), and stunted individuals have shown to retain the potential for good growth when moved to more favorable habitat (Breen 1986). Marked differences in morphology depending on habitat and age have been registered for other gastropods as well (Berg and Olsen 1989, Stoner et al. 1998). Hyman (1967) reported that some gastropods appear to grow more rapidly in agitated than in quiet water. Snails from Los Tanques tended to have more silt and calcareous deposits than other snails, with much of the characteristically irregular surface of the species concealed by these deposits. Snail buyers in Peñasco have always avoided buying complete snails (with shell) from Los Tanques to La Salina because they obtain a much lower yield than with snails from other zones since the shell is much heavier in relation to the amount of meat.

The other explanation for these differences in length and weight could be related to fishing pressure, with smaller individuals expected in heavily fished areas. However, this is unlikely since the area that has traditionally been fished the most (La Cholla) is one of the areas with larger snails. When interviewing fishers and buyers, it was never stated that sizes have changed throughout the years. In fact, statistical results coincide with local knowledge regarding snail quality classification according to zone and size. This does not necessarily suggest that fishing activity does not have an affect on age groups of local populations. Similar lengths do not necessarily imply similar ages, since snails usually exhibit determinate growth (Berg and Olsen 1989). Older individuals also tend to exhibit more foreign calcareous deposits in their shell (e.g., calcareous algae). After cessation of surface expansion, many gastropods continue to add to the shell thickness as shown by the fact that increasing shell weight, and increase of length and width is not allometric (Hyman 1967). Divers do mention that, although they do not recall any variation in sizes, they do see "newer" snails in La Cholla and El Borrascoso than in previous years. They refer to new snails as those that have a thinner shell, are cleaner, and have less calcareous deposits. This could be an indication that fishing has tended to remove the older individuals. Only a few studies have been conducted regarding age and growth of gastropods, and ages vary significantly between one species and another (Hyman 1967).

Spatial variation in the PHC of the different samples taken during the same time periods may be an indication that breeding aggregations are forming at different times within the reproductive season. This was especially evident when comparing the two aggregations from Los Tanques found on July 14. Variation in egg capsule maturity and aggregation formation could be influenced by water temperature. Although little is known of factors that evoke spawning, there is no doubt that the rise of temperature in spring sets off spawning in many species of prosobranchs (Hyman 1967).

Fishers assert that the first aggregations begin forming in shallower waters and as the season progresses more aggregations are found in deeper waters. The fact that the proportion of hatched capsules of the sample obtained from the deep waters of San Jorge island (~ 30 m) late in the season was low in comparison to the PHC's obtained for other sample sites earlier in the season supports this statement. This could be related to temperature variations between shallow and deeper waters. However, it may also be a reflection of the divers' fishing practices. Divers will usually begin fishing closer to shore since this demands less effort and there are less possibilities of suffering the bends. As the search for aggregations close to shore becomes harder, effort will concentrate on deeper waters or areas farther from shore.

Of particular concern for the management of this species was the low PHCs obtained for all sample sites and days throughout the fishing season. Except for the sample from Los Tanques on July 14, with a PHC of 0.51 (Table 6), all other sampling sites and days showed a PHC lower than 0.5, suggesting that the vast majority of capsules harvested together with the snails have not had enough time to hatch. Since it is impossible to say with the information at hand what is an adequate PHC needed to support a sustainable fishery, a strong precautionary management approach should be assumed. An analysis of management possibilities is given on Chapter 6.

Chapter 4
Management Framework

Management Roles and Objectives of the Central Government

Management Roles

The responsibility for managing natural resources in Mexico currently falls on the *Secretaría del Medio Ambiente, Recursos Naturales y Pesca, SEMARNAP* (Secretariat of the Environment, Natural Resources, and Fisheries). SEMARNAP was created in the early 1990's as President Zedillo took office and consolidates what used to be two different secretariats: the *Secretaría de Desarrollo Urbano y Ecología, SEDUE* (Secretariat of Urban Development and Ecology) and the *Secretaría de Pesca, SEPESCA* (Secretariat of Fisheries). This institution is both immense and complex, with many departments and offices complementing and/or overlapping each other. However, the Subsecretaría de Pesca (Sub Secretariat of Fisheries) controls most fishery management issues. This Sub Secretariat relies on various government institutions considered as independent entities of SEMARNAP. The most important in terms of establishing management guidelines and enforcing such guidelines are the *Instituto Nacional de la Pesca, INP* (National Institute of Fisheries), and the *Procuraduría Federal de Protección al Ambiente, PROFEPA* (Federal Environmental Protection Procurator's Office). The INP's responsibility is to provide SEMARNAP with technical opinions and reports regarding recommendations to better manage fisheries. The INP and its regional fishery research offices (*Centro Regional de Investigación Pesquera, CRIP*), is the scientific backbone of the Sub Secretariat of Fisheries. There have been long standing difficulties between these agencies, as the INP has limited access to sufficient human and economic resources to undertake the enormous tasks for which it is charged and management decisions from the Sub Secretariat sometimes are not consistent with INP's recommendations. However, recent changes in legislation specify SEMARNAP will have to base its decisions on, not only consider, the technical advise of INP (personal communication Raúl Molina, CRIP-Guaymas, Sonora, February 2000).

PROFEPA's purpose is to enforce the legal dispositions directed towards protecting Mexico's natural resources and environment and to establish the administrative mechanisms and procedures to achieve such a task. Practically all surveillance is in the hands of inspectors of this institution, who may coordinate with other entities (e.g. Mexico's navy, local managers and producers) to make surveillance more efficient. In the case of the Upper Gulf of California and Colorado River Delta Biosphere Reserve, for instance, PROFEPA has the legal capacity to fine or prosecute infractors, not the Reserve's park managers or rangers. On one hand, when PROFEPA inspectors are truly coordinated with local officials and understand the specific problems affecting resource use in a particular region or community, this strategy may take the burden of enforcement out of local managers and increase management efficiency. However, this is not always the case, as inspectors can be unaware of local issues, implementing federal law without understanding that some regulations simply do not apply to local realities. This may undermine any efforts previously undertaken by local managers to involve the community in better management processes.

As with the INP, PROFEPA also is in need of more financial and human resources. There are currently only three PROFEPA inspectors in the northern Gulf, one in each fishing community (San Felipe, El Golfo de Santa Clara, and Puerto Peñasco). In the words of an inspector "Controlling some of the fishery problems in the region is like trying to control the tides with one hand".

Fishery management is based almost entirely on access controls to the fisheries and season closures. Fishing permits controlled by the SEMARNAP have traditionally been the most important means to try to control access to a fishery. Nevertheless, a few exclusive concessions have been granted mainly for the harvest of benthic and sessile species (e.g. abalone in the western coast of Baja California). In theory, to be able to harvest any resource for commercial purposes you must have either a permit, concession, or renewal issued by SEMARNAP (Ley de Pesca y su Reglamento 1999). To obtain such authorizations, fishers must be organized into cooperatives or fisher organizations with legal standing. No permits are given to individual "free" fishers. Once the cooperative is constituted, a member will apply for the permit at the local SEMARNAP office. The cooperative's solicitation will in turn go to the state's federal office of the Subsecretaría de Pesca in Guaymas, Sonora. For final authorization or denial, solicitations may sometimes need to go through the federal offices in Mexico City as well. For this reason, fishers sometimes need to travel to Guaymas or even Mexico City to speed the bureaucratic process, and much of the efficiency of this process will depend on the political contacts of the fisher or cooperative representative. It is very common for fishers to solicit a new permit or renew old ones with much anticipation and not get an answer until after the fishing season has ended.

In the case of the resources harvested by hookah divers in Peñasco, they are all controlled by permits. Fishers will usually have to purchase five different permits: 1) a permit for *callo de hacha* (pen shells, *Pinna rugosa* and *Atrina tuberculosa*) which in reality is used mainly to harvest rock scallop since no permit exists specifically for this species; 2) one for murex snail, *caracol chino*, which does not specify which species; 3) a permit for octopus (specified as *Octopus bimaculatus*); 4) clams in general; 5) a permit for *escama*, which allows the harvest of numerous species of fish. The Sub Secretariat of Fisheries defines on the permits the geographical jurisdiction on which fishers can harvest the resource. This jurisdiction, however, is only defined on the basis of geographical landmarks and not on the distribution of resources or ecosystems. This leads to confusion and territorial problems among users.

The CRIP in Guaymas, Sonora, which is in charge of conducting INP's responsibilities in Sonora, has never given its technical opinion regarding harvest of rock scallop or black murex because it has never been solicited. However, knowing that both species are being targeted and in light of insufficient ecological knowledge of the resources, this CRIP has addopted precautionary measures by not allowing the issuing of new permits for *callo de hacha* and *caracol chino*. Also, the new policy proposed by the CRIP is that both of these permits may be issued in the category of *pesca de fomento* (developmental fisheries), and not in the category of "commercial fisheries". This policy still allows commercialization of the species, but with certain conditions stated on the permit and as long as research comprises a strong emphasis for soliciting the permit. The purpose of this is to limit fishing effort and production while at the same time studying the resources to be able to establish more conclusive future management guidelines (personal communication, Raúl Molina, CRIP-Guaymas, February 2000).

Management Objectives

In addition to the Constitution, fishery politics and administration in Mexico are based on the objectives and goals of the *Plan Nacional de Desarrollo 1995-2000* (National Plan of Development) and the *Programa de Pesca y Acuacultura 1995-2000* (Fisheries and Aquaculture Program). All natural resource management priorities, goals and processes must comply with the statutes of the *Plan Nacional de Desarrollo*. This plan establishes as a goal of Mexico's environmental policy…"to reduce the tendencies toward ecological deterioration and set the basis to strive for a sustainable development, which can give way to a better quality of life for everyone, appease the overcoming of poverty, and contribute to an economy which will not degrade its natural basis of sustenance" (Plan Nacional de Desarrollo 1995-2000). Regarding fisheries, the Plan states: " the necessity of having an integral vision that can attend to the necessities of research and evaluation of the resources, basic infrastructure, fishing fleet, processing, transportation, and commercialization… it seeks to promote the diversification and development of new fisheries and resources not exploited, as well as of industrial and rural aquaculture. For this, it will be necessary to reorganize the fisheries, making the issuing of fishing concessions, renewals, and permits more transparent" (Plan Nacional de Desarrollo 1995-2000).

In terms of decentralization, the Plan states that "it is imperative to establish a profound redistribution of authority, responsibilities, and resources of the Federal Government towards the state and municipal orders of the Government" (Plan Nacional de Desarrollo 1995-2000).

Based on the premises established in the *Plan Nacional de Desarrollo*, the SEMARNAP created a complete department in 1996 under the Sub Secretariat of Planning called *Coordinación General de Descentralización*, CGD (General Coordination for Decentralization). The CGD was created amidst the necessity of having an administrative unit in charge of defining and operating the policies of decentralization of natural resource management towards the states, municipalities, and the social and private sectors (CGD web page, January 2000).

Also based on the Plan's premises, SEMARNAP elaborated the *Progama de Pesca y Acuacultura 1995-2000*, a comprehensive program that specifies the objectives, strategies, and priorities in relation to the development and management of fisheries and aquaculture throughout Mexico. This program addresses four fundamental objectives: 1) To achieve a full and sustained use of fishery and aquaculture resources, without affecting their replenishment capacity and the environmental quality of the habitats in which they are found; 2) organize the sector's economic activities to promote the application and commitments of responsible fishing in order to set the basis for a sustainable development of the activity; 3) permanently promote social and economical development of the sectorial activities by fostering and promoting all related activities; 4) to exert sovereignty within the Exclusive Economic Zone (Programa de Pesca y

Acuacultura 1995-2000). Although it is the obligation of the SEMARNAP to elaborate this program, its formulation is based on the consultation of the productive, public, and academic sectors and the review of the Federal government (Programa de Pesca y Acuacultura 1995-2000). The Program recognizes various challenges and priorities that are to guide the efforts of the SEMARNAP to "maximize fishing in a sustainable manner". Among the most important are the following:

1) Surpass the evident lags in scientific and technological research regarding the knowledge of the abundance and availability of marine and fresh water resources, as well as of productive processes.
2) Develop adequate systems of territorial organization.
3) Design adequate financial schemes and increase support to the sector through credits.
4) Attract national and foreign investment.
5) Assure full compliment of the Law and the regulatory framework.
6) Increase national consumption of fishery products.
7) Strengthen management influence of the SEMARNAP at a local level and coordinate actions with state and municipal authorities.

Two things can be concluded from all the objectives I have presented. Mexico's political agenda clearly calls for maximizing fishery production in a sustainable manner and it strives in writing to decentralize its natural resource management responsibilities. There is an inherent irony, however, in trying to maximize production and wanting this maximization to be sustainable. First, there are many ways one could define sustainability. Second, as a practical matter, the degree of accuracy and the completeness of knowledge required for prediction are far beyond any capabilities we might expect to achieve in a fisheries environment (Wilson et al. 1994). Even with decades of experience with stock recruitment models based on the central tenant of maximum sustainable yield (MSY), fishery resources have tended to be overexploited and, in some cases, collapse (e.g. California sardine fishery, cod fishery in the Grand Banks).

Wilson et al. (1994) state that we are fortunate if we can assess stocks to within 30 to 50% of their actual value and we tend to verge on almost complete ignorance of the numerical attributes of the interrelationships among species within an ecosystem. This makes long-term predictions and control of species abundance practically impossible by relying on a numerical approach and pushing fisheries to a theoretical MSY.

Managing fisheries under policies of sustainable maximization is especially complicated with small-scale fisheries, as an adequate registration of total catches is usually lacking and the fishing activities are extremely dynamic and volatile.

Regarding decentralization, there are clear examples of SEMARNAP's political will to delegate more responsibilities at the local level. For instance, before Julia Carabias Lillo, Secretary of SEMARNAP, took office in 1994, Mexico's protected natural areas had almost no employees, equipment, or budget. One of Carabias' main objectives during her administration has been to solidify the national park system in Mexico for it to have more continuity despite the political and administration changes that will most likely arise after President Zedillo's administration terminates in December 2000. Thirty-six of Mexico's most important protected areas are better staffed and equipped with operating essentials such as vehicles, boats, radios and computers than in previous years (O'Brien 2000). Until recently, the personnel of protected areas, including the directors, were hired under temporary contracts. This led to a rapid turnover of personnel, instabilities in the protected areas, and often employment of unqualified people as not many would venture working for a protected area with such employment uncertainties. Today, personnel of the 38 priority reserves in Mexico are hired as base personnel, assuring a competitive salary and continuity of the management structure in the advent of centralized political changes (personal communication José Campoy, Director Upper Gulf of California and Colorado River Delta Biosphere Reserve, February 2000). Among other decentralization actions taken by SEMARNAP are the following:

- The signing of 13 coordination agreements with different states for the use and administration of the *Zona Federal Marítimo Terrestre ZOFEMAT* (Maritime and Terrestrial Federal Zone).
- Creation of 9 State Committees for the Sustainable Use of the ZOFEMAT and 101 Technical Municipal Subcommittees.
- 11 State Committees of Fisheries and Marine Resources.
- Transferring the administration of 24 protected areas to 13 states.
- 408 committees and subcommittees for the inspection, surveillance, and verification of natural resources (forestry, fisheries, marine and fresh water flora and fauna) in most of the federal entities.

(Excerpts from "Estrategia de Descentralización de la Gestión Ambiental en México", CGD web page January 2000).

Although there are still major gaps between the actions taken by the government and the reality in practice of how such actions are working or how they are assimilated and truly fostered at a local level, the political will for some form of decentralization and for sharing management responsibilities is evident. However, it is hard, if not impossible, to say if this decentralization process will continue during the next presidential administration. It is also evident that the government would never delegate full management responsibilities to the local level. As stated in a 1996 speech by Julia Carabias to the United Nations:

> "*No debe atropellarse la normatividad por la vía de un relajamiento de las disposiciones locales respecto a las nacionales, y tampoco permitirse que la reglamentación local se multiplique a grado tal que se convierta en un obstáculo para las actividades económicas" /* National regulations should not be trampled by striving to relax local vs. national dispositions, and we should also never allow local regulations to multiply to such a degree that they become an obstacle for national economic activities" (Carabias 1996).

Legal Framework

The law governing natural resource management in Mexico is complex, with a vast array of laws overlapping each other. The Mexican Constitution is, of course, the supreme law regulating human rights and the organization of the State. All legislation concerning the utilization of natural resources is based primarily on the premises established in article 27 of the Constitution, which states, among other things:

> *El dominio de la Nación sobre sus recursos naturales es inalienable y la explotación, el uso, o el aprovechamiento de los recursos que se trata, por los particulares o por sociedades constituídas conforme a las leyes mexicanas, no podrá realizarse sino mediante concesiones de acuerdo con las reglas y condiciones que establezcan las leyes /* The Nation's dominion over its natural resources is inalienable, and the exploitation or

use of these resources, by individuals or by associations constituted according to the Mexican laws, will only take place through concessions according to the rules and conditions established by the laws (Constitución Política de los Estados Unidos Mexicanos 1995).

However, the most important legal document directed towards specifically managing and regulating the use of natural resources in Mexico is the *Ley General de Equilibrio Ecológico y Protección al Ambiente, LGEEPA* (General Law of Ecological Balance and Environmental Protection). This law, revised in 1996, is "obligatory of the Mexican Constitution's dispositions regarding preservation and restoration of the ecological balance, as well as environmental protection in national territory and the zones on which the nation exerts its sovereignty and jurisdiction" (LGEEPA 1996). Since this law deals with all of Mexico's natural resources, it does not address fishery issues in detail. However, it sets the ethical tone to which fisheries and any other resource extraction activity should comply.

Specifically regarding fisheries, the Mexican Government formulated the *Ley de Pesca* (Fisheries Law), with the objective to "guarantee the conservation, preservation, and rational use of fishery resources and to establish the basis for their adequate promotion and administration" (Ley de Pesca y su Reglamento 1999). This law states the rules governing fisheries and aquaculture in Mexico and the sanctions that are to be imposed to infractors. However, there is an evident lack of definition and clarity of many of the concepts that appear in the Law and its regulations, as well as omission of some definitions necessary to make the scope of application of the Law more precise. In practice, there is an inadequate interpretation of some concepts contained in the Law due to their vague definition, which generates confusion among resource users and administrators. For instance, the Law does not establish clearly the requisites necessary to renew concessions or permits, therefore local authority actions are lacking in basis and motivation on which to demand documents that are simply not provided in the Law.

There is also a real gap between written Federal laws and their applications at a local level. Not only do local officials have difficulty in trying to determine how to interpret national laws (personal communication José Campoy, Director Upper Gulf of California and Colorado River Delta Biosphere Reserve), but there are also numerous arrangements between local users and officials that overturn or ignore national laws.

The most specific type of legislation concerning fishery management is that published as *Normas* (Norms) in the *Diario Oficial de la Federación, DOF* (The Federation's Official Diary). Fishery Norms specifically dictate management regulations usually at a species-specific level. The bureaucratic process to publish a Norm is lengthy and difficult (personal communication Raúl Molina, CRIP-Guaymas, February 2000), which probably is the reason why there are only 18 fishery Norms currently in force (Propuesta del Nuevo Reglamento de la Ley de Pesca 1999). Most of these Norms deal with Mexico's politically sensitive and economically most important fisheries (e.g. shrimp, tuna, sardine, abalone, lobster, totoaba). Interestingly, almost half of the country's fishery Norms deal with diving and benthic fisheries (other than shrimp). These are the following:

1) Norm to regulate harvesting of Pacific calico scallops in Baja California and Baja California Sur (Diario Oficial de la Federación (DOF), December 21 1993).
2) Norm to regulate harvesting of the populations of different species of abalone in the Baja California Peninsula (DOF, December 21 1993).
3) Norm to regulate harvesting of all lobster species in the Gulf of Mexico, Caribbean, and the Pacific, including the Gulf of California (DOF December 31 1993).
4) Norm to regulate harvesting of red urchin in the west coast of Baja California (DOF December 21 1993).
5) Norm to organize harvesting of octopus species in the Gulf of Mexico and the Caribbean (DOF December 21 1993).
6) Norm to regulate harvesting of snail species in Campeche, Quintana Roo, and Yucatán (DOF April 21 1995).
7) Norm to regulate the extraction of oyster banks in Tabasco (DOF April 24 1995).

Of these, however, none apply directly to diving fisheries in the NG. Only the lobster Norm applies to the state of Sonora, but fishers in the NG do not harvest lobster. The norm for calico clams is the only one applying to a resource used by divers in the NG, but its regulations are specific to Baja California.

Other than fishery Norms, Norm # 059 dictates the species and subspecies of flora and fauna considered as rare, threatened, endangered, and under special protection (DOF May 16 1994). Rock scallop (*Spondylus calcifer*), Mazatlán pearl oyster (*Pinctada mazatlanica*) and the Western wing oyster (*Pteria sterna*) are under the category of special protection, and the giant sea cucumber (*Isostichopus fuscus*) is listed as endangered. However, rock scallop is the most important resource for divers and the other three are occasionally targeted as well. Both oysters can be sold in the form of *callo* mixed with other bivalves (rock scallop, pen shells), and some divers feel that harvesting sea cucumber is worth taking the risk as it brings a good price. Sea cucumber harvesting resulted in a complete confiscation of equipment and permits for one diver in 1998. There is much controversy among the scientific community as to the status of different species included in this Norm, especially since information is lacking on area- specific abundance of species. There is a particular interest to revise the status of sea cucumber, as many don't believe it should be listed as endangered (personal communication Gabriela Montemayor, CRIP Guaymas, January 2000). Regarding rock scallop, the Norm does not specify the type of management it is subject to, and divers certainly do not know that it is listed under this status, let alone what this status means. Species under this status may be harvested under strict control measures. This allows extending permits and/or renewal of those already existing but it also allows the establishment of administrative season closures or any other measure geared towards conserving the resource (personal communication Raúl Molina, CRIP-Guaymas, February 2000). Norm # 059 is currently under revision.

In addition to these laws, fishery activities must comply with the statutes of the Biosphere Reserve's Management Program. To date, however, fishery regulations on the Buffer Zone of the Reserve are lacking, and none apply to diving fisheries. Most of the regulations have focused on the Nucleus Zone and the shrimp fishing industry. Diving activities that fall within the area of the Reserve are all in the Buffer Zone, in an area managed under the politics of *protección con uso activo* (zone of protection with active use). Only small-scale fishing activities are permitted in this area (trawling prohibited), as long as they comply with terms established by the SEMARNAP (Programa de Manejo Reserva de la Biosfera Alto Golfo de California y Delta del Río Colorado 1995). However, this area will most likely have more specific regulations in the future. The Management Program states that a long-term strategy for this area (5 years and more) is to evaluate the impact of small-scale fisheries, implement technological innovations in fishing gear, and elaborate specific management programs for fishery resources harvested (Programa de Manejo Reserva de la Biosfera Alto Golfo de California y Delta del Río Colorado 1995).

Finally, since divers often make use of San Jorge island, as a camp site as well as to harvest the resources surrounding the island, they must comply with the regulations established for the Islands of the Gulf of California Reserve. Most islands in the Gulf of California form part of an archipelago reserve for which a management program was recently formulated. At present, management of the islands only covers its terrestrial component but there is increasing interest to include their marine component as well (personal communication Ana Luisa Figueroa, Director Gulf of California Islands Reserve for Sonora region). Any person visiting the islands needs a special permit from SEMARNAP to disembark (Conservation International 1996). San Jorge Island is one of the northern most sea lion rookeries in the Gulf of California, and snail harvesting activities overlap with the breeding season of sea lions. Divers, being the heaviest users of the island (other than tourism), will surely have to be included as an important component of any management regime for the island.

Community Management

As mentioned in the previous two sections of this chapter, currently the government's control of diving fisheries in Peñasco mainly relies on trying to control access to the fisheries through the issuing of permits and establishing sanctions when harvesting prohibited species such as sea cucumber. However, as will be seen in the following chapter, there are different arrangements done at a community level that can undermine the government's guidelines, especially regarding controlling who fishes.

Most management, however successful, informal or unplanned it may be, actually takes place at a community level in response to the life history and behavior of the species, fluctuations in production, territoriality, and, most of all, in response to environmental fluctuations (discussed in the following section).

Life History and Behavior of Species

Divers rotate the use of rock scallop beds in response to environmental changes (winds, currents) but also in response to the size of the scallops and their availability. Most divers assert that it takes one year for rock scallops to grow to an adequate commercial size. Knowing this, they deliberately interrupt fishing for most of a year in areas where it has become too costly to search for these scallops, as they are small, hard to find, and do not bring much income.

Regarding snail, some divers actually practice a form of "re-stocking" by gathering some snails of their catch (~ 30-50) and throwing them back to the sea in other areas they believe are quality habitat for the snails. This is done in areas where there is currently not much diving activity in the hopes that in the future, with what they essentially see as a high reproductive output of the species, they will have more snails to harvest. Some divers also leave a similar amount of snails intact when they find a large aggregation, thinking that again, with a high reproductive output, they might help replenish what was harvested. It is important to clarify, however, that no diver believes these actions with snail will solve their problems. Rather, they simply experiment with these actions to see if they work.

Production

Again, divers use their knowledge of rock scallop when production in specific areas has become low, interrupting fishing for some time until scallops are of an adequate size. They refer to this as *dejar al producto descansar* (letting the product rest).

With snail, low production may interrupt fishing activity for a season or more, especially in areas that are far away like El Borrascoso or San Jorge Island. Divers state that during the 1997 season El Borrascoso was practically never used because of its low production, and most divers also decided not to use that area the following year, concentrating fishing effort more than ever in La Cholla. In 1999 they returned to El Borrascoso and claimed that production was definitely higher because of those two years of interrupted fishing.

Territoriality

There are several examples of territorial control within the community. In 1999, a local buyer brought several divers from San Carlos, Baja California, to harvest Pacific calico clams. Divers from Baja California have much experience harvesting scallop as this resource has constituted a major fishery for them for several years. Peñasco divers were asked to lead Baja divers towards scallop beds but, of course, they never did. Baja divers tried fishing in different areas but eventually gave up and returned to Baja. They were not fishing in quality areas because of a lack of knowledge, they felt pressure from local divers, and they could not cope efficiently with the peculiar tidal currents and visibility of the region.

Territoriality takes place within Peñasco's diving sector as well, especially between traditional and seasonal divers during snail season. There is an informal "rule" of not harvesting a snail aggregation if another diver has found it first. Some divers will even "claim" an aggregation by surrounding it with snail bags. However, if another diver arrives, this will usually result in some form of confrontation. The first diver may take the mask off of the "intruder", forcing him to reach the surface. Some divers go to more extreme measures, interrupting the air passage of the intruder by temporarily tying a knot in his hose until the diver has to surface. Confrontations may even take place under water. Most of the time, however, confrontations do not go beyond discussing the issue on the surface or in port. The gossip soon spreads to all divers, and there is possibly no worse punishment for a diver than knowing everybody else knows he took advantage of someone else's catch. These territorial problems will vary according to the size of the aggregations. Very large aggregations, capable of filling more than one *panga*, will usually not represent a problem, whereas medium and small aggregations usually will.

Divers mention that in years past there never used to be an issue of who had the rights to a snail aggregation. Everyone seemed to share the catch. As it has become increasingly harder to find large aggregations, however, territorial conflicts have increased.

Nature's Role in Management

Possibly the most important factor affecting the way divers fish in the region is nature itself. Water current and visibility are the two main factors that define fishing patterns and methods. For instance, which days and where to fish, how much time is employed in a fishing day, how many divers fish, and if fishing is carried out walking or swimming are all determined primarily by natural conditions. Since current and visibility are highly fluctuating in the NG, hookah diving is very dynamic both in space and time, and the efficiency as well as success of a diver depends on his ability to deal with such fluctuations.

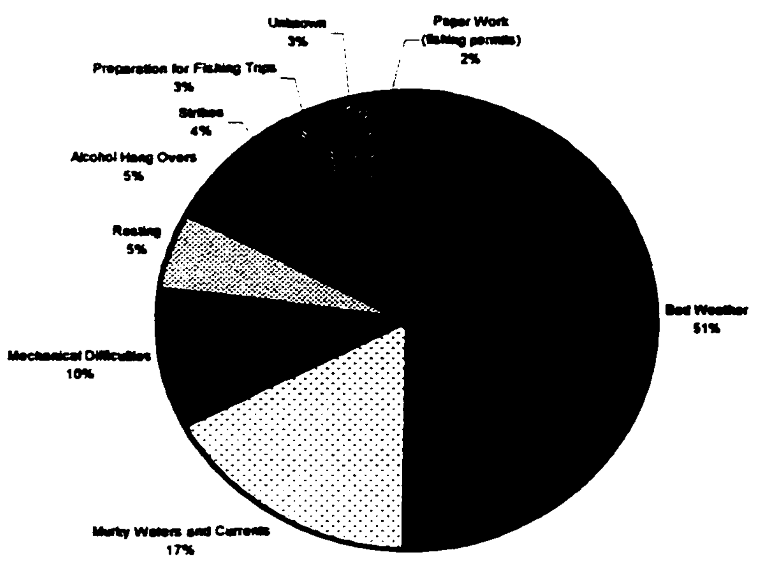
Fishermen did not harvest any snail 11 of the 38 days in which I registered fishing effort. On 9 of the remaining 27 days, only one or two *pangas* fished on these days, the other divers were either harvesting a different resource or did not fish at all. The main factors that interrupted fishing activity or caused a decrease in effort were wind and currents; the later defined by tidal fluctuations throughout the month. Strong winds usually made fishing impossible, whereas spring tides tended to increase the harvest of clams and scallops, reduce fishing effort for snail, and concentrate this effort in areas where currents were not as strong (e.g. Los Tanques, Las Conchas, and Peñasco).

Based on the diary kept by an experienced and respected diver from 1998 to the present, it can be said that ~ 50% of the year an active diver does not fish at all. From August 9, 1998 to August 8, 1999, he and his partners fished only 176 days. Figure 14 shows the reasons why this diver did not fish. Sixty eight percent of these non-fishing days were attributed to nature: 51% bad weather (mainly wind) and 17% murky water and strong tidal currents.

Strong tidal currents limit divers' activities from La Cholla to El Borrascoso, forcing them to shift their activities south of La Cholla. Sometimes, even if divers have found a large aggregation, they are forced to return to port as soon as the tide changes. The following day they will try to time their activities to find the aggregation again between the ebb and flow of the tide.

During the summer, most divers do not harvest rock scallop from La Cholla to El Borrascoso because strong south winds, particularly during July, reduce the visibility in that area. Also, proliferation of algae during the summer limits the search for *callo* overall as the algae covers the *tepetates* and *callo* is harder to find.

Figure 14. Reasons why a hookah diver from Puerto Peñasco, Sonora, Mexico interrupted fishing activities in a year, August 1, 1998 - July 31, 1999 (189 days of no fishing activity).



Chapter 5
Problems and Challenges for the Successful Management and Conservation of Benthic Resources

In this chapter, I discuss some of the issues I considered to be the main problems of hookah diving in the northern Gulf. I also discuss the challenges to the successful management and conservation of black murex in particular and benthic diving fisheries in general. I expand on this last point in Chapter 6 as I give and analysis of management possibilities and recommendations.

Fishing Season and Methods

Black murex is harvested throughout its reproductive period, and results indicate that the vast majority of egg capsules are not being allowed to hatch (Table 6). This, in combination with the fact that the species is harvested at its most vulnerable stage, that is when large numbers of the population are aggregated and exposed to be easily harvested, certainly is of concern for the health and survival of commercial stocks. Also of concern is the impact that fishing may be having on the adult population of snails, as adults are the only ones harvested.

The fishing method of walking on the bottom until finding an aggregation may represent a problem as well, as this could potentially affect habitat for settlement of snail larvae and therefore juvenile stages of the organisms. Recent studies on settlement and post settlement stages of the Caribbean conch snail indicate that these are critical stages affecting the number of individuals that survive to represent juvenile recruitment (Stoner et al. 1998). Similarly, recent research regarding settlement and survival of calico scallop larvae in the southern Gulf of California suggest that one of the most immediate threats to its fishery is habitat alteration by divers when walking on top of calcareous algae beds. These beds are considered to be critical habitat for settlement and survival of the juvenile stages of the scallop (personal communication, Diana Steller, PhD candidate from the University of California-Santa Cruz, February 2000).

Health of Fishing Stocks

There is evidence to conclude that the commercial stocks of snails have been reduced since 1992 when the fishery began in an intense manner. The CPUE for June-July 1992, based on data from the only other existent methodical analysis of the fishery (López-Reyes 1992) was 760.5 kg/panga/day. This is considerably higher compared to the CPUE I estimated for the same time period in 1999 (535.4 kg/panga/day). In addition, overall production for the 1999 season was significantly lower than in 1992. Also, the number of fishing trips conducted in 1992 (211 trips) was higher than in 1999 (139 trips), and fishers mention it has been increasingly harder to find breeding aggregations. When I asked buyers if this low production was related more to a decrease in the demand for snail than a decrease in the number of harvestable snails, they stated that the demand is there, even more than in past years, but there simply is not enough product to meet that demand.

The fact that fishers are increasingly using new fishing areas and fishing activities have shifted to deeper waters could be an indication that the number and size of aggregations found close to shore has diminished. The large production of 1992 was obtained only from snail aggregations found close to shore in the area of La Cholla, whereas in 1999 the low production had to be obtained from 9 distinct fishing zones.

Quinn et al. (1993) state that some invertebrate species may recruit more successfully in the presence of adults. Karlson and Levitan (1990) suggest that marine invertebrate populations can be particularly susceptible to sudden collapse when gradually increasing habitat destruction or fishing pressure drop populations below the densities necessary for adequate recruitment.

Fishing Zones

Most of the harvest for snail is carried out in La Cholla, which is the most productive area. La Cholla could be acting as a major source point for dispersal and recruitment of black murex in adjacent zones, therefore heavy harvest in La Cholla could be inflicting considerable pressure over the population or sub-populations of black murex in the region. On a grander scale, it appears that the massive aggregations of black murex found in the northern Gulf are not present in other regions of the Gulf of California, as the abundance of this species is replaced by an abundance of pink murex in the central and southern regions of the Gulf. Divers in Bahía de Kino, for instance, assert that although black murex is found in their region, aggregations are very small and therefore harvesting this species is not profitable (personal communication, Hudson Weaver, researcher in Bahía de Kino, University of Washington, January 2000). Similarly, divers from Peñasco with experience in other regions of the Gulf state that the aggregations in the NG are unique. This is supported by the fact that practically all production of black murex in the Gulf of California comes from the NG. Fishing activities therefore could be impacting the species in a region critical for its abundance.

Availability of Biological and Ecological Knowledge

Other than the results I present in this thesis, biological and ecological knowledge of black murex is lacking. Although numerous studies have been conducted with other muricid snails, applying this knowledge to this species represents considerable risk. Of particular importance for management is to analyze larvae settlement and post-settlement processes, movement patterns of juvenile and adult stages, and growth rates. Biological and ecological information is also lacking for most other resources harvested by hookah divers.

Coping With Sedentary and Semi-sedentary Species

The control of benthic resources harvested by hookah divers is a special case in fishery management because of the uniqueness of the fishing activity and the sedentary or semi-sedentary nature of most species harvested. The fact that at least during reproduction snails are more tangibly defined within a geographical area than other resources (e.g. most fin fish) may facilitate monitoring and assessment of basic population parameters and the spatial distribution of the fishing activities. It can also lead to well-defined zoning as a means to control access to exploitable stocks or for the establishment of marine reserves. It would appear then that resources with restricted movements might be somewhat easier to manage. This principle applies to most other resources harvested by divers. However, the same characteristics that can facilitate management can also complicate it. These benthic resources have little or limited mobility and this allows fishers to easily target exploitable stocks on numerous occasions. Obviously, this rapid exploitation may lead to over exploitation. For these same reasons, diving fisheries, contrary to other fisheries, can potentially inflict considerable pressure on the resources exploited without necessarily having a large number of divers participating in the fishery. Without adequate regulations and enforcement concerning access to commercial stocks, the complications rather than the benefits of coping with sedentary resources are most likely to take place, as fishers will strive to maximize production with the least amount of effort possible.

Open Access and Territoriality

Since Garret Hardin popularized "the tragedy of the commons" 30 years ago, his ideas about common property regimes have become the most widely accepted explanation for overexploitation of commonly held resources (Feeny et al. 1990). Hardin's theory stated that any resource held in common is subject to degradation… "freedom in a commons brings ruin to all" (Hardin 1968). To avoid the "tragedy" of overexploitation of these resources, Hardin concluded that they had to be privatized or controlled by the government (Hardin 1968). However, the tragedy of the commons theory fails to distinguish between common property and open access, and does not take into account the self-regulating capability of users (McCay and Acheson 1987).

Although access to the snail fishery is regulated through the renewal of previously issued permits and the suspension of new permits, the reality is that anyone with access to diving equipment may potentially harvest snail. *Pescadores libres* (free fishermen) without permits may arrange to be temporarily endorsed by cooperatives with legal standing and therefore capable of obtaining permits. In addition, they may simply fish without permits since enforcement is limited. Fishing permits are given to cooperatives based on the number of cooperative members. A cooperative must be comprised of a minimum of 5 members, and the cooperative may have one *panga* for every two members (e.g. a cooperative with 10 members can only have 5 *pangas*). One permit with original copies is then given to the cooperative, which in essence specifies the name of the cooperative, the species allowed to fish, the number of *pangas* the permit may be used for, and the permit's expiration. Since permits are not given to individual *pangas* or to individual members, this allows much flexibility to endorse any person to fish with the cooperative's *pangas* or with their own. Although risky, fishers may also photocopy the permits with the cooperative's consent and say they work for that particular cooperative. Since to be able to give a receipt and commercialize your product you need to have a permit, cooperatives and/or owners of numerous *pangas* benefit from this illegal process by charging free fishers an arranged amount for every kilogram they produce in exchange for facilitating their endorsement. This practice also gives way to powerful control of cooperatives and owners of *pangas* over the livelihoods of free fishermen, as well as manipulation of government officials.

In essence, then, the fishery is open to all. This gives rise to territorial and access conflicts between traditional and seasonal divers, as the former feel that they should have exclusive rights to the resource since, contrary to seasonal divers, they depend on diving resources on a year-round basis. They also claim that historically they have been harvesting snail and other benthic resources longer than seasonal divers, which should grant them rights to the fishery. However, although divers strive for this exclusivity, there is also some camaraderie involved between traditional and seasonal divers. After all, they all form part of the same fishing community of Puerto Peñasco. To a certain extent, this complicates any effort to limit access to the fishery.

Territorial conflicts within the community may also arise in the future with the calico scallop fishery as it becomes of increasing importance to the divers. This resource is easily accessible to any diver regardless of his expertise, and eventual divers may begin harvesting this resource regularly as well during the summer. When I was conducting fieldwork in summer 1999, this was the case. However, all other resources harvested by traditional divers (e.g., rock scallops, pen shells, octopus, etc.) will most likely remain exclusive for traditional divers. They demand more diving skills and are usually harvested at times when seasonal divers are engaged in other fishing activities (gill netting, long lining, or crab fishing with traps).

One ideal situation for diving fisheries of Peñasco is that there are practically no territorial conflicts with other communities. Divers from other communities usually will not harvest on Peñasco's traditional fishing grounds. This is partly due to the peculiar conditions for diving that are present in the NG, such as rapidly changing patterns of visibility and current intensity. Also, contrary to practically all other fisheries in the region, there are no significant conflicts between the hookah diving sector and the industrial offshore trawling sector. In fact, boat owners have hired some divers to help fix or give maintenance to the bottom of their boats or their propellers. The activities of both sectors usually do not overlap since they are harvesting from different fishing grounds and targeting different species (except calico clams). However, this is not to say that trawling activities don't affect recruitment of species targeted by divers, particularly black and pink murex. Although apparently not common, murex form part of the shrimp trawling bycatch (Nava 1995). In fact, divers' interest to venture northward to harvest snail the following season arose from "tips" of boat crewmen stating that large quantities of snail have been caught in their nets when trawling in the area. Future studies regarding snail movement patterns and larvae dispersal, as well as quantity of snails caught as bycatch would have to be implemented in order to answer this question more conclusively.

Conflicts between the trawling sector an the divers with regards to the calico scallop fishery may arise in the future, as it is a major component of shrimp trawling bycatch and is sold as such in large quantities to Peñasco buyers. There is such a demand for this species that fishers mention trawler boats are even targeting scallop beds from El Desemboque to Peñasco when shrimp production is low. Although the scallop fishing areas of trawlers and divers apparently don't overlap, the problem resides more in differences in the timing of fishing activities, quantity of scallops harvested by both sectors, and the prices at which they are sold. As mentioned in Chapter 1, divers cannot compete with the production and low price of scallops harvested by trawlers, therefore are constrained to harvest them from May to September, during the shrimp *veda* (season closure). During these months, since divers are the only source to obtain scallops from and production is much smaller, the price goes up. Nevertheless, this price is still very low compared to that paid for rock scallop ($30.00 vs. $90.00 pesos/kg of muscle). In essence, the price at which scallops are bought from trawler boats will set the tone for the price which will be paid to divers.

Other Sources of Cash Income

Traditional divers and their families depend almost entirely on diving for benthic resources and reef fish throughout the year. Although some may participate in other fishing activities at any given time (e.g., gill netting for corvinas and stingrays, trap fishing for blue crab), this neither lasts long nor renders sufficient profits to the divers. These other fishing activities demand very different fishing skills that the majority of divers simply have not developed. They also require different work paces to which divers are not accustomed. As put by a buyer who has divers working for him: "Once I stopped buying snail, I tried to help some of my people by giving them traps. They simply were not producing anything. They were desperate, so I told them I would receive anything they brought by diving. You see, it is important to keep them busy working. If not, I get in trouble, as I am put in a position were I have to lend them money and it is easy for them to accumulate a debt. Divers are divers, that's all there is to it. They like to know that they will go in the water early in the morning and finish their work day in the afternoon."

Puerto Peñasco, as it has grown into a larger and more cosmopolitan community, does offer other working alternatives to fishing. However, the type of job that a diver would work in is very limited and the decision to switch to another job would only take place during low production or crisis periods. For instance, prior to the beginning of the snail season in 1999, a diver and his family set up a temporary food stand during a month-long street fair. Another rare example of a diver switching professions is one diver who had his *panga* and equipment confiscated by PROFEPA for harvesting sea cucumber. This fisher opted to stop diving permanently and become a construction worker.

As for other options of cash flow during the snail season, divers also rely on large Dunker's dosinia clams and calico scallops, the latter becoming of increasing importance since divers began to harvest it in 1997. It is possible that these clams will also become increasingly targeted. Local buyers assured me that, for the first time, there were buyers from southern Mexico, particularly from the state of Guerrero, interested in buying large quantities of these large clams. Traditionally, production of clams had been restricted to the local market and for subsistence purposes.

Finally, participation in illegal activities such as turtle poaching, sea cucumber harvest, and narcotraffic may occasionally represent other sources of cash flow for some fishermen.

Demand and Fishing Pressure

Outside demand for fishing products has a major influence over the patterns and quantities of harvest. If there is an existing demand for a certain product and the channels to commercialize it are open, the product will most certainly be harvested, regardless of the state of the resource. This is, of course, if no forms of regulations have been established either by the community, government, or both. But even with regulations in place, strong demand may undermine any regulatory effort. The short-run economic benefits that this brings can surpass any management effort, especially when there are not sufficient human or financial resources to enforce regulatory guidelines.

Not only does demand provoke an incentive for fishers, but fishers also feel pressured by buyers to keep up with their demand. This is especially true when a fisher works for a specific buyer, is given financial credit by the buyer, or when there is a historical bond between the buyer and fisher. In order to export or sell the product outside of Peñasco, a buyer needs to produce a certain amount on a daily basis. Divers working for or getting credit from buyers are commonly told not to return from fishing until they have reached or surpassed a specified production.

However, as mentioned in Chapter 4, buyers will also play a key role in diminishing or interrupting fishing effort. Snail harvesting exemplifies this issue, as production increased once the main buyer was ready to receive product, but was practically stopped on July 12 when he switched to buy blue crab, as it rendered considerably more profits.

Chapter 6
Management Possibilities

Following I give an analysis of management possibilities for the black murex fishery in particular and hookah diving fisheries in general. I begin by analyzing the proposals and opinions given by fishermen and end with my final management recommendations. These are based on fishermen's input and on an understanding of the objectives covered in this thesis.

Season Closures

Season closures, or *vedas*, are the most prevalent ideas among divers to better manage the fishery. Fishermen are used to being exposed to *vedas*, as they have traditionally been one of the most common fishery management measures used in Mexico. It is not surprising, then, that this is their main management proposal. However, what was surprising to me was the intensity to which the divers were willing to establish some form of season closure and the irony of this measure considering that the snails are fished only during reproductive season.

Not all divers agreed as to what type of season closure they would like to see established. Overall, there were two different proposals, both of them highly contested among the fishers:

1) Total season closures (2 years)

   Some divers feel and advocate that the only way to assure that the fishery will recuperate to the way it was during its beginnings in 1992 would be by having a total closure for two years. These fishers believe any other measure would be too risky as enforcement is complicated and there are still uncertainties regarding the biology and population dynamics of the species.

2) Temporal season closures

Other divers mention that the best and most realistic management measure would be to only permit fishing during August, closing off May-July.

Season closures can be an excellent way to protect vulnerable stocks, as they are fairly easy to implement and enforce, being straightforward and perceived as applying more or less equally to all producers in a fishery (McGoodwin 1990). However, if management measures only rely on a season closure, other problems may arise as fishers will try to maximize production at all cost once the season opens. This may lead to an overcapacity of the fishery, resulting in increasingly shorter fishing seasons and disrupted fish markets because of severe discontinuities in supply (McGoodwin 1990). The quality of the product may also fall because of the intense measures employed to maximize production (Beddington and Rettig 1984). For instance, during the 24 hour openings for the Pacific Halibut fishery, up to 50% of the catch has been reported to be delivered after never being on ice and 30% not even gutted (Wilen 1988).

From a conservation standpoint, of course having a total closure of the murex fishery would probably be the best way to promote its recovery. However, this would be useless if not counter productive if the season reopens in the future with no regulations, as the exact same story would be relived. It would also most likely put a considerable strain either on other resources, the economy of fishers, or both during the closure. After rock scallop and octopus, snails are the most important resource for divers in terms of their cash income options. If fishers are not to be affected economically, they would need to harvest other resources during the summer. These resources would most likely be calico scallops, clams, or blue crab. Fishers stated that if they established a total season closure, then the government should facilitate their access to permits for the crab fishery. However, as mentioned in the previous chapter, it seems unlikely that divers would excel at first in this fishery. This fishery has also become highly monopolized by large cooperatives and people with strong political standing and therefore able to control and negotiate the issuing of permits. As there is considerable competition among fishers to be able to participate in this fishery, the chances of divers legally participating in it in the future appear to be slim.

Most of the issues discussed above also apply to the idea of constricting the fishery to the month of August. Only fishing during this month, however, would disrupt the market and would most likely represent a challenge for divers to sell their product. At least during the 1999 season, beginning in mid July the main buyer was focusing most of his efforts in the purchase of blue crab. Divers had to sell their catch to other smaller buyers who usually offer a lower price. These small buyers also often become quickly saturated with product as they do not have the infrastructure to process it or sell it quickly. This inevitably results in either product gone to waste, the selling of low-quality snail, or an interruption of fishing activities.

From an ecological standpoint, there is practically no way of saying how much time snails should be allowed to reproduce in order to support a sustainable fishery.

Furthermore, it cannot be assured that controlling fishing activities in relation to the reproduction stages of the species would solve the problem. There are many factors (e.g., larvae dispersal, post settlement processes, habitat alteration, natural mortality) that affect survival and therefore recruitment. However, it cannot be denied that fishing during the peak reproductive stage of the species may affect, possibly more than anything else, recruitment to exploitable stocks. It is this uncertainty which should guide the formulation of future management guidelines.

As a final note on fishing seasons, for them to be respected, the fishing sector has to be involved in their design and implementation, convinced that they are set at the right time and in their best interests. They also need to have proof that their efforts are actually giving positive and rapid results. This would require monitoring not only future production and fishing activities, but other parameters as well such as abundance of juvenile snails and recruitment to exploitable stocks. As mentioned in Chapter 3, information is lacking regarding age and growth of black murex. Fishers would have to actively be involved in this monitoring process to truly believe in the results, positive or negative.

Limiting Entry and Establishing Property Rights

As mentioned in the previous chapter, although access to the snail fishery is intended to be controlled through the issuing of permits, the reality is that it is open for all. Traditional divers, of course, propose that they should be given exclusive fishing rights to the fishery. They state that this measure would not cause much negative social or economic impact with the argument that seasonal divers can rely on other fishing activities, while traditional divers would have more difficulty finding alternatives to diving for snail during the summer. However, if this is a proposal reaching consensus among traditional divers, this certainly is not the case for eventual divers. They state that "*el mar es de todos*", nobody owns the ocean, it is open for all to harvest it. This feeling is repeated throughout the world's fisheries, but particularly in Mexico it is deeply rooted in the social ideologies of the Mexican Revolution. Seasonal divers also claim that they have as much access rights as traditional divers since most of them, although intermittently, have been harvesting snail since the fishery formally began on a massive scale in 1992 (traditional divers had been harvesting snail on a small scale prior to 1992).

Assuming that open access, not necessarily common property, is the root of many of the problems underlying the world's fisheries, different measures of access control have made headway in fishery management practices (see Wilen 1988, Christie et al. 1994, Siar et al. 1992, Smith and Berkes 1991, Lauck et al. 1998). Limiting entry to a fishery is probably the single-most effective strategy to try to bring fishing effort under direct control (McGoodwin 1990). Limited entry strategies emerged in the late 1960's as a result of the drastic overharvest of many of the world's most important fisheries caused by large fleets of domestic and foreign vessels that fished the waters adjacent to coastal nations. After the institutional structure for marine resource management was suddenly radically altered as coastal nations claimed an Exclusive Economic Zone jurisdiction of 200 miles, the scenario was open to test new or recent fishery management options, such as limited entry licensing (Wilen 1988). However, economic assessments of limiting entry efforts in the past 20-30 years have shown that single limited entry licensing alone is not very effective in freezing the problem of overcapacity of the fisheries (Wilen 1988). Increases in the size and effectiveness of vessels and gear or intensified effort by fishers can still move the fishery towards overcapacity and depletion (McGoodwin 1990). To this extent, however, hookah diving fisheries have the "advantage" of being restrained to the amount of time a diver can remain under water and to the fact that all harvest must be carried out through manual labor. Thus, within the snail fishery, effort per *panga* would unlikely increase regardless of the amount of divers participating in the fishery as effort appears to be pushed to the limits already.

As one would expect, limiting entry proposals will most likely always have opposition among fishers or even buyers. In fisheries already nearing overcapacity, the mere threat of limiting entry may give way to greater excesses of fishing effort (McGoodwin 1990). Closed areas and seasons, gear restrictions, and total allowable catches (TACs) tend to be more politically acceptable as they at least appear to apply to everyone equally, discriminating against no one (Bell 1978).

Limiting access by transferring or establishing property rights, however, can be an effective way of shifting part or much of the centralized management responsibility downward to those holding the rights to a fishery. Accumulating experience shows that many fisheries with established property rights regimes appear to be more sustainable (see Acheson 1987, McGoodwin 1990). In many cases, fishers who enjoy property rights are not forced to compete so intensely, usually maintaining their fishing effort at levels that afford them reasonable profits and sustained yields (Bell 1978).

I believe the main issues regarding transferring property rights and limiting access to a fishery involve the questions of how do you define who or what sector is more entitled to those rights and what are the inevitable social consequences that far reaching decisions like these may bring in the future. For instance, granting exclusivity to traditional divers may undermine any effort for them to participate in other fisheries. As it is, they are already contemplating the possibility of harvesting blue crab and some divers, although for short periods of time, already participate in gill net fisheries.

Territorial Use Rights in Fisheries (TURFs)

Marine fisheries are the world's most spatially extensive economic activity, and virtually all of the problems of the world's fisheries have an open access spatial dimension. The root of the problem relies in the fact that there exists a fundamental spatial inequity, spatial uncertainty, or spatial differentiation (Meaden and Do Chi 1996). A better management of space is a vital key to alleviating some of the present crises in the world's fisheries (Caddy and García 1986).

One form of access control to fishery resources is territorial use rights in fisheries (TURFs). TURFs include the right of exclusion (i.e. the right to limit or control access to a territory), the right to determine the amount and kind of use within the territory, and the right to extract benefits from the use of the resources within the territory (Christy 1982).

Forms of TURFs have been known to exist for centuries, generally associated with benthic sedentary resources. The granting of forms of exclusive rights to a fishing territory, in combination with other management strategies such as TACs, has appeared to be successful in some benthic fisheries, e.g. the gastropod *Loco* (*Concholepas concholepas*) fishery in Chile (Castilla and Fernández 1998), lobster fishery in Maine (Acheson 1987).

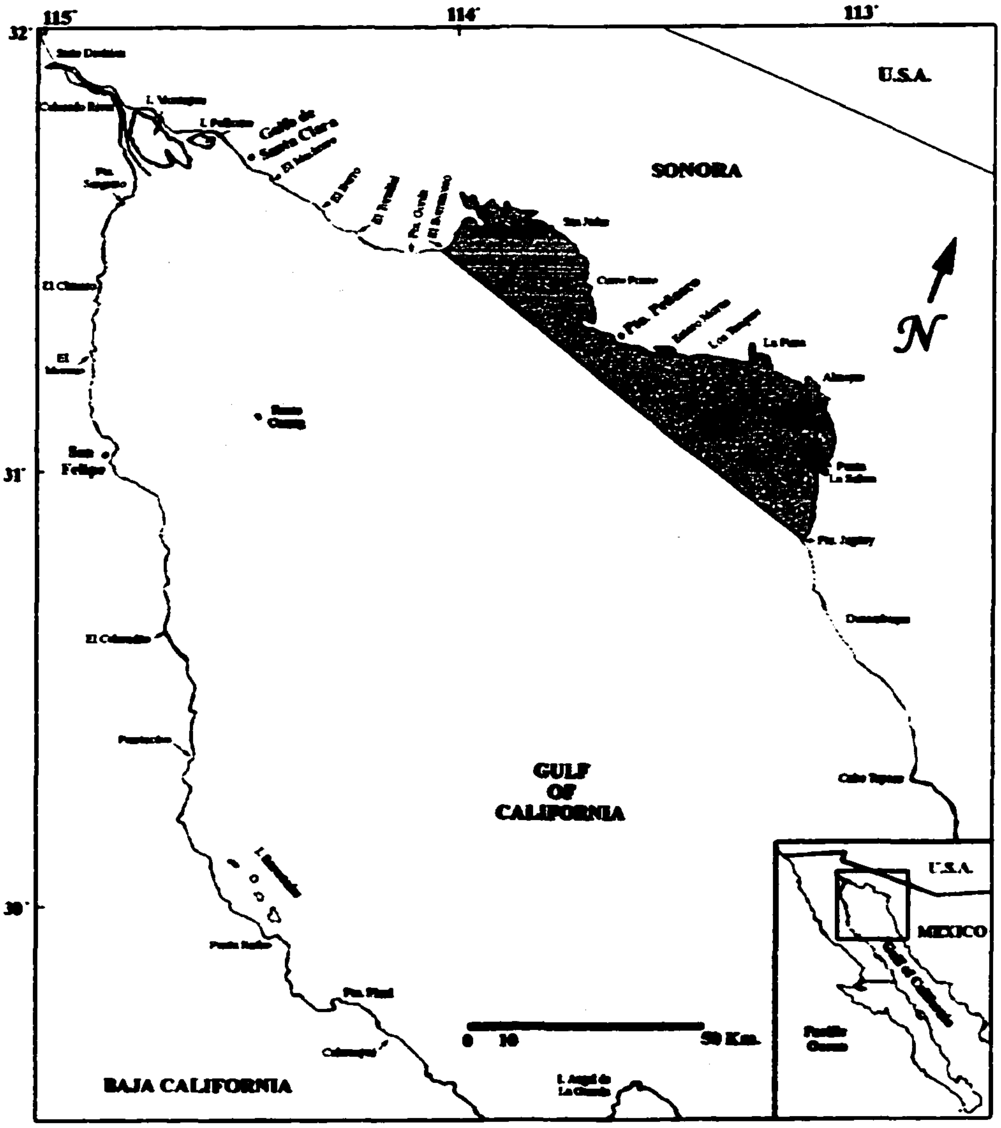
TURFs as a form of sea tenure for benthic sedentary or semi-sedentary resources are especially appealing. Since the resources are more tangibly confined within a geographical area, it is relatively easier to establish fishing boundaries. Also, since the limited movement of the resources does not define harvest areas, a higher sense of stewardship towards the resources harvested may exist as they are always found in generally the same area. Other fisheries requiring constant movement of fishing fleets according to the movement patterns of the resources will usually not foster a sense of ownership over the resources and even if they do, ownership will be highly contested as the resources will most likely be shared by other communities or sectors.

Most, if not all, divers from Puerto Peñasco strive for some sort of TURF granted to the sector as a whole, which in essence comprises the "diveable" area from Punta Jagüey to El Borrascoso, including San Jorge Island (Figure 15). Although there are currently no strong territorial conflicts with other communities, they would like to assure that in the future fishers from other communities will not be able to dive in their territory or that they will at least be legally able to control the entrance of "outsiders". Divers claim that fishing is simply not what it was ten years ago when they could fish anywhere they wanted (e.g. the Encantadas Islands, the Midriff Islands, Baja California). If and when divers get to work in areas other than the Peñasco grounds, they have to work using the *panga* and equipment of fishers from those areas or sell their product at lower prices than local divers. In essence, there is an informal concept of which communities or which divers are allowed to harvest certain territories.

Most divers assert that by granting them exclusivity to that area, not only would they be required to protect it from overharvest, but it would allow them more flexibility to rotate fishing effort for *callo* and octopus. As mentioned in Chapter 4, divers appear to rotate the use of *callo* beds as product becomes scarce or according to wind and current patterns.

As with limiting access, however, the establishment of a TURF would most likely restrict any future effort for Peñasco divers to fish in other communities. Many of these divers have friends or family members that are also divers in other fishing communities, primarily Bahía de Kino. It seems difficult that with such ties they could actually restrict their fishing activities. However, they mention that as a sector they don't have much problem with other known people coming to fish to the area as long as they fish with local *pangas*. The problem lies in the bringing of new equipment. Divers appear to want to establish a TURF even if that means that they could not fish in other places in the future. For them, territoriality is already a reality, claiming that it would just be a matter of formalization.

Figure 15. Delineation of exclusive fishing zone proposed by divers of Puerto Peñasco, Sonora, Mexico.



Marine Protected Areas: Harvest Refugia

As a result of apparently ineffective management practices, fisheries managers have increasingly lost credibility and are becoming highly scrutinized for failing to achieve conservation of marine fishery resources. Even with decades of experience with stock recruitment models, fishery resources tend to be overexploited and, in some cases, collapse (e.g. California sardine fishery, cod fishery in the Grand Banks). The blame for fishery management failure cannot be easily addressed. Many times, the blame is traced to political and economic interests that manage to overturn basically good scientific advice (Wilson et al. 1994). Nevertheless, even among fisheries scientists, there is a growing sense that much of this scientific knowledge can be flawed, and its application to fisheries management in most instances simply does not seem to work. As a result, fishery managers are increasingly focusing their efforts towards multi-species, community or ecosystem approaches (Wilson et al. 1994, Done and Reichelt 1998), leaving behind single species management practices. Nevertheless, as we face the challenge of viewing the sea and its resources as an ecosystem and try to base our management decisions under this holistic lens, we are also faced with the reality of the complex and to a certain extent chaotic nature of marine systems.

Marine systems are driven by largely changeable and unpredictable physical processes, making understanding difficult and impeding our ability to accurately predict the consequences of resource exploitation or of management practices. Similarly, marine systems have largely unstructured food webs, and the impacts of resource removal on food chain dynamics are not easy to predict (Agardy, 1997). Even relatively simple fish communities may be characterized by interactions that lead to chaotic population patterns in which the stock level of an individual species has no equilibrium tendency, but varies unpredictably within limits (Wilson et al. 1994).

In light of this complexity, as well as the declining catches and failure of many marine fisheries management practices, biologists have recently advocated the use of marine protected areas (MPA). MPAs are seen as a potentially effective strategy for protecting and/or enhancing harvestable stocks and promoting marine conservation (Carr and Reed 1993, Agardy 1997). Possibly the main reason for advocating the use of MPAs is that they can deal more efficiently with the uncertainties and volatility inherent to marine fisheries.

The ultimate goal of any MPA is marine conservation. As stated by Agardy (1997), "...the protection of critical ecological processes that maintain the ecosystem and allow for the production of goods and services beneficial to humankind, while allowing for utilization of ocean space and resources that is sustainable in an ecological sense". However, there are as many specific goals or objectives for marine protected area establishment as there are existing MPAs. Agardy (1997) recognizes at least 7 major categories of MPAs, ranging from the most narrow and spatially limited type of MPA to the broadest and largest category recognized. One form of MPA, harvest refugia (HR), is of special interest to marine fishery management and, particularly, to the snail and hookah diving fisheries of Puerto Peñasco.

Harvest refugia can be defined as a location of restricted harvesting of targeted species for the purpose of replenishing exploited populations through larval recruitment

(Carr and Read 1993). HR's are distinguished from nature reserves, which are generally established for the protection of an endangered species or community, or for the preservation of biotic diversity (Soulé and Simberloff 1986). Usually, HR emphasize on larval dispersal rather than emigration of more advanced older life stages as the mechanism of replenishment of exploited populations (Carr and Read 1993).

From an ecological point of view, establishing one large or several small HR could be a potentially ideal management strategy for the conservation of the snail fishery or, for that matter, hookah benthic fisheries in general. After I presented my results to divers regarding reproduction of snail, several mentioned the possibility of closing an area as they envisioned vast numbers of larvae recruiting other areas. However, this idea was again very contested among fishers. There are two main reasons given by fishers for why closing areas would not be at present a realistic option. These are discussed as follows:

Uncertainty

Most divers clearly see and realize that there is insufficient ecological information on which to base the design of one or several HR. They are also unfamiliar with such a management strategy, fearing that regardless of the design, it might not work.

The "Magnet" Effect

This seemed to be the biggest concern. HR, regardless of their size, would be too tempting not to be harvested, especially after a bad fishing day. In these cases, they might attract even more fishing than if not set aside as a closed area. However, this concern appeared to be expressed more on a collective than individual basis. In other words, when I asked fishers individually if they would respect a HR, they always said yes on the condition that all other divers were respecting it as well. However, since they assumed that others would not respect it, this would automatically make them break any established rules… "If I don't fish, someone else will".

Some divers mentioned that there would have to be strong enforcement at sea, not on land, in order for this to work. However, others stated that this would not necessarily be the case if a HR is essentially comprised of a whole distinct and identifiable fishing area (e.g. El Borrascoso). Everyone knows where others have gone to fish on a given day, especially when they go to El Borrascoso or San Jorge since they need to set up camp.

Interestingly, as mentioned in Chapter 4, some divers practice a form of HR management by not removing all snails within a breeding aggregation, with the idea that the offspring of those not harvested will help replenish those that were harvested. Also, divers did express a strong interest in resuming fishing activities within a low production zone like Las Conchas. This with the purpose of allowing a thorough study on the breeding aggregations, behavior of snails throughout their reproductive period, and larvae settlement and dispersal, topics that would be difficult to assess if fishing was carried out in the study area.

Probably one of the biggest challenges of a HR is to define its boundaries and assure that those boundaries are clear to everyone. Also, these boundaries might have to be constantly adapted according to changes in annual patterns of currents, and there is virtually no way of establishing their limits with a physical structure, resulting in confusion among users or in easy excuses to fish in the limits of the refugia.

Because no harvesting occurs in a HR, establishing a refuge temporarily reduces the size of the harvestable stock, therefore increasing harvest of unprotected stocks should not compensate this temporary reduction (Carr and Read 1993). Also, simply prohibiting harvest in a refuge does not ensure that populations of all target species will recover to pre harvest conditions within the refuge and begin to replenish adjacent fish populations (Dugan and Davis 1993).

When HR are established in low-quality habitats, protected stocks may not respond as desired. Similarly, recruitment overfishing can reduce brood stock to levels below that needed to replenish populations prior to the establishment of the HR (Dugan and Davis 1993). Some target species may require longer recovery times due to the infrequency of successful recruitment events, and, in some cases, artificial manipulations of brood stock are needed to rebuild population numbers after overfishing (Dugan and Davis 1993).

Finally, as with other fishery management practices, the success of a HR can be easily undermined if the refugia does not have the support of the users and if enforcement is insufficient or lacking. Fishermen will always try to maximize effort by harvesting in areas where large number of individuals, preferably of larger size, are aggregated. A HR will usually be a very productive and appealing area for fishermen since it will congregate the most valuable individuals and will simplify harvesting. Fishers should form an inherent part of the process of defining and establishing a HR. This is especially important in regions where enforcement capability is insufficient or lacking. But even if the majority of fishers believe in the purpose and benefits of a HR and they truly stop fishing in those areas, as the refugia becomes more efficient and its resources more rich, it might act as a magnet to outside fishers. This may eventually result in not only more damage to the harvestable stocks than if a HR had not been established, but it may also give way to strong territorial and social conflicts between users and undermine credibility of future management efforts.

Surveillance and Enforcement

One very common concern of fishers is that there has to exist more enforcement in order for any management guideline to work. They not only mention this as an important issue, but also would actually like to see more enforcement. They clearly state, however, that enforcement has to be fair and even to all who make use of the region's fisheries and management guidelines have to be designed with input from the fishers so they reflect the reality of the region. When asked if they would be willing to participate directly in enforcement measures, most of the divers stated that enforcement responsibilities should be in the hands of the government. Since Puerto Peñasco is a small community where practically all fishermen know and depend on each other in some form or another, rarely would they risk making an enemy in fear of not being helped in the future whenever a problem arises. This is especially true in a life-threatening situation when at sea. However, some divers mention they would participate in surveillance only if there were a process in which they were elected by the fishing sector and they worked in cooperation with PROFEPA or the Navy. This is especially true to restrict entrance of foreign fishers. In other words, although it is hard for fishers working in the same community to enforce each other, they do not seem to have a problem applying enforcement measures on outsiders or anyone threatening the livelihood of the sector as a whole. Probably the best example of this is the control local divers had over divers from Baja California who were brought to harvest calico clams. Also, in the summer of 1999, divers and the fishing sector in general were able to successfully overthrow developers' efforts to privatize and expel fishers from *"La Bajada"*, a traditional *panga* landing site.

There have been some cases in the northern Gulf of organizations created by the communities with the purpose of enforcing regulations, but particularly to assure an adequate price for a product and control the entrance of foreign fishers (Cudney-Bueno and Turk-Boyer 1998). However, organizations like these have not been able to count on the political force necessary for their proper functioning and are easily exposed to corruption (Cudney-Bueno and Turk-Boyer 1998).

Aquaculture

Aquaculture is seen by most divers as one key alternative to fishing that could solve much of their problems. In fact, the name of one of the cooperatives, *Sociedad Cooperativa de Producción Pesquera y Acuícola Islas de Sonora*, alludes to not only fishery production but aquaculture as well. Divers decided on this name with the vision that in the future they might be able to establish some form of aquaculture enterprise. They see it as attractive not only because they believe they could have more control over the selling price and earn more money, but also because it represents less physical danger than diving. This alternative is especially important to older divers, as they know they will soon have to interrupt their diving activities.

However, there are obvious limitations to pursue the establishment of aquaculture businesses. Although the area appears to have the potential to cultivate bivalves, aquaculture requires a very different mentality and form of work ethic than fishing. Aquaculture would also require long periods of trial and error before the activity is mastered. It would take years before fishermen could make an income from aquaculture comparable to that obtained by fishing.

Final Management Recommendations

If one thing can be concluded from this assessment it is that no single management regime or set of strategies can solve all the problems inherent to harvesting a resource or a group of resources. The myriad of social, political, economical, and biological issues surrounding a fishery make distilling an effective management framework a very complex task indeed, as any management decision will necessarily affect different people and even different resources at various levels. However, by making the involvement of fishers and the fishing sector overall a key component of the management process, we can strive for a more transparent process that may have more credibility among the various parties involved. This, of course, represents a never-ending challenge.

A management regime for these benthic fisheries must incorporate a combination of strategies and the inherent dynamic and changing nature of small-scale fisheries. In the following sections I give a series of recommendations that I believe could be applied for better managing benthic diving fisheries in the NG. I begin by discussing the murex fishery and end with management recommendations for diving fisheries in general.

Based on the limited information at hand regarding the ecology of the black murex and the evident depletion of the harvestable stocks, it is imperative that a precautionary approach to management be undertaken. Accepting the inevitability of errors in sustainable catch estimates, uncertainties of the marine environment, and often lack of information, fishery biologists have recently adopted management criteria that presumably err on the side of caution (Lauck et al. 1998). But even this "side of caution" is difficult to define.

In this case, there is no doubt that the timing of the fishing activity is the most obvious and immediate factor that may be exerting considerable pressure on the resource and therefore any management regime should take this factor as a first priority. It is also evident that fishers are aware of this situation and have the will and impetus to do something about it. Based on these premises, I propose the following measures to be taken:

Establish Season Closure

Although some fishers would like to see a total closure for a year or two, I believe a less drastic measure would be more efficient in terms of not only helping to conserve the fishery but also mitigating impact on other resources. Closing the fishery completely would undoubtedly increase fishing pressure on other species and possibly have considerable economic impact on the fishers. Also, the current problem would not be solved if the fishery reopens in a year or two as it would most likely be subject to the same or higher level of extraction.

The recommendation of some fishers of only permitting harvest during the month of August appears to be more plausible. There are several reasons why. Results indicate that by August approximately 50% or more of the egg capsules have hatched in most areas and dispersion of aggregated snails has begun, especially in shallow waters. This measure, coupled with the wind and current patterns that limit fishing, would not only allow more snails to reproduce successfully and most likely give way to an increase in recruitment to exploitable stocks, but would also permit more adult snails to remain as part of the stock or stocks and return to aggregate on the following season. As mentioned before, rarely will divers harvest dispersed snails since they are much harder to find (they will usually bury under the sand) and their search is too time consuming.

Fishing in August would most likely mitigate impacts on shallow water aggregations, as these are the ones that apparently disperse first. Shallow water and aggregations found close to shore are the ones that have been more heavily impacted throughout the years, forcing fishing activities to shift towards deeper water and areas farther to shore. Although it cannot be assured with the information at hand, it is possible that fishing activities could be eliminating entire subpopulations of murex and we are unaware of the consequences this could bring to overall recruitment. At present, we cannot know, for instance, how important shallow water aggregations are for recruiting snails found in deeper water or farther to shore and visa versa.

Fishing only in August would also automatically reduce the number of divers participating in the fishery to only those who are willing to wait and who are not engaged in other fisheries at that time. By August, the crab fishery is in full force, and most seasonal divers are participating in this or other fisheries (other than diving). These months also demand more knowledge of the resource as well as of diving since aggregations appear to be found in deeper waters or farther from shore. These aggregations are harder to find, and much of the success of a fishing day depends on the knowledge and capacity of the diver to locate a good fishing ground and begin the search underwater. By limiting the number of fishers, competition over resource extraction would decrease and active fishers would most likely have more chances to harvest larger quantities on every fishing trip.

One way to facilitate enforcement would be to outlaw marketing during the closure. If there are no buyers, fishing ceases. It is also easier to focus enforcement efforts on a handful of buyers than on a vast number of fishermen. This should be coupled with strict enforcement on black markets that would most likely arise after a season closure.

Assess State of Pacific Calico Scallop and Clam Beds

Divers are already targeting these resources as alternative species to snail during the summer months, and it is likely that harvest will continue to increase as snail becomes harder to find. Now that the stocks of these species appear to be plentiful, both the size and density of the scallop and clam beds should be assessed in order to determine the feasibility for higher harvest levels during June and July and determine sustainable management measures before the stocks are heavily impacted. Better markets could be found for both resources, particularly the scallops, as these have a high demand locally and in the U.S. These resources also offer the advantage of not needing to pass through middlemen or a processing plant to reach their final destination. Fishers could therefore potentially have more control over their price.

Encourage Swimming

Divers must be encouraged to swim and not to walk when searching for snail aggregations or any other resource. Swimming will minimize impact on the ocean bottom and on settlement habitat for larvae of murex snail as well as other invertebrates, commercial and non-commercial. Since it would be practically impossible to enforce this, education would most likely be the best way to cope with this issue. Most traditional divers swim underwater and, for those who do not, it is because they have opted not to, not because they do not know how to swim. There is strong pride among divers who swim, a pride that should be fostered.

Continue Studying and Monitoring

It is necessary to continue studying and monitoring both the resource as well as fishing activities. It is also essential to continue involving fishers as active participants in any future study and monitoring process. Buyers must also be involved, particularly in keeping adequate records of harvest levels in order to be able to make any future analysis of stocks and establish total allowable catches.

My ecological research was limited to one season, therefore these results should be compared with those of future seasons. It is important to establish a small area closure as soon as possible to allow more control over an experimental design and ensure that the resource can be studied more conclusively. As mentioned before, divers are interested in setting aside an area or areas for future study. Of particular importance is to study pre-settlement, settlement, and post-settlement processes of the planktonic larvae. Growth and movement patterns of these snails will also be necessary to assess.

In addition to the murex snail, it is necessary to conduct an in-depth study of the natural history of rock scallop in the region, particularly its reproductive ecology. It is also imperative to know the current status of the rock scallop banks, including their location, quantity, and density. Being sessile and broadcast spawning organisms, reproductive success or failure can be heavily determined by the density of adult organisms within banks. Species that broadcast gametes into the water column are subject to strong pre-dispersal Allee effects (depressed per capita survivorship or fecundity as populations become small) due to depressed fertilization success at low densities (Quinn et al. 1993).

Assess Feasibility of Establishing Harvest Refugia

After more information is gathered regarding larvae dispersal and identifying possible "source" areas for recruitment of murex, tangible results should be presented to the community to assess the feasibility of establishing harvest refugia. As mentioned before, fishers are interested in this option and results suggest that if there is sufficient and clear evidence that well designed HR could increase recruitment, fishers will be less reluctant to see it as a realistic option. The establishment of HR for black murex could serve a double purpose by not only increasing recruitment of snails but of most other resources harvested by hookah divers as well, particularly rock scallop, since they are all usually found within the same general fishing zones as those of murex.

Limit Entry

A truly effective means to limit entry should be implemented as soon as possible. A zero increase in the fishing fleet for all diving fisheries should be established until more information on the health of the stocks has been gathered. The operating fleet of the murex fishery should also be reduced until there is sufficient evidence that commercial stocks have recovered.

The first step to limit access to the fishery would be for the government to give legal recognition to the diving sector as a unit and issue permits to those who prove to be divers of Peñasco. One way to achieve this could be to give priority to the three existent diving cooperatives and establish mandatory diving certifications as a requisite to be allowed to fish. Mandatory diving certification would serve three purposes. 1) It would ensure that all commercial divers are knowledgeable about diving restraints and complications, therefore it could reduce accident risks. Although traditional commercial divers certainly dive more and have more practical experience than most recreational certified divers, understanding the theory behind diving could foster a more cautious behavior, such as conducting mandatory decompression stops. 2) It would certainly nurture the already existing sense of pride of being a diver, as certified divers would have a formal recognition of their activity. 3) It would act as a filter, filtering out those who are not willing to take the time and effort to become a certified diver and have legal standing.

A certification program could be administered through the *Secretaría de Marina* (Navy) in Peñasco with financial help from NGO's. Divers should also be encouraged to pay a symbolic fee as a means to assure their commitment and interest in this matter.

The INP should continue with the criteria of advising SEMARNAP to only issue permits under the category of *Pesca de Fomento* for snail and *callo*. Permits should be issued, however, to individual *pangas* (with the name of the *panga* on the permit) registered as part of a cooperative, union, or under the ownership of a *permisionario*, a person who owns various *pangas* and hires fishermen to work on his fleet. This, in addition to individual certifications, would reduce the possibilities of employing fishermen from other communities as well as control the access of fishermen within the community. This, of course, would require more communication, work, and coordination between the local SEMARNAP office and the state office in Guaymas. Fishers on numerous occasions have proposed that the local office should be given the capacity to issue the permits (Cudney-Bueno and Turk-Boyer 1998). This way, the process for obtaining a permit would be sped up and therefore be more efficient. There could be more control over the number of *pangas* registered, the number of permits issued, and the people who should be given priority to fish, since gaps and manipulations in this information increase as the process is transferred to the state offices.

Establish TURF

Exclusive rights to harvest benthic resources within a specified territory should be given to organized divers of Peñasco. The definition of this territory should be based as much on fishermen's geographical patterns of utilization as on the distribution and even geographical status of the resources harvested. I recommend paying particular attention to the territory already proposed by divers (Figure 15). Fishing permits must show clear boundaries of the specified territory. Being sedentary and semi-sedentary species, the task of tracing geographical boundaries should be facilitated.

The possibility of adopting this measure for other fishing communities in the Gulf of California where there are divers harvesting benthic resources should be considered. In recent years, for instance, the government of Chile has adopted the granting of Management and Exploitation Areas (MEA) for benthic resources (gastropods, sea urchins, and algae) throughout large portions of the Chilean coast (Castilla and Fernández 1998). This measure has apparently helped mitigate threats of overexploitation and increase the economic welfare of fishermen (Castilla and Fernández 1998).

Economic Alternatives

Efforts should be given to finding and pursuing other realistic economic alternatives divers would be interested and willing to participate in. This should not be restrained to searching for alternatives outside fishing, as fishing is their expertise and certainly the type of work that divers would do well. However, as mentioned before, there is currently much interest among divers to begin the process of establishing some form of aquaculture business as a means to deal with the uncertainties of fishing in the future. A biological, social, and economic feasibility analysis for aquaculture possibilities should be implemented. Possibilities for using aquaculture as a means of re-stocking should also be assessed.

Formalize a Co-management Regime

I conclude this thesis with a final recommendation, which has been implicit in much of my previous discussions, and that is the need to formalize a co-management regime for benthic fisheries in the NG.

Fisheries co-management, also known as cooperative management, by definition, means that government agencies and fishermen's organizations share the responsibility for management functions (Jentoft 1989, White et al. 1994). Co-management can also refer to resource management between multiple parties and their communities (Pinkerton 1994). Jentoft (1989) states that co-management is to be distinguished from other common property management systems, such as government regulations or community initiated regulations in that it takes a middle course… "It is a meeting point between overall government concerns for efficient resource utilization and protection, and local concerns for equal opportunities, self determination, and self-control".

Co-management has emerged as a way to manage fisheries resources that involves the fishermen in decision making because management by the central government alone is not effective (Harrington 1997). White et al. (1994) state that the need for co-management is especially true in developing countries where the central government lacks the financial and human resource capabilities to create, monitor, and enforce management regulations. Co-management can take different forms and the level or degree to which a central government should delegate management responsibilities to a community must vary according to the unique characteristics of the region, situation, or the existent government structure. According to Jentoft (1989):

> "The government's responsibility may be to provide the general framework for operation of the fishermen's organizations such as: the general legislation to install co-management principles; fixing total allowable catch; allocation of quotas between different fishermen's organizations; and, perhaps, also deciding the general framework for the organization of the regulatory process".

This thesis suggests that an informal type of co-management is already taking place and that the political arena surrounding benthic diving fisheries in Puerto Peñasco calls to formalize this type of management system.

Management of Mexico's fisheries, particularly of those that do not provide the country large capital gains but that are nevertheless very important at a community level (such as most diving benthic fisheries) clearly shows signs of decentralization efforts. Possibly the best current and local example of Mexico's interest to decentralize its management efforts and implement a co-management structure is INP's partnership with several NGO's and academic institutions working in the Gulf of California to better understand and manage small-scale fisheries. During the discussions in the various workshops of this interdisciplinary group, the interest for co-management is always evident, surfacing as a major objective of future management regimes (R. Cudney-Bueno, personal information).

During my last meeting with divers in January, they all proposed writing and signing a letter to SEMARNAP petitioning a consideration of their specific proposals to better manage the snail fishery as well as diving fisheries as a whole. They also unanimously called for a meeting with government officials to formally establish some form of regulation for the snail fishery, particularly a season closure. Both the CRIP in Guaymas and the Biosphere Reserve are especially interested in participating in such a meeting and fully considering fishermen's proposals (personal communication, Raúl Molina, CRIP-Guaymas, and José Campoy, Director Upper Gulf Biosphere Reserve).

In essence, fishermen are petitioning more regulations, but they want such regulations to be formally established by the government based on fishermen's full or partial input and involvement. They argue that if decisions are not formalized and enforced by the government, they will most likely not be respected. Corruption, a myriad of local interests, and outside economic pressure can surpass adherence to any rule or regulation.

Although co-management is an appealing option, there are still many issues to resolve in order to successfully establish a transparent and functioning co-management regime. A starting point, however, is to hear what the fishing sector has to say and involve it in management decision-making processes and implementation. Only then will fishermen believe in the established management structure and will regulations truly reflect the uniqueness and diversity of each fishing community and the various issues surrounding their fisheries.

Appendix: List of Acronyms and Abbreviations

CGD: *Coordinación General de Descentralización.*

CL: Capsule Length.

CPUE: Catch Per Unit of Effort.

CRIP: *Centro Regional de Investigación Pesquera.*

DOF: *Diario Oficial de la Federación.*

HR: Harvest Refugia.

INP: *Instituto Nacional de la Pesca.*

LGEEPA: *Ley General de Equilibrio Ecológico y Protección al Ambiente.*

MPA: Marine Protected Areas.

MSY: Maximum Sustainable Yield.

MT: Metric Tons.

NAFTA: North American Free Trade Agreement.

NG: Northern Gulf of California.

PHC: Proportion of Hatched Capsules.

PROFEPA: *Procuraduría Federal de Protección al Ambiente.*

SEMARNAP: *Secretaría del Medio Ambiente, Recursos Naturales y Pesca.*

TAC: Total Allowable Catch.

TL: Total Length.

TURF: Territorial Use Rights in Fisheries.

ZOFEMAT: *Zona Federal Marítimo Terrestre.*

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