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A review of the world marine gastropod fishery: evolution of catches, management and the Chilean experience

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Contents

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Abstract

Marine mollusks are among the most important invertebrate fisheries in the world. The main classes of mollusk fished are Cephalopoda, Bivalvia and Gastropoda. Marine gastropods represent approximately 2% of the mollusks fished in the world. Several species of gastropods, such as *Haliotis* spp., *Strombus* spp., *Busycon* spp. and *Concholepas concholepas*, have high economic value in international markets and play important social roles in small-scale artisanal fisheries. In the past 25 years wild-stock catches of marine gastropods have increased from 75,000 mt in 1979 to 103,000 mt in 1996. During the same period the countries involved in gastropod landings rose from 23 to 47. Gastropods are fished mainly in: (1) the American continent, dominated by the extraction of the muricid “loco”, *C. concholepas*, in Chile and Peru; strombid conchs, *Strombus* spp., in the Caribbean, and abalone, *Haliotis* spp., in California and the west coast of the Baja California peninsula; (2) Asia and Oceania, with the dominate abalone fishery, mainly in Australia and New Zealand, and the horned turban snail, *Turbo truncatus*, in Japan and Korea; (3) in Africa and Europe, the dominate species extracted are *Haliotis midae*, heavily fished in South Africa, and the common periwinkle, *Littorina littorea*, and the whelk *Buccinum undatum*, which are extracted in Europe.

This review summarizes the fishery of abalone species in California and the west coast of the Baja California peninsula. We highlight overfishing situations and the utilization of adaptive management tools, such as those in operation in Baja California, where small-scale fisher associations (cooperatives) have received exclusive access rights to abalone extraction within specific fishing zones, since 1936. We also review the abalone fishery in Australia, and the use of Individual Transferable Quotas (ITQs) and Total Allowable Commercial Catches (TACC), which have been in use since the mid-1980's. We describe the gastropod fisheries in Chile, mainly *C. concholepas*, highlighting their economic and social importance. We provide information on the evolution of catches and exports and discuss the development of novel management adaptive tools, such as the implementation of the Benthic Regime for Extraction and Processing (BREP), the introduction of Non-Transferable Individual Quotas (NTIQs) and territorial use rights for benthic fisheries, such as the Management and Exploitation Areas (MEAS). Finally, we present and discuss the necessary steps for the sustainable management of marine gastropods and other benthic resources.

Introduction

During the past 50 years world fishery catches have experienced a substantial increase. In the early 1950's total captures were approximately 20 million metric tons (mmt) and by 1996 captures reached a record of approximately 121 mmt (FAO, 1998a). This picture of growth, however, is complicated by notable modifications in the percentage contribution from different countries, regions and exploited species. Aquaculture has been responsible for most of the growth in shellfish tonnage landings in the last two decades, with an average annual growth rate of 11.8% (1984–1996) and over 20 mmt landed in 1996 (Matthews and Hammond, 1999). In contrast, marine wild-stock fisheries capture, including small-scale and artisanal activities, has shown a sustained decline during the last four decades, and catches remained constant in the 1990's (FAO, 1998a). Open access fishery policies, by-catch, fishing power increase, managerial "optimism" and pressure for greater catches (i.e., "ratchet effect", Botsford et al., 1997; Pitcher, 2001) have produced a global deterioration in the state of marine resources, resulting in an overcapitalization of the fishing fleet (Mace, 1997; Caddy, 1999). The FAO landing estimates from the mid 1990's showed that 70% of the 200 principal wild-stock marine fisheries were fully exploited, depleted, or recovering (also see Botsford et al., 1997) and that the world fishing fleet surpassed its real capacity needs by approximately 30% (Grainger and García, 1996). This situation has been promoted through a fishing behavior based on successive cycles of exploitation, depletion, and the replacement of depleted stocks or species for other "new" resources or fishing areas. Several studies have suggested that an increase in marine catches must include an improvement in management policies, and above all else there is a need for the crafting of new local and regional institutions (Botsford et al., 1997).

Since the mid-1980's several new managerial approaches have been implemented: (1) adaptive and experimental management (i.e., Walters, 1997; Botsford et al., 1997; Castilla, 2000); (2) refuge zones or marine protected areas (Baker et al., 1996; Allison et al., 1998; Castilla and Fernández, 1999); (3) exclusive fishing and territorial user rights (Vega et al., 1997; Ramade-Villanueva et al., 1998; Ponce-Díaz et al., 1998; Ostrom, 1990; Castilla 1994; Hanna and Mumasinghe, 1995; Runolfsson, 1997; Prince et al., 1998); (4) community-based and co-management strategies (Berkes, 1987, 1999; Pinkerton and Weinstein, 1995; Castilla, 1997a; Castilla et al., 1998; Castilla and Defeo, 2001); and (5) the recovery and appreciation of traditional knowledge of resources emerging from managerial approaches in fisher communities (Kurien, 1998). These approaches are transforming the paradigms that sustained the traditional fishery administration in the past (Caddy, 1999; Castilla, 1997a, b, 2000).

Small-scale fisheries, and particularly the benthic invertebrate fisheries (see definition in Castilla and Defeo, 2001), have played an important role in the development of new fishery management principles and tools. Large parts of the social, biological and technical components have come from observation, cooperation, and research carried out by scientists inside fishing communities (Defeo, 1993; Seijo and Defeo, 1994; Ramade-Villanueva, 1998; Berkes, 1999; Castilla, 1999, 2000). Nevertheless, there are few studies that detail the evolution of exploitation practices and fishery management in small-scale invertebrate fisheries in a global context. An illustrative example of these managerial changes is the fishing of marine gastropod wild-stocks. Due to their high economic value and excessive capture many marine gastropods show, or have shown, serious problems of overexploitation (Tegner, 1989; Castilla, 1996; Ponce-Díaz et al., 1998; Hobday et al., 2001). In many cases this has led to the collapse or permanent closure of the fishery. The social and economic consequences of these collapses have promoted the development of new management perspectives centered on both biological and economical sustainability (Baker et al., 1996; Prince et al., 1998; Castilla, 1997a, 1999, 2000).

This paper deals with the marine gastropod fisheries from a global perspective. We aim to: (1) gain an understanding the regional patterns of these fisheries via a review of catch statistics during the last two decades, and determining the state of exploitation and management strategies in the principal gastropod fisheries; (2) analyze the development of the abalone fisheries in California, the west coast of the Baja California peninsula, and Australia from a local perspective, and evaluate the establishment of innovative, adaptive co-mangement plans for the management of invertebrate resources in Chile, focusing mainly on the "loco", *Concholepas concholepas*; (3) identify economic, social, and biologic factors associated with the problems of overexploitation in this type of fishery, showing examples of the development and institutionalization of new management practices in benthic invertebrates, including gastropods; (4) address the strengths and weaknesses of the present management tools currently in use, and emphasize the challenges to maintain sustainable gastropod and benthic invertebrate fishery systems.

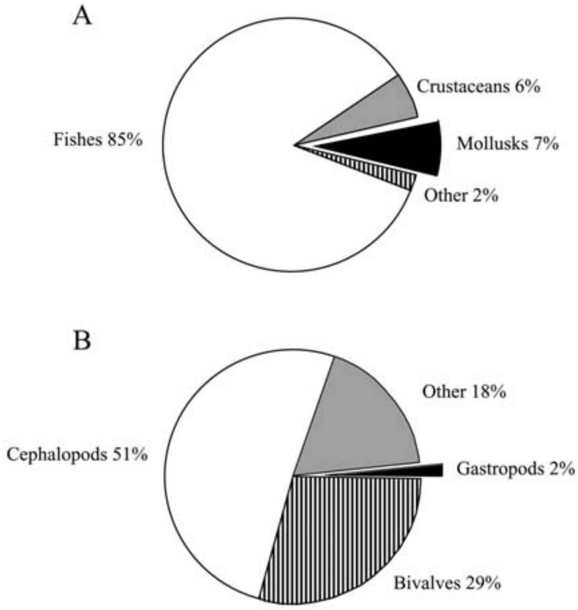

Figure 1. World fishery catches during 1996. (A) Marine fishery catches (87 072 106 mt) by main groups. (B) Marine mollusk catches (5 933 000) by main classes (taken from FAO, 1998b).

World gastropod fisheries

In terms of tonnage and economic value, marine mollusks are among the most important invertebrate fishery resources in the world (FAO, 1984, 1998a, b). Over 5 mmt of wild-stock mollusks, approximately 7% of total marine fish catches, were extracted during 1996 (Figure 1A). The main classes of mollusks fished are Cephalopoda (mainly pelagic species) and Bivalvia, which represent over 80% of global mollusk catches (FAO, 1998b). Marine gastropods represent about 2% of world mollusk catches (Figure 1B). Nevertheless, some species such as abalone *Haliotis* spp., strombid conchs and the "loco" *Concholepas concholepas* play important economic and social roles due their importance in local consumption and their high economic value in the international market. In the past 25 years, world wild-stock marine gastropod catches increased approximately 38%, from 75,000 metric tons (mt) in 1979 to 103,000 mt in 1996. However, this growth has been neither regular nor uniformly distributed in time between continents or regions (Figure 2). Fishing statistics show an increase in the number of countries incorporated into the gastropod world landing records, rising from 23 in 1979 to 47 in 1996 (FAO, 1998b). Nevertheless, only a small number of countries dominate this type of fishery. During the last two decades 76% to 88% of the world marine gastropod catches were concentrated among 11 countries (Figure 3A, B, C) and the bulk of gastropod extraction concentrated on 11 main taxa (Figure 4A, B, C), with geographically localized or endemic populations and restricted dispersal. Catches of these species drove the large fluctuations in world catch observed during the last two decades, as well as the sustained increase in catches during 1993–1996 (Figure 2).

Gastropod fisheries on the American continent

The American continent (including South, Central and North America) contains the principal gastropod fish-

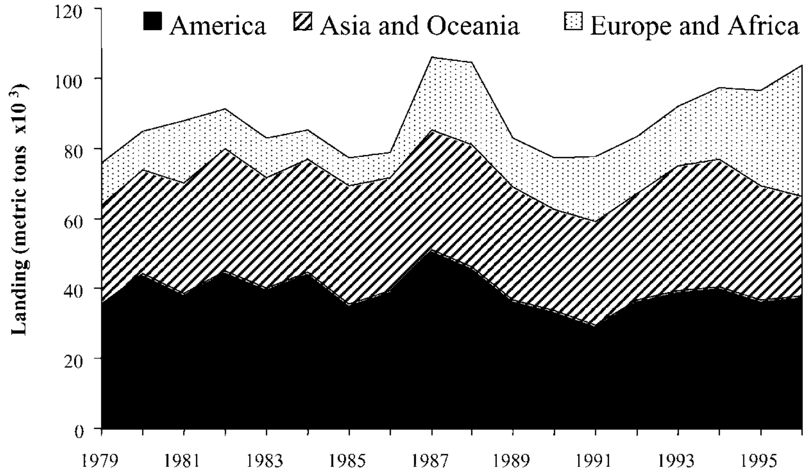

Figure 2. World marine gastropod catches by continents 1979–1996 (taken from FAO, 1998b).

eries of the world. They are concentrated in the Pacific Southeast (Chile and Peru) and on the Pacific and Atlantic coasts of Central and North America. The main fishery countries: Chile, Mexico, Peru and the USA, show overall catches averaging over 5,000 mt annually throughout the past 20 years (with the exception of larger catches in Chile between 1979–1988). These countries account for 77% to 95% of all gastropod catches on the American continent (Figure 3A). While total extractions from the Americas have remained relatively stable (Figure 2), the catches per country and species have shown large fluctuations. Between 1979 and 1988, Chile was the most important marine gastropod extractor in the world, accounting for over 35% of the world gastropod landings (1980, Figure 3A). However, after 1989, the main Chilean gastropod fishery, the muricid gastropod *Concholepas concholepas*, declined, most likely due to stock overexploitation (Castilla, 1995, 1997b; Castilla et al., 1998; see Figure 4A). Since 1989, the gastropod catches in Mexico have shown increases. The bulk of Mexico's gastropod catches are situated predominantly on the Caribbean coast and based on fisheries of *Strombus* spp. (stromboid conchs). However, the most economically valuable resource is the abalone (*Haliotis* spp.), fished on the west coast of the Baja California peninsula (Hobday and Tegner, 2000). Here, the multi-species abalone fishery declined strongly toward the middle of the 1980's when serious overexploitation problems occurred (Guzmán del Proo, 1992; Ramade-Villanueva, 1998; Ponce-Díaz et al., 1998). Peruvian gastropod catches are characterized by high diversity of species, many of which are reported by FAO (1998b) as "non-identified species". Since 1993, the trajectory of gastropod landings in Mexico remained rather flat (Figure 3A), while catch increases were observed in the USA, due to the development of the fishery of *Busycon* spp. (whelk) and also due to participation by the USA in the Caribbean *Strombus* spp. fishery (Figures 3A, 4A). The USA faced serious overexploitation problems with the abalone fisheries in California, which led the authorities to decree the commercial closure of all of these fisheries in 1997 (Parker et al., 1992; Karpov et al., 1998; Murray et al., 1999; Hobday and Tegner, 2000).

Gastropod fisheries in Asia and Oceania

Between 1979 and 1996, Japan, the Republic of Korea and Australia were leading countries in the extraction of marine gastropods, accounting for approximately 95% of the total catches in Asia and Oceania (Figure 3B). The combined gastropod catches of these areas represented the second largest extraction after the Americas. In Asia, the main gastropod fisheries are *Turbo truncatus* (horned turban) and *Haliotis gigantea* (giant abalone). *H. gigantea* is extracted exclusively by Japan while *T. truncatus* is extracted by both Japan and the Republic of Korea. In Oceania, the main gastropod fisheries are *Haliotis rubra* (black lip abalone), extracted in Australia, and *Haliotis iris* (paua abalone) and other endemic *Haliotis* species extracted on the New Zealand coast (Figure 4B).

Marine gastropod catches in Asia and Oceania show strong extraction regularity in comparison with the rest of the world (Figure 3B). Both Australia

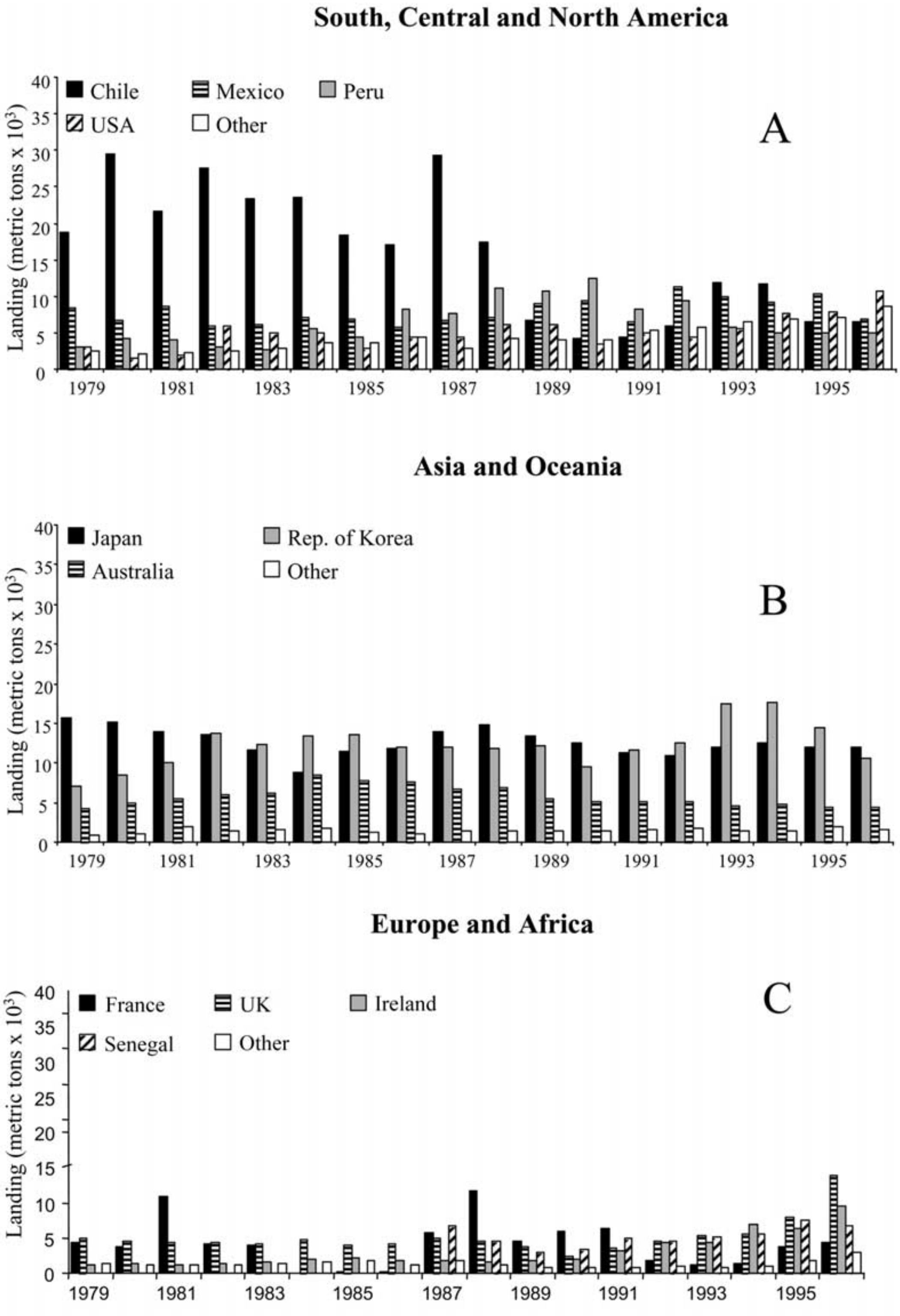

Figure 3. Marine gastropod catches by main countries (1979–1996. (A) South, Central and North America, (B) Asia and Oceania, (C) Europe and Africa (taken from FAO 1998b).

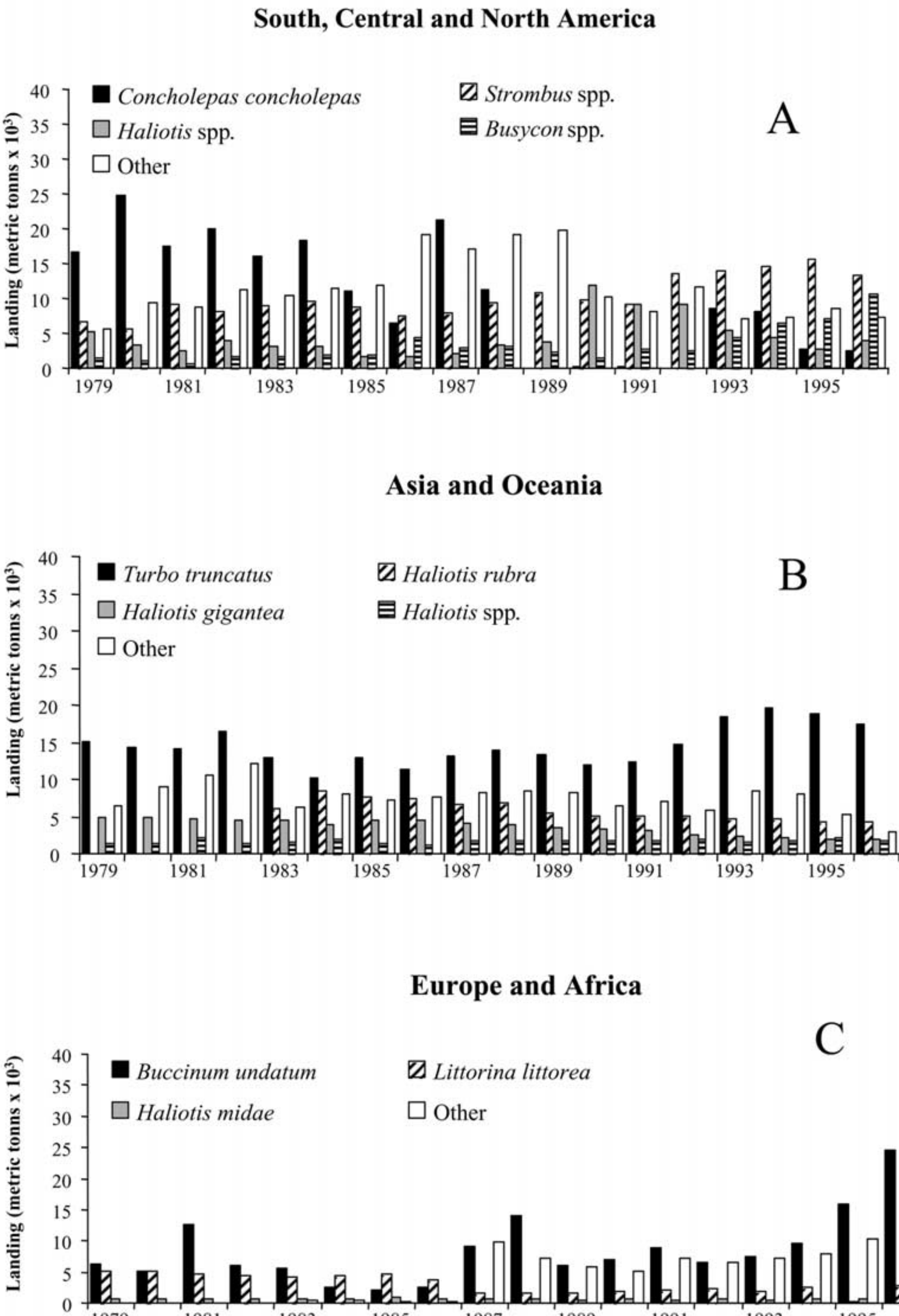

Figure 4. Marine gastropod catches by main species (1979–1996). (A) South, Central and North America, (B) Asia and Oceania, (C) Europe and Africa (taken from FAO, 1998b).

and New Zealand have developed efficient invertebrate management approaches, using the Individual Transferable Quota (ITQ) system with participation from stakeholders (Pearse and Walters, 1992; Schiel, 1992; Prince and Shepherd, 1992; Prince et al., 1998). In Asia there is strong community-based management centered on a system of fishing cooperatives (Pinkerton and Weinstein, 1995).

Gastropod fisheries in Europe and Africa

France, the United Kingdom and Ireland are the countries with the most important gastropod fisheries in Europe (Figure 3C). Between 1979–1996 they accounted for over 90% of the European gastropod catches. The main species extracted from these European fisheries are *Littorina littorea* (common periwinkle) and *Buccinum undatum* (whelk) (Figure 4C). Between 1993 and 1996 *B. undatum* catches rose from 8% to 24% of world gastropod catches. This sudden increase in the extraction of one species (*B. undatum*) accounted for the increase of European and world gastropod catches in these three years.

Africa, in contrast to Europe, has relatively low participation in gastropod fisheries. There are three African countries registered in the world gastropod fishery records, but only Senegal reports landings over 5000 mt per year (Figure 3C; FAO, 1998b). Nevertheless, the majority of countries on this continent do not have efficient landing registration schemes. The most commercially important gastropod resource in the region is the abalone *Haliotis midae* (perlemoen abalone; Figure 4C), extracted exclusively in South Africa under an ITQ management policy (Tarr, 1992).

Main gastropod fisheries

The abalone fisheries in California

In the last 150 years five abalone species: *Haliotis corrugata* (pink abalone), *H. fulgens* (green abalone), *H. rufescens* (red abalone), *H. sorenseni* (white abalone), and *H. cracherodii* (black abalone), have been commercially extracted in California. Cox (1960) presented a history of abalone fisheries in California prior to 1960. The extraction pattern for the red and pink abalone in the Californian fishery shows an increase in landings between approximately 1940 and 1950; a stabilizing phase during 1960, with peak landings of approximately 1,500 mt per year; and an overexploitation phase starting in 1968 (Tegner, 1989). Concurrent with the decreasing extraction phase, around 1970, the fishery for black, green and white abalone was developed. Commercial extraction of green and white abalone lasted less than 5–10 years, while the black abalone fishery collapsed around 1990. In May 1997 the entire Californian coast was closed to the commercial abalone fishery and the recreational extraction was closed south of Point Lobos, and restricted to red abalone along the rest of the coast (Murray et al., 1999; Hobday and Tegner, 2000).

Hobday and Tegner (2000) summarized the management history for the California abalone fishery, where several regulatory extraction tools were implemented between 1901 and 1997: minimum size limit, commercial permit fee, minimum commercial landing, recreational limit and recreational and commercial gear regulation. In spite of these management tools the abalone populations in California continued to decline, until total closure was decreed in 1997 (see above). The case of white abalone in California and Mexico is particularly dramatic, where total abundance was estimated at around 1600 specimens in 2000, and the time to extinction in California is estimated at around 10 years (Hobday and Tegner, 2000; Hamm and Burton, 2000; Hobday et al., 2001).

The cooperative fishery model for abalone on the west coast of the Baja California peninsula

On the west coast of the Baja California peninsula the same five abalone species are exploited, and, as in California, this fishery has also shown dramatic signs of overexploitation. For instance, in the central zone of Baja California abalone catches reached about 4,000 mt (meat only) in the mid 1960's, and then dropped to less than 1,000 mt in mid 1990's (Ramade-Villanueva et al., 1998). In this area the abalone fishery has been the basis of socio-economic development of early and recent human settlements (Cox, 1960; Ramade-Villanueva et al., 1998). This fishery operates on an exclusive control system first implemented in 1936, and includes abalone exploitation rights allocated exclusively to cooperative fishery organizations ("cooperativas pesqueras"), and remained in effect until 1992, when Mexican federal legislation was modified. In 1996 there were 22 cooperatives and about 200 boats were targeting abalone on the west coast of Baja California. These fisheries operated in the four major zones or geographical fishing concessions (Vega et al., 1997). The new Mexican legislation of 1996 removed abalone species allocations, although the geographical cooperative concessions are still in effect, and the abalone fishery remains in the hands of the cooperatives (Ponce-Díaz et al., 1998; Ramade-Villanueva et al., 1998). Within the cooperatives abalone management is primarily regulated on a limited entry basis in each zone, together with a minimum legal extracting size for abalone, seasons of closure and annual quotas, which are assigned to the cooperatives. The cooperatives exercise an internal control on such management measures (Vega et al., 1997). For abalone a limit on total allowable catch per cooperative (TACC) has operated since 1973. The existence of this limit, as well as the zonation of the fishery system, has made it possible to gather capture per unit effort (CPUE) data in this fishery. Nevertheless, in spite of fishery zoning and TACC management measures the Baja California abalone CPUE dropped from approximately 110 kg/day in 1973 to about 39 kg/day in 1982. Afterwards, the CPUE increased and stabilized at around 85–90 kg/day (1987–1991), and thereafter dropped to approximately 50 kg/day (1993–1994) (Ramade-Villanueva et al., 1998). Although the 1982 El Niño may have had some effects on abalone catches (mainly due to its adverse effect on giant kelp and climate change; see Shepherd et al., 1998) it is evident that on the west coast of Baja California abalone CPUE entered a decreasing trend several years before the 1982 El Niño event. According to Ramade-Villanueva et al. (1998) the TACC has proven to be the most useful management tool available in keeping this fishery alive; although, in the future it will be necessary to reduce TACC uncertainty due to the different criteria used for calculations.

The abalone fisheries in Australia

Prince et al. (1998) presented a summary of the abalone fisheries in Australia, with special emphasis on the need to establish territorial use rights fisheries (TURFs). Three species of abalone are extracted in the southern states of Australia: *Haliotis roei*, *H. laevigata* and *H. rubra.* Abalone fisheries in Australia (extracting approximately 5,000–6,000 mt/year) and Japan (extracting approximately 3,000–4,000 mt/year) dominate global abalone production FAO, 1998a, b; Prince et al., 1998). Modern Australian abalone extraction techniques (commercial diving with compressed air supplied from the surface) started in the mid-1960's, and during the last part of the 1960's most Australian states moved to limit entry: controlling the number of commercial abalone divers, first by using a system of nontransferable abalone extracting licenses, then using a system of reallocation, and later on establishing a system of license transferability. During the mid-1980's individual transferable quotas for abalone and total allowable commercial catches (TACCs) were introduced to control rising catches (Harrison, 1986; Prince et al., 1998). In spite of these management steps, the Australian abalone fisheries have shown serial depletions, particularly for individual abalone beds, since most divers tend to extract their quotas from the same abalone beds or reefs. This, according to Prince et al. (1998), gives rise to a local "tragedy of the commons" (Hardin, 1968). Therefore, size limits and quotas set over broad zones of the fishing ground for species showing aggregate distributions or "nuggets of stock", as in the case of abalone, give little protection to the most favorable dive beds, where most of the extraction pressure is focused. Hence, in cases where intricate spatial distribution of the resources and limited dispersal of larvae occur, a good match between management and stock scales is needed (Prince and Shepherd, 1992; Prince et al., 1987, 1998). In the Australian abalone fishery seems to be a mismatch of these scales, and Prince et al. (1998) have suggested that a possible solution is the allocation of territorial use rights for the fishery, allowing for individual or small communities of fishers to adaptively adjust the scale of management to the scale of the stock (for other examples see Bourne, 1986; Castilla et al., 1998; Johannes, 1998 and references therein).

Benthic invertebrate fisheries, with emphasis on gastropods: the Chilean experience

Economic, social and biological importance

The Chilean benthic invertebrate fishery, comprising over 60 species of mollusks, crustacean and echinoderms (Castilla and Becerra, 1975; Bustamante and Castilla, 1987; Castilla, 1996), is presently one of the richest in the world. In 1998 approximately 200,000 mt of benthic shellfish resources were landed in Chile, mainly through diving (SERNAPESCA, 1999). Invertebrate resources, such as the sea urchin *Loxechinus albus*, the octopus *Octopus mimus* and the muricid gastropod *Concholepas concholepas*, are traded mainly in international markets and annual

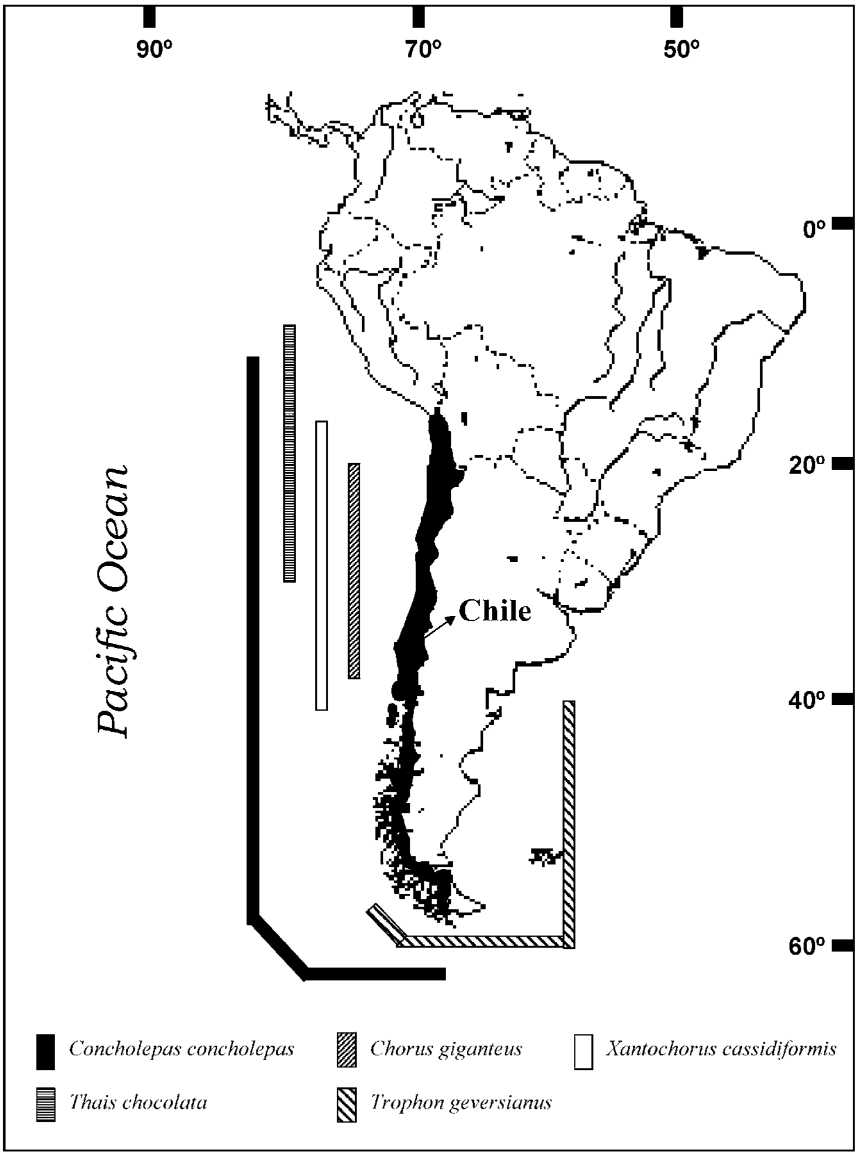

Figure 5. Geographical distribution of muricid gastropods extracted in the Chilean shellfishery (see references in the text).

reported export values are over US$100 million (Castilla, 1997a, b). In 1998 mollusks comprised over 55% of catches in the Chilean invertebrate fishery. Within mollusks, the gastropod fishery is one of the most diverse and economically important in the country (Bustamante and Castilla, 1987). Gastropod catches in Chile include at least 20 different species, several of which belong to the families Muricidae and Fisurellidae. Gastropod fisheries comprise 53% of the total gastropod extraction in Chile and compose the group with the largest economic value. The muricid gastropod *Concholepas concholepas* ("loco" or false abalone) has historically been the gastropod with the highest levels of extraction and economic importance in Chile (Hancock, 1969; Castilla and Becerra, 1975; Bustamante and Castilla, 1987; Castilla, 1988, 1997b; Castilla et al., 1998). During the last two decades, exportation of "loco" has generated revenues for Chile of over US$390 million (SERNAPESCA, 1999). Other muricid species extracted commercially in Chile are (in decreasing order of importance): *Thais chocolata* (caracol locate), *Chorus giganteus* (caracol trumulco), *Trophon geversianus* (caracol *Trophon*), and *Xanthochorus cassidiformis* (caracol rubio). These species are endemic to the southeast Pacific and the Patagonian region of Chile and Argentina (Figure 5; see Osorio et al., 1979; Stuardo, 1979; Gallardo and González, 1994; Santana, 1997; Pastorino, pers. comm.). The multispecies fishery of key-hole limpets, which includes at least 10 different *Fissurella* species (Bretos, 1988; Oliva and Castilla, 1990, 1992), is also of importance. In 1998, approximately 3,000 mt of keyhole limpets were extracted, representing 41% of the total gastropods fished in Chile that year (SERNAPESCA, 1999). The rest of the gastropod extraction is composed of four species of lesser importance: *Tegula atra*, *Adelomelon ancilla*, *Odontocymbiola* spp. and *Argobuccinum undatum*.

The gastropod fishery in Chile generates substantial revenues for the country through exports and also supplies 100% of the national demand for these products. Moreover, the gastropod fishery has a large social and economic impact on the country's small-scale fishing communities (Castilla, 1997a, b; Castilla and Defeo, 2001). Marine gastropod resources, as well as many other benthic invertebrates in Chile, are exploited exclusively by the artisanal fisher sector, mainly by divers ("hookah" divers operating from small boats, and "skin-divers") and by intertidal food-gathers (hand-picking). The resources are extracted for subsistence uses and for commercial sale (Castilla, 1994, 1997b). According to SERNAPESCA (1999), in Chile there are over 45,000 registered artisanal fishers engaged directly in small-scale fishery activity, which are distributed among approximately 200 fishing villages ("caletas", see Castilla et al., 1998) throughout the country. Approximately 14,000 of these fishers are registered "hookah" divers and about 8,000 are registered as food-gatherers. However, there are also people who work seasonally in the small-scale fishery, and according to Bernal et al. (1999) the estimated number of people engaged directly or indirectly on the Chilean small-scale fisheries amounts to approximately 450,000 (for other figures see Bustamante and Castilla, 1987; Castilla, 1994; SERNAPESCA, 1998).

Since ancient times marine gastropods have formed part of the diet of human settlers on the Chilean and Peruvian coasts (Jerardino et al., 1992), and today gastropods continue to represent an important protein supplement for fishers and members of coastal communities. Coastal food-gathering has been the technique most used to satisfy the food needs of these communities, mainly because it does not require experience or investment. In Chile, hand-picking is considered an informal activity and is not declared in the official catch reports. There are neither records nor official estimations of the type and quantity of resources extracted in this way (but see Durán et al., 1987). In spite of this, studies assessing the effects of invertebrate hand-picking on rocky intertidal ecosystems have revealed that the quantitative and qualitative effects of human predation on gastropods in the Chilean intertidal zone are of great ecological importance and cause dramatic changes in the structure and diversity of intertidal and nearshore subtidal communities (Moreno et al., 1984; Castilla and Durán, 1985; Moreno, 1986; Moreno et al., 1986; Oliva and Castilla, 1986; Durán and Castilla, 1989; Castilla, 1993, 1999, 2001).

Evolution of gastropod catches and exports

Until the middle of the 1970's, the artisanal gastropod fishery in Chile was exclusively channeled for internal demand. Catch information before the beginning of the gastropod "exportation phase", beginning around 1976, is limited (Castilla, 1997b; Castilla and Fernández, 1998); only annual catches for *Concholepas concholepas* were recorded. Based on changes in *C. concholepas* catches, the management strategies used and the export values of this resource (Figure 6), the fishery can be divided into five distinct phases. Here we provide a summary of the five phases (also see Castilla and Defeo, 2001). The first phase, 1965–1975, was characterized by relatively uniform and sustainable levels of "loco" catches between 2,000 to 6,000 mt/year, satisfying a relatively low and stable internal demand for "locos". In 1976, the opening of the national fishing activity to international markets led to a large increase in the world demand for *C. concholepas* and both extractions and price rose rapidly. This export phase, 1976–1981, was accompanied by an open-access shellfish policy, which, at the beginning of the 1980's generated an uncontrolled growth in the number of divers entering the activity (Bustamante and Castilla, 1987; Castilla, 1997a). During this phase the "loco" fishery reached record catch values, approximately 25,000 mt in 1980. This catch represented approximately 30% of the world gastropod catches reported by FAO that year (FAO, 1998b). This level of extraction was unsustainable, leading to the third phase, 1982–1988, where an attempt was made to reduce the catch effort

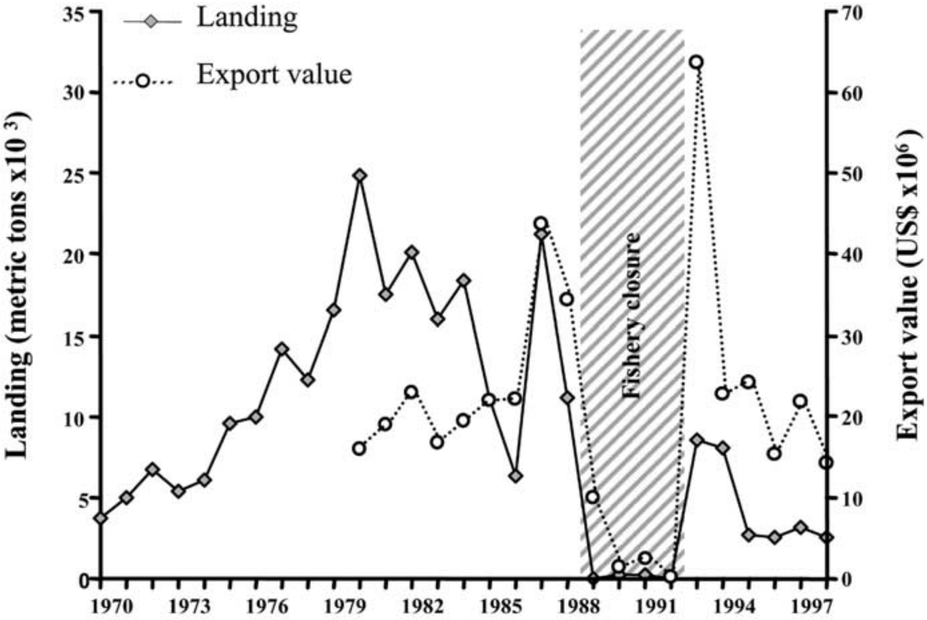

Figure 6. Catches and export values of *Concholepas concholepas* fishery (1970–1998) (taken from SERNAPESCA, Anuarios Estadísticos 1970–1998).

through the successive application of a series of regulatory measures including prolonged temporary closed seasons and total allowable catches (TAC). In spite of attempts to control extraction, regulatory measures did not stop overfishing and illegal catches; mainly because the artisanal fishers were not well integrated into the management actions. Faced with signs of overexploitation, the authorities decreed the complete closure for *C. concholepas* fishery between 1989 and 1992. This phase saw a large increase in the level of illegal extraction (Castilla, 1995). Beginning in 1993, under the new Chilean Fishing and Aquaculture Law (FAL, 1989), modern management tools were applied to the *C. concholepas* fishery. For instance, annual TAC for "loco" were defined and divided among registered divers, and non-transferable individual quotas (NTIQs) were implemented. Management measures were further supported by strong on-site control, allowing authorities to maintain catch levels around the decreed TACs. During this phase (1993–1998) the maximum export value for "loco" peaked at over US $64 million (1993) for a total catch of 8,500 mt (Figure 6).

Data for the other commercial marine gastropod species of Chile do not exist prior to 1978, but fluctuations in catch values after this year appear to be similar to those experienced by the "loco". After *C. concholepas*, the main species extracted in Chile are the muricid gastropods *Thais chocolata* and *Chorus giganteus*, and the multi-species fishery of *Fisurella* spp. For *Thais* and *Chorus* it is possible to observe a rapid catch increase phase (1978–1982), a steady catch phase (1983–1989), and a phase of sustained catch decline (1990–1998), which may be interpreted as an overexploitation phase (Figure 7). In the case of *Fisurella* spp. it is not possible to make a precise interpretation, since there are around 10 species extracted throughout the country, which are recorded as a single extraction item. In any case, the period for the largest extraction of key-hole limpets coincided with the period of the total closure of the "loco" fishery. This could be interpreted as a strategy used by the fishers and/or the processing industry to partially compensate for the lack of "locos". Still, the export values of these gastropods are much lower, and artisanal fishers consider them "secondary gastropod resources" (Figure 7). In the case of *C. concholepas*, if export values are divided by catches, the average exportation price for the past 20 years is over US $4 per kg; while all the other gastropod species group together average US $0.43 per kg. Since 1993, the export value of "locos", and other Chilean gastropods has increased. For instance, between 1981 and 1985 mean annual "loco" catch was approximately

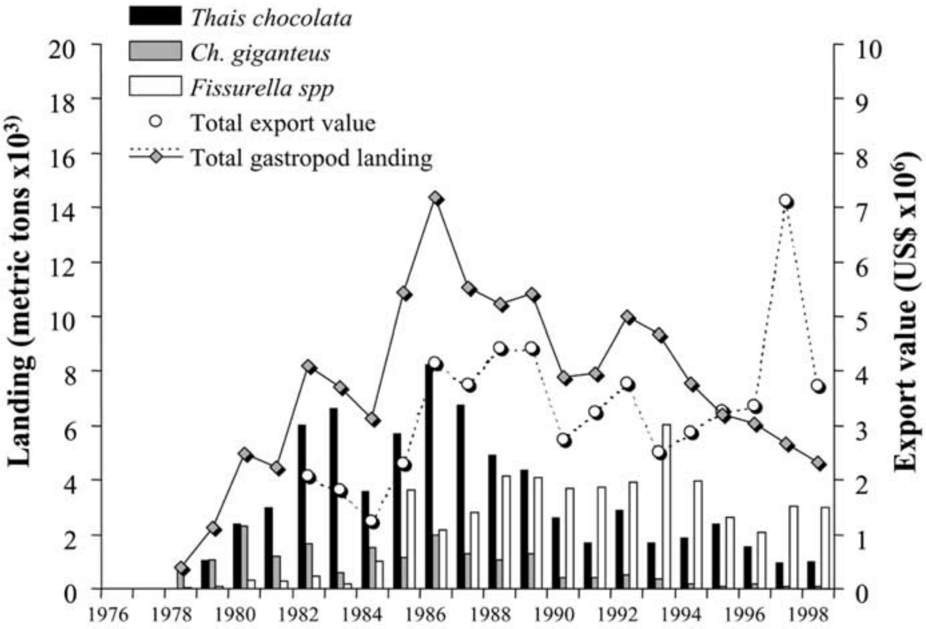

Figure 7. Catches and export value of other Chilean marine gastropod species (1976–1998) (data from Banco Central de Chile, Export Division).

16,000 mt and the mean export value amounted to around US $20 million per year. Between 1994 and 1998 mean annual "loco" catch declined to 3,808 mt (due to legal regulations) yet the corresponding mean export value was similar to previous values at US $19.6 million per year. For the "loco", this indicates that the management strategy used has been successful, where, the application of new fishing laws have allowed for the controlled supply of the resource, generating an increase in the demand. The increased values for other gastropod species may reflect a different situation. In fact, until recently the "non-loco" gastropod fisheries were subject to few regulation measures (e.g., minimum catch sizes and closure during reproductive seasons) in spite of their sustained decline in catches since 1990. Currently, there are no published studies of stock assessment for the "loco" nor other Chilean gastropod resources; however, for *Thais chocolata* studies by Avendaño et al. (1996, 1997) suggest an exhaustion of wild-stocks.

The development of management tools

In Chile, the application of novel management tools for the "loco" fishery, and the lack of management tools for the other gastropod fisheries, demonstrates the importance of economic factors over technical and/or biological criteria in the management of exploited species. The *C. concholepas* fishery represents a "flag-ship species" where management has played a key role in the implementation of innovative, sustainable, adaptive management strategies (Castilla, 1994; Castilla et al., 1998; Castilla and Defeo, 2001). During the 1980's the economic and social crisis, derived from the presumed overexploitation and closure of the "loco" fishery, provoked a strong reaction among and between the social players engaged in the fishery. All players were committed to resolving the problem of "loco" overexploitation. At the beginning of the 1990's, the presence of favorable political conditions in Chile permitted the establishment of modern management procedures (Chilean Fishery and Aquaculture Law, FAL, 1989) for the extraction of "locos" as well as other benthic resources. The FAL represented the first law of general organization of the benthic fishing activities in Chile. For instance, this legislation separates, conceptually and operationally, the industrial and artisanal fisheries, giving the latter an exclusive access zone within the first five nautical miles along the Chilean coast. The FAL created an official registration system for small-scale fishers, thus facilitating the regulation of effort and access into the artisanal benthic fisheries. Furthermore, according to the state of exploitation and biological characteristic of the resources, fisheries were divided into different management regimes (Castilla, 1994; Bernal et al., 1999). For benthic fisheries, the most important adaptive management and conservation tools incorporated in the FAL were: (1) the implementation of a Benthic Regime for Extraction and Processing (BREP); (2) the introduction of Management and Exploitation Areas (MEA's) for benthic resources; and (3) the design of Marine Protected Areas (MPA's).

The BREP is a management tool similar to the system of individual transferable quotas (ITQ) developed for fisheries in Australia, New Zealand and Iceland (Pearse and Walters, 1992; Runolfsson, 1997). It consists of a TAC divided between legally registered divers and fishers through the allotment of individual catch coupons. Unlike ITQ's, the individual quotas, as defined in the BREP, are non-transferable. Additionally, the BREP includes the allocation of processing quotas for the resource among authorized processing plants. The process is accompanied by strong control directed at the fishers, pre-established landing sites and processing plants. The BREP has been utilized in Chile, since 1993, mainly for *C. concholepas.*

The MEA's (usually less than 300–400 ha of sea bottom) are based on the allocation of Territorial Use Rights in Fisheries (TURF's) exclusively to small-scale fisher organizations, and are employed for the rational management and conservation of benthic resources (Castilla, 1994, 1997a; González, 1996; Castilla et al., 1998). The fishery authority assigns MEA's to organized fisher communities, based on their presentation of a specific three-year fishery management plan for the resource(s) to be exploited inside the MEA. The management plan has to be based on biological/environmental surveys and economic information. In Chile, basic and applied monitoring/experimental studies on *C. concholepas* (for a review see Castilla, 1999) since the mid-1980s have had great relevance for the conceptual origin and implementation of MEA's. These studies were mainly conducted in small Marine Reserves controlled by universities, and legally protected from extraction or collecting activities (Moreno et al., 1984; Castilla and Durán, 1985; Moreno, 1986; Moreno et al., 1986; Oliva and Castilla, 1986; Durán and Castilla, 1989; Castilla, 1993, 1999).

The information gathered from these studies served as a basis for orienting the scientific and technical work done in zones spontaneously protected by organizations of small-scale fishers during the 1981–1992 *C. concholepas* fishery crisis (Castilla, 1989; Castilla et al., 1993, 1998; Payne and Castilla, 1994; Castilla and Pino, 1996). The successful results of pilot-MEA plots (less than 50 ha of sea bottom), owing to cooperation between fishers and scientists, served as a model for the final development of the concept introduced in the 1989 FAL (Castilla, 1994, 1996, 1997b; Castilla et al., 1998). Hence, the MEA management tools support two new elements for benthic fishery management in Chile: (1) the incorporation of marine ecological data as an indispensable component for the administration and sustainable exploitation of benthic invertebrate fisheries; and (2) the implementation of co-management strategies where the fishers are central players in the adaptive management procedures. These tools have begun to be widely implemented in Chile since 1998 (Castilla and Fernández, 1999; Castilla, 2000; Castilla and Defeo, 2001).

As of year 2000, fisher communities have presented over 25 MEA plans to the Chilean government to manage different benthic invertebrate resources. These plans include at least a dozen species, ranging from the tunicate *Pyura chilensis*, to gastropods, mainly *C. concholepas* (listed in all the plans) and bivalves, as well as crustaceans, such a the stone crab *Homalaspis plana.* These invertebrates show a wide pattern of reproductive strategies and spatial distributions, which need to be taken into account when evaluating the extent and total area(s) of the solicited MEA; as well as considerations regarding spatial distribution of the MEA's along the coast (at present these factors are not considered). For instance, among the muricid gastropod species mentioned above, development strategies range from planktotrophic-teleplanic types, such as *Concholepas concholepas*, *Thais chocolata* and (probably) *Xantochorus cassidiformis* (Gallardo, 1981; DiSalvo, 1988; Gallardo and González, 1994; Romero, 1995), to demersal development strategies in *Chorus giganteus* (Leiva et al., 1998), and direct development in *Trophon geversianus* (Santana, 1997).

These gastropod life-history characteristics associated with nearshore larval dispersal/retention mechanisms (i.e., Poulin et al., 2002) and recruitment are key factors which have to be taken into account in the future application of this management tool, regarding the size, number and spatial distribution of MEA's along the coast (or in designing a combined network of MEA's and MPA's, see below and Castilla, 2000). For instance, it has been pointed out that benthic invertebrates with different development strategies would require MPA's with different spatial structures to preserve their effectiveness (Baker et al., 1996; Allison et al., 1998). Trade-off's in the spatial definition of MPA/MEA network schemes will need to be considered for in the future (see Castilla, 2000). Furthermore, biological / preservation / economic and consensus agreements between different social players in the small-scale fishery systems will be needed. MPA's, in the form of Parks and Reserves, are defined by the 1991 Chilean FAL as marine zones administrated by the Government to preserve a particular ecosystem units. These areas are reserved for monitoring and research. Extractive (fishery) activities can occur under special circumstances, but must be duly authorized by the government. MPA zones have not yet been implemented in Chile, and therefore, it is not possible to assess their value in attaining sustainable use of benthic invertebrates in this country. On the other hand, Chile does have a small number of Marine Reserves/Preserves, which are mainly operated by universities (see above, Castilla, 1996). As pointed out above, research carried out during the past 15–20 years in these protected areas has had an important impact on the establishment of MEA's (see Castilla, 1999, 2000, 2001). For instance, Manríquez and Castilla (2001) have demonstrated how one of these protected areas, the Marine Reserve at Las Cruces (Estacion Costera de Investigaciones Marinas), is acting as a seeding ground of *C. concholepas* for adjacent open access areas; a significant finding supporting the creation of MPA's in Chile.

Steps toward the sustainable management of gastropods and other benthic invertebrates

Following the economic integration towards international commerce (globalization) and stock collapses of some benthic resources (for gastropods see Tegner, 1989; Castilla, 1997b; Castilla et al., 1998; Ramade-Villanueva et al., 1998; Prince et al., 1998; Murray et al., 1999; Hobday and Tegner, 2000) rapid modifications occurred in fishing legislations (for Mexico see Arenas and Díaz, 1997; Ramade-Villanuueva et al., 1998; for Chile see Castilla, 1994; Bernal et al., 1999; for Australia see Prince et al., 1998; for New Zealand see Kidd, 1997). For instance, the Chilean 1989 FAL, made possible the cross-fertilization of traditional management visions, together with the implementation of novel adaptive management tools and strategies, each having different strengths, weaknesses and limitations. These instruments are generally not mutually exclusive, and through their complementary use it was possible to generate redundancy in control measures, directed towards the sustainable management of Chilean gastropods and other invertebrate species exploited by small-scale (artisanal) groups. For instance, the BREP demonstrated its efficiency as a management regulatory tool in the case of *C. concholepas* fishery, but due to elevated operative and control costs this tool presents limitations for its large-scale application in fisheries of low economic profit.

Fishery quota management systems, for instance those based on ITQ's, have been widely implemented around the world (i.e., Kidd, 1997; Shallard, 1997; Dewees, 1998) and gastropod fisheries, such as fisheries for abalones, have been part of these systems (i.e., Prince et al., 1998). Under ITQ's the race for resources has been modulated, since each quota owner is assured access to a portion of the total allowable catch. Nevertheless, for ITQ's to succeed it is essential to at least have: (1) a good scientific stock assessment evaluation at hand, and to be sure that TAC objectives are properly addressed, and (2) transparent market forces in operation. These conditions are not always present, and, therefore, in many instances where these management measures have been used illegal extractions have represented an extra problem. Furthermore, the implementation of management measures such as TAC's, ITQ's, or INTQ's (see Castilla et al., 1998) require that the scale of the management measures correspond to the scale of the stock, particularly in the case of spatially intricate resources (Prince et al., 1998).

Incentives for co-management and/or self management (Hanna, 1994; Hutton et al., 1997; Kidd, 1997; Shallard, 1997; Castilla and Defeo, 2001) in small-scale fisheries (as in the case of most gastropod resources), through the establishment of models which incorporate territorial property rights in fisheries, appear extremely attractive (although perhaps difficult to implement) and appear to have a high potential for successs. For instance, the implementation of the MEA's in Chile (see Castilla, 1994; Castilla et al., 1998) permitted a direct regulation of the overexploitation problem of gastropod species, particularly in the case of *C. concholepas*. Under this management system the communities of artisanal fishers (unions, syndicates) have the responsibility to define and implement their own management plans for benthic invertebrate resources, within the solicited MEA. They are responsible for conducting technical and biological studies through authorized research institutions. The central administration evaluates the proposed management plans, approves the allocation of each MEA and controls the subsequent execution (González, 1996). Under this co-management scheme, the establishment of technical capabilities in fishers unions represent the keystone organizational element for the development of successful management experiences. In Chile, the government has promoted discussion, cooperation and technical assistance between small-scale fishers, scientists and managers, and schemes are adapted as experience accumulates. A similar situation has been reported for the abalone fisheries managed under the cooperative associations on the west coast of the Baja California peninsula (Ramade-Villanueva et al., 1998).

Nevertheless, TURF's are not the only management tools which may generate sustainability for small-scale invertebrate fishery resources. We think that a comprehensive strategy must also consider MPA's as instruments for conservation, management and recuperation of fisheries for species with restricted movement or with limited larval dispersal (Murray et al., 1999; Castilla, 2000) Some of the potential benefits of the MPA's are: (1) the strengthening of productivity through the protection of larger sized individuals, permitting an increase in potential reproduction of the stock (Castilla et al., 1998; Castilla and Fernández, 1998); (2) the repopulation of non-protected or open access fishery zones next to the MPA's through the exportation of propagules (Manríquez and Castilla, 2001); (3) the maintenance of the structure and genetic variability of exploited metapopulations; and (4) conservation of nursery and reproductive grounds (Baker et al., 1996; Castilla, 1999). For instance, Castilla (2000) proposed the implementation of a comprehensive model for the sustainable management and conservation of invertebrate resources in Chile. The model combines MEA's, MPA's and open access fishery grounds in a spatially structured network of areas of "take" (for instance MEA's as co-management units and open access areas) and areas of "no-take" (MPA's) distributed along the coast. The model integrates management and conservation from a complementary conservation and fishery perspective.

In a social context, the model unites the granting of TURF's, with the principles of co-management and community based-management (Castilla and Defeo, 2001). In the biological and fishery contexts, the model may serve as a fertile field for the design and application of studies aimed at generating management protocols for medium and long time scales, based on the principle of adaptive management (Walters and Holling, 1990; Parma et al., 1998; Castilla and Fernández, 1999; Castilla, 2000). The effectiveness of such a management scheme requires consideration of two fundamental aspects: (1) characteristics associated with the structure, function and relationship between the institutions involved (i.e., fisher organizations, scientific institutions and management agencies); and (2) an appropriate understanding of the bio-ecological and spatial structure, resilience and dynamic of the exploited resources (Castilla, 2001; Castilla and Defeo, 2001).

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