Aquatic Ecology **36:** 41–50, 2002.

Management strategies for sustainable invertebrate fisheries in coastal ecosystems of Galicia (NW Spain)

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Accepted 18 July 2001

Key words: coastal ecosystems, fisheries management, conservation biology, benthic invertebrates, marine protected areas, population dynamics

Abstract

Artisanal coastal invertebrate fisheries in Galicia are socio-economically important and ecologically relevant. Their management, however, has been based on models of fish population dynamics appropriate for highly mobile demersal or pelagic resources and for industrial fisheries. These management systems focus on regulating fishing effort, but in coastal ecosystems activities that change or destruct key habitats may have a greater effect on population abundance than does fishing mortality. The Golfo Artabro was analysed as a representative example of a coastal ecosystem in Galicia, and the spider crab *Maja squinado* used as a model of an exploited coastal invertebrate, for which shallow coastal areas are key habitats for juvenile stages. The commercial legal gillnet fishery for the spider crab harvests adults during their reproductive migrations to deep waters and in their wintering habitats. Illegal fisheries operate in shallow waters. The annual rate of exploitation is >90%, and <10% of the primiparous females reproduce effectively at least once. A simple spatially-explicit cohort model was constructed to simulate the population dynamics of spider crab females. Yield- and egg-per-recruit analyses corresponding to different exploitation regimes were performed to compare management policies directed to control the fishing effort or to protect key habitats. It was found that the protection of juvenile habitats could allow increases in yield and reproductive effort higher than in the present system, with such protection based in the control of the fishing effort of the legal fishery. Additionally, there is an urgent need for alternative research and management strategies in artisanal coastal fisheries based on the implementation of a system of territorial use rights for fishers, the integration of the fishers into assessment and management processes, and the protection of key habitats (marine reserves) as a basic tool for the regulation of the fisheries.

Introduction

Worldwide coastal ecosystems are subject to multiple human impacts as economical and conservation interests often conflict. The fisheries crisis of the last decades and the overexploitation of a great number of stocks (McGoodwin, 1990) have been due mainly to the inadequacy of scientific knowledge, uncertainties in assessments or failures of the management systems (Ludwig et al., 1993; Hilborn et al., 1995). These problems are critical when the management of coastal ecosystems and artisanal fisheries is involved (see Freire & García-Allut, 2000, for a detailed discussion of the concept of artisanal fishery). Coastal systems have a great complexity due to the high number of human factors that influence their functioning (related directly to the exploitation of fisheries resources, but also to other types of activities that modify and destroy habitats and a number of components involved in the fishing activity (which is usually multispecific, multigear, with a diversified fleet that shows a complex spatial pattern of activity). Moreover, a great number of stocks exploited by coastal artisanal fisheries focus are invertebrates, with a strong and persistent spatial structure and population dynamics that find no fit in finfish models (Orensanz & Jamieson, 1998). Artisanal fisheries have a strong socio-economic, cultural and ecological importance in coastal areas. The small-scale coastal fisheries have a great social significance, even though the offshore industrial fisheries are the most productive on a worldwide level (McGoodwin, 1990; FAO, 1995; Orensanz & Jamieson, 1998)

In this paper, first we review the main characteristics of the Galician artisanal fisheries (NW Spain, NE Atlantic), where coastal benthic invertebrates are the main resources. Second, the implications of the life histories and population dynamics of coastal invertebrates in assessment and management are discussed. Third, a spatially-explicit population dynamics model of the spider crab *Maja squinado*, a model of an exploited coastal invertebrate in Galician coasts, is presented to compare management policies directed to control the fishing effort or to protect key habitats. Finally, alternative research and management strategies for coastal invertebrate resources, based in part in lessons from conservation biology, are discussed.

Artisanal coastal fisheries in Galicia (NW Spain)

The Galician coast is more than 1200 km long (Figure 1) supporting over 80 communities, ranging from large cities to small villages, whose economies depend largely on the harvesting of fish and shellfish. The artisanal fleets operate in numerous coastal embayments (rías) and shallow oceanic areas, harvesting in the intertidal zone and down to 60–80 m depth. Small vessels (usually under 12 m in length), divers or intertidal shellfishers carry out the fishery; a low to medium level of technological equipment is used (Freire & García-Allut, 2000).

According to the official census of the Galician fishing fleet in 1994 (Xunta de Galicia, 1995), there were 8811 vessels with 28 014 fishers (over a total population of approximately three million inhabitants). Approximately 50% of the fishers work on vessels less than 9 m in length, and 49% of the fleet pertained to productive units consisting of only one fisher. However, these data only reflect legally registered fishers. In practice, the number of people who carry out fishing activities is substantially higher, since we must also consider those individuals who are not fishing full-time, but who, during certain times of the annual fishing cycle, carry out specific fisheries to supplement their incomes. Although difficult to quantify, they must be considered in the artisanal sector as harvesting agents who also have an effect on the coastal ecosystems. The artisanal sector in Galicia provides employment and energises a complex economic sector (fishing-handling-marketing-transport-processing, etc.), and a large human population is almost totally dependent on this fishing activity.

The artisanal fisheries operating off the Galician coast are multispecific and multi-gear, exploiting a diverse array of more than 50 species (Xunta de Galicia, 1992), mainly sedentary benthic or mobile benthic/demersal invertebrates (for classification see Orensanz & Jamieson, 1998) with all or part of their life-cycle phases inhabiting shallow waters close to the coastline (Table 1). Among the most important species, from an economical point of view, are crustaceans (the velvet swimming crab, spider crab, prawns and goose barnacle) bivalves (several species of clams, razor clams, scallops and cockles; seeding from commercial hatcheries is an habitual practice in the intertidal), gastropods (abalone), cephalopods (octopus, cuttlefish and squid), echinoderms (sea urchins), and fishes (catches are generally low; only specific fisheries for bib *Trisopterus luscus* or conger eel *Conger conger*). For some species that migrate between coastal and offshore waters (such as squid and bib), the artisanal fishery only exploits one stage of the life cycle, while the demersal and pelagic fisheries on the continental shelf exploit all other stages.

Only a few species in Galicia (mainly octopus, spider crab, velvet swimming crab and goose barnacle) support fisheries that target one species (excluding bivalve semi-culture in intertidal areas). The abundance and commercial value of the other species do not allow for the development of monospecific fisheries. The current situation is the result of (1) the use of fishing strategies involving diversification, with an annual fishing cycle defined basically by the use of different gears and methods depending on the seasonality of the resources and the management regulations, and (2) the state of overexploitation or depletion of many of the harvested stocks, as will be discussed later.

Assessment and managament of benthic invertebrates

The assessment of the artisanal fisheries has traditionally been based on classical models of population dynamics developed by Beverton & Holt (1957), such

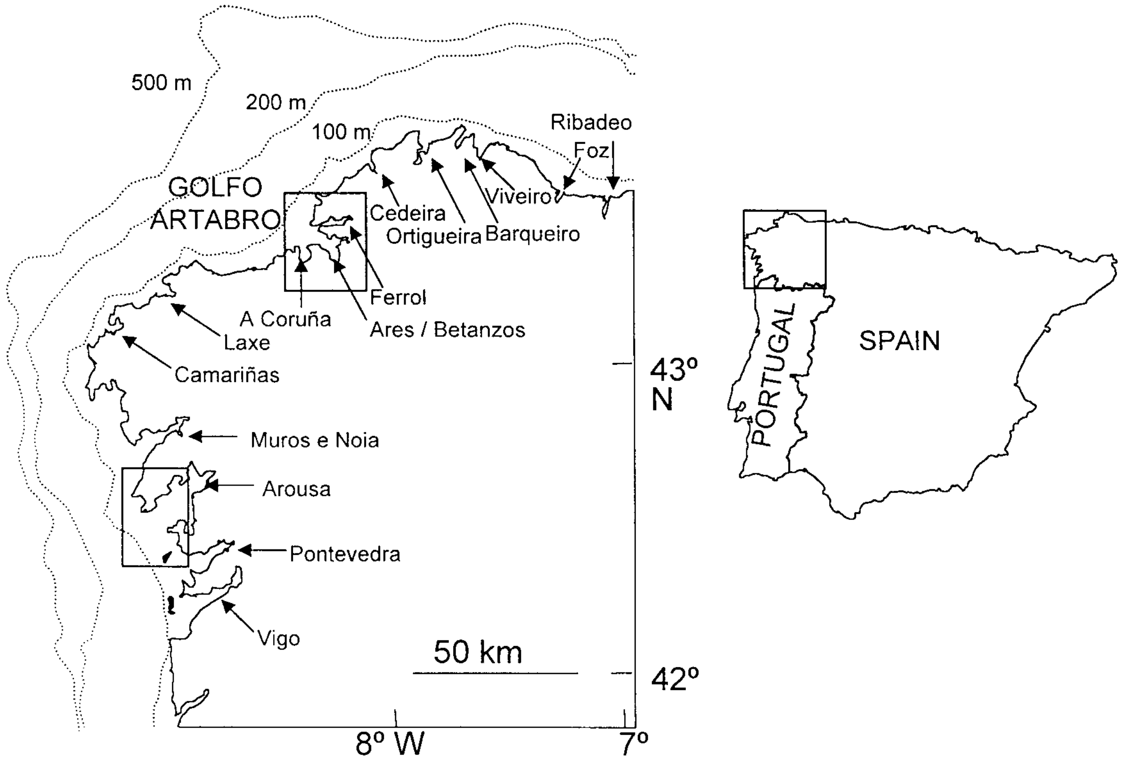

Figure 1. Galician coast in the NW of Spain showing the main coastal embayments ("rías"). The artisanal fisheries are carried out in the rías and oceanic coastal areas, from the intertidal to 60–80 m deep. Industrial and semi-industrial fisheries are developed mainly in the continental shelf (up to approx. 200 deep) and upper slope (200–500 m). The Golfo Artabro and the part of the Ría de Arousa and adjacent oceanic areas, where the data used in the modelling of the spider crab fishery were obtained, are marked.

as dynamic-pool and surplus production models and virtual population analysis (see Hilborn & Walters, 1992 and Perry et al., 1999), which are more appropriate for highly mobile demersal or pelagic resources and for the management of industrial fisheries (Orensanz & Jamieson, 1998; Caddy 1999). However, from a biological standpoint, the species harvested by the artisanal coastal fleet of Galicia, and particularly most of the invertebrate species, present a number of characteristics that render the above-mentioned analytical models not adequate to understand their population dynamics (Caddy, 1999; Perry et al., 1999) (Table 2). These species, whether sedentary benthic or mobile benthic/demersal (Table 1), have a strong and persistent spatial structure (in the sense of Orensanz & Jamieson, 1998). Therefore, management decisions must incorporate this spatial heterogeneity. In this sense, the main population characteristics of these resources include: (1) complex life cycles (planktonic dispersing larval stages and benthic or demersal postlarval stages); (2) aggregations evident on different spatial scales; (3) a meroplanktonic metapopulation structure in which the postlarval stages form a chain of local populations along the coast with low migration and dispersal levels interconnected by a planktonic larval stage; and (4) the aggregated stock-recruitment relationship is not applicable to a segment of a metapopulation (Jamieson & Campbell, 1998). The processes of physical transport of larvae to appropriate habitats for recruitment have been recently defined as a key (density-independent) process in recruitment of invertebrates (Botsford et al., 1994).

Another problem with management systems based on classical models lies is that they focus on regulating fishing effort as being the only relevant human impact on the system. In coastal ecosystems, in contrast, there are a number of activities that lead to modification or destruction of key habitats (e.g., Rothschild et al., 1994), and these may have a greater effect on population abundance than does fishing mortality.

Table 1. Main invertebrate species exploited by the artisanal fisheries operating in coastal waters of Galicia (intertidal to 60–80 m). Each species is classified according to their spatial structure and mobility (resource types proposed by Orensanz & Jamieson, 1998). The main fleets targeting each species are indicated

Common name	Scientific name	Resource type[1]	Fleet[2]
CRUSTACEANS			
Velvet swimming crab	*Necora puber*	M	B
Spider crab	*Maja squinado*	M*	B
Edible crab	*Cancer pagurus*	M*	B
Prawn	*Palaemon serratus, P. elegans*	M	B
Goose barnacle	*Pollicipes pollicipes*	SB	H
CEPHALOPODS			
Octopus	*Octopus vulgaris*	M	B
Cuttlefish	*Sepia officinalis, Sepia elegans*	HM	B
Squid	*Loligo vulgaris, Loligo forbesi*	HM	B
BIVALVES			
Clam, pulled carpet shell	*Venerupis pullastra*[3]	SB	H, B
Clam, grooved carpet shell	*Venerupis decussatus*[3]	SB	H, B
Clam, banned carpet shell	*Venerupis rhomboides*[3]	SB	H, B
Short necked clam	*Venerupis japonica*[3], *Venerupis semidecussatus*[3]	SB	H, B
Common cockle	*Cerastoderma edule*[3]	SB	H, B
Razor clam	*Ensis ensis, E. arcuatus, Solen marginatus*	SB	H, D
Sword razor shell	*Ensis siliqua*	SB	H, D
Scallop	*Pecten maximus*	SB	B
Queen scallop	*Aequipecten opercularis*	SB	B
Wart venus shell	*Venus verrucosa*	SB	B
	Dosinia exoleta	SB	B
Wedge shell	*Donax trunculus, D. variabilis*	SB	B
GASTROPODS			
Abalone	*Haliotis tuberculata*	SB	D
ECHINODERMS			
Sea urchin	*Paracentrotus lividus*	SB	D

[1]Resource type: SB, sessile/sedentary benthic; M: mobile benthic/demersal (M*, perform seasonal or ontogenetic migrations with high mobility); HM, highly mobile demersal or pelagic.
[2]Fleet: B, boat-based (using traps, gillnets, fishing lines, . . .); D, divers; H, Intertidal harvesters.
[3]Species for which semiculture practices (seedling) are carried out.

A case study: the fishery for spider crab *Maja squinado*

Here we examine the Golfo Artabro (Figure 1), constituted of various embayments and adjacent oceanic areas with a mixture of hard and sandy bottoms, as a representative example of a coastal ecosystem in Galicia. Different invertebrates and fishes are exploited, but scientific information about their population dynamics is very restricted. The spider crab *Maja squinado* is used here as a model of an exploited coastal invertebrate because this decapod crustacean has the typical characteristics of coastal invertebrate resources, and data are available for a detailed analysis of its population dynamics. Moreover, this species has a high fishery interest in the entire Galician coast

Table 2. Comparison of the main characteristics of resources exploited by artisanal and industrial fisheries world-wide relevant for the understanding of their population dynamics and their management. Secondary characteristics are indicated in parentheses

Characteristics	Artisanal fisheries	Industrial fisheries
Taxonomic groups	Invertebrates (Fishes)	Fishes (Invertebrates)
Resource type	Sedentary benthic/ Mobile benthic or demersal	Highly mobile demersal or pelagic
Location	Coastal (Offshore)	Offshore (Coastal)
Spatial structure	Strong and persistent	Weak/Strong in pelagic fishes
Spatial scale of unit stock	Small	Large
Aggregations	Yes	No/Yes in pelagic fishes
Relevance of:		
-Aggregate stock-recruitment relationship	Low	High
-Metapopulation structure	High	Low
Human impacts	Fishery, removal of individuals Habitat alteration	Fishery, removal of individuals

as more than 1,000 artisanal boats harvest this species (Freire et al., in press).

Life history, habitat and metapopulation structure

The following synthesis of the life history and population dynamics of the spider crab is based on different studies carried out in the southern (mainly the Ría de Arousa) and northern (Golfo Artabro, mainly in the Ría da Coruña) Galician coast analysing growth (González-Gurriarán et al., 1995), reproduction (González-Gurriarán et al., 1993, 1998; Sampedro et al., 1999), habitat use and migrations (González-Gurriarán & Freire, 1994; Hines et al., 1995; Freire et al., 1999), and spatial structure and population dynamics, especially of the coastal juvenile stages (unpublished data).

Spider crabs present a complex meroplanktonic metapopulation structure. Postlarval recruitment occurs in shallow rocky areas (<5–10 m) from late spring to autumn (probably in three pulses). Juveniles have a patchy distribution along the coastline, with an ontogenetic movement from rocky recruitment habitats to shallow sandy bottoms (approx. 5 to 15 m) when they attain approx. 67 to 105 mm carapace length (CL) and are 12 to 18 months old (depending of the settlement cohort) (Figure 2). Mark-recapture studies have shown that large juveniles (67 to 120 mm) inhabiting sandy bottoms remain in the same local population and exhibit strong aggregative behaviour with coordinated and restricted movements within local areas of available habitat. Body sizes given here correspond to mean modal sizes determined for females using mixture analysis to decompose the monthly size frequency distributions obtained in the Ría da Coruña from 1997 to 1999.The information on substrate types used by the different juvenile phases corresponds to the Ría da Coruña, an exposed area. In more sheltered bays, such as the Ría de Arousa, a higher proportion of large juveniles remain in rocky bottoms. Sexual maturity is attained after a terminal moult in summer (July–September) when crabs are approx. 19 to 26 months old. A small proportion of large juveniles (120 mm CL) delay maturity for another year, with a terminal moult when they are approximately 3 years old.

Postpubertal adults (120 to 155 mm CL) migrate in autumn (October–November) to deeper soft bottoms (approximately 30 to 100 m) as the development of seminal receptacles and of female gonad maturation commences. Adults originating from different juvenile populations in the Golfo Artabro mix in deep waters, constituting one or a few local populations. After mating, females return to shallow oceanic areas in January and February for egg incubation and larval release. According to fishers, males do not participate in the return migration to shallow waters, but rather remain in their wintering habitats. The annual breeding period of Maja squinado on the coast of Galicia ranges from March until November, and the number of clutches per year and per female is estimated to be three, with spawnings probably occurring from May to November.

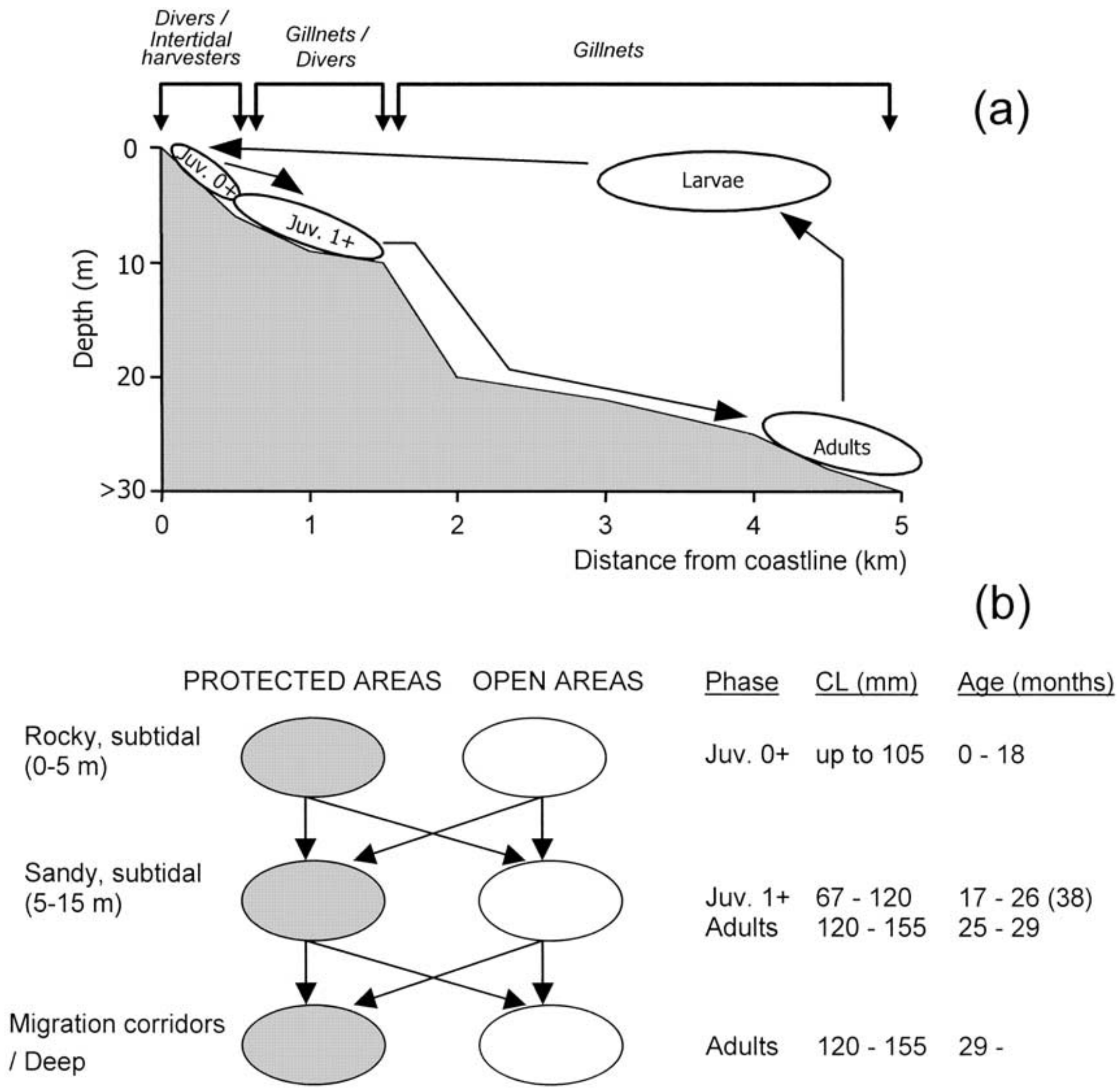

Figure 2. (a) Scheme of the life history of the spider crab *Maja squinado* in the Golfo Artabro. The spatial location of each phase and the dispersal and migratory movements connecting the different local populations are shown. For simplicity, the return of adult females after mating to oceanic shallow waters where the larvae actually hatch has been omitted. The areas where the three main fisheries operate are shown at the top. (b) Main biological characteristics of spider crabs using different habitats. CL = carapace length.The lefthand scheme represents the spatial configuration used to model the population dynamics and fishery. The arrows show the dispersal and migratory movements considered in the model. See text for further explanation.

Fishery

The commercial legal fishery for the spider crab operates mainly from November/December to May/June using tangle- and gillnets, harvesting adults during their offshore migrations and in their wintering habitats. Different analyses of the exploited stock (especially the Leslie method of stock depletion) on the southern coast of Galicia reveal an annual rate of exploitation >90% (Freire et al., in press). Considering that first hatching takes place approx. in May–June and taking into account the seasonality of the catches, <10% of the primiparous females reproduce effectively at least once. The present regulations include a minimum landing size (120 mm CL, lower than the average size at maturity in the Galician populations), protection of ovigerous females, gear restrictions, and closed seasons.

Illegal and unregulated fisheries also harvest spider crabs, mainly juveniles, in shallow waters. These fisheries are boat-based (using gillnets), or carried out by divers or gatherers in the rocky intertidal, and have high mortality rates (unpublished data). Two separate illegal fisheries will be considered here. In the rocky subtidal (approx. 0–5 m deep) divers and intertidal harvesters capture juveniles (67 to 105 mm CL) from spring (when they are approx. 10 months old) until their dispersal to subtidal sandy habitats. In these soft-bottom habitats (5–15 m), juveniles (from 67 to 120 mm CL) and postpubertal adults are exploited by divers and gillnets during their entire stay in this habitat.

Modelling the effects of different management strategies

Taking the above information into consideration we constructed a simple spatially explicit cohort model to simulate the population dynamics of the spider crab females. The objective was to perform yield- and egg-per-recruit analyses corresponding to different exploitation regimes so as to compare management policies directed to control the fishing effort or to protect key habitats. Only the main characteristics and results of the model will be outlined.

The population dynamics of a female cohort was modelled using monthly transfer probabilities among life-history stages defined by age, size and habitat. Three different habitats were represented, viz. rocky subtidal, sandy subtidal and migration corridors and deep waters, where juveniles 0+, juveniles 1+ and adults, respectively, were the dominant phases. Each habitat was divided into protected (no fishing) and open (fishing allowed) areas. Instantaneous rates of natural and fishing mortalities (M and F respectively, years^{-1}), where habitat-dependent (M_{j0} and F_{j0} for the rocky subtidal; M_{j1} and F_{j1} for the sandy subtidal; and M_a and F_a for the deep waters; note that mortalities are referred to the main stage living in each habitat, but they are applicable to all the stages in a given habitat).

The model was run with different combinations of fishing mortalities ($F_{j0} = 0$–2, $F_{j1} = 0$–2, $F_a = 0.5$–4; covering the range of mortalities estimated from the field and fishery data, subject to the constraint of $F_a \geq F_j$) and proportions of protected habitat (from 10 to 100%). Natural mortality estimates were selected to be consistent with the life history of the spider crab and with data from other species with similar life histories and habitats ($M_{j0} = M_{j1} = 1$, $M_a = 0.2$). Sensitivity analyses showed that results are robust for the uncertainties about the natural mortality (the relative performance of different fishing management policies remained similar, independently of the natural mortalities applied). Yield was estimated as biomass caught per recruit, and reproductive effort as number of eggs produced per female recruit. For this, the relationships between brood size – number of eggs – and body size obtained for southern Galician populations, differentiating the first brood of primiparous females that is smaller than later broods, were used (unpublished data).

When only the effect of fishing mortality is analysed (all habitat is open to the fishery), yield increased with increasing F_a (from approximately 36 g recruit^{-1} for $F_a = 0.5$ to 84 g recruit^{-1} for $F_a = 4$ and no juvenile fishing), although for $F_a \geq 2$, yield depended mainly of the value of F_{j0}, increasing yield with decreasing juvenile mortality. Reproductive effort declined dramatically with increasing fishing mortalities, taking values from 135×10^3 eggs recruit^{-1} for a virgin population or approximately 85×10^3 eggs for a low adult fishing mortality ($F_a = 0.5$, no juvenile fishing) to 8×10^3 eggs (for $F_a = 4$ and $F_j = 0$) and less than 1×10^3 eggs (for $F_a = 4$ and $F_j = 2$). From a management point of view, the main limitation of these results is that control of fishing mortality (regulating the fishing effort) is not possible. This is because no information is available on gear catchability, existing effort, stock size and stock spatial structure for every spider crab population along the Galician coast.

A second series of simulations analysed the effect of juvenile and adult habitat protection, and different fishing mortality combinations were used for each scenario to determine the sensitivity of this management to the uncertainties in these parameters (Figure 3). Protection of the adult habitat increased the reproductive effort, but decreased biomass yield. When protected areas were established in the rocky subtidal (juvenile 0+) habitat, yield and eggs per recruit increased, but the gain in reproductive effort was low compared to other scenarios. When sandy subtidal (juvenile 1+) habitat was protected (alone or together with rocky subtidal areas) the resulting pattern was more complex, because yield decreased when protected area size was small (up to 50% of the habitat), but increased thereafter attaining maximum values when the entire juvenile habitat was protected. Reproductive effort increased considerably when juvenile habitat was protected, and the same levels of egg pro-

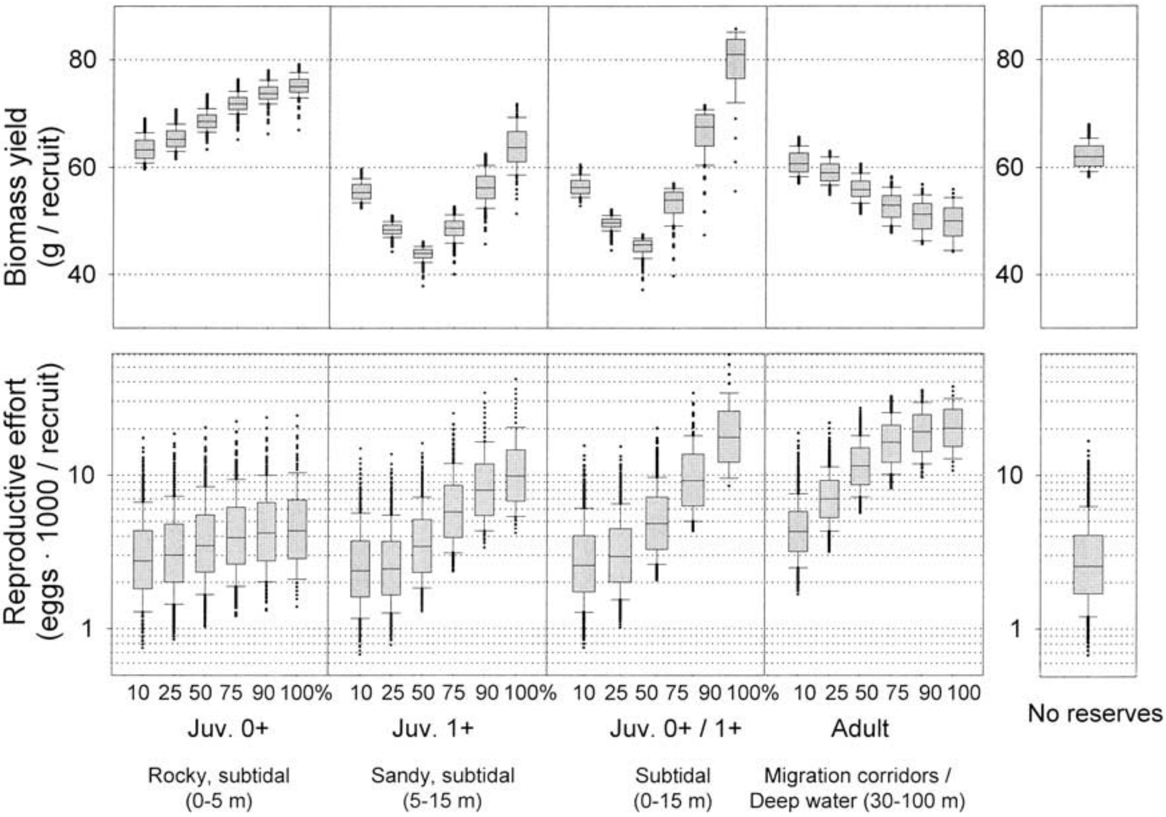

Figure 3. Simulations of the effects of different management strategies on female population dynamics and the fishery of the spider crab. Biomass yield and reproductive effort (eggs produced) per recruit are presented as a function of the proportion (%) of habitat protected. "No reserves" indicate simulations carried out with a 0% of protected habitat. Each habitat is designated by the type of bottom and depth and the main life-history phase inhabiting it. For each scenario, different combinations of fishing mortalities (F) for each habitat were used (approx. 450 simulations were performed for each scenario with F taking values from 0 to 2 for shallow waters and from 0.5 to 4 for deep waters). The boxes of the 'box-and-whisker plots' represent the median and the 10 and 90 percentiles, the bars 5 and 95 percentiles, and the dots the extreme values. Natural mortality (M) was set at M=1 for shallow areas and M=0.2 for deep areas.

duction could be attained with the closure of adult or juvenile areas to the fishery. Overall, the protection of juvenile habitats could allow increases in yield and reproductive effort higher than the present system based mainly in the control of the fishing effort of the legal fishery. In an artisanal fishery context, the protection of habitats (no-take zones) is probably the simplest regulatory measure to implement, because only habitat mapping and information on use are required. Additionally, the control of the compliance of this regulation is simpler than the control of fishing effort (especially for co-management systems, see below).

Alternative management systems for coastal invertebrate resources: learning from conservation biology

Although less documented, the state of overexploitation and biological characteristics of the spider crab (meroplanktonic metapopulation structure, aggregation, and dependence of shallow coastal habitats) are typical of many of the invertebrate species fished by artisanal fleets in Galicia. It is difficult to analyse the level of exploitation of Galician coastal resources because for most of the stocks there are no assessments, and for species for which assessments have been made, these are highly fragmentary. However, there are a number of indications of overexploitation of many of the target stocks:

(1) The depletion and collapse of stocks (e.g., lobster *Homarus gammarus*, spiny lobster *Palinurus ele-*

phas, and sea bream *Pagellus bogavareo*). At present their catches are negligible but historically they were important in the area.

(2) A consistent decline of catches from the 1940's and 1960's to the present time, e.g., in crustaceans (unpublished data).

(3) Exploitation rates of $\gg$90% per fishing season; e.g., in spider crab in the Ría de Arousa (Freire et al., in press) and the Golfo Artabro (unpublished data).

(4) Fishers' long-term observations that are consistent with the above.

The artisanal fisheries of Galicia are managed almost exclusively by the administration of the Autonomous Government of Galicia. The regulatory measures are aimed at species (minimum landing sizes, protection of ovigerous females, maximum catch limits etc.); gears (number of gears per vessel and fisher, maximum length, minimum mesh size etc.); and spatial and temporal closures (specific zones and depths for specific gears and species). These regulations are directed, almost exclusively, to the control of fishing effort, with limited attention paid to the conservation of critical habitats. For example, the habitat of spider crab juveniles has been altered or destroyed in numerous areas of the Galician coast due to different types of human constructions (sea walls, ports, etc). In the Ría da Coruña more than 25% of the coast has been altered directly. Other indirect modifications of the coastal habitat are due to changes in hydrodynamics, transport of sediments or contamination. In the Ría da Coruña these changes include a reduced entry of oceanic water (Montero et al., 1997) and, potentially, also reduced dispersal of planktonic larvae from the coastal oceanic areas (where females hatch) to shallow rocky bottoms located in the interior of the ría (adequate for settlement).

Due to the ecological and social complexity and relatively low economic value of each individual stock, the statistical data and scientific knowledge available are insufficient for a classical management of these artisanal fisheries (Freire & García-Allut, 2000). As a direct consequence the management of the coastal fisheries in Galicia is, in practice, more politically than scientifically oriented and a critical state of economic inefficiency is evident due to the overexploitation of resources. These problems, in our opinion, are linked to the fact that the biological and socio-economic paradigms in which the management policy is based are not adequate for this artisanal context. Therefore, there is an urgent need for the development and application of alternative management strategies and concomitant research. To that extent, regulations of general applicability, such as the protection of critical habitats to sustain the biodiversity in conservation biology and the integration of the fishers' ecological knowledge (Freire & García-Allut, 2000), are the key to a sustainable management of these coastal ecosystems. We will briefly outline the three main lines of action that in our opinion could allow a sustainable and efficient use of these coastal resources:

(1) The implementation of a system of territorial use rights for fishers, based in the spatial structure of the exploited stocks and in the geographical areas used by each fishing community. In this sense, a change from an open to a restricted-access system is needed to give property rights to the local fishers' communities. The successful design of this system should combine biological and socio-political criteria.

(2) The integration of the fishers in assessment and management processes, in collaboration with government agencies. An adaptive co-management system should be developed using the experience obtained in each territory in a continuous process of learning and modification of the management system.

(3) Within the regulations to be established by the co-managers (fishers and administration), the protection of key habitats (marine reserves) should be a basic tool (see also Nowlis & Roberts, 1999), together with other regulations that limit the harvest of species, sizes, and sexes or other life-history phases. In this sense, the spatial structure of most of the exploited resources is a central point both to understand their population dynamics and to design assessment and management methods. One of the parameters of interest for classical fisheries management, viz. the absolute abundance of the stock, is difficult to estimate in coastal spatially-structured resources, and efforts should be redirected towards the use of indices of abundance and distribution that could be obtained rapidly from habitat maps (Orensanz & Jamieson, 1998). The connectivity of local populations and the potential larval routes of dispersion that determine source-sink dynamics could be estimated using hydrographic information (Roberts, 1997).

Acknowledgements

This study was funded in part by a grant from the Consellería de Educación e Ordenación Universitaria (XUGA10301B97) of the Xunta de Galicia. We thank Juan Otero, who supported our field work in the

Golfo Artabro by giving logistical support and sharing valuable traditional ecological knowledge. Antonio García-Allut improved the paper through many successful discussions about socio-economic and management aspects of Galician fisheries.

References

Beverton RJH and Holt SJ (1957) On the dynamics of exploited fish populations. Ministry of Agriculture, Fisheries and Food, London. Fisheries Investigations 2 (19).

Botsford LW, Moloney CL, Hastings A, Largier JL, Powell TM, Higgins K and Quinn JF (1994). The influence of spatially and temporally oceanographic conditions on meroplanktonic metapopulations. Deep-Sea Res II 41: 107–145

Caddy JF (1999) Fisheries management in the twenty-first century: will new paradigms apply? Rev Fish Biol Fish 9: 1–43

FAO (1995) The State of World Fisheries and Aquaculture. Rome, Italy

Freire J Fernández L and González-Gurriarán E (in press) Interactions of the fishery of the spider crab *Maja squinado* with mating, reproductive biology and migrations. ICES J Mar Sci

Freire J and García-Allut A (2000) Socioeconomic and biological causes of management failures in European artisanal fisheries: the case of Galicia (NW Spain). Mar Policy 24: 375–384

Freire J, González-Gurriarán E and Bernárdez C (1999) Migratory patterns in the spider crab *Maja squinado* using telemetry and electronic tags. International Council for the Exploration of the Sea, C.M. 1999/AA:14, 11 pp

González-Gurriarán E, Fernández L, Freire J and Muiño R (1998) Mating and role of seminal receptacles in the reproductive biology of the spider crab *Maja squinado* (Decapoda, Majidae). J Exp Mar Biol Ecol 220: 269–285

González-Gurriarán E, Fernández L, Freire J, Muiño R and Parapar J (1993) Reproduction of the spider crab *Maja squinado* (Brachyura: Majidae) in the southern Galician coast (NW Spain). International Council for the Exploration of the Sea, C.M. 1993/K:19, 15 pp

González-Gurriarán E and Freire J (1994) Movement patterns and habitat utilization in the spider crab *Maja squinado* (Herbst) (Decapoda, Majidae) measured by ultrasonic telemetry. J Exp Mar Biol Ecol 184: 269–291

González-Gurriarán E, Freire J, Parapar J, Sampedro MP and Urcera M (1995) Growth at moult and moulting seasonality of the spider crab, *Maja squinado* (Herbst) (Decapoda: Majidae) in experimental conditions: implications for juvenile life history. J Exp Mar Biol Ecol 189: 183–203

Hilborn R and Walters CJ (1992). Quantitative Fisheries Stock Assessment. Chapman & Hall, New York

Hilborn R, Walters CJ and Ludwing D (1995) Sustainable exploitation of renewable resources. Ann Rev Ecol Syst 26: 45–67

Hines AH, Wolcott TG, González-Gurriarán E, González-Escalante JL and Freire J (1995) Movement patterns and migrations in crabs: Telemetry of juvenile and adult behaviour in *Callinectes sapidus* and *Maja squinado*. J Mar Biol Ass UK 75: 27–42

Jamieson GS and Campbell A (eds.) (1998) Proceedings of the North Pacific Symposium on Invertebrate Stok Assessment and Management. Can Spec Publ Fish Aquat Sci 125.

Ludwig D, Hilborn R and Walters CJ (1993) Uncertainty, resource exploitation, and conservation: lessons from history. Science, 260: 17, 36

McGoodwin JR (1990) Crisis in the World's Fisheries – People, Problems and Policies. Stanford University Press, Stanford

Montero P, Prego R, Gómez-Gesteira M, Neves R, Taboada JJ and Pérez-Villar V (1997) Aplicación de un modelo 2D al transporte de partículas en la Bahía de A Coruña. In: Prego R and Fernández JM (eds.), Procesos Biogeoquímicos en Sistemas Costeros Hispano-Lusos. Excma. Diputación Provincial de Pontevedra, Pontevedra, Spain

Nowlis JS and Roberts CM (1999) Fisheries benefits and optimal design of marine reserves. Fish Bull 97: 604–616

Orensanz JM and Jamieson GS (1998) The assessment and management of spatially structured stocks: an overview of the North Pacific Symposium on Invertebrate Stock Assessment and Management. In: Jamieson GS and Campbell A (eds.), Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Can Spec Publ Fish Aquat Sci 125: 441–459

Perry RI, Walters CJ and Boutillier JA (1999). A framework for providing scientific advice for the management of new and developing invertebrate fisheries. Rev Fish Biol Fish 9: 125–150

Roberts CM (1997) Connectivity and management of Caribbean coral reefs. Science 278: 1454–1457

Rothschild BJ, Ault JS, Goulletquer P and Heral M (1994) Decline of the Chesapeake Bay oyster population: a century of habitat destruction and overfishing. Mar Ecol Prog Ser 111: 23–39

Sampedro MP, González-Gurriarán E, Freire J and Muiño R (1999) Morphometry and sexual maturity of the spider crab *Maja squinado* (Decapoda: Majidae) in Galicia, Spain. J Crust Biol 19: 578–592.

Xunta de Galicia (1992). Plan de Ordenación dos Recursos Pesqueiros e Marisqueiros de Galicia. Consellería de Pesca, Marisqueo e Acuicultura, Xunta de Galicia, España

Xunta de Galicia (1995) Censo da frota pesqueira de Galicia (1994). Consellería de Pesca, Marisqueo e Acuicultura, Xunta de Galicia, España