Shelled Molluscs

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Abstract:

Shelled molluscs are comprised of bivalves and gastropods. They are settled mainly on the continental shelf as benthic and sedentary animals due to their heavy protective shell. They can stand a wide range of environmental conditions. They are found in the whole trophic chain and are particle feeders, herbivorous, carnivorous, and predators.

Exploited mollusc species are numerous. The main groups of gastropods are the whelks, conchs, abalones, tops, and turbans; and those of bivalve species are oysters, mussels, scallops, and clams. They are mainly used for food, but also for ornamental purposes, in shellcraft industries and jewelery. Consumed species are produced by fisheries and aquaculture, the latter representing 75% of the total 11.4 millions metric tons landed worldwide in 1996. Aquaculture, which mainly concerns bivalves (oysters, scallops, and mussels) relies on the simple techniques of producing juveniles, natural spat collection, and hatchery, and the fact that many species are planktivores.

Keywords: bivalves, gastropods, fisheries, aquaculture, biology, fishing gears, management

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1. Introduction

1.1. Uses of Shellfish: An Overview

Since prehistoric times, humans have exploited molluscan resources for multiple purposes. Shellfish have been traditionally used for such various purposes as currency (e.g., the gold-ring cowry Cypraea annulus), magical and religious symbols (in India, the sacred chank Turbinella pyrum and especially its rare sinistral form is regarded as a divine symbol of success, peace, and prosperity), horns, containers (large gastropod shells of the genus Melo are used as scoops for salt or flour in markets of South East Asia and the Pacific, and to bail out the boats of the native fishermen), or even as tools in some isolated oceanic islands.

However, the search for food has constituted and still continues to form a major reason for shellfish exploitation. These are commonly collected or cultured nowadays to fulfil the high demand of the world market, as well as for local consumption by littoral dwellers. For many coastal populations of tropical areas, shellfish, as a substitute for fish, represents an important dietary component, especially for poor people.

Other reasons for shellfish exploitation include the use of shells as a raw material for mother-of-pearl or for lime in pottery glazes, poultry food additives, or for personal adornment. Some marine species are collected to supply the interests of collectors for beautiful objects, or as a source of pharmaceuticals: a toxin recently extracted from the venomous Caribbean gastropod Conus ermineus, could be used to counteract the effects of some myasthenias and of multiple sclerosis on muscle contractility.

1.2. Production

Shellfish landings in 1996 totaled around 11.4 million metric tons. Sixty-two countries worldwide were involved in aquaculture compared to 114 in fisheries for an 8.5 million metric tons aquaculture production (FAO data). The overall shellfish culture has increased by a factor of four in less than 15 years, while total shellfish fisheries landings have remained stable. However, several increases in production by aquaculture followed fisheries collapses (e.g., Argopecten purpuratus). Therefore, this has resulted in an increasing share of the total shellfish landings by aquaculture from 46% to 75% in 1984 and 1996, respectively. Among the 128 species of commercial interest, 64 species are produced by aquaculture, most of them being bivalves. However, most of the landings (62%) are based on three species, the Pacific cupped oyster Crassostrea gigas (34.4%), the Yesso scallop Patinopecten yessoensis (14.9%), and the Japanese carpet shell Ruditapes philippinarum (13.1%). Shellfish culture has been established primarily in coastal areas and estuaries that are environmentally sensitive. Therefore, overall landings are correlated with appropriate environmental management as well as cultural practices, production costs, and market demands.

2. Species and Fisheries

2.1. Diversity of Species

2.1.1. Edible Species

Fisheries usually concentrate on a limited number of species [See tables of major and regionally important commercial species of Gastropods and Bivalves]. However, a total of more than 1 500 species of shelled molluscs are currently collected for food in the world (including about 720 gastropods and 790 bivalves), mostly at the craft level. This is especially true in the tropics where biodiversity is highest, with many species typically constituting populations of limited stocks in relatively stable environmental conditions. In temperate areas, a higher food supply, linked with the rather high density of plankton typical of cooler waters, and unstable environments result in large populations of relatively few species of bivalves (like scallops, cockles, Venus clams) or herbivorous gastropods (abalones, periwinkles). This has allowed the development of industrial fisheries.

Table 1. Major and regionally important commercial shellfish species of the world

(Species under intensive cultivation or receiving commercial aquaculture attention are indicated by an asterisk. The common vernacular names of species used here are the official English FAO names - when they exist.)

Gastropods

Scientific name	Common name	Main areas of production
*Haliotis asinina**	Donkey's ear abalone	Philippines
*Haliotis corrugata**	Pink abalone	California, Mexico
*Haliotis discus**	Disk abalone	Korea
*Haliotis diversicolor**	Varicoloured abalone	Taiwan, Japan
*Haliotis fulgens**	Southern green abalone	California, Mexico
*Haliotis gigantea**	Giant abalone	Japan
Haliotis iris	Paua abalone	New Zealand
*Haliotis midae**	Perlemoen abalone	South Africa
Haliotis ovina	Oval abalone	Philippines, China
*Haliotis rubra**	Blacklip abalone	Australia
*Haliotis rufescens**	Red abalone	California, Mexico
*Haliotis tuberculata**	European ormer	France
*Trochus niloticus**	Commercial top	Tropical West Pacific
*Turbo cornutus**	Horned turban	Korea, Japan
Turbo marmoratus	Green turban	Indo-West Pacific
*Littorina littorea**	Common periwinkle	France, Ireland, Canada
Strombus galeatus	Giant Pacific conch	Mexico
*Strombus gigas**	Pink conch (Queen conch)	Tropical West Atlantic
Strombus gracilior	Pacific fighting conch	Mexico
Strombus luhuanus	Strawberry conch	Papua N.Guinea, Philippines
*Chicoreus ramosus**	Ramose murex	India
Concholepas concholepas	Barnacle rock-shell	Peru, Chile
Babylonia areolata	Maculated ivory whelk	Thailand, China
Buccinum undatum	European waved whelk	France,Ireland, UK,Canada
Busycon canaliculatus	Channeled whelk	USA, Mexico
Busycon carica	Knobbed whelk	USA, Mexico
Cymbium glans	Elephant's snout volute	Senegal
Cymbium pepo	Neptune volute	Senegal

Mussels

Scientific name	Common name	Main areas of production
*Aulacomya ater**	Cholga mussel	Peru, Chile
*Choromytilus chorus**	Choro mussel	Chile
Modiolus metcalfei	Yellowbanded horse mussel	Taiwan, Philippines
Modiolus philippinarum	Philippine horse mussel	Malaysia, Philippines
Mytilus californianus	Californian mussel	Mexico
*Mytilus coruscus**	Korean mussel	Korea, China
*Mytilus edulis**	Common blue mussel	Netherland, Spain, France, UK
*Mytilus galloprovincialis**	Mediterranean mussel	Italy, Greece, France
Mytilus trossulus	Northern blue mussel	Canada, Alaska, Russia
*Perna canaliculus**	Greenlip mussel	New Zealand
Perna indica	Indian brown mussel	India
*Perna perna**	South American rock mussel	Venezuela
*Perna viridis**	Asian green mussel	India, China, Taiwan, SE Asia

Oysters

Scientific name	Common name	Main areas of production
Alectryonella plicatula*	Fingerprint oyster	China
Crassostrea belcheri	Belcher's cupped oyster	South East Asia
Crassostrea columbiensis*	Cortez cupped oyster	Mexico, Panama
Crassostrea cuttackensis	Indian cupped oyster	India, Sri Lanka
Crassostrea gasar	African mangrove oyster	West Africa
Crassostrea gigas*	Pacific cupped oyster	China, Japan, Taiwan, USA,France
Crassostrea iredalei*	Philippine cupped oyster	Philippines, Malaysia
Crassostrea rhizophorae*	Mangrove cupped oyster	Cuba, Venezuela
Crassostrea virginica*	Eastern cupped oyster	USA, Canada, Mexico
Ostrea puelchana*	Chilean flat oyster	Chile, New Zealand
Ostrea conchaphila*	Shell-loving oyster	USA
Ostrea edulis*	European flat oyster	France, Spain, UK, Turkey, Greece
Saccostrea cuccullata*	Hooded oyster	India, SE Asia, Australia,W.Africa, Philippines,New Zealand
Hyotissa hyotis	Honeycomb oyster	Philippines, Vietnam

Scallops

Scientific name	Common name	Main areas of production
Aequipecten opercularis*	Queen scallop	UK, France
Amusium japonicum	Saucer scallop	Japan, Australia, New Caledonia
Amusium pleuronectes	Asian moon scallop	Taiwan
Argopecten gibbus	Calico scallop	USA
Argopecten irradians*	Atlantic calico scallop	China, USA
Argopecten purpuratus*	Peruvian calico scallop	Peru, Chile
Argopecten ventricosus	Pacific calico scallop	Eastern Pacific
Chlamys farreri*	Farrer's scallop	China, Japan
Chlamys islandica	Iceland scallop	Iceland, Norway, Canada
Crassadoma gigantea	Giant rock scallop	Mexico
Mimachlamys nobilis	Noble scallop	China
Mimachlamys varia	Variegated scallop	France, UK
Patinopecten caurinus	Weathervane scallop	USA
Patinopecten yessoensis*	Yesso scallop	China, Japan, Russia
Pecten maximus*	Geat Atlantic scallop (King scallop)	France, UK, Ireland
Pecten novaezelandiae	New Zealand scallop	New Zealand
Placopecten magellanicus	American sea scallop	USA, Canada
Zygochlamys patagonica	Patagonian scallop	Chile, Argentina

Pearl oysters

Scientific name	Common name	Main areas of production
Pinctada chemnitzii	Tiled pearl oyster	India
Pinctada margaritifera*	Blacklip pearl oyster	Indo-West Pacific
Pinctada maxima*	Goldlip pearl oyster	South East Asia
Pinctada mazatlanica	Mazatlan pearl oyster	Mexico
Pinctada radiata*	Rayed pearl oyster	Japan, China, India
Pteria avicular	Swift wing oyster	China
Pteria sterna	Western wing oyster	Mexico

Clams

Scientific name	Common name	Main areas of production
Anadara antiquata *Anadara granosa** *Anadara tuberculosa** *Arca pacifica* *Arca zebra* *Scapharca globosa** *Scapharca inaequivalvis** *Scapharca indica* *Scapharca subcrenata** *Atrina pectinata* *Placuna placenta** *Cerastoderma edule** *Fulvia mutica* *Hippopus hippopus** *Tridacna derasa** *Tridacna gigas** *Mactra chinensis* *Mactra veneriformis** *Pseudocardium sybillae** *Spisula polynyma* *Spisula solidissima* *Mesodesma donacium** *Siliqua patula* *Siliqua radiata* *Donax cuneatus* *Donax faba* *Donax trunculus* *Sinonovacula constricta* *Arctica islandica* *Ameghinomya antiqua* *Chamelea gallina* *Gafrarium tumidum* *Mercenaria mercenaria** *Meretrix casta* *Meretrix lusoria** *Meretrix meretrix* *Paphia undulata* *Protothaca thaca** *Protothaca staminea** *Ruditapes decussatus** *Ruditapes philippinarum** *Saxidomus gigantea** *Venerupis aurea* *Venerupis pullastra** *Mya arenaria* *Panopea abrupta** *Cyrtopleura costata* *Pholas orientalis*	Antique ark Granular ark (Blood cockle) Black ark Chuchoca ark Turkey wing Globose ark Inequivalve ark Rudder ark Halfcrenate ark Comb pen shell Windowpane oyster Common edible cockle Japanese cockle Bear paw clam Smooth giant clam Giant clam Chinese trough shell Venuslike mactra Imperial surf clam Stimpson’s surf clam Atlantic surf clam Macha clam Pacific razor clam Sunset razor clam Cuneate donax Pacific bean donax Truncate donax Constricted tagelus Ocean quahog King’s littleneck Mediterranean striped venus Tumid venus Northern quahog Backwater hard clam Japanese hard clam Asiatic hard clam Undulate venus (Baby clam) Greater littleneck (Taca clam) Common Pacific littleneck Grooved carpet shell Japanese carpet shell (Manila clam) Smooth butter clam Golden carpet shell Pullet carpet shell Sand gaper (Soft shell clam) Pacific geoduck Angel wing Oriental angel wing	Indonesia, Sri Lanka China, Malaysia, Thailand, Korea Mexico Mexico Venezuela Japan, Philippines Japan, Philippines Indonesia Japan Japan, Taiwan, Philippines Philippines, Bengladesh UK, Netherlands,France, Portugal Japan Australia, Philippines, Papua- New Guinea, Fiji, Solomon, Palau, Indonesia Japan Korea Japan, Korea Canada USA Chile, Peru Canada, USA Myanmar India India, Sri Lanka Italy, Spain, France China USA,Canada Chile Italy, Turkey, Spain, France Indonesia, Sri Lanka USA, Canada India Japan, Korea, Taiwan India, Korea, China, Taiwan, Japan Thailand Chile USA Spain, Portugal, Ireland, France China, Korea, Japan, USA, France Canada Italy Spain, France USA, Canada Canada, USA USA, Mexico Philippines

However, the choice of the exploited species does not always reflect the potential shellfish resources of a given region, but largely depends on the social and cultural habits in area. Moreover, consumers often have very specific requirements regarding shape, color, and taste of the food. For example, shipworms are well known for the severe damage they cause to shipping and wooden harbor structures all around the world. However, coastal people in Thailand and the Philippines have for centuries anchored logs in the sea to favor development of some fleshy species of shipworms, which are considered a delicacy. The North Atlantic slipper limpet Crepidula fornicata, accidentally introduced into France from England and the US, has been massively spreading for the last 20 years, resulting in trophic depletion, and space competition in oyster beds, and therefore affecting scallops fisheries. In the Mount Saint Michel Bay (Normandy), its considerable biomass (137 000 metric tons in 1998, i.e., eight times more than the yearly production of mussels and oysters in this area) contributes significantly to increase mud deposition in this site. French fishermen systematically reject this pestilential species, whereas it is considered good to eat in Canada.

Rapid depletion of natural beds due to frequent overexploitation can also lead fisheries to move towards other targets and to exploit species that were traditionally discarded. By way of example, the tree-oyster Isognomon alatus is increasingly marketed in northern South America, as a substitute for the true oysters. In France, following the fishery collapse of the highly regarded clam Venus verrucosa, exploitation of new species such as the surf-clams Spisula spp. and the European common bittersweet Glycymeris glycymeris has emerged. However consumers often show unwillingness to change their dietary habits, and the fisheries must also find some other outlets for the newly exploited species.

Edible species of economic importance in the world market of bivalves are highly diverse. They are generally grouped into four broad categories: mussels, scallops, oysters and clams. Each of the three former ones refer almost exclusively to single families of bivalves, respectively the Mytilidae, the Pectinidae, and the Ostreidae (though some oysters from the Eastern and Western Pacific belong in fact to the related family Gryphaeidae). However, clams appear to be a convenient grouping of species, a majority of which are classified under the subclass Heterodonta. Heterodont clams are characterized by hinge dentition with two types of teeth (cardinals and laterals), similar adductor muscles, and equal valves mostly with an elongate, subrectangular, or ovoid shape. They include such diverse groups as cockles, razor shells, or quahogs. In contrast, the clam category is strongly heterogeneous for it also embraces groups not belonging to the heterodonts like the ark shells (Arcidae) or the bittersweets (Glycymerididae). Bivalves looking like true oysters but not strongly related to them, are also usually referred to as clams. Windowpane shells (Placunidae), tree oysters (Isognomonidae), and wing and pearl oysters (Pteriidae) belong to this category. Therefore, the high diversity and heterogeneous composition of the clam category explains why the food market of clams is very complex and splintered into a number of complementary segments.

2.1.2. Shellfish Species Not Used as Food

Shells, which are of economic value for their aesthetic appeal, are mostly found in tropical countries. They can be divided into commercial shells and ornamental shells.

The broadest category of commercial shells refers to molluscs harvested for their nacre or mother-of-pearl. The most important species are the commercial top (Trochus niloticus), the green turban (Turbo marmoratus), and the blacklip (Pinctada margaritifera) and goldlip (P. maxima) pearl oysters, all of which are originating from the Indo-west Pacific. Other species belonging to these genera, as well as abalones (Haliotis spp.) and wing oysters (Pteria spp.) are also used in the commercial shell trade.

The main commercial fisheries are found in the Indo-west Pacific, in the Andaman islands (India), Australia, Indonesia, the Philippines, Papua New Guinea, Solomon Islands, Vanuatu, New Caledonia, Fiji, and French Polynesia. Most of the production is processed in South East Asia, which is the center of button and shellcraft industries.

Commercial top is the most economically important gastropod species, both as a source of traditional food and as a leading export item used for buttons and jewellery. It is commercially harvested throughout the Indo-Pacific. Many small-sized traditional fisheries of Trochus exist in the oceanic islands of the South Pacific, where they are sometimes the only source of cash income. Production declined for some time with the advent of plastic buttons. However, since the beginning of the 1980s, there has been an average demand of 5000–6000 metric tons a year. The green turban is highly valued in China, Korea, and Japan for jewelery and furniture inlay. This species has been successfully introduced into New Caledonia since the 1960s. Intensive fishing has drastically reduced several populations, and attempts at juvenile production, reintroduction, transfer, and commercial legislation are under way. Mother-of-pearl coming from pearl oysters can be considered a by-product of the pearl industry, and these species have long been a major fisheries target. Shellfish decline on natural beds has also occurred in many areas, for some of them since the early part of this century. Production of pearl oysters is nowadays currently obtained by aquaculture.

The ornamental shell trade is increasing, largely because of the development of the tourism and leisure industries. It concerns shellfish harvested for their decorative value or used in shellcraft, and rare or precious shells sought by malacologists and shell collectors. In some tropical areas, rare shells taken by trawlers in relatively deep waters are now of sufficient economic importance that some companies regard them as a normal component of the trawling catches. Shellcraft produces decorative objects that may range from high quality jewellery and carved ornaments to cheap souvenirs for the gift trade. Detailed records of ornamental shell catches are scarce since most of the fisheries are represented by small craft businesses. However, it is usually considered that 5000 or 6000 species (mostly gastropods) are involved in this trade. More than 1000 species are currently used in the Philippines, which is the main shell trade center worldwide. It should be noted that many gastropod species, especially in South East Asia, are collected by fishermen for personal consumption or sold as food on local markets before the empty shell is resold to collectors or to the shell craft industry.

Some large gastropods like the Caribbean queen conch (Strombus gigas), the Indo-West Pacific bullmouth helmet (Cypraecassis rufa) and the biggest cowries (Cypraea spp.) are actively sought for cameo carving. The windowpane oyster (Placuna placenta) with its translucent, silvery flat shell, represents a special case in the shellcraft industry. Originally employed as a substitute for glass in glazing, it is now mainly used for the manufacture of trays, bowls, lampshades and numerous decorative items. A major commercial species in the Philippines, it is collected from natural beds by divers and farmed in shallow mud flats enclosed with bamboo fences. However, production is very erratic because of the conflicts between the high demand for young transparent shells for shellcraft, and the need for older, sexually mature shells for broodstock replenishment. In addition to pearls and mother-of-pearl, the exploitation of pearl oysters also produces limited quantities of adductor muscle, generally canned for exportation.

2.2. Shelled Molluscs Fisheries

2.2.1. Gastropods

The total harvest of gastropods in the world is relatively stable, with about 106 000 metric tons and 103 000 in 1987 and 1996, respectively.

Abalone landings fluctuate between 10 000 and 15 000 metric tons per year. The abalone fishery in Tasmania is one of the most important, reaching a total allowable commercial catch of about 2 500 metric tons (nearly half of Australia’s total production). Two species are harvested manually by divers: Haliotis rubra (blacklip) and Haliotis laevigata (greenlip). This commercial fishery is under a quota management system. Access to the quota (quota units) and the right to take the abalone is formally separated; there are about 350 holders of quota and only 125 divers licensed to harvest abalone. Approximately 4000 recreational abalone diving licenses are issued per year and are restricted to a catch of 10 abalones per day. Another strong abalone fishery was located in California (USA): from an annual harvest of 2500 metric tons in the 1950s, the fishery has declined to a point that all fishing, recreational and commercial, has been banned since 1997. The reasons for this decline are mainly anthropocentric (predation, overharvesting, illegal harvest, sublegal mortality, competition by other species, habitat loss, and a disease called withering syndrome).

Conch fisheries are mainly operated by traditional hand gathering or by diving. Strombus and Turbo represent the main genera harvested in the tropical belt.

The common periwinkle Littorina littorea is mainly harvested in Ireland (2800 metric tons in 1996), but it is also commercially fished in North East America (after its introduction from Europe by human activity in Newfoundland some 150 years ago).

The gastropod fisheries in Chile involve several thousands of divers: the main species Concholepas concholepas (21 000 metric tons in 1987, 2500 in 1996) is now strongly managed by using an individual quota system and the creation of sanctuaries (area de manejo).

The European whelk (Buccinum undatum) fisheries began in the sixties and have increased in the recent years, to fulfil the high demand of the South East Asian market. Basically harvested by traditional 8–16 m long potters with 500 to 1000 baited pots lifted per day and per boat, some areas are fully exploited and licensed systems of regulation are now operating.

2.2.2. Oysters

With regard to oysters, more than 11 species are the target for several fisheries. The main species remains Crassostrea virginica, which has been a major fishery in the United States since the nineteenth century. Although reaching a record high of 615 000 metric tons in 1884 in Chesapeake Bay alone, yearly production has kept declining due to shellfish diseases by the protists Haplosporidium nelsoni, Perkinsus marinus, siltation, overfishing, and habitat destruction, to reach a present level of around 100 000 metric tons over its entire geographic distribution. Hand gathering, tongs, then dredges, and hydraulic patent tongs have been the common way to harvest the eastern oyster depending on location and regulations. In several places, clam fisheries, like the Surfclam on the US Atlantic coastline, have replaced the traditional oyster fishing activity.

2.2.3. Mussels

World landings vary between 200 000 and 280 000 metric tons. The European species, Mytilus edulis, represents 50% of the total landings: the largest landings come from Netherlands, Denmark, and France by dredging. Chilean mussels fisheries based on three species (Aulacomya ater, Mytilus chilensis, and Choromytilus chorus) harvest around 20 000 metric tons per year by diving.

2.2.4. Scallops

Total worldwide landings by fisheries of scallops have reached around 500 000 metric tons since 1984, in contrast to the quick aquaculture development in Japan and China mainly. This situation is due to the numerous species involved. Actually, with an efficient fishing activity affecting the resources, the common exploitation trend is a fast increase, followed by several years of abundant production and then by a drastic resource decrease. This is correlated to the population dynamic, dominated by strong year-classes, separated by several and unpredictable poor recruitments. Once the accumulated biomass is harvested, the fishery returns to a reduced production.

This has been the case for Argopecten purpuratus in Chile and Peru (associated with the El Niño phenomenon), for Chlamys islandica in Norway, for Pecten maximus in France and the United Kingdom, and for Pecten fumatus in Australia and Tasmania. It is expected to be the same trend for Zygochlamys patagonica, recently exploited in Argentina.

This trend has been more under control for Placopecten magellanicus in Canada which industrial fleet has been regulated by a strict licensed and Individual Transferable Quota systems. This species, found in the western North Atlantic from Virginia to the Gulf of Saint Lawrence and Newfoundland has fluctuated from 50 000 to 240 000 metric tons. The main US fishing grounds have been closed for several years and are now again in exploitation (1999). Argopecten gibbus has been affected by a shellfish disease, namely Marteila sp., leading to a fishery collapse during several years in Florida.

For fisheries, several extensive bottom aquaculture operations are concerned: juveniles produced by spat collecting operations are seeded on natural grounds at densities appropriate to maximize recruitment. It facilitates the use of the ecosystem trophic capacity and meanwhile regulates the natural fluctuation of the resource. It has been first developed in Japan on Patinopecten yessoensis. This led to a production increase from several thousands metric tons in 1970 to 276 000 metric tons in 1996. A similar development is observed on Pecten novaezelandiae in New Zealand.

2.2.5. Clams

This group of shelled molluscs is the most important in terms of landings (1 ´ 106 tons of identified species and the majority of "Miscellaneous marine molluscs" at 1 045 015 metric tons) and the most diverse in term of species harvested, fishing techniques with some industrial fisheries, and numerous small scale fisheries (underestimated in the world statistics).

The industrial fisheries of North America Ocean quahog Arctica islandica (180 000 metric tons on average between 1984 and 1996), Atlantic surf clam Spisula solidissima, (170 000 tonnes) are the most important on a worldwide basis.

With average landings of 100 000 metric tons the Japanese carpet shell Ruditapes philippinarum, concerns a lot of artisanal fisheries mainly in South Asia but also in Europe following its introduction for aquaculture purposes.

The European Cerastoderma edule fisheries are diverse: some of them, like in Netherlands, are integrated into industrial and strictly regulated fisheries, others concern hand gathering by small scale or subsistence businesses.

The Italian fishing industry of the striped Venus, Chamelea gallina, in shallow waters of Adriatic Sea became very important in the 1970s following the introduction of hydraulic dredges. Average landings reach about 100 000 metric tons per year. This fishery has showed irregular landings resulting from poor fishery management and ecological problems that have caused widespread mortality rates in the recent years.

Ark shells (Scapharca and Anadara spp.) are the target species for subsistence fisheries on the tropical belt. As Japanese domestic demand for these clams is higher than local production, prices have increased significantly in the past few years. Thus, a number of South East Asian countries have recently exported increasing quantities of ark shells to Japan, both in fresh and frozen form.

Although most of the clam fisheries are fully or overexploited, there is still a lot of potential increase for clam fishing in the future due to numerous unused beds over the world.

2.3. Shelled Molluscs Cultivation

2.3.1. Gastropods

Whereas bivalve production is nowadays mainly due to aquaculture, it is not at all the same for gastropods. In 1996, aquacultural production of gastropods represented less than 2.5% of a total yield of about 137 000 metric tons in the world.

Overall abalone aquaculture, which reached about 2200 metric tons in 1996, is mainly due to production of the varicolored abalone (Haliotis diversicolor) in Korea, and of the red abalone (H. rufescens) in California. Other regionally important abalone species include in decreasing order, the Southern green (H. fulgens) and pink (H. corrugata) abalones in the Eastern Pacific, giant (H. gigantea) and disk (H. discus) abalones in the Western Pacific, perlemoen abalone (H. midae) in Southern Africa, European ormer (H. tuberculata) in Western Europe, and blacklip abalone (H. rubra) in Australia. A very recent production of the donkey’s ear abalone (H. asinina) is emerging in the Philippines.

Other gastropods like Strombus spp. and Turbo cornutus represent a very limited culture activity (27 metric tons in 1996).

2.3.2. Oysters

Cultured oysters concern species which belong to three genera, Ostrea (flat oysters), Saccostrea, and Crassostrea (cupped oysters), and represent 10 species. The main production is related to the latter genus Crassostrea with the dominant species being the Pacific cupped oyster C. gigas. Since 1984, this species has tripled in quantities to reach 2.9 million metric tons a year and 95% of the total oyster yield. In contrast, the second species in production, the Eastern oyster C. virginica, has regularly decreased from 146 000 to 94 000 metric tons mainly due to disease. Therefore, the overall trend in production is toward a monoculture on a worldwide basis. However, planting experiments of C. gigas in equatorial areas have often failed, apparently because of the sustained high temperature of the water. Therefore, it is likely that cultivation of other oyster species will arise there in the future.

2.3.3. Mussels

Mytilidae represent an important family with a production of 1 172 000 metric tons in 1996. Mostly stable since 1988, the most diverse mussel production includes five genera, namely Aulacomya, Choromytilus, Modiolus, Mytilus, and Perna. In contrast to oyster production, at least three Mytilus and one Perna species contribute significantly to landings, in decreasing order of importance M. edulis, M. galloprovincialis, Perna viridis, and Mytilus coruscus. Others Perna spp. (mainly P. perna and P. canaliculus) make up 6% of the landings.

2.3.4. Scallops

Scallop aquaculture is based on the Japanese example since 1970. After a long period of experimental trials throughout the world, the commercial culture of the northern species Patinopecten yessoensis developed. The original spat collection equipment used for intensive monitoring of larval distribution have been used for large-scale production of juveniles. Some of the animals are returned to natural scallop grounds for stock enhancement and sea ranching. The alternative is to maintain the animals for on-growing in hanging cultures in sheltered bays. The Japanese production reach about 250 000 metric tons.

These techniques have been successfully applied in other countries and are still developing. In northern China, Argopecten irradians, a species introduced from the USA in 1982, and Chlamys farreri are intensively cultured on longlines. The production, negligible in 1985, is now about 800 000 metric tons. The spat collection methods have been complemented by hatchery production. Argopecten purpuratus is now cultivated by the same techniques in Chile and at a lesser extend in Peru.

In the late 1990s, the production of sterile, triploid specimens of Mimachlamys gloriosa has been successfully tested in Japan.

2.3.5. Clams

Clams, cockles, and arkshells represent a significant share of shellfish aquaculture with 22 species of commercial interest. The Japanese carpet shell (Manila clam) Ruditapes philippinarum, the razor clams Solen spp., and the granular ark (blood cockle) Anadara granosa are the leading species with a production of 1 115 740, 342 519, and 219 926 metric tons, respectively.

Cultivation of giant clams is potentially very attractive, since these species represent the only partially self-feeding farm animals as a result of their association with symbiotic dinoflagellate algae. Cultivation methods for giant clams (including hatchery techniques) are now established, and a significant mariculture industry will probably arise in the near future. Successful results have already been obtained with mass cultivation of the three largest species (Tridacna gigas, T. derasa, and Hippopus hippopus), which exhibit relatively high growth rates.

Since 1997, attempts to produce the mangrove lucina Anodontia edntula have been under progress in the Philippines. This species, which is already a popular food, is also a partial primary producer, harboring in its gills chemosynthetic, sulfur-oxidizing, symbiotic bacteria.

The Pacific geoduck clam Panopea abrupta is another species of commercial interest, reaching in several cases an individual weight of more than 3.25 kg, and therefore aquaculture is emerging in several states.

3. Harvesting and Cultivation Techniques

Because of their sedentary way of life and their location mainly in inshore waters, the shelled molluscs are very vulnerable to fishing, but this vulnerability could be an advantage in order to make exploitation profitable if effective mechanisms of regulation exist.

3.1. Harvesting

Several different methods are used to catch shelled molluscs: hand gathering, diving, dredges, trawls and nets, and pots. Intertidal shelled molluscs are mainly exploited by hand for self-consumption, commercial, or recreative purposes. Shelled molluscs are also fished by snorkeling or free diving. With the invention of the hookah, a device which pumps surface air to a diver at depth, fishing power of the individual increased. Divers are working at depths of between 1 to 35 m. For fishing on deeper waters, dredges are needed.

Basically, a dredge is a bottom-towed gear and consists of a metal frame with a blade or teeth, to dig into the sediment and extract the shelled molluscs, and a mesh bag to collect the catch. Whereas hand dredging is observed on some intertidal beds (Donax trunculus in France), the use of dredge generally needs a fishing boat. There is a great diversity of dredge types, with specific designs used to target different species in particular beds. Simple dredges are only equipped with a blade or a knife (Venus verrucosa French fishery), or teeth (Pecten maximus European fisheries) at the mouth. Hydraulic dredges, mainly used on clam fisheries (striped Venus Chamelea gallina in the Adriatic sea, surf clam Spisula solidissima, softshell clams Mya arenaria, northern quahog Mercenaria mercenaria in the USA, and ocean quahog Arctica islandica in Canada and the USA), shoot jets of water from a manifold (equipped with digging and blowback nozzles) onto the seabed to lift out the target species.

After a tow, the gear is usually winched on board the vessel, although some have continuous-delivery hydraulic dredges: this gear continuously removes shelled molluscs from the sea bed, and then lift them onto the deck or to a conveyor belt, by pumping water down a pipe to the dredge resting on the sea bed. The industrial Dutch cockle (Cerastoderma edule) dredgers are equipped with two such dredges; with a crew of three men only, they are able to harvest between 100 and 200 metric tons a day (collecting the cockles during the morning and shelling them in the evening).

Environmental impacts of dredge fishing concern at the same time target species, benthic communities, and the substrate. The dominant types of incidental damage caused to shelled molluscs include chipped valve margins, the separation of hinges, but shelled molluscs may be buried or sand packed. Another cause of incidental mortality concerns the increase of predators on fished beds. Dredge chains, blades, teeth, or waterjets burrowing in the sand, as well as the passing through the bag of the gear, affect all the benthic community: as not all organisms are equally vulnerable, modifications on benthic assemblages are observed on various fishing areas. Mechanical impacts on the seabed induce changes in structure, nature and chemical composition of the substrate. The extent of these impacts depends on features of the bottom mobile gear (including trawls), on fishing intensity, on substrate type, and on the benthic ecosystem affected.

Otter trawls and beam trawls with tickler chains can be used to harvest some epibenthic shelled molluscs like Pectinidae (queen scallop Aequipecten opercularis in European fisheries, saucer scallop Amusium japonicum balloti in Australian fisheries, and calico scallop Argopecten gibbus in United States fisheries). Trammel nets are sometimes used to catch gastropods, for example, Cymbium olla in Portugal.

Finally, specific pots are used for fishing gastropods like the waved whelk Buccinum undatum in Europe, or the ivory whelk Babylonia areolata in South East Asia. Combined bait (fish and crabs) attracts the whelks to the trap. Pots are hauled every day.

3.2. Cultivation techniques

Since the critical stage for shellfish aquaculture is seed production, two types of cultural practices can be distinguished: seed collecting from natural populations, and hatchery techniques.

Historically, appropriate management of wild beds by predator removal and deployment of spat collectors at the right time has been the most significant way to collect seed and then to grow shellfish. Most worldwide production is still based on spat collecting techniques, which aim to provide suitable habitat for postlarvae following metamorphosis. Large natural shellfish populations constitute significant broodstock, which avoids problems of inbreeding and allows large production due to very high levels of spawning and recruitment. Compared to fishery management, population size is therefore usually a limited constraint in aquaculture. In several cases, the cultured population represents the main contribution to the broodstock. A large variety of spat collectors are currently in use depending on location, cost, and available material (e.g., bamboo, plastic collectors, shells, strings, stone, and coconut rope for mussel spat). Information on broodstock maturation, spawning timing, and larval development, plus water temperature and current patterns, are used to determine the appropriate date for spat collector deployment.

The second method to produce spat is by using hatchery techniques. This requires a complete control over the species' reproductive cycle. Maturation, then spawning, is obtained by conditioning usually a limited number of adults as broodstock. Reproductive output and larval rearing are optimized in hatcheries by controlling environmental parameters such as seawater temperature and food distribution. Spat are obtained following a period of growth in nurseries or by using remote setting techniques. Control over the spat supply and quality, as well as the capacity to use selected strains (e.g., disease-resistant strains) or genetically improved strains (e.g., polyploids) is one of the main advantages of using hatchery techniques. In specific cases, this could also be the only way to obtain large quantities of spat (e.g., species introduction, natural population collapse). Growout technology is highly variable and depends on location (tidal or subtidal).

In contrast to fisheries, traditional shellfish aquaculture requires intensive fieldwork to optimize growth: removing shellfish from spat collectors, sorting, grading. On bottom cultural practices and off bottom cultures by using racks or tables are common. Improved technology tends to develop offshore and subtidal culture by using floating long lines with suspensions (e.g., lantern nets, sacks, bags or ropes). For all cultural practices, rearing density and the control of predators and competitors are critical parameters for shellfish culture. Since food availability is limited in space and time for shellfish, farmers must balance their rearing density at a local and ecosystem level to avoid food depletion and decreased yield. Besides specific aquaculture equipment (e.g., long lines), harvesting techniques are quite similar to those used in fisheries and depend on location: hand picking, rakes, dredges, digging, and diving on managed beds. Hydraulic automatic equipment such as harvesters, conveyor belts, suction gear, and dredges are used for on-bottom culture. Onboard hydraulic equipment is also used for harvesting tidal long lines.

4. Biology

4.1. General Ecology

Shelled molluscs are ecologically important components of marine ecosystems because of their abundance and diversity, and their role in numerous interactions with other animals and plants of benthic communities, both as predators and prey. They probably comprise 15% to 40% numerically of benthic littoral and shallow water macroinvertebrates, and occupy every trophic level from primary producers to top carnivores. It has been shown that the nutrient control hypothesis can be applied to molluscan communities in shallow water tropical environments: quantitative changes in primary organic productivity induce qualitative shifts in the composition of the mollusc communities. Thus, in coral reefs that develop at oligotrophic nutrient levels of the open ocean, molluscan communities are very diverse, and gastropods (mainly predators) predominate over bivalves. In mesotrophic conditions, benthic algae and sea grasses develop, and molluscan diversity is lower but includes more bivalves and herbivorous gastropods. Eutrophic environments are dominated by oysters and mussels on rocky areas, burrowing bivalves and scavenging gastropods in soft bottoms.

As primary producers, shelled molluscs depend on a symbiotic relationship with unicellular photosynthetic microorganisms. The best known of these molluscs are the giant clams (Tridacnidae); their large shell is probably a consequence of the facilitation of the calcification process by the symbionts' metabolism. Like reef-building corals, which have similar symbionts, they contribute to the unusually high primary productivity of reef communities, by retaining and recycling nutrients within the ecosystem rather than re-exporting them to the open ocean.

Primary consumers include herbivorous and particle-feeding molluscs. Herbivorous gastropods graze on algae and encrusting lichens or scrape kelp tissue with their powerful radula. Others swallow detritus to digest decomposing plant matter. They are mainly archaeogastropods such as abalones (Haliotidae), top shells (Trochidae) and nerits (Neritidae); they also include mesogastropods such as periwinkles (Littorinidae) or conchs (Strombidae). One of the most important sources of food for marine invertebrates is suspended organic matter which comprises phytoplankton and microzooplankton, as well as their feces, bodies, and "marine snow" (secreted mucus and the microorganisms living on it). Bivalves are generally suspension feeders, using cilia and mucus to trap and sort particles from the respiratory current of incoming water; others have developed specialized strategies involving long siphons to collect particles on the bottom (deposit feeders). Some gastropods feed also on particles by means of elongate gill filaments (e.g., the slipper limpets Crepidula), but others set mucus strings or nets to trap the food, like the worm shells (Vermetidae).

Many gastropods are carnivorous and may be partial predators, eating only portions of colonial organisms, or may consume entire solitary prey, which are frequently bivalves. Active predators often drill holes through the shell or test of prey by means of their radula and use chemical secretions to soften the shell and paralyze the prey (Naticidae, Muricidae). Cone shells (Conidae) and some turrids and terebrids inject powerful neurotoxins through hollow, arrow-like teeth before swallowing the prey whole. Bivalves have almost never developed carnivorous habits, except for a group of relatively rare, deep-sea species, the septibranchs.

Shellfish aquaculture species show several peculiarities, such as a limited (scallops, mussels) or no migration capacity (oysters), therefore facilitating cultural practices. Large natural spatfall over a wide geographic distribution induces massive colonization, therefore facilitating survival rate and sustainable populations. Concomitantly, these species demonstrate a large capacity to endure environmental changes. Even drastic changes (e.g., temperature, salinity) might be endured by species cultured in estuarine environments. Behavior and adaptations to resist these changing and stressful conditions are common (e.g., valve closure, burrowing activity).

4.2. Growth

Growth can be observed and characterized via the calcification process and meat condition (somatic and gonadic tissues growth). Shellfish growth is highly variable among habitats and distribution and is a function of environmental carrying capacity (food availability) in terms of phytoplanktonic species or/and detritic matter and physical conditions (e.g., salinity, temperature). This plasticity is a shellfish characteristic and largely depends on the strong genetic variability often found in shelled molluscs. A significant interaction between genotype and environment has been found in some bivalves (e.g., Mytilus edulis, Crassostrea virginica): the relative importance of genes is determining growth rate varies at different water salinities. Bivalve species that are exposed to variable salinities in coastal waters may adapt by expressing a range of genotypes within the population. Moreover, growth is related to nutrition type (deposit feeding, filter feeding or grazing like abalone and winkle). Trophic competition is a common regulator of growth rate since high natural and stocking densities can be observed or/and rearing density can be maximized by cultural practices.

4.3. Reproduction

Molluscs exhibit an enormous diversity of reproductive mechanisms. Most species are dioecious, but they show little external dimorphism. When sexually mature, many gastropod males develop a penis and a few cases of shell dimorphism are known: male conchs (Strombidae) are frequently smaller and sometimes differently shaped than females. Hermaphrodism is known among both bivalves and shelled gastropods, but it is more frequent in the former. In simultaneous hermaphroditic species, sperm and eggs are produced simultaneously, so that self-fertilization may occur. However, many species are consecutive hermaphrodites, individuals changing sex with age (sometimes several times). The protandrous hermaphroditic slipper-limpet Crepidula fornicata is well known: it begins benthic life as male but later becomes progressively female (through a transitional, hermaphroditic stage). Several shellfish species show sex changes (reversion) over the years, which is likely related to food availability and quality. For instance, the Pacific cupped oyster Crassostrea gigas is an oviparous species with alternative protandry. In most bivalves, gametes are released in very high number into the water column where fertilization and development occur, until the larvae are ready to settle and metamorphose into benthic juveniles. Fertilization is then fully external and not under the control of the parents. Since spawning (gamete release) and fertilization are affected by dispersion, reproductive effort is large and a top priority over somatic growth. Reproduction can occur at a very early stage in life, often less than a year old (siblings) and depends on environmental constraints. Fecundity is often correlated with body size and increases with age, reaching 20 to 100 million eggs for an adult Pacific cupped oyster, for example. The probability of fertilization is often greatly improved by synchronization between male and female spawning which is probably a result of chemical stimulation. In bivalves, the liberation of sperm commonly triggers subsequent liberation of eggs, and whole populations spawn synchronously. Much greater efficiency of fertilization is achieved in higher gastropods, males having an extensible penis that is used to transfer sperm to the female genital aperture. Two types of eggs may be found in some female gastropods. Most are capable of development, but "food eggs" or "nurse cells" do not develop and are eaten by the young embryos. After fertilization, eggs may be enclosed in gelatinous masses or capsules of specific forms, which are often attached to various hard substrates. In the European waved whelk (Buccinum undatum), several females contribute to the formation of globular masses measuring up to 50 cm long and composed of numerous egg capsules fastened to one another. In a few bivalve species like the European flat oyster (Ostrea edulis), sperm is released into the sea but fertilization occurs in the pallial cavity where eggs are retained for some time.

For cultured species, broodstock conditioning at the hatchery level is achieved by providing food, and controlling physical environmental parameters (e.g., seawater temperature, light). To entirely control the process of spawning, gametes are obtained by stripping and spawning may be induced by thermal shocks or chemical stimulation (chemicals added in the water or injected in the gonads). Fertilization and larval rearing are carried out in tanks under controlled conditions to maximize yield.

4.4. Larval Stage in Relation to Dispersal and Stock Abundance

As adults, shellfish tend to a sedentary way of life and are sometimes completely sessile. The planktonic larval stage is an important factor for dispersal and enables long-distance travel in a majority of species. Two basic types of reproductive strategies can be correlated with planktonic dispersal. Species with smaller eggs or shorter intracapsular development time (in gastropods) grow more slowly after hatching, and must spend a longer period as feeding larvae in the plankton (planktotrophic species). They are more likely to disperse widely and often show a broader geographical distribution. Species with larger, yolky eggs (lecitotrophic species), long intracapsular development (which depends also on the amount of food provided by the nurse cells) or a brooding period, grow rapidly and have a more or less reduced planktonic stage; they may even hatch directly as crawling young (species with direct development) and typically have a more restricted range. Then, in contrast to the oviparous Pacific oyster, the European flat oyster is larviparous, and fertilization occurs in the pallial cavity, where the larvae are incubated to an advanced stage before release.

At the end of the planktonic stage, larvae settle and metamorphose into juveniles. In most species, the late veliger larva is still able to swim with its velum but can also crawl on the bottom using the foot (pediveliger larva). This ability to swim off and settle elsewhere before metamorphosis, if the substrate is not suitable, enhances to some extend the success of recruitment. The specific factors that induce or inhibit settlement and the metamorphosis of competent larvae can also profoundly affect recruitment: These may be physical, chemical or biological, endogenous or exogenous. Their relative importance for exploited or cultured species have not been well documented, especially for tropical environments.

For most shelled molluscs species, the larval stage is a pelagic dispersal stage depending on current distribution and migration behavior (vertical distribution). The larval stages can last for weeks, depending on environmental constraints such as food, temperature, and salinity and therefore affect spatial dispersion. However, thermal or hydrodynamic fronts in estuaries can limit larval dispersion. Survival rate is commonly a function of the temperature and salinity combination. However, many factors can effect recruitment including the availability of a suitable habitat. With a limited protection, this is a critical stage for shellfish larvae, which show at that time the greatest susceptibility to environmental changes; although this susceptibility will decrease with age. Suitable environment is more critical than population size to obtain a successful recruitment and sustainable population as demonstrated by shellfish population rebounds, following overfishing, disease or introduction. The case of the limited aquaculture activity using R. philippinarum leading to a large colonization of natural beds in European countries is an example, while leading to a new public fishery.

4.5. Migration

Besides abalone or limpet "homing," few shellfish species show a migration pattern at the adult stage. However, short distance displacement can be observed for several species (clams, pectinids), and mostly result from temporary unsuitable habitat or/and disturbance ("escaping behavior"). Some predatory or scavenging gastropod species (buccinids, muricids, and ranellids) may also move toward a main source of food and concentrate on it. Aquaculture species are usually those selected because their lack of migration behavior, therefore facilitating controls over population.

5. Stock Assessment and Management Approaches

5.1. Stock Assessment

Stock assessment could be based on indirect methods using fisheries data (landings per gear, fishing effort, age or size composition), or on direct methods through scientific surveys.

Indirect methods can be used when the quality of fisheries data is appropriate. In such cases, biomass dynamics and dynamic-size or age-structured models can be easily used in the shelled molluscs case in order to optimize the exploitation conditions of a particular population biomass. However, since the shelled molluscs fisheries are mostly small-scale fisheries, fishery official statistics data are often underestimated with a high yearly variability and degree of uncertainty. Therefore, direct stock assessment must be used.

The sedentary often gregarious behavior of shelled molluscs is a great advantage for direct assessment approaches through trawl, dredge, or grab surveys on sandy bottom beds. Transect techniques by divers could be applied on shallow rocky grounds. These methods are very useful to forecast the recruitment abundance into the fishery and limit the fluctuation in annual landings.

In aquaculture, stock assessment is required when regulations are necessary to limit trophic competition, which may affect growth rate and overall yield. Therefore, these assessments usually lead to carrying capacity and ecosystems models when significant research potential is developed. The statistical approach is usually based on aerial photographic coverage to assess rearing structure coverage combined with field samplings to estimate stocking density.

5.2. Management Strategies

Most of the numerous shelled molluscs subsistence fisheries are open access fisheries. Some characteristics of the shelled molluscs have promoted numerous management strategies at various decision making scales: high vulnerability of these resource at the fishing pressure, sedentary stocks, high recruitment variability, mainly inshore located and small scale beds, generally single species fisheries.

Most of existing management measures can be observed in the shelled molluscs fisheries. The individual size control (minimum landing size) is the most common and often the only measure used to prevent overexploitation (discarded undersized shelled molluscs have generally a good surviving rate). Local management measures are implemented in attempts to control technical characteristics of the gear (type, number, weight, belly ring, and mesh sizes) or of the fishing boat (length, power). Closed fishing seasons are implemented in selected areas as well as the limitation of the days at sea and sometimes hours of fishing. Input controls through limited entry licenses become more and more frequent. Output controls using TAC, sometimes allocated to individual fishermen (daily or annual IQ, ITQ) exist in more sophisticated regulated fisheries. The concept of sanctuaries to protect habitats or a part of the stock is spreading out, for example in Chile with the creation of an "area de manejo" in most coastal communities.

The most successful management systems are those able to prevent the fishing overcapacity dynamic within the fishery. Whatever the system adopted, it works efficiently and fairly only if two conditions are met: a serious improvement in the transparency of the landings and an equally serious improvement in the enforcement of the rules.

Site selection for aquaculture is a preliminary stage for appropriate management which should consider biological requirements, seawater quality (from a public health point of view), and coastal users, since most suitable areas are located within the coastal zone. Although limited environmental impact (side effect) is related to shellfish aquaculture, one of the increasing issues is linked to integrated coastal management. Since growout facilities are located in most of the producing countries on common and public grounds, these are controlled by state regulations aiming to zone, limit coastal impact, and specify cultural practices such as stocking densities, minimum legal size, or accredit rearing structures. When shellfish aquaculture is based upon natural spatfall, sanctuaries or/and close season can be defined to protect natural beds the overall broodstock of which can contribute to reproduction and species genetic sustainability.

6. Issues for the Future

Shelled molluscs form an heterogeneous group of animals characterized by their sedentary and usually gregarious behavior, settling, recessing, or scavenging, or moving over a limited area. Many species have their reproduction strategy based on large dissemination of gametes and planktonic larvae, which drift with coastal currents to encounter specific habitats on favorable conditions for further benthic development. This is the case for the main bivalve species, but also for several gastropods. They act as primary consumers in the foodweb, as herbivorous or particle feeders.

These characteristics explain the large group distribution on the continental shelf, forming dense resources in association with the primary productivity. Their thick shell represents an appropriate protection but sedentary behavior makes them vulnerable to fishing gear. With an increasing fishing effort and exploited accumulated biomass, recruitment variability becomes the main constraint for management, therefore leading to frequent fisheries collapses.

Several coastal species have been harvested and cultured for a long time. The high natural spatfall provides a large source of juveniles, which can be collected, easily transported, and relocated at high densities in specific areas. Aquaculture dominates many sheltered bays, with bottom culture in intertidal areas and hanging culture in subtidal areas. Progress has been recently made in the control of artificial reproduction for new strains and new species.

The management and development of resources are facing anthropic pressure, inducing competition for coastal space and improvement of the seawater quality coming from watersheds.

There are large opportunities to develop these resources. If animals from shallow waters are heavily fished, there are still unexploited and underexploited stocks with large accumulated biomass in the open sea. However progress can be expected from the management of deeper coastal waters where primary productivity is still high and conflicts with nonproductive uses reduced. Part of the future aquaculture will be to develop offshore activities. A large effort to develop links between aquaculture, fishing and ecosystem management could result in stock enhancement. Mass production of juveniles through aquaculture would ensure consistent recruitment. However, a better understanding of the consequences of different fishery techniques and open sea ecosystems is required to reach the level of on growing control.

One of the critical aspects for future and sustainable shellfish aquaculture is coastal productivity, which might be affected by seawater quality. In addition, user conflicts for space and common resources such as freshwater inputs, which supply nutrients to the coastal zone, are important. Therefore, integrated coastal management is likely to increase in importance in the near future. New rearing techniques using off shore equipment (e.g., long lines) or by reallocating leasing grounds might contribute to increased productivity and decrease conflicts around the coastal area. However such developments may increase conflicts for space with other economic activities (e.g., finfish fisheries, navigation). Besides coastal management, a critical aspect remains the shellfish pathogens which have drastically and permanently affected the production of several shellfish species over a wide geographic range (e.g., the European flat oyster O. edulis, the Eastern oyster C. virginica). Moreover, the fact that 61% of the worldwide shellfish aquaculture production is based on only 3 species demonstrates the critical need for diversification, in addition to genetic and pathology research to secure a sustainable future production.

Shelled molluscs that are not used as food are different. Markets for jewellery, shellcraft or ornaments are often small and require old, large specimens. Little is known of the reproduction and potential for aquaculture for these species. However, demand is increasing.

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Biographical Sketches

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