Marine Molluscan Production Trends in France: From Fisheries to Aquaculture

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ABSTRACT

The main activity in French shellfishing is culturing. Most culture involves oysters, *Crassostrea gigas*, and *Ostrea edulis*; mussels, *Mytilus edulis* and *M. galloprovincialis*; and to a lesser extent the scallop, *Pecten maximus*, and the exotic Manila clam, *Tapes philippinarum*. Wild species harvested include the whelk, *Buccinum undatum*; abalone, *Haliotis tuberculata*; and bivalves, such as the cockle, *Cerastoderma edule*; pectinids, *Chlamys varia* and *Aequipecten opercularis*; and several clams, e.g., *Mercenaria mercenaria* and *Venerupis rhomboides*. Recreational landings are substantial. The flat oyster, *O. edulis*, has been part of human diets for centuries. Natural beds were exploited through the Middle Ages until the last century by handpicking at low tide and by boat dredging. The effort led to overfishing, and between 1853 and 1859, a repletion program was initiated, mainly based on using wooden spat collectors, which marked the beginning of French oyster culture. In 1860, a shortage of flat oysters led to the introduction of *C. angulata*. Oyster production increased to a record high of 85,000 t of *C. angulata* and 28,000 t of *O. edulis* in 1960, but diseases hit *C. angulata* and led to its disappearance. In 1972, *C. gigas* was introduced, spread rapidly by natural spatfall, and facilitated a fast industry recovery. Oyster production now is 150,000 t of *C. gigas* and 2,000 t of *O. edulis* a year. Oysters often are deployed in ponds for fattening before marketing. *M. edulis* is produced on the Atlantic coast, while *M. galloprovincialis* is mainly produced on the Mediterranean coast. Currently, 1,613 km of bouchots are used to grow mussels, yielding 58,000 t/year; longlines yield 30,000 t; on-bottom culture, 2,000–3,000 t, and the public fishery, 20,000 to 30,000 t. The native clams, *Tapes decussatus* and *T. pullustra* have been harvested. *T. philippinarum* was introduced and hatchery cultured; production peaked at 500 t, but the clam has colonized natural areas. The common scallop, *P. maximus*, and Mediterranean scallop, *P. jacobaeus*, are harvested by dredging. The whelk is fished with pots; landings are about 15,000 t/year. Abalones are harvested by hand at low tide or by diving. Cockle harvests total about 10,00 t/year. The entire shellfishing industry employs more than 20,000 permanent people and 30,000 part-time workers. Most shellfish are marketed fresh in the shell, but some species, e.g., clams and scallops, are marketed frozen.

Introduction

The French consume around 60 species of mollusks, including bivalves, gastropods, and cephalopods. Most mollusks are harvested along the coasts of France, while less than 10 bivalve species are cultured. However, molluscan culture, usually concentrated in highly produc-

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Goulletquer, P., and M. Heral. 1997. Marine Molluscan Production Trends in France: From Fisheries to Aquaculture, p. 137-164. *In* U.S. Dep. Commer., NOAA Tech. Rep. NMFS 129.

tive estuaries and bays, represents the most important economic activity.

Most molluscan culture concerns oysters (including the introduced Pacific oyster, *Crassostrea gigas*, and the native flat oyster, *Ostrea edulis*): native mussels, *Mytilus edulis* and *Mytilus galloprovincialis*; and, to a lesser extent, the scallop, *Pecten maximus*, and the exotic clam, *Tapes philippinarum*. In addition, French Polynesia is the focus of a highly valuable pearl oyster, *Pinctada margaritifera*, culture.

Mollusks currently are cultivated over 20,000 ha (1 hectare = 0.4 acre): 14,000 ha in estuaries and 6,000 ha in tidal areas, and distributed among 60,140 leasing grounds. *C. gigas* production takes >72% of the total leased grounds. The entire molluscan industry (including mussel culture) employs at least 20,000 permanent and 30,000 part-time people.

Regarding the coastal and intertidal fisheries, most of the species are harvested by boat or at low tide by local fishermen. Although not evaluated, recreational shellfish landings are substantial, particularly on the Atlantic seaside and the English Channel. Species include the squids, *Sepia officinalis* and *Loligo forbesi*; gastropods, particularly the waved whelk, *Buccinum undatum*, and the abalone, *Haliotis tuberculata*; and numerous bivalves such the cockle, *Cerastoderma edule*; the pectinids, *Chlamys varia* and *Aequipecten opercularis*; and several clam species (e.g., *Mercenaria mercenaria* and *Venerupis rhomboides*).

Habitats

France's 5,500 km coastline is divided among three frontages: The north and west on the Atlantic ocean and English Channel totals 3,800 km, and south on the Mediterranean Sea totals 1,700 km (Fig. 1). About 51%

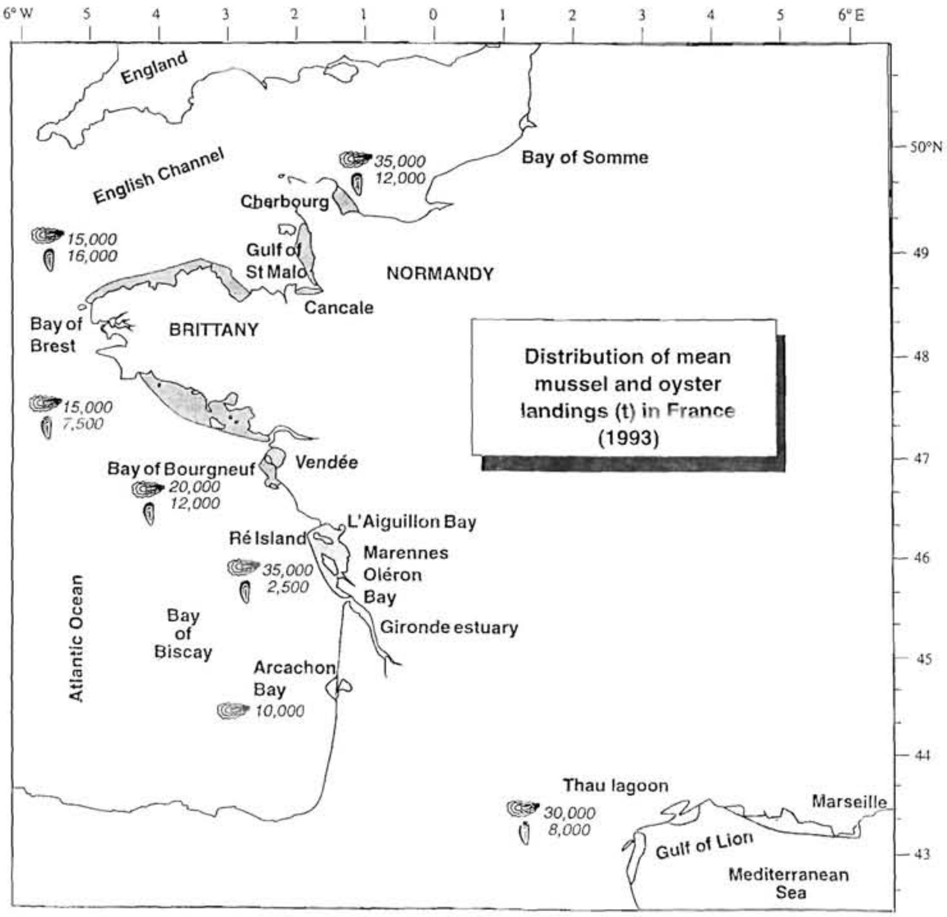

Figure 1
Oyster and mussel culture in France: distribution of the rearing areas with average production (1,000 t) in each area.

of the coasts are urbanized, 960 km intensively so. Of the 5,500 km, 800 km are located in highly productive estuaries, and 580 km are island coastlines.

The coast of France is highly diverse. On the northern and western coast, 30% are rocky shores, 40% are sandy beaches, and 30% are salt marshes, while on the southern part, 65% are mostly rocky shores, 25% are sandy bottoms, and 10% are salt marshes. France's temperate climate is affected by the Gulf Stream, with a biogeographic barrier around Brittany, which limits the spread of northern and southern marine species originating from colder and warmer areas, respectively. In northern Brittany, sea temperatures vary between 6° and 10°C in February and 15° and 17°C in summer, while summer temperatures rise above 20°C on the Atlantic coast. Salinities range from 5‰ in the oyster ponds to 20‰ on the coast in winter to 30 to 35‰ on the coast in summer. Abnormal climatic patterns caused by such variability may drastically affect shellfish population dynamics, affecting local landings (e.g., scallops). In contrast, cultured species may be particularly well adapted to the ecosystem variability, and thus be able to limit abnormal events like recruitment failure (e.g., *C. gigas* spatfall), and result in stabilized production. The main difference between the northern-western and southern frontages is the tide effect, which has determined species diversity and distribution and, therefore, molluscan culture and fishing practices. The English Channel and Atlantic coast are characterized by two cycles a day (i.e., 12 h per cycle), while neap tides alternate with spring tides every week, resulting in highly favorable trophic conditions for molluscan culture. For example, a 15.5 m record high tide range was observed in the Gulf of St. Malo, while averaging 10 m during spring tides. Moreover, the tide varies around 8 m and 4 m on the western part of the northern Brittany and Atlantic sides, respectively. In contrast, tides are almost nonexistent on the French Mediterranean seaside, prompting the farmers to develop subtidal techniques. The salinity in the Mediterranean Sea is about 35‰.

The Oyster Industry

History

The flat oyster, *O. edulis*, a native of Europe, has been part of the human diet for many centuries. The Romans built ponds to stock and sort oysters before exporting them to Rome (Grelon, 1978). Oysters were distributed in shallow bays and estuaries along the French coast.

Natural beds were extensively exploited through the Middle Ages until the last century, by handpicking at low tide or by boat dredging in deeper areas representing a large fishery (e.g., Cancale) (Pichot-Louvet, 1982). Oyster shell piles, reaching 500.000 m³, equivalent to 5 trillion shells, were observed in the southwest of France near l'Aiguillon and Bourgneuf Bays. Originating from the 10th century, they demonstrate the large oyster fishery activity (Gruet and Prigent, 1986). In the 17th century, oyster culture was initiated using ponds in salt marshes on the Atlantic coast. Oyster spat were collected on rocks and separated from each other after two years, then deployed in oyster ponds for 4–5 more years. Oyster culture increased with a concurrent decline in activity in salt marshes (Héral, 1990). In those early days, oyster spat were obtained only from fishing.

During the 18th century, fishing effort led to overfishing and destruction of natural beds. In 1750, regulations were enforced to restrict fishing during the breeding season (Héral, 1990). In Arcachon Bay and Brittany, several moratoria were enforced for a number of years. During the 19th century, landings became irregular in spite of increased regulations. But an increased demand for fattening young oysters and market demands resulted in boosting fishing effort. From 1857 to 1872, fishing effort on Cancale oyster beds increased by a factor of 13. Moreover, extremely cold winters and predation pressure affected natural spat recruitment. Coste (1861) described Cancale and Arcachon oyster stocks as drastically reduced and those from the Marennes-Oléron areas as totally exhausted.

Between 1853 and 1859, DeBon and Coste initiated a repletion and reseeding program based mainly on using wooden spat collectors similar to those used in Italy. This project marked the beginning of French oyster culture with the control of seed supply. In 1865, Michelet developed the liming tile technique for collecting spat and the oyster box for growing spat in Arcachon Bay (Roche, 1897). But the main change facilitating culture development occurred in 1852, when the French government took over the entire coastal management and established rules of ground exploitation, therefore facilitating rational exploitation (Roche, 1897).

In 1860, a shortage of *O. edulis* seed prompted oyster farmers to import cupped oysters, *Crassotrea angulata*, from Portugal to Arcachon Bay. A natural population settled in the Gironde estuary when a shipment had to be jettisoned during a storm in 1868. This species spread naturally along the Atlantic coast up to Marennes-Oléron in 1874, Ré Island in 1878, then Vendée, and finally to southern Brittany. In spite of this northern limit impeding natural reproduction, oysters were cultured in northern beds (e.g., Cancale) by transplanting seed. Both species then were cultured simultaneously, particularly in Arcachon Bay (Hinard and Lambert, 1928).

Around 1910, oyster production was equally divided between both species (Fig 2), but then a massive mor-

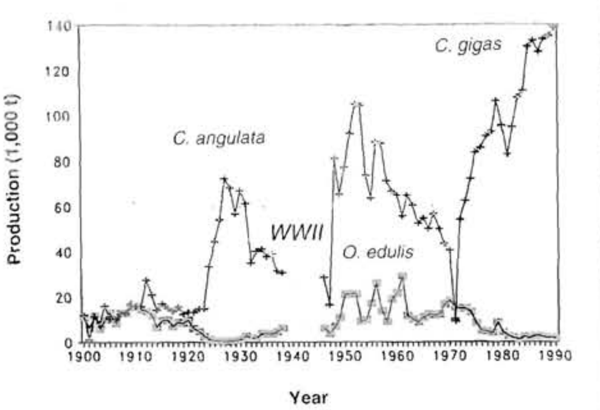

Figure 2
Historical trends in French oyster production, 1900–93.

tality, perhaps caused by a disease, struck the flat oyster, favoring an increase in the culture of the cupped oyster. The flat oyster population later recovered, but only in the southern part of Brittany, with heavy spatfalls in 1925 and 1928. Hinard and Lambert (1928) reported that *C. angulata* had replaced *O. edulis* on the spat collectors in Arcachon Bay.

Spat collecting techniques, meanwhile, became systematic in the southwest of France, using oyster shell strings and slates as well as chestnut and hazel stakes. On the Mediterranean coast, off-bottom culture was initiated around 1900 using *O. edulis* cemented onto steel ropes. Growout facilities were developed in shallow waters (3–4 m) at Seyne and Marseille. Oyster spat came from the Thau Lagoon, but in 1932 this practice was limited to one leasing ground in the lagoon. Oyster production then increased substantially by using spat imported from Brittany. Spat were cemented individually onto poles which were then hung from frameworks deployed over mussel leasing grounds. This species was cultured until 1950–51, when stocks were depleted and replaced by *C. angulata*.

On the Atlantic coast and the English Channel, oyster production increased consistently to a record high of 85,000 metric tons[1] (t) of *C. angulata* and 28,000 t of *O. edulis*, in 1960. Concomitant to the production increase, rearing areas were concentrated in highly favorable sites, usually semiclosed bays protected from storms (e.g., Marennes-Oléron and Arcachon Bays). This resulted in higher stocking densities but poorer growth and increased mortality rates (Héral, 1990; Héral and Deslous-Paoli, 1991). From 1966 to 1969, gill and viral diseases spread over several major rearing areas, leading to massive mortalities between 1970 and 1973, and the final disappearance of *C. angulata*.

[1] At 32 U.S. standard bushels in 1 metric ton.

Seed and adults of the Pacific oyster, *Crassostrea gigas*, were introduced in 1972 to reverse the ailing production and revitalize the oyster industry (Grizel and Héral, 1991). Imports of seed were to sustain farmers' production; imports of adults were to restore natural broodstock beds in several areas along the southwestern Atlantic coast. The introduction was so successful that natural spatfall in the following years in Arcachon and Marennes-Oléron Bays facilitated a fast industry recovery. Then, two diseases, *Marteilia refringens* and *Bonamia ostreae*, spread in the late 1970's and drastically reduced production of *O. edulis* in almost all rearing areas. Despite new management practices and an intensive repletion program, *O. edulis* production has remained low.

Current Status

The annual production of oysters currently supplies the French market and reaches 150,000 t of *C. gigas* and 2,000 t of *O. edulis* (whole weight), with an exchange value of F1,500 million ($254.3 million) and F120 million ($20.34 million), respectively (Fig. 1, 2). Oyster production represents more than 25% of the entire French marine seafood production.

Oyster Culture

Several methods are used to produce oysters, depending on the area. From a biological point of view, *C. gigas*' natural distribution is more restricted than that of *C. angulata*. Natural spatfall occurs regularly on the southwest Atlantic coast, mainly in the Gironde estuary and Arcachon and Marennes-Oléron Bays, affecting the traditional oyster farming practices. Similarly to *C. angulata*, seed transplanting from those bays to Mediterranean oyster culture areas (e.g., Thau Lagoon) and to Brittany and Normandy is done on a large scale. Oyster farmers benefit from dividing their production among several regions.

The seed supply is based mainly on natural spatfall, using artificial spat collectors. The spat supply is reliable and regular. *C. gigas* larvae do not require a specific substrate (assuming it is clean, without fouling and silt) many types of spat collectors are used (Fig. 3, 4). Limed tiles usually are employed in Arcachon Bay and are of particular interest for early spat removal. Plastic PVC tubes with roughened surfaces recently became the favorite, because their weight reduces field labor while maximizing the spat collecting area; automatic equipment facilitates the removal of spat.

Farmers currently are progressively and systematically shifting their spat production from using old spat collectors to PVC tubes. The tubes are immersed in seawater for several weeks, and then sun dried before

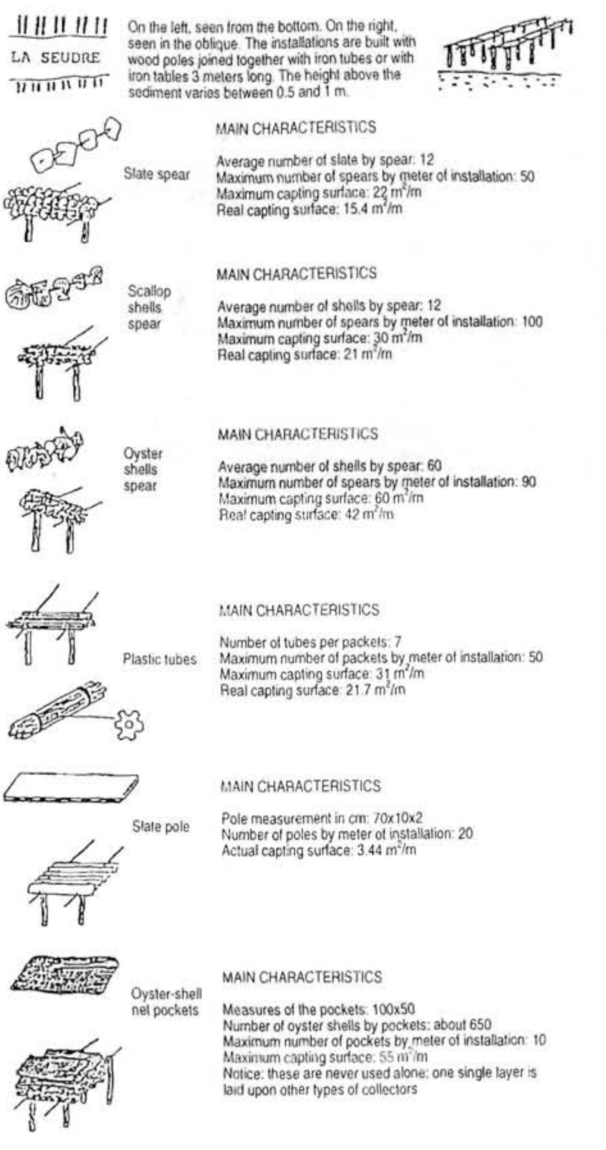

Figure 3
Several types of oyster spat collectors in use and the rack culture in France (from Berthomé et al., 1984).

field deployment, to release any potential hazardous chemicals. Monitoring larval abundance and environmental conditions are the key factors in deploying the spat collectors and maximizing spat recruitment in the two main bays, i.e., Marennes-Oléron and Arcachon. Each year, nearly 5 trillion spat settle in Arcachon Bay on 20 million spat collectors, and 10 trillion spat settle in Marennes Oléron Bay (Berthomé et al., 1984). This technique still is the major one for supplying a reliable and regular seed supply in France and is responsible for the oyster production success.

Hatcheries recently have begun to produce cultchless spat and larvae for remote setting techniques. The latter is of particular interest to oyster farmers located far from natural spatfall areas (e.g., Normandy). The choice of spat collector for *O. edulis* settlement is more specific, and usually is tiles coated with lime and sand. The lime composition varies among breeding areas (Marteil, 1976). Spat are removed after 6–10 months. More recently, use of tubular nets filled with mussel shell and deployed off-bottom has been proven more cost-effective than tiles in southern Brittany (Grizel et al., 1979).

Several techniques are used for the pregrowing and growing stages, depending on peculiarities of each rearing area. The duration of each stage depends on local stocking densities and ecosystem carrying capacity. Oysters are produced using on-bottom and off-bottom techniques, as well as in subtidal or intertidal leasing grounds. On-bottom culture, intertidally or in deep water, is carried out by first hardening the bottom and then sowing seed directly with or without their spat collectors. In intertidal areas, a plastic fence defines the rearing area and effectively reduces green crab, *Carcinus maenas*, predation. Following 1–2 years of pregrowing, spat are scraped from the cultch, sorted by weight, and then put back on the bottoms for further growth.

The mean density for *C. gigas* is 5 and 7 kg/m^2 during the pregrowing and growing stages, respectively (Bacher, 1984). Marteil (1976) reported *O. edulis* densities ranging from 0.5 kg/m^2 the first year, 1 kg/m^2 the second year, and 3–5 kg/m^2 the third and four years.

On-bottom culture requires oyster farmers to harrow or fork the oyster beds to limit siltation. One ton of *C. gigas* and *O. edulis* spat yields 20 t and 12–15 t (whole weight) of marketable oysters, respectively. In subtidal areas in southern Brittany, the density of *O. edulis* has been reduced from 0.5 to 0.1 kg/m^2 to maximize the growth rate since bonamia disease drastically reduces the survival rate of the 3- to 4-year-old oysters. Disease effects also prompted several oyster farmers to switch to *C. gigas* culture in subtidal and intertidal rearing areas. Subtidal culture is considered as more cost-effective than intertidal culture, but requires higher investment. The availability of grounds, however, has not as yet been assessed.

Rack culture on iron tables currently is the most common technique used in intertidal areas on the Atlantic coast and English Channel (Fig. 3). Spat collectors or oyster bags are attached to tables 3 m long and located at 0.5 m off-bottom. From 50 to 100 collectors/m is the usual initial density; it is decreased to 8–10/m a year later. After removal from the collectors, the seed is sorted and deployed in bags that are 1 m long and 0.5 m wide and whose mesh size depends on the oyster size. Although more efficient than on-bottom culture, this method can lead to overcrowding of oysters in bags and siltation underneath the tables by biodeposition. It there-

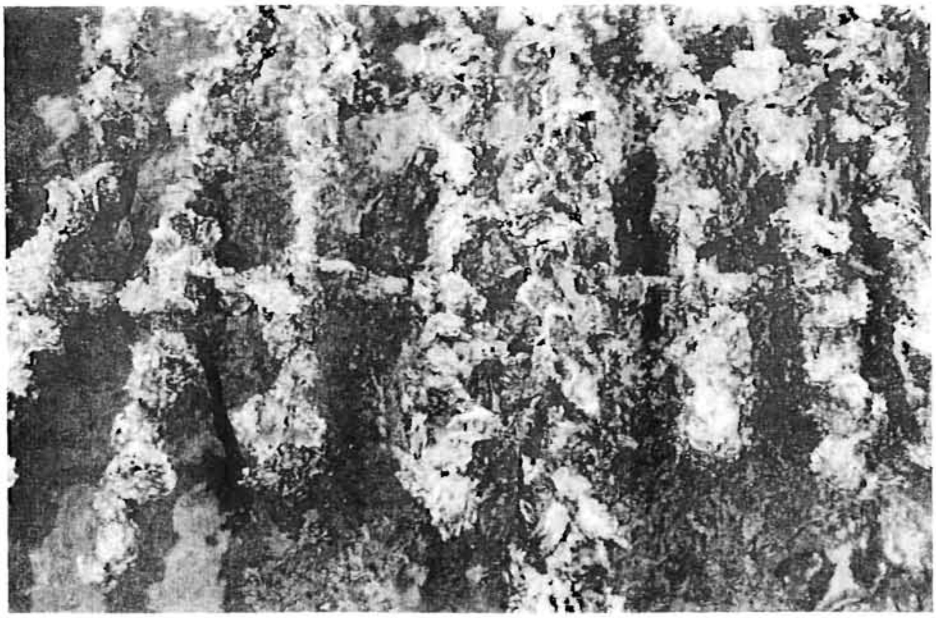

Figure 4
Detail of iron pipe spat collector covered with 8-month-old oysters, *Crassostrea gigas.*

fore requires stricter management regulations. Oyster bags weigh around 5 kg initially and 15–20 kg when the oysters reach commercial size (Bacher, 1984). Rows of tables, 30–100 m long, are placed parallel to each other, depending on the tidal current pattern and direction (Fig. 5).

At the end of the rearing cycle on the Atlantic coast, oysters are often deployed in oyster ponds for fattening (Fig. 6). Old salt marshes were converted specifically to ponds for oyster culture. Oysters are deployed at low density ($<10/m^2$) in the shallow (0.4 m) earthen ponds which are filled by gravity with seawater at high tide. During 10 days of neap tide, no water exchange occurs, and the phytoplankton blooms since the turbidity is low and the nutrient load is high.

The phytoplanktonic species, *Haslea* (*Navicula*) *ostrearia*, is of particular interest. Following this species' bloom, its green pigment diffusing in the water is absorbed by oyster gills. This process leads to green colored oysters which are particularly tasty and expensive in the market. Two brands are defined, "fines de claires" for oysters spending a month in the oyster ponds at a density of $20/m^2$, and "speciales de claire," for oysters fattened 2 months at a stocking density of $10/m^2$.

Farmers in Marennes-Oléron Bay have developed a special quality brand called "Label Rouge," which has stricter definitions than the previous ones and is based on a 17 June 1983 State Decree (Ministry of Agriculture). This brand requires the fulfillment of high standards for oysters (e.g., shape, >9% meat condition index, salinity >20ppt, color, size), rearing conditions (such as a $20/m^2$ density), at least a month in oyster ponds for fattening, tasting standards, as well as packaging and conditioning (e.g., storage temperature). The oysters should be consumed within 10 days after being packaged. This brand is a consumer guarantee for a top-rated quality product. About 25% of the French production is marketed as "fines de claires," while the "speciales de claires" and "label rouge" (red label) oysters together constitute <10% of the yearly production.

In the Mediterranean lagoons, where the tidal range is less than 1 m and the depth around 10 m, permanent growout facilities are deployed from the sea surface. The structures are 50 m long and 10–12 m wide and support about 1,000 suspensions (Hamon and Tournier, 1981). Spat collectors covered by spat coming from the Atlantic coast are hung directly under the structures; the oysters are marketed 12–18 months later. Some of the oysters are cemented individually on wooden poles and hung for one additional year to yield large fat oysters aimed at a special market (Raimbault, 1984). The average yield is 5–7 t of oysters per structure.

The Public Fishery

Fishermen harvest oysters on natural beds on the Atlantic coast every year. The beds resulted from the building of oyster bars for broodstock in the 1970's. A quota,

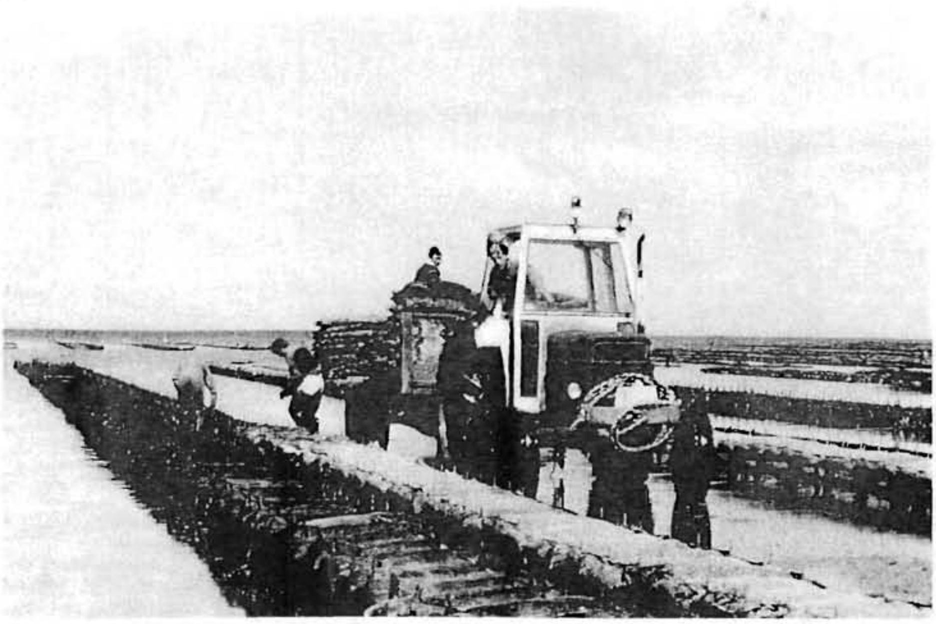

Figure 5
Harvesting oysters, *Crassostrea gigas*, grown in bags off-bottom on iron tables.

based on a yearly stock assessment, is given to authorized licensees for harvesting oysters in bacteriologically polluted areas. Landings have to be declared to the Administration, and the oysters are grown in certified areas for at least 6 months before marketing. In unpolluted areas, the public fishery is totally open during a specified harvesting season. This public fishery aims to keep a sustainable wild broodstock similar to a reserve system and to limit oyster proliferation that may interfere with culture. However, the "natural" spatfall relies mostly on the large cultured stock (e.g., >120,000 t in Marennes-Oléron Bay on 3,200 leased hectares) rather than on the wild stock (e.g., 22,000 t) (Prou et al., 1994).

Regarding *O. edulis*, a moratorium was enforced early in the century on dredging the natural beds of Cancale and the western coast of Normandy that once yielded 10,000–15,000 t yearly. Although a slight rebound occurred in 1970 with 1,600 t, landings have declined steadily to the present time with 10–20 t during the harvesting season in November 1993.

Harvesting Methods

In intertidal areas, harvesting usually is carried out manually. Oysters from bottom culture are harvested using oyster forks, stored in baskets, and then loaded onto flat boats. Around 1.5 t is harvested by each farmer during one low tide. New vehicles are being tested for culturing and harvesting oysters on hard bottoms (Fig. 7). Although not mechanized, harvesting oyster bags is an easier task and yields twice as much weight as before (i.e., 200 bags during one low-tide period) (Fig. 5). Experiments currently are in progress to mechanize this process. In the Normandy area, tractors currently are in use instead of flatboats to work on oyster fields, since the tidal range is >10 m, the intertidal area is large (e.g., several km), and the bottom is hard. In subtidal areas, dredging boats commonly are used; each harvests about 15 t/day (Marteil, 1976).

Processing and Marketing

Once harvested, oysters are brought to a processing plant where they are washed with automatic equipment and sorted by weight manually or mechanically (Fig. 8). Electronic computerized equipment recently has been developed to sort at least 8.5 t/day in up to 8 oyster-weight sizes. Oysters then are packed and marketed.

In France, oysters are sold on the fresh market without shucking, therefore explaining cultural and marketing practices. Oysters usually are eaten raw but a small market involving restaurants requires large oysters for cooking and stuffing. Half of the production is marketed for Christmas and for New Year's Eve, requiring a well organized marketing system. Oyster farmers sell about 20% of their production directly to local

Figure 6
Aerial view of oyster ponds or claires.

markets (SECODIP, 1983) (Fig. 9). Supermarkets have been increasing their market share, which currently is estimated at about 30%. Few oysters are imported or exported since the French supply and demand is balanced. Prices average F10 or $1.69/kg, but they fluctuate widely and depend on product quality and stock availability. Extensive trade occurs between the various rearing areas; they are characterized by a large variation in operating costs.

The Mother of Pearl and Pearl Oyster Industries

History

During the 19th and early 20th centuries, the black-lipped pearl oyster, *Pinctada margaritifera* (L.) var. *cumingui*, was harvested for mother of pearl shell and used for button manufacture as well as the fancy goods industry (Intes, 1982; Coeroli, 1985). This species is distributed among five archipelagos in French Polynesia including Tuamotu and Gambier. This fishery began in 1802 at Gambier archipelagos and reached a yearly production of about 500 t from 1889 to 1940. Fishermen dove to depths of 20–30 m and tore away pearl oysters from coral pinnacles.

The first regulations to protect the resource, enacted in 1904, sought to limit fishing effort. Lagoons were spatially divided into three parts and opened for fishing one after another. Despite the regulations, a record high production was reached in 1919 with 1,000 t and later 1,924 t in 1928. From 1940 to 1960, the average yearly landings declined to 700 t, demonstrating the fishery decline despite additional 1954 regulations limiting fishing effort (i.e., quotas and broodstock sanctuaries). Since then, consistent overfishing led to shrinking landings and a 50 t record low. For example, the landings in the Takapoto Lagoon declined from 400 t to less than 10 t in 1984.

From 1962 to 1964, pearl culture was successfully tested, with 1,095 black pearls being produced. Since 1972, pearl oysters have been harvested mainly to supply the pearl culture industry.

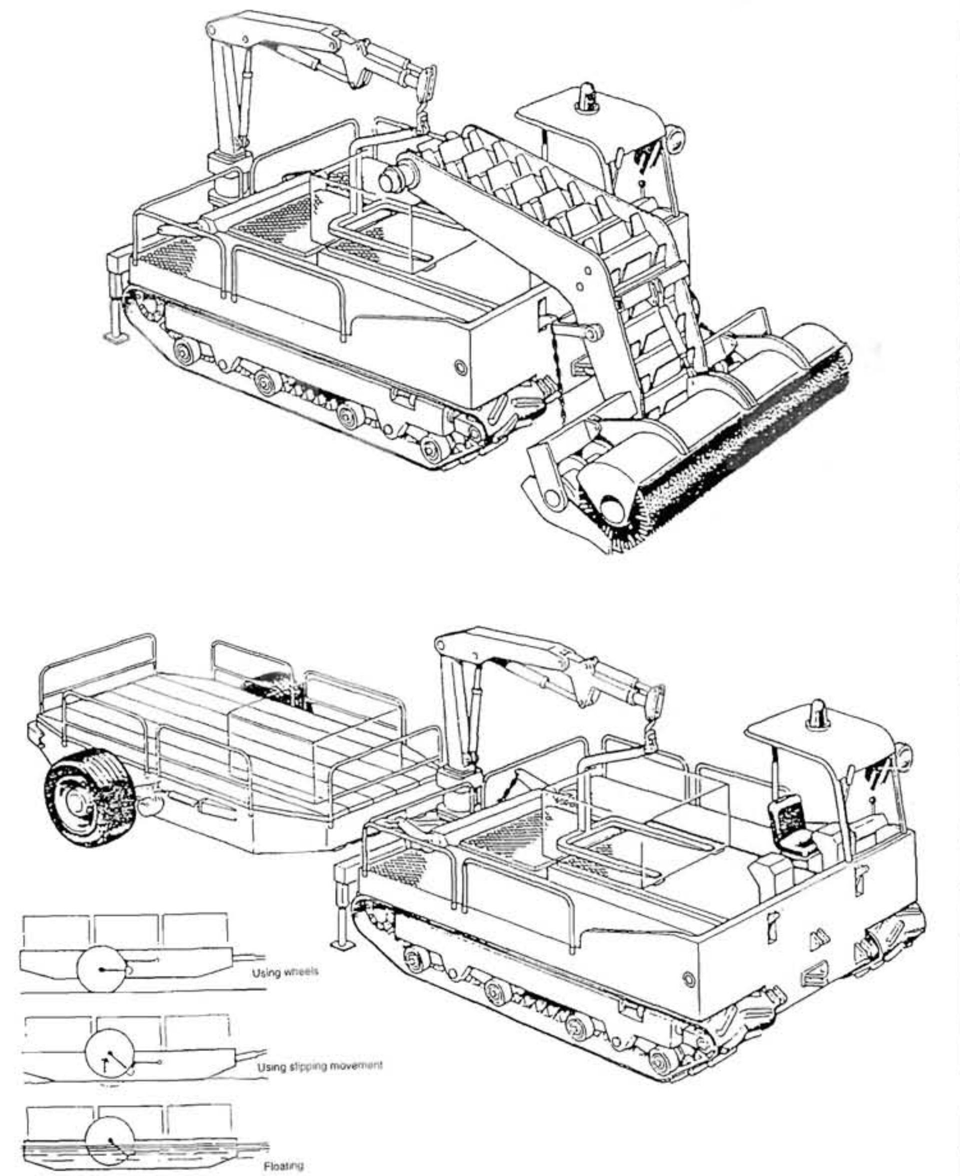

Figure 7

Recent shellfish culture equipment. Top figure shows oyster (on-bottom) harvesting machine. Bottom figure shows this machine geared with a trailer which can float or be used on soft bottom (slipping movement) and on hard bottom (wheels) (from Priour, 1986).

The first trials of mother of pearl culture were made in 1875; spat were collected in the Tuamotu and Gambier archipelagos (Coeroli, 1985). Unfortunately, the most common species collected, *Pinctada maculata,* had limited commercial value. The spat collecting method, technically under control by 1976, resulted in boosting pearl oyster culture; it was carried out by family businesses and cooperatives. About 80% of spat currently is obtained by using spat collectors, while the remainder is from collections on natural beds. Pearl culture is one of the most important industries in French Polynesia (Coeroli, 1985, Coeroli et al., 1984, Buestel et al., 1993). As early as 1976, the American Institute of Gemology (GIA) officially recognized the Tahiti pearl as "Cultured pearl of natural color." Later on, the International Confederation of Jewelery (CIBJHO) recognized the label of "Pearl from Tahiti."

Figure 8
Sorting equipment for grading oysters by weight. The equipment consists of a rotating turret with calibrated counterweights.

Current Status

Pearl culture currently ranks third behind oyster and mussel culture in commercial value. In 1976, the first black pearl exports weighed 6 kg, worth $82,000. In 1983, production reached 139 kg, worth $4,182,000 (Coeroli, 1985). Since 1980, exports of black pearls have increased by a factor of 40, and 600,000 black pearls were exported in 1992, yielding F234 million ($39.66 million) (Buestel[2]).

Culture

Pearl oyster culture is based on a 4-year rearing cycle including spat gathering (12 months), rearing (18 months), and then grafting and harvesting (18 months). Spatial management of cultured areas is similar to that currently used in culturing oysters on leased grounds in the mainland of France. Spat collectors are hung 3–10 m deep from anchored buoys. They are deployed regularly throughout the year since settlement may occur year-round. However, two settlement peaks occur: from July to August and from October to December (Coeroli, 1985; Buestel et al., 1993). Polyethylene strips and branches of trees commonly are used as spat collectors.

One year after settlement, the oysters, 6–10 cm long, are removed from the spat collectors. Each collector yields up to 50 spat. In 1985, Takapoto Island alone produced 500,000 spat in 1985. Oysters then are heel pierced, attached to strings at a density of 10 oysters per unit, and then deployed on subsurface long-lines at a 7–10 m depth range. The growout facilities are protected from fish predators (*Tetrodon* sp. and *Balistoides* sp.) with wire netting. Every 3 months, fouling organisms are removed from the oysters. Once they attain adult size, 11 cm long, the oysters are grafted by introducing into their gonads a piece of young oyster mantle (2x2 mm size) and a nucleus (6–8 mm) originating from the freshwater bivalve, *Pleurobema cordatum*. Commercial pearls are obtained in 15% of the grafted oysters 18 months later. But top-rated pearls usually are limited in number. Oysters used to be sacrificed when pearls were removed, but now a second grafting is being tested.

Marketing

Since the pearl culture industry began recently in French Polynesia, marketing of the pearls is only partly organized. Market instability has resulted from the boosting of supply and the limited professional structure in the face of well organized traders. Japanese companies control 85% of the market.

The Mussel Industry

History

Mussel production in France involves two common species, i.e., *Mytilus edulis*, which is widely distributed along the English Channel to the southwest coast of France, and *Mytilus galloprovincialis*, which is distributed mainly on Mediterranean shores. Genetic crosses of the two species are also present in several locations along the French coast (Coustau, 1991). This wide distribution has favored extensive fishing activity through the centuries, until the 19th century. However, as early as 1681, a

[2] D. Buestel, IFREMER, Tahiti Center, Vairao, French Polynesia. 1993. Personal commun.

Figure 9
Direct marketing of oysters by farmers at a small market.

royal decree was enacted to control the public mussel fishery in the Cancale area. At that time, several natural beds were already described as overfished, well before the oyster beds were overharvested (Pichot-Louvet, 1982).

Several natural beds along the French coast were reported as exhausted in 1933, but fishing effort was still high in the remaining productive areas (Lambert, 1933). Explanations for the decline included overfishing, dredging effects, recruitment variability, and destruction of the juveniles during fishing. Mussel populations meanwhile colonized ancient overfished oyster beds in several places, particularly around Noirmoutier which became an intensively fished area.

Mussel culture methods were developed as early as the 13th century, but only in L'Aiguillon Bay in southwestern France (Dardignac-Corbeil, 1979). A historical sketch describes the development of the wooden pole or "bouchot" culture by a shipwrecked sailor in 1235. While using nets to catch birds in the intertidal area of the Bay of L'Aiguillon, he noted that mussels settled on the poles and yielded a better product than did wild mussels. He then started mussel culture using wooden poles sunk in muddy bottoms. The wooden poles were deployed into two merging lines, 200–300 m long, with a 45° V shape. The poles were linked to each other with boughs. The resulting growout facility was also used as a local finfish (pound) net. A net was deployed at the V head to catch finfish at ebb tide. However, space was not rationally used by this technique, which also maximized siltation.

Following an 1852 State Decree regarding government management, laws were enacted in 1853 and 1859 forbidding the V-shaped bouchot. After that, the two lines of poles were set parallel to each other and deployed perpendicularly to the coast. This technique spread widely along the French coast during the late 1800's. In 1855, L'Aiguillon Bay was still the only area using the "bouchot" technique (Coste, 1861), but the rearing area extended quickly northward with concomitant production increases and later (1860) to the La Rochelle and Marennes-Oléron areas. More recently, the rearing areas were extended to northern Brittany (1954) and the western coast of Normandy (1965). At the turn of the century, bottom culture was developed where bouchot culture failed, for example in Le Croisic and Isigny (Lambert, 1934).

Current Status

Currently, 1,613 km of bouchots are distributed along the French coast. They yield 58,000 t[3] a year (Fig. 1, 10). Bottom culture is located mainly in the Bay of Brest, and annual harvests run from 2,000 to 3,000 t (FIOM, 1982). Harvests from longline culture were 30,000 t in 1993 (CNC, 1993). Annual landings from the public fishery show a large variability resulting from

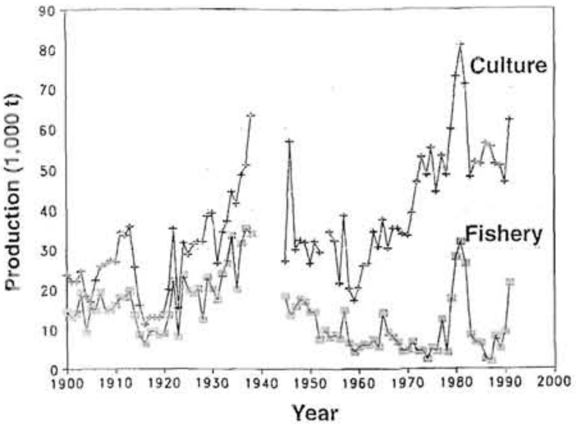

Figure 10
Historical trends of French mussel production (1,000 t), including culture and wild fishery, 1900–90.

Figure 11
Spat-collecting ropes (coconut fibers) covered with blue mussel, *Mytilus edulis*, seed.

irregular spat recruitment and usually range between 20,000 and 30,000 t. The main natural beds are located in Normandy and yielded 25,000 t on 1,000 ha in 1980 and a record high of 50,000 t in 1993. The overall production represents an exchange value reaching F650 million ($110.2 million).

Mussel Culture

Bouchot Culture—The bouchot culture technique has not changed drastically since its origin. Each pole is 4–7 m long, 15–25 cm diameter, and protrudes 2–3 m above the bed. Several wood types currently are used including pine, oak, and more recently, squared Brazilian hardwood. The bouchot structure depends on the rearing area. In southwest France, the structures are 50–60 m long with 120–129 poles in single or double lines for spat settlement and 80–90 poles for growing (Dardignac-Corbeil, 1990). Bouchots should also be spaced at least 25 m apart. In northern Brittany, bouchots are 100 m long, with 130–180 poles, and in Normandy they have <200–250 poles. Bouchots are deployed during the first trimester, and those for spat gathering, 3 months before settlement.

In the spring (May–June), spat settlement occurs intensively in several locations in southwestern France. The spat are sold to mussel farmers in the remaining rearing areas where this activity is not cost-effective (e.g., northern Brittany and Normandy). Spat are gathered by using wooden poles set in the deepest areas or horizontal coconut fiber ropes strung on the poles just before settlement (Fig. 11). The structures remain in place until July. Seed from the poles then is transferred to tubular nets that are reattached around the growing poles (Fig. 12). Mesh size depends on mussel size. The mesh tubes (3–5 m long) are placed around the poles and nailed at each end. Through August, the mussel seed spread and eventually cover the entire pole. Each pole produces between 25 and 60 kg live weight of mussels per rearing cycle (Boromthanarat and Deslous-Paoli, 1988; Gerla, 1993).

On Bottom—On-bottom culturing is based on transferring mussels from natural beds with high densities to culture plots where the density is reduced to improve growth and fattening, and to control predation. On-bottom culture is located mostly in the Boulogne area, Bay of Brest, and southern Brittany. One-year-old mussels usually are dredged in the Bay of Bourgneuf (Noirmoutier) and the Loire estuary, then taken to the culture plots where they are deployed at densities ranging from 25 to 30 t/ha. This process is carried out in spring and early summer. The rearing cycle lasts 14–24 months.

Figure 12
"Bouchot" mussel culture: Deployment of socks filled with blue mussel, *Mytilus edulis*, seed on wooden poles.

Longline Culture and Suspended Culture—In the Thau lagoon, off-bottom culture is based on fixed suspended structures similar to those used for oyster culture. Mussel reproduction occurs almost year-round, but is most intense during fall and winter. Seed is transplanted in plastic mesh tubes and hung vertically from fixed tables.

On the Atlantic coast, a reduced availability of intertidal areas for developing mussel culture led to the development of longline methods. The first trials were conducted in Pertuis Breton using raft techniques during the 1960's (Dardignac-Corbeil, 1990). New subsurface longlines recently have been developed to resist storm and wave effects along the Atlantic coast and offshore along the Mediterranean seaside (i.e., Languedoc Roussillon region) (Barnabé, 1990) (Fig. 13). Several longlines are particularly adapted to areas showing high tidal cycles on the Atlantic coast. Floats are connected together by horizontal lines that support a large number of vertical ropes where mussels are grown. Production rates reach 18–20 t/ha/year.

The Public Fishery

In the Normandy area, around 100 fishermen working on 40 boats are licensed in the public fishery, while in the Bay of Bourgneuf, around 20 fishermen are so licensed. Boat sizes run between 12 and 16 m. The fishermen also harvest scallops, lobsters, and coastal finfish. The decline of the finfisheries prompted additional entries and increased effort in the mussel fishery. In the early days (19th century), natural beds were harvested once every 3 years (Lambert, 1933), but now fishing is done every year and all year long except February, when the quality of mussel meat is reduced by spawning. (Earlier, fishing was allowed only from June to the following February.) A fishing quota now allows 500 kg of mussels/day/fisherman. No fishing activity is authorized during weekends, holidays, or nights.

Harvesting Methods

Harvesting begins as soon as the mussels reach the 40 mm marketable length after a 12–15 month rearing period. A 60–80 mm length is most common. Several techniques are used depending on areas and cultural practices. Mussels grown on wooden poles (bouchots) are harvested by hand or more often by using hydraulic fishing equipment that removes all the mussels at once (Fig. 14). A cylinder is lowered to the bottom of the pole, closed, pulled up, and the mussels are dumped onto a trailer or into containers on boats. Amphibious vehicles currently are used in intertidal areas to maximize working time. Hydraulic forks are also used for unloading.

Mussels are harvested from on-bottom culture plots and public beds by dredging with boats of 7–16 m length and engines of 40–300 hp. In unpolluted areas, mussels are dredged, cleaned, and sorted by size directly on the decks of the boats. Legal-sized mussels are packed in 25 kg bags. Undersized mussels are thrown back on the beds. In contrast, harvesting with longlines requires especially designed vessels that are 10–15 m long and are equipped with heavy lifting gear.

Processing and Marketing

In processing plants, automatic equipment facilitates washing, declumping, debyssing, and grading. Marketable mussels are packed in 15–25 kg bags and sold for the fresh market. Undersized mussels are transferred to mesh tubes that are reattached in the field around the growing poles.

Marketing is based on species peculiarities. Since *M. edulis* spawn in spring, their condition index and the

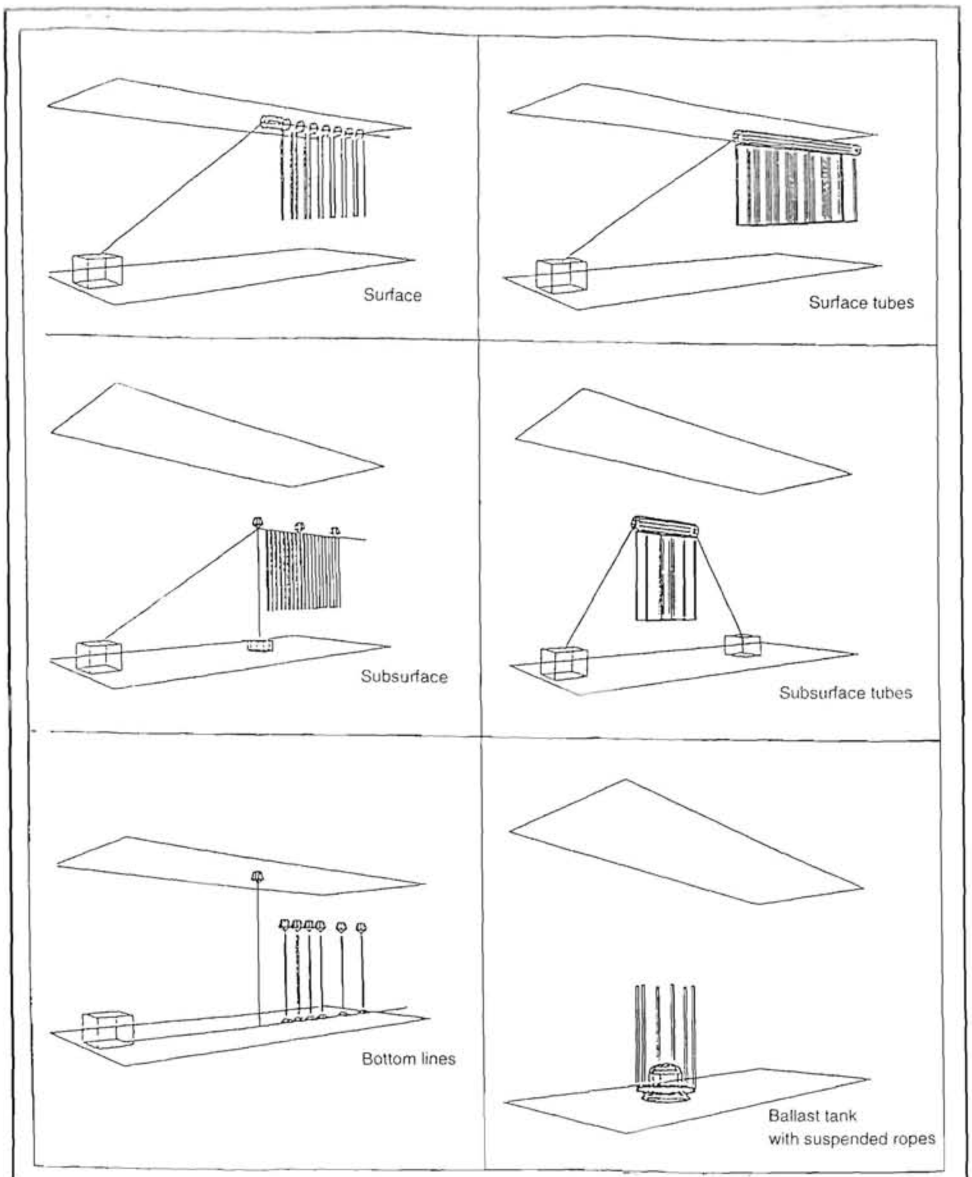

Figure 13
Various types of longline techniques: surface, subsurface, bottom lines, surface, subsurface tubes, and ballast tank with suspended ropes (from Müller et al., 1987, IFREMER/DITI, cited in Héral and Deslous-Paoli, 1991).

meat quality are low between March and May, facilitating the marketing of *M. galloprovincialis*. The commercial season for mussels harvested on the Atlantic coast and along the English Channel lasts from June to November-December. Mediterranean production is commercialized all year since no major seasonal spawning event occurs. Imports, mostly from Holland, fulfill the French demand from September to March-April of the following year. Prices for the "bouchot" mussels average F7–8 ($1.19–1.36)/kg, but fluctuate widely and depend on product quality and stock availability. In contrast, the ex-vessel value for mussels harvested on public beds peaks at F2–3 ($0.34–0.51)/kg and depends exclusively on stock availability.

The Clam Industry

History

The native clams *Tapes decussatus* and, to a lesser extent, *Tapes pullastra* have been fished extensively along

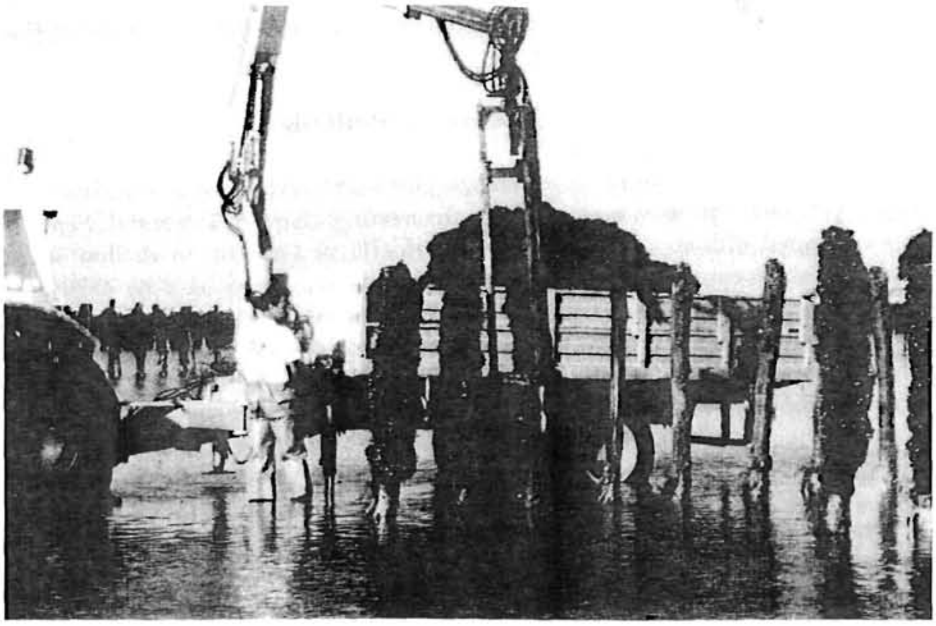

Figure 14
Hydraulic harvesting gear scraping mussels from bouchots (wooden poles).

the Atlantic coast and in Mediterranean lagoons (Vilela, 1950; Partridge, 1977). Guérin and Ganivet (1907) reported the distribution of natural beds along the French coast. Brittany and the Thau Lagoon were the main productive areas, but overfishing and irregular landings, leading to extensive imports, prompted shellfish farmers and scientists to develop clam culture.

The first experiments were based on transfers of natural spat to culture plots in Rouqueyrol in 1863, then in 1878 in the Gulf of Gien and Bay of Toulon (Mediterranean), where a broodstock sanctuary was established (LeVaillant, 1953). Trials in southern Brittany early in the century similarly relied on erratic natural spat supplies (Nicol, 1910, cited in LeVaillant, 1953). In 1955, 750 leasing grounds, mostly in southern Brittany, were seeded with clam spat (LeVaillant, 1953).

More recently, hatchery techniques provided a basis for extensive culture development by controlling the reproduction cycle. In 1972, the commercial hatchery SATMAR experimented with the Manila clam, *Tapes philippinarum*, and introduced a broodstock of 150 individuals from Seattle, Wash., to develop breeding techniques. On the basis of growth and survival rate comparisons, the Manila clam was selected for culture (Latrouite and Perodou, 1979). Early in 1980, spat production was under control in hatcheries and was sufficient to sustain a large clam production.

In 1985, clam culture practices were fully operational in several ecosystems, including tidal and intertidal areas and oyster ponds, and were proposed as a way to diversify oyster as well as mussel culture. However, in 1986, an abnormal shell calcification called "brown ring," resulting from a viral infection (Paillard and Maes, 1994), appeared in the clams in several rearing areas and reduced the landings (Goulletquer et al., 1989). Later on, in 1987 and 1988, this species extensively colonized natural beds in southern Brittany, leading to a new public fishery 2 years later. Annual production ranged from 1,000–1,500 t (whole weight) (Bachelet et al., 1993). Landings of cultured clams peaked at 500 t. Since then, large landings by the public fishery has drastically slowed the development of clam culture.

Current Status

In 1993, clam culture yielded 1,000 t distributed among Normandy (50 t), southwest Atlantic (200 t), and Brittany (700 t)[4]. Half of the production in Brittany is based on a rearing cycle including natural spat gathering and deployment in culture plots. Public beds yield around 3,000 t/year with two-thirds coming from the Gulf of Morbihan (1,000 t of *Tapes philippinarum*) and the Thau Lagoon (1,000 t of *T. decussatus* and *T. pullastra*).

[4] At 26 U.S. standard bushels in 1 metric ton

Clam Culture

Cultural practices and methods were extensively reported in the guide to Manila clam culture (IFREMER, 1988). Clam spat is produced in hatcheries, then pregrowing is carried out by nursery techniques or by seeding in semiclosed ponds or in intertidal areas using mesh nets to control predation. The latter process is fully automated, using tractors equipped with specific gear to seed the clams and deploy mesh screening over them. Additional gear allows automatic net brushing to control fouling. Grow-out facilities also include protected culture plots and semiclosed ponds. In the ponds, clams are grown in the bottom with mesh nets placed over them; appropriate mesh sizes are used with different sizes of clams (Goulletquer et al., 1988; DeValence and Peyre, 1989). The usual rearing density in intertidal culture areas is about 250 clams/m^2.

More recently, new intensive techniques were developed to counteract a food limitation that occurs in semiclosed ponds in summer. Farm fertilizer and mineral nutrients are used on an experimental scale to maximize primary production (Hussenot et al., 1992). A recent discovery of underground fossil seawater in several locations along the Atlantic coast facilitates mass production of microalgae (Baud, 1988). Standard conditions for intensive rearing (i.e., >2kg/m^2) of Manila clams were established successfully in the nursery and growing stages (Baud and Haure, 1989; Baud and Bacher, 1990).

Harvesting Methods

Hand picking and hand raking are the traditional methods for harvesting clams in intertidal areas (Partridge, 1977). In the Thau Lagoon, in shallow waters <10 m deep, clams are harvested also by skin divers using forks, and by fishermen using hand rakes from boats. For clam culture to be cost-effective, it was essential to have mechanized harvesting techniques. In intertidal areas, harrowing machines and specially-equipped tractors harvest 300 and 600 kg of clams per hour, respectively (Fig. 15, 16). A dredge was specifically developed to harvest clams in semiclosed ponds (DeValence and Peyre, 1989).

Processing and Marketing

In the processing plants, automatic sorting machines facilitate washing and size grading. Clams are marketed mostly for the fresh market; the larger ones are sold to restaurants. Clam prices have decreased from F60 or $10.17/kg (30 clams/kg) in 1983 to F50 or $8.47/kg in 1987, and to F30 or $5.08/kg in 1993, because the

Figure 15
Motorized equipment for harvesting cultured clams in soft bottom and small-acreage leases.

Figure 16

Harvesting equipment for cultured clams in intertidal hard-bottom areas.

supply has been increasing from the public fisheries in France and Italy.

The Scallop Industry

History

The common scallop, *Pecten maximus*, and the great Mediterranean scallop, *P. jacobaeus*, distributed in the English Channel and Atlantic Ocean, and Mediterranean Sea, respectively, are the most common scallop species harvested in France. Scallops used to be more extensively distributed in shallow bays and estuaries along the French coast. They were distributed near the natural oyster beds and represented a bycatch of the oyster dredging fishery (LeDantec, 1947). Fleets of small vessels designed for coastal fisheries originated from this commercial activity and dredged for scallops in winter in the relatively protected bays.

Irregular recruitment and overfishing resulted in cyclic production in several areas. At the turn of the 20th century and concomitant with railway development, the size of the dredging fleet was increasing in Normandy to supply fresh markets. But in 1906, a survey of shellfish beds described the scallop populations as overfished in this region. In 1927, a fishery rebound occurred, and 200 fishing boats dredged the beds. In 1935, the resource disappeared again (CNEXO, 1977). Before 1960, the main productive areas were located on the Atlantic coast in southern Brittany (i.e., Yeu Island) and the Bay of Brest, where production peaked at 35–45% of the total French landings (Rieucau, 1980). Scallops were marketed canned or fresh.

The cold winter in 1963, combined with overfishing during the previous years, affected the entire scallop population. Scallops in the Bay of Brest disappeared, but those in northern Brittany (e.g., St. Brieuc) were discovered following the decline of the fishery for the venerid, *Venus verrucosa*.

Fishing effort, meanwhile, increased in the eastern part of the English Channel. Landings increased progressively from 5,000–6,000 t (whole weight)[5] in 1963 to 20,000 t in 1972. Eastern Channel areas yielded 48% of the total catch; 46% were harvested in northern Brittany, mostly from St. Brieuc; and the remaining 6% came from the Bay of Brest and southern Brittany. Since a record high of 25,000 t during the 1970's, the scallop fishery has declined progressively to 6,000–10,000 t. The decline was attributed to a decreasing broodstock leading to irregular spat settlement (Dao et al., 1992). For example, Bay of St. Brieuc production shrank from 12,000 t in 1973 to 5,000 t in 1980, and the Bay of Brest from 1,000 t before 1963 to <100 t during the 1980's.

[5] At 36.7 U.S. standard bushels in 1 metric ton

The semiclosed Bay of Brest was chosen to experiment with a large-scale restocking program based on hatchery spat production. In 1978, the first trials based on the spat repletion program yielded 40% adult scallops. They were followed by a large-scale program carried out between 1983 and 1988; the broodstock was estimated to be 300 t in 1990. Although efficient (i.e., 30% survival rate at 5 years old), concomitant research demonstrated that 80% of the larval settlement variability resulted from climatic conditions, therefore limiting the broodstock effect. Instead of producing broodstock, the management strategy for the Bay of Brest and Northern Brittany shifted to hatchery production of spat (2 mm length), a pregrowing phase in cages to a 30 mm length, bed seeding for growing, and fishing for the scallops when they were 3 years old (10.2–11 cm length).

Current Status

The main productive natural beds of scallops are located in the eastern part of the English Channel, namely Bay of Seine, offshore in the Mid-Channel, and in the Bay of St. Brieuc (150,000 ha) in northern Brittany (Fig. 17). Yearly landings reach 10,000 t, well below the total French consumption of about 50,000–60,000 t, divided equally among fresh, frozen, and processed products (Dao et al., 1992). Scallops with the roe attached, namely "coraillée," are considered a delicacy and reach F25–35 or $4.24–5.93/kg while nonmature scallops peak at F15–25 or $2.54–4.24/kg. Prices are highly variable and depend upon season, as well as supply and demand. Landed prices represent a total F250 million ($42.37 million).

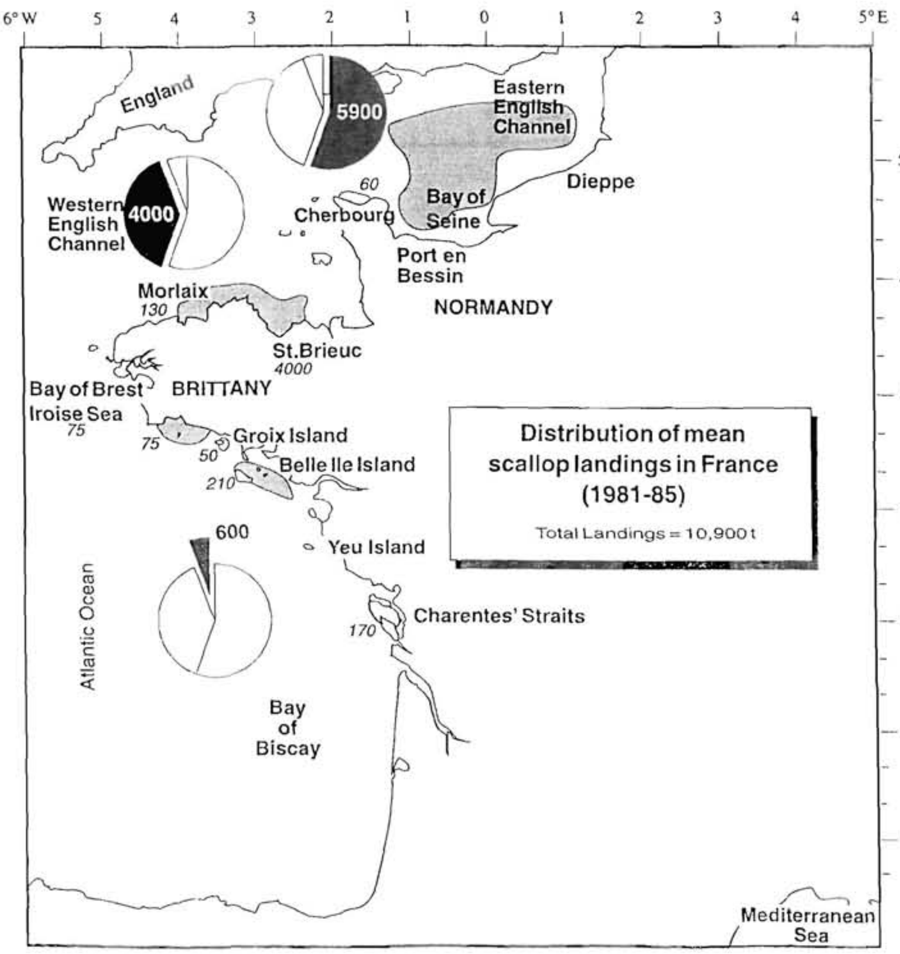

Figure 17

Distribution of mean landings (t) of the common scallop, *Pecten maximus*, between 1981 and 1985 in France.

The Scallop Fishery

The main feature of the 10 principal populations of *Pecten maximus* is highly variable recruitment, since this species is very sensitive to thermal fluctuations. A cohort abundance may vary from 1 to 10; it usually is harvested within 3 years (Dao et al., 1992). This high resource variability led to a complex management system based on administrative and professional regulations. The administrative management frame concerns legal marketable size, fishing gear, and season openings.

For the classified beds distributed within the 12-mile limit, additional regulations are proposed by professional organizations; they will then be ratified by decision makers. The regional fisheries committee, namely "Comité Régional des Pêches," and its scallop subcommittee, enacts regulations specific to each natural bed including licensee number; boat characteristics; fishing time and daily hours; dredge number and mesh size; annual, daily, and boat quotas; unloading harbors; and minimum legal size (e.g., from 10.2 to 11 cm). This committee also has the responsibility to specify the opening of the fishing season per area and eventually the closing of the fishery when the demand collapses. A minimum price limit is established by the producer organization, "Organisation de Producteurs," a special European status to optimize seafood markets.

During the 1980's, more than 3,500 fishermen and 1,000 boats were involved in the scallop fishery. In just the eastern part of the English Channel, 300 boats were harvesting scallops. Around 600–700 fishermen and 200 boats currently are involved in this fishery. Most scallop boats are 12–16 m long, and the crew size varies from 3 to 5. The current fishing season is between October and 15 May.

Although variable, the resource is predictable by stock assessments. The management system therefore aims to sustain the scallop population and secure the supply by limiting yearly landing variability instead of maximizing landings.

On the Mediterranean seaside, the scallop fishery has always been a bycatch for a fleet of bottom trawl and dredging boats. The minimum legal size for the great Mediterranean scallop is 7 cm. Landings peaked at around 100 t during the 1970's (Contat, 1983), but shrank to 33 t in 1982, to 15 t in 1988, and to a 5 t record low since 1990.

Scallop Culture

Based on the current fishery status, a cooperative program of scallop culture has been developed between scientists, professionals, and managers since 1988. Its originality is linked to the strong association of aquaculture and the fishery. The rearing cycle is characterized by:

1) Hatchery production of post-larvae (2 mm), using conditioned broodstock. Survival rate of larvae is around 40% in the hatchery and then 20% of settled spat survive in the nursery. At this stage, spat are set in flow-through systems at an initial density of 100,000 post larvae per unit;

2) A pre-growing phase is the second stage using rigid racks deployed on leased grounds in open sea. One container can be loaded with 250,000 spat in 27 racks and be easily moved from the surface. At 10–15 mm, scallops are sorted and density is halved; they reach 30 mm after 6 months. The survival rate reaches 35%.

3) Scallops finally are deployed directly on the bottom, at a 5–20 m depth, and at an average density of 10 individuals/m^2. Scallops are dredged 2–3 years later when the marketable size of 10 cm is reached (125–150 g total weight). The capture rate varies between 20 and 50% in the most productive areas (Dao et al., 1992; Fleury and Dao, 1992). The overall survival rate from the larval to adult size is about 1%.

From a technical viewpoint, the rearing cycle is under control, but it requires further optimization since its cost-effectiveness depends primarily on the products' exchange value. For example, with a 30% yield and 150 g scallops, production costs reach around F15–25 or $2.54–4.24/kg above the 1994 fishery ex-vessel value.

Harvesting Methods

Dredges are the only gear used to harvest scallops. Several types currently are in use in France (Fig. 18a, b, 19) (Dupouy, 1978; Duval and Portier, In press). Their use depends primarily on regional peculiarities and regulations. For example, the dredge specifically used in the Bay of St. Brieuc is characterized by a diving board, a 200 kg maximum weight, a width of 2 m, with 7 cm tines spaced at 10 cm intervals, and an iron bag with 72 mm meshes. In northern Brittany as well as in the eastern part of the English Channel, the use of a spring-loaded dredge (80 cm wide) is increasing. On board, the crew usually operates two to four dredges (1.5 m wide). Scallopers can gear from 6 to 24 units when using spring-loaded dredges that are on bars, 6 units (dredges) to a bar. A boat towing 24 units would have 4 bars, 6 units on each.

Since scallops should be marketed alive, fishing activity lasts less than a day and the natural beds are near the main harbors (e.g., Port en Bessin, St. Brieuc, Dieppe). The largest boats in the eastern Channel, however, may spend 2–3 days offshore. The farthest natural beds are less than 80 miles from any harbor. The quota of 250 kg per fisherman is reached at the season opening; the daily catch ranges mostly between 0.7 and 1 t per boat.

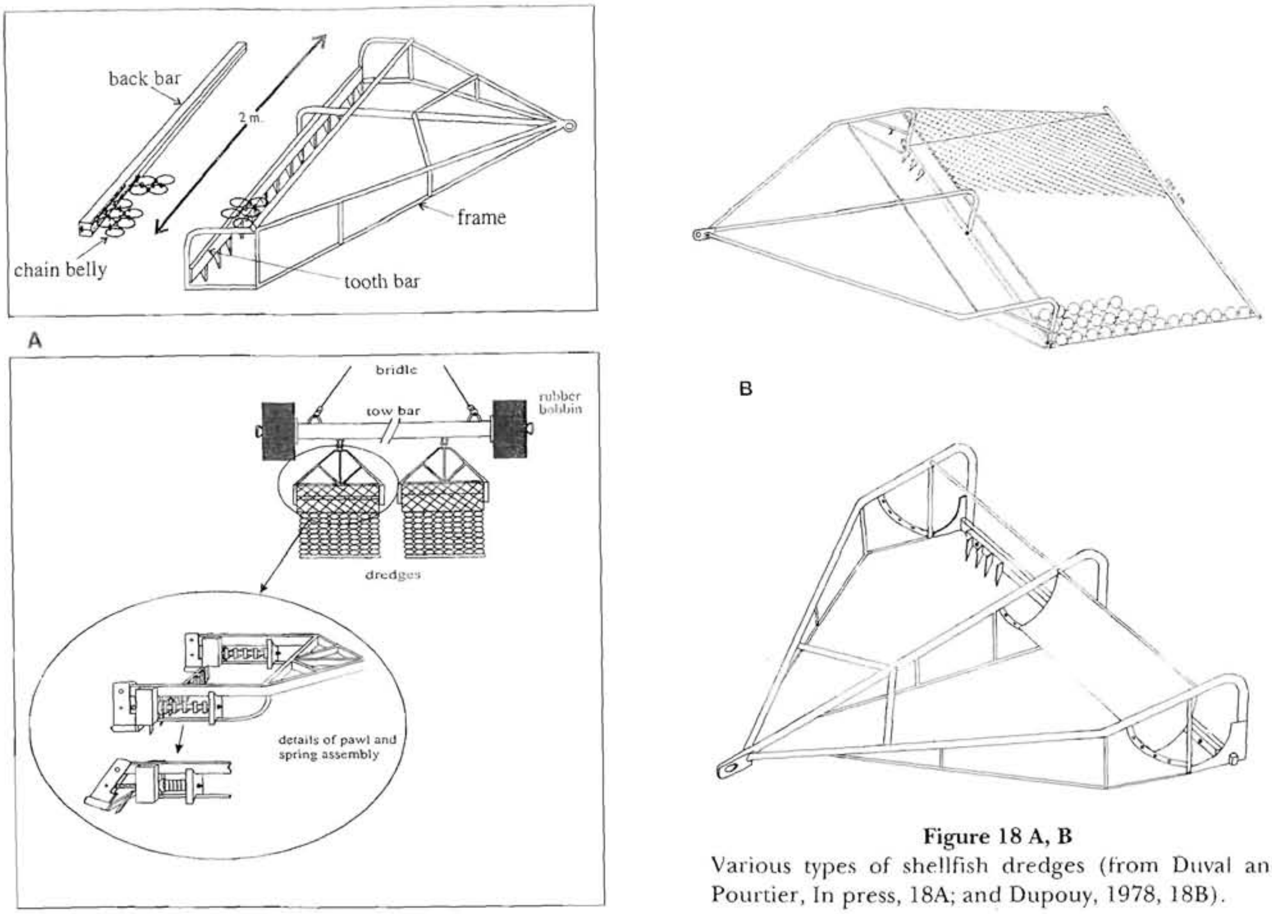

Figure 18 A, B
Various types of shellfish dredges (from Duval and Pourtier, In press, 18A; and Dupouy, 1978, 18B).

Processing and Marketing

Most scallops are marketed in the shell for the expensive fresh market. Landings of freshly shucked scallop meats, another part of the market, compete with imports from Scotland and England. French scallops are calibrated in the 10/30 and 10/20 meats per pound categories for the fishery and culture, respectively (Dao et al., 1992). The French market requires a high quality standard with less than 5% water loss during shucking. Most scallops for the frozen market as well as for processing plants are imported, except when the fishery supply is so high that a bottom price is reached. Frozen products usually are marketed by 2–5 kg packs or I.Q.F. (Individual Quick Frozen).

Other Mollusks

Among other important mollusks harvested in France, the squids, namely the common cuttlefish, *Sepia officinalis*; and the European squid, *Loligo vulgaris*, and veined squid, *Loligo forbesi*, combined; rank fifth and sixth in landings with 10,000 and 5,000 t, respectively (Chaussade and Corlay, 1988). They are caught using several types of fishing gear including squid jiggers, plastic pots, lures, seines, trammels, pelagic gillnets, bottom set gillnets, and bottom trawls (Boletzky, 1992).

The fisheries areas are located mainly in the English Channel and from southern Brittany to the Vendée region for the coastal fisheries, and the Bays of Biscay, Seine, and the Iroise Sea for the offshore fishery (Fig. 20). Squids are marketed as whole for the fresh market or frozen, as well as processed for the mantles, skinned fins, and skinned tubes. Ex-vessel values reach F10 or $1.69/kg for *Sepia* and F22 or $3.73/kg for *Loligo* sp.

Several other species are also the focus of important but local fisheries; statistical data regarding their landings are underestimated. The waved whelk, *B. undatum*, with 15,000 t (whole weight) landed (F45 million or $7.63 million landed value) is one. This species is mainly fished using plastic pots with cement bottoms weighing 12–15 kg and baited with fish and crab. In 1992, 60 boats were potting them in the Gulf of St. Malo where 90% of the catch was landed. Each boat is <10 m long and has a crew of 2–3. Since the development of the

Figure 19
Crew taking in a scallop, *Pecten maximus*, dredge.

hydraulic pot hauler during the 1980's, the fishing effort has increased substantially and a boat can lift 500 pots a day (Véron, 1992). Pots are distributed every 5–10 m along trot (boltch) lines (50–60 m long). Most of the catch is sold to the French fresh market, but some is exported to Belgium.

On the Mediterranean seaside, the purple dye murex, *Murex brandaris*, is a bycatch of the bottom trawler fleet in the Gulf of Lion. The trawlers use a special fishing gear, named "radasse," which is built like a beam trawl, using pieces of fishing net 8 m long. The murex have spines that become caught in the net. The "radasse" is trawled at 1–2 knots for 2.5 hours/tow on the fishing grounds. The murex are removed from it when the vessel returns to its harbor (Véron and Raimbault, 1992). This fishery lands around 100 t (whole weight)/year for an ex-vessel value of F3 million ($ 0.5 million).

Abalones, *Haliotis tuberculata* var. *tuberculata* on the Atlantic coast and *Haliotis tuberculata* var. *lamellosa* on Mediterranean coast, usually are harvested by local fishermen at low tide or by divers. On the Atlantic coast, where abalones have been overfished, regulations restrict the harvesting to intertidal areas. In contrast, large subtidal populations recently were reported mainly in the Gulf of St. Malo, and a limited fishery based on a license and quota system was initiated during the 1990's.

Abalones (8 cm minimum legal size) are harvested year-round, except during their July and August reproductive period. The fishery is carried out by scuba divers who use knives to remove the abalones from rocks. Landings are about 20 t (whole weight) a year. All landings must be reported to the Administration. Illegal fishing is often reported despite the regulations and enforcement and is thought to run at least 100 t a year. Abalone is the most expensive mollusk on the French market and costs around F100 or $17/kg. Most of the catch (90%), however, is processed for export to Japan.

During the 1970's, culture experiments were carried out to control the rearing cycle. Although hatchery rearing was under control, the growout stages were too long (i.e. 3–4 years) and not cost-effective. In 1994, new techniques using underground seawater were being tested to improve the efficacy of the rearing cycle.

Two additional pectinids, the queen scallop, *Aequipecten opercularis*, and the variegated scallop, *Chlamys varia*, are the targets of dredgers and trawlers in the English Channel and the Bay of Brest (Fig. 17). The queen scallop is the only authorized bivalve caught by bottom trawlers (Dao and Decamps, 1992). This species is fragile, which limits its commercial interest, and is marketed only fresh. Around 2,000–3,000 t are harvested each year mainly in the western English Channel (>1,000 t by 15 trawlers) and the eastern English Channel (>1,000 t by 30–40 dredgers and trawlers).

Instability of the natural scallop beds results largely from irregular recruitment and patchy distribution. The variegated scallop used to be harvested in the Charentes' straits, i.e., "Pertuis charentais," yielding a record high of 2,000 t during the 1960's. Harvesting ended in the 1970's when heavy fishing decimated the populations.

The remaining dredging activity now is located in the Bay of Brest where yearly landings are between 200 and 400 t. This species reaches the minimum legal size of 40 mm at 2 years old. Strict regulations limit harvesting to licensees from November to the following February (Dao and Decamps, 1992). Culture experiments were done using natural and hatchery spat from 1989 to 1991, particularly by reseeding spat in oyster ponds. Although growth rates were faster than in natural populations and market size was reached in less than a year, survival rates were still too low to expect a full implementation of this rearing cycle.

The cockle, *Cerastoderma edule*, fishery yields around 10,000 t (F33 million or $5.59 million landed value) a year (the landed quantity is underestimated). Cockles (minimum legal size 30 mm) usually are harvested at

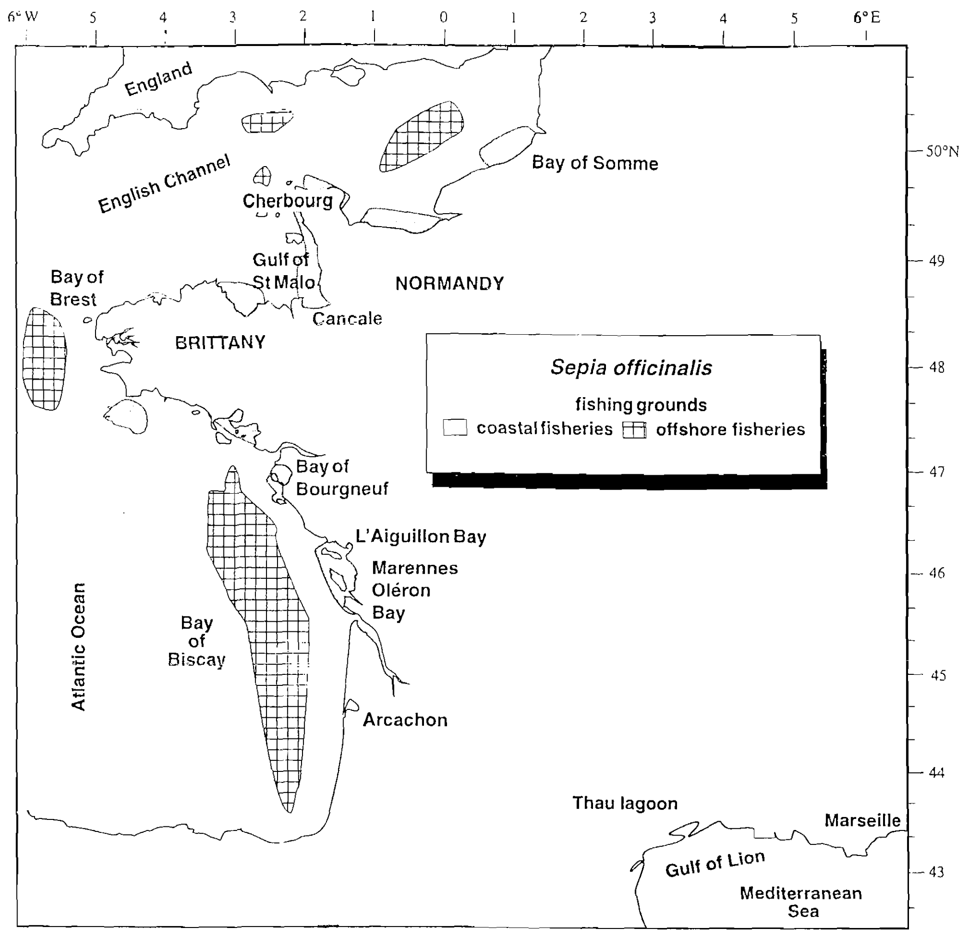

Figure 20
The offshore and coastal fishing grounds for squid, *Sepia officinalis*, along the French coast.

low tide by hand picking or using hand rakes along the Atlantic and English Channel coasts. A commercial reseeding activity is also carried out in southern Brittany (Le Croisic) where spat are deployed in culture plots at a density of 1,000 individuals/m^2; landings are 2,000–3,000 t a year.

Several venerid clam species are also the focus of extensive fisheries. In 1861 and 1863, Coste introduced the northern quahog, *Mercenaria mercenaria*, to France in Arcachon Bay (Ruckebusch, 1949; Lambert, 1949). The first clam batch reached 2 cm 2 years later, but the quahogs failed to reproduce. Later on, from 1936 to 1939, other trials were carried out in southern Brittany (Belon River), but the quahogs again failed to reproduce. Meanwhile, at the turn of the century (1910), an oyster farmer named Prunier introduced several quahogs to the upper Seudre estuary (Marennes-Oléron Bay) where they successfully reproduced. Since then, natural, but sparse, quahog beds have been reported in several places including southern Brittany; their presence demonstrates successful reproduction (Lambert, 1949).

During the 1940's, the northern quahog was the focus of culture in the Seudre estuary. Small quahogs were reseeded in oyster ponds as a byproduct of the oyster industry. Since then, quahogs have been harvested by hand raking and hand picking in this estuary. Dredges currently are used for harvesting quahogs in sandy-muddy bottoms in southern Brittany (Morbihan). Additional trials using hatchery spat were made during the 1970's, but a slow growth rate and the quahog distribution deep in mud bottoms limited the cost-effectiveness of the culture, particularly when compared with the Manila clam. The current activity centers on a small fishery limited to the Seudre estuary and southern Brittany, and a bycatch elsewhere.

The warty venus, *Venus verrucosa*, is dredged for the fresh market from September to April mostly in the

Gulf of St. Malo (95%); the remaining landings are in northern and southern Brittany (Berthou, 1992). The fishery, initiated during the 1950's, yielded a record high of 5,000 t in 1962 and 1975, declined afterward to 4,400 t in the early 1980's, and to 1,400 t in 1988. In 1986, 183 dredging boats were operating in this fishery, with 75 working more than 6 months a year. Despite the decline in landings, the fishery has remained attractive since the ex-vessel value, although variable, has increased to F20–50 or $3.40–8.50/kg. The dredge in use is specific for bivalves, rigid, with a 60 cm opening and an 8–25 cm flat board. The metallic frame has 21–25 mm grid spacing to retain only legal size clams (40 mm).

The banded carpet shell, *Venerupis rhomboides*, is also harvested exclusively by dredging in the Gulf of St. Malo and southern Brittany (Berthou, 1992). The minimum legal size is 38 mm. In 1988, 800 t were dredged for the fresh, processed, and frozen markets as well as for export.

The dredging fishery of the common European bittersweet, *Glycymeris glycymeris*, yields 2,000–2,500 t a year in the Gulf of St. Malo, southern Brittany, and Iroise Sea for the fresh market. This underexploited population would present a large potential for processing if meat tenderizing techniques were developed (Berthou, 1992).

In the same areas, dredging boats harvest around 5,000 t/year of thick trough shells, *Spisula ovalis*, and *S. solida*. The clams average about 35 mm long (range, 28–45 mm); the minimum legal size is 28 mm. Most are sold for the fresh market, and the remainder are processed and frozen for southern European countries. Only one year class usually is found in the natural beds, leading to nearly complete harvesting of local subpopulations. The populations are characterized by good sets every year and rapid growth of the clams. When fishermen shift their activity to other species or other natural beds, the *Spisula* populations recover quickly (Berthou, 1992).

Bycatches of the previously cited fisheries include the golden carpet shell, *Venerupis aurea*; chamber venus, *Circumphalus casina* and *C. rosalina*; smooth callista, *Callista chione*; sand gaper, *Mya* sp.; mature dosinia, *Dosinia* sp.; tellins, *Tellina* spp.; and otter shells, *Lutraria* sp.

In addition, there are small fisheries that involve digging by hand and with rakes. The mollusks harvested include the peppery furrow, *Scorbicularia plana*; several donaxes, *Donax* spp.; razor shells, *Solen* sp.; rayed trough shell, *Mactra corallina*; and grey trough shell, *M. glauca*.

Shellfish Preparation for Consumption

Most of the French molluscan production is marketed fresh in the shell. The mollusks are washed and graded by size. Some species (e.g., clams and scallops) can be marketed frozen. Freshness is the main criterion for French consumers, and, when required, preparation and cooking are carried out on their own. Therefore, any breading operation before marketing is rare and concerns only clams. Battered processing for shellfish does not exist in France. Canning is developed to a very limited extent and concerns only the species of low exchange values such as mussels, clams, and bycatch species from the dredging fisheries on natural beds. A small market has been initiated for smoked mussels, but the demand is low since they do not yet fit French consumption habits.

Mollusks are eaten several ways in France, including raw, cooked using various recipes, boiled, and steamed. Oysters and most of the clam species are eaten raw, and, to a limited extent, the new French cuisine has developed consumption of raw scallop, *P. maximus*, adductor muscles. Recipes are available for all shellfish species previously cited, including oysters. However, with oysters, this represents a very limited consumption and is mostly proposed by restaurants. When cooked, clams are often prepared using butter and culinary herb stuffings. Since abalone muscle is very tough, it must be tenderized with a mallet. The waved whelk, *B. undatum*, and the periwinkle, *Littorina littorea*, are the only species usually boiled in salty water and culinary herbs. Species that are steamed include mussels, cockles, clams, and sometimes scallops. The steaming process requires added ingredients such as white wine and culinary herbs.

Aquaculture and Fishery Management

Since the coastal area is the focus of multipurpose use, state regulations are required to facilitate various and simultaneous activities. For example, the 1986 state law, "Loi du Littoral," specifies the legal framework regarding coastal management. Two types of spatial management, namely "Schéma d'Aménagement et de Mise en Valeur de la Mer (SAUM)" and "Schéma de Mise en Valeur de la Mer (SMVM)" usually are proposed to organize the coastal area by specifying priority uses. The management plans are proposed by the state managers in agreement with local representatives, scientists, and administrators. A public survey meanwhile is carried out to debate the proposals.

Regarding the marine-related activities, fishermen benefit from a professional organization developed at local, regional, and national levels, and funded by taxes on business dealings. At each level, representatives of each profession are elected on an equal basis of employers and employees. Forty-eight local fishery committees, namely "Comité Local des Pêches," are distributed along the French coast. At the second level, four regional committees (i.e., Normandy, Brittany, Southwest, and Mediterranean Regions) represent the fishermen's interests in relation to the regional administration. Moreover, 18 interprofessional national committees are specialized in problems dealing with one species or a species group, i.e., "Tuna committee," "Scallop committee," to organize the fisheries.

Besides the fishery, shellfish culture has a national and nine regional committees to organize the industry. Like the fishery organization, funds are provided from taxes on commercial activities. The regional committee involves state managers, scientists, and professional organizations, and it enacts the global rules and authorizations for use of the leasing grounds that remain inalienable and under state management. For example, in the Marennes-Oléron Bay, the surface area of tables used in oyster culture should not total more than one-third of the leased acreage, and no more than 6,000–7,000 oyster bags should be placed in a hectare. In Normandy, the upper threshold is 5,000 and 6,000 oyster bags/ha on the eastern and western coasts of Cotentin, respectively. The committee debate to allot each leasing ground to applicants is based on a regional management plan, i.e., "Schéma des structures," which lists priority rules. A public survey meanwhile allows a debate over the use of each leasing ground, and recommendations are considered by the committee.

The national council of fisheries and mariculture, "Comité Central des Pêches et Cultures Marines" overviews all committees, the entire organization, and aims to provide information and improve relationships between sea-related activities and the Administration.

Public Health

Since the French shellfish market is based mainly on raw and fresh products, it is particularly important to protect the public from eating polluted or unhealthy products. Several regulations are enforced to avoid public health problems. The main framework relies on several national monitoring networks managed by IFREMER, the French Research Institute for Sea Exploitation. They include 1) the monitoring network of the coastal environment or "RNO," 2) the Phytoplanktonic monitoring network or "REPHY," and 3) the Microbiological monitoring network or "REMI" (for reviews, see Belin et al. (1993) and Berthomé (1992)). However, public health is only one of several objectives of the networks; others are marine life and environmental protection, trends, and risk assessments of environmental variables and contaminants. The networks are funded by the Ministry of Environment, Ministry of Research and Technology, and by shellfish farmers through professional taxes.

Coastal Environment Monitoring Network, "RNO"

The Coastal Environment Monitoring Network, "RNO," was started in 1974 for the water quality survey and marine life and sediment surveys that began in 1978. It resulted from the international treaty enforcements of London and Oslo (1972), Paris (1974), and Barcelona (1976). The main objectives are the monitoring of yearly trends and thresholds of seawater variables (e.g., temperature, salinity, oxygen, nutrients). Contaminant concentrations are determined four times a year in fish, oysters, and mussels at 43 sites along the French coast representing more than 100 experimental stations. Heavy metals (i.e., mercury, cadmium, lead, zinc, and copper), PCB, PAH, and organochlorines (i.e., DDT, DDD, DDE, HCH, and Lindane) are systematically analyzed.

Phytoplanktonic Monitoring Network, "REPHY"

The toxic (DSP) phytoplanktonic blooms of *Dinophysis* sp. that occurred in 1983 and resulted in hundreds of gastroenteritis cases prompted managers to establish a monitoring network to 1) protect public health, 2) protect shellfish beds, and 3) develop a long-term data base. This survey, called the Phytoplanktonic Monitoring Network, "REPHY," and initiated in 1984, has facilitated the systematic sampling of phytoplanktonic population trends and associated phenomena, as well as early detection of abnormal phenomena along the French coast. As soon as the latter is detected, an intensive survey assesses spatiotemporal fluctuations to provide insights for decision makers. Thirty-seven sectors currently are systematically surveyed monthly from September to April and weekly from May to August. When an abnormal event (e.g., gastroenteritis) or a toxic algal bloom is detected at an early stage, 73 additional sites are added to the regular monitoring. When DSP or PSP toxins are detected by scientific tests, the area is closed by state officials to impede any shellfish sales until two negative tests (i.e., two consecutive weeks) are reported.

Microbiological Monitoring Network, "REMI"

Early in the century, bacteriological control of oysters was established by private funds to guarantee shellfish quality. The state agency, Office Scientifique et Techniques des Pêches Maritimes, OSTPM, took over this bacteriological control in 1919 and organized a national network, now called the Microbiological Monitoring Network, "REMI." In 1989, the monitoring network was reorganized to include environmental quality

Literature Cited

Bachelet, G., J. Boucher, J. Daguzan, M. Glémarec, J. Guillou, M. LePennec, J. Mazurié, and S. Claude.
1993. La prolifération de la palourde japonaise *Ruditapes philippinarum* et le déterminisme du recrutement. [The Manila clam *Ruditapes philippinarum* expanding population and the recruitment process.] Equinoxe 43:4–9.

Bacher, C.
1984. Echantillonnage du stock d'huîtres du bassin de Marennes-Oléron. [Oyster stock assessment in the Bay of Marennes-Oléron.] Rapp. DEA, Univ. Paris, 38 p.

Barnabé, G.
1990. Open sea culture of molluscs in the Mediterranean. *In* G. Barnabé (ed.), Aquaculture, p. 429–442. Ellis Harwood Ltd, Chichester.

Baud, J. P.
1988. Mise au point d'une stratégie de prégrossissement intensif en nourricerie de naissains de palourdes *R. philippinarum* et d'huîtres *C. gigas* dans la région de la baie de Bourgneuf. [Intensive rearing of Manila clam *Ruditapes philippinarum* and Pacific oyster *Crassostrea gigas* in the Bay of Bourgneuf: a strategy development.] RI-IFREMER, DRV–88–031-RA/Bouin, 83 p.

Baud, J. P., and C. Bacher.
1990. Use of ground saline water for intensive rearing of *Ruditapes philippinarum* juveniles in a nursery system. Aquaculture 88:157–178.

Baud, J. P., and J. Haure.
1989. Intensive rearing of Manila clam *Ruditapes philippinarum* in ponds. Poster Abstr., EAS, Bordeaux.

Belin, C., L. Miossec, M. Joanny, and D. Claisse.
1993. Surveillance du milieu marin et santé publique. *In* P. Elziere-Papayanni (ed.), Coquillages, p. 431–442. [Coastal environment monitoring and public health. *In* Shellfish]. Inf. Tech. Serv. Vétérinaires Français.

Berthomé, J. P.
1992. Les réseaux de surveillance de l'IFREMER. *In* J. Lesné (ed.), Coquillages et santé publique: du risque à la prévention, p. 175–202. [IFREMER' monitoring networks. *In* Shellfish and public health: from risk assessment to prevention]. Ecole Natl. Supérieure Santé Publique.

Berthomé, J. P., J. Prou, D. Razet, and J. Garnier.
1984. Première approche d'une méthode d'estimation prévisionnelle de la production potentielle d'huître creuse *C. gigas* d'élevage. [Preliminary approach for a predictive assessment of Pacific oyster *C. gigas* production.] Haliotis 14:39–48.

Berthou, P.
1992. La praire commune *Venus verrucosa*, la palourde rose *Venerupis rhomboides*, l'amande commune de mer *Glycymeris glycymeris*. *In* J. C. Quéro and J. J. Vayne (eds.), Les algues et invertébrés marins des pêches françaises. [The warty venus *Venus verrucosa*, the banded carpet shell *Venerupis rhomboides* and the common European bittersweet *Glycymeris glycymeris*. *In* Algae and marine invertebrates from the French fisheries.] RIDRV-RH–92.018-La Rochelle/L'Houmeau, unpagin.

Boletzky, S. V.
1992. L'encornet *Loligo vulgaris*, l'encornet veine *Loligo forbesi* et la seiche commune *Sepia officinalis*. *In* J. C. Quéro and J. J. Vayne (eds.), Les algues et invertébrés marins des pêches françaises. [The European squid *Loligo vulgaris*, the veined squid *Loligo forbesi*, and the common cuttlefish *Sepia officinalis*. *In* Algae and marine invertebrates from the French fisheries.] RIDRV-RH–92.018-La Rochelle/L'Houmeau, unpagin.

Boromthanarat, S., and J. M. [illegible]-Paoli.
1988. Production of *Mytilus edulis* L. reared on bouchots in the Bay of Marennes-Oléron: comparison between two methods of culture. Aquaculture 72:255–263.

Buestel, D., S. Bougrier, J. Tiapari, P. Geairon, G. Jonquières, J. Prou, and J. M. Chabirand.
1993. Caractéristiques hydrologiques de l'atoll de Takapoto et croissance de l'huître perlière *Pinctada margaritifera*. [Hydrobiology of the Takapoto Lagoon and pearl oyster *Pinctada margaritifera* growth.] Contrib. IIIèmes rec. Polynésie Fr. EVAAM, Tahiti, 11 p.

Chaussade, J., and J. P. Corlay.
1988. Atlas des pêches et des cultures marines en France. [Atlas of fisheries and marine culture in France.] Montpellier, Edit. G.I.P. RECLUS, p. 28–29.

CNC.
1993. Les sept régions du CNC. [The seven regions of the National Shellfish Culture Committee.] Rivages Cult. 59:8.

CNEXO.
1977. Gestion rationnelle des stocks de coquilles St. Jacques en Baie de Seine. [Rationale management of scallop populations in the Baie of Seine, eastern English Channel.] Rapp. Sci. CNEXO, Brest, 1–2, 65 p.

Coeroli, M.
1985. Exploitation of mother of pearl and pearls. *In* B. Salvat, G. Richard (eds.). Les récifs coralliens de Polynésie française: connaissance des récifs et guide d'excursion, p. 372–377. [Coral reefs in French Polynesia: knowledge and travel guide.] Vème Congr. Int. Récifs Coralliens.

Coeroli, M., D. DeGaillande, J.P. Landret, and D. Coatanea.
1984. Recent innovations in cultivations of molluscs in French Polynesia. Aquaculture 39:45–67.

Contat, P.
1983. Les pectinidés en Languedoc-Roussillon, état des connaissances et perspectives. [The pectinids in the Languedoc-Roussillon region: status and prognosis for the future.] Rapp. IFREMER, Brest, 31 p.

Coste, M.
1861. Voyage d'exploration sur le littoral de la France et de l'Italie. [Exploratory travel along the coasts of France and Italy.] Imprimerie Impériale, Paris, 292 p.

Coustau, C.
1991. Analyse génétique et physiologique des interactions hote-parasite: le système *Prosorhynchus squamatus* - *Mytilus*. [Genetic and physiological analysis of host-parasite interactions: the *Prosorhynchus-Mytilus* complex.] Thèse Univ. Montpellier II, 133 p.

Dao, J. C., P. G. Fleury, and P. Paquotte.
1992. Eléments de réflexion pour l'évaluation économique de la filière d'élevage de la coquille St Jacques. [Evaluation of the economic cost-effectiveness of the scallop culture.] RI-DRV–92.001-RA, Brest, 76 p.

Dao, J. C., and P. Décamps.
1992. Le pétoncle noir *Chlamys varia* et le pétoncle vanneau *Aequipecten opercularis*. *In* J. C. Quéro and J. J. Vayne (eds.), Les algues et invertébrés marins des pêches françaises. [The variegated scallop *Chlamys varia*, and the queen scallop *Aequipecten opercularis*. *In* Algae and marine invertebrates from the French fisheries.] RIDRV-RH–92.018-La Rochelle/L'Houmeau, unpagin.

Dardignac-Corbeil, M. J.
1979. La mytiliculture [Mussel culture.] *In* La conchyliculture francaise, 3ème partie. "L'ostréiculture et la mytiliculture." [The French shellfish culture, 3rd part; Oyster and mussel culture.] Rev. Trav. Inst. Pêches Marit. 43(1):427–450.
1990. Traditional mussel culture. *In* G. Barnabé (ed.), Aquaculture, p. 285–341, 429–442. Ellis Harwood Ltd., Chichester.

concerns. The global approach focusing on trends and thresholds is based on fecal coliform concentration (i.e., number per 100 ml of meat) and, to a lesser extent, on *Salmonella* occurrence as contamination indicators. In 1992, 345 stations were monitored monthly along the entire French coast (5,500 km). More specifically in the mollusk farming areas and for the public health concern, the monitoring effort is increased to a weekly survey as soon as abnormal environmental conditions occur (e.g., heavy rains, agricultural practices in the watershed, tourism activity). In addition to the increased frequency, the sampling incorporates additional stations that total 278 nationally. Fecal coliforms and *Salmonella* are systematically surveyed. The fecal contamination concentration is particularly important with regards to the French and European regulations that allow only direct commercialization without further treatment below a 300 coli./100 ml meat threshold. No *Salmonella* is tolerated before marketing.

The Future

In the past, the molluscan fisheries sector has shown irregular landings due to abnormal recruitment and excessive fishing effort. Improved stock assessments and specific knowledge of factors affecting recruitment therefore are likely to improve the fishing industry economy. Although successful in several areas (e.g., scallop fishery in the Bay of St. Brieuc), comprehensive management plans, including regulation enforcement based on statistical stocks assessments, appear necessary for the natural shellfish beds showing high potential production (e.g., abalone). Fishing effort on current bycatch species (e.g., dredged clams) is particularly likely to increase and provide landings for the processors and markets. In contrast, it seems difficult to implement management plans for species showing a short life cycle and fast population recovery (e.g., mussel, cockle, and *Spisula* sp.). In other respects, it is unknown to what extent the current crisis affecting European finfisheries will affect molluscan landings.

The culture of mollusks has been a large success in France for several reasons including the extent of the natural spatfall, high ecosystem carrying capacity, good management, and good adaptation of the mollusks to cultural practices. Past events have shown that the industry can be harmed, however, by epizootic diseases or abnormal events such as dinoflagellate blooms. Markets and production can be affected. Scientific research is critical to protect public health and optimize current production.

One key element is to improve the balance between the ecosystem carrying capacity and the mollusk stocking density. For example, Heral et al. (1986) have demonstrated that oyster production in the Bay of Marennes-Oléron cannot be higher than 40,000 t for a stocking density between 90,000 and 200,000 t. Increased stocking density resulted in increased mortality rates and growth rate decline. This is a critical issue, since optimum stocking densities should be defined specifically for each rearing area, to maintain quality products as well as healthy shellfish populations, therefore limiting a risk of disease occurrence. The second key element for a sustainable industry is to prevent water quality degradation, as a guarantee for quality products (e.g., bacteriological quality). The intensive monitoring networks already developed will facilitate early reports to address the issues of abnormal events. For example, the networks will likely lead to additional improved watershed management as well as plant equipment with regard to recent EU sanitary regulations that rate the rearing areas according to water quality criteria.

Further industry advancements will be achieved by developing automatic equipment and longline techniques, which should result in improved labor conditions, reduced labor costs, and development of offshore culture in unexploited areas. Other ways to improve the shellfish industry are anticipated in the near future by implementing current research programs. For example, disease resistant strains (e.g., *O. edulis* against *Bonamia* sp.) and genetically manipulated animals currently are under review. Hatchery-produced spat from such strains would be a way to improve shellfish production.

From a marketing viewpoint, the EU development will obviously expand shellfish market possibilities within European countries and could result in increased production. Official recognition of local labels, appellations, and brand names is likely to occur in the next few years, facilitating product sales. However, new development should be considered concomitant with bioeconomic analysis of the shellfish industry. Coupling models of production dynamics with marketing systems will improve overall cost-effectiveness. It seems important also to take into account social and political approaches to facilitate sustainable development, since they are key elements in industry dynamics. New conflicts in watershed, freshwater, and coastal space uses are already anticipated, requiring insights and specific knowledge for the decision making process.

Acknowledgments

We thank P. Berthou, J. P. Joly, J. Prou, J. Vigneau, J. Morin, P. Duval, and D. Coatanea for providing valuable comments and advice to improve the manuscript and also C. L. MacKenzie, Jr., and other reviewers for their helpful suggestions.

DeValence, P., and R. Peyre.
1989. La culture de la palourde. [Clam culture.] *In* G. Barnabe (ed.) Aquaculture, p. 400–431. Techn. Document., Lavoisier, vol. 1.
Dupouy, H.
1978. L'exploitation de la coquille St Jacques, Pecten maximus L., en France. [The scallop Pecten maximus fishery in France.] Sci. Pêches, Bull. Inst. Pêches Marit. 276, 11 p.
Duval, P., and M., Portier.
In press. Techniques et engins de pêches en Manche Orientale. [Technics and fishing gears in the eastern English Channel.] RI-IFREMER DRV-RH, Port en Bessin, unpagin.
FIOM.
1982. L'offre Française et communautaire de moule de pêche. [The French and European supply of mussel from public fisheries.] Doc. 1: analyse des conditions de production et de première mise en marché, FIOM, Paris, 158 p.
Fleury, P. G., and J. C. Dao.
1992. De la pêche à l'aquaculture: l'élevage de la coquille St. Jacques. [From fishery to aquaculture: the scallop culture.] Equinoxe 38:20–27.
Gerla, D.
1993. La Baie du Mont St Michel ou une bonne gestion d'un bassin mytilicole. [The Bay of Mt. St. Michel-Gulf of Saint-Malo - or an example of optimal mussel culture management.] Equinoxe 43:19–28.
Goulletquer, P., M. Nedhif, and M. Héral.
1988. Production de la palourde japonaise *Ruditapes philippinarum* en bassin semi-fermés (claires): approche énergétique et relations trophiques. [Energy budget of Manila clam *Ruditapes philippinarum*: production and trophic relationships in semiclosed ponds (claires).] Aquaculture 74:331–348.
Goulletquer, P., M. Héral, C. Bechemin, and P. Richard.
1989. Anomalies de calcification chez la palourde japonaise *Ruditapes philippinarum*: caractérisation et comparaisons des compositions biochimiques en acides aminés par HPLC de différentes parties de la coquille. [Abnormal calcification in the shell of the Manila clam *Ruditapes philippinarum*: characterization and comparison of amino acid content in different shell parts analyzed by HPLC.] Aquaculture 81:169–183.
Grelon, M.
1978. Saintonge, pays des huîtres vertes. [Saintonge, country of green oysters.] La Rochelle, Edit. Rupella, 364 p.
Grizel, H., A. Langlade, and J. B. Perodou.
1979. Premiers essais d'une nouvelle technique de captage d'huître en Baie de Quiberon. [First trials of a new oyster settlement technique in the Quiberon Bay.] Cons. Int. Explor. Mer K. 24, 14 p.
Grizel, H., and M. Héral.
1991. Introduction into France of the Japanese oyster *Crassostrea gigas*. J. Cons. Int. Explor. Mer. 47:399–403.
Gruet, Y., and D. Prigent.
1986. Les buttes de St Michel en L'Herm (Vendée) : caractères de la population d'huîtres *Ostrea edulis* L. et sa faune associée. [Oyster shell piles in St. Michel en L'Herm (Vendée): characteristics of the flat oyster *Ostrea edulis* population and the associated fauna.] Haliotis 15:3–16.
Guerin, J., and J. Ganivet.
1907. Notes préliminaires sur les gisements de mollusques comestibles de France. [Preliminary report on natural edible shellfish beds in France.] Bull. Inst. Océanogr. Monaco 105:1–40; 131:1–12.
Hamon, P. Y., and H. Tournier.
1981. Estimation de la biomasse en culture dans l'étang de Thau. [Cultured oyster stock assessment in the Thau Lagoon.] Sci. Pêches, Bull. Inst. Pêches Marit. 313, 38 p.
Héral, M.
1990. Traditional oyster culture in France. *In* G. Barnabé (ed.), Aquaculture, p. 342–387. Ellis Harwood Ltd., Chichester.
Héral, M., and J. M. Deslous-Paoli.
1991. Oyster culture in European countries. *In* W. Menzel (ed.), Estuarine and marine bivalve mollusc culture, p. 153–189, CRC Press Inc., Bost.
Héral, M., J. M. Deslous-Paoli, and J. Prou.
1986. Dynamiques des productions et des biomasses des huîtres creuses cultivées (*Crassostrea angulata* et *Crassostrea gigas*) dans le bassin de Marennes-Oléron depuis un siècle. [Dynamics of reared cupped oysters (*C. angulata, C. gigas*) production and stocking density in the Bay of Marennes-Oléron during a century.] ICES, Maricult. Committ., F/41:22.
Héral, M., B. J. Rothschild, and P. Goulletquer.
1990. Decline of oyster production in the Maryland portion of the Chesapeake Bay: Causes and perspectives. ICES, C.M. 1990/K:20, 38 p.
Hinard, G., and L. Lambert.
1928. Tableau de l'ostréiculture française (deuxième partie). [Status of the French oyster culture.] Rev. Trav. Off. Pêches Marit. 1(4):61–127.
Hussenot, J., J. Castel, J. C. Fardeau, M. Feuillet-Girard, D. Gautier, D. Gouleau, C. Legrand, J. L. Martin, L. Pirastru, B. Ravail, Y. Rince, and B. Sautour.
1992. Stimulation de la productivité naturelle par enrichissements minéraux et organiques: étude en mésocosmes naturels. [Natural productivity enhancement by using mineral and organic fertilizers: studies in natural mesocosms.] RI-IFREMER DRV-RA/CREMA L'Houmeau, 92–15, 97 p.
IFREMER.
1988. La palourde: dossier d'élevage. [Clam culture: a guide], Ifremer Edit., Paris, 106 p.
Intes, A.
1982. La nacre en Polynésie française (*Pinctada margaritifera* L.). Evolution des stocks naturels. [The mother of pearl oyster *Pinctada margaritifera* L. in French Polynesia: oyster stock trends.] ORSTOM-Papeete 16, 48 p.
Lambert, L.
1933. La moule et la mytiliculture. [Mussel and cultural techniques.] Ostréicult. Cult. Mar. 10:1–4.
1934. La moule et la mytiliculture. [Mussel and cultural techniques.] Ostréicult. Cult. Mar. 6:1–2.
1949. Note complémentaire sur le Clam [*Venus mercenaria*.] [Additional report on the northern quahog clam *Venus mercenaria*.] Rev. Trav. Off. Pêches Marit., 1947–1949, XV(1–4)5760:118–122.
Latrouite, D., and D. Perodou.
1979. Bilan des essais d'élevage de la palourde sur le littoral du Morbihan. [Report of the clam culture experiments on the Morbihan coastal area.] Rapp. ISTPM, unpagin.
LeDantec, J.
1947. La pêche sur les côtes du Calvados et de la Manche. [Fisheries on the counties Calvados and Manche coastal areas.] Rev. Trav. Off. Pêches Marit. XV(1–4):60–87.
LeVaillant, P.
1953. La palourde: anatomie, biologie, pêche et élevage, salubrité. [The clam: anatomy, biology, fishery and culture, public health.] Thèse Dr. Vétérinaire, Alfort, 150 p.
Marteil, L. 1976.
La conchyliculture Française, 2ème partie. Biologie de l'huître et de la moule. [The French shellfish culture: 2nd part. Oyster and mussel biology.] Rev. Trav. Inst. Pêches Marit. 40(2):149–346.
Paillard, C., and P. Maes.
1994. Brown ring disease in the Manila clam *Ruditapes*

philippinarum: Establishment of a classification system. Dis. Aquat. Org., 19(2): 137–146.

Partridge, J. K.

1977. Studies on *Tapes decussatus* in Ireland. Natural population, artificial propagation and mariculture potential, with an investigation of the European major fisheries and a full annotated bibliography. Natl. Univ. Ireland, Dep. Zool., Univ. Coll., Galway, Ph.D. thesis, 336 p.

Pichot-Louvet, J.

1982. Les huîtres de Cancale. [Oysters from Cancale.] 226 p.

Priour, D.

1986. Matériels conchylicoles: quoi de neuf? [Shellfish culture equipment: something new?] Equinoxe 9:23–30.

Prou, J., S. Pouvreau, M. Héral, and V. Renaud.

1994. Estimation de la biomasse d'huîtres non cultivée dans le Bassin de Marennes-Oléron. [Oyster stock assessment on the Marennes-Oléron Bay natural beds.] RI-DRV 94–06, 27 p.

Raimbault, R.

1984. La conchyliculture en Méditerranée française. [The French shellfish culture on the Mediterranean sea.] Haliotis 14:1–22.

Rieucau, J.

1980. L'exploitation de la coquille St Jacques et du vanneau en Manche. [Scallop exploitation in the English Channel.] La Pêche Marit. 1224:150–158.

Roche G.

1897. La culture des mers. [The culture of the seas.] Bibliothèque Sci. Int., Tours, p. 162–312.

Ruckebusch, H.

1949. Le clam; Note sur *Venus mercenaria* L. Son introduction et son élevage dans le Bassin de la Seudre. [The clam; Report on *Venus mercenaria* L. Its introduction and rearing in the Seudre estuary.] Rev. Trav. Off. Pêches Marit., 1947–1949, XV(1–4)5760:99–117.

SECODIP.

1983. Marché de la conchyliculture, Bilan 1982. [The French shellfish market in 1982.] SECODIP.

Véron, G.

1992. Le Buccin *Buccinum undatum*. *In* J. C. Quéro and J. J. Vayne (eds.) Les algues et invertébrés marins des pêches françaises. [The whelk *Buccinum undatum*. *In* Algae and marine invertebrates from the French fisheries.] RIDRV-RH–92.018-La Rochelle/L'Houmeau, unpagin.

Véron, G., and R. Raimbault.

1992. Le Murex droite épine *Murex brandaris*. *In* J. C. Quéro and J. J. Vayne (eds.) Les algues et invertébrés marins des pêches françaises. [The purple dye murex *Murex brandaris*. *In* Algae and marine invertebrates from the French fisheries.] RIDRV-RH–92.018-La Rochelle /L'Houmeau, unpagin.

Vilela, H.

1950. Vida bentonica de *Tapes decussatus*. [Biology of the clam *Tapes decussatus*.] Trav. Sta. Biol. Marit. Lisb. 53:1–120.