THE SELLFISH INDUSTRY IN FRANCE
(Economic importance, risks and constraints, research priorities)

M. BONNET *, J.P. TROADEC *

RESUME. La conchyliculture constitue en France une activité économique importante dont l'essor a débuté au milieu du siècle dernier. Elle occupe actuellement 24 000 ha du domaine public maritime et sa production dépasse 100 000 t pour l'huître creuse et 40 000 tonnes pour la moule, qui représentent une valeur de 1 300 millions de francs (1983). De plus, elle offre des potentialités de développement intéressantes, soit par la colonisation de nouveau espaces, notamment en eau profonde, soit en maîtrisant l'élevage de nouvelles espèces comme c'est le cas pour la palourde dont la production vient d'atteindre un niveau significatif (300 t en 1984).

L'ancienneté et le succès de ces élevages s'expliquent par les avantages importants qui découlent de la biologie et de l'écologie des mollusques filtreurs : alimentation sur une nourriture naturelle non utilisée par ailleurs, forte densité d'élevage, possibilité de captage de naissain naturel, sédentarité des espèces qui facilite le confinement des cheptels et l'aménagement des exploitations, l'attribution de la ressource se faisant par l'intermédiaire de l'allocation des sites (concessions).

Mais ces atouts s'accompagnent de points faibles dont peuvent résulter des périodes de crise aux sérieuses conséquences économiques et sociales :

- vulnérabilité particulière des mollusques, en raison de leur caractère filtreur et sédentaire, aux dégradations de la qualité du milieu marin (pollutions, eaux colorées).

- risques d'extermination des cheptels par des maladies épizootiques favorisées par la forte densité des élevages et les difficultés du contrôle dans un milieu fluide et ouvert,

- compétition pour la capacité trophique du milieu, naturelle et limitée, pouvant conduire à des excés de biomasse en élevage susceptible d'entraîner une baisse sensible des rendements et une plus grande vulnérabilité aux épizooties,

- concentration d'activités humaines de nature diverse (urbanisation, industrie, agriculture, tourisme) pouvant réduire la capacité biotique d'un environnement côtier très sollicité.

L'aménagement des bassins et des cheptels est un domaine prioritaire en France auquel s'attache la recherche, notamment par la conception de modèles de production conchylicole permettant d'estimer les biomasses correspondant à la productivité des sites d'élevage. Des études sont également développées en pathologie et en génétique pour minimiser les risques et les effets des épizooties et améliorer les performances des souches cultivées.

* Institut Français de Recherche pour l'Exploitation de la Mer,
Direction des Ressources Vivantes, 66 avenue d'Iéna, 75116 Paris, France

ABSTRACT. Bivalve farming is in France a major economical activity, which development was initiated in the mid of last century. It occupies nowadays 24 000 ha of seabottom, leased from the French State, and production figures are above 100 000 tonnes for cupped oyster and 40 000 tonnes for mussel ; these made a gross value of 1 300 millions francs in 1983. Moreover, it shows potential for promising development, by expanding to new areas, especialy in deep sea, or by introducing new species, such as the short neck clam, which production has just reached significant level (300 T in 1984).

Long age and success of this cultivation activity come from the important advantages related to the biology and ecology of bivalves : food naturaly available, and of no use by another way, high density in culture, possibility of natural spat collection, sedentary nature enabling confinement of stocks and setting up of farms, resource allocation by means of leases.

But these strengthes are offset by specific weaknesses, which may lead to crisis situations, with serious economical and social consequences :
- specific vulnerability of bivalve molluscs, due to their filtering and sedentary features, and to the degradation of environment (pollution, red tides,...)
- risks of heavy mortality of stocks due to epizooties, enhanced by high density of stocks and difficulty of any control in an open water environment,
- competition for limited natural carrying capacity, resulting in overstocking, and then much slower growth and higher sensitivity to epizootics,
- increasing human activity of various types (urbanization, industries, agriculture, tourism) which may reduce the carrying capacity of coastal areas, highly demanded.

Planning has a high priority in France, and research is supporting it, noticeably for conceiving models of bivalve production, making possible biomass assesment in relation with productivity of culture sites. Researches are intensified in pathology and genetics to decrease the risks and consequences of epizootics and improve performances of cultured species.

I - INTRODUCTION

In France the practice of culturing molluscs goes back many hundreds of years. The first traces of mussel-farming appear in the 13th century (origins of the stick method), while culture of the European flat oyster began in the 17th century, when oysters were fattened in reservoirs in the salt marshes of the Atlantic coast. It was only in the mid-1900s, however, that this activity grew beyond the stage of simply harvesting natural beds.

This growth, which is particularly evident in the development of oyster farming, appears to have followed on three events which occurred between 1850 and 1870:

- mastery of the technique of trapping spat on collectors, whereas up to that time spat was harvested from natural beds,

- introduction of the cupped oyster, of Portuguese origin (*Crassostrea angulata)*, production of which grew very rapidly and far outstripped that of the native flat oyster *(Ostrea edulis)*,

- the first steps toward territorial development with the implementation of regulations governing exploitation of state-owned marine areas.

Figure 1 illustrates this spectacular growth in oyster production, which rose from some 10,000 tonnes in the early 1880s to 41,000 tonnes in 1911, 73,000 tonnes in 1930 and over 100,000 tonnes in 1953. It may also be seen that this growth was extremely irregular, with periods during which populations and production declined and collapsed being followed by sharp upswings for both the cupped and flat oyster.

Production collapses correspond to massive mortality due to epizootic diseases:

- for the flat oyster: epizootic disease in 1920/1927, *Marteilia* and *Bonamia*, which appeared successively in 1969 and 1979,

- for the Portuguese cupped oyster: branchial and viral infections in 1966/1973.

It is worth noting the repetition of this sequence: peak production moderate regression, appearance of one and often two epizootic diseases, collapse of production due to stock depletion. This could indicate that peaks may correspond to loads that are excessive in comparison with the carrying capacity of the shellfish ecosystem. Biomass excesses would cause a decline in production from existing stocks, along with the more serious problem of a decline in health status making the stock more vulnerable to pathogens.

A memorable drop in captures over two consecutive years (1934 and 1935) was responsible for production declines after these dates.

It is more difficult to interpret historical data with respect to mussels, since up until quite recently production statistics did not distinguish between quantities fished, which were quite large, and those resulting from culture. Analysis of these figures nevertheless shows that the increase in mussel production, which was particularly strong from 1970 on (Fig. 2), was also subject to fluctuations, although these were significantly less marked than in the case of oyster production. As opposed to oysters, mussels were not as heavily affected by parasitic diseases. As in the case of oysters, however, these fluctuations may have various causes. The production decline recorded in 1983 was due to two causes: a deficit in stock recruitment in mussel farms due to poor captures in 1982 and, to a lesser degree, prohibition of mussel harvesting and marketing during the summer because of toxicity due to contamination by the dinoflagellate *Dinophysis acuminata* (this mainly affected harvesting of natural beds).

In some areas, notably the Bay of Cancale, an increase in mussel loads led to significant production decreases, along with a rise in infestation by the parasite *Mytilicola intestinalis*. These phenomena have begun to regress since farm densities have been reduced.

This short history clearly shows that, although the shellfish industry has been a major economic development sector in France for almost a century, it has nevertheless experienced a succession of crises of varying degrees of seriousness, the dynamics of which have not been scientifically analysed. The task of determining and applying means for preventing or combatting these problems remains to be accomplished.

II - CURRENT ECONOMIC IMPORTANCE

Available statistics on the various components of shellfish production are not very reliable. Improvements in this area, presently under study by government, producers and researchers, will be determining factors in the development of shellfish culture and will have an even greater influence on planning with respect to stocks and basins.

The data available nevertheless has a relative value which makes it possible to perceive trends and identify periods of stability, separated by accidents or innovations. Evaluations made in recent years of the size and demographic composition of fishfarm biomasses have also shown that official statistics, when not closely linked to reality, most commonly underestimate actual production.

1 - Size of shellfish farms

Oyster and mussel farming has developed all along the Atlantic and Mediterranean coasts of France. These activities now cover a total area of nearly 24,000 ha, which may be divided into broad regions as follows:

Normandy - North Sea	=	1,500 ha
Brittany - Vendée	=	11,600 ha
Southwest Atlantic	=	7,600 ha
Mediterranean region	=	3,300 ha
TOTAL		24,000 ha

Most of this total is used for oyster-farming (approx. 20,000 ha), while mussel-farming, most of which is done on sticks, accounts for a total length of 1,500 km of sticks, over an area of 1,600 ha. The total area also includes some 3,000 ha of deep-water seabed allocated over the past few years, mainly in the Gulf of Lions. This allocation corresponds to the recent extension of shellfish-raising activities into deep water, most of which is still in the experimental stage.

While fish-culture areas initially covered the most easily accessible strips of coastline (normally bare at low tide) and the most sheltered areas (coastal ponds, relatively closed bays), activities have gradually progressed seaward over the past 15 years due to lack of space on this strip, and in recent times have stretched into the open sea as deep as some 20 metres.

2 - Weight and value of production (Table 1)

Oysters

Oyster production has remained around 100,000 t since 1977, in spite of the fact that flat oyster production declined significantly as a result of epizootic disease. This decline has been compensated by growth in culture of the Japanese oyster *Crassostrea gigas*, particularly in Normandy and Brittany. In 1983, a good year for cupped oysters (109,100 t), turnover in the oyster-farming industry exceeded a billion francs (1,044.8 MF), notwithstanding low levels of flat oyster production (1,500 t).

Mussels

Cultivated mussel production has varied between 40,000 and 50,000 t over the past twelve years. In 1983, when below average tonnages were produced due to low spat-collection levels in 1982, sales were 210 million francs. On the average, mussel culture adds 10,000 to 30,000 per year to mussel yields from harvesting natural beds, although these latter vary from year to year due to fluctuations in the number of breeders. Combined fishing and culture yields reached a maximum of 80,400 t in 1981.

Clams

Culture of clams *(Ruditapes philippinarum)* has recently developed as a complement to traditional oyster and mussel farming. Production, though still experimental in many sectors, reached significant levels in 1984 with some 300 t, selling at 35-40 F/kg, for sales of at least 10 million francs.

3 - Number of facilities and employment

The great majority of shellfish farms have remained very small, often family enterprises, which would explain their large numbers (10,636 in 1983, although this is certainly overestimated). These enterprises total some 20,000 direct permanent jobs and an equal number of part-time jobs, most of which go to family members. These numbers may seem large in comparison with the value of shellfish production; however, apart from the family nature of these enterprises, which may involve accepting lower individual salaries (which may form satisfactory marginal gains with respect to family income), the profitability and wage levels of these enterprises should not be judged on the basis of sales of product alone. In addition to cultivation, the activities of these enterprises may also include packaging and marketing. This is the case for 3,500 of these operations, or a third of the total industry. Direct sales to customers are also developing in some production centres.

It would be interesting to determine whether the fact that the number of direct jobs generated in the shellfish-producing industry appears to be proportionally higher than that of the fishing industry means that the labour/capital ratio in the cost structure is higher in shellfish farming than in fishing.

Whatever the case may be, and in spite of the fact that statistical data is rather unsatisfactory, the shellfish industry occupies an important place in France's maritime economy, due both to the high production and many jobs it supports, and to the large areas involved. Insofar as sales are concerned, oysters are at the top of the list of all species fished and cultivated. In 1982, sales in the oyster-producing industry were 809 MF, followed by tuna fishing at 413 MF. Mussel and oyster farming combined represent, in weight and value, between a fifth and a quarter of national live resource production.

1979	Maritime fisheries	Shellfish farming
Weight	519,900 t (76.8%)	154,500 t (23.2%)
Value	3,034 MF (79.6)	778 MF (20.4%)

An evaluation of the socio-economic importance of the shellfish industry must also take into account its development potential. Better management of existing enterprises and extension into receptive areas would probably yield an increase in production in the order of 100,000 tonnes for mussels and 50,000 tonnes for oysters. As well, diversifying facilities by introducing new species with high sales values (e.g. Veneridae, Pectinidae) and providing better response to varying market requirements, could also yield considerable additional income.

These perspectives, although they are interesting given the deficit of our commercial balance for mussels and scallops, should not cause us to neglect the many risks and constraints (environmental, biological, technical, economic and social) already facing existing operations.

III - RISKS AND CONSTRAINTS

Among the natural and/or man-made risks liable to affect shellfish production, we have chosen to discuss the following:

- poor weather conditions (storms, extreme climatic conditions)
- chemical and bacterial pollution of urban, industrial or agricultural origin
- water discoloration phenomena, whether natural or brought on by some human activity
- epizootic diseases

Certain environmental changes may affect stocks and production by:

- low collection levels
- abnormally high mortality levels
- declines in growth and weight increase

Development of the shellfish industry is also facing various constraints:

- of a technical nature, although progress in this field with respect to material, equipment and automation, as well as in the biotechnical area (hatcheries) should allow these to be gradually eliminated,
- legal and political constraints, regarding conflict with other users of the coastal strip (tourist industry, fishing, industry, agriculture, urban development), as well as the means by which territory is allocated and granted,
- commercial and economic, in connection with organizing distribution and marketing, as well as promoting demand.

1 - Poor weather conditions

These may cause serious harm when extreme intensities are attained, which shellfish-farming facilities were not designed to withstand. Recent occurrences of this type, which reached disaster proportions, include:

- the severe storm which struck the Mediterranean coast in November 1982, causing heavy damage to 500 cultivation racks in the Thau pond (20% of shellfish-farming facilities), as well as the loss of 25% of oyster and mussel stocks,
- Cyclone Hortense, which struck the southwestern Atlantic coastline in October 1984, causing the destruction of part of the cultivation facilities and stocks in the Arcachon basin (losses estimated at 8,500 tonnes of oysters),
- to a lesser extent, the storm that raged over the Marennes-Oléron basin on November 15-16, 1984, resulting in the loss of nearly 3,000 tonnes of oysters.

In addition to storms, unusual variations in temperature cause problems. The period of exceptional cold early in the 1984-85 winter led to significant losses in cultivation facilities located in open areas. The same type of losses were recorded during the very severe winters of 1956 and 1963.

2 - Chemical and bacterial pollution

Preserving the quality of waters used for shellfish-farming is a critical matter, since this cultivation is practised in coastal areas with high population densities, particularly during the summer season, and significant industrializatior. Bivalves, being filter feeders, can concentrate high proportions of substances present in their environment. In France, half the coastline is urbanized or industrialized, and it is thus essential that attention be given to the problem of proximity of activites that might interfere with one another.

Pollution and changes due to human activity may have three types of effects:

- on productivity, i.e. stock yields,
- on stock mortality, including mortality in the larval stage,
- on the wholesomeness of products from a consumer standpoint.

In all cases, stocks are highly vulnerable, given the mixing of water through tidal action and the sedentary nature of seed.

Wholesomeness of shellfish is of particular importance in Franch, where these products are normally eaten raw, especially oysters. To protect public health, present regulations stipulate that culture may only be carried out in clean zones. Where exceptions are allowed on the basis of the production potential of areas showing a certain degree of bacterial pollution, producers are obliged to put shellfish from these areas through a purification treatment in special facilities normally using chlorine or ozone.

These regulations, which have led to the setting up of a country-wide inspection system, both of cultural environment quality and of product quality, have had the following main effects on enterprises:

- to increase costs, since producers must contribute to financing inspection activities (a peak of 2.85 million francs in 1983 represented the sale of 19 million inspection labels). In addition, some producers have been obliged to invest in storage and pre-treatment facilities to ensure the safety of their product (total investment of 600 MF for the 3,000 producers involved). Product cost must also include the cost of purification treatments (1 to 1.10 F/kg), although such treatment is basically required for imported shellfish.

- to inhibit certain development initiatives.

An example of the latter is Carteau Cove, in the Fos industrial zone near Marseille, where mussel-culture activites were limited by regulation to collection and nursery growth of spat, in spite of the fact that the carrying capacity of the environment also lent itself to the production of market-size mussels. Given the results of a recent study, which indicated that the risks of bacterial pollution were greater than those of chemical pollution, there are moves now to remove the prohibition on full cultivation, provided the mussels are only placed on sale after purification in approved facilities.

With respect to pollution that might affect seed productivity or cause abnormal mortality levels, government regulations state that shellfish farms may only be authorized in clean, protected zones. Among the extraordinary occurrences of pollution which have had a major effect on culture are:

- the sinking in 1977 of the AMOCO CADIZ, the cargo of which, in spreading over the coastline, caused the loss of a major proportion of the oyster seed in western Brittany. The damage this catastrophe caused to the shellfish industry has been estimated at 114 million francs, or a quarter of the total cost of the disaster (440 millions of francs in 1983).

- the second case had a less severe effect, but its economic and social impact was the same. This was pollution due to use of self-cleaning paints based on organostannous compounds which led to mortality in the larval stage and shell malformations in cupped oysters (thick flaky shell). The use of these paints was a major factor in the severe crises that struck oyster culture in the Arcachon basin, leading to low or nil spat collections for five consecutive years and the temporary disappearance of half the fish-farming facilities. Demonstration of the harmful effects of these paints on the shellfish industry led to use of them being prohibited in France for treating the hulls of boats less than 25 m in length, which would be likely to travel through shellfish-raising areas (decree passed January 17, 1982).

On the whole, while there is a downward trend in the use of hydrocarbons, detergents and pesticides, certain highly exposed sectors are still recording rates of bacterial and chemical contamination that bear watching. It is also worthy of note that coastal municipalities have made sizeable investments in purification systems and plants.

3 - Water discoloration phenomena

Like pollution, to which they may be related insofar as their appearance may be partly an effect of inflows of nutrients, water discoloration phenomena vary as to origin, nature and effects. Whatever their diversity and complexity, however, these phenomena trigger two types of harmful effects when they develop in shellfish-bearing waters:

- fairly extensive mortality in biomasses under cultivation, resulting from the toxicity of plankton or anoxia of the environemnt,

- shellfish contamination by elements that are toxic to consumers, resulting in sales being prohibited.

Among the most noteworthy cases of mortality we may mention the "malaïgue" algae problem that occured in the Thau pool during the summers of 1982 and, particularly, 1975. This problem appears to be the result of the combined effects of a number of factors, in particular high temperatures, prolonged absence of wind causing water stratification, a high organic matter content, which set off a deterioration process leading to anoxia and the toxicity of the environment due to the presence of sulphurated hydrogen. In 1975, when the phenomenon spread to the entire basin, mortality amounted to nearly 70% of the stock (or approximately 15,000 to 20,000 tonnes of cultivated oysters and mussels), while in July 1982, when it was of lesser extent and shorter duration, some 10% of the cultivated biomass was destroyed.

Another case of extensive mortality, although of different origin, affected almost the entire stock of cultivated oysters and mussels in the Leucate pond in 1979-1980. In this case, the phenomenon took the form of an exceptional bloom of nannoplanktonic elements (chrysophyceae and chlorophyceae) which caused molluscs to lose weight and then die off.

With respect to problems resulting from contamination of shellfish products by planktonic elements containing biotoxins harmful to man, one case stands out due to the particular importance it has taken on in France in recent times. This is the phenomenon provoked by abnormal development of the dinoflagellate *Dinophysis acuminata* on the southern coast of Brittany and in some sectors in Normandy during two consecutive summers (1983 and 1984). This phenomenon, which necessitated setting up a specific monitoring system, led the government to pass measures prohibiting the sale of mussels from the areas affected. While hardships due to these prohibitions basically affected annual production, through a significant decline in quantities fished in natural beds, there were nevertheless some immediate repercussions on mussel culture facilities. Apart from the temporary suspension of sales and the associated drop in income, these phenomena had a negative impact on the reputation of the product and caused some temporary disorganization in the market.

4 - Epizootic diseases

Epizootic diseases resulted in significant seed losses, mainly to oyster stocks. These diseases affected the various species as follows (Fig. 1):

Ostrea edulis:

- 1920-1927: heavy losses inflicted on stocks by a disease that has never been precisely identified.
- 1969 to date: appearance of marteiliosis, due to the parasite *Marteillia refringens*, followed by bonamiosis, in 1979, resulting from infestation of oysters by the protozoan *Bonamia ostreae*. These two diseases, which are still in evidence, caused considerable reductions in culture of flat oysters (10,000 to 20,000 tonnes between 1945 and 1960, and 1,300 tonnes in 1983).

Crassostrea angulata:

- 1966 to 1969: gill disease which rapidly spread to all cultivation centres and caused ever-increasing mortality.
- 1970 to 1973: viral disease causing extermination of all stocks, both wild and cultivated.

For the species *Crassostrea gigas*, which has been acclimatized in France and has made it possible to reconstitute total cupped oyster stocks very rapidly, there have been no occurrences of diseases of an infectious or parasitic nature that have had any noteworthy effect on production.

In the case of the two mussel species *Mytilus galloprovincialis* and *M. edulis*, both of which are cultivated, parasitic infections have never risen to serious epizootic proportions, although infestation by *Mytilicola intestinalis* can occasionally cause significant mortality. It should nevertheless be noted that the protozoan *Marteilia maurini* has recently shown a tendency to develop in mussels. Although the pathogenic action of this parasite has not yet been demonstrated, there is no assurance that it will remain benign.

Estimating the economic repercussions of epizootic diseases gives a good idea of their extent. A good example is that of the effects of marteiliosis and bonamiosis, which have contributed to the collapse of flat oyster production, particularly in Brittany, where this was a specialty. Although there has been a recovery in oyster culture using Japanese oysters as the flat variety declined, losses have been estimated at 1.6 billion francs (1983 value) for the period 1974-1982, or 180 million francs annually. To these losses may be added a reduction in value added in the order of 1.3 billion francs over the same period.

Comparison of these losses with those caused to the oyster industry of Brittany by the grounding of the Amoco Cadiz (114 million francs, 1983 value), but for one year only, shows the possible extent of the consequences of epizootic diseases. This result, reinforced by the memory of the recent extermination of the Portuguese oyster, has motivated those involved, professionals, government and the scientific community, to coordinate their efforts in order to better ensure the health status monitoring and preventive care of stocks. Measures taken to this end include:

- strict application of regulations prohibiting planting of imported shellfish in coastal waters,
- for imported shellfish intended for consumption, it is required to store these in approved facilities isolated from the marine environment and equipped with effluent treatment systems, should these shellfish not be placed on the market immediately,
- development of a system of health status monitoring of native stocks and imported products,
- reinforcement of research programs.

On the last point, start-up in the near future of an experimental establishment for mollusc pathology and genetics at La Tremblade should be mentioned. Although it may be expected that these research fields will yield interesting progress in the diagnosis of disease and development of prophylactic or therapeutic measures and the selection of stocks with better resistance to epizootic disease, work should also be directed to improving shellfish basin management. Given the genetic adaptation capacities of molluscs, which may well limit the prospects for manipulation of their genetic heritage, as well as the fluid nature of the environment, which reduces the possibility of prophylactic intervention, it is possible that in actual practice the most efficient approach will be that of preventive ecology, through regulation of stocks.

5 - Collection problems

From year to year, the various phases of the reproductive cycle, on which depends the success in collecting cultivation stocks, show different degrees of variation, which are normally due to variations in the natural conditions of the environment. Among factors causing variability, temperature plays a major role in acting chiefly on the triggering and progress of gametogensis and spawning and by regulating the abundance of planktonic food necessary both for breeding and for development of larvae.

The extent of these variations rarely reaches such extreme levels that there would be a deficit in collections. Throughout 47 years of cultivating *Crassostrea angulata* (1925 to 1972), there were only four years with no collection. For the species *C. gigas*, there were only two deficit years (1972 and 1981) in all the time it has been cultivated in France. In the case of stick-cultivated mussels, collection deficits occur on the average every 10 or 12 years, with the last dating back to 1982.

It may thus be considered that collection problems linked to natural conditions have not constituted a major constraint for the expansion of oyster and mussel farming in France, at least not unless these problems are encountered year after year, as was the exceptional case for cupped oysters in 1934 and 1935, following which years production did in fact decline conspicuously (Fig. 1).

These natural collection facilities hinder the development of hatcheries in spite of their recognized capabilities.

A man-made imbalance in the environment did, however, have disastrous consequences for collections. This involved the oyster *Crassostrea gigas* in the Arcachon basin where, for five consecutive years from 1977 to 1981, no spat was collected. Research undertaken to explain this anomaly showed that it was not a question of the capacity of breeders to produce viable larvae, but rather a problem of larval development. It was determined that veligers had failed to find the food they required in their environment. It was also shown that organometallic-salt based self-cleaning paints had a negative effect on larva survival, since they acted directly on the embryogensis process and the development of veligers, as well as interfering with production of the nanoplankton entering into their diet.

Prohibition of these self-cleaning paints coincided with the resumption of collection in the Arcachon basin, as well as with a marked decrease in anomalies of shell formation, providing further evidence of the toxicity of these paints for the larva and adult stages of oysters. Prohibition measures did, however, also coincide with other favourable events which are not necessarily linked to them. For example, improved yields (growth and fattening of oysters) appear to be linked with the noteworthy reduction in stocks present in the basin, due to a drop in collections. It has also been noted that the basin was recolonized by barnacles, which diminished the development of water plant communities and enriched the waters with their excrements, and this may have helped increase the productivity of shellfish farms. These considerations, notwithstanding their hypothetical nature, lead us to think that this prolonged lack of collection may not have been solely the result of the harmful effects of certain self-cleaning paints, but also of overloading of the basin. The dynamics of the crisis in the shellfish industry in the Arcachon basin are indeed complex.

It would seem that, while the use of toxic paints triggered the crisis, overloading due to competition between producers, along with poor chronology in the evolution of variables that were a determining factor in the regulation of the shellfish industry (carrying capacity of the basin, annual collection, biomass under cultivation, age profile of the stock, annual sales, etc.), also played a part.

6 - Abnormal mortality

During its cultivation cycle in France, the Japanese cupped oyster is subject to mortality rates that, although they vary with site and cultivation procedures, may attain and even exceed 30%. To these rates, which are considered normal, may be added additional losses that can reach very high figures. These abnormal mortality rates occur during the summer and, to a lesser extent, towards the end of the winter period. In both cases, they do not appear to be the result of infectious or parasitic diseases or environmental pollution.

Summer mortality was particularly alarming in 1981, when it affected the Arcachon basin and, particularly, in 1982, when it extended into the Marennes-Oléron basin while continuing to affect the Arcachon basin. From observations carried out in both areas, it appears that rising temperatures played a major role in triggering the phenomenon, which seems to correspond to a physiological imbalance following a period of intense metabolic activity and a significant deficit in carbohydrate reserves mobilized for sexual maturing. Young oysters are particularly vulnerable to this syndrome, which resembles that reported in Japan (Matsushima Bay) and the United States (State of Washington).

Winter mortality, which also affects young oysters, is apparently the result of fall conditions unfavourable to the development of sufficient energy reserves to last through the winter, during which period the production of plankton that forms part of the oysters' diet is very low.

These two types of abnormal mortality, although they differ as to environmental context (summer and winter), have a common factor, a deficiency in nutrition. It is possible that, given their physiological state at the time, the young oysters are unable to make the best use of the food available, but it is also possible that this food is insufficient due to excessive trophic competition following overloading. This hypothesis will have to be confirmed by studying the evolution of morbidity as a function of biomasses. If it does turn out to be correct, this will prove that mortality among the youngest individuals acts as population-regulating phenomenon that depends on the capacity of cultivation sites.

7 - Problems of growth and fattening

Notwithstanding seasonal variations, the growth rates and quality of oysters and mussels show abnormal reductions from one year to another that have an impact on yield levels and selling prices, and thus on the profitability of enterprises.

These growth and fattening problems are sometimes caused by climate conditions which, although natural, are abnormal, leading to a significant decline in the productivity of the shellfish industry. In the Thau pond, for instance, a drop in fresh water supply during drought years was cited to explain the poor quality of mussels observed during that time. The undernourished state of oysters may also correspond to temporary temperature deficits that caused a decline or a delay in phytoplankton production.

These problems often appear to be caused or aggravated by overloading of cultivated biomasses with respect to the carrying capacity of the system. Risks of imbalance would obviously be higher in semi-closed sites (basins or ponds), where food supply replacement through water replacement is limited, than in more open environments (currents, upwelling).

While noticeable declines in yields observed in various sectors appear to be chiefly due to biomass excesses, we do not at this time have sufficient knowledge of the productivity of shellfish-raising environments and the energy requirements of molluscs to be able to verify this hypothesis, nor to develop models that would enable us to determine the appropriate loads for various basins.

Development of research on the ecology and productivity of shellfish basins is thus a priority. Basically, this research would proceed along two main lines:

- an empirical approach, aimed at determining the relationships between annual production, length of the growth cycle and morbidity on the one hand and the biomasses of existing stocks on the other,
- an analytical approach destined to evaluate the trophic requirements of shellfish stocks and their competitors, as well as the nutritional capacity of basins, and to compare these requirements and this capacity.

These two approaches are complementary, the first being likely to lead rapidly to decision-making guidelines for each basin, although it remains less heuristic than the second. The empirical approach may also yield strong signals, the nature and origin of which may then be analysed using the second method.

This question is also complicated by variations in climate and hydrology from one year to another, as well as by anthropic changes in the productivity of basins (changes in fresh water supply from rivers, increased sedimentation due to shellfish cultivation, etc.).

These research areas have developed in the Marennes-Oléron basin with the expectation that methods and models developed in other shellfish-raising centres throughout the country will also be implemented there. In this basin, which ranks first among all the oyster-raising centres of Europe by its production levels, the low yields observed over the past two or three years have given rise to two hypotheses. The first suggests that existing stocks exceed the basin's carrying capacity. The second, based on the fact that these biomasses are apparently not greater than they were in the past, suggests a decline in the productivity of the basin. This decline could have two causes: rising bottom levels due to significant sedimentation leading to a decrease in flows distributing food to the molluscs, or a drop in the inflow of nutrients which might result from increase use of the waters of the Charente River upstream by agriculture and urban centres. These two hypotheses must be tested and their respective effects evaluated if possible. A mathematical model allowing the physical and biological parameters of the basin to be integrated is currently being developed.

8 - Technical and biotechnical problems

The fact that shellfish enterprises are often old and small-scale does not mean that they have not benefitted from technological progress. Over the past fifteen or twenty years, the floating equipment used (amphibious barges, hydraulic cranes for collecting mussels on sticks, etc.) has been modernized and better adapted to the industry. As well, in certain regions where this has been feasible, for instance in Normandy, use of farm tractors has become a general practice. Use of new materials for collection and cultivation structures (plastic collection devices and scoops, aluminum racks and sticks, etc.) has also contributed to progress, as has the use of machinery for packaging (conveyor belts, sorting belts, etc.). As well, in the biotechnical area, recent mastery of techniques for producing spat in hatcheries and nursery culture and maturation processes for clams has opened up an interesting avenue for diversification, which is now moving into the development phase. Gaining control over reproduction also means that it may be possible to manipulate the genetic heritage of stocks.

There are nevertheless gaps which may detract from the yield of existing enterprises or act as a hindrance to full development of this potential, whether it be the extension to new sites or promoting the raising of new species.

For existing facilities, there is a particular need for progress in collection operations, detachment procedures, sorting and packing oysters, all of which could benefit from greater mechanization.

Extension of cultivation into new sites mainly involves moving into deeper, open waters; this is where the greatest potential lies, since the sheltered coastal areas are now practically all covered. The various attempts to move into open waters, particularly over the past ten years in the Mediterranean, have brought to light the difficulties encountered in developing cultivation structures able to resist poor weather conditions at acceptable investment and operating costs. These attempts, mainly involving mussel-farming on strings, have nevertheless confirmed the fact that in many sectors, and up to depths of 20/25 m, the waters provide good yields, as regards both quality and quantity of product. Provided the current industry and research efforts result in economically and technically viable solutions, there are interesting prospects for extension of the shellfish industry into open waters in France.

Diversification of production processes through mastering techniques of raising new species may also have several advantages: better utilization of sites by taking advantage of the complementary behaviour of molluscs, particularly on a trophic level; source of additional income, making for better profitability; better response to market demand; a decrease in the risk of epizootic diseases, which is always higher in monoculture situations. Successful cultivation of clams is an accomplishment in this area, made possible by mastering the technique of hatchery reproduction. For other species, such as scallops, of which production of natural stocks is insufficient in France, research and development activities are being directed by a different strategy:

- first, to reconstitute natural stocks from hatchery spat, in order to be able to make collections from these stocks of natural spat for cultivation (since the cost of hatchery spat at the present time is prohibitive),

- second, to find an explanation of the mechanisms that govern successful breeding in natural circumstances, in order to better perceive the possibility for forcing natural selection and to determine the best seeding methods (age of spat, time and space parameters for release, quality of spat, etc.).

9 - Competition for space

The large areas of state-owned marine space allocated to the shellfish industry (24,000 ha) gives an idea of the dominance this activity has achieved over the coastline. It is certain, however, that access to favourable sites is becoming difficult, since they are becoming increasingly rare, due both to the development of shellfish-farming operations themselves and to increased pressure from other coastal activities (agriculture, industry, urban growth, tourism, etc.). On examination, it may be seen that the main difficulties encountered by spatial expension of the shellfish industry are due to:

- choices with respect to development policy: This is the case, for example, when the authorities responsible for planning in coastal areas decide to develop other areas of activity that are judged incompatible with aquaculture. Some municipalities have been reluctant to allow the shellfish industry to operate on their territory, preferring to save the land for tourist development which would yield more income to them. One reason for this attitude is certainly the fact that, due to the legal status of state-owned coastal land, there is little financial benefit for municipalities.

- technical incompability: This occurs when the cleanliness of the areas in question does not satisfy the requirements of current legislation. An example is the bay of Fos, where industrialization has created an obstacle to development of mussel culture. A similar situation is encountered when cultivation loads have already reached levels which it would not be wise to exceed. An example is the Marennes-Oléron basin, where it was decided only to grant concessions for clam cultivation where these would be substituted for concessions already used for oyster culture, and only for a period of two years, in order to be able to evaluate the profitability of yields in this area that is already in intensive use.

- diverging interests within the marine industry. One of the most noteworthy cases of this type of situation is that opposing the extension of shellfish-raising facilities into open waters to trawling activities in the Gulf of Lions in the Mediterranean. There are already conflicts over development of clam cultivation on the foreshore which, in some sectors, has brought protests from shore fishermen and others who have traditionally had access to these areas and their natural resources. There is also a certain amount of opposition on the part of established shellfish-farmers towards development projects by agents outside their industry (fishermen or independents) or from outside their region.

More generally, development of the shellfish industry will depend on:

- the terms for granting and trading concessions,

- preparation and adoption of basin development plans (structural plans)

Basically, transfers of concessions might be made in two manners:

- on the basis of decisions based on legally defined criteria such as membership in a professional body (registered marine workers) or proof of specific qualifications or experience,

- through the use of economic mechanisms.

While the first method introduces rigidities and inequalities into conditions for access and may cause the authorities responsible for making the concessions to be subjected to strong pressures, the second may seem somewhat surprising given the tradition of free access to state-owned marine territory. Because of these traditions and the necessity of combining private interests at the enterprise level with administration of state-owned lands (development of shellfish basins and stocks, administation of the many uses made of marine territory, etc.), it may be expected that changes in this area will be gradual.

Preparation, through cooperation between the shellfish industry and the appropriate authorities, of basin development plans (choice of appropriate crops, distribution of these among industry members, deciding on optimum geographical distribution of cultivation centres, etc.) will be facilitated through the appropriate studies and scientific consultation. From this standpoint, developing shellfish production models for basins facing overloading problems is a priority.

10 - Market organization

French eating habits mean that many shellfish are eaten raw. This is almost always the case for oysters. This leads to certain constraints in market organization with respect to packaging and sale of a live product, which is additionally stored outside its natural environment, as well as the sanitary quality of this food product, which must be maintained from the time it is harvested until it is eaten. These habits also mean, in the case of oysters, that a large part of the production is consumed during the Christmas and New Year's period. In 1982, for example, 65% of sales took place during the fourth quarter, and 51% during the month of December alone. This markedly seasonal nature of sales in the oyster industry only serves to complicate organization of the market, as does the practice of direct sales from producer to consumer, which is on the rise at the present time. All of these factors might lead one to believe that the current level of production of 100,000 t of oysters corresponds to the maximum the domestic market can absorb, whereas it is likely that better organization of this market, along with more emphasis on export potential, could on the contrary justify additional production efforts.

The situation is different in the case of mussels. As opposed to the oyster, mussel consumption is spread throughout the year. The fact that quantities available are clearly insufficient, combined with seasonal drops in the quality of French production, have led to establishment of an import market which may supply up to 50% of the French market (in 1983, France imported 42,500 t of mussels, valued at 117 million francs). The size of this production gap is an encouragement to the development of domestic production of mussels, which is currently underway in several regions and in particular through introduction of cultivation structures in open and deep waters. It should, however, be noted that anticipated production gains will not necessarily stop the inflow of imported mussels, if only because the top-market quality of French production will not necessarily be in competition with low-cost imported products.

These considerations demonstrate the interest of carrying out market studies that would provide an objective estimate of the capacity of the domestic and export markets, in order to better organize marketing and make decisions on goals and the desirability of various development plans.

IV - CONCLUSIONS

Both in France and on a world scale, the shellfish industry is a clear leader in the cultivation of sea animals (3.2 million tonnes, FAO 1983). This remarkable progress may be explained by the combination of several strategic advantages of bivalves for development of marine coastal areas:

- frequent possibilities for collecting natural spat,
- diet based on otherwise-wasted natural food,
- bivalves are filter-feeders, thus allowing high cultivation densities,
- sedentary nature of molluscs, which facilitates both confinement of stocks and the disposition of facilities, both of which may be decided on to a great extent by operators, while resource attribution is effected through site allocation (concessions).

But there is another side to these advantages. In spite of the remarkable progress in the shellfish industry, there are periodic crises, in particular involving epizootic diseases, which have serious economic and social consequences. Disease is not the only problem; the crisis in the Arcachon basin, when over a five-year period no spat was collected, emphasized the need to ensure that water quality is maintained at adequate levels. It is thought that this absence of spat was due to the use of self-cleaning paints on the hulls of pleasure and working vessels.

Analysis of these crises reveals another underlying problem, even more critical for the development and improvement of this type of cultivation: the tendency of shellfish-farmers to load basins beyond their carrying capacity. This may be the result of competition between operators for an ecosystem that is limited by natural causes but not formally partitioned out to operators. In these conditions, the only option operators have is to increase their stocks in order to attempt to capture an ever-increasing share of this limited production capacity and the profits attached to it, or simply to prevent their share from decreasing as other operators' stocks increase. This hypothesis suggests that shellfish resources could in practice be only partially allocated by granting concessions, and that the knotty problems of developing and using common resources, of which the best documented example is probably the fishing industry, also affect the shellfish industry whenever operations reach a certain degree of intensity. If the practice of overstocking and the motivations for doing so are confirmed, then the question of regulating biomasses and the terms for granting and trasferring individual territories will have to be faced. This problem will nevertheless only become acute in basins which are not sufficiently open and which are overworked, where the trophic demands of biomasses under cultivation are likely to exceed the carrying capacity of basins. This may not be the case for all areas.

This conclusion, presented as a hypothesis, should not be too surprising. It may be compared to the natural tendency of the shellfish industry to expand. There may be objections to this judgement with regard to a type of culture where biomasses may be as dense as 100 t/ha (horizontal culture) or even 200 t/ha (suspended culture). Nevertheless, in terms of means of exploiting ecosystems, we are certainly dealing with an extension-prone form of culture, insofar as human intervention is limited to seeding natural ecosystems in order to manipulate its specific quantitative composition to increase production. Initially, there is no need to add food nor to physically change the environment. It is only in the more sophisticated forms of culture (e.g. cockle-farming) that spat must be produced artificially and there is an early maturing period in a more or less controlled environment.

In these conditions, it is not surprising that planning development of basins and shellfish stocks appears as the major problem facing this activity in the future, as well as being a research priority. There are a number of aspects to this problem:

- determining the trophic requirements, both quantitative and qualitative (nature of plankton forage, species, particle size), of cultivated species and their competitors,
- evaluating the productivity of basins and probably of their major variations, both from season to season and from year to year, since deficiencies may occasionally appear,
- designing and applying shellfish-culture models to enable an estimate to be made of biomasses corresponding to basin productivity and, if possible, how production may vary according to loading,
- development for each individual basin of empirical models based on historical statistics linking production, duration of cultivation cycles and morbidity of existing biomasses,
- preserving the quality of waters used for shellfish-raising along with their trophic capacity with a view to eventually being able to manipulate this capacity in semi-closed basins by varying fresh water supply and nutrient loads (purification),
- analysis, based on shellfish-raising models, of the economic and social consequences of various loading levels in order to compare the various planning goals for a given basin,
- development of regulatory methods that would facilitate the application of the development plans chosen, insofar as these methods would enable individual and collective interests to better coincide (systems for allocating and transferring concessions, biomass sharing within the limits adopted, etc.).

Applying the results of this research implies implementation of a statistics program that can evaluate and track the main variables that affect the state of shellfish stocks, in particular those which may be varied in order to achieve the most efficient operation within a given set of parameters: total area and geographic distribution of concessions, biomass and composition of stocks (species, demographic structure), as well as of competitors, cultural techniques used, production and transfers (weight and demographic structure), collection of spawn, etc. Variations from year to year of some of these variables should be recorded, since the system will be subject to external hazards (natural variability of the environment and of collections, as well as market fluctuations) which it would be useful to be able to predict and, if possible, to regulate.

This type of planning and the research behind it will be necessary and justified in basins that are heavily farmed and relatively closed. As with any development work, success will necessitate close cooperation between industry, administration and research, involving cooperation for the collection of statistics essential to the collective administration of the use of resources held partially in common, cooperation for the analysis and choice of possible development objectives and the preparation and application of appropriate development plans.

In spite of the difficulties involved in therapeutic action on a liquid environment, pathological studies are important for several reasons: to monitor the health status of the environment and take the appropriate prophylactic measures (prohibition of transfers, for example), to determine standards (e.g. densities) and cultural practices (cultivation cycle as compared to the production cycle and that of disease transmission) most likely to minimize the risk of epizootic disease.

Genetics is another discipline which holds out much hope for reducing the effects of disease and improving the zootechnical performance of stocks. The prospects offered by genetic manipulation for the selection of disease-resistent stock, or stock that would provide better yields, will depend on the ability of molluscs to maintain a differentiated genetic heritage.

The other avenue for compensating for the limits of natural basin productivity consists in introducing new species, as well as domesticating other species likely to contribute to more complete use of this productive capacity and to reduce the inconvenient aspects of monoculture, both with respect to cultivation (incidence of epizootic disease) and to marketing. Mastering new species will depend mainly on progress in aquaculture technology (culture on strings or other structures in deep waters). Progress has already been made in this direction. The same is true of diversification: recent domestication of the clam to the point of economic viability, the successful domestication of the scallop in Japan or progress made in France towards mastering the latter species are all only the initial steps toward greater diversification of the shellfish industry. Development of intensive shellfish cultivation will be greatly assisted by progress in determining how marine populations should be chosen. This progress will be of vital importance in selecting species and defining release procedures that will make it possible to encourage natural breeding and production.

BONNET M. et HERALM., 1984. French mollusc culture, achievements and development projects, main contraints and research contribution. Deuxime synuposium franco-japonais sur l'aquaculture, Seuday (Japon), oct. 1984 (sous presse).

DARGIGNAC M.J., 1986. La myticulture traditionnelle. In "Aquaculture", Edit. Lavoisier, Paris, p. 285-343.

HERAL M., 1986. L'ostreiculture française traditionnelle. In Aquaculture, Edit. Lavoisier, Paris, p. 346-390.

MAURER D. et COMPS M., 1984. Mortalités estivales de l'huître Crassostrea gigas dans le bassin d'Arcachon, aspects biochimiques et histologiques. Premier colloque international de pathologie en aquaculture marine, 11-14 sept 1984, Montepllier (sous presse).

MAURER D., HERAL M., HIS E et RAZET D., 1985 Influence d'une peinture antisalissure à base de sels organometalliques sur le captage de l'huître Crassostrea gigas, en milieu naturel. Rev. Trav. Inst. Pêches marit., 47 (3-4).

MEURIOT E. et GRIZEL H., 1984. Note sur l'impact économique des maladies de l'huître plate en Bretagne. Rapport IFREMER.

RAIMBAULT R., 1984. La conchyliculture en Méditerranée française. Haliotis, revue de la Société française de malacologie, n° 14.

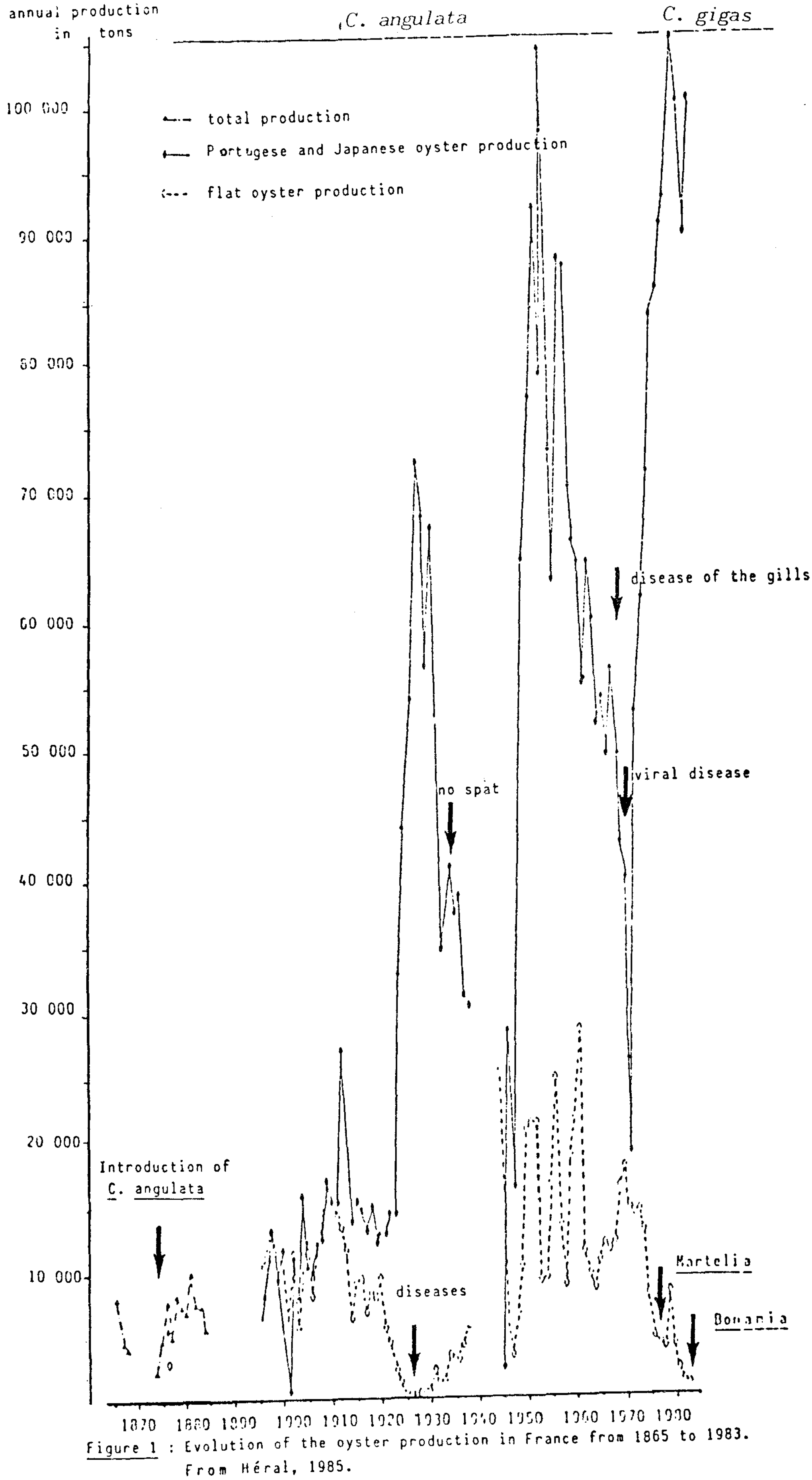

Figure 1 : Evolution of the oyster production in France from 1865 to 1983.
From Héral, 1985.

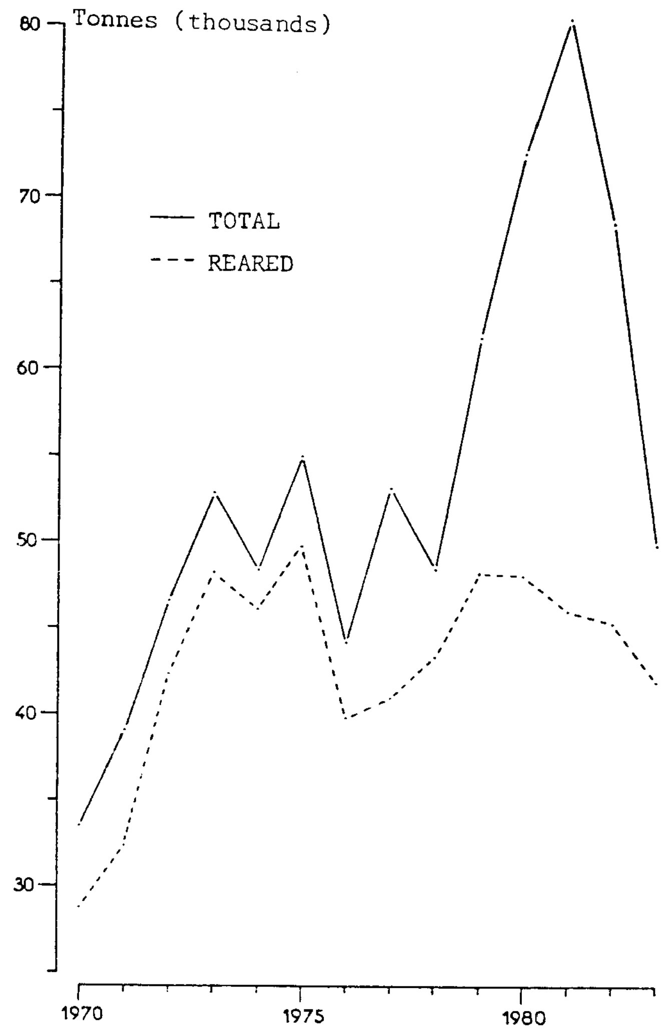

Figure 2 : FRENCH MUSSEL PRODUCTION FROM 1970

Species / Years	1977	1978	1979	1980	1981	1982	1983
Cupped oyster							
C.angulata							
Weight	96 600	91 700	100 300	95 200	82 800	87 200	109 100
Value	505 850	530 800	541 600	653 800	579 500	767 400	1 016 800
Flat oyster							
O.edulis							
Weight	3 800	3 600	6 000	4 200	2 800	2 600	1 300
Value	59 000	63 300	91 000	83 150	40 700	42 100	28 000
Total oysters							
Weight	100 400	95 300	106 300	99 400	85 600	89 800	110 400
Value	564 850	594 100	632 600	736 950	620 200	809 500	1 044 800
Mussel							
Weight	40 950	43 500	48 200	48 150	46 100	45 350	42 000
Value	123 000	130 300	145 000	193 000	184 200	204 000	210 000
TOTAL							
Weight	141 350	138 800	154 500	147 550	131 700	135 150	152 400
Value	687 850	724 400	777 600	929 950	804 400	1 013 500	1 254 800

Table 1 : bivalve farming production from 1977 to 1983, by weight (tonnes) et value (french Francs).
Are not included landings from wild stocks.