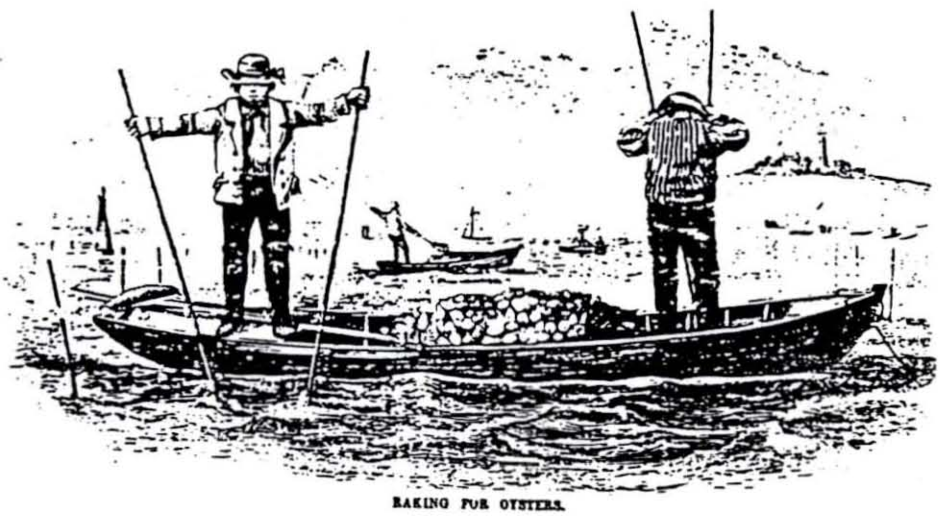
THE UNIVERSITY OF MARYLAND

CENTER FOR ENVIRONMENTAL AND ESTUARINE STUDIES

CHESAPEAKE BIOLOGICAL LABORATORY

OYSTER PRODUCTION IN EUROPE AND IN THE CHESAPEAKE BAY

Maurice HERAL



RAKING FOR OYSTERS.

IFREMER - LEC - B.P. 133 - 17390 LA TREMBLADE (FRANCE)

IFREMER

OYSTER PRODUCTION IN EUROPE AND IN THE CHESAPEAKE BAY (USA).

by

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This study was funded by the National Oceanic and Atmospheric Administration, by the Maryland Department of Natural Resources under contract F 166-89-008 and by the Institut Français de Recherche pour l'Exploitation de la Mer.

CONTENTS

This report has been achieved during a work as short-term consultant in Chesapeake Biological Laboratory (University of Maryland) in the Laboratory of Prof. B.J. Rothschild, for a period from July 7 to August 7 1989 and at IFREMER laboratory of La Tremblade.

The terms of reference of the consultance were :

1°) To compare the oyster fishery researches between the Chesapeake Bay and Europe, particularly in reference to the French coast,

2°) To evaluate the on-going Chesapeake Bay oyster stock assessment project and to provide its comments and recommendations,

3°) to work on spat settlement in the Bay.

This study was funded by the National Oceanic and Atmospheric Administration, by the Maryland Department of Natural Resources under contract F 166-89-008 and by the Institut Français de Recherche pour l'Exploitation de la Mer.

To compare the oyster production in France and in Maryland and their respective problems, two articles have been wrotten :

- The first one "oyster culture in European countries" describe the caracteristics of oyster culture with the biology of the cultivated species, the salinity and temperature tolerance, the sexual development and spawning, the larval development, the growth, the history of the fishery, the methods of culture of harvesting and the uses and processing. The main constraints are analysed like diseases, parasites, predators competitors, pollution and toxic phytoplanctonic blooms. The european and mainly French axes of researches are presented for the technics of culture, the pathology, the carrying capacity of environment for cultivation of molluscs and the genetic programms. This paper asked by Dr W. Menzel have been wrotten to be published in CRC Press as a chapter of the book "Estuarine and marine bivalve mollusc culture".

The second one "Decrease of the oyster production in the Maryland portion of the Chesapeake Bay : Causes and perspectives" describe the reconstitution of the historical landings of oyster showing three levels of exploitations of the Bay. The responsability of the overfishing and the use of the different gears is presented concurently with the decrease of the surface of the habitat mainly due to the siltation and anoxic waters. The impact of the deseases joined to the predation are presented. Alternative strategies for restoration of oyster production in the Chesapeake Bay are evaluated to allow an increase of the oyster fishery. This report cosigned with B.J. Rothschild and P. Goulletquer will be presented at the next ICES statuory meeting and published in an international review of fisheries.

The evaluation of the on-going Chesapeake Bay oyster stock assessment project have been achieved during the stay in Maryland. The recommandations have been given during different meetings particularly on :

- the technics for estimation of the biais of the different gears for sampling oysters,

- the problem of estimations of the oyster stock relevant with the absence of knowledge of the surface of the oyster bars, joined to the problem to keep or not the points where the biomass is zero and the consequences on the overestimation of the stock,

- the comparisons for the growth and survival rate between the experimental culture in suspension with on oyster bed on the bottom located in the vicinity,

- the control of the occurence of fixation of spat in the water column on shells in suspension.

OYSTERS CULTURE

IN EUROPEAN COUNTRIES

This article will be published in CRC Press in the book : "Estuarine and marine bivalve mollusc culture" Edit by W. Menzel and signed by Maurice Heral and Jean-Marc Deslous-Paoli.

Three species have been or are cultivated in Europe : Crassostrea angulata, Crassostrea gigas and Ostrea edulis. If we follow the taxonomic criteria of Grassé (1960) (1) the European oysters belong to the group of Mollusca, class of Lamellibranchia or Bivalves, order of Filibranchia, family Ostreidae with two genus :

- Crassostrea (Sacco) : two species of cupped oysters
  - Crassostrea angulata (Lamarck)
  - Crassostrea gigas (Thunberg)
- Ostrea (Linné) : one species of flat oyster
  - Ostrea edulis (Linné)

Some authors think that Crassostrea gigas and Crassostrea angulata belong to the same species. Indeed Ranson (1951, 1967) (2-3) stated that the characteristics of the larvae are the same, Menzel (1974) (4) obtained viable hybrids (F2) between these two oysters. Also Buroker et al. (1979) (5) studying the genetic variations of proteins and enzyms of the flesh revealed a genetic similarity of 99 % between C. gigas and C. angulata on 24 loci. These authors proposed the hypothesis that Japanese oysters would have been imported from Japan to Portugal by boats in the sixteenth century. However these two oysters obviously showed different characteristics in the metabolic rate (Héral et al., 1986) (6) the filtration rate (His, 1972) (7), growth performance (His, 1972) (7), (Bougrier et al., 1986) (8), (Héral et al., 1986) (6), reproduction mode (Marteil, 1976) (9), and different resistance to disease, (Combs, 1983) (10). All these latter elements converge to affirm that the Portuguese and the Japanese oysters are two physiological races with well-defined characteristics, particularly for the oyster culture.

The common names are :

Crassostrea angulata : Portuguese oyster, cupped oyster.
Crassostrea gigas : Japanese oyster, pacific oyster, cupped oyster
Ostrea edulis : Flat oyster, European oyster, native oyster.

1. BIOLOGY

A. Morphology

The cupped oysters have a dissoconque shell longer than broad with chalky deposits divided into sheets. The left valve is cupped, which allowed the visceral mass to growth (fig. 1). The right valve is flat and more irregular for the gigas oyster which can be curled with sometimes spines. The flat oyster has a rounded or oval shell, cemented on the left valve which is more curved (fig. 2). In both oysters the flesh is covered by a tegument : the mantle (fig. 1 and 2). The free space between the two lobes of the mantle is the palleal cavity that the gills divide into an inhalant part and an exhalant part. The mouth rounded by the labial palp is near the hinge, whereas, the anus is just above the adductor muscle (fig. 1 and 2).

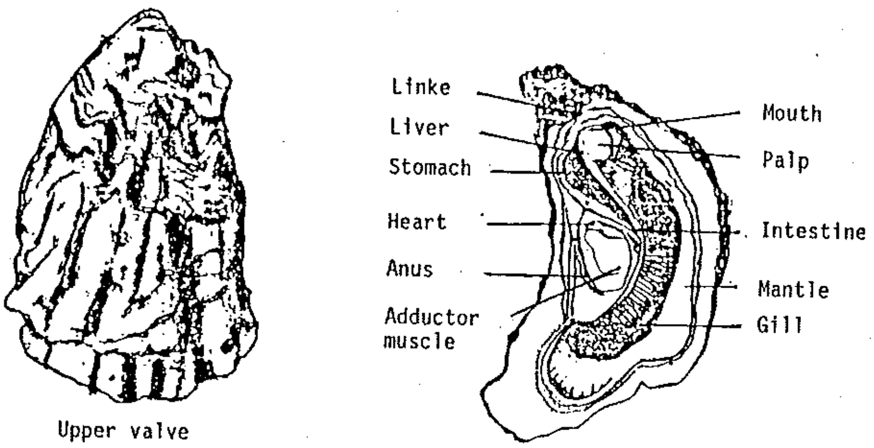


Figure 1 : Anatomy of the cupped oyster : Crassostrea gigas.

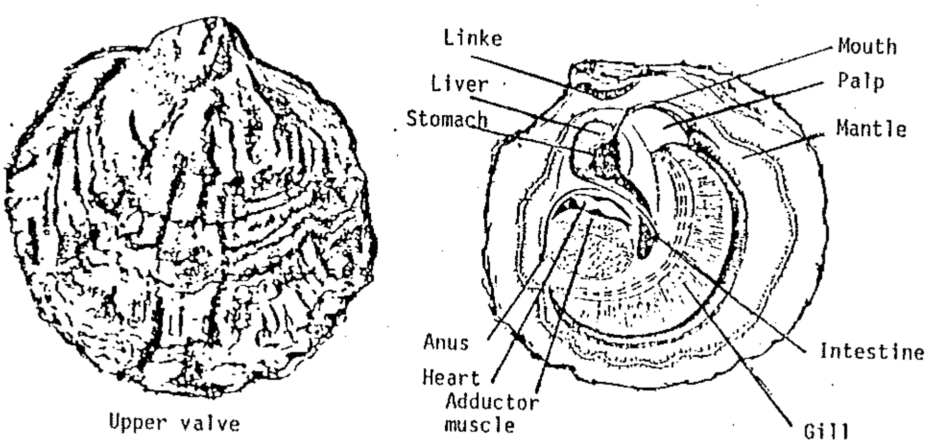


Figure 2 : Anatomy of the flat oyster : Ostrea edulis.

B. Range

Before the diseases which compromise the range of the flat species particularly on the Atlantic coast, Ostrea edulis, the native oyster, is found in several European countries. This species was abundant in the North of Europe from Norway to France passing by Danemark, Netherland, Deutschland, Belgium, Great-Britain and Ireland. It is also living on the south Atlantic coast in France, Spain, Portugal and Marocco and on the Mediterranean and Adriatic coasts particularly in France, Italy, Yugoslavia and Greece. It is or it was cultivated mainly in France, Netherlands, Spain, and at a lower degree in United Kingdom and Ireland. Crassostrea angulata is still present in Portugal and South of Spain. Introduced in France in 1866, this oyster was largely cultivated in this country until 1966-1970 when two diseases cut off the production. This species seems to be still present in Italy on the Adriatic coast.

Crassostrea gigas has taken the place of the Portuguese oyster in the culture since 1970. It has been imported first to France from British Columbia (Canada) for the adults and from Japan for the spat. Nowadays the production of cultivated cupped oyster in European countries is only Crassostrea gigas. There is a natural breeding only along the South West part of the Atlantic French coast. But this species is beginning to be cultivated in several other countries with spat produced in hatcheries mainly in Great-Britain, Ireland, Denmark, Germany, Norway, Spain and Italy.

C. Salinity and temperature tolerance

Larvae : On the Atlantic coast the reproduction of Crassostrea gigas occurs in European countries in July and August and need high level of temperature above 18°C with an optimum at 21-22°C. The salinity can vary between 25 and 35 ‰. The higher salinity is, the higher temperature needs. Thus the evolution of the larvae is compromised when temperature is under 18°C with salinity above 34 ‰ (fig. 3). Ostrea edulis lays eggs in July after the incubation of the larvae. The salinity had no importance in the range 25-36 ‰ (Korringa, 1941) (11). The temperature can vary between 14 and 22°C ; under 14°C there is no evolution of the larvae (Marteil, 1976 (9). In the lagoons on the mediterranean coast where in summer the temperature reaches 24-25°C and the salinity 37-38 ‰, there is no reproduction of Crassostrea gigas. In the open Mediterranean sea where salinity is nearly 37 ‰ and temperature in the range 19-22°C there is no reproduction of Crassostrea gigas except in the Adriatic sea where lower salinity allows a reproduction of cupped oyster. At the contrary Ostrea edulis reproduces regularly in the Mediterranean gulfs which permits a new oyster culture in open waters. The larvae of the native flat species prove less requiring about temperature and salinity.

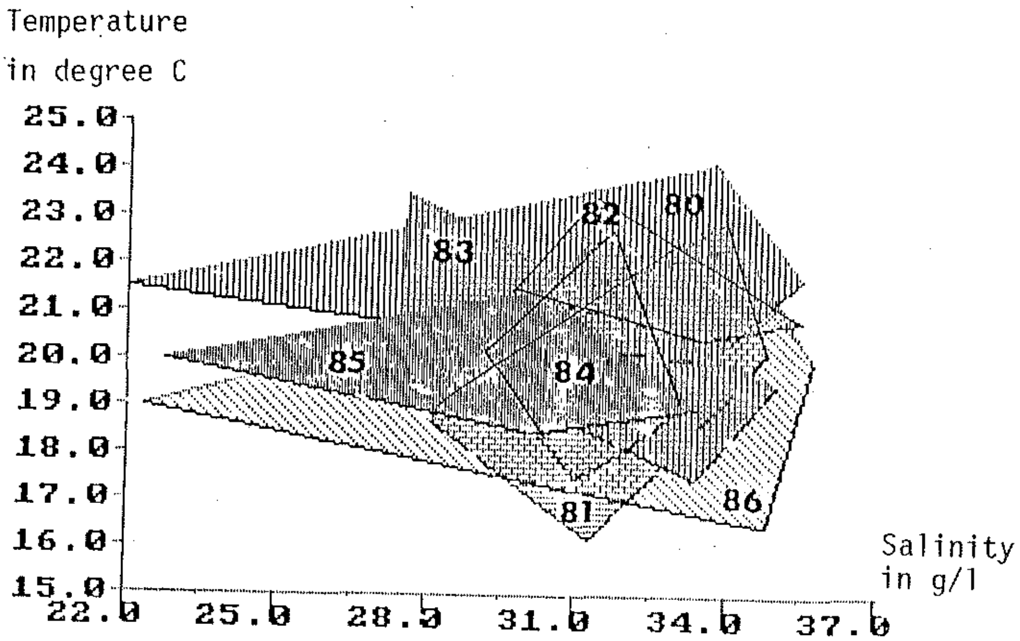


Figure 3 : Temperature, salinity diagramm of the bay of Marennes-Oleron during the evolution of the larvae of the japanese oyster (1980-1986) (from Heral, 1987).

Juvenils and adults :

The distribution of the species on the coast is mainly determinated by the conditions of temperature and salinity not only for breeding but also for growing. Crassostrea gigas is a very euryhaline species which can be cultivated in the oceanic waters but also upper in the estuaries with a mean salinity of 15 ‰ with variations between winter and summer time of 2 ‰ to 25 ‰ (Charente river, Estuary of Gironde for example). It can also be cultivated in oversalt waters, for example in the first pond of salt marshes or in "claires" with salinities which can reach 45 ‰ - 50 ‰. For the Japanese oyster growth and fattenning is affected by mean salinity lower than 15 ‰. The oyster can resist, for several weeks in winter time when rivers are in spate, even in fresh water, by closing their valves. On a tidal cycle they have an active metabolism during high tide and they stop their activity in the low tide with the fresh water input. On the other hand, above 50 ‰ of salinity mortalities are observed. For Ostrea edulis the optimal salinity was between 32 and 37 ‰ (Marteil, 1976) (9). Until 25 ‰ the growth of this species remained good. Under 20 ‰ and above 40 ‰ it became feeble.

As temperature is an extremely important parameter which controls all phenomena in mollusc physiology : filtering activity, metabolism and thus respiration and excretion, Héral et al. (1984) (12) demonstrated that if the egg-laying period is excluded, temperature is the primary explanatory factor for shell growth and the third explanatory factor for meat production of C. gigas. This oyster can have quite a high level of filtration even when temperature is at 5°C (Deslous-Paoli et al., 1986) (13) where as for the flat oyster the filtration activity is reduced at 8-10°C. In winter time the effect of ice on the oyster beds can give high levels of mortality with the mechanical action of the ice which breaks the young oysters off the collectors and carries them away with the floating ice. With negative temperatures freeze can cause direct mortality by tearing up the muscle with ice crystals or by bursting the shell. On the contrary, the effect of high temperature in summer time, during the reproduction, can bring physiological disorders causing mortalities. Summer mortalities (20 % of the oysters) of Pacific oysters appeared on South Atlantic coast of France (Maurer and al., 1986) (14). Mortalities occured mostly among one-year-old oysters, before spawning with temperature higher than 21°C. A thinning of the digestive tubule epithelium was observed but without evidence of infectious disease. Contrarily to the observations of Mori (1979) (15) for Japan and Perdue et al. (1981) (16) for America the mortality did not appear to be in relation with an eutrophisation of water and a high level of lipids bound to an over-maturation ; actually it seemed to be a physiological disorder in relation with a deficiency of the energy balance of the oyster, limited to the high thermal stress of the summer.

D. Type of substrate

During the wild cycle of life, after the settlement the cupped and the flat oysters are fixed on hard natural substrates : rocks, stones, gravels, living or dead shells, or artificial substrates : dike, clams, artificial reefs... For the cultivation the spat is fixed on cultchs which can be tiles with or without lime, slates, oyster or scallop shell, plastic tubes... For the adult oysters if they are cultivated in suspension they can stay on the collector until the marketable size or be detached and sticked on wood or rope. For the bottom culture the oysters are scrapped from the collector and spread directly on sandy or muddy grounds or cultivated on tables and racks, the oysters staying in plastic, iron, or wood bags or pockets.

E. Sexual development and spawning

Crassostrea gigas is an oviparous oyster with alternative protandry and a high level of fecundity. The oyster is male or female during a breeding season and can change sex the following year, a little percentage could remain hermaphrodite (Neudecker, 1978) (17). The environnement (temperature and nutrition) but also hormonal internal factors seemed to determine the turnover of sexual change. The Japanese oysters are mature during the first year, on the condition they have reached a minimum size of 50 mm. It appeared (table 1) that the effort of reproduction is a function of the age.

Ostrea edulis has a restricted fecundity and is larviparous. It is a species successively hermaphrodite with a consecutive rhythmic sexuality. It means that the gametes are not ripe at the same time. If we follow Marteil (1976) (9) the flat oyster is male in autumn after the settlement, the spermatozoids are lysed and the ovogonies are developping for the next breeding season when it becomes a female oyster. The sexual inversion will go on under the influence of temperature, and available food. Younge (1960) (18), showed that in Scandinavia the flat oyster changed of sex once a year, while in Great Britain and in France each oysters could, during the same summer, be several times male or female. Contrary to the cupped oyster, the fecondation of larvae of Ostrea edulis occured in the palleal cavity during the incubation time of the larvae.

	Oysters collected during 1978									
Year	1979				1980		1981			
Sex	♂		♀		ND		♂		♀	
	Q	%	Q	%	Q	%	Q	%	Q	%
Dry weight (mg)	128.2	17.8	447.4	43.1	810	42.9	1 510	55.9	1 930	61.9
Energy (Kj)	-	-	-	-	19.48	52.7	30.98	61.1	45.3	69.6
Proteins	86.7	27.7	236.3	51.1	435.7	51.0	502.6	55.2	663.7	61.9
Lipids	11.6	18.7	88.6	63.1	257.0	67.3	89.5	49.1	334.2	78.3
Free carbohydrates	5.7	33.7	16.6	59.8	9.46	30.1	30.0	57.9	22.9	51.2
Glycogen	14.3	44.3	11.5	39.0	-	-	-	-	-	-
Ash	4.1	4.4	42.6	32.3	66.1	27.7	151.8	40.5	125.5	36.0
	calculated from 24/7/79 to 21/8/79				calculated from 15/7/80 to 25/8/80		Calculated from 20/7/81 to 28/10/81			

Table 1 : Quantities (Q) and percentage (%) of the dry flesh (mg), the energy (Kjoules) and the proximate constitution of the flesh lossed by males (♂) and females (♀) during the emission of gametes. ND : non determined sex. (from Deslous-Paoli and Heral).

The duration of the sexual maturation is a function of the quantity of heat that the reproductive oyster received. Muranata et Lannan (1984) (19) showed that the mean value of day degree is nearly 2 300 degree-day for Crassostrea gigas maintained experimentally at a temperature of 18-22°C for salinities of 20 to 30 ‰. Mann (1979) (20) demonstrated that gametogenesis began only above 10.55°C. Also Héral et al. (1986) (21) described that, for the bay of Marennes-Oleron which is the main sector of reproduction of cupped oyster in the European Atlantic coast, the breeding of Crassostrea gigas appeared in mean after 2 387 degree-day and the date of spawning was depending each year on the fluctuation of the temperature, appearing with 95 % of occurency between the 12^{th} July and the 21^{rst} August. For the flat oyster Marteil (1976) (9) precised that the minimal temperature necessary to the beginning of the gametogenesis is 10°C but after a period of sexual rest which did not exist for the Japanese oyster.

The incidence of the temperature on the releasing of the gametes is also important. Lubet et al. (1970) (22) showed that there was a minimal critical temperature under which the emission of sexual products could not take place. For C. gigas it is nearly round 17 to 18°C and for C. edulis 14 to 16°C.

For the salinity Marteil (1976) (9) reported that Ostrea edulis delayed its gametogenesis in estuaries when the salinity was under 20 ‰ but variations between 30 and 36 ‰ did not seem to play a role on the date of emission and on the quantity of the gametes. For the Japanese oyster it seems that the gametogenesis is faster when the salinity was between 20 and 35 ‰.

With Crassostrea gigas, there is a total laying of the gametes at a time. In France, this oyster spaws mainly once in Marennes-Oleron bay but in Arcachon successive rebuildings of the gonads appear with 2 or 3 spawnings depending on the heat of the summer. Ostrea edulis can possibly, providing the temperature is high enough have a phase of reconstitution of the gonads after the first estival laying, which permits another spawning in autumn. On the Adriatic coast the spawning season is in March-April but for the same species it occurs in August in Norway. These differences show the role of climatic conditions on the rapidity of the gametogenesis and by consequences the date of laying.

When the sexual products are ripe, the adult Crassostrea gigas eject their gametes in the water. 20 to 100 millions of gametes can be laid at each spawning. The external fecundation of ovules by spermatozoids gives the trocophore larvae. For Ostrea edulis the fecundity is lower 500 000 to 1 500 000 of gametes. The fecundation of the ovules is internal in the palleal cavity, the spermatozoids being transported by the currents of water. The larvae are incubated there during eight to ten day before being released in the open sea ; they are colored in a typical slate grey.

F. Larval development

For Crassostrea gigas the length of the youngest well-formed larvae was nearly 60 μ and the size at the metamorphosis was close 300 μ (Imai et al., 1950 (23) ; Loosanoff et al., 1966 (24) ; His and Robert, 1985 (25)) (fig. 4). The duration of the larval life is in relation with the temperature. This time varies on the French Atlantic coast between 15 and 28 days, function of the temperature fluctuating between 20 and 26°C. The optimal temperature for the shorter larval evolution was 28°C for a salinity of 30-32 ‰ (Walne, 1974) (26). As a consequence of a insufficient temperature the pelagic phase is lenghtened. All the emissions do not give settlements because for Crassostrea gigas the temperature must be higher than 18°C (fig. 3) and for Ostrea edulis higher than 15-16°C. For the flat oyster, the planctonic stage lasts between 5 to 14 days in relation with the temperature from 17°C to 26°C. The size of the released larvae is dependent on the time the mother-oyster retained then in the mantle cavity. The mean size of the released larvae is 180 u. Setting occured when the size is between 280 and 300 u (Loosanoff et al., 1966) (27).

Figure 4 : The four stages in development of cupped oyster larvae, according to Medcof (1961) ; French oyster biologists divide the stage I into two : the straight hinged stage (24 h old larvae) and the very early umbo stage described by Quayle (1969) from His and Robert (1985).

days after the fertilization	names used by malacologist	height in μ.
1-6	Veligerous larvae D	57-105
6-18	Veligerous umbonated larvae	105-260
18-22	Veligerous eyed larvae	260-280
22-24	Pediveligerous larvae	280-300
24	Plantigrade larvae	300

Table 2 : The stages in the development of the larvae of the Japanese oyster Crassostrea gigas as described by oyster biologists and malacologists.

The action of the salinity on the duration of the larvae life is less important. Helm and Millican (1977) (28) showed that the optimal salinity for Crassostrea gigas is 25 ‰. But the recruitment can be quite good at 20 ‰ as at 35 ‰ and is more dependent on the temperature. The higher the salinity is, the more the temperature must be above 22°C (fig. 3). On a pratical point of view, each summer in the places where the flat and cupped oysters are bred and where oyster culture is developed, biologists, from Institutes of Fisheries, IFREMER in France for example, analysed twice a week since 1930 the numbers and the evolution of the larvae to predict the time where it is necessary for the oystermen to immerse the collectors and obtain good results of settlement.

G. Growth

Substantial differences in the amount of growth is recorded from the different sites of different countries and also in the same site but at different levels of exploitation of a bay (table 3 and 4). Thus growth appears to be a function of temperature ; in temperate regions, in winter time, the growth is reduced particularly for Ostrea edulis under 8 to 10°C. For Crassostrea gigas when the level of food is high enough winter growth can be obtained, this species is more tolerant to low temperatures. But the main factor which increases or decreases the growth rate is the available food which depends on two factors :

O. edulis Authors	Locality	Total weight after 12 months	Total weight after 24 months	Total weight after 36 months
Askew 1978	Emswork (U.K.)	(5 g) 30 g		
Askew 1972	Harbour (U.K.)	(5 g) 30 g		
Walne and Mann 1975	Menai Straits (U.K.)	15 g - 20 g	30 g - 35 g	40 g - 50 g
Hall, 1984	Emswork Harbour (U.K.)	10 g	28 g	50 g
Martell, 1979	Golfe du Morbihan (France)	4 g	15 g	
Kergariou Com. pers.	Cancale Bretagne (France) 1983 1984	- - - -	62 g 47 g	
Pacquotte and Moriceau, 1987	Thau Agde (France)	23 g - 35 g	30g-60g (26 months) 30 g (16 months)	
Filic, Krajnovic Ozretic, 1978	Lim Canal (Yugoslavia)	-	28 g	50 g

Table 4 : Growth performance of the flat oyster Ostrea edulis on the European and Mediterranean coast.

- The first one is the nutritional value of the bay for the oyster which is a function of the current velocity, multiplied by the quantity of food in the water and the time of immersion. So Walne and Spencer (1971) (29) in the United Kingdom or Cooke and Bany (1975) (30), in Ireland, tested the performances of different bays, lochs or estuaries for the growth of Crassostrea gigas. They obtained results with a large variability, some sites showed growth ten time more than others. In these experiments where the quantities of cultivated oysters are little and where there is no other large cultivation or wild population of molluscan in the area, the results of growth indicating the level of the trophic capacity of each sector.

- The second one is the impact of the density of breeding on the available food depending on :

. the local density which is the density of the unity of culture. For example it is well known that growth of oysters is in relation with settlement surface (Shafee, Sabatié, 1986) (31). For this reason spat produced free from support in hatcheries has a better growth that natural settlement except if the young oysters are scrapped early from the collectors. This observation for the juveniles is also valid for the adults. Several authors showed that growth was a function of the density on the ground, in the baskets or in the racks.

. the density of cultivated or wild population of molluscan in the area. For example Héral et al. (1986) (32) showed that for the bay of Marennes-Oleron there is a light correlation (fig. 5) between the decrease of the growth rate in relation with the evolution of the total cultivated biomass of the Pacific oyster for the last fifteen years. It means that each result of growth, particularly of a cultivated population has a sense only if it is associated to the biomasses presented in the coastal ecosystem.

The maximal growth of Crassostrea gigas occured in Israel in subtropical fish ponds (Hughes-Games, 1977) (33) where young oysters of 4 g reached 80 to 90 g in one year but with high temperatures and a high level of food. The better growth in European countries is 40-50 g after one year and 100 to 130 g at the end of the second year of growth. This growth as found as well in England (Walne and Spencer, 1971 (29), Askew, 1978 (34)) as in France when the stock density was low (Héral et al., 1986) (32) and in Corsica and Marocco (Shafee Savatie, 1986) (35). For Ostrea edulis, the better growth is observed in France on the Mediterranean coast with a weight of 60 g after 2 years of cultivation. This performance could be achieved also in French Britanny but with a seed density of 1 tons/ha which is 5 time less important than the traditional density.

C. gigas Authors	Locality	Total weight after 12 months	Total weight after 24 months
Askew [41]	Emsworth Harbour (U.K.)	34 g (5 g) 60 g	100 g
[29]	Newton Bay (U.K.)	52 g	
	Linne Mhiurich (U.K.)	14 g	58 g
Hall, [31]	Emsworth Harbour (U.K.)	20 g	70 g (16 months)
Walne Spencer [35]	Menai Straits (U.K.)	50 g	130 g
Cooke, Barry [36]	Rossmore (Ireland) Carlinglard Bullinakill Carna	46 g 16 g 6 g 3 g	- - - -
Meixner [42] Neudecker [43]	Flensburg Baltic North Sea (Germany)	8 g (12) 60 g	60 g
Seaman, [44]	Flensburg Fjord (Germany)	24 g	-
Shafee Sabatie [37]	Oualidia (Maroc)	(6 g) 43 g	120 g
Auger [45]	Etel (France)	12 g - 29 g	-
Deslous-Paoli [46]	Marennes-Oléron (France)	48 g	60 g
Berthomé et al. [47]	Marennes-Oléron (France)	35 g	60 g
Landrein et al. [48]	Thau (France)	35 g - 50 g	68 g 116 g (20 months)
Dosdat [49]	Corse (France)	-	100 g (17 months)
Bougrier et al. [50]	Arcachon (France) Marennes-Oléron (France) Bretagne Sud (France)	15 g (18 months) 8 g (18 months) 28 g (18 months)	58 g (30 months) 27 g (30 months) 99 g (30 months)
Héral et al., [6]	Marennes-Oléron (France)	1970 50 g 1972 33 g 1974 20 g 1975-1981 20g 1984 15 g	100 g 75 g 50 g 40 g 30 g
Hughes-Games [39]	Fish pond (Israel)	(4 g) 79 g 92 g	-
Filic, Krajnovic Ozetic, [34]	Lim Canal (Yugoslavia)	26 g	103 g

Table 3 : Growth performance of the cupped oyster *Crassostrea gigas* on the European and Mediterranean coast.
(xg) weight at the beginning of the culture.

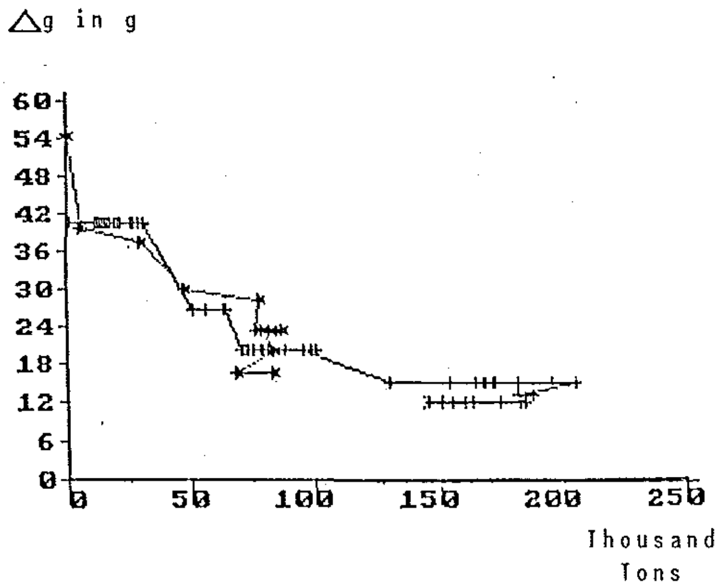


Figure 5 Evolution of the annual growth rate of Portuguese oyster (+) and Japanese oyster (✱) in relation with the total cultivated biomass of oysters in the bay of Marennes-Oléron. (from Heral et al., 1986).

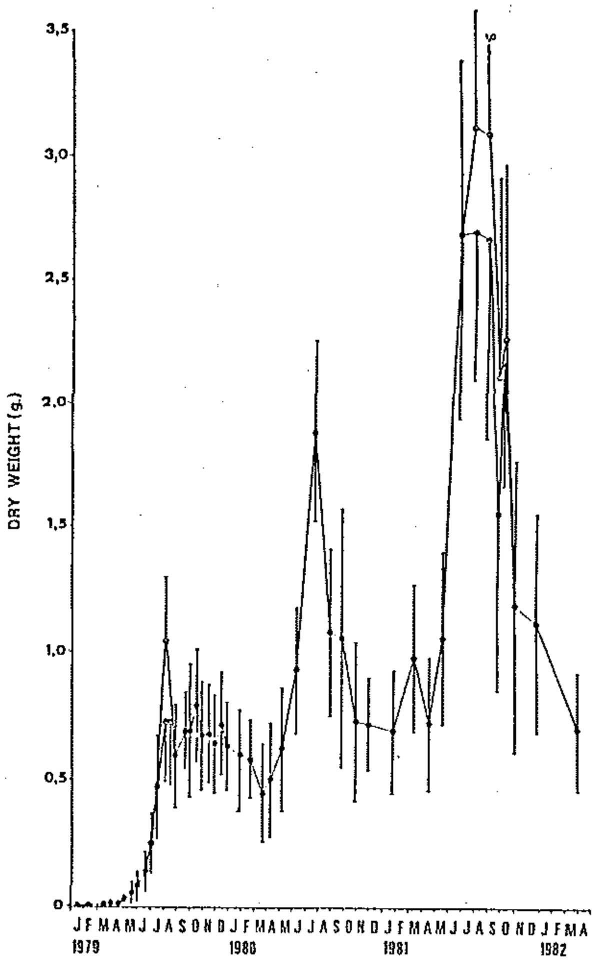


Figure 6 : Evolution of the dry weight of Crassostrea gigas cultivated in the bay of Marennes-Oléron, ( ) male, ( ) female. (from Deslous-Paoli and Heral).

The results presented are the mean values of the growth but each population is normally distributed round the mean and Askew (1978) (34) took the example where it happened that 10 % of the population was growing faster, reaching the market size in little than 11 months, those growing at the mean is no longer than 15 months while the slowest representing also 10 % required 43 months to obtain a weight of 80 g.

The growth of the flesh expressed in dry weight represents in winter time about 1 % of the total weight and in summer time until 2.5 to 4.5 %. The dry weight of the flesh show large variation (fig. 6) in relation with the reproduction and the reducing caused by a lack of food during winter time (Héral et al., 1983) (36).

2. FISHERY

A. History :

The flat oyster Ostrea edulis is the native European species. It was once very common until the last century. Shallow bays and estuaries around the coasts of Europe including Ireland and the Mediterranean one, abounded with oysters which could be picked by hand in many places at low water or dredged by boats giving a prosperous oyster fishery. These activities were ancient, Romans began to build some ponds to stock the harvest and try to collect the spat on wood fascines. During the Middle Ages and Renaissance, fisheries on the oyster bed still went on. During the eighteenth century, the increase of the population induced an ingrowth of the fishing effort with an overfishing of the beds whose the production varies depending on the intensity of settlement in preceeding years. At the end of this century the oysters beds of France, Ireland, England were largely overfished and decisions and regulations were taken to limit the period of fishing and to suspend it during the reproduction. Despite these more and more constraining regulations, the fishing effort grew in relation with an increase of the consummation encouraged by the development of transports of goods and by the beginning of the oyster culture which did not control the settlement and used young oysters coming from fisheries. At this period there was no real culture, the oysters were only keept in stocks in ponds before the sale. On the Atlantic coast, near La Rochelle, old unused salt marshes were turned into "claires" for finishing the growth and fattening the flat oysters. It was only after 1860 that in France the technique of cultchs was largely used by enlarging the Italian wooden fascines transmitted by the Romans. The techniques advanced very quickly with new materials slates, tiles with lime for the settlement but also for the cultivation with the bottom culture and the rack culture. In 1920-1921 a disease decimated the beds of flat oysters throughout Europe. It is only after 1928 that settlement began to become important again particularly in French Britanny but in several localities the wild flat oyster-beds have definitively disappeared (Marennes-Oleron, Arcachon). In Ireland, Great Britain, Netherlands and on the Mediterranean coast some oyster-beds resist and their exploitation by fishermen can go on. In 1950-1951 a new disease appeared and destroyed the flat cultivated oysters of the Thau lagoon. The breeding of Ostrea edulis continued in French Britanny which

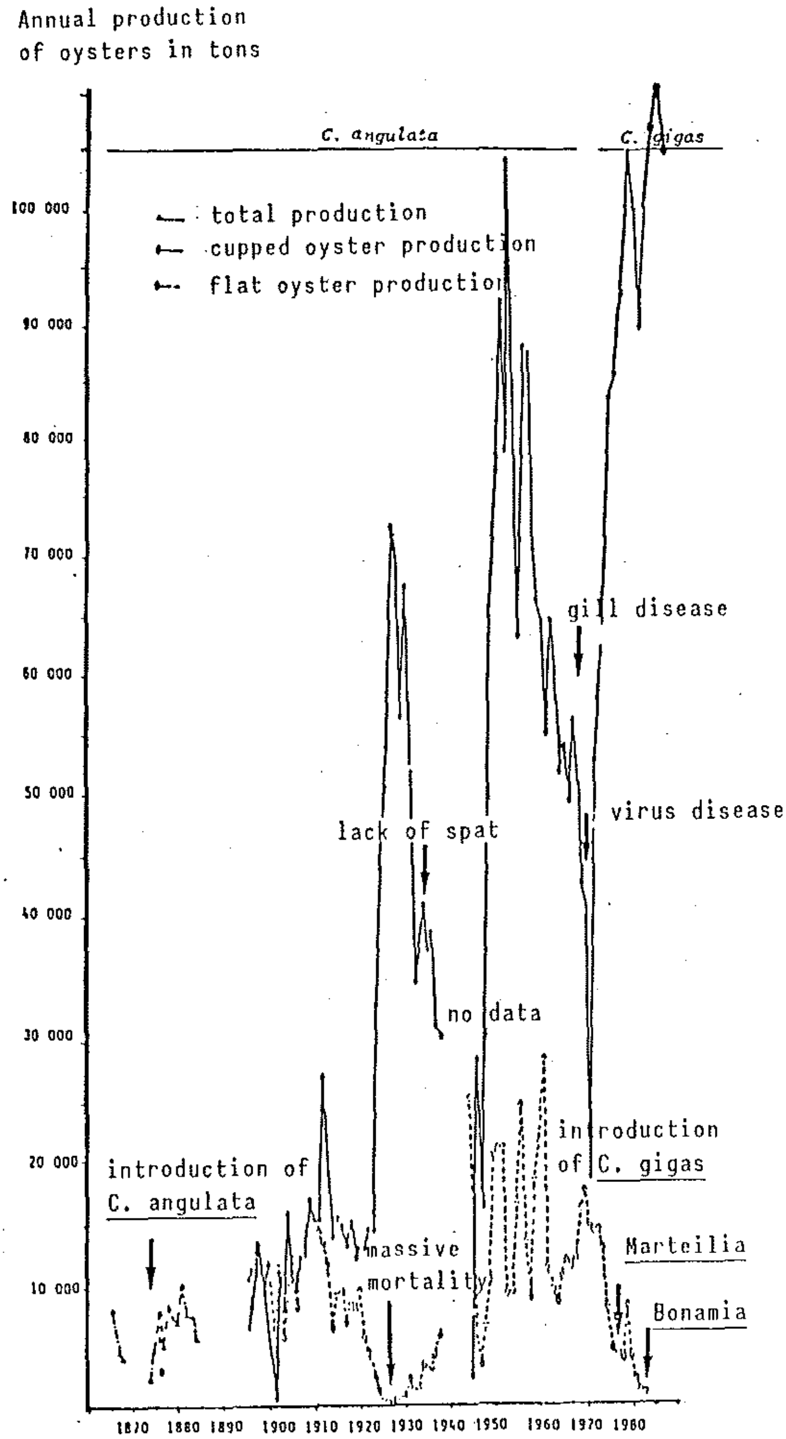


Figure 7 : Evolution of the production of oysters in France from 1865 to 1985 (source : official statistics from Fisheries Department). (from Heral, 1985).

sold juveniles to Spain (Galicia) and to Netherlands. After a phase of large expansion (annual French production of 30 000 tons) (fig. 7), the culture of the flat oysters has been attacked again by two parasites : Marteilia refringens since 1974 and Bonamis ostreae since 1979 which spread on a large number of European countries reducing the breeding in France, Holland and Spain.

Since the start of the oyster-culture (1860) cupped oysters have been imported in France from the Portuguese wild oyster-beds to palliate the lack of flat oysters. During one of these trips a boat threw its freight of oysters out in the estuary of Gironde and the species Crassostrea angulata spread quickly on the South West Atlantic Coast of France. After 1920 the cupped oyster came next to the flat oyster with an intensive development (annual French production upper than 85 000 tons) (fig. 7). From 1966 to 1969, in the whole French coasts the Portuguese oysters were touched by a gill disease and by an iridovirus which destroyed the species Crassostrea angulata in Europe. Up to this date, only some oyster-beds in Portugal are still living.

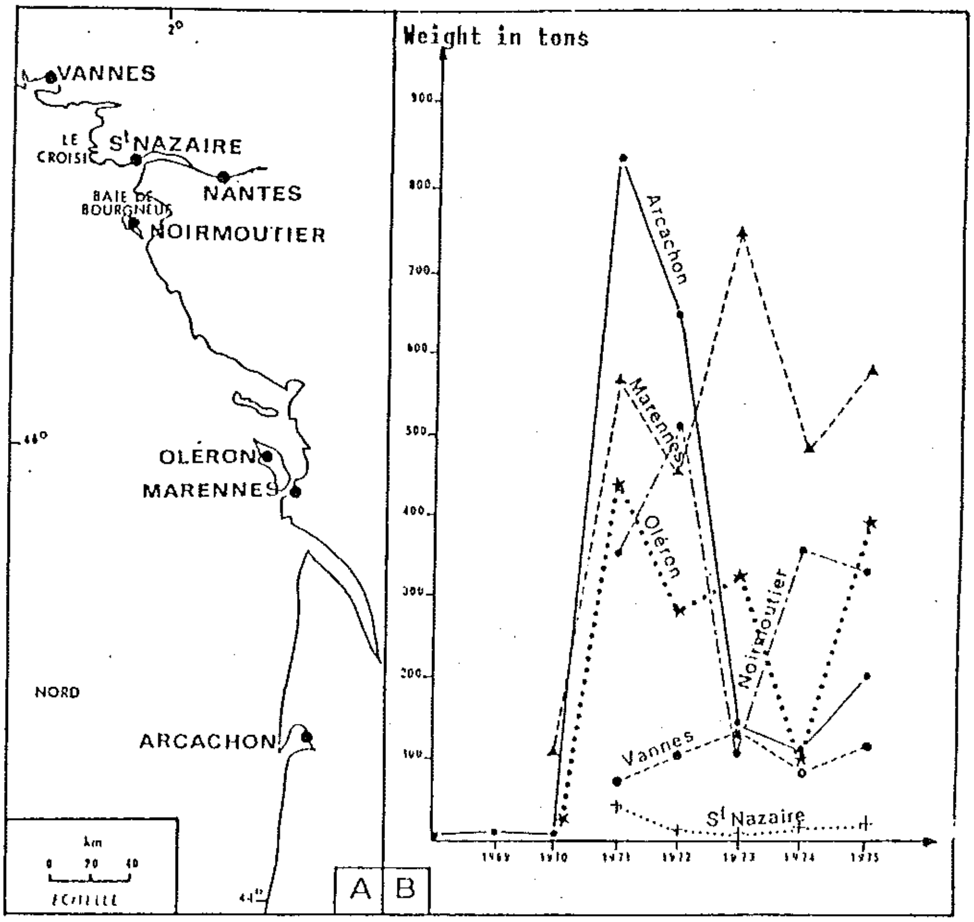


Figure 8 : Quantities of spat imported from Japan on the French Atlantic coast (from Gruet, Héral, Robert, 1976) (37).

The importation of Crassostrea gigas with spat from Japan and adults from British Columbia occured from 1968 to 1975. The reproduction of Japanese oysters has been well established since 1971 on the South West Atlantic coasts of France. The level of production in this country has reached 100 000 tons since 1980. Some others countries like Great Britain, Ireland, Germany, Norway, Denmark, Spain, Italia, Marocco... started very recently to cultivate Crassostrea gigas with spat produced in hatcheries from Great Britain or France.

This brief historical study show that during the last century, some constant events appears particularly evident in France with successive phases :

- over-fishing of natural flat oysters beds and diseases,

- importation of a foreigh species (C. angulata), bred on a large scale with high density and disease,

- importation of a new exotic species (C. gigas) and cultivation at a high level. Each time the response to the disease has been the importation of the next species, it would be better to understand the reasons of the disease and to practise management of oyster bays. Thus it appears that diseases occured after a period of hight level of production and we suggest the hypothesis that when the cultivation densities in a bay are too high, the trophic equilibrium is over-passed, growth and fattening are decreasing and the defense mecanisms of the oysters are lower. It means that by controlling the stock in culture, the risk of appearance of diseases could be lowered.

B. Importance

Statistics to estimate the level of production in the different countries are very often not realistic and can not be compared with one another (see for example Héral et al., 1986 for the validation of the French statistics on oysters).

The data coming from the last year book of fishery statistics published by the Food and Agriculture Organization of the United Nations (F.A.O.) can give bases for comparisons. For the cupped oyster which is only the Japanese one, the European production of 1981-1984 is varying between 78 000 tons and 105 000 tons of total living weight including the shell. The French production represents 99 % of the total production. For the flat oyster, the same source of data shows that the production is at a low level around 4 000 tons which represents only 4 % of the quantity of the cupped oyster (table 5). The French production which was nearly 15 000 tons is now of 1 800 tons in relation with the two disease Marteilia and Bonamia thus its represents 40 % of the total production (table 6).

	1981	1982	1983	1984
France	90 242	80 082	104 849	77 755
United Kingdom	61	58	70	144
Germany	1	1	1	1
Total	90 304	80 141	104 920	77 900

Table 5 : Nominal catches for *Crassostrea gigas* by countries in tons of total weight. Source : yearbook of fishery statistics - FAO Statistics Series vol. 58, 1986.

	1981	1982	1983	1984
France	3 242	7 059	1 369	1 773
Ireland	400	861	316	371
Netherlands	572	560	680	843
Spain	280	539	549	560
Sweden	25	13	13	11
United Kingdom	560	399	269	360
Turkey	1	0	0	9
Yugoslavia	56	82	57	181
Total	5 136	9 513	3 253	4 108

Table 6 : Nominal catches for *Ostrea edulis* by countries in tons of total weight. Source : yearbook of fishery statistics - FAO Statistics Series, vol. 58, 1986.

	1980	1983	1985	1990
Denmark	0	15	30	60-100
Federal Republic of Germany Japanese oyster	0	0	10-20	50
France				
Flat oyster	4 170	1 288	2 300	4 000
Japanese oyster	95 165	107 779	105 000	110 000
Ireland flat oyster	60	35	-	-
Italy flat and Japanese oyster	-	-	1 000	3 000
Netherlands flat oyster	-	1 000	1 500	-
Norway Japanese oyster	0	30	50	1 000
Spain flat oyster	1 700	2 350	3 000	4 000
United Kingdom Flat and Japanese oyster	800	800	800	1 200
Yugoslavia flat oyster	-	30	40	100
Total	101 895	113 312	113 735	123 430

Table 7 : The aquaculture production of oysters in tons of total weight and estimates of future production. Source Ackefors H., Murino A., Muller F., Querellou J., 1986 : Development of Aquaculture in Europe, FAO, ERC 86/4 (38).

It is interesting to note that the production of the Netherlands is increasing by 20 % of the total production in relation with the substitution of supplying the young flat oysters bought in France by a population settled in the Netherlands which is not contaminated by Marteilia and Bonamia and which resists to low temperatures (Dikema, 1984) (39). In a recent FAO paper on development of aquaculture in Europe (table 7) it appears that for 1990 a stability of oyster production for France and growth for Italy, Spain, United Kingdom and a beginning of culture for Denmark, Federal Republic of Germany and Yugoslavia are expected.

It is mainly in France that oyster culture plays a large economical role with a production of oysters of 100 000 tons and a turnover which is, at the breeding nearly 1 billion francs (150 millions of US $). This represents one fifth of the total French value of marine productions. The continuous employments for oyster culture are about 10 000 and more than 30 000 seasonal jobs are created working in 5 000 industries (Dumont, 1984) (40). The number of permanent jobs represents one third of the employment of fisheries. This activity is concentrated in some bays or estuaries playing a high social importance and is very often the first activity of these places. The induced employments are not counted but they are many satellite jobs in plastic industry, factories for crates, for boats, for tools, for special machines and so on. The evolution of the prices at the production since 1970 in constant francs 1985 shows a diminution or stagnation of the prices in relation with the ingrowth of the production of cupped oyster, caused by the allocation of new areas for breeding and reconvertion of cultivation of the flat oyster into the Japanese oyster. In a context of mass production of the cupped oyster there is a concurency between the main basins to produce at the lower price by selling under the costing price the French production of oyster could be in an overproduction, needing to find new markets.

C. Recruitment and methods of culture

The supplying of the breedings of oysters can be realised by three manners : regulated fisheries of juvenils on natural oyster beds, settlement of the spat on cultch, production of cultch-less seed by hatcheries and nurseries.

The controlled production of spat of oysters in experimental hatcheries has been well known since the works of Loosanof and Davies (1963) (41) and Walne (1956) (42). The hatcheries of production have three main objectives :

- breeding species when the techniques for the settlements are not known,
- produce cultch when the species do not reproduce in the area or reproduce only from time to time,
- pratice genetic selection.

In Europe, as the natural settlement is abundant as for the cupped oyster and the flat oyster, the production of the hatcheries remains small. Using the data from Lucas 1985 (43), the list of the hatcheries which produce oysters and which are still in activity can be completed by keeping only references for European countries.

name	address	level of production
SATMAR	La Salive Gatteville-phare 50 760 BARFLEUR (France)	commercialised 80 million in 1983
HEPC	Le Varquez 29 226 Carantec	commercialised 18 million in 1986
Aquamare	Route diette 17590 Ars en Ré (France)	commercialised 1-5 million
Tina Menor	Pesues Cantabria (Spain)	commercialised 15 million
Planta de cultivos marinos	Muelle de Parcillan Ribadeo galicia (Spain)	experimental

Name	Address	level of production
Conwy laboratory	Fisheries Experiment Station Benorth Road Conwy, Caernarvonshire (U.K.)	experimental Walne (1979)
Seasalter shellfish	Ltd. The Harbour Whistable Kent	commercialised
Boet-mor/sea food	Cus-Hastrough Gladdaghduff Co Galway (Ireland)	commercialised

Table 8 : Main hatcheries producing spat from Crassostrea gigas and Ostrea edulis in European countries.

These hatcheries, in the future, could play a large role for production if researches on genetic selection are successful in obtaining new races which perhaps would be without reproduction (obtention of triploids for example) but with better growth. Actually the cultch-less oysters present technical advantages for better growth, the density being controlled. But the higher price of this spat, ten time more than the natural settlement, allowed only a large development mainly for countries where natural recruitement did not take place (U.K., Spain...). Occasionaly in France when there is a lack of spat due to abnormal weather conditions, the hatcheries (1 or 2-year on 10) can partially make up for the deficience juveniles.

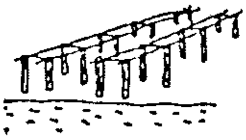
In the field Crassostrea gigas is indifferent to the type of substrate which collects the spat. This explains the large diversity of the cultches, the only requirement is that the collectors must be clean without foulings or muds, so they must be placed at the right time just before the settlement. For cupped oysters the old use of stones is less and less practised, the wood stakes and fascines are obsolate. The limed tiles are used particularly in the Arcachon Bay Allowing an early scrapping of juveniles. Seeds collecting techniques have been developed over the years involving different kinds of collecting devices : metalic bars, slate oysters and scallops shells are often used. The shells are either placed in bags or strung or iron rods or wires. For the last ten years plastic collectors have taken the place of the traditionnal collectors specially with the tubes used in packet of 7 (fig. 9). Scrapping machines have been operating for since three years for the tubes. On the contrary, the pediveligere of the flat oyster seems more difficult on the nature of the substract of the cultch. So spat collectors are usually tiles coated with a layer of lime mixed with sand. The composition of the lime is different for each bay and is described more precisely by Marteil (1979) (9). The main advantage of using limed collectors is that oysters can be removed from the collectors after 6 to 10 months. In French Brittany a new collector made of stuffed mussel shells placed in bags or in tubular nets was nearly efficient for cultivation in open waters (Grizel et al., 1979) (44) with a very low cost price under 0.01 franc by unit in comparison of 0.06 francs by unit with tiles. Sampling strategy has being applied on numbers of collectors used in the main bays to estimate the recruitements and predict the potential production which can be obtained in the years to come. In the Arcachon bay nearly 5 billion young oysters settle each year while, an average of, 10 billion spat are produced in the bay of Marennes-Oleron, allowing the furniture of young cupped oysters for the whole French production.

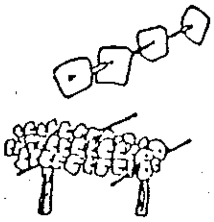
After the seed collection, oyster culture is carried out in two phases : pregrowing and maturing phase. This involves a variety of techniques with duration of each phase depending on the speed of the growth and on the cultural particularities of each bay (Marteil, 1979) (9) The three main oyster culture methods used in Europe are bottom culture, rack culture and hanging rope culture.

Bottom culture is carried out in intertidal zones as well as in deep water. The ground is prepared hardened, if it is necessary and the young oysters are sown on the ground attached or not to the collectors. In the intertidal zones to issolate them against crabs, plastic wires with or without wooden planks forming a fence are placed around the beds. This pregrowing can last one or two years. During the maturing period all

LA SEUDRE

On the left, seen from the bottom. On the right, seen in the oblique. The installations are built with wood poles joined together with iron tubes or with iron tables of 3 meters long. The height above the sediment varies between 0.5 and 1 m.

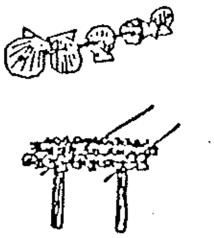




Slate spear

MAIN CHARACTERISTICS

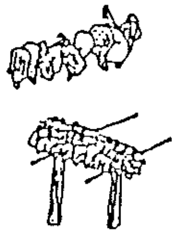
Average number of slate by spear : 12
Maximum number of spears by meter of installation : 50
Maximum capting surface : 22 m^2/m
Real capting surface : 15.4 m^2/m



Scallop shells spear

MAIN CHARACTERISTICS

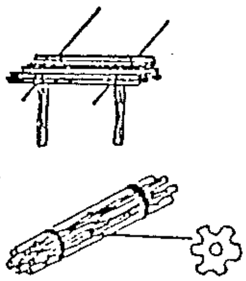
Number of shells by spear : 12
Maximum number of spear by meter of installation : 100
Maximum capting surface : 30 m^2/m
Real capting surface : 21 m^2/m



Oyster shells spear

MAIN CHARACTERISTICS

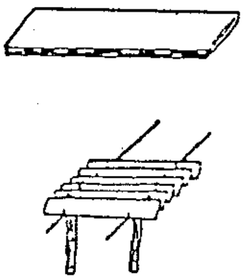
Average number of shells by spear : 60
Maximum number of spear by meter of installation : 90
Maximum capting surface : 60 m^2/m
Real capting surface : 42 m^2/m



Plastic tubes

MAIN CHARACTERISTICS

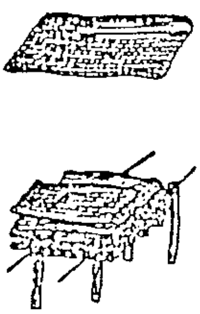
Number of tubes per packets : 7
Maximum number of packets by meter of installation : 50
Maximum capting surface : 31 m^2/m
Real capting surface : 21.7 m^2/m



Slate pole

MAIN CHARACTERISTICS

Measures of the pole in cm : 70x10x2
Number of poles by meter of installation : 20
Maximum capting surface ; actual capting surface : 3.44 m^2/m



Oyster-shell net pockets

MAIN CHARACTERISTICS

Measures of the pockets : 100x50
Number of oyster shells by pockets : about 650
Maximum number of pockets by meter of installation : 10
Maximum capting surface 55 m^2/m
Notice : Is never used alone but one single layer is laid upon other types of collectors.

Figure 9 : Different types of collectors in use in the bassin of Marennes-Oléron (from Berthomé et al., 1984).

the oysters are scrapped from the cultch, sorted by weight they are sown again on maturing beds which can be protected against the storms by fence of sow made with wood sticks 5 m high in Arcachon. The mean densities for the cupped oyster is 5 kg (total weight) on a square meter for the pregrowing and 7 kg (total weight) for the maturing phase. For the flat oysters before the diseases Marteil (1979) (9) indicated densities of 0.5 kg for the first year 1 kg the second year and 3 to 5 kg the third and the fourth year. During the growth oysters are regularly harrowed or turned over with oyster-forks. The average yield for cupped oysters is estimated so : 1 ton of spat will give 20 tons and for flat oysters 1 ton of spat produces generally 12 to 15 tons after 3 years of cultivation.

In deep water along the coast of Britanny, at a depth ranging from - 3 to - 10 meters as in Holland, the flat oysters are sown after a dredging of the stones, predators and competitors. Before the diseases the density was 0.5 kg for 1-year-old oysters, 0.7 to 0.9 kg on a square meter for two-year-old oysters. Now the densities are five time less (1 kg/m^2) allowing the optimal growth to avoid the large mortality which occurs in the third and fourth year, caused by Bonamia. Cupped oyster are also cultivated in deep water, particularly since the decay of the production of the flat oyster, at a density of 2 to 3 kg per m^2. Even if the mortality can be high (storm, predation) the mean yields are upper than in the intertidal oyster beds with a lower cost price but with a higher investment (dredging boat).

The most common culture used at the present time along the French Atlantic littoral is the rack culture on tables. The tables are generally iron-made 3 m long, 0.5 m above the ground. In the intertidal oyster beds the collectors are fixed to row of tables at a high density (50 to 100 collectors on a meter) (fig. 9). The year after, they are set aside on the tables at a density of 8-10 collectors on a meter. After the scrapping, the oysters, after being sorted, are put in containers. The most common are plastic packets of a standard size of 1 m long, 0.50 m wide and 0.10 m deep. The mesh size depends on the size of the cultivated oysters. The weight per bag is 5 kg for flat oysters and an average of 10 kg for cupped oysters but varying with the age of the oyster 5 kg per bag for the youngest and 18 kg for the oldest. The row of tables are placed in parallel on a length of 30 to 100 m. To avoid a too large density of oysters, the cultured surface should not be more than 1/3 of the total leased area. One hectare should not be supposed hold more than 6 to 7 000 oysters packets.

In the hanging method the oysters are fixed on different supports : ropes, nets, iron bars or wooden bars. They are hung from fixed tables or floating rafts. Fixed installations are mainly used in Mediterranean lagoons where there is no tide and quite a large depth (10 m). The metallic tables are 50 meters long and 10 to 12 meters wide. Each table has about 50 wooden or metallic bars which carry about 1 000 supports (Hamon and Tournier, 1981) (45). The collectors of Crassostrea gigas coming from the Atlantic sea, are directly hung under the table. One part of the oysters is commercialised after 12 to 18 months, the rest may be stuck on wooden bars with quick cement and will be commercialised one year later giving large and fat oysters. The average yield is 5 to 7 tons per table. The oysters can also be cultivated on floating rafts those are well-developed for mussel cultivation particularly in Spain (see chapter on mussels). It is the case in Galicia where the "batea" can be used for flat oyster production. In Corsica the same rafts are used for the cultivation of the Japanese oysters. Some experimental cultures of flat oysters in suspension are achieved in Brittany and on mediterranean coast in places where the disease Marteilia and Bonamia is not present.

D. Methods of harvesting

The harvest in the intertidal area is done by hand. For the bottom cultivation they are fished with oyster-forks, put into baskets at the low tide and when the tide is coming up loaded on flat boats. The yield is not more than 1.5 tons by man, by tide. For the rack culture on tables, the harvest is not mechanized, but the work is easier and faster, it cónsists in detaching the pockets from the table and load them on flat boats. The yield is very dependent on the size of the oyster beds. The average yield can be estimated to 200 pockets by day by tide which represents nearly 3 tons.

In the subtidal areas the oysters are dredged with special boats (see Marteil, 1979) (9). The yield is very high 10 tons by one hour but the daily yield is not more than 15 tons in relation with the access time and the umloading time. After the harvest oysters are was-hed with machines and sorted by weight category, by hand or mechanically. After, or the oysters will be prepared for the marked, or the cultivation will be finished by a phase of fattening. Fattening is developped particularly in the bay of Marennes-Oleron in old salt-marches which have been fit up since the seventeenth century in oysters pounds called "claires". In these earth ponds which have low deepth 0.40 m, the sea water comes in by gravity during the high tide but only during the spring tide period. In these "claires" there is a high level of phytoplancton productivity in relation with the inputs of high level of nutrients of the estuarine waters and with a low level of turbidity. But to obtain fattening, the densities of oysters must be under 10 oysters/m^2 which represent a biomass of 0.8 to 1 kg/m^2. As there is no change of water during the neap tide (10 days) the bloom of phytoplancton is very quickly grazed, if there is a too high biomass of molluscan. At a density of 20 oysters/m^2 there was no more fattening and a decrease indeed of the weight of the flesh (Zanette, 1981) (46).

In this claires a blooming of an phytoplancton algae Navicula ostrearia occurs. At the death of the cell, the green pigment diffused in the water (Robert, 1983) (47) and was absorbed by the gills of the oyster, giving them a special dark-green colour which is well delicated. The reason why this micro algae was blooming in this pound seemed to be in relation with the use by Navicula ostrearia as nitrogen source, of the organic nitrogen excreted by the oysters (Robert et al., 1982) (48).

E. Uses and processing

In European countries, oysters are sold fresh with their shells. They are very often eaten row with the necessity of fast supplies with a high level of quality particularly about the bacterial quality. Some cooked receipts are used in apple fritter or stuffed oyster but it is exception mainly in restaurants and this does not give possibilities to transformation industries to survive despite numerous trials. Nearly half of the production is sold during the christmas hollidays and for the feast at the beginning of the year. This constraint have to use mechanised structure to prepare the oyster crafts, in the largest firms, daily more than 2 000 crafts are prepared.

F. Constraints

Diseases, parasites

. Crassostrea angulata

From 1966 to 1969, the portuguese oysters were domaged by the "gill desease". The local lesions have been first attributed to a protist (Franc et Arvy, 1970) (49) The research on virus for the Molluscan bivalves were very recent its only in 1972 that Farley et al. (1972) (50) found for the first time a virus in Crassostrea virginica Also Comps et Duthoit (1976) (51) isolated viral particles in gill lesions. This cytoplasmic viral infestion caused a mortality of nearly 40 % of the portuguese oyster in France. The description of this virus permited to classify it in the group of Iridovirus.

For the second desease which affected the cupped oyster from 1970 to 1973, destroying the culture of portuguese oyster in Portugal, Spain, France and Great Britain, Comps et al. (1976) (52) demonstrated it was due to an another Iridovirus causing an viral hemocytic infections.

. Crassostrea gigas

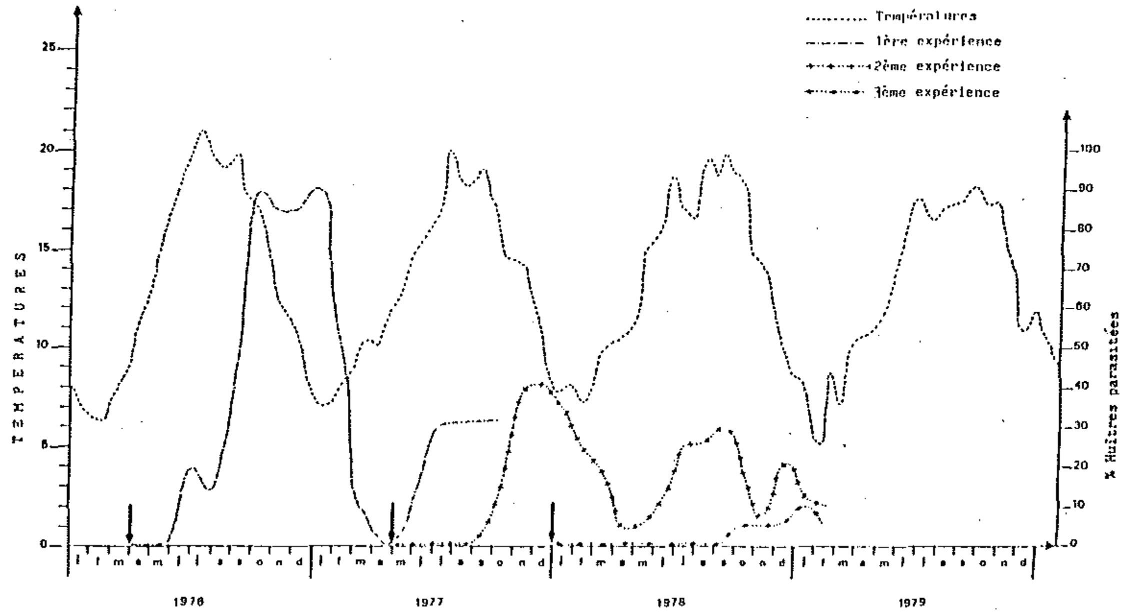
This introduced species resisted to the two iridovirus which destroyed the portuguese oyster, giving the demonstration of the specificity of the agent on the host. Meanwhile, during some summer mortalities in 1977 in the Arcachon Bay, the same virus that those of the angulata oyster have been determined on the japanese oyster (Comps et Bonami, 1977) (53), which showed that the resistance of gigas oyster to iridovirus remains perfectible.

The contamination by Mytilicola orientalis of Crassostrea gigas is recent. His (1977) (54) indicated that this copepod was present in the digestive tract of 10 to 40 % of the oysters varying with the season. It can proliferate in the instestine up to 40 individuals building an intestinal occlusion and domaging cellular wall of the digestive tube (His et al., 1978) (55). In the same way Deslous-Paoli (1981) (56) showed that an infections of more than three female caused an significant reduction of the concentration in glycogen and total carbohydrates of the total flesh.

. <u>Ostrea edulis</u>

The oldest epizootic which affected the flat oyster in France, Netherlands, England, Ireland occured from 1920 to 1927. None infectious agent have been described but Orton (1924) (57) related abnormals cellular figures which brought Grizel (1985) (58) to think it was due to an intracellular parasite.

The largest mortalities wich disorganize the production of the flat oyster in Europe began in 1968 in French Britanny. The desease spread progressively to different farming areas from 1973 to 1975 on the French Atlantic coast (Grizel et al., 1976) (59) except in the open sea water and after, with transportation of parasited French flat oysters in Spain and Netherlands. <u>Marteilia refringens</u>, is a protozoan considered to be related to the Paramyxea and not to the Haplosparidia (Despartes and Nashed, 1983) (60). This parasite and its cycle had been first describe by Combs (1972) (61) and confirmed by Grizel et al. (1974) (62) and Perkins (1976) (63). It is developping in digestive epithelium with an annual cycle. The infestation period of the oyster occured in summer time, when the temperature of water is above 17°C, but the development cycle of the parasite occurs when the temperature is above 12°C (fig. 10) (Grizel, 1985) (58). Franc (1980) (64) showed that the cycle of the parasite could have a sexual phase. The pathogenic action of <u>Marteilia</u> could be due to the desaggregation of epithelial cells of the digestive diverticulum.



<u>Figure 10</u> : Evolution of the occurence of <u>Marteilia refringens</u> in <u>Ostrea edulis</u> in relation with the temperature of the water. (from Grizel, 1985) (58).

This parasite have been found on the Mediterranean coast on Ostrea edulis in the lagoon of Thau and in Maroco (Nador), present also on Crassostrea gigas but only at young stages (Cahour, 1979) (65) on Mytilus edulis and Mytilus galloprovincialis where it can have a complete cycle (Tige et Rabouin, 1976) (66) Marteilia refringens is not associated whith mortalities for these species.

When the desease of Marteilia began to decrease, new abnormal mortalities affected flat oysters in 1979 due to a new protozoair, parasite of blood cells : Bonamia ostreae (Comps et al., 1980, (67) Pichot et al., 1980) (68).

It seemed to be the same parasites often colled "microcell" disease in relation with the size of the cells (2-3 u). The cycle of infestation is not yet elucidated. Contrary to the Marteilia, infestation can occur during the whole year.

This hemocytopathogenic parasite induced gills ulceration with perforations, indentations and hurts of the conjonctive tissue. This severe infection spred away in the different centers of North and South Brittany in France (Grizel and Tigé, 1982) (69). As a result of commercial transport activities, this disease touched the whole flat oyster culture areas in Europe. It is present in Danemark, Netherlands, (Von Banning, 1982) (70), England and Ireland but also in spain (Polanco et al., 1984) (71). Only the flat oysters of the Mediterranean coast are not contaminated, but if they are transported to the Atlantic coast they don't resist to the Bonamia. Every-where it is present it causes heavy mortalities of Ostrea edulis.

As the spat is very little contaminated by Bonamia and as the level of contaminations is function of the age, in Brittany as in Netherlands cultivation is possible at low density in open waters, with fast growth (2 or 3 years) after an eradication of all the old oysters beds. Despite these actions, Von Banning (1986) (72) precised that Bonamia ostreae has the ability to survive in very low density oyster stocks.

The lesson which can be retained with the severe deseases which appear during the last 20 years on oyster culture in European countries and mainly in France is that it is necessary to limit the transport of living population particularly of molluscan between the different countries and in the same country between the different bays. When, for economical reasons (lack of spat, importation of new races, with better growth and resistan to desease) an importation must be done, the risk to spreading diseases and parasites is very high. For these reasons international organisations have done some recommendations that national regulations have to applain (Ackefors, 1986) (73). For example ICES recommand that after having been submitted to an evaluation of the council an introduction needs mainly to keep the brood stock in a closed system or quarantine with sterilized effluents. Its only the progeny (F1 or F2) which can be introduced in the natural water. The ICES council recommended also procedures for current commercial pratice with quarantine bound to disinfection to confirm freedom from pests and diseases.

Predators, competitors :

The predators are not very numerous the main active can be the green crab Carcinus maenas which eat a large quantity of young spat on the collectors. The birds can be serious predations as ducks for mussels in Wadden sea, but for oysters the populations of "huitrier pies" oysters pius are not in large expansion. Some ten years ago, oyster men protected the oysters sawn on the buttom by erecting piece of iron to avoid to large flat fishes (teyre) to eat the oysters but this fishes became actually very rare. In open sea, the density of sea-stars are controlled by dredging to avoid the predation.

Competitors for molluscan can be very numerous particularly if we speak about the trophic competition, thought large populations of cockles, clams, mussels, consumming the same type of food could act on the growth of the oysters. The invasion of Crepidula fornicata imported in Europe from United States with the boats during the last second world war is the more active trophic competitor. Even if the energetic budget of this species (Deslous-Paoli and al., 1985 (74), Deslous-Paoli and Heral, 1986 (75)) showed that this species consummed 4 time less than the Japanese oyster, the very hight encontered biomasses oblige the oyster men to dredge and to destroy them.

The competition for space particularly on the collectors for the cultivated populations and on the rocks for the natural oyster beds is mainly between cirripeds and oysters post-larvae during the month before and after the settlement. During the other stages of the culture it is more mussels and again Crepidula which are fixed on the shells of the oysters. Sometimes they arrived to cover them forcing the oyster-men to clean the oysters and the breeding structure. Fouling is very abundant on the Mediterranean coast, with the cultural suspension techniques. The main active species of this fouling are the Ascidian with very actives metabolism (Fiala Medioni, 1974) (76). They are competitors both for the place on the substrate and about the nutritional point of view. The only remedy which is used is to put the breeding oyster structure out of the water to let them dry to kill them several days. The constraints exerced by predators and competitors are quite well mastered by the oysters men and are not a limit to the development of the culture as the diseases or pollution can be.

Pollution :

The sedentary character of bivalves make them very sensitive to natural or induced disturbances of the environment. Their filter feeder characteristics make shellfish very vulnerable to bacteriological and chemical pollution. As oysters are cultivated on the coast and particularly near estuaries, they are sensitive to the modification of the ecosystems by pollution. The areas of culture are the matter of conflicts between the different uses of water. The conflicts for the use and the quality of the inputs of fresh water will be perhaps the main problems in the future, in European countries, for the maintaining of the trophic level of the cultivated bays as the quantity and the quality of the estuarine water are changing in relation with the use of fertilizing and the development of irrigation. On the sea-shore, the conflicts for space between development of tourism and oyster culture is certain, tourism brings also directly problems of pollutions (bacterial quality of the water, products used by pleasure craft, and so on). Thus antifouling paints used on the sailing boats for destroying the fouling species which grow on the bottom careen, were build with copper oxyde, arsenic, mercury salts. Since the last ten years the Tributyltin (TBT) was used. His and Robert (1980) (77), Robert and His (1981) (78) showed that the toxicity of the paints was hight particularly for the larvae developement of the Japan oyster. Also this product at very low level stopped the growth of certain species of phytoplancton (Chaetoceros calcitrans, Isochrysis galbana) which can be used by oyster larvae food (His and Robert, 1981). (79) During the years 1977 to 1981 no settlement occured in the bay of Arcachon in relation with the development of the pleasure crafts. When the use of TBT have been regulate (1982) it induced again high level of spat cultch. More it have been shown that this product cause a malformation of the shell of the japanese oyster modifying calcification inducing growth in thickeness and inhibitions of the growth of the shell in lenght (Alzieu et al., 1981 (80) ; Héral et al., 1981 (81) ; Alzieu and Héral, 1983 (82) ; Waldock et Miller, 1983 (83)) (fig. 11). Subsequently the use of this type of paint was prohibited on boat less than 25 meters in 1982, in France and some years after in England, Germany... So this example shows that a product used for a concurrent activity can cause a severe disturbance of the production of oyster by acting on the larvae, on its food and on the growth of the shell (Heral et al., 1987) (84).

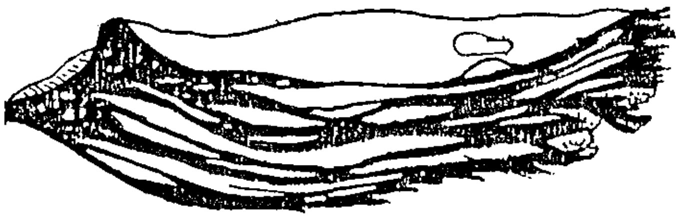


Figure 11 : Transverse section of the upper shell of *Crassostrea gigas* showing abnormal growth in thickening with inhibition in length causes by TBT (from Alzieu and Heral, 1983) (82).

Another main pollution which cost quite a lot of money for the flat oyster culture in Brittany was the stranding of tanker filled with oil near bays where cultivation of flat oysters were the main activity. The destruction of the oysters on the bottom by the agglomerate oil were due to the agglutinative effect of the treatements. The remaining of the oysters could not be sold become they have absorbed directly the dissolved hydrocarbon giving an horrible taste to the oysters, and could not been eaten for human consumption because of the toxic effect of these compounds. An economic approach of the evaluation of the consequences of the Amoco Cadiz stranding (Bounieux et al, 1980) (85) for oysters cultures has been estimated in 1980 to 114 millions of francs. It is important but largely less than the two deseases (Marteilia and Bonamia) which causes a loss of 1,6 billions of francs in turnover and 1,3 billions of francs of added value (Meuriot and Grizel, 1985) (86).

Other constraints

For these euryhaline species the freshets are note a large constraints only from the market point of view where it can be prejudicial, the taste of the oysters changing with the fresh water, causing a decrease in roles. The luck of seed until now has not been a problem for the oysters. When there is no pollution the recruitment remains high. Heral et al. (1986) (87) showed that for the Portuguese oyster only two years have been without settlement during the last century. But for Japanese oyster, 3 years without high settlement occured during the last fifteen years. It seemed to be due to the higher temperature requirements of these oysters and the needs of temperature above 18°C for the larvae evolution. If climate conditions remains cold, European countries could find hatcheries usefull to palliate to the deficiency of the natural settlement.

A new constraint is developing for European countries since the last ten years in relation with estival phytoplankton blooms producing toxines. Paralytic Shellfish Poisoning (PSP) is associated mainly with the species Gonyaulax tamarensis or excavata. It has been described in United Kingdom (Halligan, 1987) (88), Norway (Tangen, 1987) (89), Spain (Fraga et al., 1987) (90) and Portugal (Moila et al., 1987) (91). Diarrhetic Shellfish Poisoning (DSP) is in relation with Dinophysis acuminata and uncertainty with some other species of Dinophysis or of Prorocentrum (Parker, 1987) (92). DSP is present in France (Lassus et al., 1987) (93), in Netherlands (Kat, 1987)(94), in Ireland (Dunne et al., 1987)(95) and in Spain (Fraga, 1987)(96). Oysters are largely less sensitive to the toxines than mussels and clams. For these reasons monitoring based on mussel watch is followed in several countries. Examination of the phytoplankton species in the digestive trait and different bioassays with injection of the toxines extrait to rats or mice are practised. In some countries it is joined with a phytoplankton survey (France, Netherlands).

Phenomenous without toxic activity for human consumption of molluscan have occurred on Mediterranean coast causing high mortality in the cultures of molluscan due to anoxy environment. This happened in the Thau lagoon in 1975 and 1986, in conjonction with several phenomenous such as high temperature, no wind, stratification of the water and high density of organic matter, causing dystrophic crises with red water. A bacteria bloom of photosynthetic sulfide oxidizing produced the hydrogen sulfide in anaerobiosis (Caumette and Baleux, 1980)(97).

In the European countries the technical problems do not present a main constraints as lack of facilities, transportation too far from the markets, they are more economical problems bound to the demand and to the cost.

G. Management

In France the permits to harvest are giving by the public authority that leases the cultures grounds in the coastal areas to the farmers. The lease is for an duration variable with the differents countries. In France it is for a period of thirty years. The concession is transmessible to the same familial enterprise. The yearly cost is about 200 French Francs per hectare. The laws for exploitation of the grounds are fixed by the state for the type of culture, the nature of the installation, in some bays, the densities are fixed and the calendar of the exploitation during the year. The state and the local agencies entertain the bays by funding the dredging (mud, sand or parasites). Each oyster farmer is responsible of the entertain of his own grants.

The organisation of the sanitory and quality control is very differents and not yet unifed between the different european countries. Sanitary control of molluscan in France is based on the assumption that it is more effective to prevent contamination of the coast than to try to remedy its effect. In France it is the reason why the emphasis is placed on monitoring the water quality in cultivated zones. The coast line is classified into sanitary and unsanitary sectors based on criteria of number of fecal coliform in the oysters mussels or clams (fig. 12). In case where an area is classified as umsanitary, harvest is in general forbidden. It may be allowed in certain cases, but the molluscan production must be relayed in clean waters for at least one month or depurated by chlorine or ozone. In case where the water are of good bacterial quality before to be sold the cultivated molluscan must stay for 2-3 days before shipment in a "degorgeoir". It is a large insubmersible tank 50-100m^2 or larger where oysters or mussels stay in clean controlled sea water for self depuration (Coeurdacier, 1986) (98).

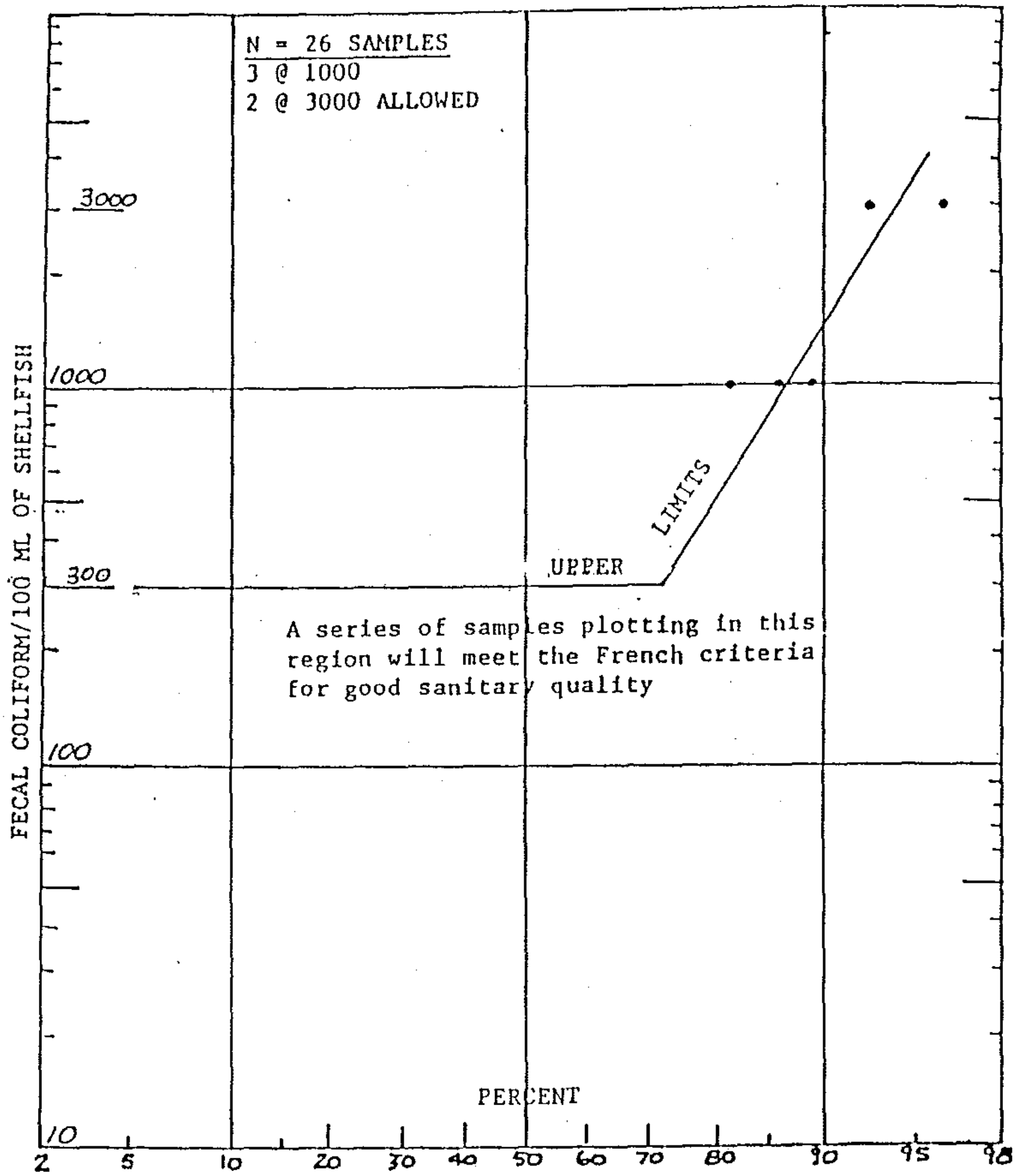


Figure 12 : Criteria for classifying a culture site as sanitary from U.S. Food and Drug Administration and Sanitary control of shellfish in France.

In Holland and England the sanitary regulation are based on the same recommendations than in France. At the contrary in Spain and Italy all the production of shellfish molluscan is treated in depuration stations where water is desinfected with chlorine or ozone. The shellfish can stay between 1 and 4 days in the depuration system in relation with the level of the contamination. The european countries followed the recommendations of the International Code of Practice for Molluscan Shellfish published in 1983 by FAO/OMS (99) for Environmental hygiene in growing areas, hygienic harvesting and transportation procedures. These hygienic regulation were based only on the bacterial quality. The sanitary laws of each country are evoluing quickly taking into account the quality of the waters : dinoflagellate and their toxins, level of chemical pollutants in the water : hydrocarbon, organic-halogenous substances, heavy metals, following the EEC instructions on the quality of molluscan shellfish waters. As for the water, the differents countries belonging to the European community, would have to unify their strategies for the sanitary quality of the products before 1992, data of the free circulation of the products between the different countries of EEC.

III. RESEARCH AND DEVELOPMENT

A. Biological and techniques

The success of filtering mollusc culture is due to :

- the possibility of settlement of natural spat,
- the use of a natural phytoplanctonic free food,
- the large adaptation of sedentary species to the variation of the environment,
- an old knowledge of the cultivation techniques.

But in spite of these opportunities and economical success, shellfish molluscan culture reveals problems as to remain to the same level of productivity for the countries where the cultures have reached a high level of production and as to develop the potentialities of culture for the other countries. Scientific research can resolve some of these problems particularly about :

- new techniques of culture specially in open sea,
- prevention and determination of epizootic diseases,
- determination of the carrying capacity of environment for cultivation of molluscans
- degradation of the quality of the cultivated waters,

- prediction of dinoflagellate blooms
- selection of species, by the genetic tools with resistance to desease or better performance of growth.

- Techniques of culture

For the development of mussel and oyster culture in open sea with roughly conditions of sea, theorical research are made by French physicians and specialists of resistance of materials to find the better subsurface long-lines which can resist to the storms (fig. 13).

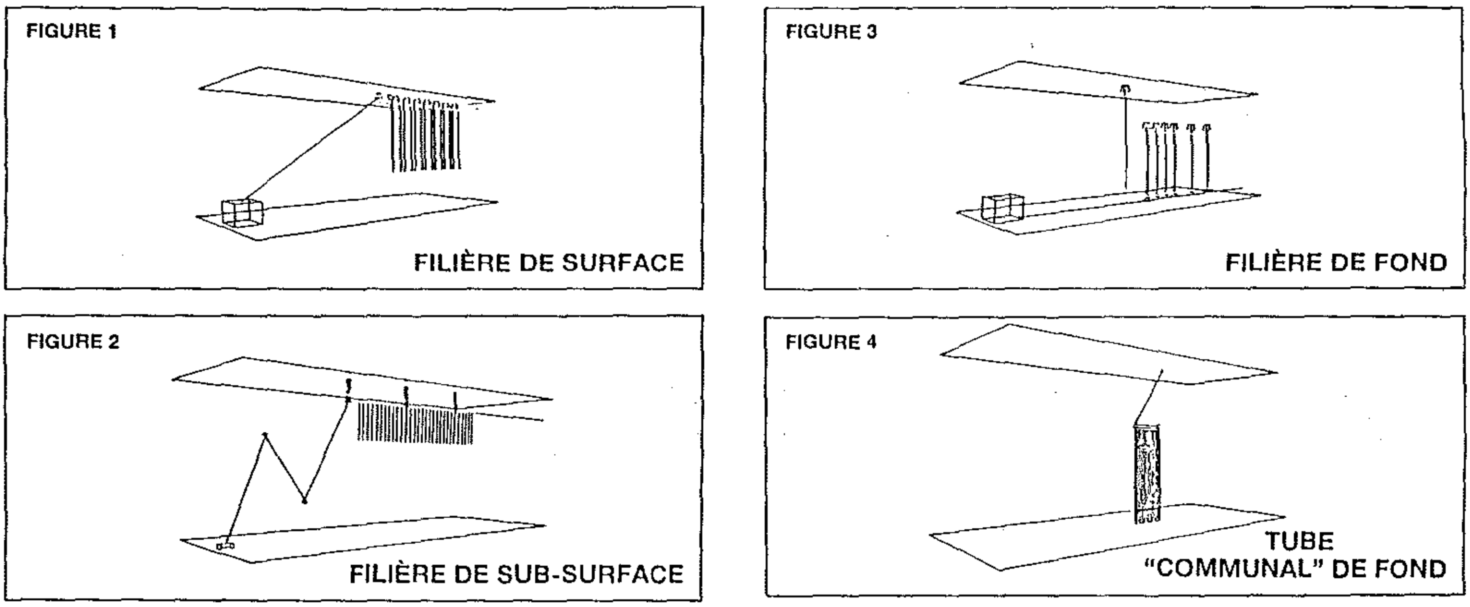


Figure 13 : Description of different long lines techniques (from Muller Feuga and Favre).

Sub marine structures on the bottom at a depth of 20 m are actually tested for the nursery of the young spat of Ostrea edulis wich has been settled on collectors fixed on long lines. Each year differents private companies are testing with the help of research organisms new materials for oyster-culture to obtain more efficient results. So differents new types of plastic collectors more easy to transport are used to obtain cultch less oysters. New vehicles for intertidal area are studied for fishing and transport oysters to increase the mechanisation of the cultures and decrease the cost price of the production (fig. 14).

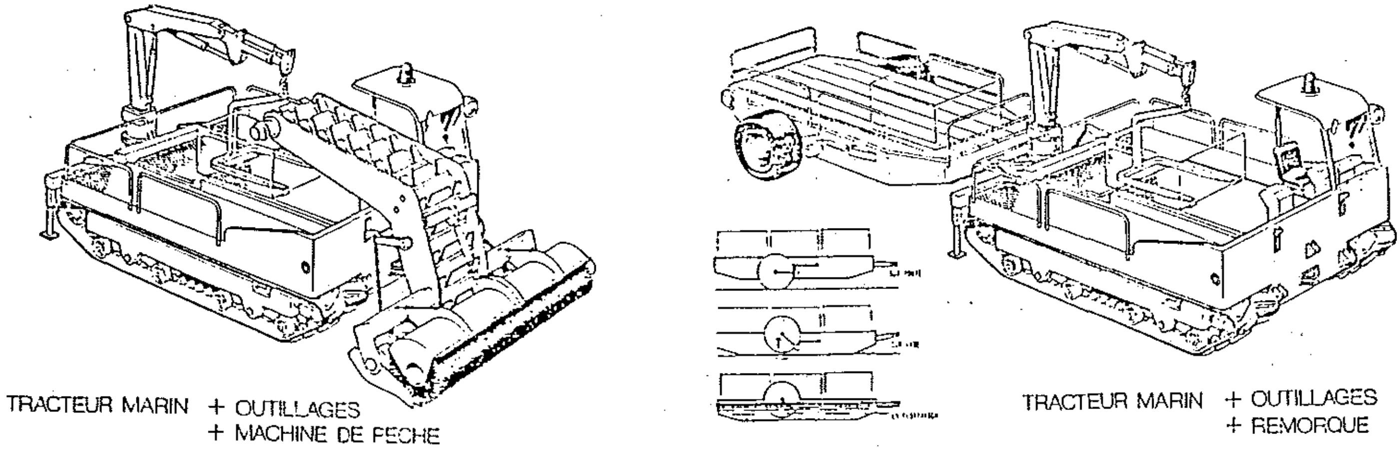


Figure 14 : New vehicles for cultivation of oysters and mussels (after Muller-Feuga and Favre).

Technical researchs are practised to optimize the final handling of shellfish (washing, grading, packaging) prior to shipment. Thus private firms and public researches on roboties are realised on the sorting of oysters by recognizing dead oysters by sound and on the shape by image analysis.

- Pathology

After the recent diseases on the Portuguese oysters and on the flat oyster, the differents European countries have strenghthened their regulations concerning clauses and conditions of molluscs importation. The quarantine as recommanded by ICES is applied even for products coming from hatcheries, it is only if the oysters are free diseases that they can be imported, particularly if producers need some spat.

To increase the control of parasited oysters, new diagnosis have been elaborated. The technics of monoclonal antibodies have been develop for the first time in mollusc pathology (Mialhe and al., 1987) (100). The first step has been to prepare purified parasites suspensions for immunnizing mice. The purification protocol has been achieved for Bonamia ostreae, parasite of the flat oyster O. edulis. The technology employed is described in the figure 15.

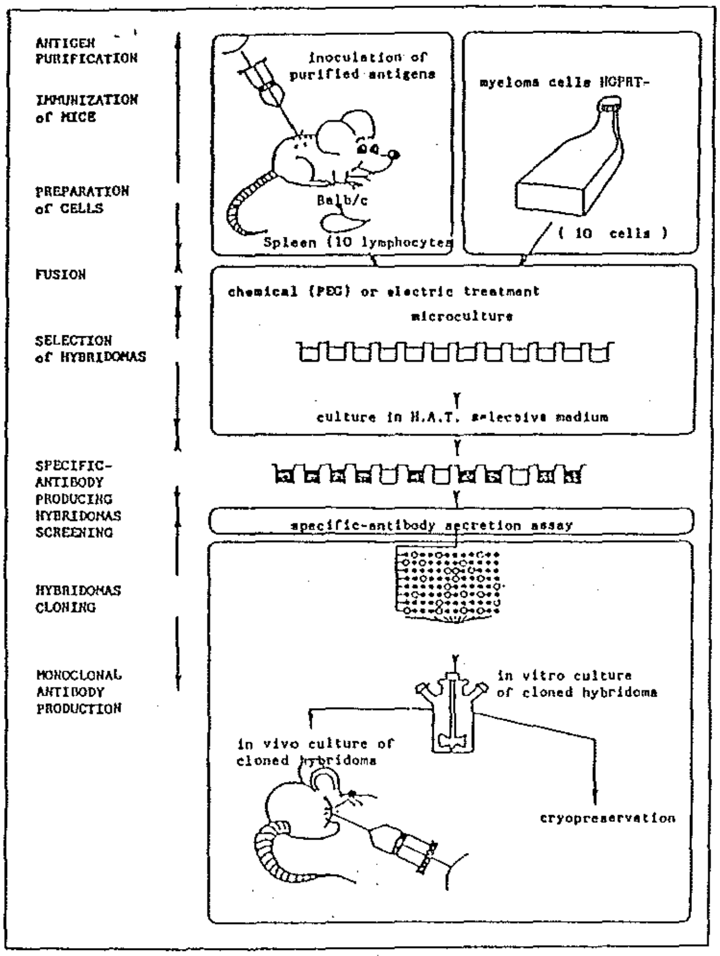


Figure 15 : General principle of hybridoma technology (from Mialhe, Paolucci, Rogier, Grizel, 1987)(100).

The application of these technics to Bonamia ostreae was described by Boulo et al. (1987) (101) and Rogier et al. (1987) (102). 700 hybridomas were obtained from a fusion between lymphocytes of a immunized mouse and myeloma cells. Eight hybridomas were selected for their Bonamia-specific antibody reactin. Two were retained to make Bonamia-diagnosis by indirect immunofluorescence. This new technics with the use of the commercialised ELISA test is largely less time-consuming than the traditional histological preparations, so the number of examinations will be larger for a better zoosanitary survey. For research, it permits precise determination of the rate of infection.

- Carrying capacity of environment for cultivation of molluscan

Two approachs are realised to estimate the carrying capacity of a bay. A global one based on dynamic and production of the cultivated species and an analytical one which husk the trophic relations. The first model take the hypothesis that the environment is constant or its fluctuation oscillate round the same mean.

The data which are necessary for the construction of a global model are :

- the growth rate of the cultivated oyster
- the survival rate,
- the estimation of the total cultivated biomass.

So, same sampling strategies have been developped to obtain these data. The more difficult is to estimate with good precision the reared stocks (Bacher et al., 1986) (103). The methodology included aerial photographs which covered the intertidal cultivated area and estimation of density obtained by sub sampling in the field. Aerial photographs all over the bay permitted to measure the areas effectively used for the molluscs culture. They are analysed either extensively for small bays or by a systematic sampling for larger areas with a precision of 3 %. Researches are going on with remote sensing (Deslous-Paoli et al., 1985) (104) and with numerical signal obtained with CCD video camera to optimize the cost and the performances. Estimations of local biomasses were obtained by a random subsampling in different strata, according to the modes of cultivation and the geographical areas. The stocks were computed as the product of biomass and cultivated surfaces. The total precision was nearly about 6 %. This approach is conducted since 1984 in the main large bay producing oysters along the French coast. It is only after having harvested precise data on stocks, growth performance and mortality rate during a long period, with a large spectrum of variation, that a precise dynamic model will be built. Nevertheless a model had been achieved with historical data (Héral et al., 1985 (105), 1986 (106)). The bay of Marennes-Oleron has been chosen because it is the main European basin for oyster production and it is presenting a large decrease of the growth performance. The evolution of the production of cupped oyster is estimated on the last century (1885-1985) with three different sources of data (fig. 16).

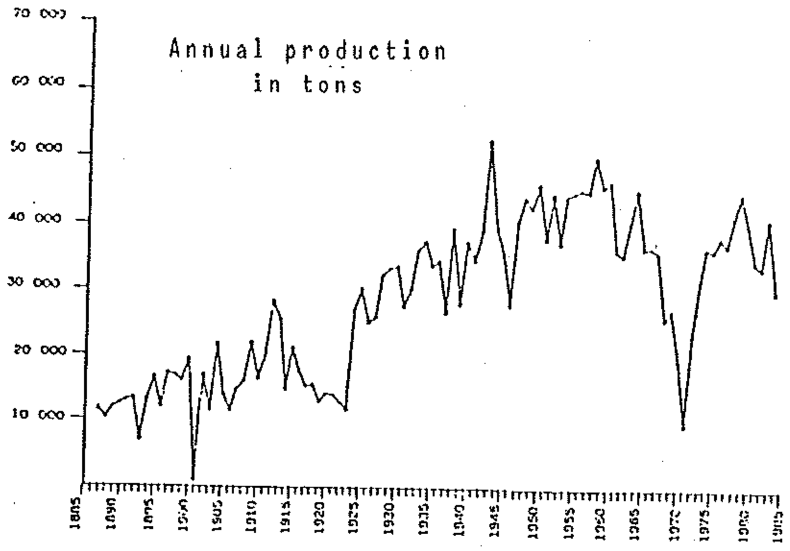


Figure 16 : Evolution of the annual production of adult oysters grown in the bay of Marennes-Oleron (from Héral, Deslous-Paoli, Prou, 1986)(106).

The growing rate and the mortality rate of the population of oysters presented an increase of the duration to obtain adults oysters while the survival rate is decreasing (fig. 17).

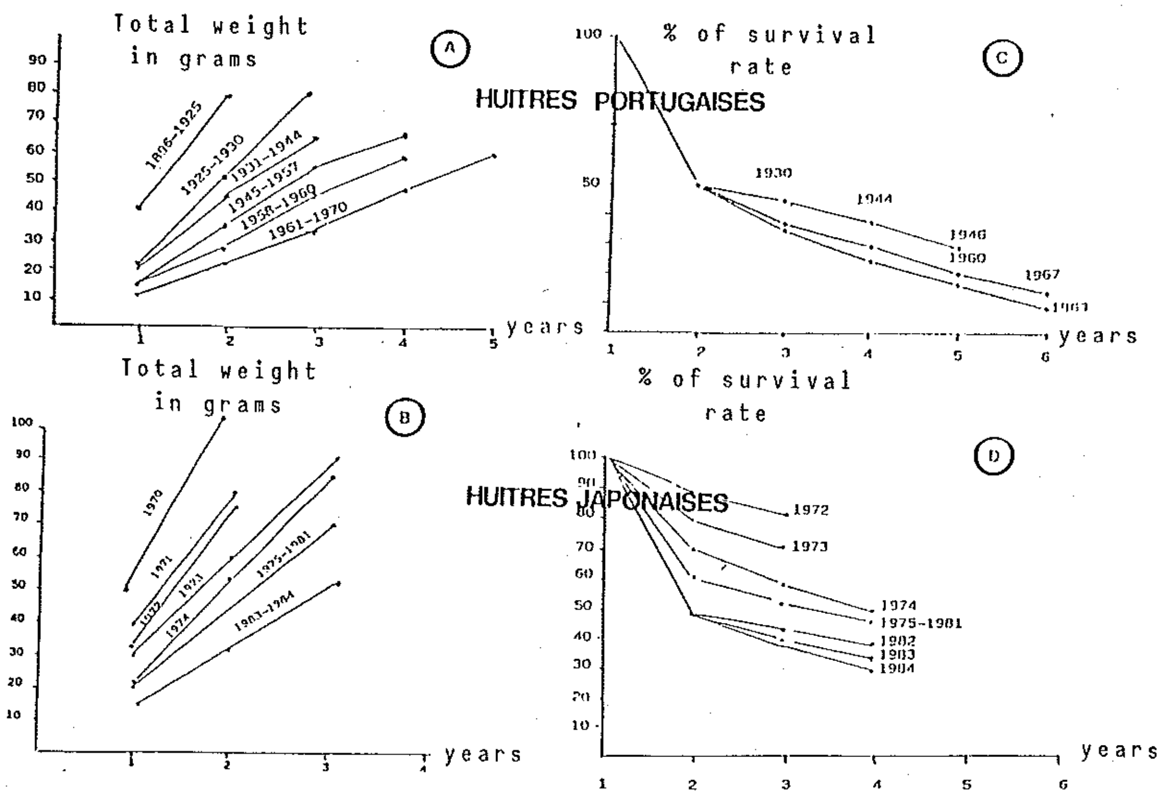


Figure 17 : Evolution of the time necessary to obtain adult oysters : (A) Portuguese oyster, (B) Japanese oyster. Survival rate after the first breeding year : (C) Portuguese oyster, (D) Japanese oyster (from Héral, Deslous-Paoli, Prou, 1986)(106).

The total biomass in culture is calculated from the annual productions and the yield of the culture : growth and mortality (fig. 18).

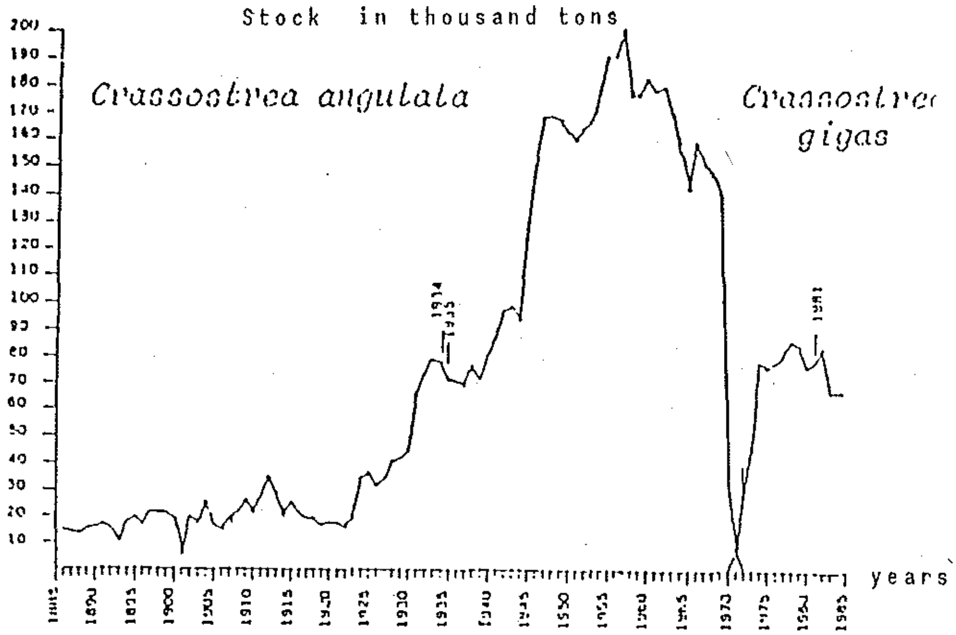


Figure 18 : Calculated evolution of the total biomass of cultivated oysters in the bay of Marennes-Oleron (from Héral, Deslous-Paoli, Prou, 1986)(106).

This simulation of the biomass gave results which are in the same order than those estimated by sampling for the three last year.

The relation between the stock function of the production showed clearly a maximum plateau of 40 000 tons. This limit corresponded to the maximum capacity of production of the ecosystem limited by the trophic capacities of the bay.

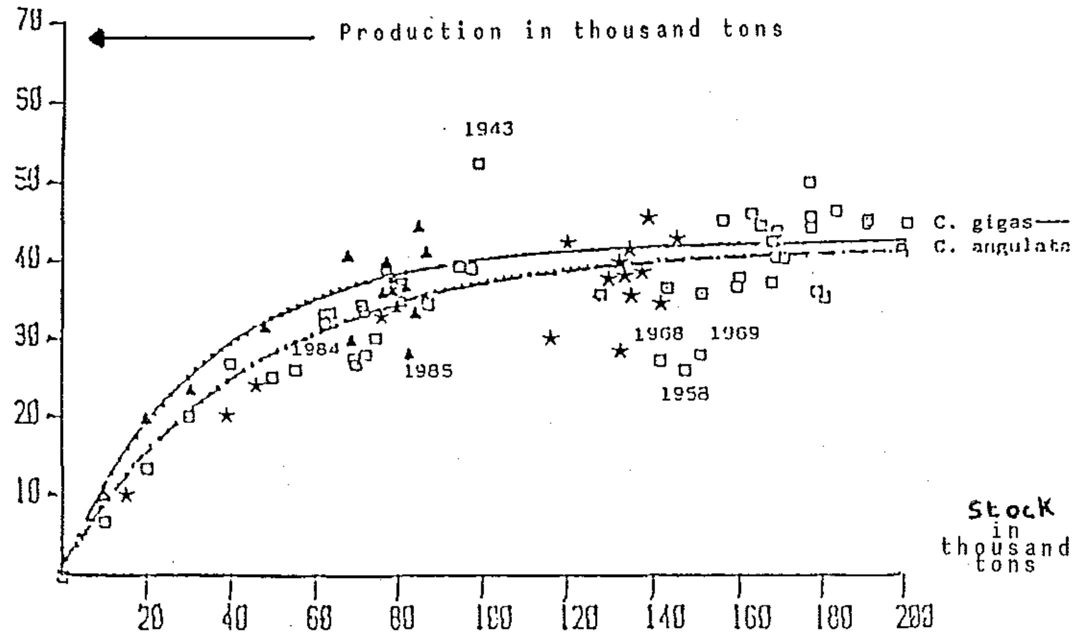


Figure 19 : Evolution of the annual production, function of the stock in culture for Crassostrea angulata (□), Crassostrea gigas (▲) and for Crassostrea gigas converted in equivalent Crassostrea angulata (★) (from Héral, Deslous-Paoli, Prou, 1986)(106).

The maximal production of the bay could be modelised by an equation of the same nature that the one used for the growth of the populations. So the equation Von Bertalanffy $P = P\ max\ (1 - e^{-KB})$ is well adjusted with the data, Pmax is the maximum production of the bay of Marennes-Oleron, B is the cultivated stock ; for Crassostrea angulata K = 0.026 and Pmax = 41 873 tons ; for Crassostrea gigas K = 0.028 and Pmax = 42 450 tons. The yield production on the stock (P/B) in relation with the stock followed a negative exponential curve as the evolution of the annual growth rate in relation with the stock (fig. 5).

The maximal production of 40 000 tons could be reached with a stock of Portuguese oyster of 130 000 tons but with a stock of Japanese oyster de 80 000 tons. This difference between the two species can be explained by the energetic demand of each oyster. For the same weight the assimilation of food by the Japanese oyster is 1,7 time more than the Portuguese oyster (Héral et al., 1986)(106). If the impact of these two oysters on the ecosystem was compared, it must be taken in count this transformation coefficient. This work showed that without management of the cultivated oysters, the stocks tended to exceed the minimal biomass which is necessary to reach the maximal potential of production. If a regulation of the stock is applied, it gives the following advantages to oyster farmers : decrease of the duration of the breeding cycle and decrease of the chronic mortalies, factors which brought better profits to the enterprises.

The analytical model is based on one side on the energetic demand of oyster populations and on the other side on the quantity of available food which is transported by the currents obtained with a numerical physical model.

A general equation of the energy budget of oyster populations has been established following the equation : $A = P + R = C - (F + U)$ avec A = assimilation, R = respiration, F = particular excretion (faeces and pseudofaeces), U = dissolve excretion, C = consumption, P = production with $P = Pg + Pr + Ps$, Pg = production of the flesh, Pr = production used for the reproduction, Ps = production of the secretions (shell, mucus). A study on oyster reef permitted to evaluate the different components of the energy budget of 1 and 2 year population. It appears that in the bay of Marennes-Oleron the faeces and pseudofaeces represented 70 % of the energy consumed (fig. 20) and the production of the flesh was 2.8 % for the one year old oyster and only 0.2 % for the two year old oyster (Heral and al., 1983 (107) ; Deslous-Paoli and Héral, 1984 (108)).

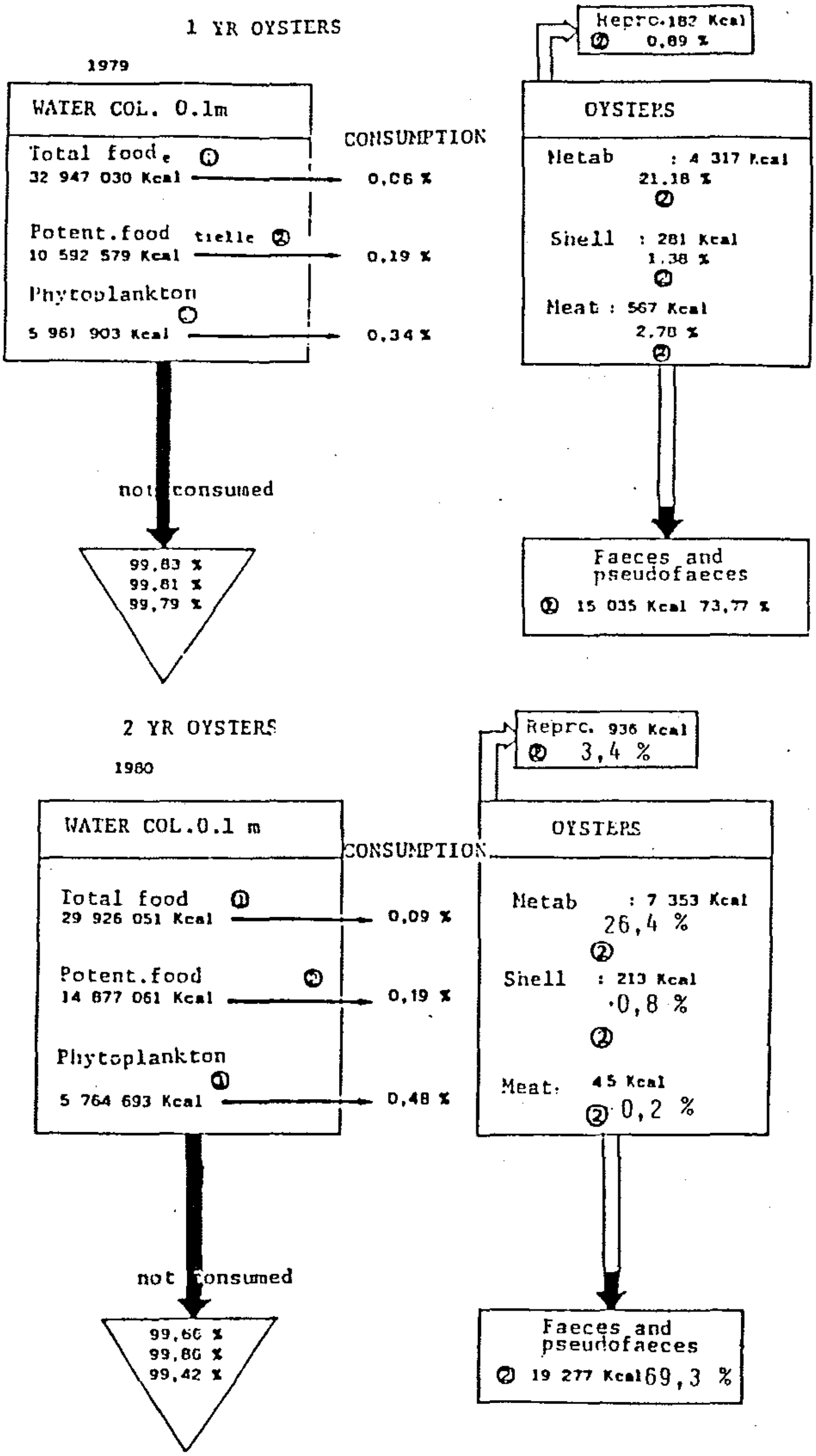


Figure 20 : Annual energy flow between a 0.1 m water column transiting at a current of 0.3 m/s and a population of grown oysters at a density of 200 individuals/m^2 (after Héral et al., 1983 (107) and Deslous-Paoli and Héral, 1984 (108)).

During the same period the available food is followed during tidal cycle each month for a neap tide and a spring tide. These data permitted to build an individual growth model taking into account the relations between respiration assimilation and the oyster weight, the temperature the seston and the particular available food (protid, lipid, glucid) (fig. 21).

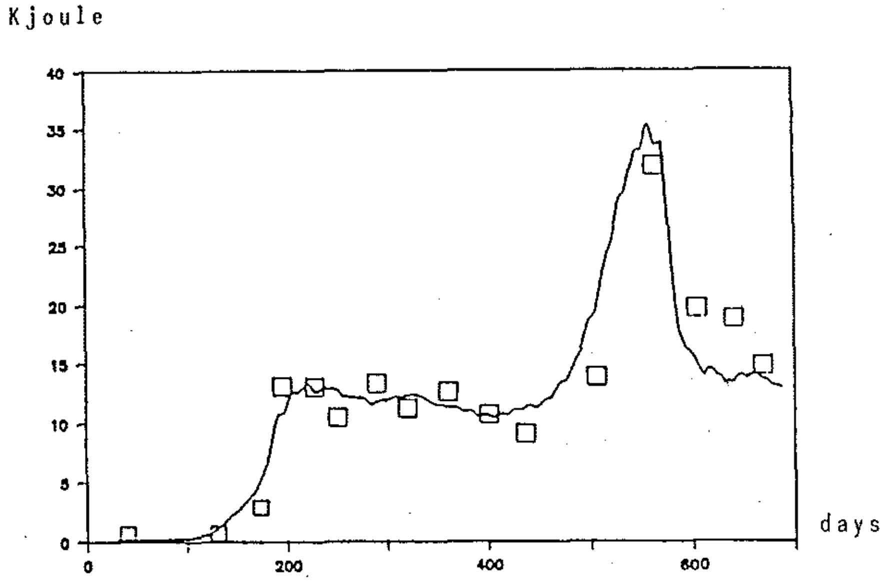


Figure 21 : Simulation of the individual growth of oysters in the Marennes-Oleron Bay expressed in K joule function of the assimilation and respiration, (□) observed data from Bacher (1987) (109).

To calculate the level of the available food in the whole bay an advection-dispersion model is used. As time and spatial scales have to be consistent with the chosen biological scale (one day), a box structure is applied to the oyster production area. The residual lagrangienne currents are calculated. The dispersion is a function of the transport and of the difference of concentration between adjacent boxes (Bacher, 1987) (109). The food is actually a driving variable and is injected at the 3 limits of the box model as the salinity with time series on 5 years averaged to smoothe the variability. The transport model is validated by the use of predicted salinity and observed salinity data in the middle of the bay (fig. 22).

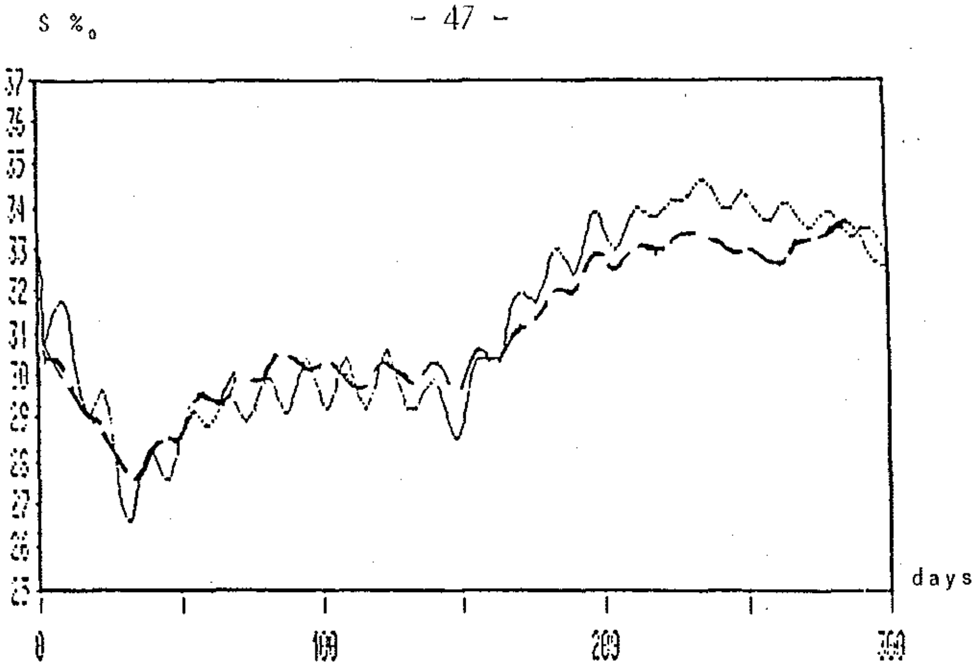
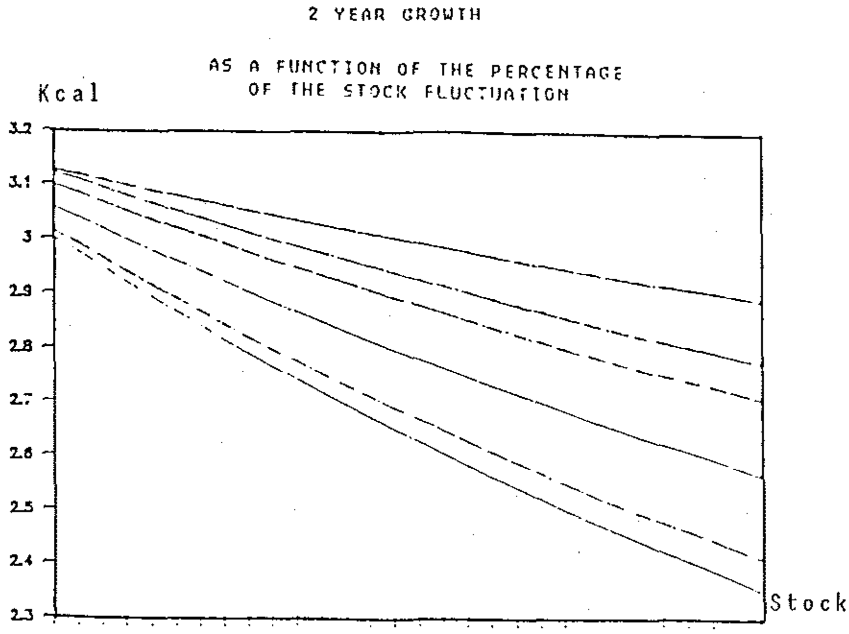


Figure 22 : Observated salinity (---) and simulated salinity (–) calculated by the advection-dispersion model in the middle of the bay (from Bacher, 1987) (109).

The ecosystem model is build with the stock of oysters in each box with two ages and the growth model function of the food which is transported by the physical model. The trophic molluscan shellfish competitors and their assimilation of food are introduced in each box as driving variables. This approach could permit to make fluctuation of the cultivated stocks of oysters and to do some previsions about the growth rate in the different areas.



Fugure 23 : Effect of the fluctuation (- 60 % + 60 %) of the stock of cultivated oyster on the individual growth rates of the oyster C. gigas in different areas of the Marennes-Oleron Bay, from Bacher, 1987 (109).

This model used, up to day too many simplying hypothesis, but it shows the way of research we need for having a tool very usefull for management. It demonstrates that a multidisciplinary approach between biologists, physicians, sedimentologists could success to obtain a predictive evolution of the growth rate of the cultivated species function of the food but also of all the factors and particularly pollutions which can largely modify the quality and the quantity of the trophic requirements.

It is evident that to be predictive it is necessary to go farther in the study of the energetic demand of the oysters for particular and dissolved substances. In an another way, a phytoplanctonic model which allows to stimulate the variations of the input of nutrients from the estuary will be helpfull for the study of the consequences of the use of freshwater on oyster production.

B. Future development

A new step can be achieved in oyster culture with the development of genetic manipulations. Recent obtention of triploids or tetraploids for Japanese oyster opened a new way. As in summer time, these oysters are loosing more than the half of their dried body weight for reproduction, it could be interested to produce sterile oysters which devote less effort in the reproduction. These chromasomal manipulations can be realised by thermal shocks (Guillet and Panelay, 1986) (110), by hydrostatic pressure or with cytochalasin B (Downing and Allen, 1987) (111). It can be estimated that the gained energy on the reproduction can be used in the somatic growth giving an answer to the decrease of the growth observed in the European closed bays. Selection of oysters would permit a large development for the hatcheries and would be a mean of regulation to avoid overstocking mainly due to the natural settlement which is too numerous in relation with the density of collectors.

Another new sector of research which is promiser for the oyster industry in European countries is the bio-economic analysis of molluscan shellfish. Coupling models of dynamics of production with marketing systems could demonstrate the differents scenarios that oyster farms can choose for their individuals development but also the interest of a group strategy which can be difficult to reconcile with the individual one.Gilly and Meuriot (1985)(112) precised that "it is essential to involve disciplines such as sociology or political science in the study of the crucial elements affecting the dynamics of the shellfish sector of the economy, e.g. :

- knowledge of the choices and strategies available to operators, either as individuals or groups
- decision-making processes leading to arbitration of conflicts on use of space and the environment, the role and conditions of using scientific information in these decision-making processes.

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DECREASE OF THE OYSTER PRODUCTION IN THE MARYLAND PORTION OF THE CHESAPEAKE BAY : CAUSES AND PERSPECTIVES.

This article will be published in ICES and proposed to "Aquatic Living Ressources" after revisions it will be signed by Maurice Heral, Brian J. Rothschild and Philippe Goulletquer.

INTRODUCTION

The American oyster (*Crassostrea virginica*) fishery has historically been the most valuable in the Chesapeake Bay. At the turn of the century Maryland landed more oysters than anywhere in the world. From that time, this fishery has been followed and studied by biologists (Ferguson et al. 1880, Ingersoll 1881, Yates 1913). From the beginning of this century until the present, landings have declined steadily and the industry was pushed more and more in crisis situations.

The Chesapeake Biological Laboratory (CBL), University of Maryland was built in 1925 with the objective to study the cause of the decline of the production of oysters (Truitt 1921, 1927, 1931). Research workers studied successively the removal of cultch, the size limits of adult oyster available to be captured, the period of fisheries, to try to restrict the overfishing. They defined sampling techniques for the systematic annual record of the oyster bars. Krantz and Merritt (1977) stated that the personnel of the Chesapeake Biological Laboratory achieved the surveys until the late 1950's (Beaven 1955). Since this date, the annual records have been registered by the state management agency: Department of Natural Resources (DNR). Intensive works of research have been done but only on one aspect of oyster biology or ecology of fishery. Bibliography is very important to try to understand the historical evolution and the main tendencies. Not many synthesis works about American oyster and oyster in Chesapeake Bay have been published. Korringa (1952) and Galstoff (1964) described mainly the biology of the *Crassostrea virginica*. For the Virginia part of the bay Haven et al. (1978) studied the status and the problems of the oyster industry. For the Maryland part, the only synthesis work on oysters has been achieved by Kennedy and Breisch (1983) including the biology, the main diseases of oyster populations and management of the Maryland's oyster industry as well as an historical background. There is no specific analysis of the different causes which induced the decline of the production. They are generally described in very short assumptions like overfishing, predation, water quality, sediment modifications or consequences of disease.

Contributing further to the uncertainty, managements attempts to protect the resource and to reverse the substantial decline have obviously been unsuccessful. In this paper, our aim is to analyze the historical tendencies of the

Table 1 : Main Characteristics of Chesapeake Bay.

Main Bay		
	Length:	322 Km
	Greatest depth:	53 m
	Average depth:	7.6 m
	Surface:	569,800 ha
	Volume:	68.109m3
	Total shoreline:	7401 km
	Tidal range:	0.9 m at mouth 0.3 m at Annapolis
	Salinity surface:	30% at mouth 15% at Annapolis
Watershed		
	Main tributaries	8 (Susquehanna, Potomac, and Jame contribute 80% of freshwater flow)
	Total tributaries	419
	Area of watershed	16,576,000 ha
	Population of watershed	13 million in 1980

production of oysters in Maryland Chesapeake Bay, in relation with the over–fishing, the use of the different gears, and their impact on the destruction of the physical characteristics of an oyster bar.

Otherwise the State of Maryland has an oyster repletion program in place for 1960. The program involves shell planting and seed shell transplanting components. The techniques and the date of shell planting are analyzed in relation with the physical and biological characteristics of the Chesapeake Bay.

In conclusion, this paper proposed new ways of research to optimize the management of the oyster Maryland production despite the abundance of the disease.

I. RECONSTITUTION OF THE HISTORICAL LANDINGS OF OYSTER

For the Virginia part of the Chesapeake Bay, productions are coming from the very exhaustive paper from Hargis and Haven (1988) who detailed how they rebuilt data for Virginia. For the Maryland part of the Chesapeake Bay oyster harvests from 1820 to 1917 are coming from Grave (1912) and Yates (1913). Ingersoll (1881) and Stevenson (1894) gave the detail of these statistics based upon the production of the different Maryland packing houses, the exportation of oysters shipped North mainly for planting in Delaware Bay, and Providence River and for immediate consumption in New York and Delaware Bay. These data are compared with an estimation of the number of boats licensed or not and their yield. The data after 1912 are coming from different reports from CBL library, from the Maryland Department of Natural Resources and from the Fisheries Statistics Branch of National Marine Fisheries Service. Krantz and Haven(1982), Stagg (1985) have however demonstrated that the present landings are under reported.

For comparisons with other American regions, the conversions have been obtained with the following data. A US standard bushel is 2 150.4 cubic inches. A Maryland bushel is 2 800.9 cubic inches and a Virginia bushel is 3 200.1 cubic inches. To convert Maryland results in U.S. bushels we multiply by 1.3 and for the Virginia bushels by 1.49. In the fisheries statistics, it is indicated that for a US bushel the numbers of wet weight of flesh of oysters vary with the seasons and the size of an oyster from 5.10 to 5.95 US pounds. A mean of 5.5 is retained.

Results in pounds (452 g) are converted in Kg by dividing by 2.2 and after expressed in metric tons.

With this calculation a Maryland bushel contains 3.25 Kg wet weight of oyster tissue and Virginia bushel 4.10 Kg wet weight and a US standard 2.5 Kg wet weight of oyster tissue. These results can be compared with some found or recalculated in the literature (Table 2).

Table 2 : Estimation of the weight in bushel in the literature

Unit	Wet Weight in Kg of Oyster Tissue	Authors
US Standard Bushel	2.2	MacKenzie, 1983
Maryland Bushel	3.64	Truit, 1945
Maryland Bushel	2.64	Haven et al., 1978
Virginia Bushel	3.18	Haven et al., 1978

Our data are in a good agreement with MacKenzie and Truit results but Haven et al. conversion rates are nearly 20% down.

To compare the different US productions with the production of other countries it is necessary to use the same international unit. The one that has been chosen following the FAO recommendation is the total weight of the oyster. By comparing the US statistics in pound of wet weight flesh and the FAO statistics in metric tons of total weight over the last 10 years the percentage of the wet weight is moving from 7.4% to 8%. Our data obtained in the field of the Patuxent River showed that, for market size oysters this percentage varies from 5 to 9% in relation with the physiological condition of the oysters. If we retain the percentage of 8%, a US standard bushel corresponds nearly to 31 Kg, a Maryland bushel to 41 Kg, and a Virginia bushel to 51 Kg of total weight. DNR reports indicate that a Maryland bushel contains nearly 350 oysters, as the weight of market size oysters of 3 inches is nearly 120 g - 130 g, it gives a result for a bushel between 42 Kg to 45 Kg which is very close with the data obtained by our conversions.

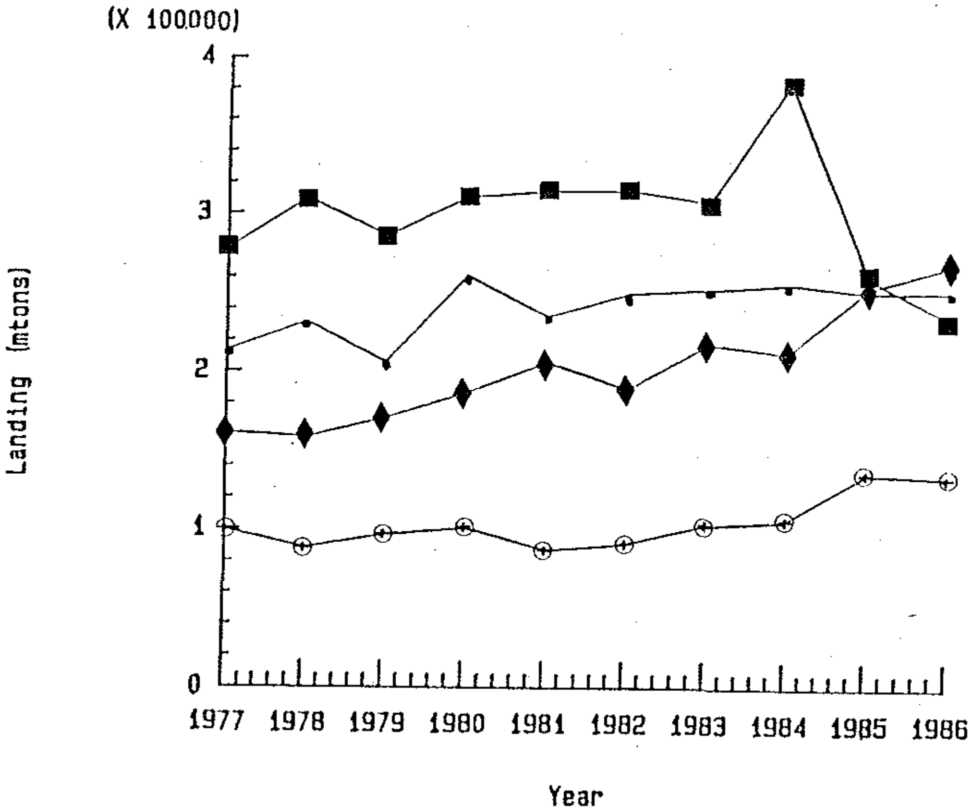


Figure 1 : Evolution of the production of oysters for USA (■), Japan (•), Korea (♦) and France (⊕) expressed in hundred thousand tons of total weight.

Table 3: Principal conversion rates for different jurisdiction standards.

Units	Volume in liters	Wet Weight in Kg of Oyster Tissue	Total Weight of Oyster in Kg
US Standard Bushel	35.2	2.50	31
Maryland Bushel	45.9	3.25	41
Virginia Bushel	52.4	4.10	51

II. EVOLUTION OF THE WORLD PRODUCTION OF OYSTERS

Over the last ten years the total production of oysters in the world (aquaculture and fisheries) has increased by 20% from 859,682 tons in 1977 to 1,011,079 tons in 1986. It is due to the fact that the production has increased in Korea by 68%, in France by 57%, and in Japan by 25%, but US have decreased by 25% since 1982.

The US landings of oyster were the first until 1986 before successively Japan, Republic of Korea and France. Since 1986 it is Korea which has been the first for the world production of oysters (Fig. 1).

It can be observed that the three countries (Japan, Korea, France) which practice aquaculture of oysters are increasing their production contrary to the US which went in for mainly fishing of oysters. It is interesting to note that these four countries produced nearly 87% of the total world landings.

III. EVALUATION OF THE UNITED STATES PRODUCTION

From the US landings it appears that the production of the Japanese oyster (*Crassostrea gigas*) on the west coast is stable with a mean production of 22,000 tons and represents 8 to 10% of the total production of oysters despite some diseases caused by a Bonamia-like protozoair. On the east coast the production of the gulf (Florida, Texas and mainlyLouisiana) is moving from 120,000 tons to 210,000 tons with a maximum in 1983, and a mean of 156,000 tons (fig. 2). The

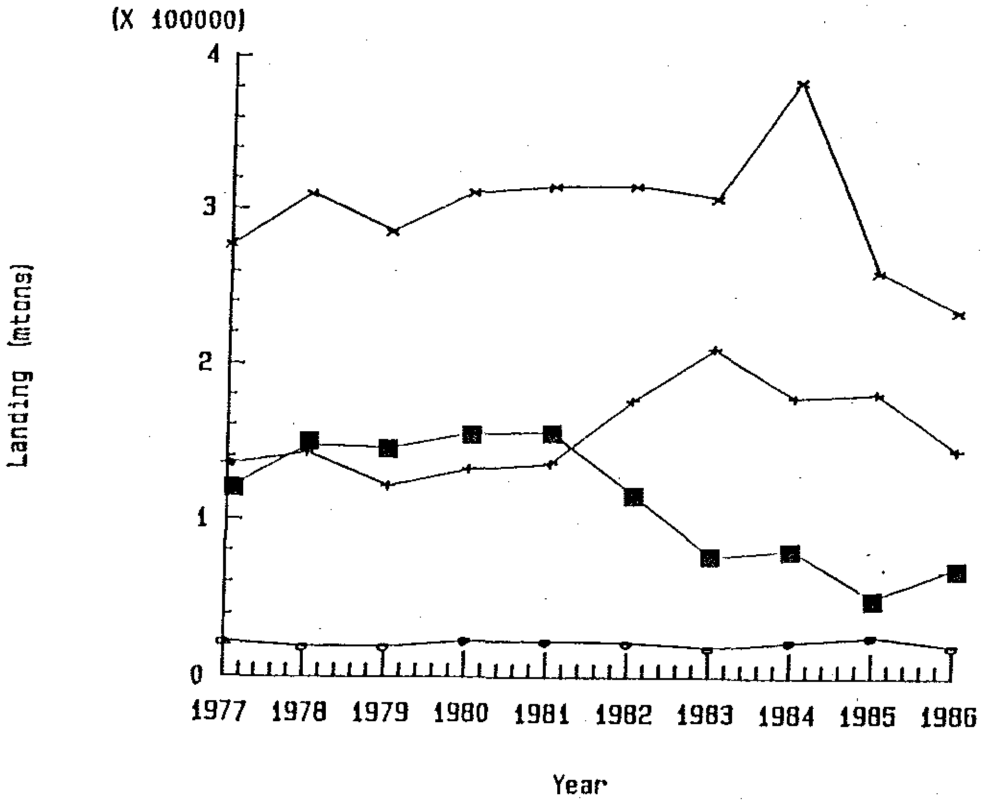


Figure 2 : Evolution of the US production of oysters (×), gulf (+), east coast (■) and west coast (□) expressed in hundred thousand tons of total weight.

gulf production which had represented mainly 45% of the US production of oysters until 1981 now represents 60 to 65% of the production. The previous Texas production of 3% reached 12% and the Louisiana production rose from 13% to 30% making it the leading state in oyster production.The causes of the variations of the Louisiana oyster industry are mainly the reflection of adverse environmental factors : hurricanes and dredging. On the contrary the good salinity conditions which occurred during the last years gave highly successful oyster sets on shells, reseeded by the Department of Wildlife and Fisheries (Keithly and Roberts 1988, Dugas 1988).

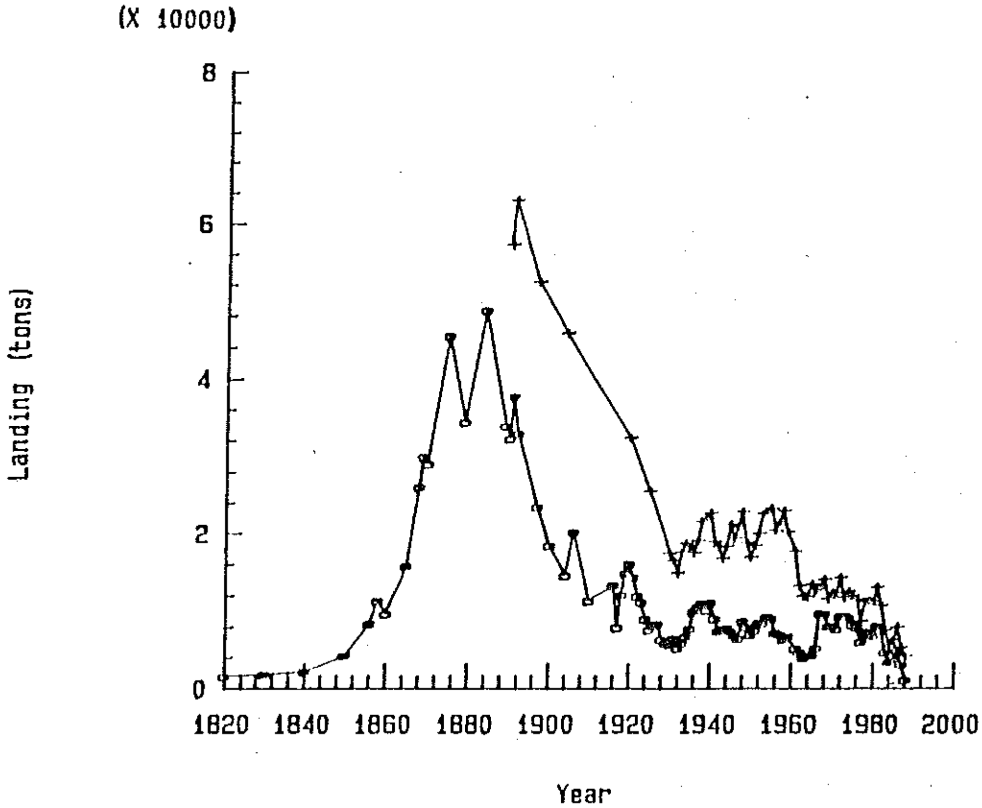
The east coast production which contains mainly the production of the Chesapeake Bay and Delaware Bay but also Narragansett Bay and Long Island Sound is declining from 155,994 tons in 1981 to 50, 442 tons in 1985 which represent only 19% of the total US landings whereas these regions were producing 40 to 50% of the total production until 1981. The large decreasing of the production of the north east coast is the cause of the decline of the US landings.

IV. CHESAPEAKE BAY LANDINGS

The Chesapeake Bay production which is obtained with the Virginia and Maryland data demonstrated the tremendous decline of the oyster landings (Fig. 3). The analysis of the oyster industry in Virginia had been well studied for the last decade (for a review see Haven et al., 1978, and Hargis and Haven, 1988).

The Maryland oyster fishery was the first in the world at the end of the last century with 990 public oyster bars spread over 116,000 ha. (Yates 1913). The private use of the bottom is not developed in this state with actually only 3600 ha of oyster ground which represent 3% of the oyster bottom, (Jensens, 1981) (fig.4). On the contrary, large surfaces of oyster beds are leased in Virginia for private use (50,000 ha private and 97,200 ha public) (Haven and Whitcomb, 1986).

The analysis of the Maryland oyster landings demonstrate that this fishery has undergone 3 levels of production (Fig. 5).



<u>Figure 3</u> : Evolution of the oyster production, in wet weight of flesh, Maryland part of the bay (□), Chesapeake bay (+),expressed in ten thousand tons of fresh flesh weight.

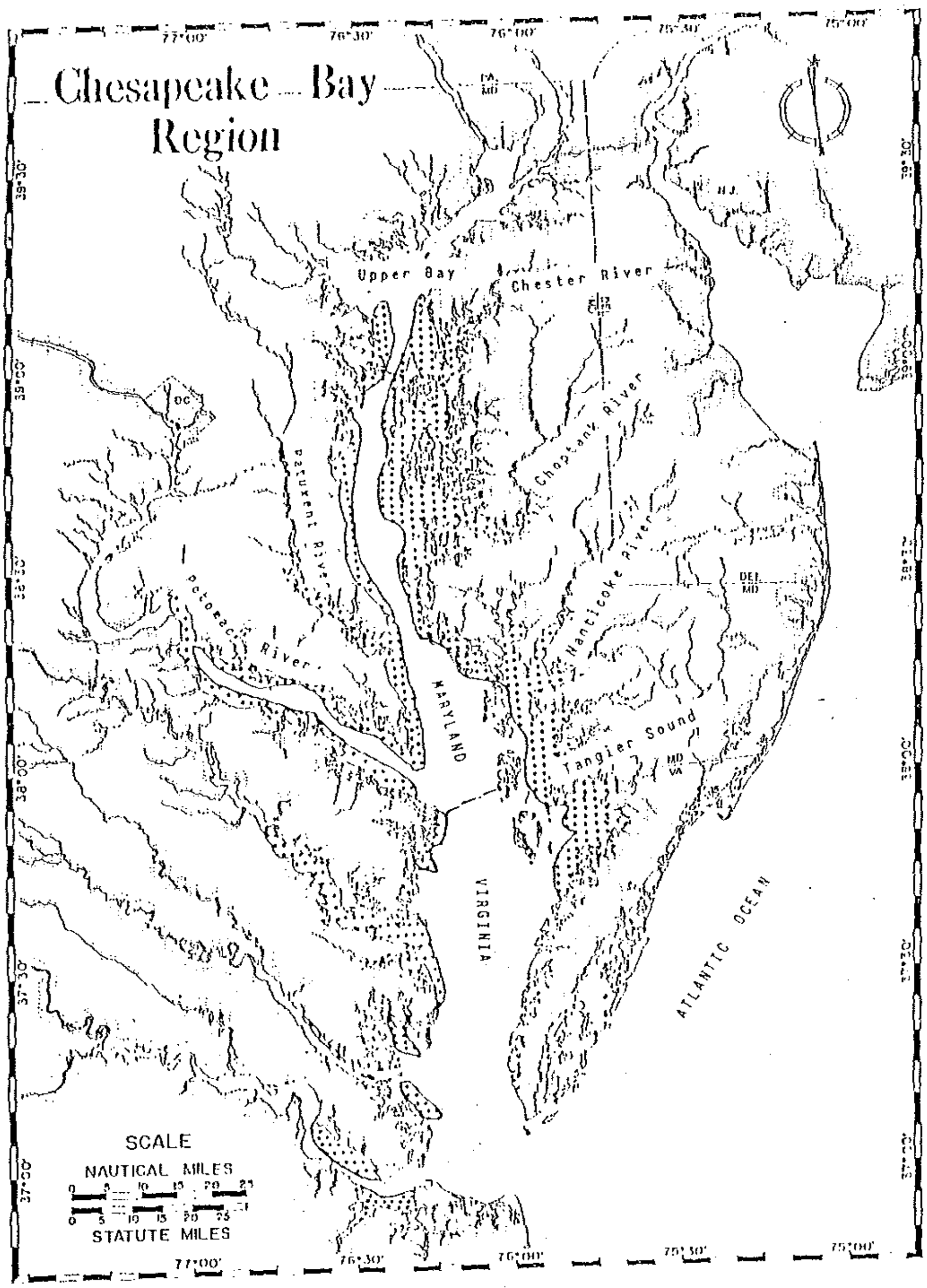


Figure 4 : Localisation of the main public oyster bars (::::::) in the Chesapeake bay.

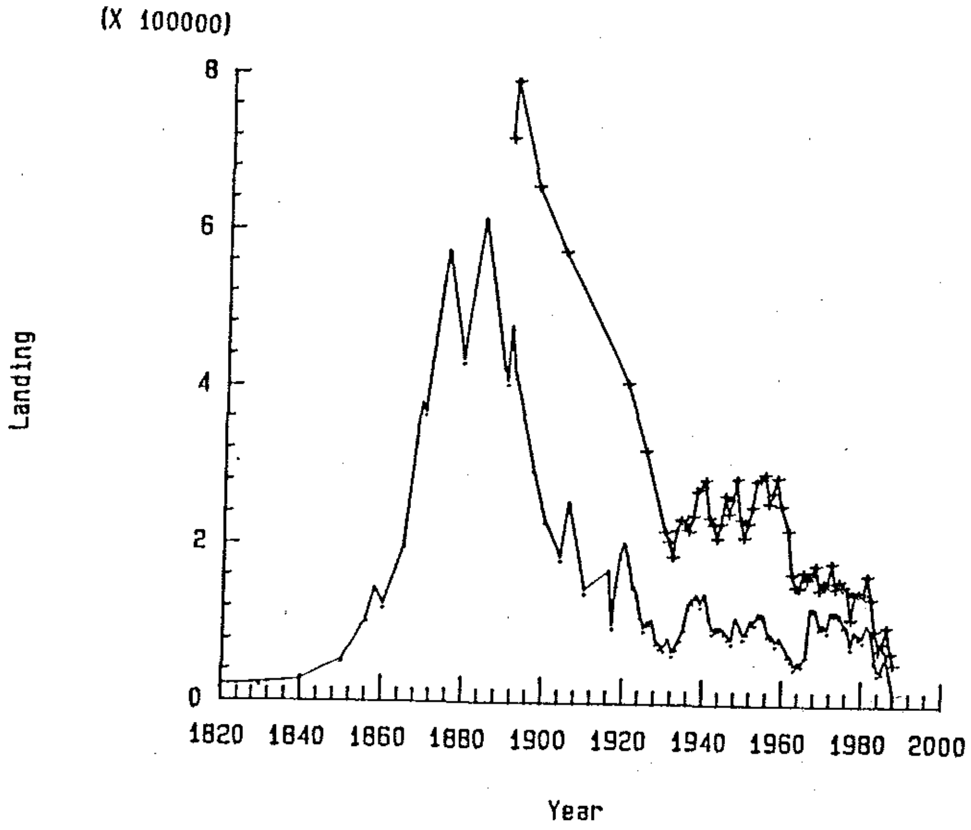


Figure 5 : Evolution of the oyster production, in total weight, Maryland part of the bay (•), Chesapeake Bay (+), expressed in hundred thousand tons of total weight.

Level 1 : From 1840 to 1890--The Greatest Fishery

Oysters have been always eaten by Indians (see the large quantities of oyster shells near their camp). The early Maryland settlers gathered oysters which were very abundant. As the population, the trade, the thoroughfare (boats, roads, railways) were largely increasing at the end of the nineteenth century, the oyster demand went on boosting. The picking turned into a very active fishery with new gears to fish the underwater populations of oysters with hand tongs and dredges. Kennedy and Breisch (1983) indicated that the number of processing establishments in the Baltimore area increased from one in 1834 to 80 in 1868. In 1879, Ingersoll (1881) perceived that they reached the number of 98 with a packing production of 314,000 tons of total weight. The maximum landing of this period was 615,000 tons in total weight in 1884. The annual production stayed above 400,000 tons in total weight during 20 years from 1872 to 1893. Like Christy (1964) and Kennedy and Breish (1983) after an examination of the old records, it can be concluded that the early harvests were probably not greatly over estimated and could give realistic idea of the level of the production which has been supported by the bay and the tributaries. If we compare the number of boats fishing oysters in 1865 with an annual production of 200,000 tons, and in 1879 with an annual production of 434,000 tons, they were respectively 2555 and 3275 with a total crew of 13,748 (Ingersoll 1881). The number of boats increased by 28% to double the production. This shows that the efficiency of the boats increased by two main means :

-extension of the fisheries by discovering of new bars. For example, the large reefs in Tangier Sound were discovered in the years 1840 (Kennedy and Breisch 1983)

-increase of the efficiency of the gears. After 1865 large dredges became legal, which offer the possibilities to fish deeper than 7 meters, depth which could not be reached by the hand tongs. Patent tongs first came on the market in 1887 (Fig. 6) and also permitted to fish everywhere.

The consequences of these large increase of the annual landings have been the large destruction of the most productive beds. Like in England and in France

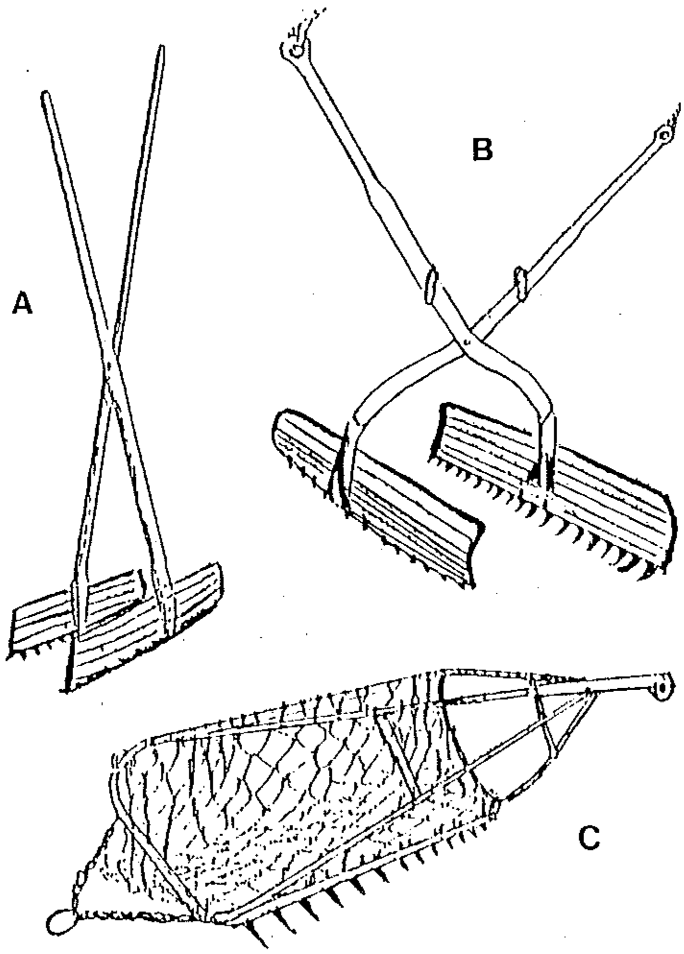


Figure 6 : Gears for catching oysters in the Chesapeake Bay : (A) hand tongs, (B) patent tongs, (C) dredge.

(Roche, 1887 ; Héral, 1989), despite regulations on the harvest season, on the type of boat and as soon as 1868 a license system for the oyster boats, the fishing pressure remained intensive.

By dividing the maximum landing (615,000 tons in 1889) by the total surface of the oyster bars described at this period (111,600 ha), with an individual weight of oyster of 150 g, the mean density of the capture is obtained. It is nearly 3.7 oyster for a square meter. This data can be compared with the survey of Winslow (1884) which found that the mean density of the oyster bars was 5.4/m2 in 1879 and with the density of Brooks et al. (1884) for another survey 3.5/m2. These results demonstrate that the landings were at the same levels as the total living stocks meaning that the fishing pressure was largely too heavy. The fisheries could reach such a high level only because the different adult age classes of all the oyster bars of the Chesapeake Bay and its tributaries have been exploited. The capital of all the previous years (an oyster can live more than 15 years) has been consumed.

To maintain this level of exploitation the annual recruitment plus the cumulative mortality must be superior to the harvest. Surprisingly that a mean density for one year class of 4 oysters by m2, which is very low, had not been obtained. Several reasons could explain the failure to keep this level of density.

- the fishing of the juveniles : during this period large quantities of spat were sold to other states for reseeding. For example, in 1879, 89,329 tons of spat were sold for bedding in northern waters from Delaware to Maine (Ingersoll 1881),

- the destruction of the spat attached to the adult oysters, by the packing houses which did not reseed the young oysters,

- the absence of permanent removal of cultch which was necessary for the fixation of the post-larvae ; the fishermen and the packing houses did not put shells or other hard substrate, back to the oyster-beds,

- the destruction of the habitat : Before the intensive fishery, the oyster reefs were very sharply defined and often set up on hard bottom. They could be of considerable thickness below and above the surface even outside of the sea at low tide. In the Gulf of Mexico, Bouma (1976) demonstrated that the base of the oyster reef was buried shell, deposited from several thousand years. Commercial harvesting has changed the nature of the oyster bars. Winslow (1887) assumed that dredging enlarged the bars by dispersing the dredged oysters out of the reef on soft bottoms. The dredges and the patent tongs had spread out and reduced the height of the reefs above the sediment. The bars were, after the intensive fisheries, broader but with much less relief. These facts modified the physical characteristics around the oysters, a non-fished oyster reef was less subject to siltation as it was above the interface water sediment. The currents and the increasing turbulence in relation with the height of the reef could avoid the sedimentation and allow the transportation of the biodeposits of the oyster populations. These can explain the observations of Winslow (1887) who found that the overworked beds had often mud and sand among the shells and that the settlement of the spat was three times less in a fished bar than on a wild bar. Otherwise it had been shown that the increase of the turbidity at the proximity of the oysters had a deleterious effect on the growth rate of oyster populations with a negative production and a decrease of the assimilation rate (Héral et al, 1983).

All these factors combined together achieved the destruction of the most productive beds. In 1881, Ingersoll, stated that the famous beds of Tangier and Pocomoke Sounds were exhausted and Winslow (1887) suggested that old beds overfished could be rebuilt with scattered materials but these recommendations have not been followed. Truit (1927) established that the overfishing of oyster beds brought about a complete depletion of one-fifth of the total oyster bars and a near exhaustion of one-third of the original oyster bars.

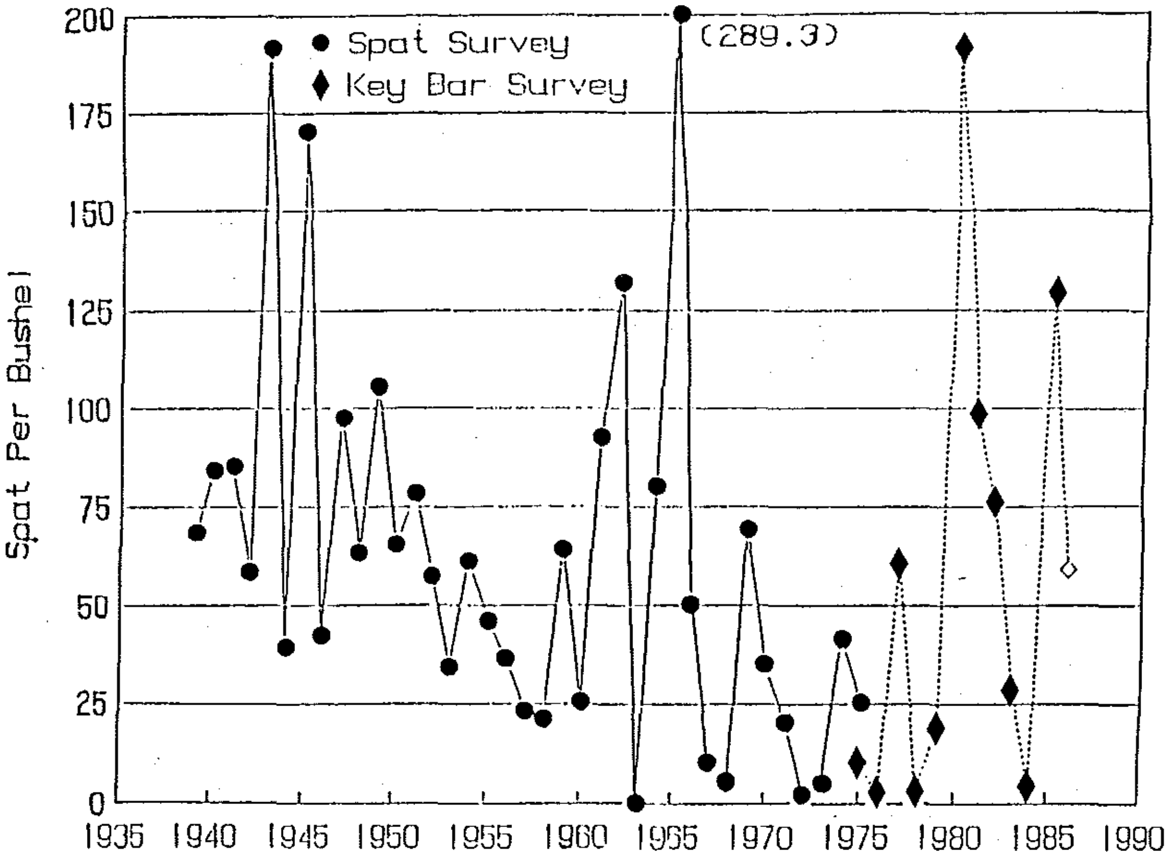
Level 2 : Decreasing and stable landings from 1900 to 1980

After a continuous decline of the landings from 1890 to 1910 characterized by the permanent overfishing, the harvest came to a stable phase which fluctuated around 80,000 tons. Krantz et Meritt (1977) described the fluctuations with a decline in harvest during the 1960's. It appeared mainly that these variations of the landings were in relation with the recruitment intensity. For a given year, the majority of the production was fished 4 to 5 years after the settlement. Periods of low recruitment 1952-1960, 1966-1978, were followed by years of high spat set (1965-1980) (fig. 7). With this set of data on spat, it appears that the fishery, during the last sixty years, have been supported by three main picks of recruitment. About each twenty years, a main spat abundance occured, even in 1980 and 1985 with a very low stock in relation with the desease. Though, first the water quality of the bay was sufficient to permit high survival rate for oyster larvae and secondly the relation stock recruitment permitted still a good record in 1985. Ulanowicz (1980) demonstrated that variations in spat density were correlated with the cumulative high salinity during the spawning season.

It is interesting to note that Virginia landings for the period 1940-1960 are superior for the first time to Maryland productions. Hargis and Haven (1988) noticed that it was due to private production from leased bottoms while the harvest from public bottoms continued to decline.

Different management operations have been achieved in Maryland to try to increase the public oyster production. After the cull law of 1890 which enforced that the shells with spat and young oysters had to return to the oyster bars, a legislation for shell planting initiated an annual placement of shell as cultch for seed on the bars. Kennedy and Breisch (1983) precised that a 10% shell tax was charged in 1927, a 20% shell tax in 1947 and in 1953 a law was taken for a 50% shell tax. It means that the oyster packers and processors had to sell at least 50% of their shucked shells to the State which organized the collect and the reseeding of the fresh shells. Funds to do these operations were coming from a tax on each bushel of processed oysters. These decisions and laws were all failures. The shells did not return to the oyster bars (1936) or the funds to sow the oyster shells were not collected (1948). Even after the law of 1953 the supply in shells was still insufficient. For this reason the Maryland Department of Natural Resources took the decision in 1961 to use "fossil" shells dredged by a contractor that would plant them from May to, normally, end of June. The mean quantity of dredged shells is 205,000 tons for a year. The highest record of shell planting has been broken in 1975 with 362,000 tons. The state always attempts to buy all the fresh shells available, but they represent now only 3% of the dredged shells.

It has been well demonstrated by Truitt (1936) that an overfished oyster bar could become a productive area again by using a properly managed shell planting



<u>Figure 7</u> : Evolution of an indice of recruitment : average number of spat per bushel in the Maryland part of the Chesapeake bay (from DNR 1987).

activity. Also, Abbe (1988) working on an oyster bar on hard bottom, in a place where the velocity of the current was high, at the proximity of the Calvert Cliffs Nuclear Power Plant, demonstrated that shell planting can be an effective mechanism for increasing oyster yields. But this operation of reseeding the dredged shells is a collective operation for the public Maryland oyster bars, and is done by only one contractor who follows the allocation and the schedule defined by the oyster committees and DNR biologists. The shells can be reseeded 2 or 3 months before the main settlement. The spawning occurred in the Chesapeake Bay from June to August (Shaw 1969, Kennedy and Krantz 1982). But some years, the largest abundance of spat could occur in September, (Truitt, 1925 ; Goulletquer, com. pers.). It is well known that oyster post-larvae set on newly-planted very clean shells better than on old shells because of the fouling and the siltation. For these reasons, Shaw (1967) recommended for the Chesapeake Bay to plant shells on the first week of July when the larvae are numerous in the water. The problem for the Maryland oyster fishery is the size of the public reseeding plan and the mean to apply it, which compelled to begin the operations too early in the season. In other states, it appears that private oyster companies working on their own grounds are more efficient, for example in Louisiana, it takes a week to scatter the shells. In Long Island Sound, Korringa (1976) reported that the private companies spread the shells in 4 days, mainly chosen function of the abundance and larval development in plancton.

MacKenzie (1983) did very good scuba survey, in the Chesapeake Bay during the normal oyster setting period. He observed that beds with high densities of oysters had much less silt than beds with only shells. Very often the Maryland beds had quantities of shells but silt partially covered them. This author recommended to avoid sedimentation by the use of dredges without bags, before the oyster setting season, or of mud-cleaning machines on boats and the employment of quick lime to control fouling organisms. Our own observations during the year 1989 showed a tremendous fouling at the bottom and, in the water column, on different substrates of the Patuxent River particularly in June and July. All these observations are going in the same direction : to obtain a better efficiency of the shell planting for settlement, it would be necessary to change the schedule of planting and the way of practicing it.

Otherwise, the "fossil" shells are not the best cultch material (Cabraal and Wheaton, 1981). They are very often broken and ruined. Comparisons between shells of living oysters, fresh shells, old "fossil" shells and the efficiency of the spat settlement demonstrated that the densities of spat were higher on living or fresh shells than on fossils shells. It could be in relation with an attractive effect of the conchyolin, the protein of the shell. It would be interesting to use fresh clam shells as the landings are important, and large amounts of shells are available. This cultch was a good one and used for managing the Louisiana oyster fishery (Dugas 1988), as it was not a heavy collector it was easier for the oysters to maintain their position on top of the soft sediment (Korringa, 1976).

The Maryland DNR annually planted nearly 205,000 tons of oyster shells on natural bars to serve as substrates to maintain the recruitment and also planted shells in areas of good settlement to carry the oyster seed from areas of high spat set to areas of low settlement. When the density of spat is higher than 300 per bushel, they are transplanted with a mortality of 10 to 15% (DNR 1987).

The allocation of the shell planting is function of the biological appropriate areas where the highest densities of spat of the previous years have been observed (for example fig. 8). The highest abundance of spat were generally located in the mouth of the different tributaries, but cultches had also been planted in places where no more recruitment had been observed for several years (Kennedy and Breisch 1983). Christy (1964) assumed that shell plantings were practiced not only where biological results would suggest it but also where the politicians of the counties demanded under the pressure of the watermen. To evaluate the efficiency of the reseeding plan, some rough calculation can be done. By inspection of the different estuaries and comparing the evolution of the production 3 years after, period where now all a year class is fished, with the quantities of shells and seed resources, it first appears impossible to know what is due to the part of the fishing and the reseeding plan. Then, very often, the landings are still declining (fig. 8 example of the Tangier sound). With a seeding of 5,000,000 bushels, a highest spat density of 200 per bushels (fig. 7) and a mortality rate of 10% per year (DNR 1985) the expected production after three years would be 91,000 tons as the landings were fluctuated between 80,000 and 120,000 tons.

After some very high level of recruitment (1945, 1965, 1980) even if the harvest increased (+ 61,500 tons, 5 years after 1965), it never went above 120,000 tons, which is 6 times less than the landings of the end of the nineteenth century. The fishing did not retrieve the prosperity despite the effort in management of the public oyster bars:

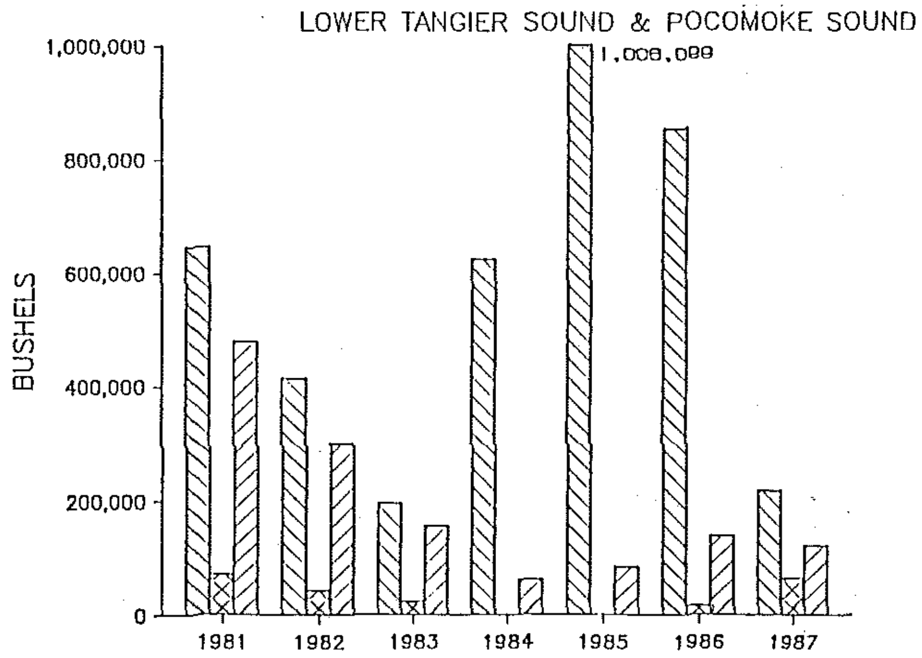


Figure 8 : Example of management activity (planting oyster shell and seed) to harvest in Lower Tangier Sound, ▨ bushels of shell, ⊠ bushels of seed, ▧ bushels harvested (from DNR 1987).

- the market size limit of 9 cm,
- the reduced season of fishing from the 15 September to the 31 March,
- the daily catch limits by boat function of the gears and the number of crew,
- the reseeding plan.

This can be mainly due to the loss of suitable habitats for oysters. Seliger et Boogs (1988) demonstrated that there is a tremendous decline of the surface of oyster bars in the tributaries. By comparing the results of Yates survey (1913) and their survey obtained by echosounder calibrated with sampling by dredge and by scuba diver, they found that only 14% of the surface was still covered by oysters and shells in Chester River, Broad creek and Tred Avon River. A work with an underwater microphone calibrated with sampling by hydraulically patent tong showed the same tendency in Pocomoke Sound with only 19, 5% of the original surface of public oyster ground (Whitcomb and Haven 1987). Furthermore, the elevation of oyster reefs above the surrounding bottoms was not great because of the fishing activity. In a recent survey of the Virginia part of the oyster bars, Haven et al (1981) showed that only 21.9% of the oyster bars classed at the beginning of the century were still surviving. Obviously the overfishing and the use of the gears contributed to these destructions but the sedimentation rate can also be a major factor in the reduction of oyster harvest. We have already described the action of the siltation upon the decline of the spat settlement particularly in relation with the reseeding plan. Galstoff (1964) specified that many productive oyster bottoms along the East Coast had been destroyed by the siltation. In the Chesapeake Bay the inputs of particular matter in suspension have mainly two origins : the erosion of the shore and the large input from the rivers.

The 3,950 miles of the shore of the Maryland part of the Chesapeake Bay and its tributaries are constantly eroded by currents, tide effects, wind and storm effects, fetches, and stream flows. Wolman (1968) calculated that about 2400 ha of land have been eroded during nearly a century, which gives an average loss of 6.5 ha per Km of shoreline and an annual output of 0.2 x 10^6 tons. The hurricanes (cyclonic storms) had tremendous effects on the erosion, the inputs and resuspension. In the Chesapeake Bay the Hurricane Agnes in June 1982, was an obvious example which delayed the recruitment of oysters and which contributed to the destruction of the clam fishing. The Hurricane Elena in

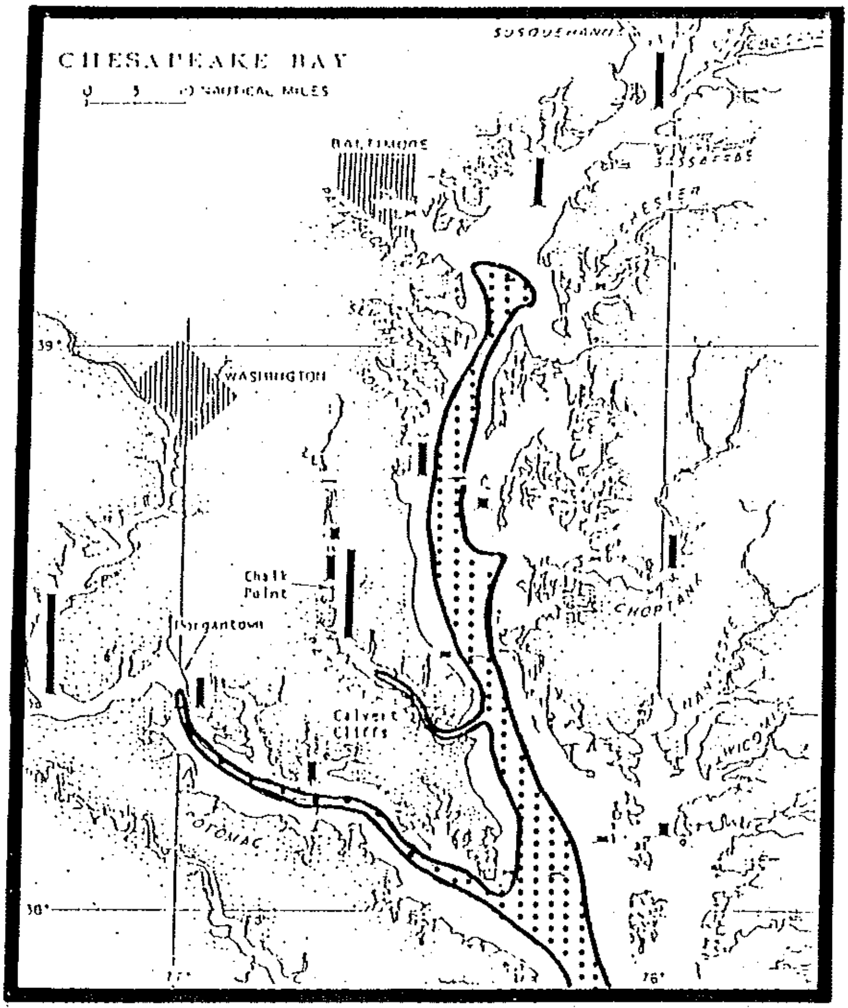


Figure 9 : Spatial distribution of average annual benthic biomass in relation with the region affected during summer by anoxic bottom waters [::::] from Holland (1987).

September 1985 destroyed a part of the oyster reefs in Florida. It removed and buried the oysters covered them in muddy sediment where they died (Berrigan 1988).

All the rivers flowing into the bay carry enormous loads of sediment. For example the Susquehanna River, up per part of the Bay, discharged 0.6 x 10^6 tons of suspended sediment per year, the Potomac River 2.3 x 10^6 tons per year and the Patuxent River 8.7 x 10^6 tons per year (Schnube, 1968). The total amount of sediment coming from the land was estimated to 8 million tons per year (Wolman 1968). 70% of the inputs were coming during the peak runoff from February to May fonction of the year. 70 to 80% of these inputs sediment in the bay and its tributaries. Thus, a sedimentation rate of 30 cm per year was measured in the channels up to Chesapeake Bay Bridge. In Patuxent River the sedimentation rate reached 2.1 m from 1859 to 1966 at Upper Marlboro. Schnubel (1968) found that all the sediment carried by the Susquehanna was deposited in the upper bay. But the Potomac carry its sediment on a very long distance into the Bay. There is in the Chesapeake Bay a natural tendency to sedimentation in the channels and on the border but the influence of man's activity on the sedimentation rate in the bay is important. The deforestation and clearing for agriculture had multiplied the inputs by 4 to 8. On the other hand, the urbanization has promoted the erosion of the land. 25 to 30% of the one million tons reaching the Potomac estuary are coming from the area of Washington, D.C. After a thunder, what is typical is the sudden changing of the colour of the bay becoming yellow gray. The sedimentation rate on oyster bars can also be increased by the dredging operations. They are practiced to maintain the circulation of large boats to words the harbour of Baltimore but also in all the tributaries to maintain and develop recreative activities (yachting, marinas...). The clam fishing, when this activity is done by several boats in the vicinity of oysters, in places where the velocity of the current is little, can also contribute to an increase of the sedimentation rate on the bars.

So, it appears clearly that the surfaces for the habitats of oysters are limited in the upstream of the bay and in the different tributaries, by the heavy siltation rate. At the opposite they are limited down to the bay by the anoxic conditions which occured in summer time. A synthesis of the anoxic waters which arrived from 1950 to 1985 (Seliger and Boogs, 1988) demonstrated that the annual volumes of anoxic bottom waters in the Chesapeake Bay showed no statistically trend to increase. The anoxias are in direct relation with the stream flow of Susquehanna River. The fresh river flow induces a stratification in spring and summer which inhibits vertical mixing. The respiration of benthic sediments and the water column under the pycnocline consumed the oxygen available to achieve to a total depletion. The more severe summer anoxia in the upper Chesapeake Bay occurred in 1984 (Seliger et al 1985) for the waters deeper than 6m. The anoxic waters, when the conditions are severe may reach the mouth of the different tributaries. Benthic organisms living under 6m depth are killed, only fast growing species which can reproduce all year are present (Holland 1987, Fig. 9). Thus this appears to be another strong limiting factor of the available habitat for oysters.

In the early 1960's MSX disease invaded the Chesapeake Bay. The haplosporidian *Minchinia nelsoni* coming from Delaware Bay destroyed the oyster population there in 1957 (Haskin et al. 1965). This disease had a very severe impact on Virginia oyster landings (Fig. 3) which declined by 50%. In Maryland, as MSX activity was salinity-limited, it caused mortalities only in Tangier Sound's harvest. MSX disease then regressed and virtually disappeared from the Maryland part of the Bay from 1965 to 1981.

Level 3 : 1981 - 1988: Large decrease of the production caused by high mortalities

The annual survey achieved by DNR biologists recorded, between 1980 and 1982, mortality levels of 30 to 50 % for adult oysters. Normally, with the same design of sampling from 1970 to 1980 the oyster adult mortality was variable from 5 to 20 %. A period of low mortality occured from 1984 to 1987. After the 1986 fall mortalities increased again in 1987-1988 for the adult oysters, though the cumulative mortality of a year class could reach 90 %. During that period the harvest pressure remained permanent despite the high levels of oyster mortality and caused the disapearing of most of the adult oysters.

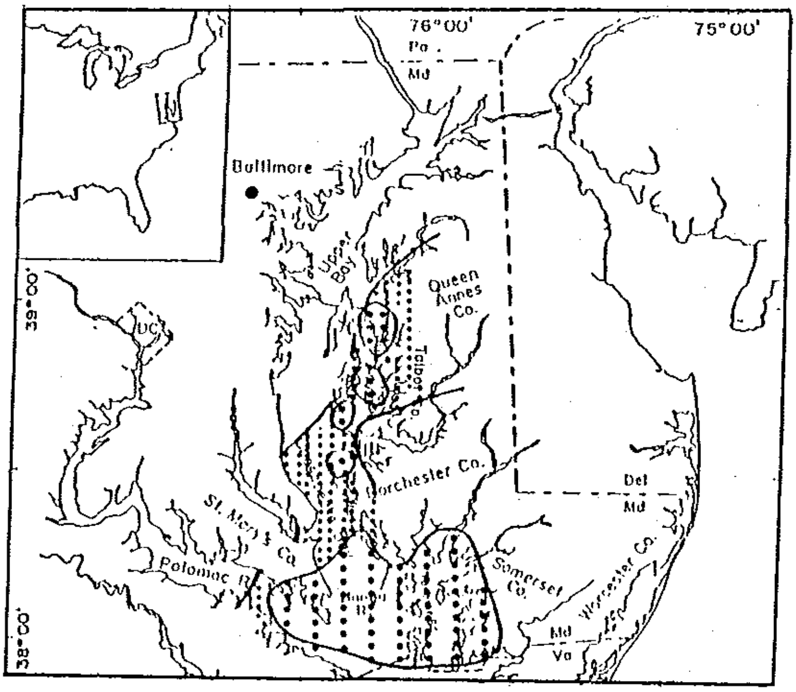
Numerous factors can cause these high levels of mortalities particularly diseases, predation or degradation of water quality.

Two main diseases are related to mortalities in the Chesapeake Bay, the ascetosparan parasite *Haplosporidium nelsoni* (MSX) and the protozoan *Perkinsus marinus*.

MSX bay invaded the oceanic of the Chesapeake bay in Virginia from 1961 to 1966. MSX was salinity dependent under 15 %. The infections remained low and disapeared below 10 % (Haskin and Ford, 1982). Later in 1981–1983 and again in 1986–1987 a new MSX outbreak occured in Virginia and Maryland along with a particular dry period which caused salinity increases in the Bay. The prevalence of MSX infections were not very high, rarely above 20 % (source DNR maps), but only few bars in the upper low salinity part of the bay were free of disease, high salinity conditions with warm winters created good conditions again for MSX. The infections occured mainly in spring and summer over 5 months. As early as the first year, the mortalities occured at the end of the summer and the year after at the end of the winter, with a cumulative rate of annual mortality of 30 % (Andrews, 1966). Furthermore, the MSX infections acted upon the physiology of the oysters. Newell (1985) reported a decline of the filtration rate in relation with MSX abundance with a reduced condition index and a reduced rate of stored glycogen (Barber et al., 1988). A clear inhibition of gametogenisis has been shown in relation with infection intensity but without correlation between annual fluctuation in parasite rate and oyster recruitment (Ford and Figueras, 1988).

Resistance strains of American oyster have been obtained by Ford and Haskin (1987), by crossing in direct lines oyster parents from natural oysters which survived to MSX epizootie, during 6 generations. This delayed infections and mortality rather than proved as a real resistant selection, but these strains could provide practical interest for oyster men.

The second more important parasite is *Perkinsus marinus*. This protozoan inhibited gonad development (Menzel and Hopkins, 1955). "Dermo disease" was present from the Gulf coast on the North east Atlantic coast to Delaware bay. This disease has been reported for the first time in Maryland by Otto and Krantz (1976) at the entry of the Chesapeake bay. The parasite is not salinity dependant. DNR survey during 1988 fall, demonstrated clearly that the whole bay was contaminated (fig. 10) with a very high prevalence rate, sometimes the totality of oyster population was infested. *Perkinsus marinus* was pathogenic during warm temperatures, under 20°C, the oysters expelled the pathogens (Andrews, 1984). The abundance of this dermodisease is correlated to the density of oyster populations because infections are caused by the dilution and dispersion of the parasites free in the water when the oyster died. Mobile vectors could also transmit the infection and particularly the ectoparasitic gastropod *Boonea*



<u>Figure 10</u> : *Perkinsus marinus* distribution during the fall 1988 survey (from DNR unpublished data). > 50 %, > 20 %.

impressa (White et al., 1987–1989). Contrary to MSX spat and young oysters are not usually infected by *Perkinsus marinus*.

The superimposition of the maps of the oyster mortalities from 1981–1983, 1986 and 1987 with the respective abundance of MSX and dermo disease could place in a prominent position the correlations between prevalence of the diseases and mortalities in the different areas. Though, mortalities higher than 20 % occured in 1981–1983 in the upper Bay in front of Baltimore without abundance of MSX and Dermo. These mortalities could be related to environmental conditions with unusual high temperatures in summer along with hypoxic conditions. Beaven (1946) demonstrated that for this area, many mortalities were correlated with high run-off of the Susquehanna River. There was a good agreement between mortality rate and MSX abundance for Tangier Sound and the mouth of Choptank river in 1981–1983, 1986 and 1987. But in 1981–1983, MSX was abundant in the mouth of the Patuxent river but without abnormal mortality and at the opposite, MSX was absent in the South of Potomac river in 1981–1983 and 1986, places were high mortalities occured. In fall 1987, mortalities largely increased and reached 75 to 100 % in Tangier Sound, mouth of Potamac river and in the mouth of Choptank river where the prevalence of Dermo was above 50 % and MSX above 20 %. The mortalities which did not overpassed 25 % were located up the river and in the upper bay where MSX and Dermo disease were less abundant.

Thus it seemed that the high levels of mortalities are more closely related with *Perkinsus marinus* abundance than with the *Haplosporidim neslsoni*.

Many predators despite the meso salinity of the bay, can also increase the mortality rate of oyster populations. Webster and Medford (1959) noted that the flat worm *Stylochus ellipticus* could be a very active predator of young spat in the Chesapeake bay, while drill species are not abundant in the Maryland part of the bay in relation with the low salinity. But the largest predation could be the blue crabs : *Callinectes sapidus*. Predation rate was directly proportional to crab size and inversely to oyster size (Bisker and Castagna, 1987). These authors demonstrated that blue crabs could eat 16 spats (crab/day) and large crabs can cause significant mortalities until a shell height of 25 mm. Normally the blue crabs did not success to eat adult oysters except when they are thin-shelled (Lunz, 1947). Larson (1974) found blue crab densities up to 13m-2 in the James river. It is interesting to note that the highest densities of blue crab for males and

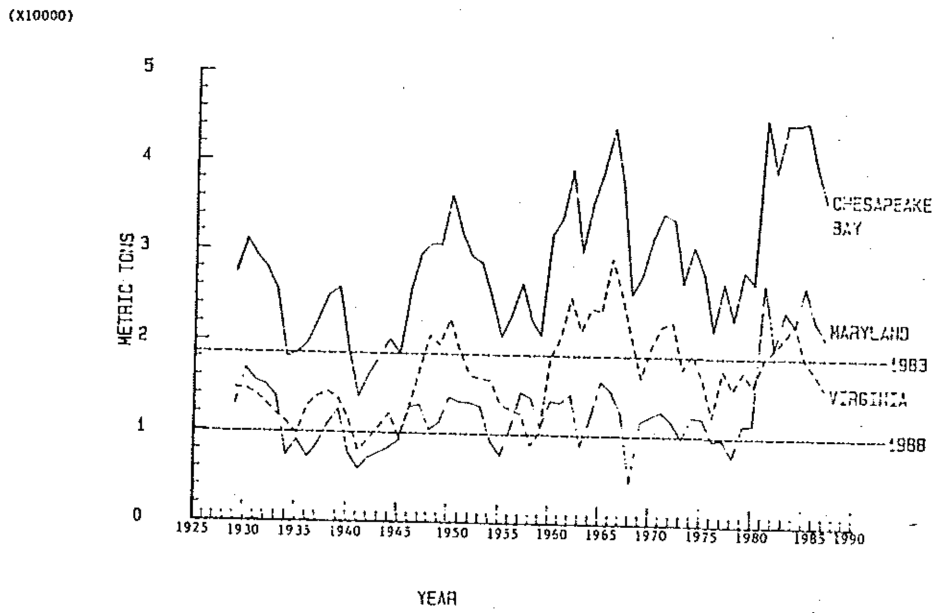


Figure 11 : Evolution of the blue crab commercial catch 1925-1987 in Virginia, Maryland and in the Chesapeake Bay expressed in ten thousand metric tons.

females occured in summer time on the border and in the tributaries of the Chesapeake bay.

The blue crab activity is one of the most important fishery of the Maryland with a professionnal but also a large recreational fishery. The evolution of the blue crab commercial landings showed an increase twofold between the year 1975 and 1981 (fig. 11) remaining at an annual production higher than 40,000 tons for the bay until 1986. The mud crab *Panopeus herbstii* is also present at high densities in the Chesapeake Bay (Larson, 1974) ranged salinities from 10 to 34 % (Schwartz and Carbo, 1960). This crab achieved a higher predation on oyster (Bisker and Castagna, 1987) but the densities in the whole bay and their evolution are not known. However, the large increase of blue crab population could play a role in the increment of the mortality rate of the oyster since 1981.

The degradation of the water quality is very often given, particularly by the watermen as an increasing factor of the oyster mortality rate. As the pollutants are more active for bivalves on the larvae than on adults it can be noted that the main spat set which occured in 1981 and 1985 demonstrated that in summer the environmental conditions permitted a normal growth rate and metamorphosis of the larvae. Except for some large discharges of fresh water in the upper bay, the high sedimentation rate and the anoxic bottom waters can either separatly or together cause mortalities. The concentrations of heavy metals in the bay are under the level which caused mortalities of oyster larvae for the American oyster (Calabrese et al., 1973, 1977 ; Mac Innes and Calabrese, 1978). The impact of organotin compounds is interesting to study more in detail as this pollutant is very active at very low concentrations for oyster larvae (for a review on oysters see Héral et al., 1989). TBT evaluations of the concentration in the water column of Chesapeake Bay marinas were above the toxicity limit for *Crassostrea virginica* larvae (Hall, 1988). But in non marina areas the reported concentrations were not toxic for the oyster larvae in terms of acute toxicity. So it appears that chemical pollutants and particularly heavy metals and their salts could not play a direct role in the increase of the mortality rate of the oyster larvae and of course on adult oysters.

ALTERNATIVE STRATEGIES FOR RESTORATION OF OYSTER PRODUCTION IN THE CHESAPEAKE BAY

These reflections mainly concern the Maryland part of the bay, similar proposals could be applied for Virginia especially for aquaculture on private bottoms but Hargis and Haven (1988) have already done strong recommandations to improve the oyster production of this state.

While keeping the same type of socio-economical watermen structure based for oyster production on a public oyster fishery, a restoration of the production can be achieved by changing inadequate public management which has contributed to the decline. For several decades oystermen have obviously practised overfishing and, at a higher rate these last years. They fish more adult oysters each year than the number of oysters of the coming year class corresponding to the recruitment minus the cumulative mortality, which are both function of the natural conditions and of the management operations (shell planting, reseeding...). Overfishing plus natural mortalities established critical conditions, in several rivers, lacking populations of adult oysters created severe conditions for spat set in the vicinity. Limiting the landings by shortening fishing season and enforcing a licenced boat system might not be enough. It could be interesting to create sanctuaries in different parts of the bay to maintain stocks for reproduction. Furthermore, fisheries should be controlled by closing bars, and rotation ensured round the bay by opening 1/4 or 1/5 (time of the mean growth rate) of the most productive oyster bars each year.

To practise the management it would be very useful to have an actualized estimation of the surface of the public bars with living oyster. It is unecessary for the Maryland state to keep and try to manage bottoms with mud and empty shells. Of 990 bars with a surface of 116 000 ha, as estimated at the beginning of the century, what is the reality nowadays ? The liberated old oyster bottoms could give new surfaces which could be leased for concurent activities like private oyster culture in Maryland. With the knowledge of the spatial distribution of the stocks, first the management for the fisheries could be planned (sanctuaries, rotation), secondly the reseeding plan could be optimized.

In the reseeding plan, before immerging cultches, the right place, the right time and the right mean must be chosen. The allocation of shell planting must not be mainly decided under social constraints but for biological reasons. The habitats must be favourable particularly far away from anoxic bottom waters during summer, in places where salinity remains high enough to facilitate the survival rate of the larvae. Sedimentation must be low, first to keep the cultches as clean as possible, secondly to guarantee a good survival rate of the young spat. Sectors of high spat settlement in the past years must have a prior right, but prospection of new areas round the sanctuaries which would be created must be achieved.

A lot of scientific work and oyster men practices have showed, round the world mainly in Japan, France... that it is recommanded to immerge spat collectors when the swimming oyster larvae are abundant. It occurs 10 to 15 days before the settlement to avoid fouling and sedimentation. In Chesapeake Bay, Maryland part, it is done 3 to 4 months before the spawning period. This delay is mainly due because the Department of Natural Ressources of Maryland (DNR) uses only one private contractor for the whole bay. Even in a same fishery context, it can be proposed that all the oyster fishermen, who make profit by the collective operation, reseed the cultches in 15 days, when the biologists find the oyster larvae in water.

For the technical aspects of the reseeding plan, the efficiency of the cultches (oyster shells, clam shells, concrete, slates, stones...) must be compared with dredged fossil shells which are actually used. The comparison must be done in terms of biologic attraction for oyster larvae, hardness and stability of the cultch, behaviour against fouling and rugosity of the bottom covered with the cultch to avoid siltation. As a matter of fact the depth of the shell layer could be very often reduced, as the spat of the below did not survive. An optimisation of the density of shell in relation with the number of spat and the cost of the operation must be achieved.

Reseeding the spat in areas without recruitment, in places where growth rates are very fast and mortality low can be good management operations, but it could be also a disaster by spreading the disease. Before the spat reseeded, systematic sampling of the abundance of diseases must be done, even if the spat is not directly infested by a parasite, it could carry the disease as a safe host. In the same time, before reseeding the spat in areas where MSX and Dermo are present, it is a necessity to eradicate the previous parasited oysters by a total catch of all the year class. This comment is particularly valuable for Dermo disease which contaminates the oyster by proximity. Furthermore, the spat must be reseeded in places where the habitat of the oyster is the most favourable to growth rate. The density of the reseeded spat must remain low to permit, first good physiological conditions to fight against the disease, secondly to avoid contamination by proximity which is in direct relation with density.

As the landings have remained very low, for several years, demonstrating the failure of the oyster fishery, an alternative can be a development of aquaculture of oysters. This proposal will completely change the social characteristics of the watermen Maryland community as it will require developments of enterprises, large investments etc. So there is an urgent need of sociological but also economical research to estimate the conditions and the consequences of the development of oyster culture in this area. From the biological point of view, the first problem with aquaculture is the choice of the species. As the native oyster is mainly attacked by two diseases, it is not sure that aquaculturists must go on with American oyster. Two main hypothesis would be investigated to proceed on the *Crassostrea virginica* or to introduce *Crassostrea gigas*.

With the American oyster, natural spat can be collected on bottoms or with collectors in suspension. Everywhere in the world the collectors are more efficient when they remain in suspension. It is the same for the cultivation with faster growth rate in different suspensions. As the size of a market oyster could be obtained in two years with this type of structure, it permits to avoid the high mortality rate which occured with MSX mainly the third and the fourth year. In this scheme it would be better to have natural spat less expensive and more resistant to disease. An analysis of the world evolution of oyster production demonstrates clearly that the largest countries producing oysters are depending on natural recruitment. On the contrary the history of the production of molluscan with juveniles produced in hatcheries remains irregular and at a low level of production, even with new techniques like "eye larvae". This is mainly due to the size of the hatcheries which cannot always increase their level of production and also to the diseases which frequently occur in the very intensive overcrowded structures. Relying on hatcheries may become a necessity when they are able to produce some particular strain showing resistance to disease or fast growth rate or even new "species" obtained by hybridation or by genetic manipulation.

For *Crassostrea virginica*, some selected strains are available. By population selection of fast growth oyster and by breeding them together during several generations, a strain with fast growth (the market size could be reached after 12 to 18 months) is now commercialised at the Piny point hatchery under contract with DNR. Moreover the strain resistant to MSX (Ford and Haskin, 1987) allows to reduce mortality. Triploïds of *Crassostrea virginica* could also be obtained presenting normally better growth rate by comparison with diploïds in relation with the allocation of the energy which decrease in the gonadic production (Allen, 1986). The problem is that the percentage of triploïds produced in a sample will vary a lot. For this reason it would be better to produce tetraploïds and to cross them with diploïds which will guarantee a percentage of 100.

The introduction of another species must be evaluated. The species of oyster which is produced round the world giving more than 70 % of the total production is the Japanese oyster : *Crassostrea gigas*. This species is widely distributed in North America on the west coast but non officially present on the east coast, even if, in the Chesapeake Bay Hargis et Haven (1988) reported that this oyster, cultivated on the west coast were "soon processed or repacked in Virginia". The choice of this species could be explained first by the fast growth rate of this oyster it can occured market size in one year when the nutritionnal and temperate conditions are favourable (Héral, 1989). Secondly this oyster is very resistant to different diseases : the two viruses which destroyed the cupped european oyster (Grizel and Héral, 1989) but also resistant to the protozoans *Marteilia refringens* and *Bonamia ostreae* which caused severe damage to the european flat oyster *Ostrea edulis*. No publications described if *Crassostrea gigas* is resistant to *Perkinsus marinus* and to *Haplasporidium nelsoni*. There is an urgent need to achieve these experiments. On the other hand it is noticed on the west coast of US a new disease Bonamia like which caused hight mortality rate on adult oysters (Bauer, com. pers.). Morphology and immunodiagnostic studies demonstrated that this parasite is a new species different from the microcells of the flat oyster (Boulo et Hervio, com. pers.). In hatcheries from the west coast it has been noticed mortalities in relation with vibrios and bacteriae creating infection of conchiolinous ligament and periostracum (Elston et al., 1982, Elston, 1985). A virus on *Crassostrea gigas* was also affected larvae causing large mortalities in hatcheries.

After this survey of disease we can concluded it will be very risked to import *C. gigas* from the west coast. The danger to import diseases in Chesapeake Bay is soon very large with the trade in Virginia between east coast and west coast. An importation can be done from Japan or Europe were no disease are described for the cupped oyster. Even if, for example, the historical case of *C. gigas* implantation in France staid a success, it is important to underline that this type of operations can present considerable dangers, particularly for the sanitary point of view (Grizel and Héral, 1989). Also, it is necessary, when the situations are not dramatically urgent to take a maximum of precautions to realise importation and to follow the recommendation of ICES on introduction of species (quarantine, production in hatcheries of F1, etc...)

Another question with the introduction of *Crassostrea gigas* is the behaviour of this species in the Chesapeake Bay. The habitat of the japanese oyster, seems to be more marine than the one for American oyster it is not sure that this oyster could reproduced with low salinity in the tributaries and in the upper bay. Moreover the *gigas* oysters are more sensitive to pollution than american oysters. For example with organotin (TBT) *Crassostrea virginica* presented a decreased of growth rate only at 2 μg.l−1 without shell thickening. It appeared on *C. gigas* under 1 μg.l−1 until 0,01 μg.l−1 (Héral et al., 1989). The TBT concentrations largely exceed this level in the Chesapeake Bay particularly in marinas and some tributaries (Hall, 1988). This demonstrate that the quality of the water could be a limiting factor for another species of oyster.

As for *Crassostrea virginica*, triploïds of *Crassostrea gigas* could be obtained (Allen, 1987). as they are not able to reproduce, it can limit the spreading of the new species. Hybrids of American oyster and Japanese oyster, could be produced but the resistance to the disease is not known. By comparison with the hybridation of *Crassostrea angulata* and *Crassostrea gigas* it appeared that the hybrids had the same characteristics than the parents for growth rate and for disease resistance (Bougrier et al., 1986).

Another alternative is to change the species but to manage it in a fishery. To optimize the production, the problems would be the same that we have presented at the beginning of this paragraph for the american oyster fishery.

It must be kept in mind that by changing the species, it is the whole ecosystem of the bay which would be modified. When the environmental conditions are optimal this oyster can spread very quickly created again large oyster reefs which by their filtration activity can largely help to "clean up the Bay" as it have been done in South San Francisco Bay (Officier et al., 1982) and proposed by Newell (1988) for the Chesapeake Bay.

It is urgent to take these great decisions to maintain an oyster industry in Maryland :

- the choice between fishery and aquaculture, or fishery together with aquaculture,
- the choice of the species of oyster.

After these main decisions which are mainly politics with many social and economical consequences, technical recommandations would contribute to increase the production if a large agreement is obtained between water men, administrations, politics and biologists.

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