Rev. sci. tech. Off. int. Epiz., 1996, **15** (2), 551-561

Appearance and spread of diseases among bivalve molluscs in the northern hemisphere in relation to international trade

T. RENAULT *

Summary: *Bivalve mollusc culture is a well-developed marine aquaculture activity in many countries around the world, notably in the northern hemisphere. During the development of this activity, numerous countries have been confronted with infectious diseases of varying severity and duration. Research has been conducted to determine the aetiology, epidemiology and control measures for these epizootics. Major epizootics in bivalve molluscs have been caused by viruses, bacteria, fungi and protozoan parasites.*

Moreover, important commercial relations exist in marine mollusc culture between different geographical areas. This must be taken into account in explaining the appearance and the spread of some infectious diseases in several countries around the world. The author concentrates on some viral and protozoan diseases of bivalve molluscs reported in the northern hemisphere, in view of their economic impact and their spread related to movements of molluscs through trade.

KEYWORDS: Bivalve molluscs – Infectious diseases – International trade – Northern hemisphere.

INTRODUCTION

Aquaculture ventures world-wide have grown dramatically over the past two decades, and mariculture accounts for much of this growth. Significant strides have been made in the design and implementation of more efficient and cost-effective growing areas, feed and harvesting techniques. The economic impact of aquaculture will certainly increase in the years ahead.

Among the cultivated marine species, bivalve molluscs constitute a group of major economic importance. Indeed, mollusc culture is a well-developed industry in many countries, notably in the northern hemisphere, e.g. the United States of America (USA), Canada, Japan, Korea, France, Spain and the Netherlands. Thus, millions of dollars' worth of oysters, mussels, scallops, cockles and various species of clams are harvested each year around the world.

* Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), Laboratoire de Génétique, Aquaculture et Pathologie, Unité de Recherche en Pathologie et Immunologie Générales, B.P. 133, 17390 La Tremblade, France.

Advances in mollusc culture have made it increasingly apparent that mass mortality and mass morbidity are major problems requiring solution. Indeed, epizootics in commercially-exploited species have repeatedly struck the related industries, sometimes causing virtual extinction of the species. The most significant epizootics of molluscs have been caused by viruses, bacteria, fungi and protozoans. Crustaceans have also been recognised as pathogens. Recently, rickettsias have been associated with mortality, particularly of burrowing bivalves. Although mortality has mostly been associated with pathogenic agents, there have been cases where poor environmental conditions or bad husbandry have been responsible. In other cases, it is probable that the responsible pathogens have not been identified.

In the case of infectious diseases, the frequent introduction of economically important animals from other geographic areas – with the aim of establishing new products – has resulted in the introduction of devastating pathogens which have caused mass mortality among native stocks. This review therefore focuses on some protozoan and viral diseases of bivalve molluscs reported in the northern hemisphere, in view of their economic impact and rapid spread related to movements of molluscs.

EPIZOOTICS IN EUROPE

Iridoviral infections

'*Maladie des branchies*' ('gill disease') was identified as the cause of recurrent mass mortality in Portuguese oysters (*Crassostrea angulata*) in France from 1966 onwards. During certain years, the disease affected over 70% of the population. Maximum losses occurred in 1967 on oyster grounds in the Marennes-Oléron and Arcachon regions on the French Atlantic coast; the rate of losses subsequently declined. In 1968, survivors of the previous epizootics recovered from the disease, showing cicatrisation of the old lesions.

The first gross sign of disease on gills and palps is the appearance of one or several yellow spots. These spots increase in size, and the tissues at the centre die, become brown and eventually leave a perforation which enlarges to cause a deep indentation and, in advanced stages of the disease, total destruction of affected filaments. Yellow or green pustules develop on the adductor muscle and on the mantle, and mantle perforations may occur as on the gills (1, 11, 12).

Electron microscopy demonstrated that the globular cells, measuring 30-40 μm in diameter, which become apparent during the necrotic changes of the gill tissues, are hypertrophied host cells containing intracytoplasmic viral entities. The virions are icosahedral in shape and have a diameter of approximately 300 nm. A central electron-dense core, 190 nm in diameter, is surrounded by an electron-light zone followed by another dense layer, 45 nm in thickness. Two unit membranes, separated by a clear zone, enclose the particle. Feulgen-positive staining reaction suggests the presence of deoxyribonucleic acid (DNA). There is no evidence for nuclear involvement. The various properties of the entity, as well as its assemblage within the cytoplasm, characterise it as a member of the Iridoviridae (19, 21, 15). It bears some resemblance to the lymphocystis virus of fish.

'*Maladie des branchies*' also affects Pacific oysters (*Crassostrea gigas*), although to a lesser extent. The gill lesions are always reduced, suggesting partial resistance in this

species. Pacific oysters transplanted into French waters from Japan, in 1968, exhibited lesions in 27% of individuals, while 56% of a lot obtained from Korea showed the infection. Interestingly, the incidence in *C. gigas* imported from British Columbia was only 14% (35, 12). *C. gigas* cultivated in France appears subsequently to have acquired complete resistance to gill disease, as no gill-diseased individuals of this species were found between 1969 and 1971, although mortality among *C. angulata* reached 70% (14). Thus, the mortality among *C. gigas* is probably attributable to another virus which was unknown at the time but was subsequently discovered by Comps and Bonami (20).

In 1970, epizootic mortality in *C. angulata*, caused by an iridovirus, occurred in the estuary of Marennes-Oléron on the French Atlantic coast and was paralleled by a similar event at Etel, Brittany. By 1971, the disease had also reached the Arcachon region. Vast mortality led to almost the total extermination of *C. angulata* in French Atlantic waters in 1973. Electron microscopy revealed the presence of icosahedral viral particles, 350 nm in diameter with an electron-dense core 190 nm in diameter, within the cytoplasm of connective tissue cells (18, 15). The agent was in all respects very similar to the virus associated with '*maladie des branchies*'. *C. gigas* seemed to be resistant to the disease and, after the extermination of *C. angulata*, replaced the latter species in France (35, 8). However, in regard to *C. gigas* cultivated in Arcachon and Marennes-Oléron, some animals contracted a viral disease. Indeed, in 1977, a 15% mortality was noticed in oysters kept in a purification plant in Arcachon. As was the case for *C. angulata*, affected Pacific oysters exhibited virtually no external signs of disease, except for a greyish discoloration of the visceral mass in some cases. Histological examination, however, revealed considerable degeneration of connective tissues and the presence of atypical cells. Electron microscopy demonstrated the presence of icosahedral viral particles, 350 nm in diameter and with a 250 nm electron-dense core, in the cytoplasm of affected cells. With respect to its morphology and morphogenesis, the virus closely resembled the two former iridovirus types (20, 15, 16, 21).

Comps (16) concluded that '*maladie des branchies*' in its characteristic form is a specific disease of *C. angulata*, but some doubt still exists concerning this hypothesis. Uncontrolled introductions of *C. gigas* from different countries since 1966 may have led to the importation of a new exotic virus which found a highly susceptible species, *C. angulata,* in Europe. Indeed, an iridoviral infection was observed among *C. angulata* reared in different areas of Brittany after reintroduction of animals from Portugal (9). This observation could be explained by the presence of iridoviruses in the field (presence of healthy carriers in another species) or by the introduction of infected animals from Portugal.

Marteiliosis

Since 1968, recurrent serious mortality has been recorded in European flat oyster (*Ostrea edulis*) populations in France, particularly in the region of Marennes on the Atlantic coast and in Brittany. The disease syndrome soon became known as '*maladie des Abers*', named after a locality in Brittany where unusual oyster mortality was first experienced, and was later named '*maladie de la glande digestive*' ('digestive gland disease') after the main infestation site in the oyster. The causative agent was first observed and described by Comps (13), who compared it to the haplosporidians. Grizel *et al.* (27), who studied the organism in detail and named it *Marteilia refringens*, tended to relate it to the Microspora.

M. refringens has an unusual life cycle not previously observed in protozoans. Sporulation of this organism involves a series of endogenous budding which produces sporoplasms within sporoplasms. From the occurrence of the various developmental stages in different tissues of *O. edulis*, Grizel *et al.* (27) inferred a tentative life cycle for *M. refringens*. Primary infestations presumably occur in epithelia of the gut and/or the gills. Sporangia mature in the digestive diverticula and are discharged via the gut. How the oyster becomes infested, and by which stage, has not yet been determined. Experimental attempts to transmit the disease to healthy oysters in the laboratory have met with failure, although field experiments were successful (H. Grizel, personal communication).

'Aber disease' is accompanied by severe pathology. Infested oysters become progressively emaciated and the digestive gland assumes a brownish to pale yellow colour. Upon deprivation of its glycogen reserves, the mantle becomes transparent and shell growth ceases. The visceral mass loses its pigmentation and, in heavily infested individuals, appears shrunken and 'slimy'. These signs, however, are not pathognomonic, as they may also be exhibited by oysters not suffering from Aber disease. On the other hand, *M. refringens* may also be found in apparently healthy individuals with normal gonads.

Deaths from Aber disease usually commence in May, peaking in June to August and then gradually diminishing, with decreasing losses persisting until December or January. From March to April, the parasite is quiescent. In southern Brittany oyster beds, *M. refringens* cannot be found during this period, while in the colder waters of northern Brittany, sub-clinical infestations persist throughout the winter. From transplantation experiments, it became evident that new infestations occur between May and August (26, 28). Long-term observations suggest that old mature sporangia containing refringent inclusions are present from May or June on, but are eliminated completely by the end of January, whereas young plasmodia persist during the winter and re-initiate new clinical infestations in May of the following year (10, 4).

In 1967, the first drastic wave of mortalities occurred in a small estuary on the north-western coast of Brittany, in Aber Wrach. Occasional mortality had been noticed in this estuary, perhaps up to 50% in some previous years, but in the summer of 1967, mortality exceeded 90% (13, 31). By the time the parasite was recognised, oysters from Aber Wrach had already been transferred that year to the bay of Brest, to Marennes, and to Galicia in Spain. By 1970, Comps was reporting abnormal mortality in the Marennes basin associated with the presence of the parasite (13). He also reported similar mortality in the Brest estuary, in Aber Benoît, in Arcachon and in Spain. The next few years saw a slow increase in the frequency of mortality, and in 1975 the disease was present in various locations in northern Brittany, around the Brest estuary and in the Morbihan region (southern Brittany). At the same time, oysters from diseased stocks continued to be exported to the Netherlands and to Spain. At first, neither country appeared to be having difficulties with the introduced animals. By 1975, however, it was clear that some areas of Spain at least were subject to severe mortality from Aber disease. In contrast, no significant losses were noted in the Netherlands (5). Indeed, although numerous infected stocks from Brittany were introduced into Dutch oyster farms in 1974, 1975 and 1976, the pathogen *M. refringens* did not show any virulence/spread in the Netherlands. This observation offers an interesting point of discussion. Known physical circumstances cannot be considered as an explanation for the difference, because temperature range, salinity

and techniques of farming are the same as in France. In addition, the fact that a well-developed parasite was observed in imported and infected oysters after some months of stay in the Dutch farming areas indicates that the physical conditions were unlikely to be the limiting factors preventing disease spread. These facts suggest that the entire cycle of the parasite could not take place in Dutch farming areas.

Bonamiosis

Bonamia ostreae is the most recently-discovered ascetosporan pathogenic to bivalves, and was first noticed on Tudy Island, Brittany (France), in June 1979 (22, 36, 40). The protistan locates in the cytoplasm of haemocytes and causes gill ulceration and breakdown of connective tissues, accompanied by massive haemocytic infiltration. Occasionally, internal lesions involving the stomach epithelium may be observed (17, 40).

Two cell types of the parasite are apparent. The most frequently seen are the 'dense forms', generally round and 2-3 µm in diameter, with a dense cytoplasm rich in ribosome-like structures. The cells contain the following elements:

– one or two mitochondria

– densely-structured particles, 130-170 nm in diameter and in peripheral location

– a very dense body, approximately 0.5 µm in diameter and without apparent structure, later identified as reserve material.

'Clear forms', sub-spherical to elongate and amoeboid, 2.5-4 µm (exceptionally up to 7 µm) in length, possess a nucleus with a voluminous nucleolus and differ from the 'dense form' with respect to the structure of their mitochondria and the densely-structured particles. A third type of organelle is present in the form of membranous 'saccules', which are sometimes arranged in groups of two to four. Morphologically comparable to a Golgi apparatus, they are associated with vesicles, 50-90 nm in size. Some saccules have a circular profile, thus forming 100-150 nm vesicles, within which morphogenesis of the densely-structured particles – later identified as haplosporosomes – takes place.

In June 1979, *B. ostreae* was discovered in flat oysters raised on Tudy Island, Brittany (France), in beds affected by high rates of mortality (22). This protozoan, previously undetected in molluscs cultivated along the French coast, was soon found in most farming centres of Brittany where European flat oysters were cultivated (40). In 1981, the most affected areas were the St Philibert River and Tudy Island, but mortality has also been observed in the Crach River and in Quiberon Bay (all in southern Brittany). In northern Brittany, there is strong resistance to the disease in all the most important centres, especially in St Brieuc Bay, Paimpol and, to a lesser degree (mostly in deep water), in Cancale. The parasite has also increased and spread in rivers used for short farming periods (Elorn, Morlaix and Penzé in western Brittany). Only a few natural breeding areas off the Brittany coast remain unaffected by the disease. Areas in which there is no breeding of edible oysters (such as Vendée) remain free of disease, as does the Mediterranean coast, even after several transfers of infected animals. The prevalence of the parasite infection varies from one site to another, and also from one age-class of edible oyster to another.

This parasite has been found in several other European countries, including Spain, the Netherlands, England and Ireland (6, 7, 37). For example, the English outbreak of

bonamiosis was initially identified in relaid oysters from a few creeks in the Fal and Helford rivers of Cornwall, south-west England, after serious mortality was reported. As oysters had been moved from the infected beds before the disease was diagnosed, follow-up sampling showed that it had been transported to several sites in the receiving area in Essex.

The parasite was most probably introduced into France following the importation of spat from hatcheries on the West coast of the USA. The identity of *B. ostreae* and 'microcells' imported from California in the 1960s (32) was discovered, on the basis of epizootiological and morphological evidence, by Elston (24). This discovery was later supported by determination of antigenic identity.

EPIZOOTICS IN NORTH AMERICA

'Dermo disease'

Recurrent oyster mortality in the Gulf of Mexico, occurring since the 1940s, was blamed on oil pollution until the discovery of a pathogenic agent, *Perkinsus marinus,* by Mackin *et al.* in 1950 (34). In brief, the life cycle of *P. marinus* consists of vegetative reproduction in which uninucleate anaplospores enlarge and undergo successive bipartition (alternating karyokinesis and cytokinesis) to form sporangia of 4-64 cells, which liberate uninucleate, coccoid or cuneiform aplanospores, measuring 2-4 μm in longest axis.

P. marinus produces systemic infestations in *Crassostrea virginica*. Gross signs of 'dermo disease' are severe emaciation, gaping and pale appearance of the digestive gland. Considerable shrinkage of the soft tissues is common in heavy infestations. All tissues of the oyster are susceptible to invasion, although external epithelia and peripheral nerves are not usually penetrated. Initial host response to infestation is marked haemocytosis and migration of haemocytes to the sites where the parasite is located, resulting in extensive inflammation. Heavy accumulation of *P. marinus* cells ultimately results in liberation of the pathogens into the lumen of the digestive system.

P. marinus has been found to be responsible for recurrent devastating oyster mortality, particularly in waters of southern USA. Ray (38) reported the agent in numerous samples from various localities in the Gulf of Mexico, with prevalence as high as 100%. Moreover, in the 1950s, 'dermo disease' was the primary cause of oyster deaths in waters in Virginia (USA) during the warm season. Increased mortality rates experienced in Chesapeake Bay (Virginia/Maryland, USA) since about 1940 may reflect the introduction of this pathogen. Recruitment on public beds and repeated planting on private beds ensured that a few old infested oysters functioned as a reservoir for infestation of newly-planted healthy oysters. *P. marinus* was also present in Delaware Bay (Delaware/New Jersey, USA) during the mid-1950s, paralleling the introduction of imported Virginia seed oysters. The disease never became a serious problem, as was the case in more southern waters, and almost completely disappeared when oyster imports ceased in the late 1950s. *P. marinus* proliferates and causes mortality during warm weather, and its low incidence in Delaware Bay, the northern limit of its range, is probably a consequence of relatively cool temperatures.

Haplosporidian diseases

Haplosporidium nelsoni and *H. costale* are known to cause serious diseases and heavy economic losses among *C. virginica* populations on the Atlantic coast of North America. Both pathogens were first recognised in the late 1950s and have since been studied in great detail.

In the spring of 1957, approximately 50% of the *C. virginica* planted on New Jersey oyster grounds in Delaware Bay died within six weeks. In the autumn, the overall mortality at the centre of the outbreak approached 85%. Histological examination revealed a protistan previously unreported from *C. virginica*. Initially, this was referred to as 'MSX' ('multinucleate sphere X'), by virtue of the spherical shape of the plasmodium, and the disease syndrome became known as Delaware Bay disease. Later, the causative agent was identified as a haplosporidian, originally named *Minchinia nelsoni* (30).

The first appearance of Delaware Bay disease in Chesapeake Bay in 1959-1960 dramatically changed the whole oyster culture industry in the area. MSX rapidly replaced and displaced *P. marinus* as the major cause of oyster mortality in the bay. As a consequence, previously flourishing oyster beds collapsed and, after 1960, only trial plantings were made in high-salinity waters (3).

Non-specific gross signs of *H. nelsoni* infestation include mantle recession, gaping, emaciation, pale colour of the digestive gland; rare specific signs include diapedesis, relative decrease in numbers of phagocytes, relative increase in numbers of hyaline haemocytes, phagocytosis, fibrosis, cellular infiltration, abscess formation, ulceration, excessive pigment cell formation, mechanical disruption, pyknosis and necrosis. Initial infestations occur in the gills and palps. The pathogen is thought to enter the host through the epithelia of the filtering organs. The intermediate disease stage is characterised by local infestation and infiltration of connective tissue in and adjacent to the epithelia of gills, palps, oesophagus and stomach. In advanced infestations, there is a general invasion and infiltration of the connective tissue and circulatory system by hyaline haemocytes.

To date, all attempts to transfer *H. nelsoni* to healthy oysters in the laboratory, by placing infested and healthy oysters in the same aquarium or by transplantation of infected tissues, have failed. Likewise, routes of invasion and methods of transmission of the pathogens in the field remain unknown, as does its entire life cycle (2, 29, 25). Long incubation periods may account for the failure of laboratory infestation experiments (3).

The geographic range of *H. nelsoni* extends from southern Massachusetts to North Carolina (39, 33). *H. nelsoni* appeared in Delaware Bay in the spring of 1957, and two years later it caused a summer population decline in Mobjack Bay (Maryland). *H. nelsoni* infestations spread throughout lower Chesapeake Bay in one year (1960), affecting oysters over long distances from the Mobjack Bay focus. In each estuary, the disease rapidly spread throughout the area. MSX is present on the eastern shore of Virginia (23), and in the coastal bays of New Jersey. It has also been recorded in North Carolina and in Long Island Sound (39), in Massachusetts (33), and in Great South Bay on the south shore of Long Island, but has not been the cause of widespread losses in these areas.

H. costalis, the second haplosporidian pathogen of *C. virginica*, has a more restricted distribution. It was initially referred to as 'SSO' ('seaside organism'),

because it occurred only on the coast of Virginia and in Chincoteague Bay (Virginia/Maryland), where salinity is higher than 25 parts per thousand.

CONCLUSION

In practice, diseases would be more effectively managed if zoosanitary controls were regularly performed at several stages of production, but also before any transfer of molluscs on a large scale. By analysing the studies of epizootics in bivalve molluscs, the conclusion can be drawn that most have been investigated using available techniques, i.e. histology and transmission electron microscopy. These techniques are fundamental in pathology but there are several limitations: they are time-consuming and do not enable infection to be quantified. These techniques are therefore not amenable to large-scale application, and there is now a need to develop new methodologies for diagnosis in shellfish pathology.

*
* *

APPARITION ET PROPAGATION DE MALADIES LIÉES AU COMMERCE INTERNATIONAL CHEZ LES MOLLUSQUES BIVALVES DANS L'HÉMISPHÈRE NORD. – T. Renault.

Résumé : *L'élevage de mollusques bivalves est une activité aquacole marine très développée dans nombre de pays de la planète et notamment dans l'hémisphère Nord. Dans l'exercice de cette activité, nombre de pays ont été confrontés à des maladies infectieuses plus ou moins graves et durables. Des recherches ont été menées pour déterminer l'étiologie, l'épidémiologie et les mesures de prophylaxie concernant ces épizooties. Celles-ci sont principalement dues à des virus, des bactéries, des champignons ou des protozoaires.*

De plus, la production de mollusques marins donne lieu à d'importants échanges commerciaux entre différentes régions du monde. Ce facteur doit être pris en considération lorsque l'on cherche à expliquer l'apparition et la propagation de certaines maladies infectieuses dans plusieurs pays du monde. L'auteur met l'accent sur certaines maladies des mollusques bivalves, dues à des virus ou à des protozoaires, qui ont été signalées dans l'hémisphère Nord, compte tenu de leurs retombées économiques et des échanges commerciaux à l'origine de leur propagation.

MOTS-CLÉS : Commerce international – Hémisphère Nord – Maladies infectieuses – Mollusques bivalves.

*
* *

APARICIÓN Y PROPAGACIÓN EN EL HEMISFERIO NORTE DE ENFERMEDADES DE LOS MOLUSCOS BIVALVOS RELACIONADAS CON EL COMERCIO INTERNACIONAL. – T. Renault.

Resumen: *El cultivo de moluscos bivalvos es una actividad acuícola bien implantada en muchos países del mundo, sobre todo en el hemisferio Norte. Durante la fase de desarrollo de esta actividad, numerosos países han debido enfrentarse a brotes de enfermedades infecciosas de severidad y duración variables. Diversas investigaciones se han llevado a cabo a fin de determinar la etiología, epidemiología y medidas de control adecuadas para dichas epizootias. Las epizootias más importantes de los bivalvos han sido causadas por virus, bacterias, hongos y parásitos protozoarios.*

El cultivo de moluscos marinos da lugar además a importantes intercambios comerciales entre distintas áreas geográficas, y ello debe ser tomado en cuenta cuando se quiere explicar la aparición y propagación de algunas enfermedades infecciosas en varios países del mundo. El autor examina una serie de enfermedades víricas y protozoarias de los bivalvos registradas en el hemisferio Norte, importantes tanto desde el punto de vista de su impacto económico como de su dispersión ligada al movimiento comercial de moluscos.

PALABRAS CLAVE: Comercio internacional – Enfermedades infecciosas – Hemisferio Norte – Moluscos bivalvos.

*
* *

REFERENCES

1. ALDERMAN D.J. & GRAS P. (1969). – 'Gill disease' of Portuguese oysters. *Nature*, **224**, 616-617.

2. ANDREW J.D. (1976). – Epizootiology of oyster pathogens *Minchinia nelsoni* and *M. costalis*. *In* Proc. 1st International Colloquium on Invertebrate Pathology. Kingston, Canada, 169-171.

3. ANDREW J.D. (1979). – Oyster diseases in Chesapeake Bay. *Mar. Fish. Rev.*, **41**, 45-53.

4. BALOUET G., CAHOUR A. & CHASTEL C. (1979). – Epidémiologie de la maladie de la glande digestive de l'huître plate : hypothèses sur le cycle de *Marteilia refringens*. *Haliotis*, **8**, 323-326.

5. BANNING P. VAN (1979). – Haplosporidian diseases of imported oysters, *Ostrea edulis*, in Dutch estuaries. *Mar. Fish. Rev.*, **41**, 8-18.

6. BANNING P. VAN (1982). – Some aspects of the occurrence, importance and control of the oyster pathogen *Bonamia ostreae* in the Dutch oyster culture. *In* Proc. 3rd International Colloquium on Invertebrate Pathology. Brighton, Great Britain, 261-265.

7. BANNISTER C. & KEY D. (1982). – *Bonamia*, a new threat to the native oyster fishery. Fisheries Note, Ministry of Agriculture, Fisheries and Food. Directorate of Fisheries Research, Lowestoft, Great Britain, 9 pp.

8. BONAMI J.-R. (1977). – Les maladies virales des crustacés et des mollusques. *Oceanis*, **3**, 154-175.

9. BOUGRIER S., RAGUENES G., BACHERE E., TIGE G. & GRIZEL H. (1986). – Essai de réimplantation de *Crassostrea angulata* en France. Résistance au chambrage et comportement des hybrides *C. angulata-C. gigas*. International Council for the Exploration of the Sea. Comité Mariculture 1986/F:38.

10. CAHOUR A. (1978). – Epidémiologie de la maladie de l'huître plate, *Ostrea edulis* (L.). Thesis, Université de Bretagne Occidentale, Brest, 110 pp.

11. COMPS M. (1969). – Observations relatives à l'affection branchiale des huîtres portugaises (*Crassostrea angulata* Lmk). *Rev. Trav. Inst. Pêches marit.*, **33**, 151-160.

12. COMPS M. (1970). – La maladie des branchies chez les huîtres du genre *Crassostrea*. Caractéristiques et évolution des altérations, processus de cicatrisation. *Rev. Trav. Inst. Pêches marit.*, **34**, 24-43.

13. COMPS M. (1970). – Observations sur les causes d'une mortalité anormale des huîtres plates dans le bassin de Marennes. *Rev. Trav. Inst. Pêches marit.*, **34**, 317-326.

14. COMPS M. (1972). – Observations sur la résistance d'huîtres du genre *Crassostrea* au cours de la mortalité massive de 1970-1971 dans le bassin de Marennes-Oléron. International Council for the Exploration of the Sea. Shellfish Benthos Committee, Comité Mariculture 1972/K:22.

15. COMPS M. (1978). – Evolution des recherches et études récentes en pathologie des huîtres. *Oceanol. Acta*, **1**, 255-262.

16. COMPS M. (1980). – Les infections virales associées aux épizooties des huîtres du genre *Crassostrea*. International Council for the Exploration of the Sea. Special Meeting on Diseases of Commercially Important Marine Fish and Shellfish, Copenhagen, No. 6.

17. COMPS M. (1982). – Recherches sur un protiste, parasite nouveau de l'huître plate des côtes françaises. *Malacologia*, **22**, 1-2.

18. COMPS M., BONAMI J.-R., VAGO C. & CAMPILLO A. (1976). – Une virose de l'huître portugaise (*Crassostrea angulata* Lmk). *C.R. hebd. Acad. Sci., Paris*, **282**, 1991-1993.

19. COMPS M. & DUTHOIT J.-L. (1976). – Infection virale associée à la 'maladie des branchies' de l'huître portugaise *Crassostrea angulata* Lmk. *C.R. hebd. Acad. Sci., Paris*, **283**, 1595-1596.

20. COMPS M. & BONAMI J.R. (1977). – Infection virale associée à des mortalités chez l'huître *Crassostrea gigas* Thunberg. *C.R. hebd. Acad. Sci., Paris*, **285**, 1139-1140.

21. COMPS M. & DUTHOIT J.-L. (1979). – Infections virales chez les huîtres *Crassostrea angulata* Lmk et *Crassostrea gigas* Th. *Haliotis*, **8**, 301-307.

22. COMPS M., TIGE G. & GRIZEL H. (1980). – Etude ultrastructurale d'un protiste parasite *Ostrea edulis* L. *C.R. hebd. Acad. Sci., Paris*, **290**, 383-384.

23. COUCH J.A. & ROSENFIELD J.T. (1968). – Epizootiology of *Minchinia costalis* and *Minchinia nelsoni* in oysters introduced into Chincoteague Bay, Virginia. *Proc. natl Shellfish Assoc.*, **58**, 51-59.

24. ELSTON R. (1980). – New ultrastructural aspects of a serious disease of hatchery-reared larval Pacific oysters *Crassostrea gigas*. *Proc. natl Shellfish Assoc.*, **70**, 122.

25. FORD S.E. & HASKIN H.H. (1982). – History and epizootiology of *Haplosporidium nelsoni* (MSX), an oyster pathogen in Delaware Bay 1957-1980. *J. Invertebr. Path.*, **40**, 118-141.

26. GRIZEL H. & TIGE G. (1973). – La maladie de la glande digestive d'*Ostrea edulis* Linné. International Council for the Exploration of the Sea. Shellfish Benthos Committee, Comité Mariculture 1973/K:13.

27. GRIZEL H., COMPS M., BONAMI J.-R., COUSSERANS F., DUTHOIT J.-L. & LE PENNEC M.A. (1974). – Recherche sur l'agent de la maladie de la glande digestive de *Ostrea edulis* Linné. *Bull. Inst. Pêches marit.*, **240**, 7-30.

28. GRIZEL H. & TIGE G. (1979). – Observations sur le cycle de *Marteilia refringens*. *Haliotis*, **8**, 327-330.

29. HASKIN H.H. (1976). – Epizootiology of *Minchinia nelsoni* in oysters. *In* Proc. 1st International Colloquium on Invertebrate Pathology. Kingston, Canada, 166-168.

30. HASKIN H.H., STAUBER L.A. & MACKIN J.G. (1966). – *Minchinia nelsoni* n. sp. (Haplosporida, Haplosporidiidae): causative agent of the Delaware Bay oyster epizootic. *Science*, **153,** 1414-1416.

31. HERRBACH B. (1970). – Sur une affection parasitaire de la glande digestive de l'huître plate, *Ostrea edulis* Linné. *Rev. Inst. Pêches marit.*, **35**, 79-85.

32. KATANSKY S.C., DAHLSTROM W.A. & WARNER R.W. (1966). – Observations on survival and growth of the European flat oyster, *Ostrea edulis*, in California. *Calif. Fish Game*, **55**, 69-74.

33. KRANTZ G.E., BUCHANAN L.R., FARLEY C.A. & CARR H.A. (1972). – *Minchinia nelsoni* oysters from Massachusetts waters. *Proc. natl Shellfish Assoc.*, **62**, 83-85.

34. MACKIN J.G., OWEN H.M. & COLLIER A. (1950). – Preliminary note on the occurrence of a new protistan parasite, *Dermocystidium marinum* n. sp., in *Crassostrea virginica* (Gmelin). *Science*, **111**, 328-329.

35. MARTEIL L. (1976). – La conchyliculture française. 2. Biologie de l'huître et de la moule. *Rev. Trav. Inst. Pêches marit.*, **40**, 149-345.

36. PICHOT Y., COMPS M., TIGE G., GRIZEL H. & RABOUIN M.-A. (1980). – Recherches sur *Bonamia ostreae* gen. n., sp. n., parasite nouveau de l'huître plate *Ostrea edulis* L. *Rev. Trav. Inst. Pêches marit.*, **43**, 131-140.

37. POLANCO E., MONTES J., OUTON M. & MELENDEZ M.I. (1984). – Situation pathologique du stock d'huîtres plates en Galice (Espagne) en relation avec *Bonamia ostreae*. *Haliotis*, **14**, 91-95.

38. RAY S.M. (1966). – Notes on the occurrence of *Dermocystidium marinum* on the Gulf of Mexico coast during 1961 and 1962. *Proc. natl Shellfish Assoc.*, **54**, 45-54.

39. SINDERMANN C.J. & ROSENFIELD A. (1967). – Principal diseases of commercially important marine bivalve Mollusca and Crustacea. *Fish. Bull. Fish Wildl. Serv. U.S.*, **66**, 335-385.

40. TIGE G., GRIZEL H. & COMPS M. (1980). – Données sur le nouveau parasite de l'huître plate. Situation épidémiologique. International Council for the Exploration of the Sea. Special Meeting on Diseases of Commercially Important Marine Fish and Shellfish. Copenhagen, No. 39.