Report on the impact of recent *Crassostrea gigas* mortality in France and its consequences to oyster farming in Northern Ireland.

FABRICE RICHEZ - RICHEZ MARINE CONSULTANCY
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*Aquaculture Initiative,*
13 Innovation House,
Down Business Centre,
46 Belfast Road,
Downpatrick,
BT30 9UP

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TABLE OF CONTENTS

INTRODUCTION

1. IMPACT OF THE OYSTER HERPES VIRUS DISEASE ON THE FRENCH AND NORTHERN IRELAND SECTOR
   1.1. Facts on the French industry
   1.2. Role of the inter-professional organisation in France
   1.3. Ruling and institutional framework for Shellfish farming in France
   1.4. Specialisation of the French oyster industry
   1.5. Impact of mortalities on different sectors of activity
   1.6. Impact on production and market price
   1.7. Impact to the Northern Ireland oyster industry

2. REVIEW OF RELEVANT RESEARCH CARRIED OUT ON MASSIVE OYSTER MORTALITY AND ASSOCIATED DISEASES
   2.1. Research institution and centres on oyster mortality in France
   2.2. Actions that were put in place by IFREMER to tackle the massive oyster mortality issues since 2008
   2.3. IFREMER surveillance and research program on oyster mortality
   2.4. Oyster mortality before 2008
   2.4.1. History of French oyster production from the 1920’s to the 1990’s
   2.5. Findings from 1990 to 2006
   2.6. Characteristics of the mortalities from 2008 to 2012
   2.7. Characteristics of the mortalities that happened after 2008
   2.8. Potential causes of mortality since 2008
   2.9. Effect of site and aquaculture practices (exposure time and density) on survival rates
   2.10. Theories on the origin of the virus
   2.11. Theories on the emergence of OsHV-1μvar
   2.12. Aquaculture practices that stimulated the emergence of the variant OsHV-1μvar
   2.12.1 Pathogenicity of OsHV-1 μvar
   2.12.2. Effect of herpes virus on C. gigas
2.13 Horizontal and vertical transmission of OsHV-1 \( \mu \)var

2.14 Factors impacting on the spread of pathogens in oyster farming

3. REVIEW OF HOW THE FRENCH SECTOR HAS RESPONDED TO THE EMERGENCE OF OSHV-1 \( \mu \)VAR

3.1. Responses of the French professionals to oyster mortality

3.2. Production strategies put in place by aquaculture professionals

3.3. Production strategy II: Development of specific aquacultures practices

3.4. Development of new techniques and further investigations

3.5. Other responses and initiatives

3.6. The potential use of mussels that act as a biological curtain to reduce mortality rates

3.7. The ultimate solution: production of selected oysters

3.8. Sanitary measures put in place in Europe

4. TRANSFER OF KNOWLEDGES AND OUTLOOK OF THE OYSTER SECTOR IN NORTHERN IRELAND AS A RESULT OF THE FRENCH EXPERIENCE

4.1. Seed supplies

   Potential of remote setting techniques to produce seed in Northern Ireland

4.2. Seed supplies: SWOT analysis

4.3. Potential of deep sea and suspended culture techniques to produce oysters at low mortality rates

   General considerations

4.4. Deep sea and suspended cultures: SWOT analysis

4.5. Factors contributing to mortality outbreaks

4.6. Recommendations that may help to reduce the risk of mortality

4.7. Strategy to develop in an epizootic context

4.8. Diversification for retail and development of other parallel activities

4.9. Overall statement, recommendations for long term development
EXECUTIVE SUMMARY

Since the 1990's, massive mortalities of Crassostrea gigas (i.e. the Pacific oyster) were often referred to as a “summer mortality” and were related to a combination of environmental factors, such as the state of the oyster and the presence of pathogens in the sea. The recently detected variant OsHV-1 μvar is the major pathogen associated with the massive mortalities that have hit oysters since 2008. Characteristics that differentiate these mortalities from previous summer mortalities are their recurrence in the last five years, ubiquitously around the French coast, and at a high degree of intensity. Mortalities also affect seed more than juveniles and to a lesser degree adults. They occur in waves during the summer, following the south - north temperature increase and begin once temperatures reach 16°C.

Mortalities were also reported in many other production countries. The Island of Ireland and the UK are also affected, but to a lesser extent. It is suspected that these differences in mortality are caused by colder sea temperatures, a lower degree of intensification of oyster farming and the implementation of appropriate sanitary measures to contain the spread of OsHV-1 μvar.

International research into the causes of these massive mortalities allowed a better understanding of the virus and how it affects the oysters. The BIVALIFE consortium, a European research network for the surveillance of the disease should give a better understanding of how it affects the oysters and how to control it.

As a French response to the massive mortality outbreak, many research initiatives (private and national) are underway to produce a selected oyster that has a higher survival rate. Producers have opted for two production strategies: 1) avoiding mortality (factor “isolation” in pond, nursery, and disease free containment areas) and farming at cold sea temperatures; 2) the development of specific aquaculture practices to reduce mortality (i.e. oysters positioned higher on the shores, late seed transfer, higher densities in oyster bags) along with more specific technology (i.e. off-shore, longline suspended culture).

Some producers who have access to large quantities of natural seed are in favor of fast production cycles with farming at high density to produce strong resistant seed at a lower cost. When seed is rare and expensive (i.e. hatchery seed), safer aquaculture practices are put in place to try to reduce mortality the first year (i.e. work on higher shore with slower growth of the seed). New technologies were also developed, such as in deep water or suspended cultures for shortening the production cycle and therefore to increase business turn over.

Remote setting techniques could be developed in Northern Ireland, to locally produce seed on artificial collectors, this would have the advantage of reducing shellfish movements and the spread of diseases. More specific to the Island of Ireland, this technique could compensate for the shortage of hatchery seed experienced by producers situated in “disease free” compartment areas.

Today there is a market opportunity to grow market sized oysters for the French market and also to produce oyster seed and juveniles at the best cost rate in the “disease free” compartments. For these reasons, this may be the right time for Northern Ireland to further develop and invest in the oyster industry.
INTRODUCTION

Massive mortalities on C. gigas have been regularly reported in different parts of the world since the 1950's (Lynch, 2012; Renault, 2011; Renault, 2012). These mortalities were often referred to as “oyster summer mortality” and may have affected different development stages such as spat or adults. Scientific investigations have concluded that mortalities were linked to multifactorial interactions between the oyster, the environment and the presence of pathogens (wwz.ifremer.fr/ “Bilan du défi Morest, 2006”). Moreover, some studies also showed a causal link between pathogens such as OsHV and spat mortality outbreak during the summer period (Garcia et al., 2011).

From 2008 in France, the summer mortality situation aggravated when oysters started to die massively and ubiquitously around the French coast. Since then massive mortalities have occurred every year, with mortality rates averaging 80% of the stock. Typically, mortalities affect seed and juveniles oysters, from the spring in successive waves to the autumn and follow a south-north gradient path, closely following the increase of temperature from April onwards. Severe mortality events in C. gigas were recently reported from the main European oyster production countries from summer 2008-2009 (EFSA, 20110) and in other parts of the world from 2010 (Renault, 2011).

Major pathogens that affect C. gigas are OsHV-1 along with Vibrio spp., but the variant OsHV-1 μvar has become dominant since its discovery in France in 2008 with a higher mortality rate and a higher incidence rate (Garcia et al. 20011). OsHV-1 μvar has been described using real time PCR detection technology and PCR product sequencing (Segarra, et al. 2010).

The newly reported OsHV-1 μvar was found at high levels and was the dominant pathogen in samples of oysters during massive mortality events and it is therefore associated as the major pathogen agent that caused the mortalities since 2008. However, it cannot be the only cause for mortality on its own as its DNA was found in oyster samples in Italy and Spain without mortalities (Dundon, 2010; EFSA, 2010; www.eurl-mollusc.eu1). OsHV-1 μvar is highly contagious, and horizontal transmission has been demonstrated during its replication phase. Many cases of co-infection with Vibrio splendidus, and the presence of other Vibrio spp. were also reported, but their significance in the mortality since 2008 is still uncertain.

Compared to France, the Island of Ireland has been less affected by massive mortalities and OsHV-1μvar has not been detected in 19 oyster production areas (17 in the ROI, 2 in NI). These differences could be explained by a lower degree of intensification of oyster farming (e.g. production: 7,000 tonnes from Ireland verses 80,000 tonnes in France in 2011), limited shellfish movements between productions areas, and lower summer temperatures often below 16˚C.

The Northern Irish oyster production is mostly exported in bulk to France where it is finished and depurated before being sold to the local retail market. The most of the seed are also purchased in French hatcheries, and at a lesser extent from UK hatcheries. Therefore there is a constant man-made migratory flux of oyster seed between France or UK and the Island of Ireland. A consequence of this is a rapid spread of pathogens between oyster production areas.

OsHV-1 μvar is not a pathogen listed requiring an obligatory declaration (in OIE’s Aquatic Animal Health Code). However, taking into account the large scale of the mortalities and economic implications on the oyster industry, the French, British and Irish authorities have engaged with the European Commission, to produce legal safeguard measures to avoid the further spread of the disease to oyster production bays considered as virus free (http://www.oie.int/doc/ged/D11038.PDF).

Many research and monitoring have been carried out in France by IFREMER and Universities to identify the factors (i.e. environmental, pathogen, state of the oyster) inducing mortalities on such a scale. Investigations into best aquaculture practices and technologies to reduce these mortalities have already been extensively carried out by applied research centres in aquaculture or by oyster farmers. Factors that have been identified as having an impact on mortality rates associated to the presence of OsHV-1 μvar are: the sea temperature, the degree of intensification of aquaculture, culture practices (period of seed transfer, culture densities, handling of the oyster, duration of emersion at low tide), methods of culture (suspended, bottom culture, in bags), site proximity and hydrodynamics, pollution, the presence of other pathogens and the genotypic resistance of the oyster to the virus, and the condition of the oyster (age, maturation, triploid, diploid).

Taking into the factors cited above, it has been found that it should be possible to avoid the horizontal spread of OsHV-1 μvar with appropriate sanitary measures such as shellfish movements, avoid mixing of oyster batches. Mortality rates may also be reduced with late transfer of seed after the “critical periods”, or by keeping seed on higher shores. It is also possible to reduce or avoid mortalities, taking into account the isolation factor (ponds, nursery, off shore, away from main oyster production areas) or below critical temperatures (below 15-16˚ C). Deep water cultures techniques may also be used to avoid mortalities at cold temperature.

1 (http://www.eurl-mollusc.eu/Main-activities/Tutorials/Herpes-virus-OsHV-1)
or to gain productivity by shortening the production cycle.

Today, there is a great market opportunity for Northern Ireland to produce disease free seed at a competitive rate. The market for bulk oysters is also very good as a result of French production losses averaging 50,000 tonnes. The only commercial hatcheries situated in “disease free” compartment are situated in the UK and are running under capacity so they cannot supply every oyster farmers situated in bays with similar sanitary status.

The aim of this report is to give a good understanding to Northern Irish oyster farmers about the French situation. An overview of research carried out about the disease in France has also been given, following a path of progression from the first records of mortalities, the summer mortalities and the massive mortality outbreak since 2008. Then, from what was learned in France, the report looks at what practices or aquaculture technology can be used to reduce the impact of mortalities in Northern Ireland. Also, what are the opportunities to further develop the Northern Irish oyster industry in an epizootic context. Many case studies are used to illustrate this report to try to give the best representation of the actual situation.
1. IMPACT OF THE HERPES VIRUS DISEASE ON THE FRENCH OYSTER INDUSTRY AND ITS IMPACT IN NORTHERN IRELAND

1.1. Facts on the French industry.

Oyster farming was first developed centuries ago to face a problem of overfishing and shortage but these days this industry is an integral part of the heritage in French coastal communities. In reality it has fully integrated into the environment and contributes to the economic development of coastal regions alongside other coastal interests (e.g. nature protection, navigation, tourism). Its socio-economic impact is of considerable importance, it generates a turnover of an estimated €259 million (2009), and accounts for 29% of the turnover for the main species sold by the French fishing and aquaculture industry. In terms of tonnage, it represents 65% of all shellfish species in France (franceagrimer, 2011).

The French shellfish farming industry comprised 2,952 businesses in 2009 (21% less than in 2001), which employed 17,840 people directly, corresponding to 9,455 permanent jobs, 47% jobs being seasonal (Agrest, 2009). The French industry had a credit balance of 28 million euros in 2007 with exports higher than imports (9,000 tonnes exported vs 3,700 tonnes imported) (www.agriculture.gouv.fr/la-conchyliculture, 2011). One third of all businesses are located in Poitou-Charentes Region, followed by the Mediterranean region and then South Brittany.

The species most commonly grown in France is Crassostrea gigas, “l’huître creuse” (i.e. the Pacific cupped oyster) and then to a lesser extent Ostrea edulis, “l’huître plate”. (i.e. the native oyster). Ostrea edulis represents 2.5% of the nation’s oyster production with 2,000 tonnes (aquaculture.ifremer.fr/ huître plate). Using conventional aquaculture techniques, it takes three to four years to grow an oyster to commercial size on the Atlantic coast, and two to three years in the Mediterranean Sea because oysters are always underwater and the water is warmer.

C. gigas have also been introduced in many countries around the world, having expanded from 437,000 tonnes in the 1970’s to 4.4 million tonnes in 2003. This species has become so successful in France that the FAO2, ranks its production as the 4th largest worldwide (115,000 tonnes in 2003). Other significant production countries were in Asia, with China (3.9 million tonnes), Korea (238,000 tonnes) and Japan (261,000 tonnes). In 2008, France produced 128,500 tonnes of oysters; since the massive mortality outbreak, production has been down to nearly 80,000 tonnes (2011).

1.2 Role of the inter-professional organisation in France.

The CNC3 is the National Committee for Shellfish culture. It is the inter-professional organisation that represents the oyster farming industry from the production to the distribution. Membership of the CNC is mandatory for all 3,700 members of the profession (mussels and oyster producers). Their representatives are elected by their own members. The CNC is subdivided at a regional level into 7 CRC4 situated in the zone of production: (see Fig. 1 below).

The CNC is regulated by the law n° 91-411 of May 2nd, 1991 related to sea fisheries and marine aquaculture inter-professional organisations. The new law n° 2010-844 of July 7th, 2010 deals with the modernisation of agriculture and fisheries, this allowed a better optimisation of its functions by the articles L912.6 to L912.7 of the rural code. (www.senat.fr, www.legifrance.fr). To carry out its missions, the CNC is placed under the supervision of the Minister of Agriculture, Food, Fisheries, Rural Affairs and Spatial Planning (MAAPRAT). The Role of the CRC, within their remit territory, is to represent and promote the interests of the oyster farming industry. Much consideration is given to the management and protection of the shellfish resources, the scaling of production to planned levels, the promotion of the shellfish products and also of the organisation itself. The role of the CRC has been of major importance to encourage and engage research programs and technical investigations on mortality in partnership with IFREMER and research centres. More recently it has been promoting an initiative of the National program which is looking to develop the production of selected oyster families presenting higher survival rates.

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4  CRC: “Comité Régional de la Conchyliculture”, The Regional Committee of Shellfish Farming.
Fig. 1: Map of France with production of C. gigas by CRC district (www.cnc-france.com).
1.3 Ruling and institutional framework for shellfish farming in France.

At a departmental level, the state services represented by the DDTM\(^5\), IFREMER\(^6\) and the CNC are charged to ensure the co-management of resources and shellfish farming activities. In particular, these organisations ensure the application of measures established by decree concerning the conditions of use of aquaculture licenses and license applications during the operation of mariculture. Therefore, each department as defined has its own aquaculture division, and oyster farmers themselves are playing an important role in the management of their activities. These conditions are described in a document called the “Schema des structures” (this includes the area used for aquaculture, the number of structures, method of culture, production cycle, species cultivated).

1.4 Specialisation of the French oyster industry.

Oyster production sites are part of 14,000 ha of licensed area situated on the DPM (Public Maritime Domains). From the English Channel to the Atlantic Ocean and the Mediterranean Sea, the French coast presents a very large variety of ecosystems. Oyster aquaculture technology is characteristic of each region and depending on the environmental resources available, oysters can be farmed directly on the bottom; off the bottom on trestle or in cage; in suspension in cage or in lantern-like net.

Depending on business targets and marketing opportunities, oyster farmers have also specialised into a specific sector of activity, such as the production of seed and, or half grown oyster, or only the finishing and expedition, or the full production cycle. This specialisation has also resulted in multiple transfer of oysters between regions across the country and also at an international scale.

There are also businesses that have diversified into the production of two species (usually oysters with mussels, this represents 12% of the producers). Diversification with different species, can be done separately or sometimes in polyculture (e.g. clams/prawns, or winkles/oysters). This is a strategy which has financially helped many businesses go through a period of crisis, such as this one occurring now with the massive oyster mortality.

1.5 Impact of mortalities on different sector’s activity.

Hatchery nursery:

Oyster seed (diploids or triploids)\(^8\) are produced in a hatchery at a specific stage of development (from 0.8 to 1 mm) under controlled conditions throughout the year. They are transferred into a nursery for further growth from T4\(^9\) or T6 up to T10 or above. There are five hatcheries in France, making up 30% to 40% of the overall annual French seed requirements (Source: Tristan Renault). This percentage is variable and would depend on the hatcheries capacity and the success of natural setting rates. In the future the new challenge to the hatcheries is to produce a selected seed issued from genetic selection of families presenting higher survival rates. A target date for the production of selected seed under the French hatcheries genetic selection program has been set for 2015 (see Chapter 3). A comprehensive list of UK, Irish, and French Hatcheries can be found in Annex 1 and are geographically situated on the map Figure 4 in Chapter 2.

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\(^{5}\) DDTM: “Directions Départementales des Territoires et de la Mer”, The Departmental Direction of the Sea and Territories.


\(^{7}\) Finishing: in this context this is the finishing stage to improve test and texture of the oysters, also called “affinage” in French.

\(^{8}\) Triploid: a sterile oyster having 3 time the haploid number chromosome in the cell nucleus.

\(^{9}\) T. "Taille" translated in English as grade (G) is the unit used to classify an oyster by size. A T20 or G20 oyster is an oyster that is retained on a 20 mm mesh size sieve. This measure is used to classify seed and juvenile oysters into different grades: a T7- T8 is an oyster seeds weighing between 0.4 to 0.6 g; a T20 - T25 is an oyster seeds weighing 10 to 15 g. (Source: D. Mille, CREAA, 2008).
The main advantage of French hatchery situated in the “Polder de Bouin” is the use of geothermic underground sea water wells rich in nutrients and sterile, that is used for the phytoplankton culture to feed the oyster larvae and seed.

Major losses occur when seed are transferred at sea for pre-fattening (T15-T25) and availability of this grade is scarce because of high mortalities at this stage and shortage of hatchery seeds (Source: Marina Godet, France Naissain).

Hatcheries are regularly carrying out analysis for the detection of OsHV-1 and the variant OsHV-1 μvar and oyster listed diseases as an obligatory declaration (in OIE’s Aquatic Animal Health Code)10, at different stages of growth of the oyster seed in a recognised laboratory. In fact, in France, seed are transferred from hatcheries to outdoor nurseries and therefore are more likely to become contaminated at this stage. At a national level, no official OsHV-1 μvar detection programme is developed in commercial hatcheries. Also as a preventative measure, because it is not possible to guarantee that 100% of nursery seed are all disease free, seed imported from “non-disease free” areas are forbidden for transfer into a “disease free area”, (Dr Deborah Cheslett, MI)11. Guernsey Sea Farms Ltd., Morecambe Bay Oysters and Sealsalter Shellfish (Whistable) are the only fully commercial scale hatcheries/nurseries situated in a “disease free” area, and so they can still supply oyster production areas which have a similar high sanitary status (principally in the UK and Ireland). Today their production capacity is less than the total demand and they cannot supply every oyster farmer on the Island of Ireland so regular customers are prioritised.

Since 2009, some seed produced by commercial French hatcheries have come from the “Plan de Sauvegarde”, this was the safeguard plan put in place by the French Ministry of Agriculture, the CNC and IFREMER to help hatcheries to produce triploid seed presenting higher survival rates produced from a cross of selected female oysters from MOREST12 and selected tetraploid13 male oysters (see Chapter 3).

In 2003, French hatcheries were producing 780 million seed, but by 2009 financial investment and technical progress rapidly doubled this number (WGMASC, 2003). The shortage of seed since 2008, actually boosted the production capacity to over 1 billion of seed by 2011 and a provisional capacity of 4 billion seed for Génocean in its own for 2012 (Sources: www.decideursenregion.fr; Éric Marissal interview, Mars 2012). Since 2008 prices from hatcheries/nurseries are relatively stable, unlike for juvenile seed (T15-T25) and half grown oysters. The price for T4 triploid is €10/1000 (France Turbot, Satmar Vendée Naissain), €7/1000 (Génocean); and average for T6 at €11-12.5/1000, and up to €18/1000 for T8 (Cultures Marines n°254, mars 2012).

Natural seed producers:

Called “naisseur” in France, natural seed producers, obtain their seed from natural wild settlements on artificial collectors. The natural settings success is dependent of the natural conditions (e.g. salinity, temperature, tides and currents, weather). The quality and quantity and size of seed collected are very variable from year to year and very heterogeneous between sites. It is not uncommon to have two or more ‘waves’ of significant levels of setting on one collector in the same year. The principal areas for seed collection are Marennes-Oléron, Arcachon and Bourgneuf’s Bay (see Figure 4).

For the last 10 years, the setting rate in the Bassin d’Arcachon has become very unpredictable, with booms and crashes of seed, there have been zero settings (2002, 2005, 2007) or very poor settlement (year 2009, 2010, 2011) or overabundant settlement (years 2003, 2006, 2008) (Stephanie Pouvreau, 2012). The average number of seed per tile in March 2012 at Arcachon was only 30 to 50 compared to a few hundred before 2008 - and in some exceptional years thousands per tile, see photos below. This seasonal variability is less marked at Marennes-Oléron and setting rates are much higher, with settings of over 100 seed per “coupelle” recorded, compared to 10 at Arcachon (IFREMER project Velyger, online database access). As a result of increasing sea temperature from global warming and a well-established population of C. gigas around the French coast and with a south to north setting trend since its introduction, since the 1970’s, the situation is changing for the “naisseurs”. Producers from “Baie de Bourgneuf” (Pays-de-Loire) and Brest (Brittany) are now starting to collect seed from natural setting (IFREMER, annual report: Velyger, 2011). The production of natural seed is estimated at 1,390 tonnes, with a turnover of €7.9 million for the sale of natural seed against €11.1 million for hatchery seed (Agrest, 2009).

10 OIE: Epizootic International Office.
11 Deborah Cheslett, Marine Institute of ROI (interviewed for this report in March 2012).
12 MOREST: MORTalité ESTivale de l’huître, Oyster summer mortality.
13 Tetraploid: Tetraploid oysters (cells with four sets of chromosomes) are spawned with Diploids oysters (cells with two sets of chromosomes) to create triploid (three sets of chromosomes), sterile oysters.
Producers from Arcachon do not understand why the setting rates which used to be high at Arcachon are so low. It appears on the observatory network\textsuperscript{14} (Sources; IFREMER\textregistered s project Velyger) that small larvae are present in abundance, but medium and large ones have disappeared. A larval dispersal from the sea current could not be solely responsible for this during these last 4 years. Every producer in the bay has pointed out the problems of pollution for example from the increasing pressure of tourism in the summer (e.g. the appearance of PPCPs\textsuperscript{15} in waste water, the sudden overload of the waste water treatment plants in the summer or the reduction of fresh water inflow in the bassin d’Arcachon). The actual situation could also be compared to the one between 1977 to 1981 when during 5 years there was a total failure of natural setting because of the use of TBT\textsuperscript{16} base made anti-biofouling paints (Maurer D. & Borel M., 1990). There are also pollution events from local industries such as in July 2012 with the accidental discharge of 100 to 500 m\textsuperscript{3} of oily and corrosive liquid from a paper factory into the Lacanau river, streaming into the basin d’Arcachon (article in the newspaper “Sud Ouest”, B. Dubourg & M. Kagni, 2012). Added to that is the fallout of the herpes virus on the local industry. At Arcachon, producers have had to face two problems since 2008: mortality on larvae and mortality of seed. As a direct consequence, prices have become unaffordable (up to €10/1000 for good quality, well graded seed) and many producers at Arcachon are now setting their seed further north in Poitou-Charentes and Pays-de-Loire. This shortage of seed is very well reflected with a drop in production in Arcachon from 2008 (10,500 tonnes) to 2011 (5,500 tonnes) (source: Jean Charles Mauviot, Director of the CRC Arcachon). Moreover, for a producer at Arcachon, unlike in other bays, natural setting is also limited by the surface he can use to collect natural oysters (max. 15% of the production area), as pre-defined in the “schéma des structures”, the document regulating aquaculture licenses mentioned earlier.

With such high mortality levels since 2008, and poor setting rates for the last 3 years at Arcachon, there are not many (if at all) natural seed producers left, as it is not profitable anymore to produce natural seed as your sole income. Many producers and producers-dispatchers or producer breeders are also “naïseurs” themselves and operate the full production cycle. Only 2\% of all businesses in France are producing half grown seed (Agrest, 2009), and since 2009 this trend has been decreasing more and more (Source: O. Laban, President of the CRC Arcachon).

The work involved in preparing collectors, placing them at sea and detaching them is considerable, especially for the tiles. These collectors are still used because they are the best in comparison to plastic collectors (e.g. tubes, plénos, coupelles). And even if settings are very low, “naïseur/ breeders” are still putting them at sea every year; the problem is that it is impossible to predict if the year is going to be a success or not. For many producers, last year’s setting was a pure waste of time, energy and money.

\begin{itemize}
\item \textbf{Producer breeders}\textsuperscript{17}
\end{itemize}

This sector represents 24\% of the industry, producing their own seed, but they also buy hatchery seed and are supplying all sizes of oysters (i.e. half grown and large) that will be sold to producer-dispatchers or trading agents (article in the newspaper “Littoral”, 2011). These days because mortality is so high on collectors, it is more difficult to find half grown oysters for sale and volumes are small, prices are high (€4/kg, for 30 gram oysters, which is €120/1,000 oysters). Small businesses (i.e. 15-30 tonnes production

\textsuperscript{14} IFREMER Observatory network, Project Velyger: database access for temperature, maturation , setting rate, and reports: www.ifremer.fr/velyger/
\textsuperscript{15} PPCPs: Pharmaceuticals and Personal Care Products.
\textsuperscript{16} TBT: Tributyltin compounds, considered toxic chemicals
\textsuperscript{17} Producer breeder, in French : “producteur éleveur”.

13
per annum) are still able to stay profitable in those areas where there is a good natural setting (e.g. Marennes or Vendée). For others with none or a poor natural setting rate, times are becoming very difficult, buying hatchery seed and then losing 80% of it the same year is not affordable. There are also a lot of concerns for producers who have not bought enough seed after the 2008-2009 mortality. The gap of marketable oysters from 2011 (2-3 years after mortality) makes it difficult to reinvest in seed when there is not enough oysters for sales.

The experience of professionals such as Mr Francis Gaboriau could well illustrate the present situation: “I am a species that will soon be extinct, because producers breed from natural seed only and working within the Bassin Marennes Oléron alone, I can tell you there are not many like me”, he answered when asked to describe his business situation as a producer breeder in the Bassin of Marennes Oléron. Natural seed (often referred to as wild seed) are collected using trestles, rods and tubs. Most of the mortality happens in the first year (with levels as high as 70-80%), but by 18 months old, oysters detached from collector tubes are no longer affected by the mortality. Oysters are grown for 3-4 years, with a finishing stage in ponds to add a small value, then sold to local producers-dispatchers or a commercial agent. Oysters cannot be sold directly, this would necessitate the use of depuration centres under permanent food safety management procedures based on HACCP principles (Lee R., Lovatelli A., Ababouch L., 2008). Small four year old oysters that have very slow growth (either called “brûlots” or “boudeuses”) are also sold to be grown in another bay.

Since high seed mortalities occurred in 2008 Mr Gaboriau’s annual production has dropped to 15 tonnes/year, (50% less than in 2008). But as his deadline for retirement is soon, everything is paid off and there are no more investments or staff to pay, and his production costs are kept very low. Seed is free and abundant and the only impact on the business is a lower volume of sale due to the high mortality rates. The loss of profits resulting from a lower volume of sales is compensated by higher prices. Today this rather small business is still profitable because of the increase in the price of oysters. Prices for producers selling in bulk have been rising by an average of 50% since 2008, climbing from a range of €1.80/kg for n°3 and €2.10/kg for n°2 to €3.50/kg for both sizes, which is 50 cents higher than the price offered on the Island of Ireland for standard quality oysters (Annex 3). Juvenile oysters (called in French “garniture”) which have been sold only at 90 cents /kg for 20 years are now sold between €2.50 and €3.20/kg, depending on size. In the past, bottom culture producers at Quiberon could get small oysters cheap, but today prices are too high for them: growers keep them for their own production because they are worth more. During all the stages of the production cycle, oysters are moved from place to place all around the Bassin, with collectors for natural setting in one area and small oysters going back to a site deposited in another area, before being transferred on to the production site until July to avoid mussel seed. Then large oysters are put in ponds for the final stage. But if all the natural resources are exploited according to the best methods of culture at each stage of the production cycle, the pathogens are also moved around between generations using this cultural practice.

In conclusion, Mr Gaborio’s business would not be worth much if he had to sell it tomorrow, and as it would be difficult for someone else to take over, he will keep going on as long as sale prices are maintained, until retirement. This case scenario happens for similar scale businesses in other regions, and it is even more difficult for young farmers who still have to pay loans on their investments.

Producer dispatchers

This sector represents the majority of the profession and they follow the full production cycle from seed (natural setting or hatchery) to marketable oysters. There are two types of producer dispatchers:

1) Small family businesses: they grow all their oysters that will be sold directly to local consumers. This activity is well developed and represents 28% of the volume of oysters sold. Larger businesses will pack their products for the mass market retail network (17% of the volume of oysters sold) and buy more oysters from other growers to top up their own production (Agrest, 2009).

2) Business that would sell part of their production as bulk to dispatchers/ wholesalers/ agents/ other producers and the other part for retail.

Impact on producer dispatchers is highly variable, depending on the scale of the business, the intensity of mortality, the degree of diversification, the availability of natural seed or not, the length of the cycle of production, the use of sites in other bays (e.g. the setting of oysters at Marennes and in Vendée or other production sites in Normandy and in Ireland). There are producers working with only one group of species and others that diversify with two or more species, usually mussels. For Norbert Proteau, a producer-dispatcher of mussels and oysters at Marennes, if “I hadn’t had mussels, I would have closed down long ago.”

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18 HACCP: Hazard Analysis Critical Control Point. An internationally recognised system which identifies, evaluates, and controls hazards which are significant for food safety. (Sources: Lee R., Lovatelli A., Ababouch L., 2008).
Photo left: small purification centre on the Island of Oléron. right: oyster farmer hand sorting oysters before depuration at Arcachon. Many small and new businesses are single handed and poorly mechanised. They are the ones the most affected by the mortality because they haven’t the funds to buy seed.

As a result of the shortage of production, some producers are unable to satisfy their market demand and have had to stop making sales at the Saturday market for a few months (source: O. Laban, President of the CRC Arcachon). To complete their production, oysters can be purchased in bulk from other farms or from imports with an agent. However, such an operation may not always be suitable to everyone, depending on business size, location and specialisation. Taking an example, standard oysters n°3 bought in bulk at €3.50/kg from another French producer could be sold at €5.20/kg, which is €1.20/kg of a margin. From that, an average cost of 50 cents /kg can be deducted for depuration, and packing. On top of that there are additional costs such as mortality losses, handling, stocking, marketing, delivery, which are highly variable from business to business. The marketing also has to take into consideration the origin and the product specificity which are different from locally grown oysters. So that buying oysters from other producers, when available, might not be a lucrative solution, often dispatchers just want to maintain market share but with no margin.

The economic situation in France is difficult, but so far consumers have adapted to the increase in the retail price for oysters and thus have helped to maintain oyster farming as a profitable activity. Oysters that are sold directly at the farm, or at the Saturday market, represent a big part of the sale of French production. Other regional products such as wines or fish soups can also be sold alongside with other local seafood products (e.g. whelk, sea-urchins). The demand is very strong at the moment, and oysters are selling very well.

Mr Balmefrozol works with his father in the “Bassin de Thau” (i.e. Mediterranean region). Sharing his experience with us, he argued that he was not worried about the future of his profession. His business is small but big enough to be profitable to all his family. His father is to retire soon and he may have to hire an employee, but in his opinion the mortality question is not so dramatic. The first consequence of mortalities is the shortage of oysters for sale, and even higher prices of sale do not make up for the loss in profit that would have been generated by higher production before mortality occurred. A minimal production volume has to be reached to keep the business afloat, extra oysters are profit: under a certain production level, whatever the price, the business cannot be profitable. The second consequence is the higher cost per unit of seed with 80% mortality and extra labour to sort out dead oysters. In the Mediterranean, juvenile oysters (20 grams) are glued in three’s by cement on a rope. All the dead oysters have to be sorted out from the live ones before applying this technique. For a small business, this is manageable; for a larger business, it requires the employment of extra labour (Mr Balmefrozol has even invented an artisanal system of grading with holes in a fish box to help with the grading of dead juveniles). But what has made the difference between loss and profits is the increase of 73% in the selling price since 2009. Medium oysters sold directly at the farm after depuration (in plastic bags) went gradually from €3.80/kg (2010) to 4.80/kg (2011), and now in spring 2012 at €5.20/kg. A further increase of 20 cents is expected next year.

From a marketing point of view, there are the usual customers who understand and pay the difference because they can afford it, others who take in only half a dozen instead of a dozen. Then there are the oyster ‘amateurs’ who do not pay much attention to the price. This situation seems to better relate to growers who can manage their production at low cost with no or few employees than larger business with 10-15 employees. Ultimately, all depends on the added value of the type of product that is for sale, it should
be noted that the price on the top quality range products has not increased much (10-15%) since the crisis because prices were already high. For example, nº3 “special de claires” (Marennes-Oléron) would be sold around €8/kg at the farm (David Hervé, “Le Cabanon de l’huître”, Marennes).

Sale price couldn’t increase further for the consumer, but most understand the difficulties of the business at the moment. “They are still buying oysters, but in less quantity”. As Mme Jacquet, a regular market-goer at Montpellier in the south of France, puts it: “The customer that used to come every week for his dozen oysters is now coming every 2 weeks or just once a month instead”. The only advantage of diminished stocks is the better quality of oysters. Farmers are taking greater care of them, so they are well-shaped and meatier (article in newspaper “Sud Ouest” B. Dubourg, 2011).

The situation becomes more critical for larger businesses supplying superstores with less added value, more equipment, higher risks, and employees to be paid, getting 80% mortality is much more difficult to handle. Only well-organised structures, with the right investments, having bought enough seed even when they were having mortality and sorting out natural seed from other bays or growing their oysters on sites with low mortality (such as in Northern Ireland) or with shorter production cycles can afford to pursue business. It has been recognised by all the professionals interviewed that the ones having only 60% mortality of seed are still making good profits.

 DispatchQueue and wholesalers

Dispatchers businesses buy about 23% of the total volume of bulk oyster sales. These oysters will be re-sold at all levels of the distribution network (40% to the mass market resell, 45% to fishmongers and restaurants) (Agrest, 2009). They are all equipped with a purification centre. Many dispatchers are located in the Poitou-Charentes region because of their use of small ponds called “claires” which are often used for finishing the oysters before sale. This region was actually selling 48% of the overall French production in 2009 (46,979 tonnes; sources: Agreste, 2009) meaning that this region sells more than it produces. These businesses are affected by the shortage of oysters due to mortality, also by the higher prices for bulk oysters and difficulties to raise the prices for sale to the retail sector. Crucially dispatchers selling exclusively to superstores cannot guarantee volumes anymore. However, the mortality situation is well known and customers have adapted to price rises. Dispatchers are not directly affected by seed mortality as they are not producers and they do not handle seed. Since the mortality crisis, and with an increasing risk of unpaid customers, margins have been tight. Many ask to be paid upfront or take out insurance.

Wholesalers are fish merchants buying oysters from producers/dispatchers. Product is also sold to all the distribution network, plus some bulk is sold to other producers/dispatchers or for export. The impact of mortality on wholesalers is less because their sales are not reliant only on oysters (sources; Codimer Import-Exports, Gujan Mestras, Bassin d’Arcachon). The demand in bulk oysters being high and wholesale prices being relatively low, volumes of transaction on Pacific oysters have been lower since 2010.

1.6 Impact on production and market prices

French production has fallen from about 130,000 tonnes (2008) to 80,000 tonnes (2011), that is a reduction of 50,000 tonnes of oysters on the market (www.agrobiosciences.org). The region that has been the most impacted is South Brittany and Normandy (where production has respectively fallen from 2008 to 2010 by 70% and 40%), because there is a shortage of natural seed from Arcachon and Poitou-Charentes. Producers from all regions are trying to keep up with their production targets so they are increasing by many fold the number of oyster seed collectors (especially in Poitou-Charentes where natural setting rates are the best).

Beside heavy losses at the nurseries and juvenile stages, some difficulties encountered by hatcheries during the mortality crisis were unpaid invoices at the first years of the epizootic. However producers have become so dependent on hatchery seed that they have to comply with their payments obligations, even when heavy losses on seed occurs. Also, many producers who didn’t buy enough seed from the start of the epizootic or the ones who lost everything (100% mortality on seed on consecutive years) find it difficult to afford seed because of a shortage in funding (from the production shortage) and their inability to obtain a loan from a bank.

In 2007, the price index was very low. A parallel could be made with the period of lowest prices for exported bulk oysters from the Island of Ireland. The sudden increase in prices in the last two years is well marked. It corresponds to the first shortage of marketable oysters from the first mortality in 2008.

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19 “Claires”: small ponds in clay fed by seawater with tidal current, rich in plankton, used to improve the taste and internal overall aspect of the oysters. “On the Atlantic coast near “La Rochelle, salt marshes were turned into “claires” for finishing the growth and fattening the flat oysters” (Héral, M., M. Deslou-Paoli. 1991). “These ponds are used for “greening” and fattening the oysters which are stocked at a density of ... The fines de claire remains for several weeks while the “huitres spéciales” several months” (Héral M., 1989)
Logic tells us that prices will be maintained for 2012, some producers even expect further increases.

### Table 1: Evolution of the production by regions since 2002. Evolution of the production since 1996 can be found on the CNC website/comprendre/Statistiques (Sources: cnc-france.com; July 2012).

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<td>CRC Normandie - Mer du Nord-</td>
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<tr>
<td>CRC Bretagne Nord</td>
<td>16,000</td>
<td>16,000</td>
<td>25,000</td>
<td>19,000</td>
<td>- 24%</td>
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<tr>
<td>CRC Bretagne Sud</td>
<td>17,000</td>
<td>20,000</td>
<td>20,000</td>
<td>6,000</td>
<td>- 70%</td>
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<tr>
<td>CRC Pays de la Loire</td>
<td>20,000</td>
<td>18,000</td>
<td>10,000</td>
<td>7,000</td>
<td>- 30%</td>
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<tr>
<td>CRC Poitou-Charentes</td>
<td>25,000</td>
<td>25,000</td>
<td>27,500</td>
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<td>- 27%</td>
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<tr>
<td>CRC Arcachon Aquitaine</td>
<td>15,000</td>
<td>10,000</td>
<td>9,000</td>
<td>7,000</td>
<td>- 22%</td>
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<tr>
<td>CRC Mediterranée</td>
<td>13,000</td>
<td>10,500</td>
<td>10,000</td>
<td>7,600</td>
<td>- 24%</td>
</tr>
<tr>
<td>National</td>
<td>136,000</td>
<td>126,500</td>
<td>128,500</td>
<td>82,800</td>
<td>- 36%</td>
</tr>
</tbody>
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Graph 1 right represents the IPGA since 2000, it shows the evolution of the prices for retail oysters such as fishmongers, restaurants. The IPGA\(^2\) is an index that measures growth in food product prices at the Paris-Rungis market. It is calculated using statements from the Market News Department of the Ministry of Agriculture and Fisheries. Statistics can be downloaded on the INSEE\(^2\) website.

1.7 Impact to the Northern Ireland oyster industry.

The situation before 2008

The oyster production in Northern Ireland is essentially for the export of bulk oysters to producers/dispatchers, or wholesalers in France, Germany, UK, and Italy. France is the primary European producer and consumer of oysters, the bulk of the production is sold back to France. The main disadvantage for a producer in Northern Ireland is the insignificant sale of shellfish to local or a national market. In France, producer-dispatchers with a depuration centre, have the possibility to sell their product at the farm to the local market and tourist market, as well as to the retail market, e.g. covered markets, fishmongers, and also to restaurants, as well as to local wholesalers/ dispatchers. All these sales have a low transport cost. Added to this, in France there is the OP (Organisation of Producers) which is a voluntary grouping of professionals to support and defend the interest of regional producers. Compare this to Northern Ireland, where the bulk of sales are made with long-term regular buyers (producers dispatchers). Small businesses often sell to France with an intermediate trading agent, who sells mostly to other producers. But transport costs are significant, and there

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\(^2\) IPGA: “Indice des Prix de Gros de l’Alimentaire”, the Food price wholesale index. The IPGA is a Laspeyres index. It refers to the value of a basket with a constant structure and content, corresponding to the base year (currently the year 2000).\(\text{www.insee.fr}\)

December 2007 was a difficult time for exports across the Island of Ireland, supply was much greater than demand. Trading agents could not deal with all the Irish stocks and priority was given to regular traders. Prices of standard oyster n°3 dropped from €2.20/kg to €1.80/kg. Some explanation among observers was that this was due to lower consumer buying power, a higher percentage of milky oysters because of a warmer autumn, the overall increase of triploid oysters available with better yield, and a saturated market. Aquaculture development officers in the Republic of Ireland were advising producers to keep medium oysters up shore to slow the growth and at the same time to improve the flesh content to have a product of better quality. There was a hope that sales would have improved for Easter, but this did not happen. For small and medium oyster exporters this was a difficult time: once staff and investment were paid, there was not much profit made. Even before 2008, there was not much motivation for developing the industry, which had not fulfilled its potential and many sites that were initially developed were abandoned or even sold to French growers seeking space.

The French see oyster sites on the Island of Ireland as a very good opportunity to develop their production as French sites were overcrowded and the production cycle was becoming longer (e.g. it takes 3-4 years to produce an oyster in France, against 2-3 years in the Island of Ireland). This was similar to the situation in the 1970-1980's when producers relocated within France from Arcachon / Charentes to Normandy. For larger Irish businesses that ran their business as a full time job, the production and investments were scaled to be profitable in the long term and sales were not such a critical problem because they already had a very good business relationship with regular customers. The smaller producers were under a lot more pressure at this stage in the pricing cycle. There have been advantages to the French oyster sector becoming interested in relocating to the Island of Ireland. There was an overall improvement of aquaculture methods and oyster quality. There has been a change in mentality with more sustainable aquaculture practices (aquaculture sites were tidied up, with a better arrangement of farming structures and more efficiency of the workforce, etc.). To be sold with ease and at better price, products have to respond to the French market requirements: this is usually for products with specific quality criteria (i.e. the indices of flesh, the shape of the shell, the conditioning). From this situation, initiatives such as the Irish Quality Oyster scheme were developed in the Republic of Ireland (Irish producers and BIM initiative, Website: www.irishqualityoysters.ie).

The situation after 2008

From 2009, the market situation switched in the opposite direction. The mortality outbreak that happened in 2008 had now happened for a second consecutive year, and the appraisal of OsHV-1 μvar as the major causal agent for the mortality became more unequivocal. Therefore, demand for seed and half grown oysters increased. Because of better climatic conditions (i.e. colder weather) and a lesser degree of intensification of production (only 6,000 tonnes for the ROI, 260 tonnes from NI, 1,200 tonnes for all of the UK; sources: Aquaculture Initiative and newspaper "The Guardian", June 2010), oyster sites on the Island of Ireland, although affected, were less affected by the problem of mortality.

As a response to the oyster mortality, French producers moved more seed from the south-west further north to Brittany/ Normandy but in June 2009, mortality had spread Northward through France. Some producers then decided to export seed to the Republic of Ireland as a safeguard plan, just before the French Ministry decided a ban on oyster Export (28th of May). Between June and August 2009 OsHV-1 μvar was identified in fifteen sites in the Republic of Ireland where abnormal mortality was recorded. All affected areas had received seed from France and four bays had also received seed from England and the Channel Islands (there was one case with seed from England only; D. Cheslet, interview 2012).

On the oyster French market, the demand became greater than supply, so demand for imported oysters from Ireland and the UK became greater. The first signs of oyster shortage were apparent in 2010-2011 with a production shortfall of 45,700 tonnes in comparison to 2008 (Sources: CNC website). For some Irish/Northern Irish growers who were not greatly affected by mortality, this was an opportunity to make a profit. Prices jumped from €2.2/kg in 2009 to €2.8/kg in 2010 and €3/kg in 2011 (for a standard n°2 & 3) corresponding to an increase of 73%. In 2010, it was still possible for new French buyers to place new orders from the month of July from the Island of Ireland, and the market was open to the best offer. In 2011, regular French buyers had to secure their supplies for Christmas sales with their usual suppliers and sales opportunities for new buyers were closed: the oyster market for exports was sealed. The competition is now very tight between buyers, regardless of quality, all oysters were sold at a minimum of €3/kg for n°2 & 3 long before Christmas sales. The production shortage of the Pacific oyster also impacted on the price of the native oysters which reached record prices (between €4/kg to €4.75/kg in Dec. 2011 , late spring 2012). For some producers in Northern Ireland, it has been a missed opportunity, because no seed was bought or inversely seed was sold in fear of the insecure situation and lack of information, especially when more massive mortality were recorded from 2009. Overall, massive mortality rates in areas

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22 BIM: “Bord Iascaigh Mhara”, The Irish Sea Fisheries Board.
23 Grade unit related to the weight of the oyster: n°5: 30g - 45g; n°4: 46g - 65g; n°3: 66g - 85 g;
22 n°2 : 86g - 110g; n°1: 110g - 150g; n°0: >151g. Quality standard: indices de flesh below 10.5
where OsHV-1 μvar has been detected are still acceptable, not critical.

The lesson to learn from the market experience of 2007-2008 is that the actual strong market situation for bulk oyster export could soon or later end. If unexpectedly the massive mortality rate decreases or if a seed with a higher survival rate is produced by the hatcheries, then the oyster farmers on the Island of Ireland will have only two to three years to be prepared for a new market fall: a scenario is that the oyster production could become greater than the demand on the French market. Also, it is important to acknowledge that the survival rate during massive mortalities should improve with the development of better aquacultures practices; hatcheries are producing more seed; a lower production in France may also mean a better oyster quality and a faster growth. For these reasons the French production could start to slowly increase again in the coming years.
2. REVIEW OF RELEVANT RESEARCH CARRIED OUT ON MASSIVE OYSTER MORTALITIES AND ASSOCIATED DISEASES.

2.1 Research institution and centres on oyster mortality in France.

IFREMER: the French Marine Research Institute

IFREMER is the French Research Institute for the Exploitation of the Sea (public institution founded in 1984).

IFREMER is organised under 4 departments, one of which is the Department of Biological Resources and Environment (REB). This department is dedicated, among other things, to fundamental research in mollusc aquaculture. One of its main goals is to limit the impact and the spread of diseases affecting species of commercial interest through the development of rapid and specific diagnostic tools, in-depth knowledge of the infectious processes and derivation of selected animals. IFREMER is internationally recognised for its work in pathology, immunology and genetics of marine bivalves.

A part of the REB, is the Research Unit of Genetics Improvements, Animal Health and Environment (AGSAE) which is represented under two operational units: the Genetics and Pathology Laboratory (LGP) at Bouin, and at La Tremblade (Director of the Research Unit and LGP: Tristan Renault). The LGP has a key statutory role under French legislation and EU Directives in the prevention and control of disease supported by laboratory based diagnostic services. Since 1995 LEG of La Tremblade has been appointed the EU reference laboratory for mollusc diseases and the OIE reference laboratory for Bonamiosis and Marteiliosis. It is also the National Reference Laboratory (LNR) for bivalve diseases. Complementary information on main activity, research programs can be found on the dedicated website of AGSAE.

THE BIVALIFE consortium

IFREMER has been appointed as coordinator of a project called “BIVALIFE”, funded under the 7th Framework Program (FP7). It is a collaborative European project which was launched in February 2011. The project title is “Controlling infectious diseases in oysters and mussels in Europe”. It has as a principal objective: “To provide innovative knowledge related to pathogens infecting oysters and mussels and to develop practical approaches for the control of infectious diseases and resulting mortality outbreaks these pathogens induce” (Source: bivalife project summary, IFREMER).

This consortium will address pathogenic risks issues identified by the European Commission and related to the increase in international and intra-Euro shellfish trade exchanges. Details of the project can be found at CORDIS website. It is constituted of a consortium involving twelve partners from seven nations: France, Italy, the Republic of Ireland, Israel, Spain, Netherlands and the United Kingdom. More information can also be found on the dedicated website of BIVALIFE.

The main outcome is an improvement in infectious disease management. The development of recommendations will foster competitiveness in shellfish production. It will eventually propose recommendations for the management and best aquaculture practices in an epidemiological context. At a hatchery level, progress will be made to produce disease free seed with better management of brood stock, larvae and spat settlements using reliable, accurate and validated diagnostic tools. The development of enhanced traceability of health status will help with international transfer of oyster stocks.

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24 REB: Ifremer Department “Resources Biologiques et Environnement”. (Director: B. Beliaeff, Ifremer Center at Nantes.)
26 LGP: “Laboratoire de Génétique et de Pathologie”
27 LNR: “Laboratoire National de Référence”
28 (BIVALIFE website: http://www.bivalife.eu)
29 CORDIS: Community Research and Development Information Service. (Website: http://www.cordis.europa.eu/fp7/.)
Research centres on applied aquaculture

Regional research centres involved in research in aquaculture are “the Cépralmar” in the Mediterranean, “the CREA” (Poitou-Charentes), “the SMIDAP” (Pays de Loire), “the SMEL” (Normandy). These are non-profit “1901 law” organisations co-financed by the regions and the department or the European Union (IFOP). These work in partnership or in membership with the IFREMER alongside with other organisations such as aquaculture professional schools, universities, laboratories, CRCs. Research programs are carried out on fisheries and aquaculture sustainable development or on aquaculture orientated technical research such as the use of new aquaculture techniques, marine coastal environmental monitoring or the monitoring of the development stage of oyster larvae, and oyster mortalities. They are making the bridge between fundamental and applied research and are working in tight collaboration with professionals of the shellfish industry.

Agreed and recognised laboratories

Several laboratories help in the detection of infectious diseases and to set up management measures adapted to their detection. To do so, a network of agreed laboratories for the research of OsHV-1 and vibrios, has been set up with the objective to increase the capacity of analysis requested by the competent authorities. Added to that is the development of a network of recognised laboratories to target the presence of infectious agents but without mortality (in 2011, there was 13 agreed and 9 recognised laboratories).

The IFREMER has actively participated in the set up of these laboratories, notably in the framework of its mission as the National Laboratory of Reference (LNR) for shellfish diseases, by the organisation of four sessions of technology transfer of molecular diagnostics for the research of OsHV-1 and vibrios, but also in the organisation of comparison trials between laboratories. Therefore, since 2009, it has been possible to check if different laboratories were getting comparable results during analysis of reference materials.

2.2 Actions that were put in place by IFREMER to tackle the massive oyster mortality issues since 2008.

- The research of pathogenic organisms present in oyster batches presenting mortality and coming from different regions used by REPAMO and the LGP where routine technical investigations were carried out.
- Technical support to researchers for the development of sophisticated analysis (electronic microscopy, phylogenic analysis).
- Staff expertise mobilised in areas of shellfish disease and into genetics to answer questions from the professional and administrative authorities.
- The development of pathologic experiments (i.e. mortality induced).
- The development of epidemiological analysis of the mortality phenomena to determinate what are the causal factors of oyster mortality in relation to the presence of pathogenic agents.
- The setting up of a network of agreed and recognised laboratories for the research analysis of specific oyster pathogens.
- To support the oyster industry, the LPG has put in place the safeguard plan (“Plan de Sauvegarde”, see Chapter 3) for the selection and production of selected oysters (presenting higher survival rate) to supply commercial hatcheries connecting as a whole professional organisations, such as MAAPRAT and IFREMER.

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30 Law of July 1, 1901 (in French association loi 1901) relating to the contract of association : In the French law, an association is a convention by which two or several people share, in a permanent way, their knowledge or their activity (non profitable).
32 Vibrion: a curved, rod like, motile bacterium (of the genus Vibrio).
33 Informations extracted from the report published by AERES.
• Involvement in a collective oyster selection program with the CNC to produce a resistant strain of oysters that will be used to restock natural oyster beds, see Chapter 3 The National Program of oyster selection (SCORE35).

• Scientific and technical support to the DGAL 36 and the MAAPRAT on investigations about the introduction of C. gigas from Japan and Brazil.

• The development of research work and molecular tools allowing the description and analysis of the massive mortality phenomena since 2008 and to help in the development of selection programs.

2.3 IFREMER surveillance and research programs on oyster mortality.

THE REPAMO

The REPAMO (“Mollusc Pathology Network”) is a French Network for the surveillance of mollusc disease that meets the obligations of European Directive 2006/088/EC 37. The coordination of this network has been assigned to IFREMER since 1992 to insure a compulsory regulation and a public activity service delegated by the DGAL. The enforcement authority implicated in the surveillance of the mollusc is the DDTM with whom the producers have an obligation to report any suspicious or abnormal mortality. The REPAMO collects and manages data related to laboratory tests and information concerning sampling that are recorded in a national confidential database. After analysis, results are compiled in at least an annual report which is sent to all the network partners.

The test sampling also allows mapping of the geographical distribution of targeted pathogens. The REPAMO adapts its strategy according to epidemiological context, quantity and diversity of species, evolution of regulations and the data it has received (Guichard, 2011). The objectives of the network are articulated under 3 protocols:

(I) To ensure the surveillance of the listed disease present in France: Bonamia ostrea and Marteilia refringens (active surveillance).

(II) To detect the appearance of emerging or exotic diseases and follow their course.

(III) Surveillance of the health status of farmed and natural populations of mollusc (using active targeted surveillance, outside periods of crisis).

The REPAMO protocol (II) for surveillance of the increase of mortality for C gigas:

The increase of mortality for C. gigas oyster is looked at as part of a mixture of active and passive surveillance (Protocol II). The enforcement authority in charge of the surveillance of molluscs is the DDTM38, the Departmental Direction of the Territories and the Sea, to which producers have an obligation to report any suspicious or abnormal increase of mortality (article 10 and Annex I of Directive 2006/88/EC).

One of the consequences of passive surveillance could be the under-declaration of mortality events and an underestimation of certain parameters (mortality rate, date, environmental parameters); (Garcia et al., 2011). It could be because epidemiological criteria are misinterpreted by the producers or not recorded accurately. On the other hand, in some cases it could have led to an overestimate of the mortality because of a government aid of funding to alleviate losses. The level of increase in mortalities that is considered to represent “an increase of the mortality” has to be agreed by the producer and the relevant authority (in France, the DDTM).

35  SCORE: “Sélection Collective de l’huître creuse Crassostrea gigas à des fins de captage ORiEnté” the name given to the collective selection program oriented to natural setting.
37  European Directive 2006/088/EC on animal health requirements for aquaculture animals and products thereof, and on the prevention and control of certain diseases in aquatic animals.
38  DDTM: “Directions Départementales des Territoires et de la Mer”, Departmental Direction of the Territories and of the Sea.
Once a case of mortality has been reported (i.e. passive surveillance), a sample of oysters is sent along with epidemiological information about the oysters (e.g. method of culture, origins, zootechnics\textsuperscript{39} history) to the analysis unit of the LGP (IFREMER - La Tremblade). Some of the samples are sent to an external agreed laboratory for detection of the OsHV-1 μvar. A report of the results is then sent to the coordinators of the REPAMO network. From there, results are transmitted by the REPAMO coordinator to the DDTM. General information bulletins with the main results of analysis are published monthly by the network coordinator (and weekly in a crisis situation). An annual report of the overall results is also published every year (Guichard et al., 2011a, "Bilan 2010 du Réseau REPAMO").

\textbf{The MOREST (2001-2005):}

Summer mortalities before the massive 2007 disease outbreak on young oysters had led to a research program coordinated by IFREMER, called MOREST (meaning in English: “summery mortality of the oyster”). This project was initiated to study the main factors accounting for the abnormal death of oysters chiefly occurring in summer. It had involved the partnership of 27 organisations: research centres, professionals, universities and the CNRS\textsuperscript{40}. The finalisation of the project led to the development of a model, taking into account interactions between oysters, infectious agents and the environment. The main focus of the program was on the monitoring of oysters, oyster health and welfare and environmental parameters in situ. Three aquaculture sub-tidal sites were first selected to carry out the research investigations, a deep water site was later selected. Coordination of the program was led by J. F. Samain (IFREMER); (Bilan MOREST, 2006).

\textbf{The IFREMER shellfish observatory, RESCO: (2009-2012)}

The shellfish observatory (RESCO) is part of the IFREMER “sustainable aquaculture” quadrennial program (2009-2012). RESCO integrates previous monitoring databases such as the MOREST or the REMORA\textsuperscript{41} (notion of continuity) and it is also tightly connected to the other Velger and REPAMO monitoring networks. It’s function is to ensure the monitoring of oyster batches placed under surveillance into representative sites along the French coast. This monitoring program allows tracking of oyster mortality and following up zootechnic performance. Objectives are to acquire growth performance data, survival rates and breeding information from different oyster origins and size as representative of French oyster production sites. In parallel to that, on site environmental parameters are monitored (salinity, temperature and phytoplankton). In time, data management of all records will enable the rapid identification of hydro-climatic and biological abnormality problems in reference to historical data. This monitoring takes place on 14 sites along the Atlantic coast and in the Mediterranean Sea and current results and annual figures are available online\textsuperscript{42} along with links to regional status reports (published by LER or Technical Centres of Applied Aquaculture).

\section*{2.4 Oyster mortality before 2008.}

\subsection*{2.4.1 History of French oyster production from the 1920’s to the 1990’s.}

Native flat oysters, \textit{Ostrea edulis} were the most common oyster species farmed in France until it went through successive massive mortality events: first in 1920-1921, and then in the 1970’s with marteliosis followed by bonamiosis. This last one almost completely wiped out the natural and farmed stocks resulting in the native oyster production collapsing from 15,000 to 20,000 tonnes to only 1,800 tonnes (Grizel, 1985; Héral et Deslous-Paoli, 1991).

At the same time, as the native oyster was impacted, the Portuguese oyster was as well. The Portuguese oyster (\textit{C. angulata}) that had been accidentally introduced in 1866 to the French coast had experienced a very successful expansion reaching up to 85,000 tonnes in the 1960’s (Héral et Deslous-Paoli, 1991). But two succeeding epizootics caused the decline of this species. A “gill disease” was responsible for the first wave of massive mortality, from 1966 onward and the pathogen was identified as member of the Iridoviridae. The second epizootic in 1970-1973, was fatal to \textit{C. angulata} was also associated with an Irido-like virus, that was actually very similar to the first one, but without visual symptoms (Héral, 1986; Renault, 1996).

\textsuperscript{39} Zootechny is the art of managing domestic or captive animals, including handling, breeding, and keeping (New Oxford American Dictionary, 2nd Edition)

\textsuperscript{40} CNRS: "Centre National de la Recherche Scientifique", the National Centre for Scientific Research

\textsuperscript{41} REMORA: REseau MOllusques des Rendements Aquacoles. The IFREMER Shellfish Yield Monitoring Network (Survival, Growth, Flesh index), created in 1993.

\textsuperscript{42} (RESCO website: http://wwz.ifremer.fr/observatoire_conchylicole)
Japanese oysters (C. gigas) were first unofficially introduced in France in 1966 by innovative oyster farmers (Le Borgne et al., 1983). What actually happened is that this new species saved the French oyster industry in 1970-1973 because it was resistant, (even though it can be affected) to the recurrent “gill disease” (Héral, 1986). In the hope that C. gigas could replace C. angulata, batches of oysters were introduced to France on a massive scale from Japan in 1971 to 1975 with a programme of putting 5 million juveniles settled on shells and also with 562 tonnes of adult oysters from British Columbia. This massive introduction of C. gigas may have led to the introduction of an exotic virus which impacted on C. angulata greatly in Europe (Renault, 1996). By chance C. gigas became well acclimated to the French coastal environment and naturally, rapidly established new oyster beds and as soon as 1975, natural spatfall was sufficient to sustain the French oyster production (Grizel et Héral, 1991; Goulletquer et al., 1998).

From the 1990's oyster settlements started spreading further north along the Atlantic coast (I. Le Berre et al. 2009). Natural settlement became extremely important in many coastal French regions (i.e. Brittany and Normandy). Recently some cases of natural settlement have been reported in ROI, Northern Ireland, Netherlands, Denmark, Norway, Sweden. The introduction of C. gigas in Europe became so successful that once well established in some environments, an oyster bed can out-compete or displace habitat from native species (Nehring S., 2006; Wang J. et al., 2007), or vector other marine aliens or diseases (Haupt T.M., 2009, Grizel et Héral, 1991)

The French oyster industry reached a high level of production during the 1980's (100,000 tonnes; Héral, 1989; Héral, et Deslous-Paoli, 1991) with a production peak in the 1990's up to 150,000 tonnes (Goulletquet al., 2002).

Since its introduction in France, sporadic mortalities have hit both seed and adult C. gigas. The first mortalities from infectious disease were recorded at Marennes in early 1977, and were related to irido-like virus, this caused a reconsideration of the initial resistance of C. gigas from when it was introduced. (Comps M. et Bonami J.R. 1977). Episodes of mortalities arose in different production regions of France (1982-83, 1988, 1994-1995) with a chronic level of mortalities getting quite significant in the 1990's (Soletchnick et al., 2009).

2.5 Findings from 1990 to 2006.

The 1990's have been marked by significant losses of up to 80-100% of the juveniles, and to a lesser extent adults. First massive mortality happened in 1991 on larvae and seed in hatcheries, then at aquaculture sites where it carried on until 1995. Manifestations of the mortality typically happened in spring and summer and since these events, recurrent seasonal mortalities occurred in France. This phenomenon of mortality was already described in the literature of the past 40 years (Renault et al., 1994, EFSA et al., 2010; Garcia et al, 2011).
The massive mortalities that happened in 1991-1992-1993 were assigned to a member of the Herpesvirividae family (Garcia et al., 2011) and the first records of this type of virus was made by Farley et al. (1972) in adult C. Virginica on the East coast of the USA (Batista et al., 2007). In 1995, a virus detected during a mortality outbreak was characterised as member of the herpesvirividae family and named ostreid herpesvirus - (OsHV-1). The virus has been since reclassified in the order Herspesvirales as a unique member of the Malacoherpesviridae family (Garcia et al., 2011). The same authors found that with seed mortality outbreaks between 1998-2006, the average occurrence of OsHV-1 was 35% and varied from 6% to 65% depending on the year.

Findings more specifically noted in the MOREST research investigations:

The importance of climatic aberration with positive NOA\(^{44}\) indices (North Atlantic Ocean), characterised by a mild winter have led to a bad nutritional and poor physiological state of the young oysters in the summer.

Rich trophic conditions leading to a greater reproductive effort can lead to a greater risk of mortality especially when the temperature increased to 19-20°C. Also mortality increased for oysters under stress, close to sediment with the diffusion of toxic substances (i.e. sulphur, ammonium). Other stress considered were the presence of pesticides and other pollutants.

There was a better resistance by triploid seed than diploid, and lower mortality rates on certain families of oysters in some regions.

The presence of infectious agents such the bacteria Vibrio splendidus and Vibrio aestuarianus or OsHV-1 were greatly associated with the stress factors and weakness of the oysters as responsible for the summer mortality. It was also denoted that OsHV-1 was more associated to the mortality of juveniles.

- Since the 1990’s abnormal C. gigas mortalities had been affecting French production significantly, this was associated with the presence of OsHV-1 and a causal link could be demonstrated.
- The outcome of the MOREST program (IFREMER, 2006) concluded that summer mortality patterns were a result of multifactorial interaction between environmental parameters, the presence of pathogen agents and the physiological state of the oyster.

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\(^{44}\) NAO indices: The North Atlantic oscillation (NAO). The NAO is traditionally defined as the normalized pressure difference between a station on the Azores and one on Iceland. Stronger winter storm crossing the Atlantic ocean, cold and dry winter, are characteristics of a positive NAO index (CRU, 2012, Annex 1)
Fig. 2 right: Historic of production and massive mortality event that marked the French aquaculture of the oysters *O. Edulis*, *C. angulata*, *C. gigas* since aquaculture began.
2.6 Characteristics of the mortalities from 2008 to 2012.

- In 2008, 7,250 cases of massive mortality affecting 60-80 % of the oyster stock were declared by French shellfish farmers. The herpes virus OsHV-1 was detected in 86.5 % of the samples analysed (3,015 analysed). Mortality occurred in three successive waves: a first peak at the end of May-June (Mediterranean, Marennes and South Brittany) a second major event started at the end of June-mid July (these were at the same sites, plus in North Brittany and Normandy) and the last mortality at the end of July-August (mainly in Aquitaine). (Cochennec-Laureau, 2010)

- In 2008, other cases of massive mortality on juveniles of *C. gigas* were reported in Spain and Portugal, affecting only a limited number of oyster batches (imported from France). In the Republic of Ireland, there was report of mortalities on 3 sites which had received seed from France (hatchery and natural). (Cochennec-Laureau, 2010)

- From 2009 the work of the REPAMO network has highlighted potential spatial trends, with summer mortality occurring earlier (from end of April) along the French coastline according to a south-north gradient (Cochennec-Laureau, 2010). Data relative to the detection of the virus OsHV1 μvar in 2009-2010 confirmed the presence of the virus associated with mortality (Guichard, et al., 2011).

- Severe mortality events were reported in France since 2008 and some other European oyster producer countries: ROI, Portugal, UK (2010), Netherlands (2011). Virus presenting similarities with OsHV-1μVar has been associated with high mortality, outside of Europe too, including New Zealand (2010, 2011), Australia (2010), Japan (2010), (Renault, et al. 2012; Cochennec-Laureau, 2011; EURL).

2.7 Characteristics of the mortalities that happened after 2008.

- The most important characteristic that the mortality events occur in all rearing sites at the same time (Renault, 2012).

- Mortality equally impacts all oysters of different origins (diploid/triploid/hatchery/wild).

- The mortality affects oyster seed more than juveniles and to a lesser extent adults (Blin & Richard, 2008).

- OsHV-1μvar has replaced the OsHV-1 reference strain as the dominant strain in oyster samples. Unlike the reference strain, the variant μvar can be found in oyster samples all year round (Cheslett D., interview 2012).

- There is a high mortality intensity (up to 100%) in some areas (Garcia et al., 2011).

- Massive mortality is happening at a colder temperature (16°C) than in cases before 2008 (18-20°C); Cochennec-Laureau, 2010, Garcia et al., 2011).

- From 2009, massive mortalities are succeeding the South - North temperature gradient from April to August (Cochennec-Laureau, 2010).

A big increase of mortality on juvenile oysters began in the Mediterranean Sea in 2007. From June 2008, mortality outbreaks were reported from all French production areas and the main European producing countries. Mortality first struck seed, but then also affected juvenile45 oysters (average 30%) and adults (average 5-10 %). Mortality was described as acute, with mortality rates up to 100% reported in some bays and ranged from 40% to 100% with an average of 80% all over France (EFSA Journal, 2010; Renault, 2011, Renault 2012). Mortalities were happening in short severe bursts, and accelerated when sea temperatures were rising. Wild oyster beds situated near oyster farms were also affected, but to a lesser extent. A mild winter and a rainy spring would have caused a pre-maturation of the juveniles, becoming weaker and sensitive to environmental stress. This state of weakness would favour disease incidence including OsHV-1 infection (Le Bere, 2009; EFSA, 2010).

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45 Juvenile oysters are 12 to 18 months old oysters.
2.8 Potential causes of mortality since 2008.

- **Host**
  - Pacific oyster
  - Spat and juveniles
  - Trophic conditions (fast growing oyster more susceptible)
  - Genetic: certain families

- **Pathogen**
  - OsHV-1 μvar
  - Co-infection possible with other pathogens

- **Environmental parameters**
  - Mortality starts when sea temperature increases to 16°C.
  - Mortality rate decreases above 24°C in investigations in the Mediterranean Sea.
  - Water quality and pollution affect the immune response of the oyster.
  - Isolated sites are less affected by mortality

**Figure 3:** Schematic representation of multifactorial risks associated with the disease (Sources: “Final Report”, International OsHV-1 μvar workshop, Cairns, Queensland, Australia).

- **The physiological state of the oysters:**

In a study, Soletchnik et al. (2007) compared mortality records for one and two year old oysters over the last 10-12 years between 1993 and 2005. Results showed that mortality in one year old oysters was greater in the summer (49% of annual mortality), and adults mortality happened mainly in the spring (51% of annual mortality). Since 2008 mortalities struck seed, and to a lesser extent juveniles and even less with adults. Mortality outbreaks in the recent years were affecting oyster seed more and at higher levels than previously recorded - up to 100%, (Blin & Richard, 2008).

Gametogenesis, is less of a factor associated with mortalities because it is now believed that both triploids and diploids are equally affected: MOREST had shown that there was a better survival rate with triploids than with diploid individuals. This phenomena could have been related to a lower metabolic effort for triploid oysters. But results from 2008, support the idea that there is no difference of mortality levels between wild seed and hatchery-bred seed (EFSA, 2010). Similar findings were reported by Pernet et al. (2011) where all types of seed (diploids/ triploids, natural/ hatchery) were equally affected during the OsHV1 μvar epizootic.

In the MOREST results, the first seasonal mortality occurred after sexual maturity, close to the spawning period in the MOREST. In the later studies in the Mediterranean, mortality was coinciding with the initiation of the gametogenesis, way before spawning. (Pernet et al., 2011). Oysters use a lot of energy at the initiation of the gametogenesis and thus, it could be possible that initiation of gametogenesis could be related, to a weakness of oysters in terms of pathogen susceptibility.

Investigations by Soletchnik et al., (2006) showed that carbohydrate metabolism contributed to the physiological stress of oysters leading to mortalities events. In his studies he found that growth and gonad maturation stopped during the month of May- June. It was suspected this was due to a problem with carbohydrate metabolism. Further studies should investigate metabolism disorder during the maturation process in relation to food supply quality (that may be related to environmental changes).
The presence of the virus and other pathogens

The identification of the new viral variant, OsHV-1 μvar coincided with the appearance of the massive increase in mortality. The variant OsHV-1 μvar was first recorded in virus positive samples for the first time in 2008 (Segarra et al, 2010). OsHV-1 was detected in almost 75% of the samples analysed from all locations. The genotype μvar was detected in 40% of virus positive samples in 2008 and in 100% of collected batch in 2009 (Guichard et al., 2010). In another research investigation, 300 virus samples were collected along the French, Irish and Jersey coasts between 2008-2010, OsHV-1 μvar was detected in 257 of them, the reference OsHV-1 was not detected at all during this survey. In addition to the OsHV-1 μvar, an even newer genotype, containing only nine consecutive deletions named OsHV-1, μvar 9 was found in five samples out of 300 (C. Martenot et al, 2011). Any interpretation about the significance of the presence of this novel genotype, at this stage, would be too speculative.

OsHV-1, and more likely the variant μvar are the major pathogens associated with increased mortality of C gigas since 2008. However, it may not be sufficient by itself as other factors appear to be important (EFSA, 2010). Oyster mortality were reported for the first time in Japan in 1945, and the USA in the late 1950’s. Mortalities were more related to a combination of several major factors involving, environmental conditions (temperature, salinity,), the pathogens, the state of the oyster (gonad maturation, etc.) and physical stress on the oyster (handling, transfer, etc.), (Garcia et al, 2011). According to the EFSA, OsHV-1 μvar seems to be the dominant viral strain, but it is not clear if this is a result of increased virulence or other epidemiological factors.

Three vibrio species (Vibrio splendidus, V. aestuarianus and V. harveyi) were frequently observed and also seemed to be directly related to the mortalities. Up to 2010, their role in the mortality was not yet answered (EFSA, 2010). Also, it is important to remark that Vibrio splendidus is part of a complex group within which exist different strains of pathogens and non-pathogens. Therefore, the detection of the Vibrio splendidus, at a generic level has to be interpreted cautiously. This general detection doesn't allow you to know if the agent detected is able to induce mortalities (Renault, “IFREMER conference day”, 2012).46

In 2010, analysis carried out by agreed laboratories for the detection of viral DNA OsHV-1 μvar found that 100% of the samples analysed were positive, compared to 89% in 2011. Bacteriological analysis, from the same laboratories since 2010 found that the DNA of Vibrio splendidus was found between 45 to 85% of the sample analysed, and the percentage of the DNA Vibrio aestuarianus was detected from 7% up to 45% of the samples analysed (Renault, “IFREMER conference day”, 2012).

Further investigation about the causation factors of the mortality in the Mediterranean Sea demonstrated that mortality was directly related to the presence of OsHV-1 and the bacteria Vibrio splendidus: Mortality events were always consistent with simple infections by OsHV-1 or multiples infections of OsHV-1+ Vibrio splendidus (Pernet at al., 2011). Blin (2009b), who studied the mortality in Normandy also reported that in 2009 OsHV-1 was detectable in oyster samples, 15 days before the first mortalities was reported. However, Vibrio splendidus was detectable in every oyster batch as soon as they were transferred at sea. It seems that the concentration levels of Vibrio splendidus decreased during the mortality peak, then reappearing again during the phase of mortality decrease.

Sea temperature

Once infected by a virus, environmental factors and in particular water temperature must reach a threshold before an oyster will express a disease to such level to then die:

“An increase or sudden change in temperature of the sea water is shown to be an important risk factor predisposing the disease” (EFSA, 2010). It was also noted that summer mortality in the Mediterranean (with temperature closer to 24°C) was more related to OsHV-1, whereas autumn mortality with temperatures closer to 17°C was more related to V. splendidus (Pernet at al., 2011).

Although a temperature of 19°C was the physical factor associated in setting off the mortalities in the MOREST work, mortalities started to be reported 1 month earlier than in 2008 (from the end of April in the Mediterranean) and at lower sea temperatures (16-17°C). (Blin, 2009b; Cochenec Laureau 2010).

If the NAO positive indices could have been taken into account for the mortality of 2008, it would have been close to zero during winter 2008-2009; and so it is not possible to take this into account for the mortality observed in 2009.

46 On the 18 of January 2012, IFREMER organised a public conference day on exchange and information about the massive mortalities of cupped oyster.
Mortality outbreaks with oysters infected by OsHV-1 μvar occurs when the sea temperature reaches 16°C unlike the “summer mortalities” which was associated with losses at around 19°C. Up to now, no outbreak has been reported when the temperature was inferior to 16°C (EFSA, 2010). It has been found that massive mortality outbreaks happen when temperature ranges between 17°C and 24°C in Thau Lagoon; above or below this temperature window, oysters do not die (Pernet et al. (2011). Cochennec-Laureau (2010) reported that the spread of mortality from one oyster batch to an other, was associated from 2009 to the sea temperature of 16-17°C, lower than the one identified during previous mortality events (19°C).

Le Deuff et al. (1996), found that there is a positive effect of high temperature on OsHV-1 infections: In an experiment investigating the effect of the temperature on the induction of OsHV-1 infection in oyster larvae, it has been observed that high temperatures (25°C-26°C) promote early production of viral particles and are associated with the highest mortalities levels. Differently, larvae held at lower temperatures (22°C-23°C) exhibit no viral infection, but are in fact a carrier that may represent a reservoir of virus that can be transmitted and switch from a persistent to an infection stage at a later time (Le Deuff et al., 1996). Similar findings were observed by Sauvage et al., (2009): A higher temperature was promoting an earlier viral production and a rapid spread of the disease could be capable of causing sudden and massive mortalities. In the experiment, the 2 day delay after the increase of the temperature would correspond to the delay necessary for the virus to initiate an intense replication phase. Temperature would be therefore one of the major factor acting on the mechanism of infection (as notably documented in Samain et al., 2005).

Pollution and pesticides

- Interpretation from the MOREST suggested that pesticides could have an effect on inducing oyster mortality, through weakening or suppressing the natural resistance of juvenile oysters (Source: http://www.ifremer.fr/morest-gigas/).

- It has also been demonstrated that Pacific oysters exposed to a mixture of 8 pesticides at concentrations reported in the field were more susceptible to a bacterial infection in laboratory conditions (Gagnaire et al., 2007).

- The bio-vigilance network program (part of the IFREMER sustainable aquaculture program) has led to a similar conclusion. It has observed a negative correlation between the occurrence of aneuploid oysters in natural seeds and oyster growth and survival rate. Remnant pollutants washed up at spring time into natural seed production bay catchments (Arcachon, Marennes) would induce the phenomena of aneuploidy47, weakening the young oyster and so its resistance to diseases. So the role of pollutants in the marine environment has to be taken into consideration as a factor potentially responsible for the abnormal mortality since 2008 (Benabdelmouna et al., 2011).

2.9 Effect of site and aquaculture practices (exposure time and density) on survival rates.

Many experiments have been carried out on the effect of density on mortality rate, but results are often contradictory and inconclusive and may vary between seed and half grown or from one year to year or from a region to another (Soletchnick et al, 2009, Soletchnick, 2011, Cochennec-Laureau et al., 2011).

In most situations, lower densities do not seem to affect the mortality rate, as once the disease hits, mortality spreads rapidly all over a production site. On the other hand, it has been found in experiments carried out by SMEL in Normandy, that oyster bags with higher density (x10 times higher than at normal densities) had 15-20% less mortality (Blin, 2008). Similar results were found in South Brittany, when densities equal to 9,000 seed /bag reduced mortalities by 12% (C.A.P. 2000/Cochet Environement/ Ameria, cited by Soletchnick, 2011). In any case, over-density in bags results in slower oyster growth and higher variation of the oyster size/shape.

The effect of exposure time on the survival rate also showed some variance in experiments, but to a lesser extent: In the Pays-de-Loire, mortality were significantly lower in 2010 for oysters situated on higher shores. This findings were even more pronounced for triploid seed (SMIDAP, cited by Soletchnick, 2011). Similar findings were obtained the same year at Marennes with lower mortality rates (40% instead of 70%) on higher shores. However, during trials at Brest in 2009 with seed of different age, placed at higher or lower shore or completely under water, these differences were not observed (Soletchnick, 2011).

47 Aneupoloidy: gain or loss in the number of chromosomes, different from euploidy which is the multiplication of an integral set of haploid number of chromosomes (eg. triploids 3x = 30 chromosomes or tetraploids 4x = 40 chromosomes).
Furthermore, in experiments carried out in South Brittany (Association C.A.P. 2000) results were significantly different for seed placed on sites with longer exposure times. There is up to 16% less mortality on sites with exposure time greater than 50%. These differences were not as big when the exposure time is shorter. On the downside, growth is considerably reduced on sites with long exposure time: the growth can be reduced by 30% at sites with exposure time higher than 50%.

In any case, it has been found that it is on the deepest sites that higher mortalities were observed. In another study, the exposure figure presents only a real advantage (i.e. 20% higher survival rates) when oyster are positioned at very high intertidal levels of the shores (Cocheonc-Laureau, 2011).

It has been suggested that oysters having a limited trophic/ nutritional level through higher density or longer exposure time are less at risk because they have a lower metabolism, lower growth, and later maturation during the “critical periods” of mortality in the summer (Blin et al., 2009a). Moreover it has also been reported that overcrowded farming structures or the notion of “seed load” or biomass at a production site seems to lead to a rapid dissemination of an infectious disease (Pernet et al, 20011, Blin 2008, Sotechnick, 2011).

### 2.10 Theories on the origin of the virus.

The origins of the variant OsHV-1 μvar are still unclear and there are multiple theories. There is the question of whether the virus had already been present for millions of years in the environment or if it is the product of a genetic mutation of the original strain.

Until recently, most scientists believed that the virus discovered under the “μVar” form had emerged from a recent mutation of the virus initially identified in France as OsHV-1. It is also known as the virus of reference (virus purified in 1995 from oyster larvae from a French commercial hatchery).

However, according to Segarra et al. (2010), 13 mutations have been reported differentiating OsHv-1 reference type and OsHV-1 μVar. In fact, the variant μvar shows at least 2 genes with an important number of mutations. This would indicate that the variant μvar and the reference strain would certainly not have a direct affiliation, but that they would be more like cousins: they share a common ancestor, but one didn't recently arise from the other. It is important to point out that the herpes virus is a DNA virus and has a lower mutation rate. RNA viruses (e.g. the flu virus) have a higher mutation rate. In other words, OsHV-1-μvar is most likely not a recent mutation of the reference form. Information concerning these points was already published by IFREMER (Serra et Al., 2010; Renault et al., 2012)."

- Higher seed density may reduce mortalities, but findings are often contradictory.
- High oyster biomass at a production site may promote the spread of an infectious disease
- In many cases, longer exposure time seems to lower mortality rates, but only when seed are placed on higher intertidal levels of the shore
- Both practices (higher densities, longer exposure times) result in a reduction of growth.

In this context, it is essential today to pursue research investigations on the diversity of the virus OsHV-1 with the aim of a better understanding of the basis of its virulence, especially of its variant in relation to environmental parameters. Research work in this context for the complete sequencing of many viral isolates is underway.

### 2.11 Theories on the emergence of the OsHV-1 μvar.

The remaining point of divergence is about where does it come from and why or how did it appear and why did epizootic events occur almost simultaneously on a worldwide scale? According to Hine et al., (1992) “The movement of *C. gigas* has occurred before adequate disease studies could have been undertaken, and therefore resulted in the spread of pathogens of *C. gigas*.”

On commenting for this report, Mr Renault considered the two following theories:

- “The variant was not present in France until recently and it was introduced from other regions in the world probably in 2008 by an unknown method e.g. water ballast or other introduced host species. Since then it has found favourable conditions in France to develop and spread. More particularly, work carried out shows that viral forms close to the virus OsHV-1 μvar were detected before 2008 elsewhere than in France: i.e. in China (2002) and in New Zealand (2005).”

OR

- “The variant OsHV-1 μvar existed before 2008 (under its actual or ancestor form) in France, but it was not the major form. There is a diversity among infectious agents, and of course within viruses: this variant could have become dominant as a result of more recent modifications, i.e. from a recent genetic mutation of a variant as a result of recent changes.

"To support the last theory, it seems to be important to compare isolated virus collected in France before 2008 and to compare them to check if they are totally identical to the virus identified as μvar isolated in 2008 in France. Neither of these theories can be excluded at this moment”.

It has been published in the Journal of Virology (Renault at al., 2012) that the virus detected in China (2002), Japan (2010) and New Zealand (2010) are similar to the variant OsHV-1 μvar. But they present differences that allow a phylogenetic separation (those virus are defined as related when compared to OsHV-1). The variant found in New Zealand is actually of an earlier type than the European one. So it could be concluded that if OsHV-1 μvar found in Europe and in other part of the world are not all identical, therefore it is possible that similar forms of them have evolved separately in different parts of the world and would have become virulent at around the same time.

The reason for the emergence of the variant OsHV-1 μvar since 2008 and almost simultaneously in many different parts of the world is still unclear. However as previously, it is important to take into consideration the effect of environmental factors such as environmental changes and pollutions and the use of inappropriate cultural practices (high degree of intensification, overcrowding, oyster imports from other countries) as a possible cause of the emergence of OsHV-1 μvar. Numerous oyster transfers could have contributed to the dissemination of this genotype (Segarra et al., 2010).

2.12 Aquaculture practices that stimulated the emergence of the variant OsHV-1μvar.

Aquaculture purists working only with natural wild seed may be prone to believe that hatcheries are at the source of their problem, especially with the introduction of triploid infected seed from overcrowded rearing conditions. And of course, hatchery growers (in Eric Marissal opinion, Director of the hatchery Génocean) may think that they are in no way responsible for the sudden appearance of the virus and that cultural practices and a higher degree of intensification of aquaculture are responsible for it. Then there are people sharing both views, taking into account both factors, questioning all the aquaculture management systems in place for 30 years and more recently in hatcheries.

For Deborah Cheslett, (MI) there are still lot of uncertainty regards how the disease was introduced into the Island of Ireland “the first bays that were infected with the herpes virus were all the ones that had imported seed from France, and in one of the bays there was only seed that had been imported from a hatchery. It is not possible to say if the herpes virus came from hatchery or wild seed, they could have come from both. Hatcheries are in fact breeding grounds for pathogens and this is also why appropriate hatchery sanitary measures are in place to keep levels of pathogens low”.

Eric Marissal shared with us his views on the emergence of the virus. “Since 1974 when oysters were imported from British Columbia and Japan, the pathogens were already present. From the start, every summer in the Bassin d’Arcachon and in the Poitou-Charentes as well, on certain areas there were mortalities. With the emergence of the oyster farming industry further north, in Normandy and Brittany (these regions didn’t have oyster farming before), oyster farmers and notably those from Charentes found that natural oysters were not dying over there while they had recurring mortalities in the bay where they were born. At the time this was not so problematic. At the start, they left oyster spat on the collectors, allowing for the mortality, and produced half grown in the same bay. Then they removed the batch of seed before they started to die and transferred them to Normandy to grow them at half
grown size. Then they brought them back to Arcachon / Charentes to finish them. They might have combined with the reproduction of the oysters where they were born, giving descendants, which would have been taken away from the viral pressure (or selection), and this was carried out repeatedly for 30 years. There was a migratory flux, where more and even more seed was taken out from the viral pressure occurring in the warm water (small mortality) to be removed into cold areas. Oysters that were naturally unselected and were repeatedly brought back produced offspring that were more sensitive. This was a never ending circle and at some stage a critical threshold was reached when most of the population became sensitive. Once this had happened, the virus (i.e. group herpes) adapted itself so as to be more active in the cold waters in Normandy. This could be why the variant is more active in colder waters.

The other theory is if the variant was already there and became opportunistic or if there was a mutation of the main strain OsHV-1. Saying it was already there a long time before within the “herpes group” adapting to cold water, it became dominant and appeared in the 2008 explosive situation of mortality. At that stage in the process, there is no possible return, the critical threshold has already been passed. This would explain why OsHV-1 μvar has completely replaced OsHV-1 in the positive virus samples since 2010. If a change ever occurred in the conditions, OsHV-1 μvar could be assumed to be the emergence of a new genotype (as suggested by Segarra et al. 2010). It seems that this virus cannot mutate easily because it is extremely stable. This virus is in fact part of the same viral cohort of the wild oyster”.

According to Eric Marissal’s opinion, the virus has appeared exclusively in relation to zootechnics. “But it could have been another virus, or a bacteria or anything else. It was the one that was the best placed in relation to what farming practices have undergone in the oyster. In Japan, there are other mighty pathogens but techniques are diverse: other techniques bring forth other pathogens. Today this virus kills oysters: the disease is embedded within the oyster culture and a new population of oyster from Japan cannot change the virus. Let us take, for example, the rabbit and myxomatosis. Putting rabbits in a hutch will not stop myxomatosis from killing them. The only issue for the rabbit is vaccination, or being a resistant rabbit. The immune system of an oyster being very simple and scientific knowledge being still insufficient, vaccination is not an option today”. The last comments of Eric Marissal lead us to the question, how to deal with OsHV-1 μvar, acknowledging that there is no possible treatment.

2.12.1 Pathogenicity of OsHV-1 μvar.

Facts about OsHV-1 μvar.

• OsHV-1 μvar has replaced the classical OsHV-1 as the dominant strain isolated during mortality events on oysters in France from mid-2008. The genotype μvar has been found in 47% of the oyster samples analysed in 2008, then 100% in 2009 and 96% in 2010. The virus was also detected and was responsible for massive mortalities in other oyster production countries (Renault, 2011).

• The available information suggested that OsHV-1 infection is a possible cause but may not be a sufficient cause and a particular genotype OsHV-1 μvar appeared to be the dominant genotype in the mortality event between 2009-2010 (EFSA, 2010; Renault, 2011).

• It should be considered that OsHV-1 μvar has been reported in the absence of mortality. In a study realised by Dundon et al. (2011) the μvar variant was detected in 2010 in oyster samples in Italy from seed originated from France but no abnormal mortality was associated to with presence. The same study demonstrated that co-infection with OsHV-1 reference strain and μvar is possible.

• According to EU regulations, OsHV-1 and Vibrio spp. are not agents that require compulsory notification, neither is it listed in the OIE’s aquatic code (International Epizootic Office). Therefore accurate data of its presence is scarce (EFSA, 2010, T. Renault, 2011). However, member states may take measures to control and prevent the spread of the disease within the framework of article 43 of Directive 2006/88/EC (European Commission, Guidance document, 2011).

• OsHV-1 has been associated with summer mortality of oyster reared hatchery larvae since 1991 in France (Le Deuff at al, 1994) and in New Zealand (Hine et al, 1992). Subsequent sporadic oyster mortalities were also observed in French hatcheries in 1992, 1993, 1994 (Renault, 1994). Since 2008, mortalities in France were associated with the variant OsHV-1 μvar (Segarra et al, 2010).

49 (author’s comment: now we know that it cannot be a mutation of the reference strain)
50 To illustrate further the myxomatosis example, it could be added that when the disease was imported to Australia to control the rabbits, it was devastating, the rabbit population fell from 600 to 200 million in 2 years, but the remaining population became resistant and survived.
• In the report published by Pernet et al. (2011) massive mortality occurs in temperature range of 16°C to 24°C. However there are still doubts about how the temperature influences the onset of the disease: is it the rapid increase of the temperature or by reaching of a certain threshold? (Garcial et al., 2011).

• The virus spreads quite quickly, in an experimental transmission of a herpes-like virus to axenic larvae of C. gigas, all larvae were moribund within 48 hours of inoculation. Virus belonging to the subfamily of the herpes-viridae are characterised by a productive cycle of less than 24 hours (Matthews, 1982, cited by Le Deuff, 1994). This would also explain why that high 2008 mortality outbreak happened in a short time.

• The genotype OsHV-1 μvar is characterised in the deletion of 12 base pairs in ORF433 of the genome in comparison to OsHV-1 (GenBank # AY509253), and 13 other mutations (Segarra at al., 2010). The term μvar is therefore used only when these differences have been detected (Renault, “IFREMER conference day”, 2012).

• The diagnostic test that should be used for detection and identification of OsHV-1 μvar is real time PCR51 and conventional PCR (European Commission Guidance document, 2011).

• C. gigas is the only species currently known to be affected by the OsHV1 μvar (EFSA, 2010, European commission, 2011, Renault 2011). Other species can host this genotype.

• The herpes virus is a shellfish pathogen that poses no human health risk. (REF).

2.12.2 Effect of herpes virus on C. gigas.

The virus can be found in adult bivalves (probably under a persistent form) but without any mortality (Arzul et al., 2001; EFSA, 2010). If adult oysters can host the virus, they also represent a “reservoir” and that can infect new generations under certain conditions (Blin & Richard, 2008).

Infected larvae with OsHV-1 show a reduction in feeding and swimming activities and sediment in the water. Mortality on larvae can reach 100% within 6 days. (Le Deuff et al., 1994, Barbosa-Solomieux, 2005). Viral DNA was detected in very early stage (2 days old larvae), showing that infection can take place at an early stage (Barbosa-Solomieux, 2005).

Results of a diagnostic test carried out by the REPAMO between 1997 and 2006 indicated OsHV-1 was found in most of the samples during outbreak mortalities and in moribund oysters. The infectivity of the pathogen was demonstrated in oyster juveniles during experimental trials, thus strongly linked to the oyster mortality events (Schikorski et al., 2011a and 2011b).

In Schikorski et al (2011a), adult oysters appear to be less sensitive to OsHV-1 μvar than spat; this might be explained in part by the existence of a higher anti-viral immune response in adults. Furthermore, the persistence of OsHV-1 in asymptomatic adults (carrier with no effect) was demonstrated by detection of viral DNA and proteins during experiments carried out into detection of the virus among three successive generations of Pacific oysters (Arzul et al., 2001b; Barbosa-Solomieu et al., 2005).

Whereas mortalities had been impacting on adult oysters previous to 2008, from then on the mortality was now impacting on more on oyster seed, and more severely and at exceptional levels, (Blin & Richard, 2008; Pernet et al., 2011). Consistent high levels of mortality were observed on seed from 2009 to 2011. However, as concluded in the report by Pernet et al., (2011) the difference of survival between adults and seed could rather be a reflection of natural selection, the first year there are mortalities: by year two the survivors would not show the mortality. Similarly to the finding in the MOREST, mortality could be impacting adult and juvenile in the same way. Therefore the hypothesis that the difference of mortality between seed and adult reflects an energy deficiency for the seed rather than the adult cannot be verified (Pernet et al., 2011).

Also, in a study on the effect of age and environmental factors on survival and oyster mortality, Dégremont et al. (2010b), demonstrated that “sensitive” selected seed that survived a mortality outbreak were performing just as well the following year as, so-called “resistant” selected oysters. Therefore, it was advised that “farmers could grow oysters that survived a mortality outbreak which had occurred when these oysters were at seed stage, without greater risk of another mortality outbreak when these seed are older”. In this report, a “resistant” oyster refers to selected oyster with higher survival rate to summer mortality. The same author
also demonstrated that some selected strain of oysters (G1 and G2A) from the MOREST work had higher survival rates, therefore oyster farmers could use selected oyster seed “resistant” to the summer mortalities.

Parental origin might be important in relation to the appearance of disease among oyster larvae. Le Deuff et al., (1996) has compared the effect of temperature on the induction of the herpes virus OsHV-1 to oyster larvae. When comparing the presence of the virus in larvae at different temperatures from parents of different origins, larvae originating from a particular brood-stock (i.e. that originate from Brest in Brittany) did not demonstrate any contamination, suggesting that one mode of transmission of the virus could be vertical, from parent to larvae.

Further investigations have actually suggested that resistance to mortality is a highly heritable trait: the identification of markers or genes associated with the resistance to a summer mortality outbreak is likely to contribute to the development of genetically improved oyster strains (Sauvage et al., 2010, Dégremont 2010a). Multiple programmes of genetic selection are currently underway in French hatcheries (see Chapter 3.5 “The ultimate solution: production of a selected oyster”).

Deborah Cheslett (Marine Institute of ROI), has remarked that there was a difference in sensitivity of seed grown in the Republic of Ireland between oysters of various origins (such as it was found in the MOREST). For example, seed which comes from a disease free hatchery are much more sensitive to the herpes virus when exposed to it than are French seed. Deborah Cheslett says that “French oysters have been exposed to the main herpes virus strain (the reference strain) since the 1990’s and have built up a resistance”.

In terms of the idea of viral concentration: it appeared that there was an increase in the viral concentration a few days before a mortality outbreak, then a decrease after the mortality in moribund oysters. Also, living oysters will have a significant lower amount of viral DNA, than dead ones (Sauvage et al., 2009).

### 2.13 Horizontal and vertical transmission of OsHV-1 μvar.

There is evidence of susceptibility to OsHV-1 in Ostrea edulis, Pecten Maximus and Ruditapes philippinarum. So OsHV-1 and the variant may be transmitted from one species to another and therefore the natural host of OsHV-1 is uncertain. It has also been suggested that interspecies transmission could have been promoted by intensive rearing in modern hatcheries, and that OsHV-1 is itself a mutant of a virus infecting single bivalve species that has gained the ability to cross species (Arzul et al, 2001a, 2001b). “At present there is no investigation on susceptibility of OsHV-1 μvar made on other molluscs” (EFSA, 2010).

The horizontal transmission of the virus has been demonstrated by mixing of an infected population with healthy ones. Healthy oysters after two days of cohabitation with infected OsHV-1 μvar oysters will get contaminated and start to decline in health (Schikorski et al., 2011b). The horizontal transmission process also happens between oysters on site, where it is strongly suspected that older oysters are playing a role of “reservoir or host” (Blin, 2009b).

SMEL reported on the mortality situation in Normandy in September 2008, and found that mortality rates were much higher in sectors where large quantities of seed were farmed. The total biomass factor at a bay scale seems to play a significant role in the dissemination of the mortality (Blin & Richard, 2008).

Vertical transmission has been difficult to demonstrate in the lab and the research is inconclusive. First, it was suggested by Le Deuff et al., (1996) that there is a possible transmission of the virus from parents to off spring because the Herpes like virus OsHV-1 was detected in 6 day old larvae from infected parents, but not from other parents of different origin (i.e. Brest). It was also found that the OsHV-1 could be present in a latent form in oyster parents and could be activated by stress in these hosts.

Similar finding in experiments carried out by Arzul et al. (2002) suggested that “the virus was able to survive in its host after a primary infection without inducing disease and mortality... Spawning constitutes a period of stress which could contribute to reactivate the viral replication in adults. ...Produce virions would then be transmitted to larvae and vertical transmission is therefore more than suspected”. It is important to note that these experiments didn’t take into account the possibility of the transmission of the virus through a media (i.e. transmission could have been really due to horizontal transmission in the water).
Another study from Barbosa Solomieux (2005) supported previous results, but it was also found that the detection of viral DNA in parental oysters did not systematically correspond to a productive infection or result in a successful transmission to the progeny. It was suggested in this work that OsHV-1-infected females may transmit to their offspring some kind of protection or resistance against viral infection.

However, at this stage this earlier work is contradictory to more recent work: Achim Janke a researcher at the Cawthorn Institute in New Zealand (http://www.cawthorn.org.nz) did a full test to check if vertical transmission was possible. In their experiments, Achim Janke took broodstock that were positive for OsHV-1μ var. They removed the sea water, stripped the broodstock, got the gametes, and then the larvae were placed in uncontaminated sea water. The result of this test showed that all larvae were OsHV-1μ var negative, so this is significant evidence supporting the idea that vertical transmission does not take place.

A more conclusive report about these findings is due to be published soon which will hopefully clarify the subject. This also shows that further work is required to investigate the possibility of vertical transmission.

### 2.14 Factors impacting on the spread of pathogens in oyster farming.

A study on the cause of the massive oyster mortality in the Mediterranean Sea (Lagoon of Thau) has been initiated by the CRCM52 and carried out by IFREMER (Pernet et al., 2010; 2011; 2012). The aim of this research was to improve understanding on the causes of the massive mortalities and more particularly in relation to the farming conditions.

First it was confirmed that mortalities coincided with infection by the pathogens OsHV-1 and the bacteria *Vibrio splendidus*. Then it has been noticed that mortality rates were variable in relation to (I) the background of the seed, (II) hydrodynamic factors (III) farming practices as outlined below:

(I) If oysters have already been exposed to the virus, they have a better chance to survive (90% of the oysters that survived the 2009 mortality did then go on to survive in 2010). Oysters that have not been exposed to mortality outbreaks in the past would die massively if transferred to an infected area, regardless of their size and age.

(II) The virus spread through the lagoon of Thau by hydrodynamic factors: it could travel more or less a long distance, depending on speed of the currents and maintain its infectivity outside it’s host. Also it would be very important to assess the length of time during which the virus can remain infective outside of its host, and to develop appropriate cultural techniques.

(III) Certain farming practices help to reduce high mortality (farming density, method of culture). For example, mortality rates are lower (10%) on rope culture at a lower density than in the more crowded Australian hanging baskets (80%). Disease spreads faster in a crowded environment where pathogen concentration becomes higher in the host and the surrounding water.

The scientific view by the EFSA (2010) concluded that husbandry practices such as the introduction of non-certified infected spat, movements and mixing populations and age groups are probably important risk factors. Oysters older than 18 months can be a source of the virus OsHV-1 (main strain and μvar) and it is not safe to transport these oysters to areas unaffected by increased mortality.

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52 CRCM: “Comité Régional Conchylicole de Méditerranée”, The Regional Committee for Shellfish Cultures of Mediterranean.
Fig 4: Schematic representation of shellfish movements in France, Ireland and the UK. Seed that originate from production bays (South West) are supplying seed to all other regions, including Ireland and UK. Adults and half grown are then transferred back to their place of birth or other production bays from Ireland/UK to France. This migratory flux of oysters shows how pathogens can spread between regions and within months of infection.
3. REVIEW OF HOW THE FRENCH SECTOR HAS RESPONDED TO THE EMERGENCE OF OSHV-1 μVAR

3.1 Responses of French aquaculture professionals to oyster mortality.

As there is not yet a resistant strain of oyster from natural selection or from hatcheries, oyster farmers have had to deal with the consequence of heavy oyster mortality for the last four years.

There is no miracle solution to reduce mortality outbreaks, and what can be applicable in one region may not be applicable elsewhere. Regions that present similar approaches applicable in the context of methods of culture and farming technics are Arcachon, Poitou-Charentes, Pays de Loire. Brittany with Quiberon, Normandy and the Mediterranean present territorial characteristics that are completely different. As well, what is applicable or not in France may or not be applicable in Northern Ireland. The aim of this report is to assess potentially applicable solutions with technological transfer from France to Northern Ireland, or at least to give direction for further applicable research.

Some methods might be successful in trials or on small scale projects, but they can also be economically non-viable in the area where they take place (for example the use of deep farming sites in the Mediterranean Sea for the entire production cycle). However some findings can be applicable in other regions because environmental parameters are more suitable (e.g. more sheltered bay, better access to sites). Further investigation and innovation in new farming technology should be continual and could eventually lead to successful new methods in the future.

The Herpes virus crisis has meant that French oyster farmers, are so concerned to protect their businesses that it has resulted in the emergence of multiple private initiatives.

In the very beginning the first option was to avoid mortalities. This was only possible on sites were no massive mortalities have been recorded (e.g. like in the 19 disease free bays in the Island of Ireland). Then, it has been found that there was less mortality on seed infected by OsHV-1 μvar when they are grown at deep sites or at cold temperatures. Also, it has been found that the “isolation” factor (farming in pond or nursery, offshore) could considerably reduce mortalities. When disease is inevitable on a site, the other strategy was to develop specific aquaculture practices and technologies trials to test what farming practices could best reduce mortalities (i.e. oyster densities in bags or exposure).

Two main strategies were developed to counter mortalities:

I) Avoid mortalities.

II) Development of specific aquacultures practices

3.2 Production strategies put in place by Aquaculture professionals.

Production strategy I: Avoid mortalities.

➡️ Les Claires de Bonsonge, Marennes (Poitou-Charentes): growing half grown oysters in Claires

Oysters have been cultivated in small ponds (called “Claires”) since 1825, and this was how Mr. Nicouleau, business director of “les Claires de Bonsonge” grew oysters when he started his production-dispatch business 25 years ago. These claires are also used to grow prawns and clams (two species also originated from Japan) along with the culture of oysters. It has been found that oysters placed in ponds are much less, or not at all, affected by mortalities during the summer.

These ponds are commonly used to finish oysters before sales (a method called “affinage”) or to produce a specific product called “pousse en claire” from half grown (i.e. 30 - 40 grams oyster). The production cycle is short, it takes only 6 months to produce 60 - 80 grams oysters, and so oysters double their weight. Added to that there is a considerable added value with a superior quality of the finished product: the Red Label “Pousse en Claire” refers to oysters with a firm, abundant flesh and the notable flavour of the region. The average retail selling price for a “Spéciale de Claires” nº3 at 12€/kg is twice as profitable compared to 5.20/kg for a standard oyster.

To obtain a superior quality, oysters are laid one by one in April at very low densities (5/m²), into a wallet-like large net placed over the clay at the bottom of the ponds. These ponds are filled up by gravity with sea water at high tide and they are topped up by pumps from a channel connected to the ocean. Since the mortality epizootic broke out, only half grown diploid oysters from Normandy (30 months old) or triploids from SATMAR (18 months old) have been purchased. The final outcome of this particular technique is that the oyster doubles in weight in 6 months.

The transfer to ponds has to be done before the temperature increases, as by then the oysters are well acclimatised. There is a high variation of the environmental parameters in water ponds, depending on the season and if there are water changes or not. Water temperature can range from 17˚C in May and peak at between 22-26˚C in August. The salinity ranges between 34‰ to 39‰ (Bouquet et al., 2011). To avoid overheating and oxygen depletion, the depth has to be adequate (over 1 meter deep) otherwise mortalities under certain eutrophic conditions could happen. Water is also regularly pumped, even during the critical period of threatened mortality.

The reason for low mortality on half grown oysters under these conditions is still unknown. It should be remarked that farming densities are low, the water circulation is poor and the virus might not be active over 24˚C (Pernet et al., 2011). The origin of the oysters varies and does not make any difference to survival. It could be also suggested that intense solar UV radiation and low depth could have an aseptic effect through the water. As such it has already been verified that with a system of UV treatment in a confined area, it is possible to inhibit the virulent effect of the virus (Tristan Renault, Ifremer, interviewed in Cultures Marine nº 251). The Laguna waste water treatment station of Mèze-Loupian (34, France) is an applied system that further illustrates this hypothesis: it uses 1.1 meters deep water ponds to kill pathogenic germs as part of a waste water purification process. Hydrodynamics in ponds are also quite different than at sea and a slower inflow or low water movements could affect the dispersal of pathogen in the ponds. Similar views on hydrodynamic factors were considered in the studies carried out by Pernet et al. (2011) in the Lagoon of Thau.

So the technique “pousse en claire” is a very well specialised branch of the industry. It could be carried out with half grown oysters, produced from deep water ongrowing with no mortality, so that the full production cycle from seed to adult can avoid mortality.

Photo above: Ponds called “claires” are specific to the region Poitou-Charentes and Pays de Loire. Top right: Satellite photo of “Claire” by Google Earth with positioning of the top left photo of a “claire” (camera symbol on map). Photo bottom: Google Maps overview of sector Marennes - Cayennes which gives an overview of the scale of the oyster industry in Poitou-Charentes.

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54 Pousse en Claire: translated by the author as growth “in shallow ponds”. During its time in claires (from 4 to 8 months) and at very low density (2 to 5/m²).

55 More infos related to the “pousse en claire” can be found at the website: www.huitresmarennesoleron.info
Le Cabanon de l’huître, (Poitou-Charentes): Production of seed with no mortality, in ponds (short cycle)

David Hervé is a producer/dispatcher, owner of “Le Cabanon de l’huître”, an important and renowned family business for the past three generations in the Poitou-Charentes region. Their production cycle goes from nursery seed to fully grown oysters on trestles at sea.

A particular approach of this business is the use of ponds to start the production of seed in short cycles (2 months) with very little mortality. This system has been used in the last two years and it is still at development stage. First observations demonstrated that there was no mortality on seed grown in ponds whereas at the same time at sea, seed were dying.

Trophic conditions are high and seed are growing fast at warm temperatures so they are immersed/exposed 24 hours to avoid desiccation and overheating and to mimic the tides for hardening the seed. T4 purchased from hatchery are placed in short lanterns (7 stacks) hung on a metallic frame that can be easily removed from the pond to mechanise the exposure. Ponds are deep (1.8 meters), and a 0.4 to 0.8 meters deep settling pond is used as reservoir where UV radiation can have a sterilisation effect on pathogens as described in the previous section.

Water is regularly renewed to improve the biological productivity, even when there is massive mortalities at the same period at sea. According to the experiments carried out by the CREAA (Bouquet et al.2011), the effect of water change on mortalities is unclear, however it has been found that there are problems of nutrient losses and macro-algae over-growth in pond in the summer when there is no water change. In the same CREAA study, it also noted a horizontal transmission of pathogens when seed batches of various origins were mixed in the same pond which resulted in an increase of the mortality rate.

This technique has the inconvenience that it requires a lot of space to produce a small quantity of oyster seed in lanterns, so cycles have to be short (every two months during the summer from April). After 2 months of pre-fattening in the ponds, seed are transferred at sea for further growth. Results on the survival rate at sea are not available yet, but it is expected that the survival rate will vary depending on the period of transfer, the site and temperatures. Growth of the seed in ponds is also highly variable, but typical figures shows that seed can reach the size T15 T20 within two months.

This technique is not directly applicable to Northern Ireland, but the relation between the isolation of oysters and epizootic events occurring in the same area is interesting. Further investigation into environmental characteristics of ponds and testing the seed health status under these conditions are essential to better understand why seed are less affected by mortalities.

Mr Bluzat, Cherbourg: adaptation of remote setting techniques and use of disease free sites to avoid mortalities

Jean-Paul Bluzat farms oysters in bags on trestles at Quineville (region Normandy), beside Cherbourg. The intertidal site is accessible by tractor. Seed is produced on-site using the technique of remote setting of the oyster larvae on artificial collectors. The full production cycle is long: from larvae to adult, it takes 2-3 years to produce a triploid and 4-5 years for a diploid oyster. Due to shortages in wild seed, triploid oyster seed are also purchased from the local hatchery.

This technique uses larvae seed from a hatchery and produces oyster spat on artificial collectors in a semi-controlled environment: the setting phase is started in sea water temperature-controlled tanks, the outgrowing phase takes place at sea. The same technique was already in use before the herpes mortality outbreaks so nothing is technically new – just more relevant. It is simple to apply, quick but labour intensive for handling collectors, but does not require extra staff or expensive investments. It also allows independence for seed production, as long as the hatcheries are producing a good quality of larvae and that there is a regular supply, as the technique can be operated in spring and summer. The technique does not require a lot of expertise, setting rates keep improving with experience and good knowledge of the local environmental conditions, the type of collectors used and the choice of best seasonal windows.

More specifically, after delivery larvae are transferred into on-site water tanks into which they swim freely before setting and metamorphosis on the artificial collectors. After 5 days, once the setting phase has ended, collectors are transferred at sea where the seed can continue their growth before being detached. After detachment, they are placed into oyster bags as normal. Seed set in April- June can be detached from July to September, once they reach T6-T12mm.
As a preventive disease measure it was not allowed by law to transfer any seed from May to September 2010 in Normandy. Seeded collectors were therefore kept in concrete ponds (the ones usually used for oyster stockage). No more food was added to the pond and there was poor water exchange during this period. By doing that, newly settled oysters were isolated from their environment during the epizootic event. In September 2010, the seed was tested for the herpes virus, detached and no mortality was observed. Seed was transferred to Port Bail, one of the few disease free areas in France. No more seed was added in this particular bay after the 2008 mortalities and there was nobody else farming oysters anymore around. A second trial of this technique was used last year. Since then, seeds are regularly tested for the herpes virus by research scientists from the University of Caen and the Laboratory Duncombe.

At Mr Bluzat facilities the survival rate for detached seed from larvae is usually ranging between 15% to 20 % (national average too). Higher setting rates, up to 50% and exceptionally 70% have been reported by Mr Denis Guet, a teacher in applied aquaculture from the Lycée de la Mer de Gujan Maestras, Dept. 33. Such levels of mortalities are expected and there are variations from site to site. At this stage and using this technique mortality rates are influenced by the quality of larvae, natural selection, environmental parameters, predation at sea, the type of collectors used. There is also higher risk of bacterial infection at 25°C if water is unclean\textsuperscript{56} in the setting tank. Since the massive mortalities, the overall survival rate for detached seed using remote setting techniques dropped from 15-20% to 2-3% as seed settled on collectors are also affected by mortalities.

Table 2 below shows that remote settlement can be a low cost option to produce your own seed. Remote settlement could be a way forward for NI as it requires less capital expenditure and effort than a full hatchery facility.

At a 15% survival rate for detached seed (marked yellow), the cost of diploids and triploids seed produced from remote setting techniques (€3.36 and €5.76/1000, respectively) was well below the price of diploid and triploid seed from a hatchery. By avoiding mortality, Mr Bluzat would be well below actual seed prices: i.e. €10 for natural seed, €12 for triploids from most hatcheries.

\textsuperscript{56} Eutrophic: “body of water rich in nutrients and so supporting a dense plant population, the decomposition of which kills animal life by depriving it of oxygen” (New Oxford American Dictionary, 2nd Edition).
<table>
<thead>
<tr>
<th>Survival rate for detached seed (%)</th>
<th>Diploid T6 seed</th>
<th>Triploid T6 seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>€ 10.00</td>
<td>€ 17.28</td>
</tr>
<tr>
<td>7</td>
<td>€ 7.20</td>
<td>€ 12.34</td>
</tr>
<tr>
<td>10</td>
<td>€ 5.04</td>
<td>€ 8.64</td>
</tr>
<tr>
<td>15</td>
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<td>20</td>
<td>€ 2.52</td>
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</tr>
<tr>
<td>50</td>
<td>€ 1.01</td>
<td>€ 1.73</td>
</tr>
</tbody>
</table>

Table 2: Cost for detached seed, using remote setting techniques at different survival rates in relation to the initial cost of diploid or triploid larvae (Prices of larvae include the cost of algae paste) 57

The more specific strategy employed by Mr Bluzat was to try to avoid mortality by 2 means:

I) By keeping the collectors in isolation in tanks during the summer. Detached seed are transferred at sea in September and no abnormal mortality was observed at this stage.

II) By transferring the detached disease free seed (seed in oyster bags at this stage) into a disease free environment. No results on survival rates are yet available.

3.3. Production strategy II: Development of specific aquaculture practices.

L’Oléronaise (Poitou-Charentes): seed selection at early stage, farming at high density

Mr. Massé is the director of L’Oléronaise, an important family business well known for the quality of their oysters at Marennes Oléron. Oysters are farmed in bags on trestles and finished in ponds before dispatch. A variety of products are sold through different quality brands to add the maximum value to the final product (“Pousse en claire, Spéciales, Oléronaise Médaille d’argent”). More oysters are bought from other farms to compensate the production shortage. His oyster parks are just below the bridge of Marennes-Oléron which he can access from one of his flat bottom fast aluminium boats before low tides.

Mr. Massé would advise that the best practice in the area is to expose the oysters to the mortality at the earliest stage of their life so to reduce the production cost. Oysters previously exposed to mortalities are stronger and more resistant in the second year so seed that survived the first year are safe. Traditionally the advantage at Marennes-Oléron, is the high availability of natural oyster settlement on collectors. However, the average natural seed setting rate had been getting lower in the last few years this was due to the high mortality losses, and therefore more artificial collectors are being used to collect them (see photo below of the “coupelles” collectors). Unlike at Arcachon, there is no restriction on the amount of collectors that can be used and the increased number of collectors was pointed out as a possible cause of the lower setting rate - no more larvae but more artificial collectors = less seed / collector. Mr Massé bought 270,000 new collectors, but he said that other businesses have bought up to 700-800,000 new collectors. The demand for collectors is such that even getting them is difficult. The shortage of oysters is also off set with triploid oysters from the hatchery, which grow faster and are well suited to supply the summer markets. A production cycle for this region is typically two-three years for triploids, three-four years for diploids, depending on the production site.

By naturally selecting the stronger seed from the start, it helps to reduce the production cost because there is less labour involved. Also, if the oysters die early, there is a better use of the natural resources because there are more nutrients, trace minerals and less oyster biomass wasted from their death at a later stage. There is also less decaying flesh from moribund oysters on production sites, and so less risk of disease infection. It could be added that the 20% more resistant seed that stayed alive might breed and in the long term improve the natural genetic strength of the oyster. Higher seed concentration in the bay could also lead to faster cross-

(Cost of diploid larvae: €440/1,000,000; cost of triploid larvae: €800/1,000,000) + €64 for algae paste food.
contamination during a disease outbreak, were high mortality rates across all the production sites of Marennes-Oléron are around 70-80%.

Two years ago, Mr Massé tried to reduce mortality by putting seed on higher intertidal zones (tidal coefficient 50% with oyster bags placed onto 70cm high trestles) and the first results seemed to be optimistic; the idea was to slow the growth. However, as mortality rates were not significantly different the following year, and taking into account the slower growth this did not give any conclusive results and this technique was abandoned.

The only factor that seemed to have reduced mortality was to work in cold water sites. This was observed when seed was sent to the Republic of Ireland with the help of a trading agent. “The problem is that if oysters are brought back to warm waters the following year, they start to die. What you don't get the first year you get it the second year”, Mr Massé explained. If in the first year there is only 50% mortality on seed, the second year there should be another 20-50% mortality. So it’s not worth the effort and cost to keep too many weak seed when they are free and abundant (i.e. natural settlement).

Photo above: new collectors to be used this year for natural setting in the Poitou-Charentes region (these palettes can be seen everywhere in the basin). Photo right: sites at Marennes below the bridge of Oléron. Bags of oysters are placed on site just before low tide.

Mr Massé’s point of view is that “ideally the solution for this region is to detach the natural seed from the collectors, and place them straight away in oyster bags at high density (5000 seed/bag). With 80% mortality just before the oyster is 1 year old, the bag might be ending with 1000 seed/bag, which is all right if seed are not purchased (i.e. natural setting)”. The surviving larger oysters are then transferred into a wider mesh bag and the dead seed fall through the bags and so there is no need to sort dead from live seed. Working at lower density does not make any difference because the mortality is uniformly equalised over all the production site; when bags are not heavily stocked they would become almost empty after mortalities and as a result aquaculture sites were not used efficiently and labour cost for handling are higher.

The newer collector often used in Poitou-Charentes are the coupelles type because it is possible to produce seed one by one, the detachment is well mechanised and it gives satisfying results. This technique would not be economically feasible if there was poor and irregular natural oyster setting like in Arcachon for the last few years, or in the Mediterranean Sea.

Mr Massé thinks working with triploid oysters is different, there are costs involved to buy seed. In this case it is better to slow the growth to try to reduce the mortality, at high density and on higher shores for longer exposure time. Oysters are not even de-doubled to improve the growth, so they are straight away placed from 4 mm bags to 12 mm bags once the seed are 30-40g, the smaller dead shells will fall through as well. There is no grading involved in between to promote regular and fast growth. So, by trying to reduce most mortalities the first year by slower growth, then in the second year, it’s still possible to obtain an oyster in 2.5 - 3 years instead of 2 years, which is a decent result (see Annex 2).

For Mr Massé, there is no miracle solution; in his opinion, the only way mortalities could be avoided is by working on your own in a bay, away from contamination with other oyster farms, with limited and controlled transfer of oysters. This is, in one way, going back to Strategy I (isolation, confinement). He is also hoping that, eventually, resistant oysters will be bred and oysters will become genetically more resistant with time by natural selection.
Cheap, abundant seed collected from natural setting in Poitou-Charentes are put under high viral pressure. This involves fast growth in deeper sites and at high densities (strategy II).

Otherwise,

More costly triploid seed are put in safer farming condition. This involves slower growth with work at higher shore and at high density.

Girard Frères, Arcachon: alternating slow growth (longer exposure time) and fast growth (deep water culture).

Girard Frères EARL is a medium size producer - dispatcher, growing 200 tonnes of oysters a year in the Bassin d’Arcachon at la Teste de Buch. As already reported in Chapter 1, producers at Arcachon have to face problems of mortality on seed and poor setting rates.

The full production cycle is carried out, “coupe/les” collectors are used for collecting oyster seed in July-August that will then be detached in the next March-April. From there, batches of T6, T12 seed are placed in bags to be put on higher shores for hardening (coefficient 50%)58. Mortality rates are reduced from 80% to 40-60% using a longer exposure time, for reasons that are not well understood. But it seems that the exposure of the oyster at a higher tidal coefficient reduces time to feed and lowers metabolism. Oyster spending less energy on growing are developing into stronger shellfish. It could also be suggested that filtering less; oysters are more isolated, so less exposed to the virus during its active and highly contagious phase.

Oysters that have survived the first epizootic danger period are then placed in bags to grows inside a cage structure like the ones used in deep water culture. This technique allows the use of new areas outside the crowded shallower production sites. Oysters are still growing in the winter because they are under water all the time (like in the Mediterranean). The technique is well mechanised and all the work can be done by using cranes on boats and forklift. The access to the sea is carried out from a 6x4m flat bottom aluminium boat propelled by powerful hydraulic pumps that allow heavy loads. The bags of seed are stacked over removable individual iron frames. The idea is to allow a maximum of flow between seeds to maximise the growth. The disadvantage of this growing method is that oysters are not handled at all during this period and therefore the half grown oysters (30-40 grams) are not a very good shape.

Photo left: cages used for deep water sites. Photo right: flat bottom: aluminium boats used in France to access oyster site when no tractor can be used. This one is equipped with a crane and a wider 4 meter one is also used for greater stability.

The following spring, the same process is repeated again: half grown oysters will be transferred back to site with long exposure time for 4 months during the critical danger period of mortality, and at this stage mortality rates are more like the usual (10-20%). After that, the half grown oysters are transferred back again in deep water for another 4 months from August to November. Around this time, 70% of the oysters are ready for sale so oysters are placed on a stockage site for the winter and spring sales. The overall mortality in 2011 over Arcachon is 60-80 %. This technique allows keeping mortalities down toward the 60% figure.

58 In France the magnitude of tidal fluctuations is measured using a “coefficient de marée” or tidal index.
Combination of fast and slow growth technique allow to reduce mortality while keeping short production cycle:

- Seed are put higher up shore for hardening in the summer, so they have a longer exposure time (slow growth but stronger seed).
- Juveniles are transferred to deep water cages during the winter to promote growth (fast growth but bad shape of half grown).

The main advantage of using deep water sites is that it allows to catch up time and so reduces the production cycle to 2-3 years (see Annex 2). Oysters are ready for sale at 27-31 months instead of 38-42 months using the normal method of culture. Allowing shorter production cycles compensates for the shortage of oysters for sale due to mortality. These measures are not enough to close the gap between supply and demand that is why Girard Frères also imports fully grown and half grown oysters from Ireland, Spain and regions in France.

**Figure 5:** Comparison between production cycles for diploids, triploids and hardening seed in alternation with deepwater sites for oysters grown on the Atlantic coast with theoretical mortality rates. Red areas correspond to the critical period of mortality. (Sources: Girard Frères EARL and Bouquet A.L., 2000).
3.4 Development of new technique and further investigations.

The use of deep water sites, to avoid mortality: Research investigation by IFREMER in the Mediterranean.

A study on the oyster mortality in Mediterranean has been commissioned by the CRCM\(^5\) and was carried out by IFREMER and the Cépralmar (Pernet et al., 2011). Two different production areas were investigated beside the town of Sète in South of France: a deep water site (30 meters depth) situated 2.5km off shore and a shallow site (4 meters depth) in the sheltered Lagoon of Thau.

Photo above: shellfish “tables” used in the Lagoon of Thau, south of France for oyster and mussel rope culture.

The methods of culture are quite different from the ones used on the Atlantic coast. The absence of tides allows the use of rigid structures that support lanterns to grow seed or hanging ropes where 30-40 gram oysters are glued in three’s (see photos below). The production cycle is short, about 2 years because oysters are always under water in a warm bay and the coastal zone rich in phytoplankton.

No mortalities were observed when farming seed at the deep water sites, in cooler conditions of greater than 20 meters on the off shore sites. The problem with using this technique is that to avoid mortalities, the full production cycle has to be operated at deep water sites. Mortalities could start if, exceptionally, deeper waters warm up for a short period of time or if juvenile oysters are brought back to the shallower and the warmer water of The Thau Lagoon.

On the other hand, costs to operate at deeper sites are higher and not economically feasible for a full production cycle. If one or two year old oysters have to be returned to the Lagoon of Thau to finish their growth, then it has to be done outside the critical temperature range (16°C - 24°C) to reduce mortality.

For the same reason, it has also been recommended to transfer seed before or after the temperature period at risk. Oysters maintained in cooler deep water (where temperatures are low) are not affected by mortality, but regardless of their age or size, they die as soon as they are transferred back into the shallows of the Lagoon of Thau (80% mortality recorded during transfer). Also, all ages of oysters are affected by mortality unless they have been previously exposed to an epizootic (CRCM, Pernet et al., 2011).

Leaning toward deep water farming has to be for a full production cycle only, avoid transfer during period at risk.

It is worthwhile recalling that summer mortalities were first associated with pathogens and temperature above 19°C. With the detection of the new pathogen OsHV-1 μvar in 2008, this temperature threshold is now 16°C. So it is important to be cautious when investing a lot of effort and money into new technologies, and take care to work at temperatures below 16°C. It is also worth considering the possibility of the emergence of another pathogen virulent at colder temperature. Occasional mortalities have already been reported in Normandy below these temperatures, but no relation as yet has been made to specific pathogens agents.

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\(^5\) CRCM: “Commite Regional de la Conchyliculture Mediterranee” The National Committee for Shellfish Cultures.
Photos left to right: oyster bags for stocking, rope pearl net and lanterns used in suspended cultures. It has been observed in the Mediterranean Sea that oysters kept at deep water sites where the temperature rarely reaches 16°C are not affected by mortality. Pearl nets and lantern nets are also used by some hatcheries as a technic for pre-fattening oyster seed, and they may be hung up on longlines.

The use of deep sea offshore site (CREAA) and late transfer of seed at oyster park or on longlines

The CREAA is investigating what zootechnical practices would reduce abnormal mortality of seed in Poitou-Charentes (Bouquet et al., 2011). Part of this study investigated the use of longlines 60a, these were developed since 1995 for the culture of oysters in suspension or at the bottom. This technique involves placing seed in lanterns nets or oyster-bags fitted in a metal cages-like frame, which are suspended under a longline. Another part of the study was for the same type of cage system to be laid under the longline, on the sea-floor for culture at low depth (12-15 meters deep). The use of deep water sites was initially developed to try to resolve problems of overcrowding and poor oyster growth (Mille D., 2008). Another type of cage system was experimentally used for off-shore deep sea culture (26 meters deep).

When comparing temperatures with mortality rates, it was found water temperatures were 3°C to 7°C less for July and August between oyster parks and surface longlines. Both types of sites had reached temperatures above 16 °C by the end of May. Mortalities hit in May-June at the oyster park, and in June-July at the longline site and then in August-September at deep sea site.

Comparison of mortality rates (April to September) between different production sites showed that there was some difference between oysters placed in bags at traditional oyster park (70%) or at longline site (77%). The most of the mortality on parks in Poitou-Charentes happens in early summer, so late transfer of seed in June - July may be better advised. Similarly, Dégrémont et al. (2010b), advised oyster farmer to transfer seed spat after the critical summer period. The seed can be transferred to another site where the mortality risk is known to be low. However, if it is possible to avoid the mortality the first year, there is no guarantee to avoid the mortality the second year. In this study mortality at deep sea off-shore sites or in ponds can be considerably reduced, however the growth was not as good as that on longlines or at an oyster park.

The experiments carried out by the CREAA concluded that several strategies could be developed in Poitou-Charentes to make the most of the environmental and technical resources in an epizootic context. Best results, would be obtained with a good compromise between lowest mortality rates and best growth. Therefore, in Poitou-Charentes, taking into account environmental parameters and technology available, the best strategy could be defined as below:

1.) Pre-fattening seeds in ponds from March to June with no mortality.

2.) Later transfer of seed (from hatchery or from ponds) in June-July on suspended longline, or to higher parks (10% less mortality than at lower parks) with the hope to obtain mortality rates below 50%. Or offshore deep water cultures (less than 26% mortality rate).

60a Longline cage-like frame dimensions are (H:1.70m.;W:0.93m.;D: 0.52m) and can hold 10 stacked bags. 57b Offshore cage-like frame dimensions are (H:0.70m.;W:1.54m.;D: 1.2m) and can hold 12 stacked bags/cage.)
Growth in ponds is able to avoid the mortality on parks, however growth performances are not great (ratio biomass:food availability, has to be taken into account, especially in confined ponds). So ponds are used for pre-fattening the seed and for short cycles only. Mortality rates are considerably reduced if seed are kept in ponds, but seed put on parks the next year will have high mortality rates. Finding from Bouquet et al. (2011) and Pernet et al. (2011) and Dégremont (2010b) seem to indicate that strategies to avoid mortalities the first year will result in a catch up of the mortality the second year if seed are put back under viral pressure.

### 3.5 Other responses and initiatives.

**Sourcing oysters from wild stocks**

In the Bassin d’Arcachon natural setting rates on collectors are a big problem for small and medium businesses that do not have another site in the north to obtain natural seed at production cost. These businesses have to face a new situation as they are not used to be short on seed, so the current practice today to help them keep up with production, is the collection of wild oysters that have always grown on residual objects immersed, (see photo of the bicycle below). These are now being collected from trestles and from left overs on the bottom. These oysters that were of not much interest before the herpes crises, are now being collected. As well as helping to keep the aquaculture sites clean, they represent today a valuable source of income for those who want to make the effort to go and collect them. A survey to evaluate the stocks of wild oysters on the bottom was commissioned by the CRC in June 2011 (article in newspaper “Sud Ouest”, B. Dubourg, 2011). The study concluded that there were 131,000 tonnes of oyster in the Basin alone, only 16,600 tonnes of which there were farmed oysters. 85% of the oysters are actually wild, 50,000 tonnes of which are dead and 65,000 tonnes alive. These wild oysters are not well shaped, but as suggested by Olivier Laban (president of the CRC Arcachon), they might remind you of a “traditional oyster”.

### 3.6 The potential use of mussels that act as a biological curtain to reduce mortality rates.

A €6 million patent has been granted by the INPI to a business society “Cambon et Fils”, which is a mussel production company at the Lagoon of Thau, in the Mediterranean Sea. This patent gives to “Cambon et Fils” the exclusive right of the use of their invention which is a technique that could reduce the mortality rates of oysters. The principle is simple: it has to do with the use of mussel culture between suspended oyster culture or around oyster parks. Through their filtration process, the mussels remove pathogens from the water, acting like a biological curtain placed between the oysters and pathogens, and so the viral charge in the oyster is lower. This technique requires a large concentration of mussels. There is a lot of scepticism from local professionals about the effectiveness of this technique; there are already a lot of mussels in the Lagoon of Thau and still oysters keep dying at 40% to 80% like in other bays. In the opinion of Mr Balmefrezol, owner of a small oyster and mussel family business at the nearby village of Bouzigues in the same area, “the mortality may happen 1 or 2 weeks later with mussels mixed with oysters, but mussels cannot make a hermetic curtain around the oysters and seed will still be later affected the same way.” Other oyster producers share a more optimistic opinion: “I put mussels around my tables of triploids, and if it doesn’t do any good, it won’t do any harm either”.
At a meeting presenting the patent, Mr Cambon’s solicitor specified that “The patent means that the INPI has accepted that there was a monopoly for the exploitation of the technique and the INPI doesn’t guarantee the technical efficiency of the process”. There is a general disapproval by the oyster farmers about the brief, mussels and oysters have always cohabited in the Bassin de Thau, and aquaculture has always been licensed for the culture of mussels and oysters. At Arcachon, Olivier Laban (President CRC) said that “This process is wrong and mentioned that there are 75% morality on oyster seed and yet they are cohabiting among mussels and this does not reduce the impact of mortality at Arcachon” (source: interview France 3: “des moules contre la mortalité des naissains”). As mentioned earlier, mussels at Arcachon and other regions are a problem of the oyster farmer because they are setting everywhere, even on oysters and farming structures.

The introduction of oysters from Japan and Brazil

An initial mission to Japan has been organised by the CRC to try to reproduce what has already been done with Japan in the 1970’s: this is to reintroduce a new brood stock of oysters, more resistant, from Japan (Bay of Miyagi). For Mr Mauviot, president of the CRC Poitou-Charentes, who was part of the French mission by the oyster industry: “This could have been the miracle solution. Natural oyster beds were restored in the 1970’s with this new species of oyster and it was successful”.

However, there are too many dangers related to the introduction of new pathogens in the environment, but for Mr Mauviot preventive measures which highlight these dangers are not well founded: “The virus was already brought in here in the 1970’s, and, on top of that, ship ballast and pleasure boats coming from all parts of the world are equally the cause of the introduction of exotic organisms”. It could be mentioned that at the International OsHV-1 workshop at Cairns, Queensland, Australia (9-10 July 2011), it was hypothesised that international spread of the disease may have taken place in association with biofouling (i.e. oysters attached to the hulls of ships).

This approach also had difficulties from the Japanese authorities, however four small samples of oysters were imported from Japan between October 2010 and February 2011. Importations from Japan are not normally authorised, but in the name of scientific research an exception was made to the rule by the European Commission on September 15th, 2010. These oysters were directly sent to the laboratory of genetics and pathology of IFREMER at La Tremblade. Experiments were carried out to identify which species they were related to and to search for the presence of infectious agents, notably exotic ones. Tests about the resistance of the imported oysters to the pathogen agents OsHV-1 μvar and Vibrion of V. Splendidus and V. Aestuarianus, were also under way in May 2011. No listed diseases listed under the OIE’s Aquatic Animal Health Code were detected, however a parasite of the genus Haplosporangium was found (sources: Tristan Renault).

From these trials, it was possible to conclude that there was a stronger resistance of these oysters to the viral infection. Taking into account the analysis results realised by IFREMER, the ANSES recommended not to import alive oysters from the Miagi prefecture in Japan. Taking into account difficulties related to the importation of oysters from areas that would potentially host exotic pathogens for France, and these related to the evaluation of their resistance to OsHV-1 μvar, it has been also recommended to look for a different solution (Anses – Saisine n° 2011-SA-0072).

A complementary bibliographic analysis has been carried out in other third countries. The second choice is to import adult oysters from Brazil. Analysis for pathogens has been carried out by IFREMER and a report of the results obtained has been sent to the DGAL.

The use of magneto-therapy in oyster bags

Resulting from the experience by the “AURIS” business society, in the last few years concerning the use of magnetic fields giving a positive effect on reducing the mortality of bees. Mr Goulven Brest (the president of the CNC) has decided to carry out similar experimentation with oysters. The idea was to verify the theory that magnets placed into oyster bags could reduce mortality on seed. AURIS, that had already conceived the “BeeMag” system for beehives, was commissioned to develop specific magnets that were placed in a waterproof casing, 2,000 magnets have been supplied to the oyster farmers in April 2011 over seven different areas in the Atlantic and Mediterranean. These experiments were carried out at a regional level by the CRC and local aquaculture applied research centres. When questioned on the subject, Mr Mauviot (president CRC Arcachon) mentioned that the use of magnets in oyster bags had made no difference. However they should have been put earlier into the oyster bags.
3.7 The ultimate solution: production of a selected seed.

The fall-back plan with the production of an oyster presenting higher survival rates

Hatcheries are becoming an essential safety-link to industry, as they secure the supply of seed to oyster farmers. Unlike natural setting the harvest rates of which are erratic from year to year, they allow a predictable management of production. At the request of professionals, hatcheries have produced triploid oysters which enable the shortening of the production cycle by one year and the marketing of “all season oysters” for summer. The next challenge is the production of genetically resistant oysters to stabilise an industry in crisis. At the Assizes for the Shellfish Culture in 2010, a solution has been adopted as a plan aiming to partially and temporally compensate for the shortage of seed until a sustainable solution was found. Each year since 2010, annual conventions are signed between the CNC, the MAAPRAT, IFREMER and private hatcheries. In this context, IFREMER has produced and supplied oyster brood-stock of tetraploids males and diploid females issued from oyster families that were identified as “resistant” during summer mortalities before 2008 (during the MOREST project, see Chapter 2). It was evident that the solution was the production of a resistant “R” seed issued from the selection of families having the lowest mortality rates. These batches of “resistant” oysters were given to the French hatcheries by IFREMER, with the objective to supply oyster farmers with an oyster potentially presenting higher survival rates. The choice of triploid oysters was given to avoid the reproduction in the natural environment of animals with a low genetic variability.

In 2010-2011, the first 2 generations of selected oysters were given to professionals, but trials were not successful and mortality rates of up to 90% were recorded on those seed. Last year’s production did not reach expectations because of high mortality (200 million seed instead of 1 billion). However, at the shellfish observatory of the IFREMER research centre the different families from the MOREST project were tested. Offspring of these families were selected over two generations, notably one family gave the best results at a national level. This family called the “G2A”, had an average of 15-20% mortality over the 15 sites of the shellfish observatory. This selected family was given to the hatcheries to produce a third generation of seed for the 2012 season (Sources; Gerard Mauviot, Director CRC Arcachon at interview on March 2012).

Long term solutions into the production of a selected oyster seed had to involve further work for the production of genetically selected families. CRC and private hatcheries couldn’t agree on a system of work and as a response to this failure, four hatcheries decided to group together to create an organisation called the SFC 61, and at the same time Mr Marissal (Grainocéan hatchery) created Génocean. The initial disagreement between the National Plan and the CRC was that there was an obligatory route by private hatcheries for the access to selected seed in the future (G. Mauviot, interview March 2012). Both hatcheries are now working separately on their own program for the production of a selected oyster seed using the common principle of family selection.

The National Program of oyster selection (SCORE)

In parallel to the two private initiatives, a National Program of oyster family selection was put in place upon request of the MAAPRAT in 2011, involving the participation of IFREMER and the LGP, the SYSAFF, CRCS and under the Direction of the CNC. This program is quite different from the family selection of “R” issued from the MOREST, which was seen more as a feasibility study to check if there were different higher survival rates during epizootic events among oyster families. Today the aim is to create 50 top families which will be used for further family selection to produce an oyster strain with a high genetic diversity. The final outcome of such a program, different from the two private hatchery programs, is to produce a resistant oyster brood-stock that will be used to restock natural oyster beds in the environment and to reinforce their natural resistance.

This selection program called “SCORE” will be carried out over 1,500 to 2,000 families, initially and will be performed by the CNC at the IFREMER station of Bouin.

The other objective of this program is to examine how a new group of oysters settled on tube-collectors will reproduce and disperse in the various bays producing natural seed. These oysters will be genetically identified with the use of markers or micro-satellites so that it will be possible to track them (in larvae, juveniles, brood stock). Therefore, it will be possible to study the diffusion of this group of oysters in the natural environment. The final outcome is to optimise the technique of efficient restocking once a resistant oyster is found at the program of family selection. It might take 10 to 15 years before the first results on mortality become apparent in the natural environment. This selection of resistant families being issued from the National Program, will also be available to private hatcheries (G. Mauviot, interview March 2012).

61 “R” seed; (“R” for Resistant as opposed to “S” for Sensitive). This terminology is often used in the literature to describe a selected oyster with survival rates to pathogens.
Overview of the different oyster selection programs:

- There is the safeguard plan with the selection of “R” seed issues from the MOREST. These families of selected oysters were given to French hatcheries to supply selected hatchery seed for the oyster farmers (next generation 2012).
- Two private initiatives Génocean and SFC hatcheries for the selected families.
- The National selection plan with the SCORE program, for the selection of 1500-2000 families for the restocking of the wild oyster beds.

Principle of familial selection

Both private initiatives are different in their funding and conception but they both aim to produce oyster families that will perform better in terms of farming and “resistance” to disease. The main difference between the two hatchery programs is the number of families selected (initially 400, then 600 SFC; initially 200, then 3,000 Génocean). This principle of family selection and related performances has already been methodically used in animal farming or in vegetable culture for centuries.

Offspring of these families will be bred on a site with low mortalities (i.e site A). Duplicates of the families will also be sent to 2 other sites with a history of mortality (i.e. Sites B&C). So at the end of each summer, the numbers of surviving oysters in ‘B & C’ will be counted for each family. The families that will present the lowest mortalities will then be selected from site ‘A’ to create a new generation.

Fig. 7  Schematic representation of family selections for the successive production of 400 families of resistant oysters, such as in the SFC program. The same principle is used by Génocean and the National program, with different numbers of family selection.

The SFC63 genetic selection program

Four hatcheries (the SATMAR, France Turbot, Sobado and Vendée Naissain) have united in 2009 with the creation of SFC, (Shellfish French Selection) that is implemented at the research station of Noirmoutier (Pays de Loire). Their objectives are to produce a disease-resistant oyster, with the selection of 400 families (sons and daughters of 1 couple) by generation every two years from the breeding of 120 brood stock by sex (i.e. 240 oysters in total). This capacity will increase up to 600 families once the selection principle will be validated for large scale. The selection of these resistant families started 2 years ago, and the last generation will be selected in 2012, so the commercial scale of seed production will be available for producers only by 2014 or 2015 (Communiqué de Presse, SFC president Stéphane Angeri, La Manche libre, 07/04/2011).
The Génocean genetic selection program and interview with Eric Marissal (Director Génocean)

For Eric Marissal, “As regards the immune system in the oyster, it’s total blackout”, meaning there are no investigations about it because nobody knows anything about it. “And so the second solution is the resistant strain. Here, there is some hope: if there really was a selection, it would mean that in a natural population of oysters there are resistant individuals, which implies something relatively easy to do”. Génocean is doing four settings a year, with a capacity of 1 billion seed at a time in provision for 2012.

“Resistant means an oyster that does not die in the presence of the virus. Hence, there are two possible options:

- Either there is a dominant characteristic: by crossing an individual with this characteristic, all descendants will have this dominant character.

- Or it is related to a genetic panel. If we imagine that the number of the resistant genes is 49 (like in a lottery for example) and only 6 good numbers have to be found, there is a chance of 1 to 13,983,816 to find the right combination. This is a selection with no major gene involved. Sometimes this panel of genes might be 200 or 400, so the number of possibilities could be counted by millions.

To see which option is the most likely, Eric Marissal decided to a test of familial selection, by crossing 60 males and 60 females this produced 200 families (not all possible crosses were done). If it had been a major gene, by crossing so many oysters it would have been possible to find one, but it was not the case. So, resistance is a result from a combination of genes, meaning that it will involve the use of thousands of families. But this is a problem because there are millions of combinations: it is not possible to cross millions of families to find the right one”.

As a result of this, Génocean set up its own program of family selection: “Starting the genetic selection by crossing 3,000 families64, it will be possible to find which families have better survival rates when their offspring are put in a situation of mortality (families are put in a situation of extreme viral pressure on suspended culture62 in lantern nets). From there, 300 best descendants will be selected to be crossed again so as to produce 3,000 more families and then put in a situation of mortality. The number of combinations realised is exponential, and by a selection process it is hoped to find the right combination. There will be many possibilities, with better survival rates during the selection process. Like in the lotto example, by reducing the range of possibility, there is better chance to win”.

From such a complex problem, Génocean will start to get worried if there are no encouraging results within the next 5 years, taking into account the €1.5 million of investment for such a project. This is also why a test was done before starting the project.

This test started with the selection of one generation of 200 families, taking the 6 best to produce a second generation. For the first generation there was a mean survival rate of only 1% (meaning a mortality rate of 99% between all families), with the best survival rates at 12% for the best families. As for the second generation, there was a mean survival rate of 10%, with the best survival rate of 44%. This summer of 2012, there will be the third generation, and if results are the ones expected, then Génocean will start again with 3,000 families: with a large base of genetic diversity.

The families of resistant oysters produced with the test will be kept, but they will not be used for the program of selection, the pyramid of the genetic diversity being too narrow.

At the test, it was found that there were 3% of families that were resistant, i.e. 6 out of the original 200. So by starting with 3000 families, they can expect to obtain 100 selected families these families are collectively called TRESOR.

The term TRESOR granted to these 100 families was used because it signifies that 100 families are enough to make a genetic selection for the 20 coming years. The initial selection has to be strong, starting from a solid base and at the same time with a high genetic diversity.

The French model that Eric Marissal wanted to put in place with the CRC, but which did not work, was an association between

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64 3,000 families corresponds to 3,000 crossing of identified male and female separately.
natural setting and selection. It was a model that would have promoted the outlook of the French hatchery all around the world: “Hatcheries do not kill the natural setting, they contribute to the maintenance of a traditional activity”.

Shellfish farming is in the top five sectors in the world with tonnage and with a turn over higher than many other species. Tomorrow the industrialisation of shellfish farming will be an obligatory route, such as with the domestication of the farmed salmon. But unlike the salmon, shellfish are already farmed traditionally everywhere in the world.

3.8 Sanitary measures put in place in Europe.

➡️ Before 2010

Mortality in 2009 started earlier in the year than in 2008 and as a preventative measure to limit the spread of the viral epidemic, the French Ministry of Agriculture decided to stop shellfish transfer between bays of production from the 28th of May 2009 and during the critical period of mortality (the same ban measure was applied the following year). Dispatchers, whose principal production is based in Ireland and Normandy, were particularly affected by such measures. For others, the transfer of seed from Marennes to Ireland was done just in time before the ban, so that millions of seed were more safely placed in the colder Irish waters. For hatcheries, this legislation stopping shellfish transfer had dramatic consequences because hatchery seed could no longer be sold and had to stay in the nursery.

However these measures were not sufficient to stop the spread of the disease as two months after the third ‘wave’ of massive summer mortality, all French production bays were affected. It has not been possible to develop efficient sanitary measures since the first two years of mortality (article in Aquablog, June 2009).

In France, within a year, almost every site became affected by massive mortalities (only isolated sites such as nurseries, ponds, off shore sites deep sites were spared). In the Republic of Ireland, it was very different; in 2008, only three places where seed was imported earlier that year from France were experiencing between 15% and 75% mortality, so the disease was just emerging. But between June and August 2009, 15 bays had massive mortalities, 14 of which OsHV-1 μvar was detected - this number accounted to 19 in 2010. It could be remarked that massive transport of natural and hatchery seed from France to Ireland happened just before the shellfish movement ban in May 2009.

In 2008-2009 no certification for the detection of OsHV-1 μvar was required for shellfish transfers because the herpes virus was not regulated. Some producers/hatcheries had tested for it but there were no official certificates to say that they were.

➡️ From 2010

In 2010, the UK experienced mortalities at Whitstable Bay, in the Thames estuary, and at Grouville Bay, South-east Jersey, but managed to contain the virus after immediate containment measures were established at the time of detection.

Following the spread of mortality in other European countries (UK, Ireland, France) in 2008 and 2009, sanitary measures have been implemented by the European Commission.

The main legislation appeared in the 2006/88/EC Council Directive which was the framework for the shellfish sanitary preventive measures. This was the first test of the legislation with an emergency disease situation, and this is why it took so long to implement such measures. In addition, producers were strongly advised to test samples of oysters from containment areas prior importation to protect disease free area.

In March 2010 came the new Commission Regulation 175.2010/EU that required a “disease free” certificate for the transport of seed from an infected to a non-infected area (so called “disease free area”, meaning where OsHV-1 μvar has not been detected). Testing as laid down in the regulation must take place, and be certified by the competent authority in France. This was applicable only for areas that had OsHV-1 μvar and increased mortality.
“The regulation requires a surveillance program to be established for the early detection of the virus in areas that have not previously been affected. In accordance with Article 2(2) of Commission Regulation No 175/2010/EC it also requires containment areas to be established once the virus is detected in an oyster growing area, until such time as the mortalities subside and two mortality checks, 15 days apart, demonstrate that mortality has ceased” (Dáil Éireann Debate, Vol. 722 No. 2).

As a response, Northern Ireland established a sampling and testing programme in accordance with regulation 175/2010/EC to ensure early detection of any occurrence of OsHV-1 μvar in farms or mollusc farming areas and to control movements from containment areas and areas previously subjected to containment measures. The proposed zone (‘declared area’) was the entire country of Northern Ireland with the exception of Lough Foyle and Carlingford Lough which border the Republic of Ireland (DARD, 2010). A surveillance programme has now been established but excludes Lough Foyle, Carlingford Lough, Killough Bay, which tested positive for OsHV1 μvar, although no mortalities were detected. Some mortality was recorded by DARD from herpes in NI during the summer of 2012.

Commission Decision 2011/187/EU has updated the regulation and now transfer of seed can only be done within other bays with similar or inferior sanitary status.

The containment areas which were established in 2010 to control increased mortalities in oysters of the species Crassostrea gigas in connection with the detection of Ostreid herpesvirus 1 μvar (OsHV-1 μvar) have now had their restrictions lifted (www.marine.ie).

A surveillance programs for the early detection of OsHV-1 μvar was also put in place to protect the remaining disease free bays from the spread of the disease (The problem was that levels of virus can be very low in oysters and it could have passed undetected).

Today 19 bays across the Island of Ireland still have a “disease free status”. The main objective of the legislation is to protect the areas within the Community which are free of OsHV-1 μvar, and should remain so. This was achieved through the establishment of “disease free” compartments, where bio-security measures were put in place and where a targeted testing regime was established, to ensure that the health status of each compartment is known and can be protected: (source: European Commission, 2011 “Guidance document in relation to new OsHV-1 μvar regulation”; Marine Institute, 2011).

There is good communication with the oyster farmers, so it is hoped that these bays will remain herpes virus free.

Producers in Ireland and the UK have to get a “disease free” certificate only if they are situated in a disease free compartment. Otherwise, seed can be sent to areas that are already not into a “disease free” compartment. The problem with the Republic of Ireland and the UK is that there is perception of a shortage of seed in the situated in a “disease free” compartment because the three UK hatcheries are not capable of supplying seed to everyone. Only these bays can exchange seed between each other and buy seed from the only hatcheries available under a “disease free” compartment.

- Commission Regulation 175/2010/EU required a “disease free” certificate for the transport of seed from an infected to a non-infected area. It also requires containment areas to be established once the virus is detected in an oyster growing area.

- Commission Decision 2011/187/EU has updated the regulation and now transfer of seed can only be done within other bays with similar or inferior sanitary status. The containment areas which were established in 2010 to control increased mortalities have now had their restrictions lifted.

- “Disease free” compartments, have been established, where bio-security measures are put in place and where a targeted testing regime are established, to ensure that the health status of each compartment is known and can be protected.
4. TRANSFER OF KNOWLEDGE AND OUTLOOK FOR THE OYSTER SECTOR IN NORTHERN IRELAND AS A RESULT OF THE FRENCH EXPERIENCE.

4.1 Seed Supplies.

Potential of remote setting techniques to produce seed in Northern Ireland.

 Advantages of the technique

• “Remote setting” is a technique employed in oyster hatcheries for the setting of oyster larvae on a collector (any kind of substratum). The first remote setting techniques were successfully used at a commercial scale in 1978 in Oregon at the Whiskey Creek Oyster Hatchery that was built exclusively to produce oyster larvae (Gordon and B. Jones, 1988). This technique has the main advantage to produce detached seed at low cost, thus making the cost of seed still economically viable after heavy losses. Taking into account the cost of larvae (i.e. around €500 for one million seed with food for them), it could be estimated that the cost price to produce diploid seed would match the price of hatchery seed (based on €10/1000 at T6-T10) from a level of 15% survival rate for detached seed, see Table 2. The other advantages of remote setting are a regular supply of seed and the possibility to obtain oyster seed at any time, between early spring or late autumn.

• Guernsey and hatcheries in Morecambe and Whitstable are under-capacity to supply seed to all the bays situated in disease free compartments across Ireland and the UK. In the scenario of French hatcheries successfully producing resistant oyster, only bays in non-disease free areas would be able to access to them at first.

• Seed cannot be imported from France to bays under the surveillance program because, even with “disease free” certificates, there is no guarantee of their sanitary status when they are transferred for pre-fattening in outdoor conditions into non disease free areas. Seed can host the virus at an undetectable level (D. Cheslet, interview 2012). On the other hand, Petton et al., (2010)63, (cited by Cochennec-Laureau, 2010) has demonstrated in a laboratory experiment that certain batches of seed were initially negative for the OsHV-1 μVar, but could be detected positive and host the disease when subject to a sudden increase of temperature for a period of one month (from 13˚C to 21˚C). This technique, once validated could be used to target the sanitary status of seed in hatchery. At the moment, it cannot be guaranteed that pre-fattened seed at an outdoor nursery cannot be contaminated with the herpes virus when they are located in non-disease free areas, as the whole of France is non-disease free.

• There are further implications for Northern Ireland: the remote settlement technique would enable producers to obtain locally grown seed so as to limit the risks of disease transmission from contaminated areas. This should help to alleviate the actual problems of seed shortage all over Northern Ireland. It could also be a business opportunity for producers wishing to specialise in the production of seed as there is no better time to market seed in the Island of Ireland (where in the Republic there are still 17 oyster production bays classified disease free).

 Disadvantages of the technique

• Competency and necessary skills: even if the principles are straightforward, inexperienced persons will make errors that will eventually lower the setting and survival rate for detached seed. Experience will come with time and the technique might seem complicated or too technical at first. Meticulous work is required!

• Higher losses of seed for young oysters than in the nursery (predators, environmental exposures, handling losses).

• Dependence on hatcheries for the supply of larvae. In the future, the SATMAR (the major oyster larvae suppliers in France) might

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not keep supplying larval supply for remote setting on artificial collectors. Two other sources of larvae available at the moment are from the Republic of Ireland hatcheries, further investigation has to be carried out in sourcing of larvae from the UK and the hatchery in Northern Ireland in particular. French hatcheries have invested in oyster hatchery and nursery large-scale technology for the past 20 years. Added to this, special environmental resources (e.g. warm sunny weather, the use of nutrient-rich ponds or underground warm water (i.e. Polder de Bouin, Poitou-Charentes) ensure that the production capacity and production costs are much more competitive than ROI and NI ones.

• Primary investment is required for small equipment (tanks, collectors, pumps, heaters) and indoor space in a building, if possible beside the sea. There is a need for energy/power as well.

✈️ Profitability

• The cost of producing the seed is low, taking into account only the cost of the larvae (including algae paste food for larvae): €504 and €864 for 1 million diploid and triploid larvae, respectively. At a 15% survival rate for detached seed, the cost of diploids and triploid seed produced from remote setting was well below the price of hatchery seed. The advantage for Northern Ireland producers to develop remote setting techniques in a disease free area is that 15% to 20% setting rate is easily achievable, which makes the price for detached seed very competitive on the market in an epidemiological context. Therefore, at the moment there is a very good opportunity for Northern Ireland oyster farmers to specialise in seed or juvenile oyster production. Another advantage is for a short production cycle with a quicker turn over.

✈️ Improvement: increase in the survival rate for detached seed

Under normal conditions, the survival rate for detached seed from larvae usually ranges between 15% and 20%. Higher setting rates (50% and exceptionally 70%) have been reported by a teacher in applied aquaculture, Mr Denis Guet (Lycée de la Mer de Gujan-Maestras, Dept. 33).

Table 2 (Chapter 3) compares the cost of remote settle larvae at different survival rates to the cost of hatchery seed. Remote settlement seed with a survival rate of only 5% to 10% is competitive with the cost of hatchery seed. This is quite achievable, especially now with the higher price for seed for Northern Ireland producers.

Improving the survival rate for detached seed also increases the genetic diversity of an oyster batch, and therefore the genetic strength against the herpes virus. A wider range of oyster seed would express a better disease resistance. It is also rudimentary to try and minimise the external factors that affect the survival rates of larvae and seed. The primary factors are:

• The quality of larvae (well fed, actively swimming, size greater than 300 μm). A good homogeneity of the larvae is also important (all seed should be delivered at the same development stage from the hatchery, with foot and eye spot well visible). Setting should happen within 24 to 48 hours after immersion in setting tanks. Bad quality larvae will not metamorphosis very well and die at the bottom of the tank or will give poor survival rates once settled. The sourcing of disease-free larvae from existing French or UK/Irish hatcheries needs to be looked into.

• The water quality in the setting tank (same salinity as at the hatchery) and the use of clean water to keep levels of pathogens as low as possible. It is important not to expose larvae to the herpes virus before the transfer to sea water. It has been already mentioned in Chapter1 that infected larvae with herpes virus will lower feeding rates and swimming activity so that the mortality can reach 100% in a few days (eurl-mollusc.eu).

• The type of collector used: the collectors giving the best results are natural collectors such as tiles, oyster or mussels shells. Other collectors in plastic do not perform as well, especially when they are new. However they have the advantage to be reusable and to produce one by one seed with “coupelles or plenos”. Other collectors are “tube” type ones and detachment of seed can be easily mechanised.

• The environmental conditions, the time of the year for the transfer to sea water and the presence of predators. Once settled, cold temperature doesn't affect the larvae, as long as there has been a transition phase before the transfer from the setting tanks
to the sea. Oysters will not grow fast at cold temperatures, and the ones settled in May will catch up with the ones settled in March. An early transfer will also have significantly less predation - up to 75 % setting rate has been obtained at the Lycée de la mer at Gujan-Maestras (Aquitaine region) when using this method of transfer into claires. Collectors need to be protected from predators by the use of bags or nets. More information on trials of remote setting techniques tested in the Republic of Ireland is available in an unpublished report by contacting BIM. It is important not to expose the newly settled oysters to the air at low tide during the first 15 days after transfer into sea water as UV, wind and heat would desiccate the seed.

- A good understanding of the site’s characteristics such as hydrodynamics, currents and wind exposure is needed. Site access, types of collectors used, predator controls are essential factors to be taken into account for a successful remote setting on artificial collectors.

- The use of appropriate oyster bags or net to protect collectors from predators like crabs, prawns, starfish etc. Depending on the area and the type of predators, different types of mesh bags can be used. Old bags rolled up also make excellent protectors. Detached seed can also be put in “box bags”, which are traditional bags modified to look like a rectangular box. They are used to improve growth rate on oyster seed (i.e. better water flow through the bag). Such bags are used by the SATMAR in Brittany and are giving excellent results.

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Remote setting considerations for Northern Ireland:

In a disease-free area, remote setting can be a profitable technique applicable to NI.

In non-disease-free area, the survival rate for detached seed has to be optimised.

Trials of this technique using various collectors and using at best the natural resources is a necessary stage before starting a large scale production.

➡️ Development: to put in place or upgrade a hatchery specialised in massive larvae production for remote setting techniques

Remote setting is an uncommon technique used in France and it is at trial phase in the Republic of Ireland since 2009. So no hatchery is dedicated to the production of larvae only. French and UK hatcheries are designed to be profitable for the production of seed out of nurseries and have not much interest in producing oyster larvae (until recently, the SATMAR was the main supplier in France). Hatcheries that would have the potential and willingness to supply larvae are Redbank Shellfish (Co. Clare) and Jean Le Dorvan (Co. Galway), but other small hatcheries may be approached. However these hatcheries are not up to scale and do not have the 20 years of technological advances in oyster seed production already acquired by other oyster specialised hatcheries.

Undoubtedly, a program for the set-up of a hatchery dedicated to the production of oyster larvae (specialisation of the equipment to larval stage only) would automatically lead to an enormous potential to supply seed to Ireland, UK and France. Such a program could also be carried out under a common approach between Northern Ireland and the ROI, as both share the same geographical situation, similar sea conditions and a similar health status with surveillance programs.

The main outcome for Northern Ireland would be the independence of seed supply. Ultimately, and if successful, this would lead to less chance of importing pathogens. It would also be possible to obtain seed for areas classified as disease-free.
This would generate a specialisation of the industry by regions with larvae producers, seed producers, half grown producers and full cycle production producers to respond to the specific need of the market.

**MAIN OUTCOME OF SUCH A PROGRAM:**
- To produce high quality larvae (diploids and triploids)
- To produce larvae at competitive cost rates
- To provide support and expertise to producers wishing to investigate remote setting.

### 4.2 Seed supplies, SWOT analysis.

#### Analysis of the present situation in Northern Ireland

<table>
<thead>
<tr>
<th>Bay in disease free compartment</th>
<th>In bays were OsHV-1μVar was detected</th>
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</thead>
<tbody>
<tr>
<td>- 2 bays in Northern Ireland: Larne Lough and Dundrum Bay, 1 hatchery in NI (Island Shellfish, 4m-5m seed/ year).</td>
<td>- 4 bays in Northern Ireland: Carlingford Lough North, Lough Foyle, Strangford and Killough where Herpes virus was detected.</td>
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<tr>
<td>- No mortalities on seed,</td>
<td>- No massive increased mortality yet observed.</td>
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<tr>
<td>- High potential of development to produce disease free seed for the two bays in Northern Ireland and the 17 bays in the Republic of Ireland</td>
<td>- Possibility to import seed from non disease free area, (natural, hatchery).</td>
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<tr>
<td>- Possibility to produce large quantities of half grown seed at competitive rates to respond to the French shortage</td>
<td>- Cooler water temperatures than in France, low degree of intensification (only 260 T).</td>
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<tr>
<td>- Shortage in seed supplies, bays not exploited.</td>
<td>- Lower mortality rates than in France if mortality happen because colder sea temperature.</td>
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<tr>
<td>- Seed supplies only from Guernsey Morecambe Bay and Whitstable.</td>
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<tr>
<td>- Competitive production cost if seed were available.</td>
<td>- Production cost higher if mortality happen, uncompetitive for Irish producers.</td>
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<tr>
<td>- High potential for development of production.</td>
<td>- Some mortality have occurred in Foyle.</td>
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<tr>
<td>- Contamination with herpes virus if contaminated seed were voluntarily or accidentally introduced.</td>
<td>- High potential to develop the production to respond to the higher demand.</td>
</tr>
<tr>
<td>- The emergence of a new disease if no prophylactic measures and appropriate aquaculture management practices are not in place.</td>
<td>- Adaptation of the virus to cooler environment, occurrence of an even newer more virulent variant of the herpes virus.</td>
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66 SWOT: Strength, Weakness, Opportunities, Threats
## Remote setting techniques using larvae produced locally

| S | • Independence in seed supplies for area under surveillance program.  
• Reduce migratory flux of oysters to Northern Ireland, reduce further introduction of pathogens, competitors, predators, parasites, exotic species, new herpes virus variant.  
• Low cost of seed when technique is mastered.  
• Possibility to receive seed at early spring (March-April) and profit by the spring bloom.  
• Possibility to set oysters at end of summer to get seed ready for next spring.  
• Simple technique, expertise is easily acquired with experience. |
|---|---|
| W | • Supply of good quality of oyster larvae - erratic results from previous trials.  
• There are no hatcheries dedicated to the exclusive production of larvae.  
• Hatchery has to be implemented in disease free area.  
• Need a small site that dries out only at spring tides, with low level of predation.  
• Initial investment is low, but consequent expenditure for small structures, especially for collectors and fiberglass tanks.  
• Training required (erratic results from previous trials).  
• Technical aspect that might put off inexperienced oyster farmers.  
• Attention to details, time consuming for preparation and setting. |
| O | • Potential to develop the technique under a common ROI/ NI project.  
• Possibility to work with NI & ROI existing hatcheries. Conversion or upgrade for large scale oyster larvae production. |
| T | • Failure to produce larvae with high setting rate.  
• Failure to produce detached seed with high survival rate. |
Remote setting and alternative sourcing larvae from French hatcheries

| S | • Work in partnership with French hatcheries to import high quality larvae at competitive rate.  
  • Possibility to produce setting resistant and triploid seed.  
  • Working with experienced French hatcheries.  
  • Possibility to introduce larvae disease free. |
|---|---|
| W | • Need of a quarantine site for imported larvae.  
  • Difficulties in detecting virus on oyster larvae (low levels of viral contamination undetectable).  
  • Seed have to be put into high environmental pressure to detect the presence of virus. |
| O | • Contaminated seed can still be used in bays that have the herpes virus.  
  • Development of seed production under European program to supply Europe with disease free oysters.  
  • Opportunity for French hatcheries to produce resistant families of oysters with high genetic variability (no mortality of seed), see Chapter 3 “Principle of family selection, site “A” in Fig. 7.  
  • For example, Redbank shellfish hatchery in ROI has the potential for quarantine and working in isolated environment (equipped with 10 x 1000 m³ ponds). |
| T | • Failure to produce disease free seed, uncertainty of the outcome of such practice. |
Development of a local hatchery in partnership with a French hatchery

<table>
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<th>Bay under surveillance program only</th>
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4.3 Potential of deep sea and suspended culture techniques to produce oysters at low mortality rates

General considerations

In France, problems of space have pushed for the development of new off-shore or deep sea techniques and the setting up of new aquaculture sites outside France (such as happened in the Island of Ireland with the setting up of large French business). Much attention must be paid to hydrodynamic factors when selecting a deep water site because tidal flow and currents might spread pathogens from one production site to another. It was found in experiments carried out by Pernet et al., (2012), that mortality for oysters maintained outside the main production area was sporadic and coincided with currents coming from the farming area where mortality was occurring.

Longlines can also be used to suspend collectors used for the remote setting of oyster larvae. As the seed is suspended, there are no predators like crabs and growth is fast so there is the possibility to reuse the collectors twice a year (one setting in April, a second in June-July).

Suspended culture is well suitable to grow disease-free seed in summer on a site where OsHV-1 \( \mu \text{var} \) has not been detected and ideally away from other production sites. Such technique can be used to grow non-disease free seed only if water temperatures keep cool in the summer, otherwise a deep sea technique where such temperatures can be found is more appropriate.

The use of these techniques at sites where OsHV-1\( \mu \text{var} \) was detected might expose seed to high viral pressure. For this reason, the
hatchery Génocean uses lantern net techniques for the familial selection of seed that have the highest survival rates. However, the production cycle can be reduced by one year because feeding rates are higher.

Production cost for techniques using deep sea and offshore techniques are much higher than culture in bags on trestles with access by tractor, and they require special equipment. Therefore for Northern Ireland, such techniques are more appropriate for the production of seed only (sites ashore are still under-exploited). Suspended culture is not appropriate in winter if the site is not sheltered and in this context, deep water cultures in cages are more appropriate.

The choice of the production sites should be made in relation to hydrodynamic factors e.g. nutrient rich currents, proximity of other farms, depth, temperature lower than 17°C, access, navigation safety and shelter. Sites too exposed for longlines in the winter could be used for deep sea culture in the winter.

4.4 Deep sea and suspended cultures.

• The use of deep water sites:

<table>
<thead>
<tr>
<th>Bay in disease free compartment</th>
<th>In bay were Herpes virus was detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>• Shorten the production cycle of juveniles in cages during the winter to produce half grown oysters.</td>
</tr>
<tr>
<td></td>
<td>• Less handling of seed on sites (work done at the farm, mechanisation possible).</td>
</tr>
<tr>
<td></td>
<td>• Potential in producing half grown oysters, shortening the production cycle will generate a shorter turn over.</td>
</tr>
<tr>
<td>W</td>
<td>• Sites availability</td>
</tr>
<tr>
<td></td>
<td>• Initial cost of equipment (need a boat ideally with crane and cages).</td>
</tr>
<tr>
<td></td>
<td>• Other techniques to produce half grown oysters are cheaper in Northern Ireland, (culture on trestles with easy access by tractor, with better handling and better quality oysters).</td>
</tr>
<tr>
<td></td>
<td>• System to be used only in winter (juvenile oysters will be put under high viral pressure in summer).</td>
</tr>
<tr>
<td>O</td>
<td>• Potential in producing half grown oysters.</td>
</tr>
<tr>
<td></td>
<td>• Technique that can be used in combination with culture on trestles for hardening 1 year old seed.</td>
</tr>
<tr>
<td>T</td>
<td>• Site access (licensing), Environmental Impact Statement may be required.</td>
</tr>
<tr>
<td></td>
<td>• Same as across.</td>
</tr>
</tbody>
</table>
4.5 Factors contributing to mortality outbreak.

- In the report “Current situation and proposals for improvement” Chevassus-au-Louis (2010) mentioned some headlines contributing to amplifying the phenomena of mortality. These headlines were commented such as below:

- “Multiple transfer of oysters from one site to another”. The only restriction put in place is the sanction for moving affected oysters or material to disease-free areas (where no mortality has been reported and recorded with active monitoring). Movement of shellfish between infected areas is still permitted. In France, the disease got shifted around as a very normal part of the oyster industry management, which is to buy spat from a hatchery or natural settlement and then shift it to one bay, then another bay. As an example of good practice, the Australian industry is mobilising to contain the OsHV-1 μvar which was found in 2011 in Sydney harbour. Affected areas were quickly shut down to avoid the spread of the disease. Restrictions imposed on the affected areas mean that no oyster material or equipment can be moved to another area (ABC rural, 2011). Similar measures were taken in the UK and Ireland at the first detection of the disease (containments areas).

- “The total absence of information about the eventual difference of sanitary status between oyster production sites”. Restriction
measures for shellfish transfer are in place only for containment areas (oysters only that have similar sanitary status can be transferred within these areas). There is no information on the oyster sanitary status in other production areas.

- “The mixing of oyster batches of different age or of various sanitary status”. It has been found that concentration of the viral particles is higher in the oysters just before they die. The virus is extremely virulent at this stage and can travel from site to site under specific hydrodynamic conditions, as noticed by Pernet et al. (2011). Oyster seed isolated with low levels of viral infection are not affected by mortalities under certain conditions (i.e. transfer in ponds, at low temperatures). However, mortality rates increases when oyster batches of different origins are mixed in the same “isolated area” (Bouquet et al, 2011). Further research need to be carried out onto the mode of transmission of OsHV-1 μvar to fully assess what risks are associated by oyster transfer and what are the best aquaculture techniques to reduce massive mortalities. At the moment there are no measures put in place to stop oysters hosting OsHV-1 μvar getting constantly mixed with uncontaminated oyster batches.

- “No sanitary clean-up of oyster production sites”. This option is difficult to implement but a contributing factor to the increase of infectious risk”. This option is almost impossible to implement in France, taking into account the scale of the French production and the size of the bays. This radical practice would also have to take into account the presence of other species, equally capable of hosting the disease, and the life time of the oyster virus outside its host. Such a practice could be only applicable on a small scale for isolated bays.

### 4.6 Recommendations that may help to reduce the risk of mortality.

#### Zootechnical solutions to reduce massive mortalities

- Research centres and IFREMER are carrying out investigation to look for zootechnical solution to reduce summer mortalities. It has been found that mortalities rates can be limited (below 50%) when oyster batches are isolated (ponds, nurseries, isolated sites at sea) (Bouquet et al., 2011). When temperatures are below critical levels (16°C), in deep water sites (at 26 meter deep on the Atlantic coast or in deep water sites in the Mediterranean sea), and with late transfer of seed at sea.

- Summer sea temperatures on the Island of Ireland are generally cooler than around the French coast (Mediterranean Sea and Atlantic, English Channel). In fact, sea temperatures off the Irish coast range from an average of 10°C off the south-west coast to less than 7°C off the north-east coast during February, and from 16°C in the south to 13°C in the north Irish Sea in August (Met Éireann). The development of appropriate zootechnical practices to reduce mortalities should take into account these advantages. Also, environmental monitoring in Northern Ireland (tidal currents, temperature) should help assess the different aquaculture potential between production sites.

- Research in the Mediterranean Sea (Pernet et al., 2011) has demonstrated that seed that has never been exposed to the disease will have high mortality rate when transferred to warmer sites with high viral pressure. The same observations were made by Bouquet et al. 2012: Seed that was saved under certain conditions the first year (i.e. ponds or deep water) were exposed to high mortality rates the next year when placed on trestle bags ashore. In the case that mortality cannot be avoided the second year (no site availability, high temperature), seed or juveniles grown in oyster bags should be placed higher on the shore to minimise losses (10% less in Poitou-Charentes; Bouquet et al., 2011).

- Such practices as described above are easy applicable, however, they would be inefficient without a single bay management approach. In France the volume of production is scaled at a business level to be profitable and so, a reduction of overall densities and the widening of sites cannot be done unless other sites are created (e.g. offshore sites, aquaculture sites in other countries).
Sanitary measures to reduce the dissemination of OsHV-1μVar:

- Opt for farming at lower density and avoid the over-crowding of farming structures at a basin level. The density factor in oyster bags doesn’t affect survival rates (Bouquet et al. 2008), but it might affect the dissemination of the virus as there less mortality is recorded at less overcrowded sites (Blin & Richard, 2008; Pernet et al., 2011).

- Avoid site proximity, favour large alleys to separate farming structures. Wherever possible, seed should be separated from older generations to avoid horizontal transmission. Take hydrodynamic factors into account to avoid the spread of disease between production sites (F. Pernet, 2011).

- Avoid oyster transfer during critical temperatures in the summer (F. Pernet, 2011). Favour late seed transfer, depending on local conditions (Bouquet et al., 2011).

- Once mortality starts, it affects seed of all origins (i.e. natural or hatchery). This demonstrates the highly infectious nature of OsHV-1μvar and the high degree of intensity of the mortality (Blin & Richard, 2008). Nevertheless, it is recommended to prefer the supply of locally produced seed and to avoid the mixing different origins in the same production areas, so as to reduce the risks of pathogenic horizontal transmission (Pernet et al., 2011).

- As caution measures, producers should avoid keeping all their seed at the same site. Half grown and adults should be kept, when possible away from newly imported seed taking into account hydrodynamic factors. Preferably, seed should be kept at cooler sites in the summer, or higher shore to try to reduce risks of massive losses.

- Testing for OsHV-1 and other pathogens should be carried out for all new transfers.

- Disinfect the equipment before transfer of oyster from bay to bay.

Considerations for NI producers to avoid or reduce mortalities:

- Opt for LOW WATER TEMPERATURE sites for seed (below 16°C).

- Opt for “ISOLATION” (even for seed already infected).

The Notion of Single Bay Management/ CLAMS

- The CLAMS (Coordinated Local Aquaculture Management System) on the Island of Ireland has already successfully striven to defend the interest of the aquaculture industry in a coordinated sustainable manner. In the context of the massive oyster mortalities and because of the highly contagious nature of the virus OsHV-1 μvar, the CLAMS or similar scheme could stimulate further common action and the implementation of sanitary measures at a bay scale. Communication between shellfish growers is essential. As such, producers meeting such as the one held annually by the ISA® should help for better transfer of knowledge about trials and experiments and the development of best aquaculture practices.

The adoption of prophylactic measures

- The introduction of aquaculture material is prohibited in areas under surveillance, unless by authorisation and if special disinfection measures have been taken.

- Ideally, dying oysters should be removed to stop epizootic spreading (unfortunately this is only applicable at small production scale).
• Avoid the mixing of generations within a same production site to minimise horizontal transmission. Avoid the transfer of oysters back to their place of birth unless they are triploids (so as to avoid the reproduction of sensitive oysters).

• Professional consciousness: good communication is the only way professionals can understand the gravity of the problems related to shellfish transfers.

Better traceability and limited shellfish transfer

Most of the Northern Ireland oyster production will be sold in bulk to France. The current practice in France is to re-park oysters just after delivery until they are depurated and sold. These transfers are done regardless of environmental conditions, zootechnical history and the physiological state of the oyster (milkingness, size, age, stress from harvest, handling). As suggested in the EFSA report (2010), there is a need for oyster buyers to be aware of the history of the product he is buying.

Hine (1992) emphasised the fact that “The international movement of spat” poses a continuing risk of disease introduction, until pathogens in such seed have been identified”. With the implementation of Commission Decision 2011/187 EU, oyster transfers are authorised only between areas that have similar or inferior sanitary status.

One might say that shellfish transfers between bays with a similar history of oyster mortalities associated to OsHV-1μvar isn’t a huge issue. But this practice actually allows a constant mixing of pathogens between different populations of oysters. As such, it has been acknowledged that oyster seed may carry pathogens when they are transferred to Brittany and Normandy for further growth and that they may carry back to their bay of origin for finishing. Added to that, oysters can be found in any bay that have already been through an epizootic event and include moribund or dying oysters and seed from different origins. When environmental conditions are favourable (temperature increase), the OsHV-1μvar is present both as in an active form, and has better chance to spread among all oysters and at the same time (see Fig. 8 below). In France this typically follows a South-North gradient.

Fig. 8: mode of disease transmission of the herpes virus through different oyster generations.

In the case of the emergence of a new pathogen, all bays of production in France would be infected in the same manner. So one could say that the industry has not learned yet from its past experiences with *O. Edulis* with Marteliosis and Bonamiosis or *C angulata* with the “gill disease” and today *C. gigas* with OsHV-1μvar. Advanced research and new technologies have allowed us to detect OsHV-1μvar in 2008, and already other variants have been found in different parts of the world.

Remote setting could be a solution to stop the shellfish transfer between production bays in France. A dedicated hatchery for this purpose could be designed to produce massive quantities of larvae, as survival rate from remote setting much lower than from a nursery system. Production of larvae is cheap because there is not much feeding involved - unlike in a nursery.

In the report published by the CRAA (Bouquet et al, 20011) it has also pointed out that the “isolation” factor seems to considerably reduce the chance of massive mortalities. This notion of “isolation” could be extrapolated on a bay scale, like in Ireland and the UK, where mortality has not yet been recorded. It has been emphasised that good survival rates were observed only in ponds where

69 Spat = oyster seed.
batches were not mixed.

In the Republic of Ireland its worth recalling that the massive mortalities in 2009, were in areas that had all received seed from France, and some from other origins. These areas all had intensive production in comparison to other less affected bays. Several of them also had previous records of summer mortalities (South West & South East). At the time it happened, mortalities were related to stress in hot summers with the handling of milky68 oyster and on another occasion, the mortality was associated with extreme rainfall. No pathogen was found. It is interesting to note that similar facts were observed in 2008 in France: only very few areas were not affected by massive mortality these were small areas with a limited number of oyster farmers and fewer shellfish transfers, (Miossec et al., 2009, cited by EFSA, 2010). In the Republic of Ireland, it is also curious that some adjacent farms were not affected the same way, one would have massive mortalities, the other one nothing.

The suggestion of shellfish transfer ban measures between production bays is totally economically unrealistic for the shellfish industry at a European scale. However, it would be an idealist approach to stop the spread of an infectious disease which is making huge losses to the oyster industry.

However, more realist measures could involve shellfish movement restrictions, more sanitary controls, and appropriate sanitary management practices at a bay scale. For example, even further specialisation of the industry into geographic areas, taking into account the hydrodynamic factors, so one production area (or an entire bay) could be more specialised to produce only seed and half grown oysters, another one only for the finishing-expedition, etc. The overall idea, without going too much into details about how it should be done is to avoid the mixing of different generations of oysters, so to limit the transfer of the disease from older to younger oysters. The same applies when introducing seed of various origins in the same bay, or when producer-expeditors transfer oyster from other regions.

According to Blin (2009b) and Garcia at al. (2011), oysters over two years old and other species can also play the role of reservoir for OsHV-1 transmission. When the presence of the virus was detected, disease control measures should be implemented including the establishment of a containment area and the restriction of movements out of the containment area” (Segarra et al., 2010). As a response to the increase of massive mortalities in 2009 and 2010, the French authorities have put in place shellfish transfer restrictions measures for oyster seed and juveniles (Cochennec-Laureau et al., 2011). Moreover, other economically realistic managements practice, as such could be further developed. According to the EFSA, (2010) “measures are urgently needed to improve the general level of bio-security in the oyster aquaculture industry in Europe”.

4.7 Strategy to develop in an epizootic context.

Temperatures were low in the Island of Ireland in 2011 and there were less reports of mortality. The winter was very mild and if sea temperatures keep increasing this year, there might be a higher level of mortality than expected in 2012. Preventive measures have to be taken in such circumstances, like not putting all seed together, so as not to lose all the seed at once at the start of mortality. From what was learned in France, it would be recommended to place the seed on a higher level of the shore in early spring for hardening and slowing of the growth, depending on the trophic levels after all the feeding has to be sufficient and on-site temperatures. This is a current practice in oyster farming in France, but yet its effectiveness has not been proved everywhere (Bouquet et al. 2012 found 10% less mortality at higher sites in Poitou- Charentes).

We have also seen that an appropriate production strategy can help business to reach their production target. In France, there is particular concern on business profitability when there is poor added value to the oyster, so that in order to make a profit, a business has to reach a production threshold, determined by the production cost. So, shortening the production cycle using triploid seed, or using deep water techniques can help to achieve such targets.

In Co. Donegal (ROI) oyster farmers are placing oyster bags in cages that are positioned by tractor equipped with a forklift on the lowest zones of the shore. This system is well mechanised and allows to handle the oysters rapidly during the spring tides. Triploid oysters are growing faster, and the regular handling to turn the cages produce well shaped oysters.

Other techniques were developed in France to shorten the production cycle (the use of deep water sites in cages, longlines or the culture in suspension in Mediterranean Sea). Culture on the bottom for part of the cycle, from half grown to adult, or at specific times in the year i.e. summer, are techniques that may need some consideration for producers in Northern Ireland.
The development of remote setting techniques could help in solving problems of seed availability. As discussed in the previous chapters, it would allow an independent supply of seed for oyster farmers in Northern Ireland, with high quality seed, naturally selected to grow locally.

What this report has been trying to demonstrate is that professionals in France have developed techniques that are well adapted to their production targets, environmental conditions and site availability. A production strategy related to business profitability and aquaculture practices are adapted to seed availability and viral pressures. The development of the aquaculture industry in Northern Ireland has to go through an assessment of environmental resources and aquaculture site characteristics (hydrodynamics, temperatures, productivity, depth, access) and trials of different existing culture techniques, to see which one is best adapted. In the author’s view, the development of new techniques is time, money and energy wasted when there is enough technology already available in France and to a lesser extent in the Republic of Ireland that can be used in Northern Ireland. Of course, techniques, production strategy and aquaculture practices have to take into account the healthy status of each bay.

4.8 Diversification for retail and development of other parallel activities.

French producer-dispatchers have responded to the mortality crisis with more initiatives for diversification. For many of them, the focus is on the sale of oysters at the highest added value possible and at the highest price. This is usually achieved in France with product demarcation such as the controlled appellations of origin, Red Labels, special quality oysters. More effort was put into direct sales, associated products and activities with thematic holidays for tourists. As such, it is not uncommon to find small shops selling shellfish and other regional products in a set up beside the depuration tanks, with direct road access for tourists and local residents. The image promoted by these small shops is “locally grown at the farm, fresh and natural oysters”.

There are many marketing approaches to increase sales, such as the ‘degustations’ at the farm or rest places with a sea view on oyster parks. Customers targeted are local, sporting and tourist organisations involving jet skiers, canoeists, cyclers, sport performers stopping at the farm for lunch. There are also tours organised by offices of tourism with visits to the farm, boat trips, and sampling of the local oysters with a glass of wine. The arrival of the tourist in the summer is always welcome by oyster farmers and a lot of effort is dispensed to promote a good oyster farming public perception with advertisement campaigns with the support of the CRC’s.

This approach could be further developed in Northern Ireland, even if people in the UK and the ROI are not the biggest shellfish enthusiasts. Added value would generate more income for established businesses and a good back up plan if the price of the oysters was to fall again. The operation should also be suitable for grant aid as it would generate indirect employment to the rural economy of Northern Ireland.

4.9 Overall statement, recommendations for long term development.

*C. gigas* is a species that has a considerable economic significance in France and with a huge potential of development for Northern Ireland. As discussed in this report a key solution to the shortage in supply seed for production bays situated in a disease free compartment area is the development of oyster larvae remote setting techniques. Independent seed supply and locally produced seed could be viewed as a sanitary measure that would help to contain the spread of the oyster herpes virus at a national scale and to stop the migratory flux of pathogens and other alien species at a European scale.

Since the 1990’s, at an international level, oyster production countries have put a lot of monitoring and research effort to try to understand the causes of massive oyster mortalities. The recently discovered OsHV-1 μvar have been associated to the mortalities since 2008, but lots of questions still remain on factors associated to its dispersal and virulence. The BIVALIFE consortium is a
step forward for the collaborative research into the disease at a European level. The Marine Institute in the Republic of Ireland is actually carrying out epidemiological investigation onto three sites (on top of the 17 sites under surveillance program) and results will become available soon. Other work is being carried out by the 11 members of the consortium, so a better understanding of the disease infectious nature, detection, control will hopefully come to light.

Communication is a necessary step to understand what happen at a national and international level, and what can be done to reduce mortalities and make business more profitable. In this time of incertitude about the future of the oyster industry, professionals, researchers, law enforcing authorities don't share all the time the same views on the best way to handle the mortality situation.

Outlook on the state of the industry is promoted by international and national conference in aquaculture, such as the one organised by the CRC Arcachon at the end of November 2012. The aim of this event is to bring together scientists, politicians and producers from 25 countries and to discuss oyster farming issues across the world. Themes will include the state of the oyster resources, the different means of production, management and commercialisation of oysters and the state of the ecosystem.

In Northern Ireland, as well as in the ROI and GB, communication has been a key process to keep many bays disease-free.

The durable development of the shellfish industry, notably in an epizootic context, has to take into account international considerations. The funding of this report by The Department of Agriculture and Rural Development in Northern Ireland, along with the Aquaculture Initiative, is an example of what can be done to improve and make changes in a crisis situation. Much research and different approaches are underway to find a solution to the problems of mortality with the herpes virus OsHV-1 μvar on several continents.

This report has shown the scale of the herpes virus problem in France is very great. However, this crisis in the French oyster industry provides some clear opportunities for the Northern Ireland producers to meet the changes in supply and demand in the biggest buyer of oysters in the EU.

Learning from previous experience (C. angulata, O. Edulis), better aquaculture practices with tighter sanitary measures at a national and international level and controlled shellfish movement from bay to bay may be beneficial to put in place. As a consequence, aquaculture professionals are focusing their effort on how to reduce massive mortality to make this industry more profitable.
Development, outlook on the oyster aquaculture industry:

- On the French side, it is hoped that progress will be made for the production of selected oyster with better survival rates.

- Some farming practices may reduce mortality rates. New production strategies and best farming practices were developed by professionals and research centres in France as a response to diminish or counter the problem of mortalities.

- In the coming years, the BIVALIFE (European consortium) should lead to better understanding of how the disease affects the oysters and how it is possible to control it.

- Shellfish transfers promoted the spread of pathogens. However, effective sanitary measures have preserved the “disease free” status of two production areas in Northern Ireland.

Market opportunities for Northern Ireland

- There is a production shortfall of 50,000 tonnes of oyster in France since 2010.

- There is a strong market demand resulting in high prices of sales.

- There is a good market opportunity for the supply of seed and juvenile oysters to French/ UK/ ROI producers.

- Furthermore, there is a specific market opportunity for the supply of oyster seed “OsHV-1μvar free” to 19 bays on the Island of Ireland classified as “disease free”.

- “Disease free” compartments can be seen as a way for Northern Ireland to produce oysters at competitive cost rates (no mortality losses).

Oyster farming development for Northern Ireland:

- Strategies developed in France might not all the time be applicable to the Island of Ireland (different environment and aquaculture resources). Therefore Northern Ireland and the UK need to develop their own production strategies. Also, professionals should be encouraged to develop aquaculture trials, pursuing advances already made in this direction.

- The development of such program in Northern Ireland should take into consideration the following factors:

  - The monitoring of environmental parameters, notably the sea temperature.
  - The preservation of disease free compartments.
  - A targeted production strategy (seed, juveniles, fully grown).
  - Aquaculture sites availability, an assessment of the environmental resources.
  - The technology available (trestles, deep water culture, the use of ponds, etc.)
  - The potential for the development of new technology (i.e. longlines, remote setting)
LIST OF ABBREVIATIONS

• ANSES: “Agence nationale de sécurité sanitaire de l’alimentation, de l’environnement et du travail”. National agency for sanitary safety of the food industry, Environment and work.
• AFSSA: “Agence Francaise de Securité Sanitaire des Aliments”. French agency for the sanitary safety of food.
• BIM: “Bord Iascaigh Mhara” The Irish Sea Fisheries Board.
• CREEA: “Centre régional d’expérimentation et d’applications aquacoles”, Regional Experimental Center of Applied Aquaculture.
• CNC: “Comité National de la Conchyliculture”, The National Committee of Shellfish Farming.
• CSO: “ Comité de Survie de l’Ostreiculture”, translated in english as “the Survival Committee for the Oyster farming”.
• CRCM: “Comité Regional de la Conchyliculture Mediterranee” The National Committee for Shellfish Cultures.
• CNRS: “Centre National de Recherche Scientifique” the National Centre of Scientific Research
• CORDIS: Community Research and Development Information Service.
• CRC: “Comité Régional de la Conchyliculture”, The Regional Committee of Shellfish Farming.
• CRU: Climatic Research Unit.
• DARD: Department of Agriculture and Rural development.
• DDTM: “Directions Départementales des Territoires et de la Mer”. Departmental Direction of the Territories and the Sea.
• DGAL: “Directions Départementales de l’Alimentation” Departmental Direction of Food.
• EFSA: European Food Safety Authority.
• EURL: European Union Reference Laboratory.
• DDTM: “Directions Départementales des Territoires et de la Mer”. The Departmental Direction of the Sea and Territories.
• DGAL: “Directions Départementales de l’Alimentation”, General Directorate for Food.
• DREFA: Department for Environment Food and Rural Affairs.
• HACCP: Hazard Analysis Control Point.
• IFREMER: “Institut français de recherche pour l’exploitation de la mer” The French Research Institute for Exploitation of the Sea.
• INPI: “Institut National de Propriété Industrielle - Republic Française”. National Institute of Industrial Property.
• IPGA: “Indice des Prix de Gros de l’Alimentaire”, the Food price wholesale index.
• LERN: “Laboratoire Environnement Ressources Normandie” Laboratory of Environmental Resources in Normandy.
• LGP: “Laboratoire de Génétique et Pathologie” The Ifremer Laboratory for Genetics and Pathology.
• LNR: “Laboratoire National de Reference” the National Reference Laboratory.
• MOREST: “MORTalité ESTival de l’huitre”, Oyster summer mortality.
• MI: Marine Institute, Republic of Ireland.
• NAO indices: The North Atlantic Oscillation.
• OIE: Epizootic International Office
• ORF4: Open Reading Frame 4.
• PCR: Polymerase Chain Reaction.
• PPCPs: Pharmaceuticals and Personal Care Products.
• REPAMO: “REseau de PAthologie des MOllusques” Shellfish Pathology Network.
• SFC “Selection Française Conchylicole”, the French Shellfish Selection.
• T: “Taille”, translated in English as grade (G). Unit used to classify an oyster by size. A T20 or G20 oyster is an oyster that is retained on a 20 mm mesh size sieve.
• TBT: Tributyltin compounds, considered toxic chemicals


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- **La Manche libre, 2012.** “Mortalité des huîtres: La course de vitesse”. www.lamachelibre.fr
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- **Sud Ouest, Philippe Baroux**, 7 Mai 2010. “Les huîtres aux œufs d’or Sud Ouest”.

[74]
**WEB SITES**

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- OIE:.http://www.oie.int/international-standard-setting/aquatic-code/
- The BIVALIFE consortium: www.ifremer.fr/bivalife.
- Legifrance: www.legifrance.fr
- EURL: www.eurl-mollusc.eu
- Ostrea: Forum, advertisement in oyster farming; www.ostrea.com
- Caisse d’Epargne: http://www.decideursenregion.fr; 05/03/2012. L'actualite des entreprises Bretagne Pays de Loire :“La PRI ostricoile de Bouin operationelle en Juin 2012.”
LIST OF CONTACTS

CRC's
C.R.C. Poitou Charentes
President: Gerard Viaud
Z.A Les Grossines, Rue Sergent Lecêtre
17320 Marennes - France Tel: +33 5 46 85 06 69

C.R.C. Arcachon Aquitaine
President: Olivier Laban
Director: Jean Charles Mauviet 15, rue de la Barbotière - BP 53 33470 Gujan maestras - France Tel: +33 4 67 43 90 53

C.R.C Mediterranean
Director: Denis Regler Maison de la Mer Quai Guitard 34140 Mèze - France Tel: +33 4 67 43 90 53

Professionals
Bruno Nicouleau
Oyster farmer
Le Lindron 17320 Marennes - France
Tel: +33 5 46 85 27 26

Gilles Massé
Oyster farmer
EARL Gilles Massé
Chenal d'Arceau
17550 Dolus D'Oléron - France
Tel: +33 5 46 75 37 32

David Hervé
Oyster farmer
"Le Cabanon de l'huitre"
2 avenue Beaupréau
17390 Ronce-Les-Bains - France
Tel: +33 5 46 36 03 88

Jean Francois Girard
Director
Codimer
7, Port Larros
33470 Gujan Mestras
France
Tel: +33 5 57 73 09 50

Olivier Girard
Oyster farmer
Girard Frères EARL
7, Port du Rocher
33260 La Tete de Buch - France
Tel: +33 5 56 66 20 83

Stephane Alain Jacquet
Oyster farmer
Ets. Jacquet
Le Mourre Blanc -34140 Mèze - France
Tel: +33 6 18 04 07 86

Francis Balmefrezole
Oyster farmer
Le Mas d'Agent
440 Chemin du Mas d'Argent
34140 Bouzigue - France
Tel: +33 4 67 78 35 59

Norbert Proteau
Oyster farmer
Pont Moëze,
17320 Hiers-Brouage, France
Tel: +33 5 46 85 28 21

Jean Paul Bluzat
Oyster farmer
Atelier-4, le Marais
50310 Lestre,
Normandie - France
Tel: +33 233 54 16 18

Lionel Lafont
Oyster farmer
Port Rocher
33260 La Teste-De-Buch
Tel: +33 5 56 66 74 36

Beatrice et Jean Claude Rabette
Oyster farmer - retired
31, Route de Beaugay
17320 Hiers-Brouage - France
Tel: +33 5 46 85 39 92

Institutions - Research

Dr Fabrice Pernet
LER Languedoc -Roussillon
Station Ifremer de Sète
Pôle “Mer et Lagunes”
Av. Jean Monnet
BP 171 - 34203 Sète - France
Tel: +33 4 99 57 32 77

Dr Tristan Renault
Chief of the LPG
Station Ifrerner - La Tremblade
Avenue du Mus de Loup
Ronce les Bains
17390 La Tremblade - France
Tel: +33 5 46 76 26 49

Dr Deborah Cheslett
Shellfish Health Manager
The Marine Institute
Shellfish Health Unit
Rinville, Oranmore,
Co Galway - Ireland
Tel: +353 91 387 249

Judith Tener
Fisheries & Environment
DIVISION, DARD. Dundonald House
Upper Newtownards Road Ballymiscaw,
Belfast
BT4 3SB - Northern Ireland
Tel: 028 905 24991

Anne Lise Bouquet
Aquaculture advisor
CREAA
Prise de Terdoux
17480 Le Chateau D'Oleron
Tel: +33 5 46 47 51 93

Denis Guet
Teacher in aquaculture
Lycee Technique de la Mer
29 allée de la barbotière
33470 Gujan maestras
Tel: +33 5 56 22 39 50
ANNEX 1 LIST OF HATCHERIES

REPUBLIC OF IRELAND HATCHERIES
Redbank Shellfish
New Quay, Burrin,
Co Galway, Ireland
+353 657078189
E-mail:  iconnellan@eircom.net

Boet Mor Seafoods Ltd
Cushastrough, Claddahduff
Clifden Co Galway
Ireland
+353 9544698
E-mail:  kermor@eircom.net

UK AND NORTHERN IRELAND HATCHERIES
Mark and Penny Dravers
Guernsey Sea Farms Ltd.
Parc Lane, Vale
Guernsey GY3 5EQ
Telephone: +44 1481247480
Fax: +44 1481 248994

Seasalter Shellfish (Whitstable) Ltd. Old Roman Oyster Beds, Reculver, Herne Bay, Kent, CT6 6SX Tel: +44 1227363359 Fax: +44 1227740518
Website: info@oysterhatchery.co.uk
Website: http://www.oysterhatchery.com

Morecambe Bay oysters
Old Gravel Works
South Walney Island
Barrow-in-Furness
Cumbria
LA14 3YQ
Tel: +44 1229474158
Fax: +44 1229869884
Email: info@morecambebayoysters.co.uk
Website: http://morecambebayoysters.co.uk

B Johnston & Dr D Saville Island Shellfish
68 Millbay Road,
Islandmagee
Co Antrim BT 40 3RG
Tel: +44 2893382690
E-mail:  Billy.johnston@btopenworld.com

FRENCH HATCHERIES
La SATMAR “La Saline”,
47 route du Val de Saire 50760
GATTEVILLE-PHARE FRANCE
Tel: +33 233234160 Fax: +33 233231255
E-mail: satmar@wanadoo.fr
Website: www.satmar.fr

France Turbot
Chemin des Ileaux, L’Epine
85330 NOIREMOUTIER
+33 228129500
Website: www.adrien.fr

Génocean/ Grainocean,
Contact: Éric Marissal (Director)
14, Cours Déchézeaux
17410, SAINT MARTIN DE RE
+33 5 46292929
E mail: Geno@club-internet.fr

Vendée Naissain/ France naissain(EARL)
Contact: Marina Godet (Sales Manager)
Stephane Angeri (Production Manager)
Polder des Champs
85230 BOUIN
+33 2 51497407
E-mail: Vendee.naissain@wanadoo.fr
Website: www.francenaissain.com

SOBADO
Polder des Champs
85230 BOUIN
+33 2 51497407
E-mail: Sobado@wanadoo.fr

Novostrea Bretagne
M. Hervé Leroy
Banastère
56370 Sarzeau
E-mail: contact@novostrea.eu
ANNEX 2
TIMESCALE FOR OYSTER PRODUCTION STRATEGIES

ANNEX 3
PRICING FOR BULK OYSTER FOR DECEMBER 2012

<table>
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<tr>
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<th>C. Gigas diploid</th>
<th>C. Gigas triploid</th>
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<tr>
<td>Standard 3 &amp; 2</td>
<td>3/kg</td>
<td>Standard 3 &amp; 2</td>
</tr>
<tr>
<td>Standard 1</td>
<td>2.5/kg</td>
<td></td>
</tr>
<tr>
<td>Special 3</td>
<td>3.6/kg</td>
<td>Special 3</td>
</tr>
<tr>
<td>Special 2</td>
<td>3.5/kg</td>
<td>Special 2</td>
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Aquaculture Initiative,
13 Innovation House,
Down Business Centre,
46 Belfast Road,
Downpatrick,
BT30 9UR.

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