Aquafish Solutions Limited
Aquaculture and Fisheries Consultants

DEVELOPMENT OF A PACIFIC OYSTER AQUACULTURE PROTOCOL FOR THE UK – TECHNICAL REPORT

FIFG PROJECT NO: 07/Eng/46/04

For: Sea Fish Industry Authority

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DEVELOPMENT OF A PACIFIC OYSTER AQUACULTURE PROTOCOL FOR THE UK – TECHNICAL REPORT

FIFG PROJECT NO: 07/Eng/46/04

FOR: SEA FISH INDUSTRY AUTHORITY

TECHNICAL REPORT

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AUTHORS NOTE

This study has been undertaken on behalf of the Sea Fish Industry Authority under funding from the Financial Instrument for Fisheries Guidance (FIFG). This Technical Report is intended as a reference document to assist the Project Partners in deciding whether or not to adopt a Protocol-type approach with respect to the culture of the Pacific oyster, *Crassostrea gigas*, in Marine Protected Areas. The views and suggestions expressed in this report are those of the Authors and are not therefore necessarily representative of the Sea Fish Industry Authority or the other Project Partners and should not therefore be viewed, either explicitly or by implication, as recommendations or guidance by any Project Partner.

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EXECUTIVE SUMMARY

A. Background

1. There is concern on the part of the statutory nature conservation agencies (SNCAs) over the potential for wild settlement to occur of the Pacific oyster, *Crassostrea gigas*, due to aquaculture activities and the subsequent impact that this may have on native marine species and habitats, in particular those protected by national and European legislation. From an industry perspective the potential for impact of the Pacific oyster in Marine Protected Areas (MPAs) is constraining existing and proposed Pacific oyster farm developments.
2. Both industry and SNCAs have identified the need to investigate an industry protocol-type approach to ensure that Pacific oyster farming is compatible with the conservation objectives set for MPAs under national and European legislation.

B. Overview of the Technical Report

1. This report is the first study to consider for the UK as a whole the multiple aspects of the implications of wild settlement of Pacific oysters. This has been achieved through a collaborative work program between the shellfish aquaculture industry and the UK SNCAs.
2. Subject areas covered include a review of relevant current and future legislation; the development of regional seawater temperature profiles with biological models for conditioning, spawning and recruitment; implications of climate change on future levels of wild settlement; impact of wild settlement on other commercial species; factors affecting success at settlement; hatchery production; the role of triploid oysters in biological containment and shellfish culture; case studies on the impacts of wild settlement; a review of on-going research and recommendations for future work.

C. Pacific Oyster Culture in the UK

1. Commercial cultivation of the Pacific oyster is now widely practised in the UK with production levels exceeding 1,000 tonnes per annum. Significant Pacific oyster culture activities also take place in Jersey, Channel Islands at around 700 tonnes per annum. Seed production for England and Wales in 2006 was estimated at 708 million of which a significant amount was exported to Ireland.
2. Numerically at least, the industry is dominated by small producers with the majority of farm sites being located intertidally utilising diploid seed.
3. An analysis of the questionnaire responses for the main production areas indicate that intertidal and subtidal bottom culture are the dominant forms of farming Pacific oysters in South East England. Industry in the South West and Northern Ireland by comparison is comprised mainly of farms undertaking bag and trestle culture.

4. There were no reports during the questionnaire survey of suspended offshore cultivation of Pacific oysters taking place. Offshore cultivation would however potentially offer a reduced risk of spawning events due to the generally lower seawater temperatures and more stable environmental conditions where spawning inducement shocks are less likely to occur.

D. Non-Native and Legislative Issues

1. The Pacific oyster is a non-native species to the UK that was introduced in the 1960s due to its excellent attributes as a candidate for aquaculture. Released under General License (Wildlife and Countryside Act, 1981) in the 1980s, it was originally thought to be incapable of spawning in UK waters. There is now however increasing evidence of wild settlement of oysters taking place. In some parts of Europe this species is now being classified as invasive. This change in status seems to be linked to the impact of climate change on seawater temperatures.
2. Terminology and ecological definitions help shape perception and inform legislative controls although they can be the source of confusion. The term 'naturalised' for instance does not imply a degree of legislative acceptance of the Pacific oyster within the native ecosystem. SAGB and SNCAs should therefore seek to agree common definitions regarding the use of terminology with respect to non-native issues.
3. There are developments underway within UK legislation that correspond to a shift in perception regarding the status and risk posed by the Pacific oyster. These legislative changes have implications with respect to Pacific oyster culture.
4. The main current legislation in Great Britain covering the introduction of non-native species is The Wildlife and Countryside Act (1981) (WCA). The equivalent legislation in Northern Ireland is the Wildlife (Northern Ireland) Order 1985. Schedule 9 of the WCA, which identifies species requiring control, is currently under review as part of which a Risk Assessment (RA) of the Pacific oyster has recently been undertaken. As RAs inform new regulatory controls the terminology and invasive ecological status are critical factors as the 'scoring' of a non-native within a RA is strongly influenced by determination of its status (e.g. 'established' and 'invasive').
5. The Habitats Regulations, which transposes the Habitats Directive into UK law, are the central legislation for the protection of Special Areas of Conservation (SACs) and under Article 7 these regulations also encompass Special Protection Areas (SPAs) and Ramsar sites classified under the Birds Directive. New aquaculture activities, or the reissuing of an existing license, in these areas will be considered a plan or project, and these may only proceed if the competent authority has ascertained that it will not adversely affect the integrity of a European site, although management or mitigation options may be available to prevent any adverse effects. It is important to note that an Appropriate Assessment may be required even if a plan or project is not inside a European site.

6. The Water Framework Directive (WFD) includes a non-native listing of 'high impact' species which after recent review now includes the Pacific oyster. There is concern that the Pacific oyster will compromise WFD objectives in achieving good ecological status. As the WFD covers all estuarine and inshore coastal waters then all Pacific oyster culture sites will fall within classification zones.
7. In contrast to the possible UK stance on Pacific oysters, France has no plans to include a non-native component to the WFD. No other comparable non-native legislative controls have yet been identified.
8. The Environmental Liability Directive, due to come into force by the end of 2008, extends the 'polluter pays' principal to any activities that can give rise to ecological damage to a protected habitat or species. However, the complexity of applying this measure to a marine setting may make this legislation difficult to enforce.
9. The 'Aliens and Locally Absent Species in Aquaculture' regulation, due to come into force in January 2009, allows Member States to be able to control aquaculture species movements that may cause adverse ecological impacts. This new legislative measure for the control of species movements could possibly be used to restrict future Pacific oyster seed supply if these movements were thought to pose a risk of an adverse environmental impact.

E. Seawater Temperature Profiles and the Impact of Climate Change

1. UK regional historic, and predicted future, seawater temperature profiles have been developed incorporating biological models for conditioning, spawning, recruitment and high level recruitment of the Pacific oyster. These provide a useful tool for risk assessment purposes with respect to predicting the likelihood of wild settlement of Pacific oysters on a regional basis under current environmental conditions and with respect to anticipated seawater warming due to climate change.
2. Refinement and updating of these regional models should be considered as an on-going process. UKCIP08 and satellite data together with updates on biological variables should be incorporated when available in order to increase the accuracy of the models and to provide confidence when implementing any protocol strategies.
3. There is a lack of basic data with respect to actual seawater temperatures being experienced on shellfish culture sites. Acquiring this information would greatly increase the accuracy of the regional models. Over 30 possible sites have therefore been identified covering the UK that would be suitable for consideration for the deployment of temperature data loggers. This research could be undertaken in collaboration with industry and would provide an extremely cost-effective source of data.
4. A national survey of the distribution and abundance of Pacific oysters in UK waters should be undertaken. This work could incorporate a spatfall monitoring program. Information gained

would provide a baseline against which to measure the effectiveness of any protocol strategies and to assess the impacts of climate change on levels of wild settlement.

5. There is a wide variation in temperature profiles between regions. Low risk regions with respect to wild settlement include Scotland and North East England; moderate risk regions include Northern Ireland, Wales and South West England; high risk regions are Southern England and South East England.
6. Changes in seawater temperatures over time have been significant. When introduced in the 1960s the Pacific oyster presented little risk of wild settlement. However since the late 1980s in particular, seawater temperatures have increased steadily with the greatest increase being experienced in South East England.
7. Current climate change predictions show a projected increase in temperatures of 0.4 ^{o}C per 10 years which would take most moderate risk regions from an intermittent recruitment potential to regular recruitment by 2040.
8. An analysis of the commercial species *Ostrea edulis* (Native oyster) and *Mytilus edulis* (blue mussel) with respect to the impact of climate change shows that that the Pacific oyster is better adapted and suited to warming seawater conditions. Decreases in blue mussel biomass in the Dutch Wadden Sea are now believed to be attributable to climate change and not competition with the Pacific oyster.
9. The potential affects of climate change on commercial shellfish species requires assessment. Such work should evaluate the likely impacts of Pacific oysters on other commercial species in the future.

F. Factors Affecting Settlement Success

1. There is a need to investigate whether Pacific oyster populations on the Continent could be contributing to the levels of wild settlement seen in South East England. Larval dispersal, genetic profiling and hydrographic movements would need to be investigated. If it is shown that larval drift from Europe is occurring then this has implications for what effective management measures can be adopted in the South East.
2. Significant settlements of Pacific oysters have now been identified in the South East of England, and the size of the wild population in that area appears to be such that it may now be impossible to prevent further settlement events occurring. Management of oyster farming in this region may need to be considered in light of this issue. An investigation should be carried out of the population structure of these oysters, proximity to farms, local hydrographic conditions and local seawater temperature profiles to gain a better understanding of how these wild populations have developed.
3. In general, the patterns of observed wild settlement of Pacific oysters are correlated approximately with the occurrence of cultured stock. Some settlement anomalies not

apparently associated with local farm culture would benefit from revisiting as would some of the historical reported sightings of Pacific oysters in Wales and Scotland.

4. A literature review would seem to indicate that Parc or bottom culture in the intertidal zone can result in a greater level of reproductive effort in Pacific oysters than those held in bags on trestles. However, with subtidal culture there is some evidence that growth rates may not be as high as those of intertidal culture, even though these oysters have a permanent access to food resources. The degree of exposure in intertidal culture has a significant effect on reproductive effort with longer immersion times generally leading to a higher availability of energy resources for reproduction. The relative effect of culture type on reproductive effort will however vary over time and between sites.
5. The results of the questionnaire survey indicated that wild settlement of Pacific oysters only occurred to any significant extent in the South West and South East of England, although incidences of settlement were also reported for North Wales and Northern Ireland. Settlement in the South West is sporadic whereas the South East experiences regular settlements of oysters which are often used by growers as a source of seed or as marketable oysters, mirroring the traditional Native oyster fisheries in that region.

G. Broodstocks, Selective Breeding and the Use of Triploids

1. The choice of Pacific oysters to use as broodstock in UK hatcheries is largely based on those that are fastest growing or those exhibiting a range of positive characteristics. After investigation it would appear that it is unlikely that the use of faster growing oysters, or hatchery practises such as culling slow growing larvae, would lead to the selective pressure necessary to produce oysters more likely to spawn in UK marine environmental conditions.
2. Due to the significant resources required to undertake selective breeding, any program for the development of non-spawning strains of Pacific oysters would require a collaborative European approach. France is the main European producer and consumer of oysters. However, their research efforts are currently targeted more at understanding the basis of the invasive nature of Pacific oysters and at developing solutions to the significant problem of summer mortality in the French oyster industry. As such it seems unlikely that a collaborative European project to develop non-spawning oyster strains would be of interest to French researchers.
3. Triploid Pacific oyster seed can be produced by induction through shock (chemical, thermal or pressure) or via the use of a tetraploid technique. The induction method generally has a success rate of 80-90% whereas theoretically the tetraploid technique can produce 100% batches of triploid embryos (often termed ‘mated’ triploids due to the process by which they are produced). At present triploid production in UK hatcheries is only undertaken by the chemical induction method.

4. The tetraploid technique for producing triploid oysters is the subject of a European patent which expires in 2015. Discussions with the patent holders as part of this study have however confirmed that there is still scope for a UK hatchery to obtain a licence to utilise this technique.
5. Mated triploid seed is available from a French hatchery although there has been reluctance in the past on the part of UK growers to import Pacific oyster stock from France. If the use of triploid seed by growers is to be encouraged then it would seem preferable in the first instance to support research, development and refinement of techniques for use by UK hatcheries. Of the non-chemical induction methods for triploid production, thermal shock would seem to be the best candidate for development as a practical tool for use in a commercial hatchery environment.
6. The relative reproductive potential for both chemically induced and mated triploids have been assessed based on fecundity values calculated in recent research. These calculations show that whilst triploid Pacific oysters are not absolutely sterile their reproductive potential when compared to diploids is greatly reduced.
7. The most effective use of triploid Pacific oysters for biological containment is where those oysters are placed in areas free from diploids as the presence of diploid oysters increases the chances of the production of viable embryos from triploid x diploid crosses.
8. The reported reversion of a proportion of triploid shellfish, especially with age, to a mosaic or diploid state is not believed to affect gonadic tissue. The results of discussions with researchers have led to the conclusion that reversion in triploid oysters is not considered to be a risk in terms of its affect on biological containment.
9. Recent research indicates that triploid Pacific oysters are generally more resistant than diploid oysters to summer mortality events. In addition, genetic predisposition or resistance to summer mortality does seem to play a key role in determining relative mortality levels. To date there have been no widespread incidents of summer mortality in the UK although there is some evidence that isolated incidents have taken place. Climate change may lead to these types of mortality events becoming more frequent.
10. Feedback from growers as part of the post-questionnaire interviews would seem to confirm that triploid Pacific oysters will outperform diploid oysters in areas of high productivity but may do less well when compared to diploids in areas of marginal or poor productivity.

H. Protocol

1. The main objective of the project is to create a framework and template under which husbandry, management and monitoring practises will be identified that will help to mitigate or eliminate any environmental impacts on MPAs due to wild settlement of Pacific oysters. Although the Habitats Regulations is the main current legislative driver it is hoped that the protocol will provide a template to address the needs of new legislation as it is brought into force.

2. The protocol will require discussion and agreement between industry, the SNCAs and other relevant organisations if it is to become an effective means of ensuring that commercial activities can continue to operate in a sustainable and responsible manner.
3. The protocol is likely to adopt some form of adaptive management technique, requiring for example different levels of monitoring and management actions according to the potential risk posed by a particular Pacific oyster farm, which is in turn dependent on criteria such as location, size and an area's nature conservation interest. This project will seek to deliver a protocol framework and template that is acceptable to all parties.
4. The diverse nature of the temperature profiles of the different regions around the UK with respect to the likelihood of successful settlement of Pacific oysters means that the choice of any risk based strategies to be implemented under the protocol will be primarily assessed in terms of the current and predicted seawater temperature profiles of a region.
5. In economic terms it is in the interest of the industry itself to implement measures to limit any environmental impacts of wild settlement of Pacific oysters. Whilst wild settlement provides a source of free seed there may be long-term deleterious consequences for industry if secondary settlement (overcatch) or reduced carrying capacities due to trophic competition become widespread.

I. Conclusions

1. The technical report produced as part of this study has been developed so as to inform the development of a protocol framework and template for the culture of Pacific oysters in the UK. The collaborative nature of such an undertaking means that this report is intended to inform all parties equally.
2. Given the legislative developments currently underway in the UK it is possible that legislative pressure will be brought to bear on Pacific oyster growers in a number of regions in the future so as to ensure that shellfish culture activities do not adversely impact on the environment in which they are undertaken.
3. If current predictions prove to be correct and management and mitigation options are not identified and adopted, then climate change will by 2040 cause regular recruitment of Pacific oysters in regions around the UK that currently only experience intermittent recruitment events.
4. In the case of South East England it remains to be established whether the current level of wild settlement of Pacific oysters will negate any efforts to reduce environmental impacts in this region. A large biomass of Pacific oysters along the European coast and a long planktonic larval phase may also be adding larval inputs from European sources and this could therefore significantly undermine any nationally imposed controls. The level of risk posed therefore from European sources needs to be established as a priority. However it should be noted that the precautionary stance of the Habitats Regulations could require

removal of local effects regardless of other potential external sources of larval input even before the relative loads have been fully defined.

5. The use of triploid Pacific oysters is one method that has been suggested as a means of reducing or eliminating the environmental impact of Pacific oyster farming in MPAs. However, to be successful the use of such oysters often requires different husbandry and management techniques than that used for diploid oysters. Growers of diploid stock may need to lower stocking densities and invest in new equipment and infrastructure in order to achieve success. Changes such as these have cost and resource implications that can affect the economic viability of a business. These economic impacts need to be better understood and defined. Methods by which growers of diploid stock could be supported both financially and technically in any such transition to triploid production would need to be investigated.
6. In terms of the use of triploid Pacific oysters, limitations in the range of productivity levels in which economically viable growth rates can be achieved means that they cannot be considered as an all-encompassing solution to the issue of wild settlement of Pacific oysters.

DEVELOPMENT OF A PACIFIC OYSTER AQUACULTURE PROTOCOL FOR THE UK – TECHNICAL REPORT

OVERVIEW & INTRODUCTION

Project Overview

There is concern from an environmental perspective over the potential for wild settlement to occur of the Pacific oyster, *Crassostrea gigas*, due to aquaculture activities and the subsequent impact that this may have on native marine species and habitats, in particular those protected by national and European legislation. From an industry perspective the potential for impact of the Pacific oyster in Marine Protected Areas (MPAs) is constraining existing and proposed Pacific oyster farm developments.

Project Objectives – Industry Perspective;

This project seeks to identify current and possible future environmental impacts of Pacific oyster cultivation within MPAs. The project will then seek to recommend husbandry and management techniques that will where possible mitigate or eliminate these potential impacts. This is in line with Key Recommendation 7.5.1 under the SAGB English Shellfish Industry Development Strategy (Lake and Utting, 2007). These techniques or protocol options will then require discussion and agreement between industry trade associations and the statutory nature conservation agencies (SNCAs) if they are to become an effective means of ensuring that commercial culture activities can continue to operate in a sustainable and responsible manner.

The potential impact of climate change means that determination of these cultivation protocols is therefore something that requires addressing as a priority. A Memorandum of Understanding between the Shellfish Association of Great Britain and Natural England has identified the need to investigate and agree under what conditions the Pacific oyster can be grown and exploited and not have adverse impacts on designated features within European Marine Sites (Action 10 under SAGB-NE MoU Work plan). The current study will help address this action point.

Project Objectives – Statutory Nature Conservation Agencies' Perspective;

This project under the terms of the FIFG funding will address a number of issues related to the development of Pacific oyster farming in English waters but will also be of relevance to UK waters generally. The information derived will provide background information to inform the debate that is needed between the SNCAs, industry and inshore managers with regard to the cultivation of Pacific oysters within MPAs.

Whilst the scope of the present study does not allow consideration of any possible issues regarding Pacific oyster cultivation outside MPAs, the SNCAs have indicated that wider environmental and amenity issues also need to be reviewed.

Introduction

Decline of the Native Oyster;

The Native oyster, *Ostrea edulis*, or flat oyster as it is also known, was once a major commercial fishery, peaking in the mid 1800s after the end of the Napoleonic Wars. Indicative, if not wholly reliable, figures for numbers of oysters passing through Billingsgate at the time put the level at about a staggering 500 million. The first official oyster statistics were not produced until 1886 by which time production levels had dropped dramatically to around only 40 million per annum. This reduction in supply saw prices rise by about seven to eight times their original level from 1860 to 1889 (Neild, 1995) and it was at this stage that the oyster changed from a food of the poor to a dish more commonly associated with the wealthy. Today the stocks of this once abundant species remain at very low levels. Two centuries of over exploitation, TBT (tri-butyl tin) pollution in the 1980s, mortalities due to severe winters in the 1930s and 1940s, competition from exotic pests such as the slipper limpet in conjunction with the parasitic disease *Bonamia* have all meant that current standing stocks are severely depleted.

Introductions of New Oyster Species;

The decline of the native species of oyster led during the last 100 years to significant importations taking place of part-grown American (*Crassostrea virginica*) and Portuguese oysters (*Crassostrea angulata*) (Utting and Spencer, 1992). Importations of American oysters into the UK ceased in 1939 and following large–scale mortalities between 1966 to 1970 of Portuguese oysters on the Continent their importation was banned. The continued low stock levels of *O. edulis* led to the Pacific oyster (*Crassostrea gigas*) being introduced under quarantine into the MAFF Fisheries Laboratory at Conwy in 1965 from stocks held in Canada. Early trials soon showed that it was sufficiently hardy to survive in UK waters and its fast growth rate meant that it reached market size in 3-4 years. Nowadays commercial production is widely practised and three commercial hatcheries are in operation in Great Britain supplying both the UK together with significant exports to Ireland. Pacific oyster seed production for England and Wales in 2006 was estimated at 708 million as compared to 63 million seed oysters in 2000 (CEFAS, 2007).

Other species of oyster have also been tested in UK waters, including the New Zealand flat oyster *Tiostrea lutaria*. Individuals of this species were released into the wild by the Conwy laboratory in 1963 but died out in the severe winter that year. A subsequent introduction was made in 1970 into the Menai Straits from seed produced in Conwy. As this species broods its larvae and is susceptible to mortality through cold winters and *Bonamia* it was thought that there had only been a limited geographic spread of this species in the wild. Richardson *et al*. (1993) reported a spread of less than 1km in 25 years. However, a recent survey has shown a more extensive spread to nearly 10km of shoreline with evidence that warming spring temperatures may be improving spawning potential (Morgan, 2007).

Pacific Oyster Production;

Official production statistics for the Pacific oyster in 2006 for the UK showed a total production of 1,290 tonnes made up of 680 tonnes in England; 12.5 tonnes in Wales; 251 tonnes in Scotland and 346 tonnes in Northern Ireland (CEFAS, 2007). Production in England and Wales for the period 2001 to 2006 rose from 225 tonnes to 680 tonnes representing an increase of over 300 per cent. Of the production in England and Wales approximately 64% takes place in the South West of England, with a further 30% from farms located in East Anglia. In Scotland over 80% of the Pacific oysters produced were farmed in the Strathclyde region (CEFAS, 2006). By way of a comparison, production for Jersey in the Channel Islands is thought to be around 700 tonnes per annum whereas France produced around 110,000 tonnes in 2004. World production of Pacific oysters was estimated to be about 4.4 million tonnes in 2004 (FAO, 2007).

Legislation;

There are a number of developments underway within UK legislation which could have a significant impact on Pacific oyster culture. Non-native species issues have been raised up the political agenda resulting in Parliamentary briefing notes (POST, 2008) and the formation of the Non-Native Species Secretariat (NNSS) to help co-ordinate a Great Britain Non-Native Strategy which was launched in May 2008. These legislative changes correspond to a shift in perception regarding the status and risk posed by the Pacific oyster. This change in perception has occurred in part due to the identification of the development of Pacific oyster reefs on the continental coastline and observations of wild settlement in the UK.

The main current legislation in Great Britain covering the introduction of non-native species is The Wildlife and Countryside Act (1981) (WCA). The equivalent legislation in Northern Ireland is the Wildlife (Northern Ireland) Order 1985. Under this legislation in Great Britain it is an offence to release (or allow to escape) into the wild any kind of non-native animal, except under licence. The Pacific oyster was however put under general licence in the late 1980s and as such MAFF (the predecessor of DEFRA) and DAFS (the predecessor of SEERAD) were able to authorise the cultivation of Pacific oysters as a commercial species in UK waters. However, Schedule 9 of the WCA is currently under review for which a Risk Assessment of the Pacific oyster has recently been undertaken. There is therefore the potential that the Pacific oyster may be included in the Schedule 9 listing of non-natives species requiring control.

The Habitats Directive is the key legislation for the protection of identified Special Areas of Conservation (SACs) whilst Special Protection Areas (SPAs) and Ramsar sites are protected within the Birds Directive. It is understood that these legislative drivers are currently having a direct impact on limiting Pacific oyster cultivation within potentially affected sensitive waters. Shellfish operators hoping to undertake new activities will be required to undertake an Appropriate Assessment to ensure the proposed operation will not impact on the SAC protected features. Indeed the Habitats Directive has been cited as a key driver for why action must be taken in addressing concerns about wild settlement of Pacific oysters in the Strangford Lough SAC in Northern Ireland. An internal EHS report by Quercus (Guy and Roberts, 2008) contains recommendations for a management plan for Pacific oysters in Strangford Lough in Northern Ireland. It is probable that legislative pressure will also be applied to Pacific oyster culture operatives in a number of regions in the future.

The Water Framework Directive (WFD) is a major new legislative driver to ensure waters of good ecological status are achieved in all river basin and inshore coastal waters. The WFD also includes a non-native listing of ‘high impact’ species which has recently been reviewed and now includes the Pacific oyster. There is significant concern that the Pacific oyster will compromise WFD objectives to achieve good ecological status. As the WFD covers all estuarine and coastal waters then all Pacific oyster culture sites will fall within classification zones. Implementation of the non-native components of the WFD remains uncertain at this stage and the current River Basin Plans are not understood to currently map Pacific oyster status. It is reported that invasive non-native species were among the most significant water management problems in nine out of eleven river basins in England and Wales (POST, 2008).

The ‘Aliens and Locally Absent Species in Aquaculture’ regulation is a new legislative measure for the control of movements which is due to come into force in January 2009. The Pacific oyster is a named long-term aquaculture species that is not affected by all articles. However, there is scope for Member States to control aquaculture species movements that may cause adverse ecological impacts and thereby require a Risk Assessment prior to allowing any movements. This measure could be used to control Pacific oyster seed supply.

An Environmental Liabilities regulation is due to come into force by the end of 2008 which extends the ‘polluter pays’ principal to any activities that can give rise to ecological damage to a protected habitat or species. However, the complexity of applying this measure to a marine setting with multiple potential sources of wild oysters may limit the effectiveness of this legislation.

Wild Settlement of Pacific Oysters;

When the Pacific oyster was reintroduced into the UK in 1965 it was thought that it would not be capable of successfully spawning and recruiting due to the generally cooler UK sea temperatures than that experienced in Japan from where this species originates. However it appears that there is now evidence of recruitment into the wild from stocks held under culture conditions.

It seems increasingly likely that climate change may be leading to sea temperature increases around the UK. If this is the case then it is possible that this may increase the incidence of spawning events in areas such as the South West of England and may well also lead to successful recruitment in areas which may have previously been too cold to support recruitment of this species. Reports of sporadic settlement of Pacific oysters in some South West of England estuaries started in the early 1990s (Couzens, 2006a). On the Atlantic and North Sea coasts of mainland Europe wild populations of Pacific oysters have increased in recent years, probably as a result of sea temperature rises, and reefs of this species can now be found in France and up to the Danish Wadden Sea. Reports of large scale growth of Pacific oyster reefs in the Bay of Brest and Wadden Sea have raised concern about potential invasive impacts and it is understood that ICES is preparing an Alien Species Alert Report on the Pacific oyster.

There is concern that Pacific oysters may spread out from farm sites through natural recruitment processes possibly changing the benthic community, sediment ecology and nearby filter feeders and that therefore permitting cultivation to take place or increase could threaten the integrity of a Marine Protected Area (MPA). A general increase in awareness of the potential impacts of non-native species has led to greater scrutiny by environmental organisations of any new proposed Pacific oyster culture developments or modifications to existing activities in MPAs. Also, following a European Court Judgement in 2004 (7th September 2004, case C-127/02) concerning shellfisheries in the Dutch Wadden Sea, existing farms upon renewal of site leases will be subject to an Appropriate Assessment Process to determine whether they will have a Likely Significant Effect on European marine site features and thus become subject to an Appropriate Assessment. This process already existed for proposed farms where, for example, authorisation was sought for a Several Order or permission from the Crown Estate, and an assessment was required before permission was granted.

From the industry and SNCAs' perspective this has led to significant amounts of time being expended on impact assessments, as uncertainties over the potential effect of Pacific oysters remains. Furthermore for industry this leads to uncertainty when planning new business developments leading to a lack of confidence in committing time and capital to new commercial activities.

Summary;

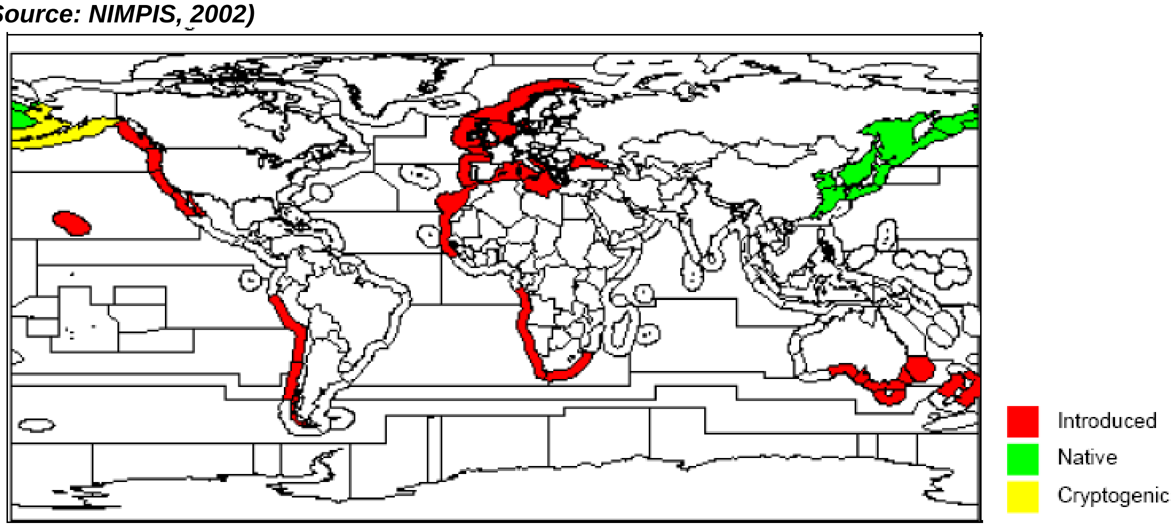
In comparison to other European shellfish producers the level of Pacific oyster production in the UK is small. In many areas of the UK competition for space in the marine environment has meant that suitable areas for Pacific oyster cultivation have been and remain hard to obtain. However, alternative culture techniques such as suspended culture, which is widely practised in Australia, instead of the traditional bag and trestle system, would be one way of opening up new opportunities for an increase in available sites with a consequent potential for increases in production levels. The potential for production of Pacific oysters at new sites around the UK when coupled with the proposed development under the Marine Bill of the new network of Marine Conservation Zones can only mean that there will be increasing occurrences of commercial activities within or near MPAs in the future.

SECTION 1 – NON-NATIVE & LEGISLATIVE ISSUES

1.1 Overview

The Pacific oyster, *Crassostrea gigas*, native to the north-western Pacific is widely distributed throughout the world. The Pacific oyster's good growth performance under a variety of environmental conditions makes it well suited for aquaculture, but also gives it the potential to become a highly successful invasive species. A key factor in the widespread use of the Pacific oyster around the globe has been the belief that wild establishment would not occur in many of the areas where it has been introduced. Initial studies often showed that the temperature regime in many new culture settings was considered unfavourable for the development of wild populations, yet with climate change and global warming this has proven not to be the case. The history of the introduction of the Pacific oyster to the UK is considered in more detail within Sections 4.1.1 and 4.1.2.

Figure 1. Pacific oyster world distribution
(Source: NIMPIS, 2002)



The number of countries where the Pacific oyster is currently considered invasive is changing rapidly and has become the subject of much debate. In Europe the HARBASINS conference on the status of the Pacific oyster in the Wadden Sea took place in April 2007 (Nehls and Büttger, 2007), whilst the International Conference on Shellfish Restoration in November 2007 presented the current status of the Pacific oyster in France (Hily and Lejart, 2007).

There are many non-native species which have no impact on the host ecosystem yet the few which do are now increasingly being recognised as a serious threat. Unfortunately, it is not always possible to determine at an early stage whether a species can change from a 'benign' non-native to an invasive ecosystem modifier.

The legislative status of a non-native species such as the Pacific oyster is strongly influenced firstly by whether it can become established in the wild and then whether it will have any ecological or economic impact. In consequence Section 1 of this report reviews both the ecological status and the current legislative framework with respect to the Pacific oyster.

1.2 Definitions and Policy

Terminology and perceptions are important as they inform actions and the subsequent enforcement of legislation. The process by which a non-native species becomes established and spreads in a new environment is described by a number of terms and scientific ecological definitions which may be interpreted in different ways by both scientists and the public.

The following sub-sections consider some of the key terms.

1.2.1 Non-native;

Natural England (NE), using DEFRA guidance, define 'non-native' as:

> "a species that does not originate in local waters and which has been introduced from other parts of the world by humans, either deliberately or accidentally"
> (Defra, 2003)."

Delivering Alien Invasive Species Inventories Europe (DAISIE, 2008) considers non-native to be synonymous with alien. However, some earlier definitions have varied in their scope. For example, Eno *et al*., (1997) drew a distinction between 'non-native' (considered established) and 'alien' (not considered established). Eno *et al*., (1997) defined non-native as:

> "a species that has been introduced directly or indirectly by human agency (deliberately or otherwise) to an area where it has not occurred in historical times (last 5000 years) and which is separate from and lies outside the area where natural range extension could be expected. The species has become established in the wild and has self-maintaining populations."

Another term frequently interposed with non-native and alien is 'feral' which is commonly used to describe wild settled Pacific oysters in Australia (see Section 5).

1.2.2 Established;

NE define 'established' as:

> "a non-native species in a new habitat successfully producing viable offspring with the likelihood of continued survival (Review of non-native species policy, Defra 2003)."

NE consider that Pacific oysters are breeding in the wild and producing offspring which reach maturity in English waters and are now established in the wild (as shown in Table 1). Although there is some uncertainty regarding the status of some regionally reported cases of wild settlement (see Section 3.4) other more extensive areas of wild settlement have become apparent during this study where it is probable that a wild population is self-sustaining. It is concluded that the Pacific oyster is likely to be established in some areas although this phenomena may to be regional.

The distinction between a non-native being 'present' or 'established' is an ecological barrier that provides a differentiation within the Risk Assessment process (Section 1.3.2). In consequence, the presence of a non-native is deemed of less threat than an established non-native. However, in some legislative determinations the burden of proof to support a precautionary approach is much lower indicating action before 'establishment' has been proven.

Feedback from the UKTAG (Janet Cowden, pers. comm.) on the forthcoming WFD on this issue stated:

> "The high impact species, once present, will quickly become established. In fact, by the time you have ascertained that they are established with reproducing populations it will be too late to do anything about them."

WFD related issues are discussed at greater length in Section 1.4.

1.2.3 Naturalised;

Naturalisation is a term which has created confusion with terminology/perception problems and some minor variation between the conservation agencies as indicated in Table 1.

Table 1. Pacific oyster non-native status from statutory nature conservation agencies' responses

Agency→	**NE** ***(Note 1)***	**CCW** ***(Note 2)***	**EHS** ***(Note 3)***
Could *C. gigas* be considered naturalised?	Yes *(Note 4)*	No	Awaiting study
When would *C. gigas* be considered naturalised?	Already	~100yrs	>10yrs
Is *C. gigas* invasive?	Yes	On verge	No evidence (awaiting study)

Note 1: NE = Natural England
Note 2: CCW = Countryside Council for Wales
Note 3: EHS = Environment & Heritage Service (Northern Ireland)
Note 4: From NE perspective naturalisation = establishment (see text)

NE responded: "Natural England has considered that 'naturalised' means the same as 'established'. " In contrast CCW responded: "We do not consider the term 'naturalised' as synonymous to 'established'." Further clarification was obtained from CCW regarding this term - **"**It is not that species become native but that they have become integrated into the ecosystem, are treated as if they were native and no action is taken to remove them." However, the point is made that a significant period of time is required to ascertain its true invasive potential before it can be known whether it may impact upon native fauna and flora.

In essence 'naturalised' is a term which means different things to different people as it seems to imply a degree of acceptance following successful adaptation to a new environment. Natural England make the point that "becoming 'established' or 'naturalised' in the wild does not imply that a species has therefore become native."

The term is also debated between ecologists as highlighted in Richardson *et al.* (2000) who analysed definitions of 'naturalisation' between different sources and concluded that there are a number of categories of naturalisation with differing concepts to how well established, frequently reproducing or successfully spreading the species is. They suggest inconsistent and imprecise definitions overlapping with 'colonisation' and 'invasive' stages of development.

From a French perspective there would appear to be acceptance of the Pacific oysters' naturalised condition. Lapègue *et al*. (2007) writing for IFREMER states:

> "Oyster farming is mainly based on these "wild" populations, with commercial hatcheries producing now about 20% of the spat (mainly triploids). Although this species has been introduced recently, we can consider the populations as 'naturalised'."

In the UK being a 'naturalised' non-native does not infer any degree of acceptance by the host country as demonstrated by the legislative moves outlined in Section 1.4. However, no evidence has yet been obtained of restrictive controls being placed upon French operations under common European Directives. It has not been possible to ascertain whether this is due to a different attitude towards the balance between commercial needs and ecosystem protection, or because the realisation of a potential problem came too late for effective controls to be put in place.

1.2.4 Invasive;

The Convention on Biological Diversity (CBD) defines invasive non-native species as those threatening biological diversity. Other definitions take on further dimensions as considered below.

It would appear as though consideration of the Pacific oyster as an invasive species is undergoing a significant reappraisal in recent years. Eno *et al*., (1997) considered the environmental impact of the Pacific oyster as being "No effects are recognised in Europe." By 2005, English Nature's '*Audit of non-native species in England'* (English Nature, 2005) only considered the slipper limpet and Chinese mitten crab as strongly negative on the grounds that they are both habitat modifiers. Responses from the conservation agencies within this study (see Table 1) suggest that the Pacific oyster is either considered invasive or on the verge of becoming so. Both NE and CCW also consider harmful effects on human interests as 'invasive' features.

Richardson *et al*. (2000) propose that 'invasive' should describe the biological process of colonisation and should have no inference to environmental or economic impact. They suggest that terms such as 'pests' and 'weeds' are sufficient for this purpose but make the distinction that the small number of invasive species that "change the character, condition, form, or nature of ecosystems over substantial areas may be termed 'transformers'." This viewpoint is counter to that expressed by the Non-Native Species Secretariat (NNSS) (Niall Moore, pers. comm.).

1.2.5 Naturalness;

Conservation agencies are tasked with protecting the natural environment – a role fundamentally linked to an understanding of what is 'natural'. The University of Aberdeen is currently undertaking a PhD study into the psychology of non-native issues and aims to deconstruct our actions and perceptions towards what is 'natural' and how we treat non-native species (Rene Van Der Wal; Sebastian Selge, pers. comm.). Previous work by this group has shown that perception on non-native issues is highly subjective. To society in general much of the terminology behind definitions can present different images, as will our concept of whether a species looks or sounds attractive. The public would not associate a *naturalised* black swan with an *alien* giant hogweed – yet both have been placed upon Schedule 9 of the Wildlife and Countryside Act as listed invasive species.

The distinction between native and non-native control is becoming blurred – the Wildlife and Countryside Act – Schedule 9 (see Section 1.4) lists undesirable 'non-natives' with recent proposed additions to include the boar (formerly native) and sea-buckthorn (native with regional presence). The Water Framework Directive in its non-native controls is also uncertain on the line between native / non-native controls:

> "UKTAG considers that further work is necessary before the presence of native but translocated species can be fully taken into account in classification. UKTAG recommends that such work be undertaken in time to provide methods for application in the next river basin planning cycle."

The issue of non-native and native pest control is likely to be further confused as climatic shifts may make some native species regionally invasive. The NNSS National Strategy document (NNSS, 2008) recognises the importance of climate change on shifting species range and allowing some currently benign non-native species to become invasive. Furthermore, the report accepts that further policy and scientific debate will be needed to address the issue of climate change driven non-native colonisation.

The conservation agencies objective to conserve and enhance the natural environment is therefore a difficult role in an environment which is largely modified by man and where global warming makes change inevitable. Some schemes assess the impact of the non-native species on the 'natural' environment by assessing the balance of ecosystem services (COPI, 2008) which is considered more in Section 1.3 with respect to the Pacific oyster.

1.3 Pacific Oyster: Risks and Threats

1.3.1 Benefits and Threats;

A threat is an indication of a potential negative impact. The vast majority of non-native species do not have a significant impact upon native ecosystems. However, the few that do can have a significant impact. The distinction between whether a non-native species is problematic is not always clear as there are often conflicting factors with a number of benefits and threats.

The Pacific oyster presents a mixed ecological and economic benefit and threat to UK waters as shown in Table 2. The decision as to whether a non-native species can offer positive benefits will of course depend on an individual's perspective. As such the use of the terms 'positive' or 'negative' in Table 2 with respect to ecological impacts is not meant to ascribe a positive aspect to these benefits but rather just highlights ecological changes. Perspectives in this respect are considered more fully later in Section 1.3.1.

Table 2. Summary of ecological and economic impacts of the Pacific oyster

	Positive	**Negative**
Ecological	Increases species diversity	Wild settlement can decrease habitat diversity
	Ecosystem services: improves water quality with removal of nutrients and microbes	Wild settlement could compromise some other species in some settings
Economic	Valuable commercial species	Wild settlement could compromise other commercial species (blue mussel, Native oyster, cockle)
	Wild settlement can provide 'free' spat and halfware source as well as marketable oysters	Wild settlement can present significant operational costs to oyster growers through fouling and reduced growth

Aquaculture can provide significant benefit to the economy and the environment. Food production by shellfisheries can have significantly less environmental impact, a lower number of food miles and lower carbon footprint than alternative terrestrial protein production systems.

Wild Pacific oyster settlement provides some economic gains through the collection of spat and halfware that can be introduced into the culture system. This is currently a widespread practice in France and recently undertaken in South East England within the Colne estuary system.

Opinion is divided as to the value of larger wild Pacific oysters for consumption. Smaal *et al.* (2005) proposed fishing of Pacific oysters as a potential control measure in the Wadden Sea with an added economic benefit:

> "Harvesting Pacific oysters is at present not allowed due to nature conservation directives. The quality of the oysters for consumers is excellent. Therefore there is a chance to harvest good quality product and meanwhile manage the size and spatial distribution of the stock. However, once the oysters have developed reefs the product quality for the consumers decreases dramatically due to clumping, increase of shell size and decrease of meat content. Combining management and harvesting requires therefore timely action."

Although shore gathering of wild Pacific oysters by the public has been observed the general industry impression is that the lack of a uniform physical product would hamper attractiveness to customers. Furthermore, there is little current demand for a processed product that would avoid these aesthetic limitations.

Shellfish can perform valuable eco-system services by improving water quality, supporting nursery areas for fisheries and removing nutrients. The 2010 CBD COPI report (COPI, 2008) highlights the use of changes in ecosystem services and their relationship to the well being of humans in assessing the cost of the loss of biodiversity. The case study model for Invasive Alien Species (Appendix 3 of COPI, 2008) shows how various invasive species have impacted on a range of ecosystem services. It is not however clear how to assess non-native species that may present a range of positive and negative features as is the case for the Pacific oyster.

Ruesink *et al.* (2005) reviews the impacts of oyster culture around the world from an ecosystem and economic perspective:

> *Increasing Biological Diversity and Abundance* - “Lenihan *et al*. (2001) used the native oyster *C. virginica* to compare fish and epibenthic invertebrate (blue crab, mud crabs, grass shrimp, and amphipods) assemblages on experimentally constructed reefs with assemblages on soft-sediment bottom in Pamlico Sound, North Carolina. Fish abundance was 325% greater, and epibenthic invertebrate abundance was 213% greater per trap placed on reefs than on the unstructured sand/mud bottom, a finding consistent with observational studies.”
>
> *Improving Commercial Fisheries Performance* - “Oyster introductions may also enhance estuarine-wide production of other economically valuable species, such as finfish and crabs. Peterson *et al*. (2003) calculated that over a 20-year to 30-year period, a restored oyster reef could enhance the cumulative amount of fish and large decapod biomass by 38 to 50 kg per 10 m^{-2} of bottom area, discounted for present-day value. This positive effect would occur only where the introduction involved a reef builder and local species of fishes responded positively to that habitat through enhanced recruitment and use of the substrate as refuge and as foraging ground.”
>
> *Improving Water Quality* – “Recent experimental results indicate that transplants of native oysters can significantly increase water quality in small bodies of water, such as tidal creeks (Nelson *et al.* 2004). Therefore, the probability is high that introductions of oysters that survive at high densities could improve water quality.”

From an ecological perspective Pacific oyster reefs increase species diversity yet their habitat modification properties are treated differently from ‘native’ biogenic reef formers that arguably perform the same function (e.g. native blue mussel and *Sabellaria spinulosa* worms). The Wadden Sea review by Nehls and Büttger (2007) showed that species diversity above Pacific oyster beds was significantly greater than mudflats but not significantly different from that of blue mussel beds, although some species varied in abundance with often increased epibenthic abundance on the Pacific oyster beds. However, although Pacific oyster reefs may perform a similar ecosystem function to other native reefs and may increase species diversity and abundance their ability to settle and modify a wide range of marine settings is the principal feature that makes them invasive.

French researchers Hily and Lejart (2007) compared species abundance and diversity on mud flats against mud with Pacific oyster reefs and rocky shores against rocky Pacific oyster reefs. Both species diversity and abundance increased significantly in both settings when Pacific oysters were present. However, the homogenization of habitats was seen as the principal area of concern – the mud/Pacific oyster environment contained 38% of characteristic rocky shore species, whilst the rock/Pacific oyster environment contained 10% of characteristic muddy shore species. Habitat loss can be considered one of the most significant negative features of wild Pacific oyster settlement. Under favourable conditions wild Pacific oyster settlement can occur not only upon rocky substrate but also upon sandy and muddy sediments. Once settled a few oysters can then provide a substrate for further oyster settlement so encouraging reef formation. The presence of a reef in a formerly sandy or muddy area may well increase species diversity owing to the more complex three-dimensional structure and firm surface for epibenthos – at the loss however, of the original habitat.

Natural England considers that naturalised Pacific oysters do not provide any ecological benefit to the marine environment of English waters, as they consider it to be an invasive non-native species that out-competes and smothers native species and habitats. The HARBASINS study of the Wadden Sea reviewed by Nehls and Büttger (2007) suggest that the picture may be more complex. This study showed that Pacific oyster reefs do not exhibit lower species diversity than blue mussel beds and have not led to any species loss. There is concern in relation to food sources for wading birds which are known to feed less effectively upon Pacific oyster reefs than upon the previous blue mussel beds. However, this study also showed that the decline of the blue mussel and the associated threat to wading birds relates to climate change effects on the ecosystem (see Section 2.6).

The negative impact of Pacific oysters on other native commercial species is often raised as a cause for concern with both trophic and space competition occurring due to wild Pacific oyster settlement. The potential negative economic impact upon the oyster industry itself should not be underestimated. Widespread wild settlement upon cultured stock, or overcatch, will impose a significant operational cost in terms of their removal through techniques such as dipping in boiling water to preferentially kill the newly settled spat. These issues are considered extensively in Section 2.6.

At the moment wild settled biomass of Pacific oysters in the UK is less than that of cultured oysters and food is not likely to be limiting. In contrast, reports from France suggest that wild biomass levels exceed cultured biomass with a resultant suppression in growth rates. Any site specific assessment for the potential of trophic competition between cultivated and wild Pacific oysters must consider the locally available resource (phytoplankton content and hydrodynamics) and other competing species. In the case of the Bay of Brest 2,000 tonnes of cultivated oysters competes with an estimated 15,000 tonnes of wild oysters. Although this sounds dramatic it should be noted that the same area is currently supporting an exploding population of >150,000 tonnes of slipper limpets which will clearly far outstrip wild oyster trophic competition. It is notable that the good performance of the oyster industry offshore of Plouguerneau in France is attributed to the cold upwelling waters in this area that prevents wild settlement. Further consideration of management options to limit impact will be provided in the Pacific Oyster Protocol (POP). However, avoidance of widespread settlement would be in the interest of the shellfish industry.

Wild Pacific oyster settlement may have a significant economic impact on the leisure industry and provision of coastal amenity functions. On some North Sea coasts concern has been raised over the potential for injuries resulting from the extremely sharp edges of Pacific oyster shells (The Independent, 2008). Experience from France has also shown that shell related injury and damage is a problem in some areas. Recreational enjoyment of the shoreline within the UK is a major economic force and injuries and damage resulting from wild oysters would be likely to generate strong reactions against any local aquaculture businesses deemed responsible.

Although negative economic threats are important considerations the principal legislative driver is the potential threat to the environment. The Pacific oyster has been shown to occupy a vast number of marine settings with populations capable of surviving in sheltered estuarine, semi-exposed euryhaline and exposed oceanic conditions on a range of substrates.

This ability to occupy a wide number of marine settings has lead to the following conclusion by some researchers:

> "*Crassostrea gigas* is the species which has the largest ecological potentialities to occupy the benthic habitats in the intertidal zone of Western Europe."
> (Hily and Lejart, 2007)

In summary, the Pacific oyster presents a range of positive and negative ecological and economic features. The principal problem is that the majority of negative features only become apparent when it is too late to intervene. The balance between these positive and negative effects will differ according to each individual's perspective thus creating division when decisions for action are required. Furthermore, the balance of positive and negative features will also vary on a geographical and temporal basis. In consequence, the Pacific oyster may currently present more of a problem in South East England than in South West England yet in a changing world this balance is shifting. The world is not in 'steady state' and there is an increased risk of wild settlement through future warming of the seas. This study aims to provide a balanced ecological and economic view from a long-term and wider perspective. It is recommended that the cost of early potential management controls within the proposed Pacific Oyster Protocol (POP) is weighed against the cost of delayed action or inaction.

1.3.2 Risk Assessments;

Risk is the probability of a known loss. Risk assessments go beyond the consideration of incidence to the potential impact of the threat. Assessing the level of threat by undertaking a Risk Assessment (RA) can provide a scored output to try and quantify risk. Research priorities as specified in the UK BRAG report (2005) clearly place 'audit' and 'risk assessment' at the forefront of research efforts followed by impacts of environmental change, modeling, pathway vectors, monitoring, management, economic costs and social perceptions.

Risk assessment protocols have been developed for terrestrial non-native species which have been subsequently adapted to non-native species generally. *Review of Non-native Species Policy: report of the working group* (DEFRA, 2003) describes how the European and Mediterranean Plant Protection Organisation (EPPO) protocol originally designed to assess the risk posed by quarantine pests has been used as a template for risk assessments. Risk assessments are central to the current UK approach to evaluate the impact of particular non-native species. A number of the legislative measures rely on risk assessments as a central feature.

Table 3. Summary of legislative risk assessments

Legislative Measure	Risk Assessment (RA) Criteria
Wildlife and Countryside Act – Schedule 9	NNSS *(Note 1)* apply an ecological and economic RA with a precautionary factor
Water Framework Directive (WFD)	UK TAG *(Note 2)* apply a RA to a 'grey list' non-native species if of uncertain ecological impact
New Aquaculture Regulation	Ecological RA (no economic factors) with a precautionary factor

Note 1: NNSS = Non-Native Species Secretariat is a government umbrella organisation set up in 2006 to provide a strategic focus to non-native research, policy and implementation issues
Note 2: UK TAG = UK Technical Advisory Group (WFD text)

NNSS has prepared a RA on the Pacific oyster undertaken by the Non-Native Risk Assessment Panel (NNRAP). This RA, which is currently under peer review prior to release, is likely to have a significant implication for future policy decisions with respect to Pacific oyster management.

The WFD consideration of RA is provided in UK TAG (2007) which states:

> "Risk analyses will normally be based on evidence of the severity and probability of adverse impacts derived from studies of other comparable sites in which the species concerned has become established."

Enquiries to UK TAG revealed that "for high impact species a risk assessment is not needed as we already know they are damaging the environment. The grey list species will be risk assessed to investigate whether those species are potentially threatening habitats. " (Janet Cowden, UK TAG, pers. comm.). As described in Section 1.4.5 the Pacific oyster has been placed on the high impact 'red' list with no perceived need for a RA.

RA's can aim to weigh up the threat and opportunities at a 'balance of probabilities' level or can be enhanced to account for uncertainty to shift the risk scoring to a 'beyond reasonable doubt' level. Simberloff (2006) asserts that the RA process of assessments of 'Low' 'Medium' or 'High' risk are based on guesstimates using imprecise knowledge for many factors and that the precautionary uncertainty factor is an "ad hoc algorithm" which compounds the uncertainty. The value of a RA and the distinction between a 'balanced' and a 'precautionary' view is likely to be a contentious middle ground debate between industry and conservation agencies.

An alternative approach to RA as followed in relation to non-native marine species in Australia is to adopt a Hazard Analysis and Critical Control Point Procedure. This follows a series of logical steps and outlines where things can or need to be done to reduce the risk (Clare Eno, pers. comm.).

This study suggests that temperature regime is a major influence on Pacific oyster recruitment and should be reflected therefore in any RA. Section 2 analyses UK regional temperature regimes on an historical and predicted basis in regard to the potential for Pacific oyster recruitment. Although this technique is not definitive it does suggest a regional variation in terms of risk and an underlying trend of increasing risk. This issue and associated recommendations are covered in Section 2.

1.3.3 Predation in the Natural Environment;

Risk assessments will need to establish the likelihood of a non-native species spreading in the wild without containment from potential predators. A key factor in the success of wild settled Pacific oysters will therefore be how they perform in the natural environment and whether predation will limit expansion.

Conservation agencies contacted as part of the current study (see Appendix 3) reflected the common view that Pacific oysters are not subject to significant predation. In consequence, once established the Pacific oyster can potentially out-compete native species and thus dominate marine habitats.

Spencer (1990) considers shore crabs, drills or tingles, starfish and to a lesser extent birds as predators of the Pacific oyster. A recent review by Ruesink *et al.* (2005) showed that oysters provide significant food sources for predators, whilst Smaal *et al.* (2005), working in the Wadden Sea, indicated high first year Pacific oyster mortality, at about 80%, due to predation and overcrowding.

A differential between mortality in Pacific oyster spat and adults would tend to be supported by Spencer (1990) who showed that Pacific oysters of <10g were highly susceptible to crab predation, whilst Spencer *et al.* (1994) showed that larger wild Pacific oysters in the Exe (mean length 100mm) had low mortality of around 16% over 1 year. Predators found in rocky intertidal areas such as sea stars and crabs reduced monthly survival rates of the Pacific oyster introduced in western Canada by 25% relative to caged oysters (Ruesink *et al.*, 2005).

The potential impact of other predators such as oyster drills could also influence future predation patterns. Smaal *et al.* (2005) mentioned the impact of the predatory non-native gastropod *Ocinebrellus inornatus* which has impacted on French cultured oyster stocks. It is not known whether climate change will favour growth of this new species and allow it to reach the UK.

In summary, there are Pacific oyster predators which are likely to significantly reduce spat recruitment. Indeed it is highly probable that the formerly low levels of episodic wild Pacific oyster settlement in the UK may have been partially contained by predation for many years. However, the successful establishment of large scale settlement despite this high level of predation indicates that wild settlement can far outstrip predation.

1.4 Legislation

1.4.1 Legislative Overview;

A summary of the current and proposed principal legislation regulating non-native species is provided in Table 4 below.

Table 4. Summary of main legislation in force in the UK of relevance to Pacific oyster culture

Legislative Measure	Area of interest	Status
Habitats Directive and Birds Directive	Protection of designated areas and features: SACs, SPAs and Ramsar sites	In force since 1992. May also include sea areas adjacent to protected areas
Wildlife & Countryside Act – Schedule 9	Primarily concerned with the release of NNS into the wild	In force since 1982. Schedule 9 problem species periodically updated
Water Framework Directive	Of relevance to all water bodies including estuaries (transitional) & coastal waters	Basin plans Dec. 2008. Non-native enforcement scheme yet to be developed
Aquaculture Alien and Locally Absent Species Regulation	Aquaculture movements	To UK regulations by Jan. 2009
Environmental Liability Directive	Increased 'polluter pays' powers	To UK regulations by Dec. 2008
Aquaculture Planning Regulations	Concerned with the planning requirements for aquaculture developments	Already in force via NERC Act 2006 and Town & Country Planning (Marine Fish Farming) (Scotland) Order 2007

Historically non-native species issues within the UK have been dealt with by a number of government agencies, in a variety of sectors, using a range of legislation. Recently the profile of invasive non-native species issues has risen up the political agenda (POST, 2008) and there has been a drive to strengthen and harmonise legislation. In 2003 a review of non-native species policy was produced (DEFRA, 2003) with a key recommendation that non-native species issues within Great Britain required a co-ordinated and strategic direction to optimise the use of resources and effectiveness of policy. This resulted in the formation of the Non-Native Species Secretariat (NNSS) which launched its GB National Strategy in May 2008 (NNSS, 2008).

Although the GB strategy is concerned with *invasive* non-native species it recognises that the invasive potential is not constant and therefore widens its scope to include all non-native species. The GB NNSS strategy has adopted the Convention on Biological Diversity (Section 1.4.2) three stage hierarchical approach to prevention, detection/surveillance and control/eradication. The emphasis of the strategy is upon prevention and early action before major problems become established.

1.4.2 Convention on Biological Diversity;

The Convention on Biological Diversity (CBD) was adopted in 1992 and ratified by the UK in 1994. Many of the objectives of the CBD are met through the UK Biodiversity Action Plan (UKBAP) which was also adopted in 1994. The CBD requires contracting parties to prevent the introduction of, control or eradicate, those alien (i.e. non-native) species which threaten ecosystems, habitats or species.

Although DEFRA is responsible for the implementation of the CBD the Joint Nature Conservation Committee (JNCC) has been commissioned to support their Alien Invasive Species programme.

2010 – Biodiversity Target. In 2002 the parties to the CBD committed themselves "to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth." This was subsequently endorsed by the United Nations General Assembly and incorporated as a Millennium Development Goal. In March 2007 the G8 Environmental Ministers meeting at Potsdam made a commitment to undertake a global study of the economic significance of the loss of biological diversity. This included strengthened international co-operation on invasive alien species and support of the Global Invasive Species Programme (GISP).

In May 2008 the European Commission produced a study on "The Cost of Policy Inaction – The Case of Not Meeting the 2010 Biodiversity Target" (COPI, 2008). A central component of this study is to model the change in biodiversity to 2050 using the underlying drivers of population development, economic development, energy use and food production. The study acknowledges that certain drivers such as invasive species and changes in coastal marine ecosystems are not modelled. However, many of the tools developed can be applied to marine settings such as the Mean Species Abundance (MSA) indicator and the Millennium Ecosystem assessment based upon Ecosystem Services (considered further in Section 1.3.1).

1.4.3 Habitats Directive;

Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora came into force in May 1992. The central aim of the Directive is to conserve biodiversity across the area of the European Union through a coherent network of Special Areas of Conservation (SACs). This is transposed in UK law under the Habitats Regulations which also transposes the Birds Directive (79/409/EEC).

The Habitats Directive has formed the current 'front-line' for recent conflict between conservation agencies and aquaculture developments proposing to use the Pacific oyster. A number of operations have been prevented from using diploid Pacific oysters with consequent delays in business planning and thus investment placed on-hold.

The Habitats and Birds Directives are European legislation that give EU Member States the power and responsibility to designate Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). Competent authorities (normally the Sea Fisheries Committee in English and Welsh waters out to the 6 nautical mile limit) must undertake an Appropriate Assessment before authorising or licensing any new fishing or aquaculture activities which either alone or in combination with other plans and projects would be likely to have a significant effect on an SAC, SPA or Ramsar site.

Article 7 of the Habitats Directive ensures that the obligations Member States must undertake to avoid deterioration and disturbance of SACs are equally applied to areas classified under the Birds Directive. As a result all the provisions of the Habitats Regulations, which transposes the Habitats Directive into UK law, need to be applied not only to SACs but equally to SPAs and Ramsar sites.

Individual marine SACs, SPAs or Ramsar sites are designated for specific features and as such potential conflict between marine users including shellfish farmers will need to be addressed on a site specific basis. However, the conservation agencies have been approached to identify the key features requiring protection from Pacific oysters within SACs. In general the key features identified as likely to impact upon SAC designations are the Pacific oyster's ability to transform habitats and therefore affect the native ecosystem. NE are specific in their concerns which particularly include the potential for reef formation in muddy habitats which could impact upon wading birds, fish nursery grounds and habitat diversity. NE also raise concerns about the potential impact of any measures to remove wild settled Pacific oysters. In summary**,** the key concern is the Pacific oyster's ability to transform habitats and therefore impact native ecosystems as this would be considered an adverse effect on the integrity of a designated European site.

Full responses by NE, CCW and EHS are provided in Appendix 3.

1.4.4 Wildlife and Countryside Act 1981;

The Wildlife and Countryside Act (WCA) is the central basis of nature conservation legislation in Great Britain. There are a number of provisions relating to marine conservation including 'Section 14' which covers the prevention of the introduction of alien species (listed in Schedule 9 of the Act).

At present Schedule 9 is being reviewed and at the moment the Pacific oyster is not present on the new list for inclusion, although as indicated in Section 1.3.2 a RA is currently being undertaken on the Pacific oyster which may result in its addition. Other major habitat modifiers such as the slipper limpet and Chinese mitten crab have been proposed for Schedule 9 - the same species which share 'high impact' status with the Pacific oyster in the WFD 'red' list (see following Section 1.4.5).

The WCA allows for controls to be implemented to prevent the release of listed non-native species into the wild. Recent amendments to Schedule 9 also prevent the sale of listed species.

The WCA is not applicable in Northern Ireland as Northern Ireland has its own Wildlife (Northern Ireland) Order 1985 which is currently under review. Pacific Oysters have not been proposed for addition to the Wildlife Order under the current review.

1.4.5 Water Framework Directive;

Both NE and CCW have highlighted the potential for wild settled Pacific oysters to threaten 'good ecological status' within the Water Framework Directive (see Appendix 3).

The Water Framework Directive (WFD) is a major piece of legislation which will integrate future surface water environmental issues. The WFD uses a series of chemical and biological indices to provide a catchment based classification of surface waters from headwaters to the sea with grades from 'High' to 'Poor'. WFD covers all coastal waters in England, Wales and Northern Ireland out to 1 nautical mile, whereas in Scotland it is out to 3 nautical miles.

The Environment Agency will be responsible for implementing the new regulation with guidance from the UK Technical Advisory Group (UK TAG). UK TAG has been assembled to provide guidance to the Environment Agency on water body classification, classification standards, a common implementation strategy and establishing a monitoring framework.

The potential deterioration due to the presence of high impact non-native species is one of the biological criteria upon which classification will be based. A report outlining the classification criteria is provided by UK TAG (December, 2007):
http://www.wfduk.org/UKCLASSPUB/LibraryPublicDocs/sw_status_classification

This report provides a listing of high impact non-native species placed within Annex B - also known as the 'red list'. Until recently the only two marine invertebrate shellfish on this list were the slipper limpet and the mitten crab – both high impact habitat modifiers identified by Natural England in their 2005 audit as the two most strongly negative marine species. Other non-native species were placed upon a 'grey' list (potentially problematic and requiring a risk assessment) and a 'green' list of perceived limited risk. The red list was reviewed recently in spring 2008 prior to which the Pacific oyster had been classified on the non-problematic green list. However, in April 2008 following this review the Pacific oyster was placed upon the red list:
http://www.wfduk.org/tag_guidance/Article_05/Folder.2004-02-16.5332/alien_tag_table

Enquiries to UK TAG for this change revealed that:

> "The Pacific oyster, *Crassostrea gigas,* has already demonstrated the capacity in France and elsewhere in Europe to dominate rocky areas to the virtual exclusion of native species in that area. Known to breed in the UK in the wild; invasiveness likely to increase with warming sea surface temperatures."

Current regional maps of surface water bodies at risk from alien species pressures (http://www.defra.gov.uk/environment/water/wfd/article5/index.htm) provide a bleak picture for coastal and transitional (estuarine) waters with the vast majority of coast classified as "probably at risk".

It is probable that the WFD will be a significant future driver for the strategic framework and local basin implementation of non-native issues. In consequence local basin plans involving both public agencies and industry are likely to include Pacific oyster culture and wild settlement within their remit.

It is unclear at this stage what implications this will have with respect to any legislative controls and potential penalties for Pacific oyster culture. UK TAG feedback has stated:

> "The Pacific oyster is a species that is very important in terms of being farmed but I do think that a cautious approach is required to ensure it does not become established as it does have the capability to cause a lot of problems."

The Environment Agency regional teams recognise the scale of the problems presented by non-native species and the practical issues involved in focussing effort on achievable objectives. In practice, non-native issues will be prioritised to provide a workable framework but are unlikely to present the same level of protection to all affected surface waters as current SACs (Ben Bunting; James Farrell, pers. comm.).

The draft Basin Plans are due to be presented in December 2008 although it is understood that these will not include comprehensive mapping and determinations of non-native issues in the current round. There is potential that the next round of basin planning could help provide resources to better quantify site specific wild settlement and help implement a working Pacific Oyster Protocol (POP) in consultation with local oyster farmers and stakeholders. It is recommended that UK TAG and local EA teams are fully integrated into the next phase of POP implementation.

UK TAG feedback has indicated that although the WFD is a European Directive it is not clear at this stage the degree to which other Member States might be implementing a non-native component. The GB NNSS strategy document (NNSS, 2008) identified that as the WFD was a European Directive that an EU position is needed on alien species issues and that the European Commissions ECOSTAT group is beginning to examine the issue of using alien species within an ecological classification scheme.

1.4.6 Aquaculture "Alien Species" Regulation;

Council Regulation (EC) No 708/2007 "concerning use of alien and locally absent species in aquaculture" was adopted on 11 June 2007 and is due to come into force in the UK by January 2009. This piece of legislation primarily concerns movements of aquaculture species but could have a major implication for Pacific oysters as a potential means of controlling new seed movements.

Brown *et al.* (2006) recently devised a protocol for shellfish movement in which the forthcoming 'Alien Species' regulation was considered. At the time of publication concern regarding the Pacific oyster was only just emerging and received little attention: "Evidence from Holland would also indicate that there should also be concern over *Crassostrea gigas* spreading and outcompeting mussels. This should be kept in mind particularly in view of rising sea water temperatures." In consequence the Pacific oyster was not cited as a species that might require movement controls.

The Pacific oyster is specified in Annex IV of the regulation as a long-term aquatic alien species for which not all articles apply. However, some relevant articles do apply and there is latitude for Member States to decide whether additional restrictions are required for such long-used species.

Article 4 (which applies to long-used aliens) states:

> "*Measures for avoiding adverse effects* - Member States shall ensure that all appropriate measures are taken to avoid adverse effects to biodiversity, and especially to species, habitats and ecosystem functions which may be expected to arise from the introduction or translocation of aquatic organisms and non-target species in aquaculture and from the spreading of these species into the wild."

Article 9 applies to 'non-routine' movement controls which will require a Risk Assessment, specified in Annex II. A non-routine movement is the movement of an aquatic organism which does <u>not</u> fulfill the following:

> "has a low risk of transferring non-target species and which, on account of the characteristics of the aquatic organisms and/or the method of aquaculture to be used, for example closed systems as defined in 3, *does not give rise to adverse ecological effects*;"

This implies a movement that *could* give rise to an adverse ecological impact would require an RA. It is possible that such a requirement could be applied to Pacific oyster seed movements on a regional basis according to the potential threat posed to the receiving waters. In some areas the movement could be considered of low risk as there may already be adverse wild impacts regardless of any commercial addition. Alternatively in some areas the movement could also be considered low risk because the receiving waters are still significantly cold and well below the threshold for potential recruitment. In contrast, other areas may be considered at high risk and require a RA as the level of wild population is low but the potential for recruitment is high.

1.4.7 Environmental Liability Directive;

The Environmental Liability Directive (ELD) 2004/35/EC extends the current ‘polluter pays’ principal to cover environmental damage. This includes adverse effects on Sites of Special Scientific Interest (SSSIs) and EU protected habitats/species wherever they may occur.

In principal this regulation could possibly be applied to an aquaculture operation causing damage through the release of viable oyster larvae which might impact on a protected feature. However, in practice there is a high burden of proof to identify the ‘polluter’, to show that the damage is quantifiable and to demonstrate a causal link between polluter and impact (Niall Moore, pers. comm.) In the case of the Pacific oyster wild settlement sites may be within range of a number of potential larval sources making it hard to show that any one farmer was at fault. Consultation on the ELD closed on 27/5/08, whilst the regulation will be transposed to UK law by the end of December 2008.

1.4.8 Aquaculture Planning Regulations;

The Natural Environment and Rural Communities (NERC) Act 2006 places a number of enhanced duties on fisheries managers with associated powers to fine offenders in order to help conserve biodiversity and protect special features. In essence, Sea Fishery Committees (SFCs) must “have regard” for conserving biological diversity during the exercise of their functions.

As the SFCs are statutory consultees in the granting of permits for coastal aquaculture developments they can be fined if they fail to comply with the consultation procedure. A key aspect of this enhanced duty is to have regard for x25 marine habitats and x88 more sensitive marine species. In addition, the NERC Act has made the SSSI protection within the Wildlife and Countryside Act 1981 more robust whereby even inadvertent damage of a protected feature by a fisherman may be liable to prosecution and a fine.

This legislation may be relevant in terms of a shellfish farm which proposed to use Pacific oysters in an area where wild settlement and recruitment may threaten nearby protected features or species.

The Town and Country Planning (Marine Fish Farming) (Scotland) Order 2007 is a recent piece of devolved legislation which has placed the planning requirements for offshore mariculture in the hands of the Local Planning Authority. A principal driver in this change was the perceived potential conflict of interest that the Crown Estate held in its role as both landlord and regulator. It has also aimed to streamline decision making on aquaculture operations which spanned both intertidal and subtidal seabed (or even land based operations) which had formerly been required to go through separate planning requirements. It is uncertain how the 23 new Marine Planning Zones will consider non-native issues within their local planning regulations.

1.5 Summary

The Pacific oyster is non-native to the UK. It has a vast distribution around the world by virtue of its good growth characteristics under a wide range of environmental conditions which has made it an excellent candidate for aquaculture. In the UK the introduction of the Pacific oyster was to assist industry revival following problems with the less robust native species. Many of the waters in its introduced range were originally considered to be too cool to allow effective wild reproduction. However, wild settlement is now occurring at an increasing level and the number of areas where it is now being classified as 'invasive' is increasing. This change in status would appear to be linked to climate change and warming of sea temperatures.

Terminology and ecological definitions are important as they shape perception and inform legislative controls. Despite some discrepancy in 'naturalisation' definitions it appears that this term does not imply a degree of legislative acceptance in the event that the Pacific oyster becomes well established within the native ecosystem. Terminology and invasive ecological status are critical in how non-natives are judged in Risk Assessments (RA) which inform new regulatory controls. The 'scoring' of a non-native within a RA is strongly influenced by its determination (e.g. 'established' and 'invasive'). In the case of the Pacific oyster in the UK there may be grounds to debate whether current wild settlement is primarily derived from cultured stock or is self-sustaining. Regardless of the larval source the increasing presence of wild settlement in some areas and the Pacific oyster's potential to dominate and modify habitats are the principal features that define it as 'invasive'. This potential threat to designated protected sites is the key issue regardless of any positive ecological functions which the Pacific oyster may be considered to perform in the natural environment.

Species control according to 'nativeness' can present problems when the line becomes blurred between 'translocated' native and non-native legislation – especially in a changing world where native species can become 'invasive'. It is possible that definitions of 'pest' and 'weed' are more appropriate. From a perception perspective the shellfish industry might find it hard to accept a universal 'invasive' label if at their local site wild settlement is not occurring, or is very rare. However, there is a parallel between the Pacific oyster and the wild rabbit in terms of its history of introduction and potential for impact. For the rabbit, people accept a transient label of 'pest' when the species is in the wrong place, at the wrong time or in too high a number.

It appears very likely that industry will have to adopt best practice and avoid potential impact on designated features in order for new cultivation opportunities to be taken up, and if existing sites are to be able to continue. In addition to the principal environmental concerns and potential conflict with the leisure industry an overview of the benefits and threats show that from an economic perspective it may well be in the shellfish industry's own best interest to consider undertaking controls. Although the current situation might provide some operators with 'free' seed, the long-term development of widespread wild settlement could be deleterious for industry with the potential for significantly increased operating costs coping with secondary settlement (overcatch) and ultimately reduced shellfish growth rates through food resource competition.

Legislative regulation of non-natives generally and the Pacific oyster in particular is about to change. At present only the Habitats Directive has any real impact upon industry and only in a very few cases within designated protected areas. However, tightening of the Wildlife and Countryside Act is highly probable, the Water Framework Directive has also identified the Pacific oyster as a 'high impact' species and the new Aquaculture Alien Species regulation due to come into force in 2009 could be used to control seed movements.

In contrast, legislative control of the Pacific oyster on mainland Europe does not appear to match the UK stance. France experiences a similar temperature regime to the UK and has suffered significant wild oyster settlement in recent years and yet there are no plans to include a non-native component to the WFD. Furthermore, Member States can elect how to apply the new Aquaculture Alien Species regulation to ‘long used’ non-native species such as the Pacific oyster. In addition to the current links between NE and the tri-national Pacifics working group in the Wadden Sea, there may be merit in more cross-channel liaison to better inform industry and conservation agencies about risk assessment, legislative harmonisation and management in this respect.

In the case of the UK it remains to be established whether a ‘Fortress Britain’ approach to marine non-natives and the Pacific oyster in particular will be effective. A high density of Pacific oyster stocks around mainland Europe and a long planktonic larval phase may potentially undermine any nationally imposed control. As a matter of urgency the level of risk from European sources needs to be established although it should be noted that the precautionary stance of the Habitats Regulations could require removal of local effects regardless of other potential external sources of larval input even before the relative loads have been fully defined. Although, we are fortunate that the overall residual currents and our relative isolation provide some protection for the UK, the pattern of wild settlement seen in France provides a stark illustration of the cost of inaction. The Pacific Oyster Protocol (POP) could be a vital measure in responsible industry self-regulation. Effective and honest collaboration between industry, conservation agencies and other relevant organisations is also required in order that sustainable solutions can be found to the issues surrounding the cultivation of Pacific oysters in the UK.

1.6 Recommendations for Future Work

Section	Work/Research Required	Action Taken During Current Study (where applicable)	Importance	Potential Organisation to Action or Participate	Possible Sources of Funding
1.6.1	SAGB, SNCAs and DEFRA need to agree common definitions regarding the use of terminology with respect to non-native issues. A meeting will need to be held to agree standard terms and definitions.	A suggestion has been made to SAGB that this could be included as part of the further development of the MoU.	Currently this area of work is hampered by the use of differing meanings in terminology.	- SAGB - SNCAs - DEFRA	N/A
1.6.2	Consideration of the 'Cost of Inaction.' Assessment of the likely short-term and long-term balance of threats and benefits.	Identification of the range of ecological and economic factors for consideration.	Acting now may reduce impact on industry later.	- SAGB - SNCAs	UK BRAG
1.6.3	European information exchange. A number of industry and SNCA representatives need to experience Pacific oyster impact and meet with European regulators first hand to see if we can avoid the same problems in the UK as have been experienced in Europe.	Identification of French workers and sites where recent Pacific oyster settlement has had a major impact.	Industry needs to see an example of the potential impact upon their sites. SNCAs need to investigate the potential for an EU harmonised legislative approach.	- SAGB - SNCAs - Industry	- Seafish - DEFRA - Industry

SECTION 2 – SEAWATER TEMPERATURE PROFILES FOR THE UK & THE IMPACT OF CLIMATE CHANGE

2.1 Overview

The influence of temperature is central to the reproductive success of the Pacific oyster as it is one of the key factors controlling reproductive development. This section therefore considers both spatial and temporal variation in temperature around the UK and its potential influence upon settlement.

This section seeks to address the following specific key concerns:

-*What is the regional temperature pattern and how is it likely to influence Pacific oyster settlement?* There is an indication that certain regions are experiencing more wild spawning than others. This section reviews regional and long-term temperature regimes around the UK in relation to known biological milestones of potential conditioning, spawning and recruitment. Corresponding observations of settlement will be reviewed in Section 3.

-*How has the temperature regime changed in the past since the Pacific oyster has been introduced?* A number of regions have been observing an increasing incidence of wild settlement events. This phenomena has been attributed to global warming through climate change on the continent, e.g. in the Wadden Sea (Nehls and Büttger, 2007), Brest (Hily and Lejart, 2007), and within the UK (Couzens, 2006a and 2006b).

-*What is the likely future temperature regime in the face of global warming?* The regional trends considered in this Section are also extrapolated using current sea surface temperature climate predictions to provide an outline indication of the future scale of Pacific oyster wild settlement events.

-*How well has the temperature regime criteria modelled observed spatfall*? A case study from the documented Yealm estuary and South Devon sites has been used to see if predictions match observations. Problems with using actual local temperature data sets are explored and preferred measurement regimes considered.

-*How will changing temperature patterns affect other commercial species and their potential interaction with the Pacific oyster?* The ‘invasive’ characteristics of the Pacific oyster have led to concerns over possible conflict with other commercial species such as the Native oyster and blue mussel. This Section reviews current data and the complex pattern of interactions between species and also examines whether some of the perceived problems attributed to Pacific oysters may in fact be associated with wider global warming issues.

2.2 Influence of Temperature on Pacific Oyster Success

2.2.1 Temperature Requirements for Pacific Oyster Settlement;

Wild Pacific oyster spat settlement is dependant on a number of variables of which temperature is one of the key factors. This section reviews the requirements for the three key stages in reproductive success: 'conditioning,' 'spawning' and 'recruitment.'

Confounding factors which might delay or reduce the potential for recruitment are considered in Section 2.2.2. Factors such as acclimatisation that may allow an increased risk of settlement are discussed in Section 2.2.3. Other temperature related issues that might affect Pacific oyster success are considered in Section 2.2.4.

Most of the Pacific oyster conditioning literature relates to hatchery based operations when oysters are obtained from the wild in the spring and are already at an uncertain state of gonad development. Table 5 outlines some of the literature values obtained.

Table 5. Pacific oyster conditioning degree days

Temperature (^oC)	**Duration (Days)**	**Degree Days (above 10.55 ^oC)**	**Source**
24	28	377 *(Note 1)*	Helm and Bourne (2004)
20	42	397 *(Note 1)*	Helm and Bourne (2004)
19	42	355	Rico-Villa *et al.* (2006)
20	60	567	Robert and Gerard (1999)
15	133	592	Mann (1979)
18	91	678	Mann (1979)
21	49	512	Mann (1979)
		592 (*Note 2*)	Mann (1979) & this study

Note 1: Range of values presented
Note 2: Derived value from Mann (1979) ~600 degree days used in this study

Table 5 above shows a range of conditioning times. Mann (1979) was selected for use in this study as other studies used stock which may have already been partially conditioned.

Mann (1979) compared spawning conditioning for both the Pacific and Native oyster by studying growth, conditioning and biochemical composition for test oysters at a range of temperatures from 12-21 ^oC. Test animals were obtained in November when biological reserve levels were low before commencing conditioning at the test temperatures. Mann derived a biological zero of 10.55 ^oC for the onset of gametogenesis with a 592 degree day requirement above this base temperature before the Pacific oysters were sufficiently ripe to allow spawning. Mann also showed that under these conditions spawning occurred at temperatures above 18 ^oC.

The degree day calculation is shown as follows:

$$\mathbf{D = d\,(t - t_0)}$$

Where: D = degree day requirement; d = number of days to attain ripe state; t = temperature of animal exposure and t_0 = temperature below which no evidence of gonad development.

Mann (1979) formed the basis for previous assessments by Eno (1994) of environmental temperature regimes associated with wild settlement. This study has also adopted this basis for assessments of conditioning and spawning.

It is recommended that current on-going research (see Appendix 1) is monitored closely in order to obtain a more relevant field study based conditioning value when it becomes available.

Recruitment values for degree days are a function of both temperature and nutrition with most literature values originating from hatchery based studies. As a crude benchmark larval duration is considered to be just over 2 weeks at 25 ^{o}C and 3 weeks at 20 ^{o}C. However, as demonstrated by Rico-Villa *et al*. (2006) the microalgae diet is important in larval development and survival. An overview of recruitment degree days is provided in Table 6.

Table 6. Pacific oyster recruitment degree days

Temperature (^{o}C)	**Duration (Days)**	**Degree Days (above 10.55 ^{o}C)**	**Source**
		350 *(Note 1)*	Eno (1994)
28	14	244	Robert and Gerard (1999)
25	15.5	224	Utting and Spencer (1991)
25	16	231	Rico-Villa *et al.* (2006)
23.1	18	226	Robert and Gerard (1999)
22	18	206 *(Note 2)*	Magoon and Vining (1981)
18	30	224 *(Note 2)*	Magoon and Vining (1981)
		225	This study

Note 1: Uncertain origin
Note 2: Presented in Pauley et al. (1988)

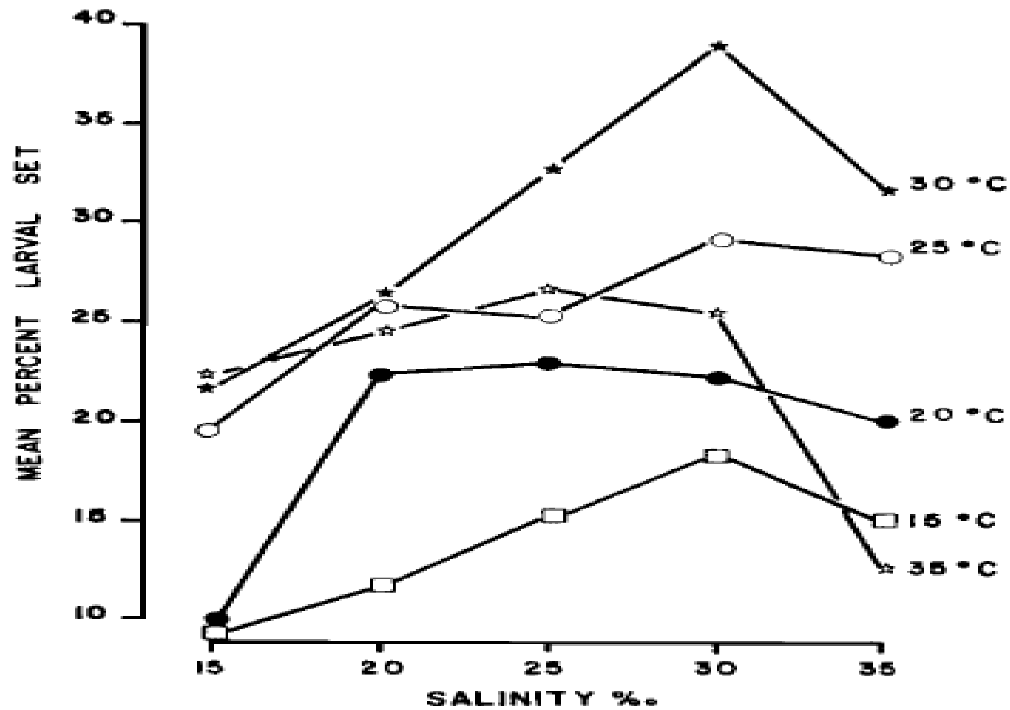
It should be noted that the period of larval recruitment will be over a period of many days and will as such provide a range of degree day times of which most values in Table 6 above tend to be the earliest recorded. A 225 recruitment degree day period has been adopted for this study in line with the temperature/duration regime of the majority of previous studies. Coupled with the ~600 degree days required for conditioning a total of 825 degree days will be needed to ensure settlement within a summer season.

The 942 (350+592) recruitment degree day period used by Eno (1994) in her evaluation of wild spat settlement is of uncertain origin and not used in this study. However, Eno's methodology in the use of the conditioning biological zero of 10.55 ^{o}C derived by Mann (1979) was adopted. It is however not known how appropriate this baseline may be as little is reported of larval development under reduced temperatures in the natural environment. Clearly hatcheries tend to operate under increased temperatures in order to speed development, whilst cooler operational temperatures are likely to not only extend the larval phase but the duration of the metamorphosis stage. Figure 2 shows that the rate of larval settlement under 15 ^{o}C was markedly reduced. In the natural environment this differential is likely to be increased as a longer larval phase will provide increased potential for predation.

Pauley *et al.* (1988) consider larval development under a range of temperatures and salinities as shown in Figure 2. This demonstrates that settlement is generally good above 20 ºC and 20 ppt with optimum settlement at a temperature of 30 ^{o}C and a salinity of 30 ppt. This corresponds well with the findings of Helm and Millican (1977) who studied hatchery larval development under a range of culture conditions and showed high rates of survival of >90% at 20 ^{o}C, 24 ^{o}C and at

28 °C but somewhat reduced survival at 32 °C and therefore proposed an optimum culture temperature for larvae of 28 °C. This upper temperature limit also matches work on Pacific oyster spat by Flores-Vergara *et al.* (2004) who showed that the survival at 32 °C was < 50% after 5 weeks whereas at all other temperatures it was >88%.

Figure 2. Remote setting of Pacific oyster larvae at various salinities & temperatures
(after Chew, 1983 – reviewed in Pauley et al., 1988)



Hatchery based research is not the most appropriate data source to help assess settlement risk in the UK but until more research work is undertaken this hatchery data provides the only available basis on which to undertake these risk assessments. It is probable that lower temperatures in the natural environment and non-optimal diet (Section 2.2.2) will significantly increase larval phase and reduce the recruitment success of the Pacific oyster. It is recommended that further work is undertaken on larval development using a more representative temperature and nutritional profile in order to establish the larval 'biological zero' point. This will help in better assessing settlement rates and associated risk.

2.2.2 Confounding Factors in Settlement;

It should be noted that temperature regime is not the only factor that will determine settlement. A number of other factors will influence both conditioning and whether viable larvae survive and develop to achieve settlement in a particular area.

2.2.2.1 Nutrition: Nutrition during the larval phase influences both the speed of development and the overall survival to metamorphosis. Many of the hatchery related studies cited in Section 2.2 investigated microalgae factors including the blend of phytoplankton species and PUFA content to optimise hatchery performance. As with any biological system variation in development was experienced which provided a spread of developmental times. For example, Rico-Villa *et al.* (2006) recorded metamorphosis times of between 16 to 26 days. This produces a corresponding range of 230 to 380 degree days. It is probable than in the natural environment phytoplankton availability will be significantly more variable than within the laboratory and will therefore at best increase the range of degree day periods, but at worst could be limiting and prevent metamorphosis.

2.2.2.2 Adverse hydrodynamics: Eno (1994) showed that the Fleet Lagoon, which is a shallow tidal enclosure in Dorset containing a Pacific oyster farm, had a suitable temperature regime for successful recruitment, yet no wild settlement had been observed. Eno postulated that the flushing regime and the Pacific oyster's extended larval life might have resulted in the removal of potential recruits from the area.

2.2.2.3 Unfavourable biotic factors: King *et al.* (2006) recorded a number of potential confounding factors that strongly influenced Pacific oyster growth and performance away from the conventionally accepted norms. A comparison was undertaken in North Wales between a warm 'Inland Sea' area against 'high' intertidal and 'low' intertidal culture sites. Conventional culture wisdom, as defined in the MAFF culture manual (Spencer, 1990), would indicate that the best growth and conditioning performance would be achieved in the Inland Sea where the stock was continually immersed and received the highest temperatures. This would be followed by the Menai Strait 'low' stock which was immersed and feeding for most of the time whereas the Menai Straits 'high' stock which feed for the shortest period should perform the poorest. King *et al.* showed that the expected pattern was in fact reversed with the theoretically best site exhibiting stock that performed the worst. This study showed that although the warm Inland Sea experienced high chlorophyll *a* content (indicative of good primary productivity) the dominant species present was non-optimal and may have retarded development. Furthermore, the inversion of the expected Menai Straits site performance was attributed to a heavier infestation with mudworm (*Polydora*) of the lower placed oyster stock which may have resulted in retarded growth rates.

Steele and Mulcahy (1999) compared the reproductive biology of Pacific oysters from two sites on the south coast of Ireland for variations in maturation rate and condition indices. Qualitative data were compiled by examining gonadal development using histological sections. Temperatures were sufficient to allow spawning at one site and yet spawning did not occur within Cork Harbour stock despite a higher temperature regime. The Cork Harbour oysters reached ripeness and then started a process of gametic resorption. This lack of spawning was not attributed to the monitored levels of temperature, dissolved oxygen and chlorophyll but was tentatively attributed to levels of pollutants in the water. Oyster condition in Cork Harbour was significantly affected by the presence of blistering due to tributyltin (TBT) levels in the water and also by *Polydora* sp. Infestation in the shell.

In addition to the potential impact of TBT upon adult development this highly toxic molluscicide has also been shown to kill and deform Pacific oyster larvae thus reducing recruitment potential. Champ and Seligman (1996) included a report of the impact of TBT levels on Pacific oyster larvae from both field observations and tank experiments. Following the introduction in 1971 of the Pacific oyster to the Arachon basin in south west France there followed a number of years with significant wild settlement within this warm semi-enclosed bay where summer temperatures regularly exceed 22 ºC. From 1976 to 1981 however there was greatly reduced settlement or spat failure along with depressed growth rates and shell thickening – classic signs of TBT contamination. This change in oyster settlement and growth occurred at the same time as an observed increase in the number of pleasure craft. Tank studies showed that at concentrations above 20ng/l TBT the majority of Pacific oyster larvae died within 14 days with the rate of abnormalities also correlating to concentration. Following the implementation of a TBT ban within France in 1982 conditions recovered in oyster settlement and growth to previous levels (MARLAB, 2004).

In the UK the EA reports of monitoring of marine waters show a significant reduction in the number of sites exceeding the 2ng/l Sn Environmental Quality Standard since the ban on TBT use on vessels under 25m in 1987. Biological indicators such as the occurrence of imposex in the dog whelk *Nucella lapillus* have also demonstrated a reduction in impact of TBT following the ban.

Many oyster fisheries have traditionally been close to ports and areas with high levels of vessel operation and known levels of TBT contamination (e.g. Thames estuary, Carrick Roads). With the banning of the use of TBT antifouling on smaller vessels and Integrated Pollution Controls on some of the larger shipyards, environmental levels of this contaminant have been significantly reduced in recent years. It is likely that historically Pacific oyster recruitment may therefore have been retarded in some contaminated areas by TBT and that improved water quality is therefore removing this limitation on wild settlement and development.

2.2.2.4 Biological resource debt: Child and Laing (1998) showed that although the Pacific oyster was able to feed and assimilate food at 6 ^{o}C and 9 ^{o}C it underwent loss of body mass in the form of metabolised protein at 3 ^{o}C. In consequence, prolonged winter exposure below this point would lead to loss of body mass and a loss of biological reserves. Shellfish need to boost their biological reserves in the spring prior to spawning as gametogenesis and subsequent conditioning require considerable energy resources. It is therefore probable that exceptionally cold winters in cold regions (such as North Sea coasts) could leave a resource debt that will need to be replaced prior to conditioning. Such debt repayment would delay reproductive timing. The degree day methodology takes no account of cold winter resource debt. All of the North East England and South East England monitoring sites studied exhibited winter temperatures below 6 ^{o}C and may have incurred some biological debt. All other sites in England and Wales had winter temperatures that were generally above 6 ^{o}C.

Despite the presence of a number of factors which can reduce the risk of recruitment, temperature remains a good technique for a conservative risk assessment by providing an area based ‘potential’. There may be a case for site specific mitigation due to local factors, e.g. micro-climate/environment variations, however temperature regime should be viewed as an easy to use and practical initial screening tool.

2.2.3 Acclimatisation;

The ability to acclimatise is of relevance to mortality, growth rates and ultimately reproductive performance. There is some evidence to indicate that the Pacific oyster may acclimatise to withstand higher temperature conditions. Rajagopal *et al.* (2005) studied mortality in cooling systems in relation to thermal treatment to remove fouling which proved ineffective against the Pacific oyster. The workers indicated that previous exposure to sub-lethal high temperatures could make the Pacific oyster more resistant to subsequent thermal treatment.

Differential conditioning of wild stock is a big concern in the study of Pacific oyster acclimatisation. Genetic variation within any population will allow some individuals to condition more rapidly than others. An increased potential for spawning from individuals which more readily condition could favour such stock in a cold environment leading to genetic ‘drift’. However, in a culture setting where stock is maintained and induced in a controlled hatchery environment no such drift should be possible. Data from other molluscan species has shown that acclimatisation and early spawning can be achieved on a *phenotypic* rather than *genotypic* basis (Nova Mieszkowska, pers. comm.) This means that spawning potential can be raised in the life of the animal rather than over many generations of natural selection. If this can be demonstrated then old mature wild stock may pose a higher level of risk in terms of wild settlement than cultured stock.

There is mounting evidence to suggest that wild oysters can develop reproductive adaptation. Cardoso *et al.* (2007) compared spatial patterns of wild oyster development between Bordeaux in France and two sites off the Netherlands coast (Oosterschelde estuary and Texel in the Wadden Sea). This study found that larger gonads with smaller eggs were produced in the northern sites whilst the more southern site exhibited lower production of markedly larger eggs. In addition to a greatly increased egg production for the Wadden Sea sites this also suggests that as the smaller eggs are likely to require a longer development phase then this may lead to the possibility of a wider dispersal range. The Bordeaux site exhibited a temperature regime similar to South West England whilst the Wadden Sea site had a temperature profile closer to that of South East England. It is possible that a similar gradient of reproductive potential exists in the UK. However, temperature is not the only feature that will influence reproductive potential and Cardoso *et al.* (2007) discusses other factors, such as food availability, which would complicate a simple relationship between conditioning and latitude.

The potential for acclimatisation is currently being studied by a number of workers in the UK (Claire Guy; Nova Mieszkowska; Liz Cook, pers. comm.) This area of work is clearly of high importance as this phenomenon could raise the level of risk posed by wild stocks. It is therefore recommended that research on acclimatisation of spawning potential is closely reviewed and the findings incorporated into any further developments of the POP.

2.2.4 Summer Mortality;

The temperature regime and gonad conditioning are also linked with 'summer mortality' a complex phenomena in which a number of bivalve species may suffer significant mass mortality events in the summer often immediately prior, or subsequent, to spawning. It is possible that increasing summer temperatures may give rise to more significant summer mortalities of both cultured and wild Pacific oyster stocks. Reports regarding wild settlement in North Kent have indicated periods of Pacific oyster mass mortality (Willie McKnight, pers. comm.) suggesting that wild stock may still be susceptible.

Soletchnik *et al.* (2005) studied a range of oyster condition and environmental parameters within the Marennes–Oléron bay associated with x4 culture conditions 'on bed' against 'off bed' (trestles) and 'high' exposure against 'low' exposure. In this case the highest mortality (25%) was associated with 'on bed' culture and prior to spawning (June-July). This was not attributed directly to spawning although reduced food availability at times when oysters were preparing for spawning was thought to be a contributory factor.

Soletchnik *et al.* (2007) studied a number of French sites using long-term data sets and observations of mortality to try and assess patterns of mortality against environmental variables. The study showed that there was variation in the mortality related associations for Year 1 and Year 2 oysters and that there were strong inter-annual and regional patterns in related environmental parameters. Chlorophyll *a* content and temperature were two of the principal components that give rise to variation in mortality with other features including salinity and turbidity.

Whilst summer mortality may impact upon the Pacific oyster it should be noted that many other bivalve species also suffer in a similar fashion. Myrand *et al.* (2000) studied blue mussel summer mortality in the Gulf of St Lawrence. This study showed that significant summer mortality events were suffered between July and September with losses of up to 65%. These events occurred after spawning and when temperatures had reached 20 ^{o}C. In this case temperature was highly significant with the mortality event confined to mussels cultured in a shallow lagoon, whilst culture of the same stock in deeper cooler offshore waters suffered no loss.

The adaptability of bivalve species to high summer temperatures and resistance to phenomena such as summer mortality could be a key feature in the relative performance of potentially competing species. It is possible that summer mortality may exert natural selection on wild spatfalls of Pacific oysters providing more hardy strains better able to cope with higher temperatures and resisting further summer mortality events. Indeed recent work on summer mortality has focussed on the genetic link between mortality and specific family lines (Samain *et al*., 2007).

At the time of going to press, 2008 has seen a massive summer mortality event in France which has preferentially killed up to 100% of oysters under 50mm over a large section of the French coastline. This summer mortality event is reported to be the worst since the loss of the Portuguese oyster in 1970 (Liberation, 2008).

In summary, there are many factors which influence summer mortality events that make it hard to infer any climate change related trend. The inter-relationship between commercial species considered in Section 2.6 may not be a gradual transition favouring the Pacific oyster with global warming. It is possible that specific ‘events’ may lead to seismic shifts in population dynamics where one species can be radically reduced whilst other more hardy, resilient and adaptable species thrive. It is not possible to predict at this stage whether the UK Pacific oyster stock may suffer greater losses in the future as a result of global warming or whether these events may hit other species harder. It is recommended that a watching brief on summer mortality events is maintained with respect to the relative impact of these events on differing commercial species and in order to help evaluate how climate change in the UK may alter the incidence of these events.

2.3 Data Sources and Working Groups

2.3.1 Introduction;

There are a range of temperature data sources and groups working with various aspects of metrological, oceanographic and climate change analysis.

Table 7 provides a summary of some of the main groups and institutions.

Table 7. Summary of marine climate change working and data collection bodies

Group	Summary
The Marine Environmental Change Network (MECN)	Use of long-term marine environmental data to separate natural fluctuations from anthropogenic impacts
Marine Climate Change Impacts Partnership (MCCIP)	Co-ordinated advice on climate change impacts around our coast and in our seas
UK Climate Impacts Programme (UKCIP)	Partnership between public, private and voluntary sectors to assess how a changing climate will affect all aspects of life. National lead with regional delivery groups
The Met Office & Hadley Centre	Provides a focus in the UK for the scientific issues associated with climate change
The Natural Environment Research Council (NERC) Earth Observation Data Acquisition and Analysis Service (NEODAAS)	Satellite data to support UK research scientists with remote sensing data and information

2.3.2 Marine Environmental Change Network (MECN);

The Marine Environmental Change Network (MECN) is a collaboration between organisations in England, Scotland, Wales, Isle of Man and Northern Ireland collecting long-term time series information for marine waters. http://www.mba.ac.uk/MECN/

MECN is coordinated by the Marine Biological Association of the UK (MBA) and is funded by the Department of the Environment, Food and Rural Affairs (DEFRA). Participants include the Dove Laboratory who maintain the Port Erin observatory and the Plymouth Marine Laboratory who maintain the Western Channel Observatory. These long-term data sets include collection of biological data which can be valuable indicators of climate change.

MarClim (now housed under MBA) was a four year multi-partner funded project created to investigate the effects of climatic warming on marine biodiversity (http://www.mba.ac.uk/marclim/index.php?sec=info). Nova Mieszkowska was a key participant in MarClim and now works within the MECN at Plymouth MBA and is undertaking a project on Pacific oyster conditioning (see Appendix 1). The MBA undertakes a range of monitoring activities which tend to be focused on more pristine open coastal sites and therefore may miss 'local' anthropogenic effects within estuaries which tend to be the key area where Pacific oyster culture occurs.

Agri-food and Biosciences Institute, Northern Ireland, (AFBI) are a partnership group within MECN that undertake buoy monitoring from a number of sites in Northern Ireland as shown in Figure 3.

Figure 3. AFBI coastal monitoring buoys
http://www.afbini.gov.uk/index/services/specialist-advice/coastal-monitoring/monitored-sites.htm

Although the Irish Sea monitoring point has data available from 1993 many of the Northern Irish inshore monitoring points only have data from more recent years. Graphical temperature data can be viewed on the APFI website from 2002 to date, however, digital data output will require additional time for retrieval (Matthew Service, pers. comm.) and could not be performed within the current study. Visual assessment of the most recent years output shows that the monitoring points placed within embayments such as Strangford Lough, Carlingford Lough and Lough Foyle experience summer temperatures notably warmer than offshore sites.

2.3.3 Marine Climate Change Impacts Partnership (MCCIP);

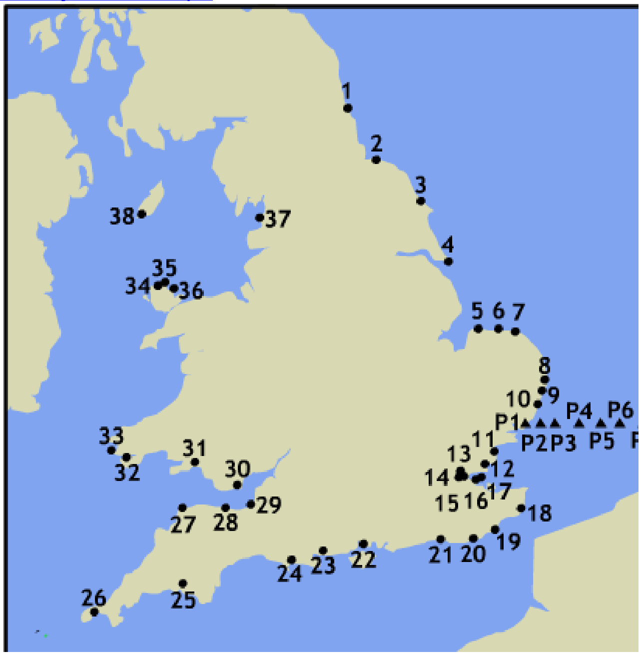
The United Kingdom Marine Climate Change Impacts Partnership (MCCIP) brings together scientists, government, its agencies and NGOs to provide co-ordinated advice on climate change impacts around our coast and in our seas.

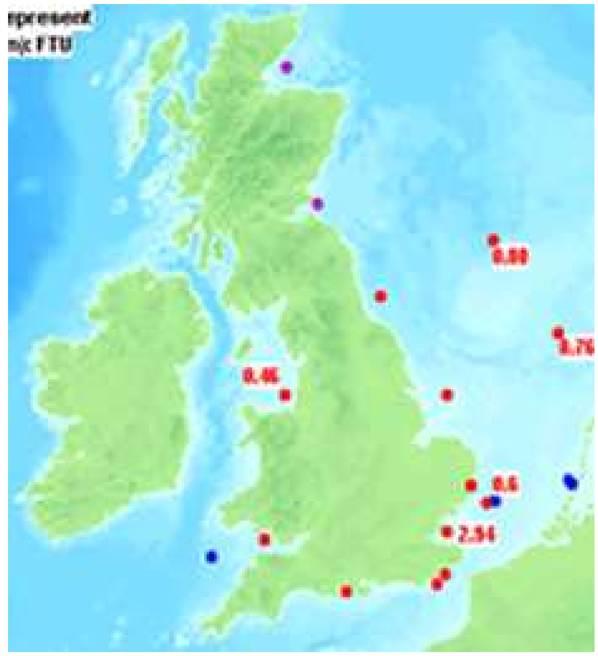
The primary aim of MCCIP is to provide a co-ordinating framework within the UK for the transfer of high-quality marine climate change impacts evidence and advice to policy advisors and decision-makers. In particular, the Partnership acts as the primary focus for the supply of evidence and advice to partners to enable them to individually and collectively plan for the challenges and opportunities presented by the impacts of climate change in the marine environment.

The MCCIP Secretariat is based at CEFAS Lowestoft and has provided access to the Coastal Temperature Network and the Smartbuoy network as shown in Figure 4 overleaf.

Figure 4. CEFAS supported marine temperature collection programmes

Coastal Temperature Network	**Smartbuoy**
http://www.cefas.co.uk/data/sea-temperature-and-salinity-trends.aspx	http://www.cefas.co.uk/data/marine-monitoring.aspx





The inshore Coastal Temperature Network has been the primary source of data used in this report within Section 2.4.

The work of the MCCIP is well summarised in a series of Annual Report Cards which summarise marine climate impacts. The 2007–2008 Annual Report Card is available on: http://www.mccip.org.uk/arc/2007/PDF/ARC2007.pdf

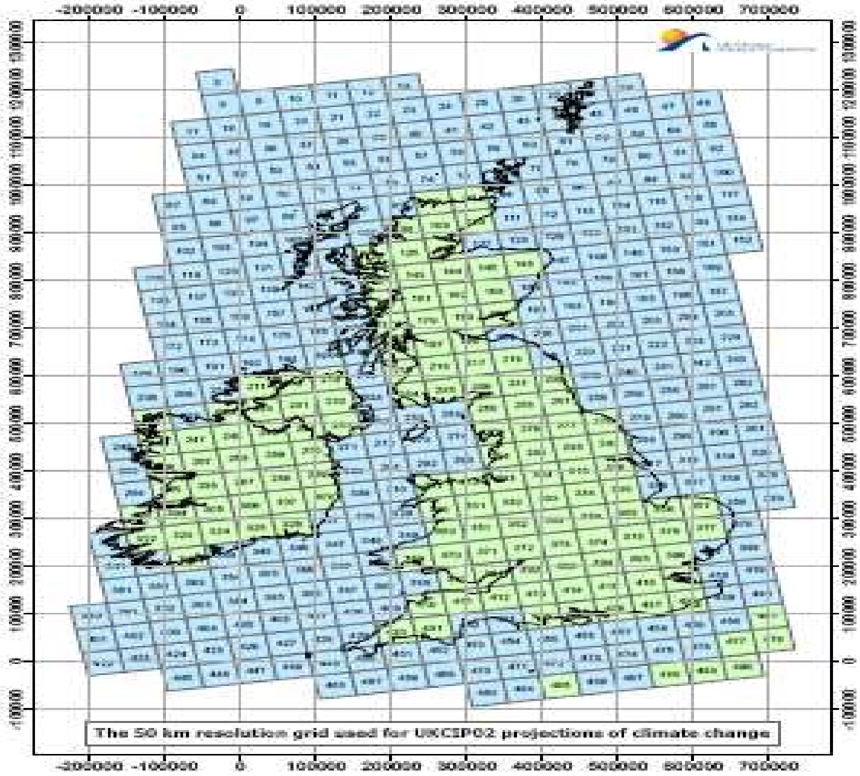
2.3.4 UK Climate Impacts Programme (UKCIP);

The UK Climate Impacts Programme (UKCIP) is a DEFRA funded program to provide a framework for regional assessments of local climate change impact through a number of regional stakeholder partnerships. Each regional partnership has produced their own local strategy for a range of climate change consequences to both the natural environment and various aspects of society. An overview of these plans can be found on:
http://www.ukcip.org.uk/index.php?option=com_content&task=view&id=76&Itemid=189

These regional plans use climate change predictions (see Figure 5) to assess regional temperature changes some of which have been reviewed in Section 2.4. The essential thrust of the UKCIP strategy is upon adaptation with the aim of managing change, minimising threats and maximising opportunities. For example, SWCCIP (2003) reporting on impact in South West England highlights the potential threat to biodiversity yet ironically presents the "potential to farm more 'exotic' fish species" as an opportunity. This suggests a more engaging approach towards non-natives and change than that presented by current legislation.

Local policy strategy is strongly informed by UKCIP support to ongoing model revision. Regional reports are based on either UKCIP98 or UKCIP02 depending on the date of publishing. This national model output is nested within the Hadley model HadCM2.

Figure 5. 50km UKCIP02 grid for climate change predictions



UKCIP08 is due to be released in the autumn 2008 and will include marine projections of sub-surface marine variables (such as water temperature and salinity) at several water depths. These are expected to be available for each 12km x 12km marine grid square for a single future scenario of greenhouse gas emissions (labelled Medium) for the period 2010 to 2099. Marine projections will be based on the results from the Proudman Oceanographic Laboratory POLCOMS model, which is being used to provide a three-dimensional hydro-dynamical simulation of the shelf seas around the UK with support from Plymouth Marine Laboratory.

2.3.5 Met Office and Hadley Centre;

The Met Office and the Hadley Centre are focussed upon historical measurement programmes with weather forecasting and climate change predictions respectively. In practice many of the programmes and data sources become inter-woven as future models are based upon our knowledge of systems and past conditions. For example Sea Surface Temperatures (SSTs) can be obtained by the Met Office from:

- Marine Automatic Weather Stations (MAWS) http://www.ncof.co.uk/Marine-Automatic-Weather-Station-Network.html

- Satellite imagery from the Along Track Scanning Radiometer (ASTR) http://www.metoffice.gov.uk/research/nwp/satellite/imagery/sst.html

- Model SST's output is archived from the two NCOF Shelf Seas models. The Atlantic Margin Model (AMM) is a 12km resolution model and has been archived since 2000. The Medium Resolution Continental Shelf Model (MRCS) is a 6km resolution, but the archive is only 3 years. http://www.ncof.co.uk/Coastal-Seas-Modelling.html

The MAWS buoys help ground-truth the ASTR values to convert the satellite 'skin' temperature measurements to more representative 'bulk' measurements. Between the two systems the Met Office can provide good spatial and temporal SST data around the UK from the late 1980s. Validated output can be obtained on a daily, weekly or monthly basis. This data helps build the Hadley Centres sea surface temperature model 'HadISST1' which is used to nest the smaller regional models mentioned above.

Outline discussions have been made with the Met Office regarding data availability although it is apparent that data from certain sources are only available on a commercial basis (Adam Leonard-Williams, pers. comm.).

The Hadley Centre also hosts the Technical Support Unit (TSU) for the IPCC (International Panel on Climate Change) Working Group II (WGII). WGII assesses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and options for adapting to it. Section 2.6 provides recommendations for a UK wide climate change shellfisheries impact study. The TSU WGII might provide valuable input or links to appropriate regional studies.

2.3.6 NEODAAS;

The Natural Environment Research Council (NERC) Earth Observation Data Acquisition and Analysis Service (NEODAAS) is funded by NERC to support UK research scientists by providing remote sensing data and information. This service is hosted at 2 sites: data processing is provided by the Remote Sensing Group at the Plymouth Marine Laboratory; data reception and acquisition is provided by the Dundee Satellite Receiving Station at the University of Dundee. NEODAAS processes the output from a number of polar orbiting sensors including MERIS (providing primary productivity output), SeaWiFS (providing turbidity output), MERIS (providing water radiance) and AVHRR (providing atmospheric processes and sea surface temperature output).

2.3.7 Summary;

There are comprehensive data sets available, and several study groups looking at, both offshore and terrestrial temperatures with climate change predictions. However, there are no readily accessible data sources to provide a definitive temperature regime for the inshore waters where Pacific oysters are cultivated. These sites are transitional waters mid-way between offshore Sea Surface Temperatures (SSTs) and terrestrial temperatures. Clearly deeper culture sites in a well flushed water body may better reflect offshore temperatures, whilst a shallow inter-tidal culture site with large drying tidal mudflats may more closely reflect terrestrial temperatures.

This study has used available inshore long-term data sets and predictions with caveats and it is suggested that these provide a good initial screening of regional and temporal risk. However, a more robust methodology will be required in order to provide an increased level of confidence with regard to the application of this technique to actual shellfish culture sites.

It is recommended that a number of actions could be undertaken to better assess the risk of wild recruitment:

1) A more comprehensive assessment of the regional historical temperature changes since the late 1980s could be obtained using available satellite data. This has the advantage over the CEFAS Inshore Temperature Network used in this study of better spatial and temporal resolution which could provide meaningful data to offshore sites close to culture areas.

2) Site specific measurements at culture locations could allow generation of local ‘ground truthing’ exposure factors between the nearby offshore data (see Point 1 above) and adjacent Met Office terrestrial data. A rough estimate of the costs involved gave a capital cost of less than £5K for 25 robust temperature mini-loggers that could be used over 5 years to obtain exposure factors for all registered UK shellfish beds.

3) UKCIP08 will shortly provide high resolution marine and terrestrial grid climate change predictions for the UK. These can be applied locally using the site specific factor derived in Point 2 above.

2.4 Regional Temperature Profiles

2.4.1 Temperature Calculations for Conditioning and Recruitment;

The temperature related factors considered in Section 2.2.1 have been used in the following section to derive factors for 'conditioning', 'spawning' and 'recruitment' potentials. It is suggested that the temperature requirements for each of these stages in reproduction can be used as thresholds to measure potential risk.

These reproductive events are defined in Table 8 below.

Table 8. Pacific oyster temperature biological thresholds in degree days

Stage	Threshold Criteria
Conditioning Potential	600 degree days *(Note 1)*
Spawning Potential	600 degree days attained by July to September *(Note 2)*
Recruitment Potential	825 degree days *(Note 3)*
High Recruitment Potential	825 degree days attained by July to September *(Note 4)*

Note 1: Using 10.55 ^{o}C biological zero (See Section 2.2, Table 5)
Note 2: Jul.-Sep. assumed trigger of >18 ^{o}C
Note 3: 600 + 225 degree days. Using 10.55 ^{o}C biological zero (See Section 2.2, Table 6)
Note 4: Jul.-Sep. assumed temperature >15 ^{o}C to allow high rate larval development

The methodology outlined in Table 8 above is intended to provide guidelines and not definitive limits as even hatchery populations are subject to variation in each life stage. The complexities of the multiple parameters in the natural environment will further compound the level of scatter in reproductive potential.

Historical temperature data used in this section have been derived from selected stations from the CEFAS Coastal Temperature Monitoring Network (see MCCIP details in Section 2.3.3). Predicted temperature data used have been based on the MCCIP 2007 Action Report Card output.

The CEFAS Coastal Monitoring stations used throughout this section are not necessarily located in shellfish waters and are intended for illustration of a theoretical 'potential' if shellfish were to be cultivated at this point. In reality individual shellfish waters will vary on a site specific basis. It is probable that some intertidal and shallow water sites will have experienced an even warmer summer profile as they are subject to greater terrestrial warming – however, other hydrodynamic and nutritional factors will influence actual recruitment and retard or even prevent development as considered in Section 2.2.2.

2.4.2 Regional Temperature Variation;

The impact of regional temperature regime upon the success of Pacific oyster culture has long been recognised from a growth potential aspect. Spencer (1990) provided a regional overview of temperatures for the UK (Table 9 below). These temperature data have been used to calculate degree days and reproductive potential in the same fashion as described in the previous section. The six months of highest summer temperatures (May to October) are used to obtain monthly degree days which are aggregated to provide a cumulative degree day total for the whole summer. Conditioning ("C"), Spawning ("S") and Recruitment ("R") potentials are also depicted.

Table 9. Regional temperature variation and Pacific oyster conditioning (Source: Spencer, 1990)

Mean Temperature ^{o}C

Area	May	June	Jul.	Aug.	Sep.	Oct.
Loch Spelve (Mull)	8.4	9.9	11.2	12.2	12.2	11.8
Loch Sween	9.5	11.3	12.5	14.2	13.6	12.1
Loch Mhuirich	10.5	13	16	16.1	15.6	13.2
Brancaster	11.6	15.2	17.2	17.9	15.4	11.9
River Crouch	12.5	16.3	18.8	18.5	16.2	12.5
Poole	12.4	15.8	18.1	18.0	15.8	12.6
Teignmouth	11.2	13.7	16.2	16.7	16.2	13.7
Milford Haven	11.0	14.1	15.4	16.2	16.0	14.5
Menai Straits	10.9	13.7	15.8	16.6	15.2	12.6
Inland Sea(Anglesey)	14.6	15.8	15.9	16.2	14.1	12.7

Monthly Degree Days (Note: using 10.55 ^{o}C gametogenesis biological zero)

Area	May	June	Jul.	Aug.	Sep.	Oct.
Loch Spelve (Mull)			20	51	51	39
Loch Sween		23	60	113	95	48
Loch Mhuirich		74	169	172	157	82
Brancaster	33	140	206	228	150	42
River Crouch	60	173	256	246	175	60
Poole	57	158	234	231	163	64
Teignmouth	20	95	175	191	175	98
Milford Haven	14	107	150	175	169	122
Menai Straits	11	95	163	188	144	64
Inland Sea(Anglesey)	126	158	166	175	110	67

Cumulative Annual Degree Days

Area	May	June	Jul.	Aug.	Sep.	Oct.	C?	S?	R?
							Note 1		
Loch Spelve (Mull)			20	71	122	161			
Loch Sween		23	83	196	291	339			
Loch Mhuirich		74	242	415	571	653	y		
Brancaster	33	172	378	606	756	798	y	y	
River Crouch	60	233	489	735	910	971	y	y	y
Poole	57	215	449	680	843	906	y	y	y
Teignmouth	20	115	290	480	656	753	y	y	
Milford Haven	14	120	271	446	615	737	y	y	
Menai Straits	11	105	268	456	600	663	y	y	
Inland Sea(Anglesey)	126	283	449	624	734	801	y	y	

Note 1: C = 'Conditioning' considered as 600 degree days / S = 'Spawning' considered after 'C' with trigger temps in Jul.-Sep. / R = 'Recruitment' considered if >825 degree days.

Table 9 shows that for the UK regional temperature regimes considered by MAFF prior to 1990 there was little reason for concern with respect to wild Pacific oyster spat settlement for most sites. Scottish conditions were sufficiently cool that in some areas the Pacific oyster was unlikely to even exceed the 600 degree days conditioning temperature. Even where this could theoretically occur conditioning would be attained so late in the season that temperatures would not exceed 18 ^{o}C to trigger spawning and gametes would be reabsorbed.

In much of England and Wales the temperature regime was sufficient to allow conditioning and spawning but there were insufficient degree days for larval recruitment - even in shallow warmer inshore areas such as the Inland Sea on Anglesey. It should be noted that the temperature data in Table 9 are average data and it is therefore probable that the scatter of inter-annual variation could have provided some warmer years when limited spatfall may have occurred episodically at sites below the mean recruitment potential.

The River Crouch in South East England and Poole on the South coast were the only sites in the 1990 MAFF listing with a theoretical recruitment potential greater than 825 degree days. Furthermore, these sites exceeded the 'high recruitment potential' threshold as they would have attained the 825 degree days in September. This would have been early enough in the summer when temperatures were still above 15 ^{o}C to predict higher recruitment success (Section 2.2.1). However, the cold winter temperatures in this region may well have provided a 'biological debt' (Section 2.2.2) that could have delayed the onset of gametogenesis. Another possibility is that the presence of TBT at that time may have inhibited or slowed development. Overall the data in Table 9 suggests that prior to 1990 the potential for ongoing wild spatfall was limited and generally only existed in a few areas in warm years.

2.4.3 Regional Degree Day Assessments of Conditioning and Recruitment Potential – Tabular and Graphical Outputs;

- A more comprehensive analysis of these regional temperature trends using actual annual maximum annual degree day data are presented in Figures 6 to 11. These plots provide an indication of the 'Conditioning potential' and 'Recruitment potential' thresholds of 600 and 825 degree days respectively.

- The annual regional data is summarised in Tables 10 to 15.

- Maximum annual degree data has been used to calculate the 'Recruitment potential' which has been grouped regionally and averaged on a 10 year basis and presented in Figures 12 to 17.

- A regional appraisal of these results follows after the graphical output.

Figures 6, 7, 8, 9, 10, 11. Regional temperature trends for the UK based on historical data with indications of likely spawning and recruitment events with Pacific oysters (individual Figures shown respectively on the following two pages);

Figure 6. N.W. Eng. & N. Wales historical sea temp. regime with recruitment events

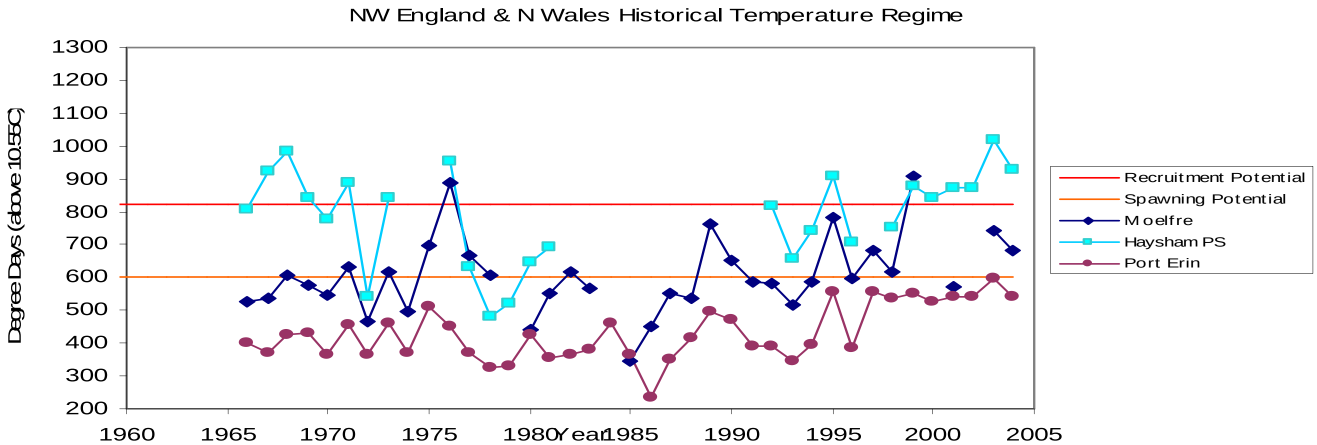


Figure 7. S. Wales & Bristol Chl. historical sea temp. regime with recruitment events

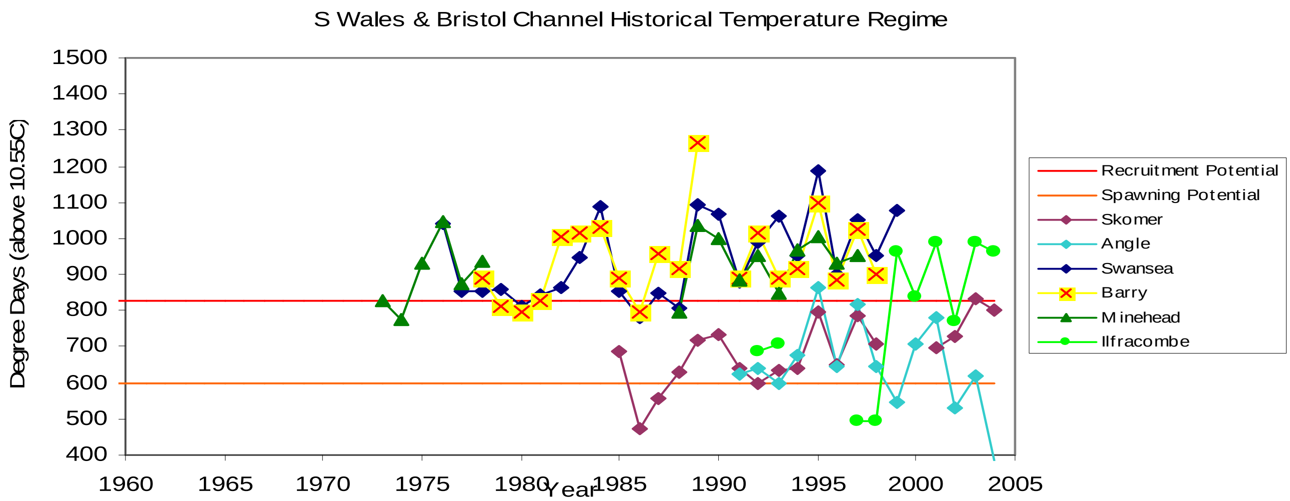


Figure 8. S.W. England historical sea temp. regime with recruitment events

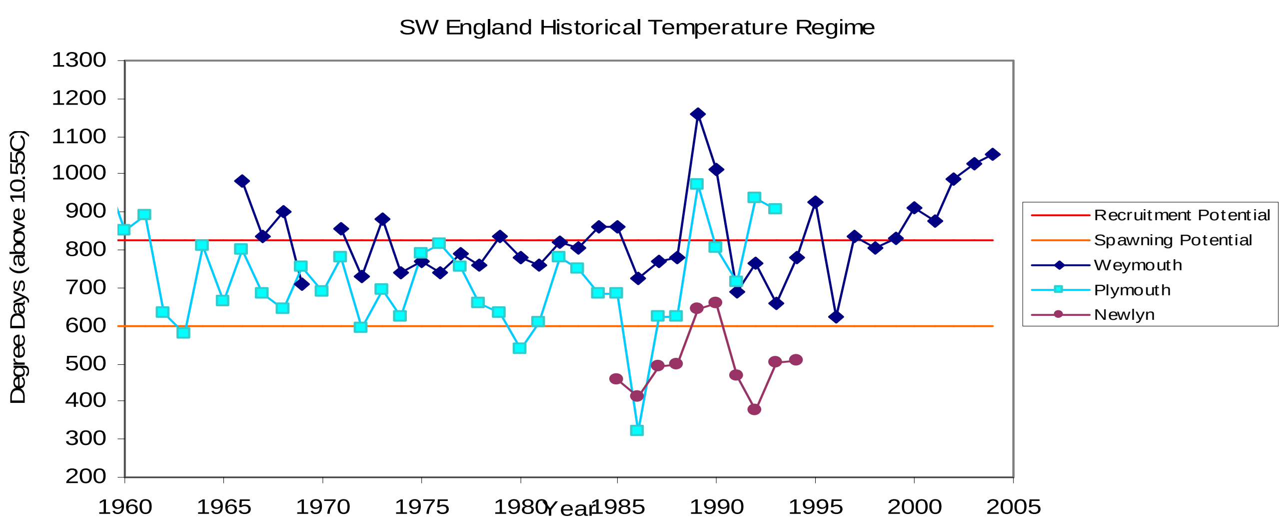


Figure 9. Southern England historical sea temp. regime with recruitment events

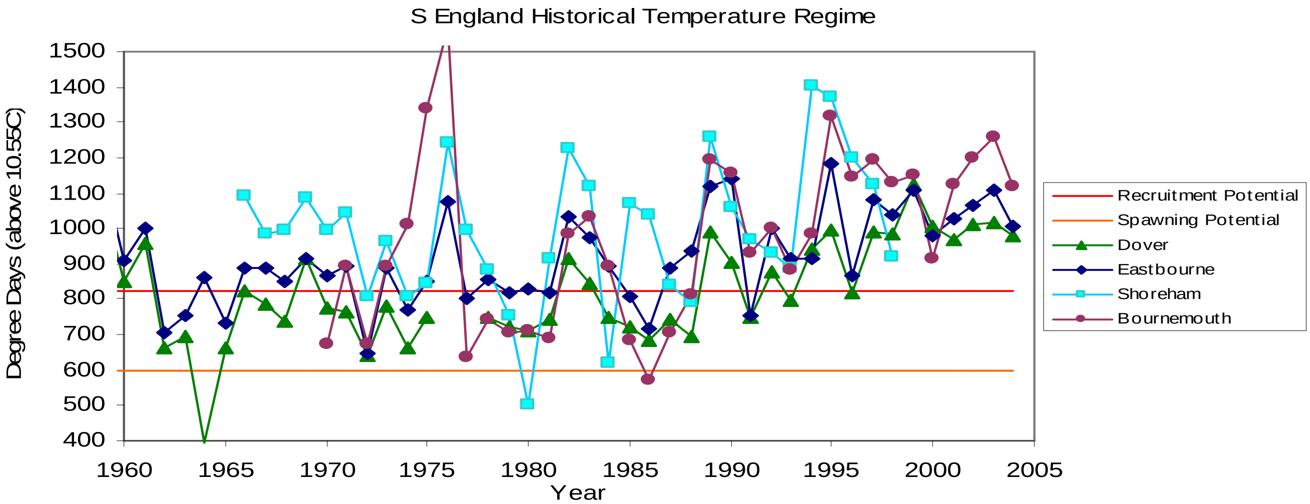


Figure 10. S.E. England historical sea temp. regime with recruitment events

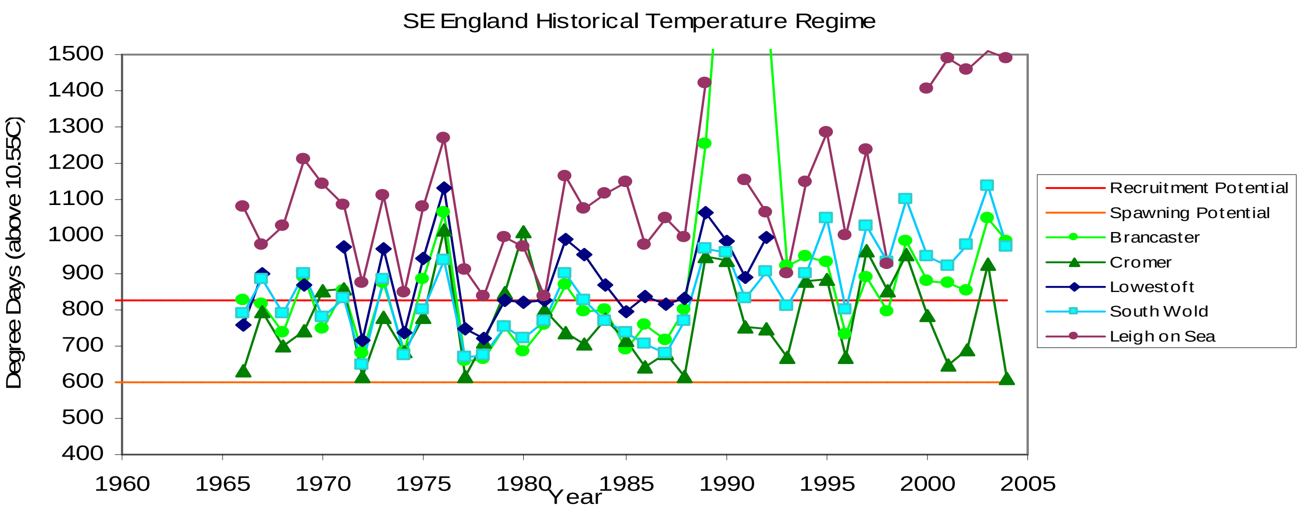


Figure *11. N.E. England historical sea temp. regime with recruitment events*

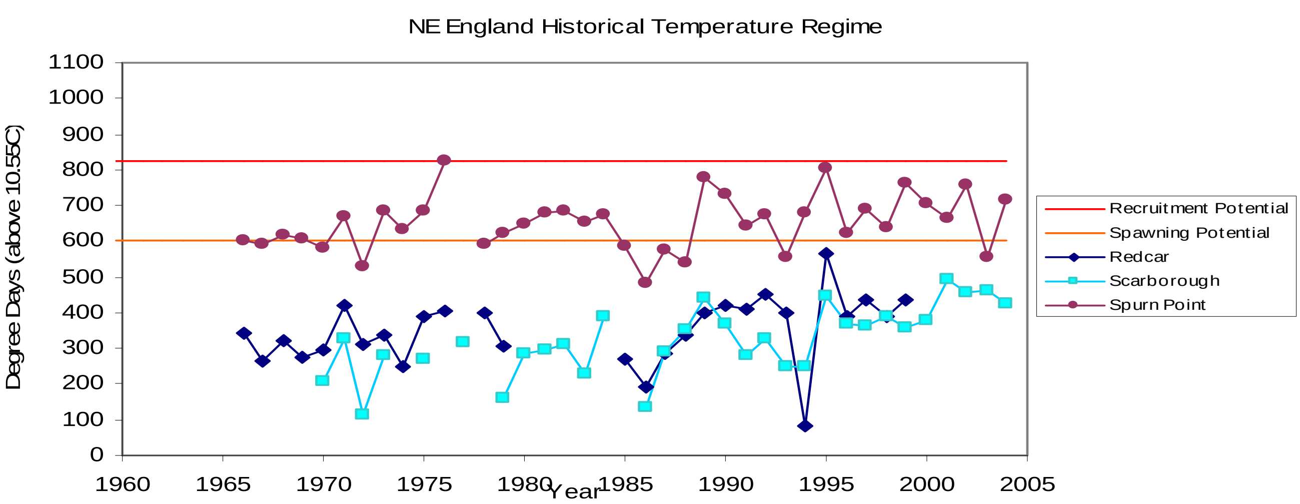


Table 10. Area: N.W. England, N. Wales & Irish Sea – regional data

Date Range *(1)*		1965-1974	1975-1984	1985-1994	1995-2004
Port Erin	Conditioning DD *(2)*	0%	0%	0%	0%
	Spawning Potential *(3)*	0%	0%	0%	0%
	Recruitment DD *(4)*				
	High Recruitment Pot. *(4)*	0%	0%	0%	0%
Haysham PS	Conditioning DD *(2)*	88%	67%		100%
	Spawning Potential *(3)*	88%	67%		100%
	Recruitment DD *(4)*	50%	17%		78%
	High Recruitment Pot. *(4)*	38%	17%		33%
Moelfre (Anglesey)	Conditioning DD *(2)*	33%	63%	20%	75%
	Spawning Potential *(3)*	0%	25%	10%	50%
	Recruitment DD *(4)*	0%	13%	0%	13%
	High Recruitment Pot. *(4)*	0%	0%	0%	0%

Note 1: Incidence rates calculated for 10yr range if >50% data return
Note 2: "Conditioning DD" if >600 Degree Days attained (above 10.55 ^{o}C biological zero)
Note 3: "Spawning Potential" if >600DD obtained in Jul./Aug./Sep. with temperatures above 18 ^{o}C trigger
Note 4: "Recruitment DD" of >825 Degree Days attained. "High pot." if attained in Jul./Aug./Sep. with temperatures above 15 ^{o}C

Figure 12. Area: N.W. England, N. Wales & Irish Sea – 'Recruitment Potential' based on a 10 year average of maximum annual degree day data

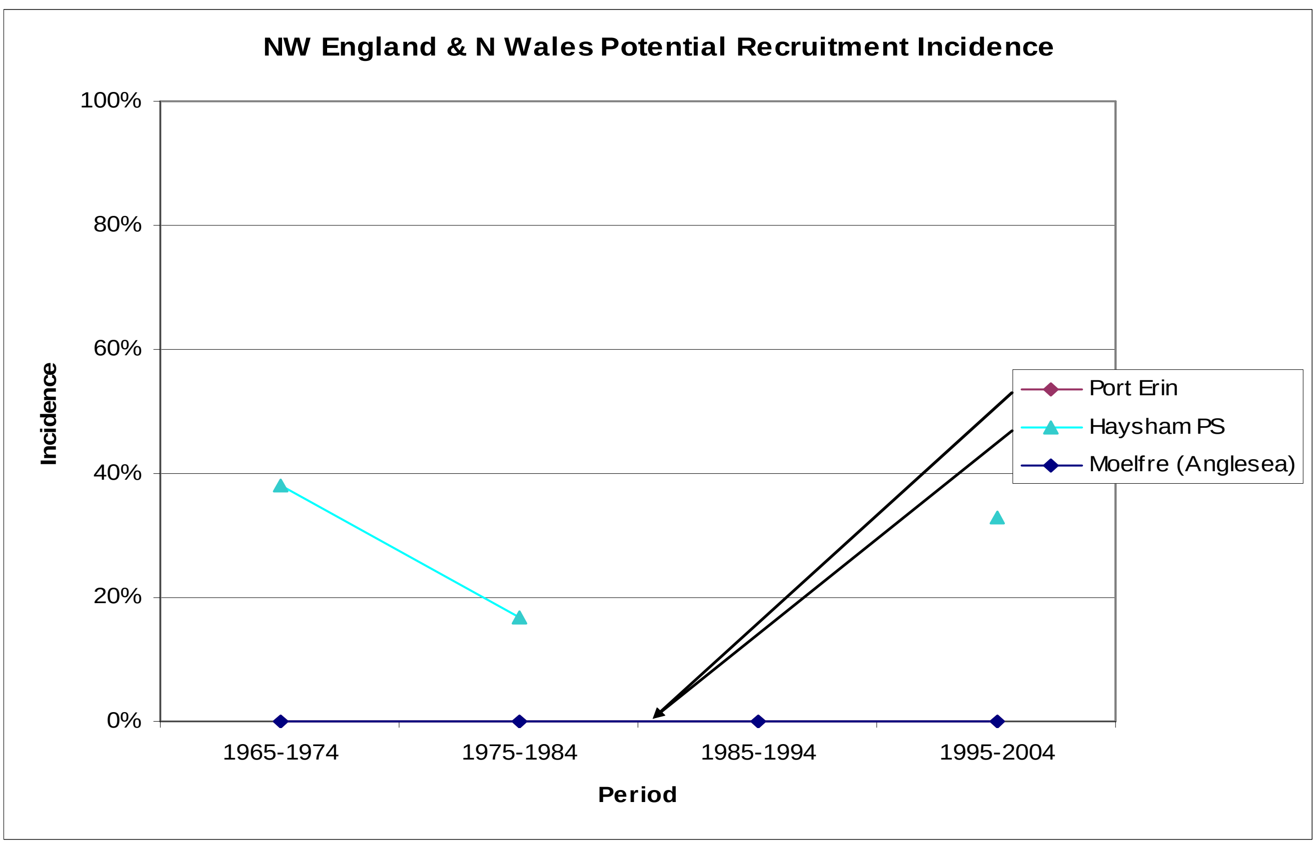


Table 11. Area: S. Wales and Bristol Channel - regional data

Date Range *(1)*		1965-1974	1975-1984	1985-1994	1995-2004
Skomer	Conditioning DD *(2)*			80%	100%
	Spawning Potential *(3)*			0%	0%
	Recruitment DD *(4)*			0%	0%
	High Recruitment Pot. *(4)*			0%	0%
Angle	Conditioning DD *(2)*			100%	70%
	Spawning Potential *(3)*			0%	40%
	Recruitment DD *(4)*			0%	0%
	High Recruitment Pot. *(4)*			0%	10%
Swansea	Conditioning DD *(2)*		100%	100%	100%
	Spawning Potential *(3)*		100%	100%	100%
	Recruitment DD *(4)*		67%	80%	100%
	High Recruitment Pot. *(4)*		22%	40%	80%
Barry	Conditioning DD *(2)*		100%	100%	
	Spawning Potential *(3)*		100%	100%	
	Recruitment DD *(4)*		57%	89%	
	High Recruitment Pot. *(4)*		43%	44%	
Minehead	Conditioning DD *(2)*		100%	100%	
	Spawning Potential *(3)*		100%	100%	
	Recruitment DD *(4)*		100%	86%	
	High Recruitment Pot. *(4)*		25%	57%	
Ilfracombe	Conditioning DD *(2)*				75%
	Spawning Potential *(3)*				75%
	Recruitment DD *(4)*				63%
	High Recruitment Pot. *(4)*				0%

Note 1: Incidence rates calculated for 10yr range if >50% data return

Note 2: "Conditioning DD" if >600 Degree Days attained (above 10.55 ^{o}C biological zero)

Note 3: "Spawning Potential" if >600DD obtained in Jul./Aug./Sep. with temperatures above 18 ^{o}C trigger

Note 4: "Recruitment DD" of >825 Degree Days attained. "High pot." if attained in Jul./Aug./Sep. with temp. above 15 ^{o}C

Figure 13. Area: S. Wales and Bristol Channel – 'Recruitment Potential' based on a 10 year average of maximum annual degree day data

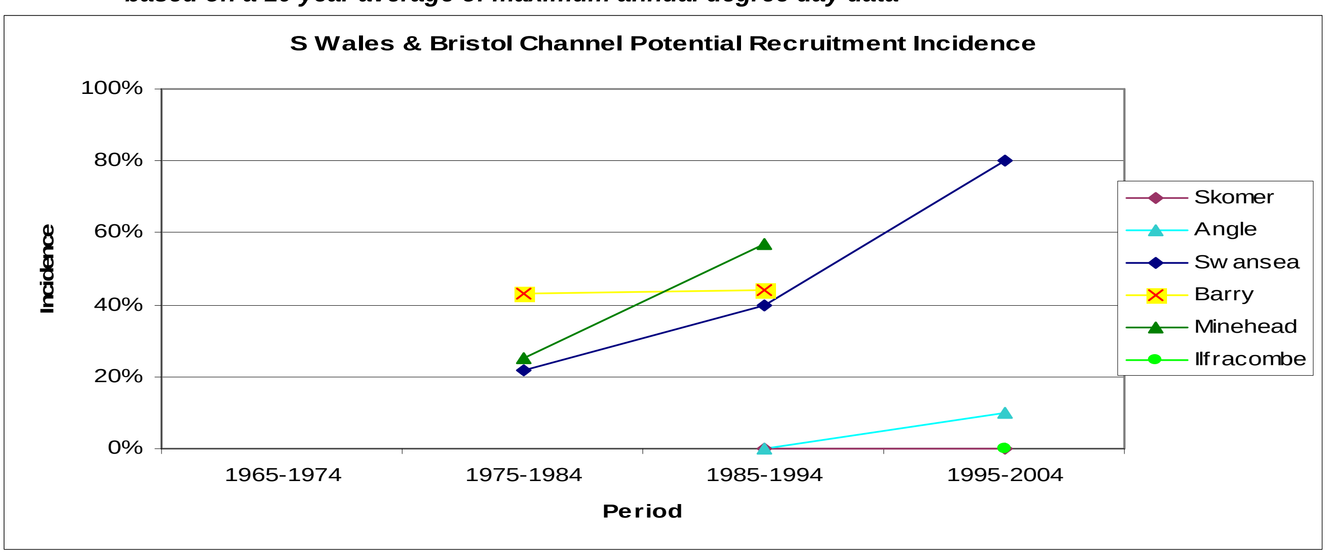


Table 12. Area: S.W. England – regional data

Date Range *(1)*		1965-1974	1975-1984	1985-1994	1995-2004
Newlyn	Conditioning DD *(2)*			20%	
	Spawning Potential *(3)*			0%	
	Recruitment DD *(4)*			0%	
	High Recruitment Pot. *(4)*			0%	
Plymouth	Conditioning DD *(2)*	90%	90%	89%	
	Spawning Potential *(3)*	10%	50%	44%	
	Recruitment DD *(4)*	0%	0%	33%	
	High Recruitment Pot. *(4)*	0%	0%	0%	
Weymouth	Conditioning DD *(2)*	100%	100%	100%	100%
	Spawning Potential *(3)*	75%	50%	60%	90%
	Recruitment DD *(4)*	63%	20%	30%	80%
	High Recruitment Pot. *(4)*	0%	0%	20%	20%

Note 1: Incidence rates calculated for 10yr range if >50% data return
Note 2: "Conditioning DD" if >600 Degree Days attained (above 10.55 ^{o}C biological zero)
Note 3: "Spawning Potential" if >600DD obtained in Jul./Aug./Sep. with temperatures above 18 ^{o}C trigger
Note 4: "Recruitment DD" of >825 Degree Days attained. "High pot." if attained in Jul./Aug./Sep. with temperatures above 15 ^{o}C

Figure 14. Area: S.W. England – 'Recruitment Potential' based on a 10 year average of maximum annual degree day data

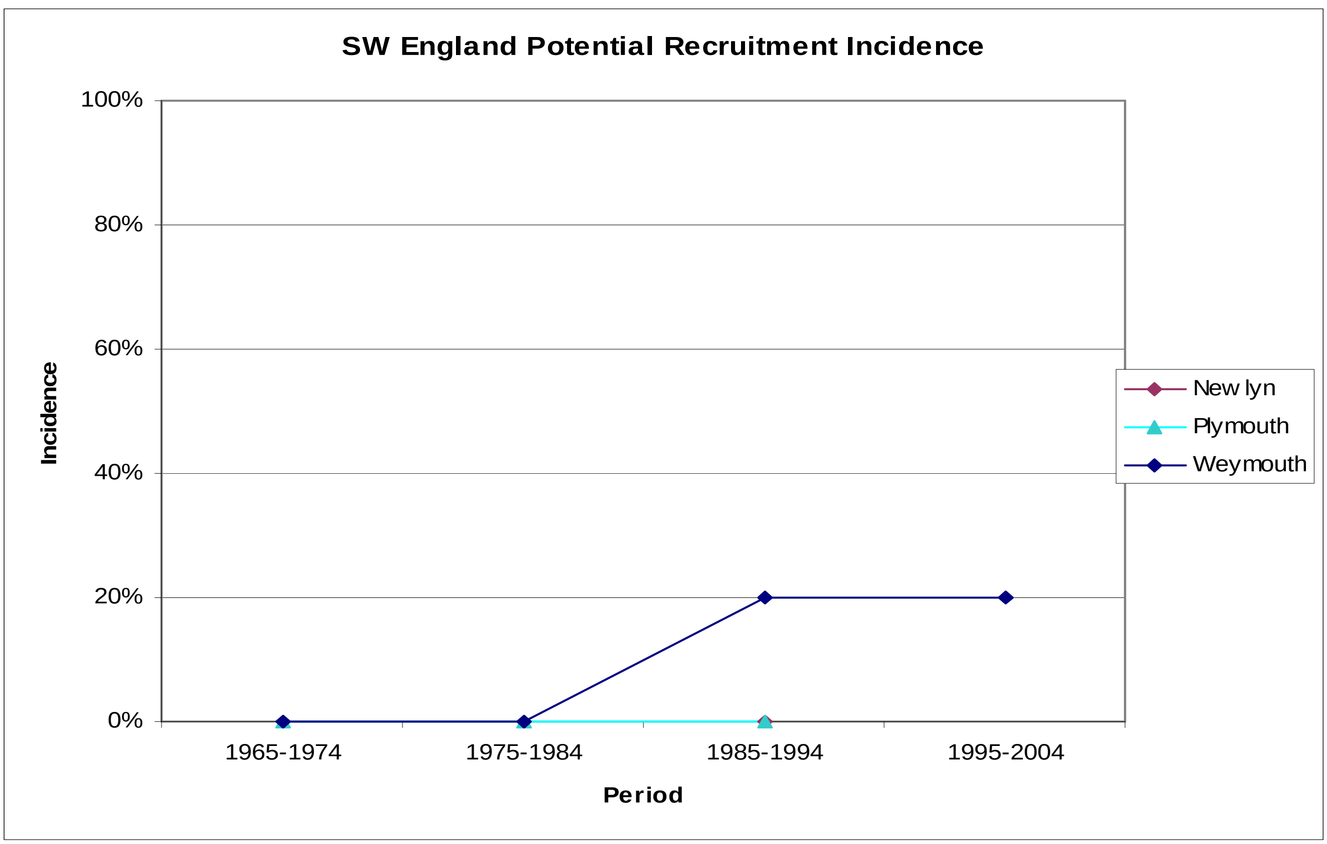


Table 13. Area: S. England – regional data

Date Range *(1)*		1965-1974	1975-1984	1985-1994	1995-2004
Bournemouth	Conditioning DD *(2)*	83%	100%	90%	100%
	Spawning Potential *(3)*	67%	90%	80%	100%
	Recruitment DD *(4)*	50%	50%	60%	100%
	High Recruitment Pot. *(4)*	17%	40%	20%	90%
Shoreham	Conditioning DD *(2)*	100%	90%	100%	100%
	Spawning Potential *(3)*	100%	80%	100%	100%
	Recruitment DD *(4)*	78%	70%	90%	100%
	High Recruitment Pot. *(4)*	78%	40%	70%	100%
Eastbourne	Conditioning DD *(2)*	100%	100%	100%	100%
	Spawning Potential *(3)*	90%	100%	90%	100%
	Recruitment DD *(4)*	70%	60%	79%	100%
	High Recruitment Pot. *(4)*	0%	30%	20%	90%
Dover	Conditioning DD *(2)*	100%	89%	100%	100%
	Spawning Potential *(3)*	70%	56%	70%	100%
	Recruitment DD *(4)*	10%	22%	40%	90%
	High Recruitment Pot. *(4)*	0%	0%	10%	30%

Note 1: Incidence rates calculated for 10yr range if >50% data return
Note 2: "Conditioning DD" if >600 Degree Days attained (above 10.55 ^{o}C biological zero)
Note 3: "Spawning Potential" if >600DD obtained in Jul/Aug/Sep with temp. above 18 ^{o}C triggers
Note 4: "Recruitment DD" of >825 Degree Days attained. "High pot." if attained in Jul./Aug./Sep. with temperatures above 15 ^{o}C

Figure 15. Area: S. England – 'Recruitment Potential' based on a 10 year average of maximum annual degree day data

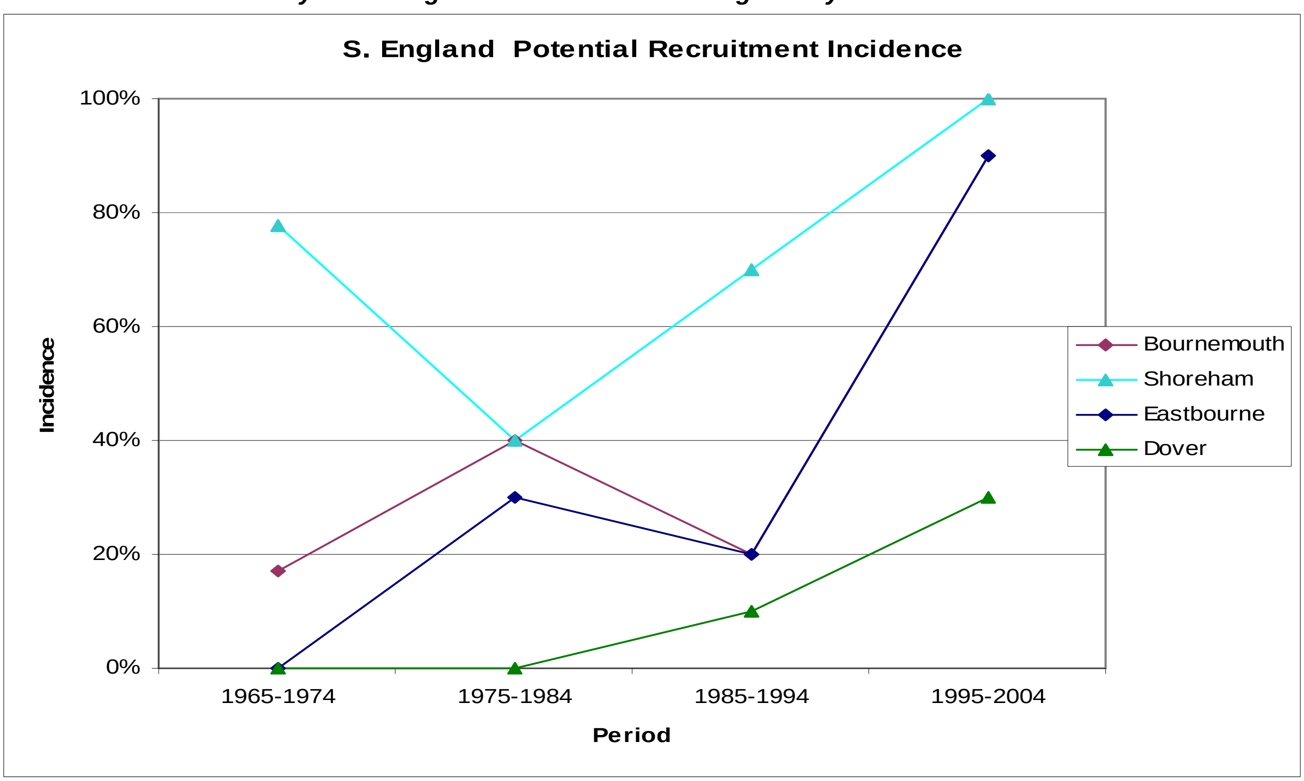


Table 14. Area: S.E. England – regional data

Date Range *(1)*		1965-1974	1975-1984	1985-1994	1995-2004
Leigh-on-Sea	Conditioning DD *(2)*	100%	100%	100%	100%
	Spawning Potential *(3)*	100%	100%	100%	100%
	Recruitment DD *(4)*	89%	90%	100%	100%
	High Recruitment Pot. *(4)*	56%	70%	89%	100%
South Wold	Conditioning DD *(2)*	100%	100%	100%	100%
	Spawning Potential *(3)*	100%	80%	100%	100%
	Recruitment DD *(4)*	44%	30%	50%	90%
	High Recruitment Pot. *(4)*	11%	10%	30%	80%
Lowestoft	Conditioning DD *(2)*	100%	100%	100%	
	Spawning Potential *(3)*	100%	100%	100%	
	Recruitment DD *(4)*	57%	70%	62%	
	High Recruitment Pot. *(4)*	29%	40%	38%	
Cromer	Conditioning DD *(2)*	100%	100%	100%	100%
	Spawning Potential *(3)*	78%	80%	90%	90%
	Recruitment DD *(4)*	22%	30%	30%	40%
	High Recruitment Pot. *(4)*	0%	10%	30%	30%
Brancaster	Conditioning DD *(2)*	100%	100%	100%	100%
	Spawning Potential *(3)*	100%	100%	100%	100%
	Recruitment DD *(4)*	33%	30%	60%	80%
	High Recruitment Pot. *(4)*	11%	30%	60%	60%

Note 1: Incidence rates calculated for 10yr range if >50% data return

Note 2: "Conditioning DD" if >600 Degree Days attained (above 10.55 °C biological zero)

Note 3: "Spawning Potential" if >600DD obtained in Jul./Aug./Sep. with temperatures above 18 °C trigger

Note 4: "Recruitment DD" of >825 Degree Days attained. "High pot." if attained in Jul./Aug./Sep. with temp. above 15 °C

Figure 16. Area: S.E. England – 'Recruitment Potential' based on a 10 year average of maximum annual degree day data

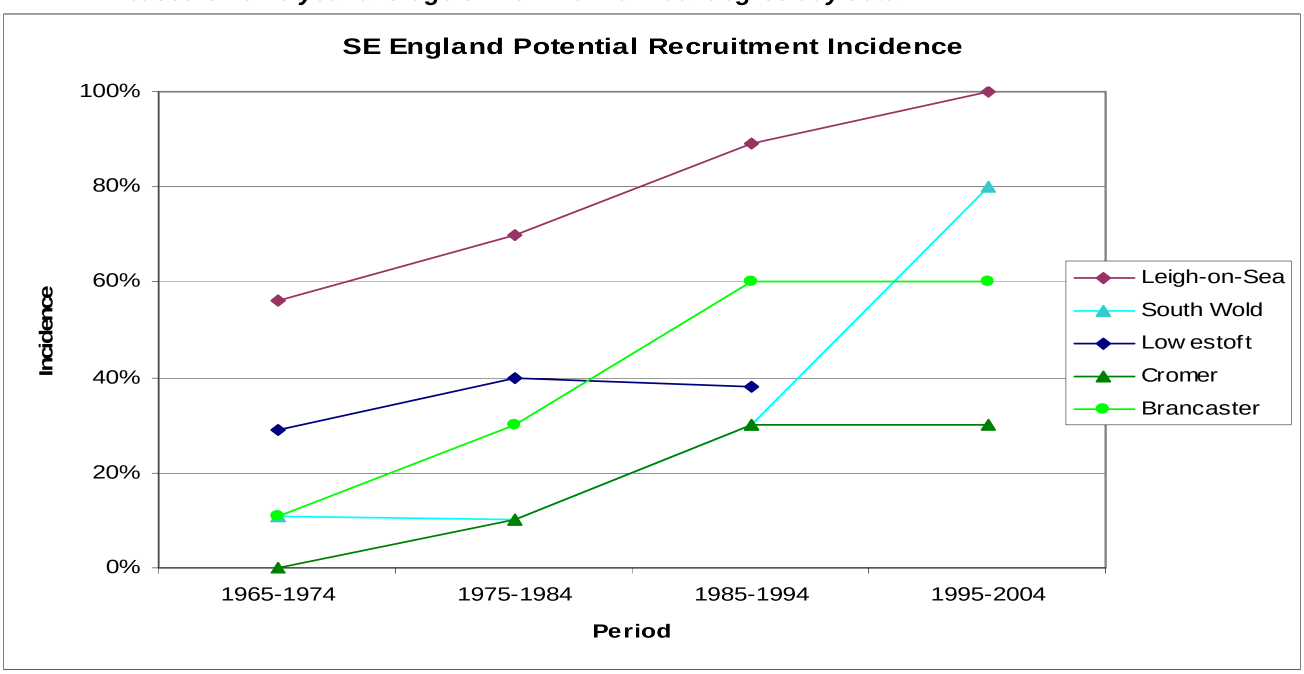


Table 15. Area: N.E England – regional data

Date Range *(1)*		1965-1974	1975-1984	1985-1994	1995-2004
Spurn Point	Conditioning DD *(2)*	67%	89%	50%	90%
	Spawning Potential *(3)*	22%	78%	50%	80%
	Recruitment DD *(4)*	0%	0%	0%	0%
	High Recruitment Pot. *(4)*	0%	0%	0%	0%
Scarborough	Conditioning DD *(2)*	0%	0%	0%	0%
	Spawning Potential *(3)*	0%	0%	0%	0%
	Recruitment DD *(4)*	0%	0%	0%	0%
	High Recruitment Pot. *(4)*	0%	0%	0%	0%
Redcar	Conditioning DD *(2)*	0%	0%	0%	0%
	Spawning Potential *(3)*	0%	0%	0%	0%
	Recruitment DD *(4)*	0%	0%	0%	0%
	High Recruitment Pot. *(4)*	0%	0%	0%	0%

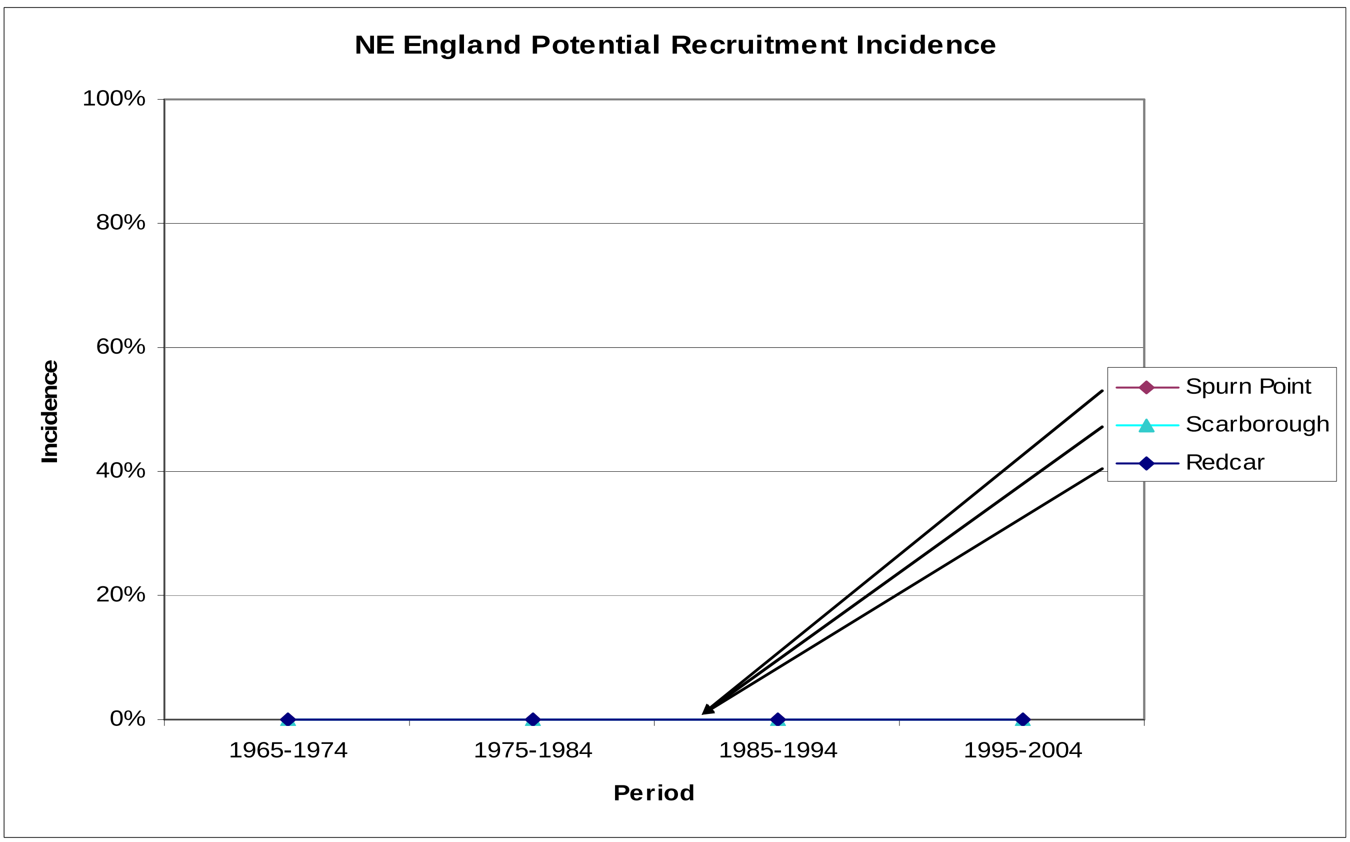
Note 1: Incidence rates calculated for 10yr range if >50% data return

Note 2: "Conditioning DD" if >600 Degree Days attained (above 10.55C biological zero)

Note 3: "Spawning Potential" if >600DD obtained in Jul/Aug/Sep with temperatures above 18C trigger

Note 4: "Recruitment DD" of >825 Degree Days attained. "High pot." if attained in Jul/Aug/Sep with temperatures above 15C

Figure 17. Area: N.E England – 'Recruitment Potential' based on a 10 year average of maximum annual degree day data



2.4.4 Regional Degree Day Assessments of Conditioning and Recruitment Potential – Analysis;

2.4.4.1 North West England and North Wales (Irish Sea): Data for the Irish Sea generally show a low risk of Pacific oyster recruitment although there is the risk of local inshore warming as Haysham PS has periodically attained temperatures in excess of the High Recruitment Potential. However, in the case of a power station monitoring point it is uncertain whether any cooling water discharge may have skewed local results.

The long-term temperature data from Moelfre on Anglesey would suggest no risk of recruitment potential for North Wales. However, there is a possibility for local inshore warming particularly within the shallow Inland Sea. Comparison of Moelfre against the temperature records for the Menai Straits and the Inland Sea in Table 9 (Spencer, 1990) indicate a comparable profile for the Menai Straits, whilst the Inland Sea is 2 to 3 ^{o}C warmer on average in May and June as a result of rapid warming. This equates to ~150 degree days which early in the summer would bring an increased chance of 'High Recruitment Potential' for the Inland Sea. However, King *et al.* (2006) also studied these two Pacific oyster culture areas and showed reduced growth and conditioning performance in the Inland Sea relative to the Menai Straits despite the temperature differential which was attributed to biotic factors.

The spatfall observed on the Menai Straits in 1993 (Spencer, *et al*. 1994) has been attributed to the warm summer of 1989 when temperatures were around 1 ^{o}C above the average in April to August. However, the degree days for Moelfre, although increased, were insufficient to achieve recruitment. The apparent spatfall must therefore have been as a result of local inshore warming. This highlights the limitation of using the available CEFAS data set and the need for site specific 'grounding' of data sets.

2.4.4.2 South Wales and Bristol Channel: This region shows a marked variation on both the English and Welsh coasts with markedly warmer waters further east up the Bristol Channel whilst more westerly monitoring points tend to be influenced by deeper cooler waters. Although the temperature regime in the East of this region would suggest an increased theoretical risk of recruitment, the area is not well suited for bivalve culture with massive turbidity levels and therefore no Pacific oyster culture operations. In the far West of this region the data from Angle and Skomer probably best reflects the temperature regime within Milford Haven which is the only area where wild settlement has been observed within this region (see Appendix 3B). These data points suggest a low risk of recruitment in this area although it is possible that local warming may occur at the head of the estuary.

2.4.4.3 South West England: The limited data presented for this region suggests a gradient from west to east up the English Channel with increasing temperatures and associated risk potential. Cornish temperatures in the far West at Newlyn were far beneath the recruitment potential and would suggest no recruitment risk. Unfortunately, this monitoring point has not been operating since 1994 and as such may no longer accurately reflect the current risk. A low risk of recruitment was obtained from the Plymouth data (although again the data set stopped in 1993), whilst Weymouth data suggested a number of years for recruitment with a periodical 'High Recruitment Potential'.

Temperature and degree day assessments have been performed for South Devon estuaries (Eno, 1994) and are considered more fully for the case study in Section 2.5. Wild spatfall has been periodically recorded in this region which is reviewed in Section 3.4.

2.4.4.4 Southern England: The temperature regime for the monitoring points within this region suggests a high incidence of years with a theoretical 'High Recruitment Potential'. The limited amount of Pacific oyster culture along this coast probably explains the apparent low levels of observed wild settlement (see Section 3.3). However, it is recommended that observations should be sought in this 'high risk' region in order to provide a better appreciation of potential larval settlement beyond the near-field spawning zone.

2.4.4.5 South East England: The temperature regime for South East England indicates a high risk region with a large number of years with 'High Recruitment Potential'. There is a good deal of site specific variation with some sites such as Leigh-on-Sea markedly warmer than others, yet all sites in the last decade show a significant incidence of High Recruitment Potential especially in the Essex / Kent areas. This corresponds to key settlement observations as considered in Section 3.3.

2.4.4.6 North East England: The temperature regime in the North Sea appears to drop off rapidly above the Wash indicating a low level of recruitment potential risk. Indeed although Spurn Point temperatures should be sufficient to allow spawning on some years, data from Redcar and Scarborough have yielded no years with conditioning and spawning potential. Degree days in these sites rarely exceed 300 degree days. Only one registered shellfish bed at Holy Island operates in this area with Pacific oysters.

2.4.4.7 Northern Ireland: As indicated in Section 2.3.2 it was not possible to obtain long-term temperature data within the time frame of the current project. Fortunately, additional hydrodynamic data for the sea loughs are available from SMILE (Sustainable Mariculture in Northern Irish Lough Ecosystems). Table 16 provides a summary of the temperature ranges of the sea loughs within the region which support oyster culture.

Table 16. Summary of Northern Irish sea lough temperature ranges (Source: http://www.ecowin.org/smile/carlingfordlough.htm)

Area→	**Carlingford Lough**	**Strangford Lough**	**Larne Lough**	**Lough Foyle**
Temperature Range	3 to 20 ^{o}C	2 to 19 ^{o}C	4 to18 ^{o}C	2 to 20 ^{o}C

Although the temperature range information is limited a 'surrogate' match from England should allow a rough approximation of the potential annual temperature regime. For example, Lowestoft has a temperature range from 4 to 18 ^{o}C which is of a similar scale to Northern Irish loughs.

2.4.5 High Recruitment Potential Overview;

To summarise the detailed regional assessment provided in the previous section an analysis of the whole data set has been performed to allow alternative presentations.

The occurrence of 'High Recruitment Potential' events for all selected sites have been calculated and presented for the 1966 to 2004 data period in Figure 18. This overview provides a summary visual indication of High Recruitment Potential years and regional zones. It is clear from Figure 18 that 1989 demarks a change in high recruitment potential. In consequence, the data that have been analysed in Table 17 below highlight the stark increase in high recruitment potential since 1989.

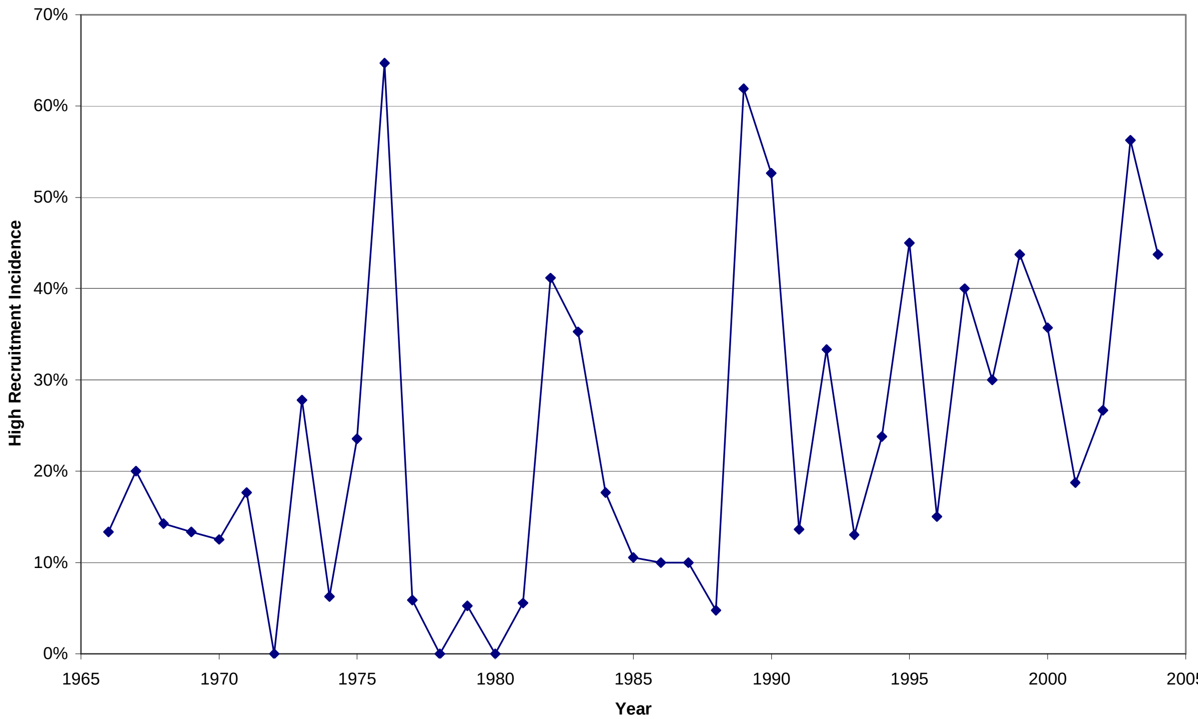
Table 17. Regional pattern of high recruitment potential for 1966 to 1988 and 1989 to 2004 H.R.P. is considered to be where 825 degree days are attained by July-September. % figures reflect the number of years during the period where H.R.P. is achieved.

Site No.	Region	Station	% High Recruitment Potential	
			1966-1988	1989-2004
1	N.W. & N. Wales	Port Erin	0%	0%
2		Haysham PS	15%	25%
3		Moelfre	0%	0%
4	S. Wales & Bristol Channel	Skomer	0%	0%
5		Angle	0%	0%
6		Swansea	8%	73%
7		Barry	20%	44%
8		Minehead	6%	44%
9		Ilfracombe	0%	0%
10	S.W. England	Newlyn	0%	0%
11		Plymouth	0%	0%
12		Weymouth	0%	25%
13	S. England	Bournemouth	14%	69%
14		Shoreham	39%	90%
15		Eastbourne	8%	69%
16		Dover	0%	25%
17	S.E. England	Leigh-on-Sea	43%	93%
18		South Wold	5%	69%
19		Lowestoft	24%	75%
20		Cromer	3%	38%
21		Brancaster	10%	75%
22	N.W. England	Spurn Head	0%	0%
23		Scarborough	0%	0%
24		Redcar	0%	0%

The 'High Recruitment Potential' data have been used to provide a time series of percentage incidence across all sites, which is presented in Figure 18.

This plot clearly shows that certain years such as 1976 and 1989 stand out as exceptionally warm years nationally.

Figure 18. Time series of percentage incidence of High Recruitment Potential across all regions



The top 10 High Recruitment Potential years which would have provided the greatest national settlement potential have been ranked and presented in Table 18 below. It is notable that 6 out of the top 10 high recruitment years have occurred in the last 10 years of available data (1995 to 2004).

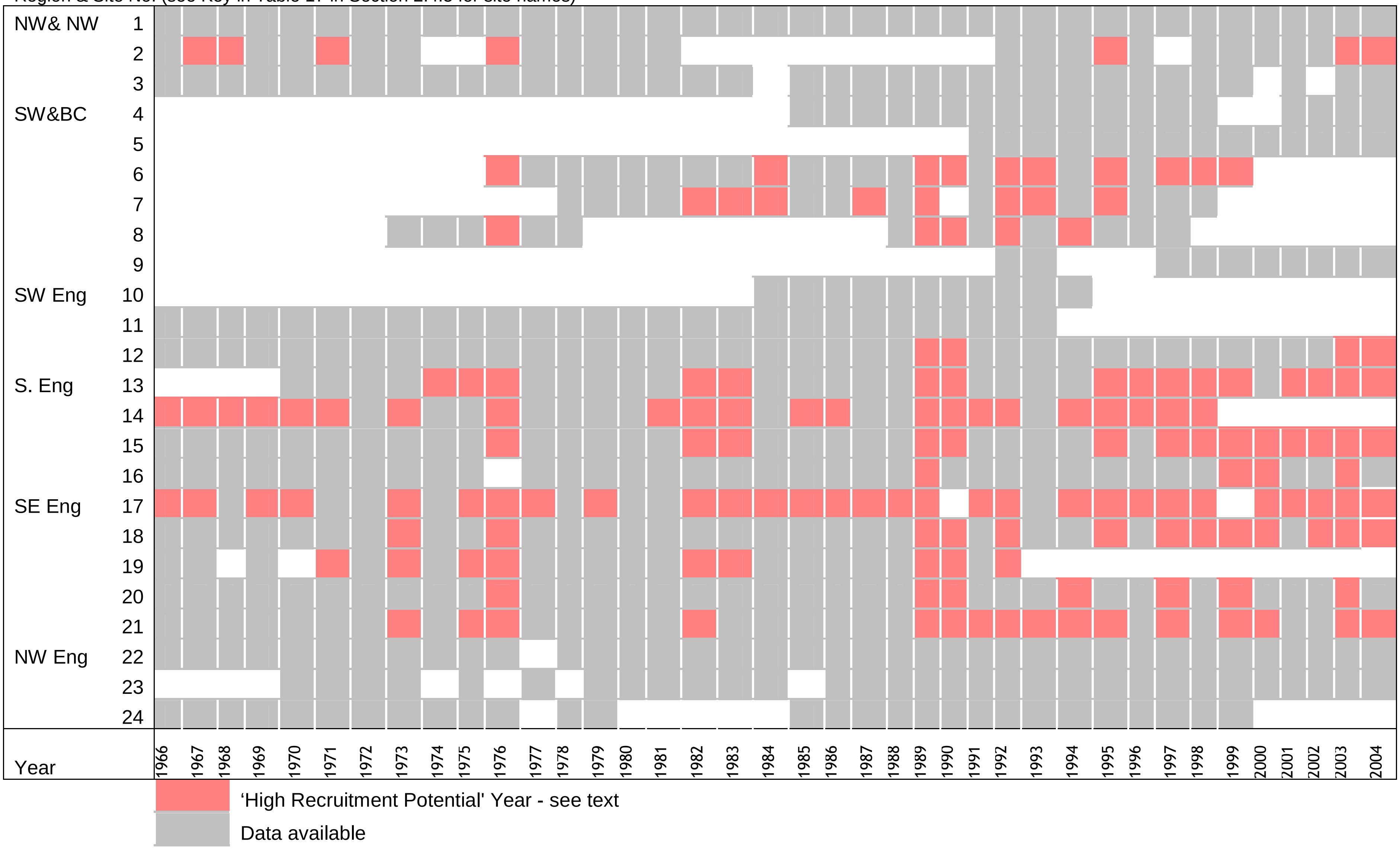
Table 18. Top 10 Highest Recruitment Potential years with respect to the Pacific oyster

Rank	**Year**	**High Recruitment Potential - % Incidence for all Sites** ***(Note 1)***
1	1976	65%
2	1989	62%
3	2003	56%
4	1990	53%
5	1995	45%
6	1999	44%
7	2004	44%
8	1982	41%
9	1997	40%
10	2000	36%

Note 1: High Recruitment Potential as defined in Section 2.4.1. % incidence for all selected CEFAS Coastal Temperature Monitoring Stations described in Section 2.3.3

Figure 19. Overview of H.R.P. years for Coastal Temperature Monitoring Network sites

Region & Site No. (see Key in Table 17 in Section 2.4.5 for site names)



2.4.6 Derived Historical Temperature Rise Rates;

As indicated in Section 2.4.2, 1990 regional temperature regimes would suggest a low chance of spawning in Scotland, a low chance of recruitment for most of England and Wales, whilst South East England estuaries were on the threshold of recruitment.

However, since the warm summer of 1989 there has been a marked warming of inshore waters throughout the UK. Analysis of the long-term data sets provided by the CEFAS Coastal Monitoring Temperature Network show significant rises in all regions as demonstrated in Table 19 below. The average summer rise between 1966 to 1988 and 1989 to 2004 varies between 0.5 °C and 1.6 °C with the greatest rises in the South East of England. This is calculated to equate to a long-term rate of warming of 0.3 to 0.9 °C/10yrs.

Table 19. Recent changes to UK summer sea temperatures and Pacific oyster conditioning (Source: Using data from selected CEFAS Coastal Monitoring Stations)

Summer Temperature Rises (°C) (difference between 1966 to 1988 vs. 1989 to 2004)							**Average Rise**	**Rate ***
Area	**May**	**June**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**(°C)**	**(°C/10yr)**
Weymouth	0.98	0.85	0.70	0.84	0.17	-0.46	0.51	0.3
Dover	1.21	1.14	0.91	1.35	0.84	0.30	0.96	0.5
Leigh-on-Sea	1.13	1.23	0.92	1.74	0.57	0.44	1.01	0.6
Brancaster	1.80	1.55	1.71	2.14	1.12	1.15	1.58	0.9
Scarborough	1.16	0.88	0.98	0.89	0.83	0.51	0.87	0.5
Port Erin	0.64	0.39	0.46	0.68	0.59	0.45	0.53	0.3
Moelfre (Anglesey)	0.92	0.56	0.86	1.09	0.79	0.57	0.80	0.4

: *Median years in 1966 to 1988 & 1989 to 2004 ranges used to calculate warming rate.

Recent Additional Monthly Degree Days						
Area	**May**	**June**	**Jul.**	**Aug.**	**Sep.**	**Oct.**
Weymouth	30	26	22	26	5	
Dover	38	34	28	42	26	9
Leigh-on-Sea	35	37	28	54	18	14
Brancaster	56	47	53	66	35	36
Scarborough	36	26	30	28	26	16
Port Erin	20	12	14	21	18	14
Moelfre (Anglesey)	29	17	27	34	24	18

Recent Additional Cumulative Annual Degree Days						
Area	**May**	**June**	**Jul.**	**Aug.**	**Sep.**	**Oct.**
Weymouth	30	56	77	104	109	109
Dover	38	72	100	142	168	177
Leigh-on-Sea	35	72	100	154	172	186
Brancaster	56	102	155	222	256	292
Scarborough	36	62	93	120	146	162
Port Erin	20	32	46	67	85	99
Moelfre (Anglesey)	29	45	72	106	130	148

Table 19 above shows that additional cumulative summer degree days range from around 100 in the West and South West of England and Wales, to 150 to 200 degree days for much of the South of England and North East English coast, whilst some South East of England areas have experienced a massive rise of nearly 300 degree days. When superimposed on the regional pattern of potential recruitment considered in Section 2.4.2 this recent temperature rise moves many areas within range of the recruitment potential threshold, whilst the South East of England has well exceeded this limit suggesting a regular recruitment potential.

2.4.7 Predicted Temperatures;

Climate change predictions have been developed for both marine and terrestrial settings as shown in Table 20 below. In common with historical data sets, determinations for inshore waters in the vicinity of Pacific oyster culture areas are problematic as individual sites will receive a 'blend' of marine and terrestrial influences.

Table 20 shows that there is a high level of variation both on a regional basis and according to the level of marine influence. In essence it would appear as though the largest increases will occur for South East England and for those sites with greater terrestrial influence.

Table 20. Overview of marine and terrestrial climate change predictions

Area	Prediction	Warming Rate (^oC/10yr)	Predicted Extra Degree days/ yr 2020	2030	2040	2050
N.W. (Rockall) *(Note 1)*	Low	0.05	9.1	18.2	27.3	36.4
	High	0.2	36.4	72.8	109.2	145.6
S.E. (Southern N. Sea) *(Note 1)*	Low	0.15	27.3	54.6	81.9	109.2
	High*	0.4	72.8	145.6	218.4	291.2*
S.W. England (land) *(Note 2)*	Low (by 2050)	1 to 1.5 *(Note 3)*				263
	High (by 2050)	2 to 3.5 *(Note 3)*				570

Note 1: Source: MCCIP - Annual Report Card 2007–2008. Applied to 182 days of year (summer)
Note 2: Source: SWCCIP (2003)
Note 3: Monthly variation (calculated below)
****: Rate used in illustrations within this study***

Prediction		May	Jun.	Jul.	Aug.	Sep.	Oct.	Annual
Low	(^oC by 2050)	1	1.5	1.5	1.5	1.5	1.5	
	(degree days/month)	31	45	46.5	46.5	46.5	46.5	262
High	(^oC by 2050)	2	3.5	3.5	3.5	3	3	
	(degree days/month)	62	105	108.5	108.5	93	93	570

Figures 20 to 25 present the underlying (10yr mean) historical trend of the maximum degree day output with superimposed predictions to 2050. Figures 20 to 25 illustrate that by 2050 even current 'low risk' regions in the North East and North West of England are likely to be theoretically capable of supporting Pacific oyster settlement. Furthermore, it should be noted that these illustrations display the underlying trends and do not show the inherent inter-annual scatter. In consequence, episodic Pacific oyster spatfalls are likely to occur long before the graphic indication of attaining the 'recruitment potential.'

As indicated in Section 2.3 no long-term temperature analysis has been possible for Northern Ireland and Scottish waters within this study. Once data sets have been obtained indicative predictions can also be applied using the rates provided in Table 20.

In view of the level of uncertainty between the differing levels of predictions this study has used the 'high' Southern North Sea prediction of 0.4 ^oC/10yr but without any land influence in its illustrations (Figures 20 to 25). This means that the calculations should be generally conservative for offshore settings. However, it is probable that areas subject to a high level of land influence could be subject to even larger temperature rises. Conversely, a Pacific oyster farm operating in deep water off the West coast of Scotland will receive global warming rates much closer to the Rockall predictions of 0.2 ^oC/10yr.

The predicted 0.4 ^{o}C/10yr value matches well with the observed historical temperature rise for most regions as described in the previous Section. However, Table 19 (Section 2.4.6) indicates an even more extreme temperature rise may be appropriate for some regions such as South East England suggesting an increased level of risk in such areas (0.9 ^{o}C/10yr). A more comprehensive assessment will be required when the latest climate change predictions are released by UKCIP08 later this year (Section 2.3.4).

Another source of regional variations is the seasonality of any warming predictions. In the absence of seasonal regional predictions this study has applied the MCCIP SST prediction throughout the year for 6 months/yr to all sites. However, Table 19 shows that much of the historical warming has been 'front end loaded' to the early summer which will greatly enhance the potential for spawning and recruitment. Furthermore, different regions have a differing period above the 10.55 ^{o}C biological zero. For example, many northern regions only exceed the biological zero temperature for 5 months/year, whilst for some of the southern regions this may be 7 months/yr. In consequence, there may be scope to adjust down the risk for northern regions and increase the risk factor for southern regions.

It should be stressed that whilst predictions are a necessary tool in trying to assess future risk they offer no guarantees. Other confounding factors could occur that will shift both the rate and the pattern of climate change. MCCIP (2008) also gives a prediction that the North Atlantic Conveyor may weaken by 30%. The North Atlantic Conveyor is the oceanographic process than drives the Gulf Stream which is the major ocean/atmosphere heat transfer process that warms the British Isles in the winter and cools it in the summer. Although the level of confidence on this prediction is low the implications for this change would strongly influence the potential risk posed by Pacific oyster settlement.

It is concluded therefore that the overview predictions provided in this study provide an indicative illustration of the potential impact upon degree days and Pacific oyster settlement.

It is recommended that more accurate regional assessments are undertaken following the release of the UKCIP08 predictions in the autumn 2008 which will provide output for both terrestrial and marine grids throughout the UK.

Figures 20, 21, 22, 23, 24, 25. Regional temperature trends for the UK based on historical data and predicted degree day maxima with indications of likely spawning and recruitment events with Pacific oysters (individual Figures shown respectively on the following pages);

Figure 20. N.W. Eng. & N. Wales hist. & predicted sea temp. regime with recruitment events

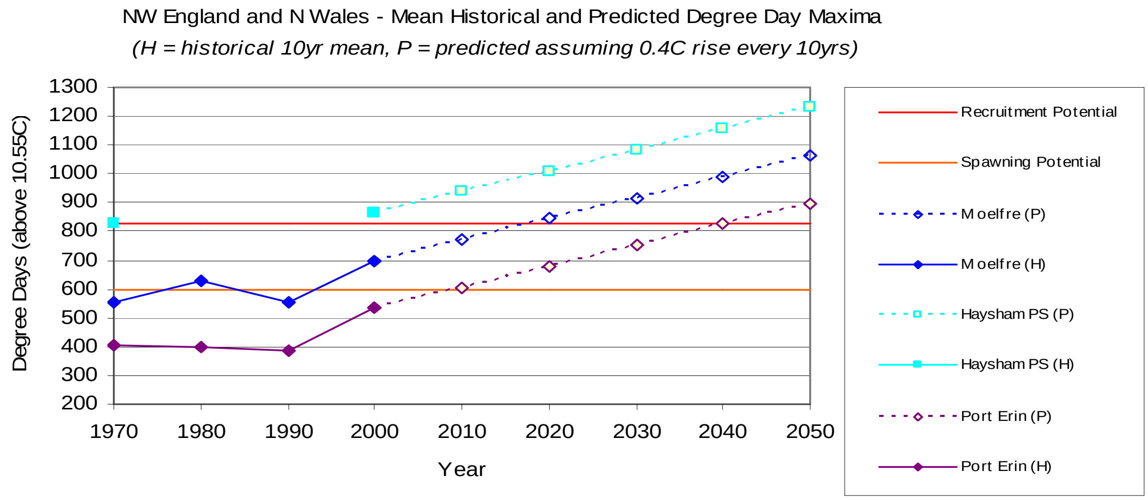


Figure 21. S. Wales & Bris. Chl. hist. & predicted sea temp. regime with recruitment events

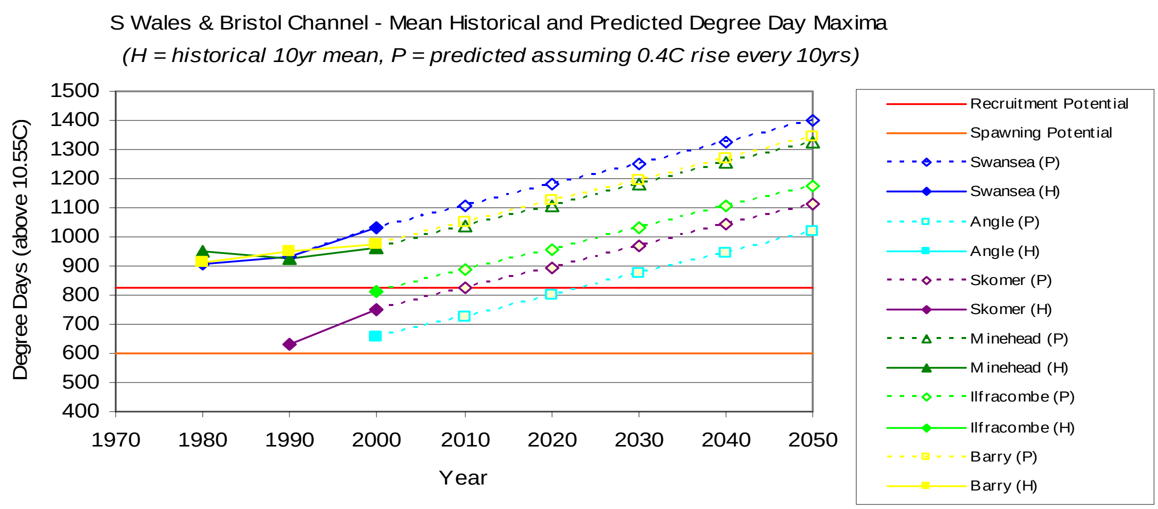


Figure 22. ***S.W. England hist. & predicted sea temp. regime with recruitment events***

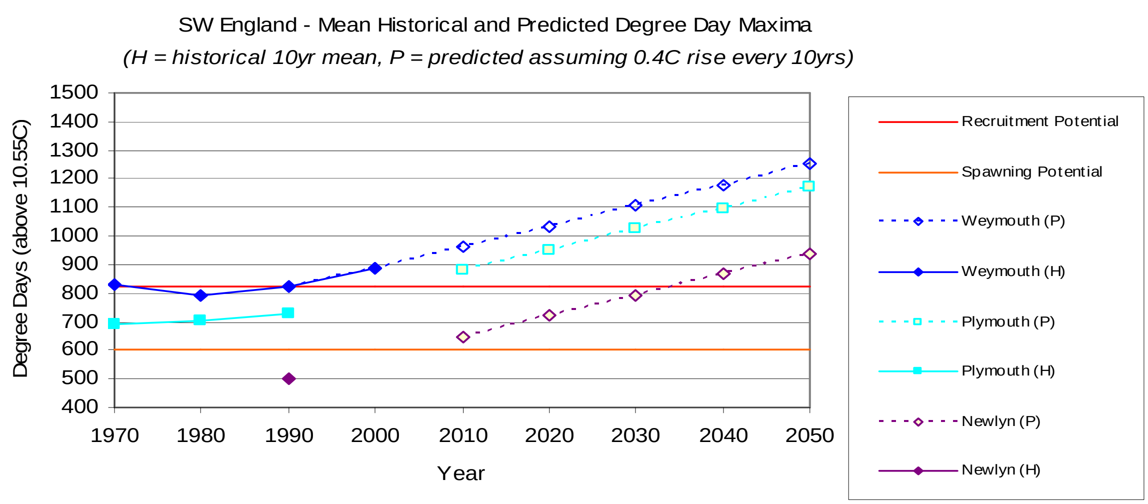


Figure 23. S. England hist. & predicted sea temp. regime with recruitment events

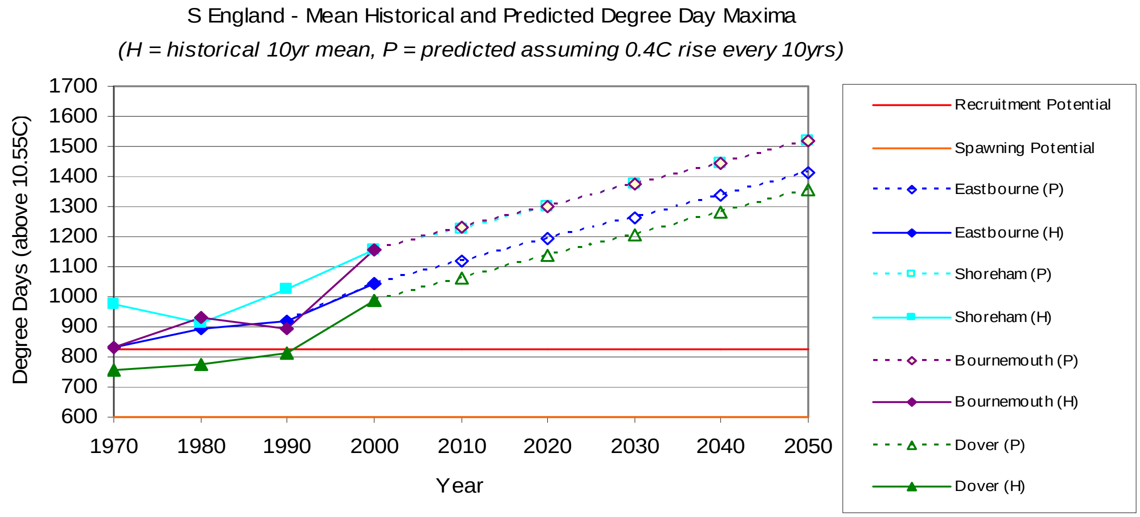


Figure 24. S.E. England hist. & predicted sea temp. regime with recruitment events

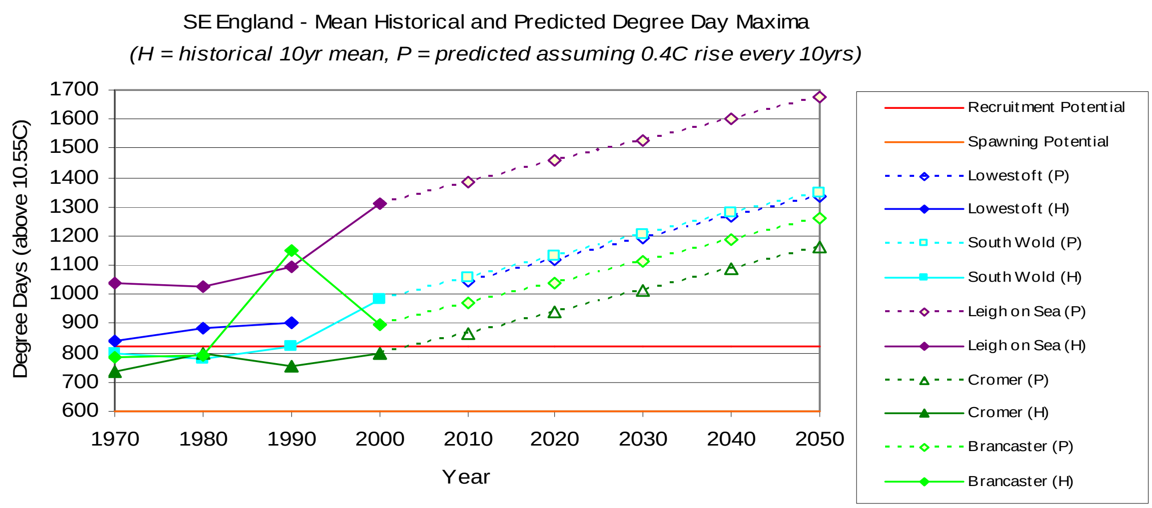
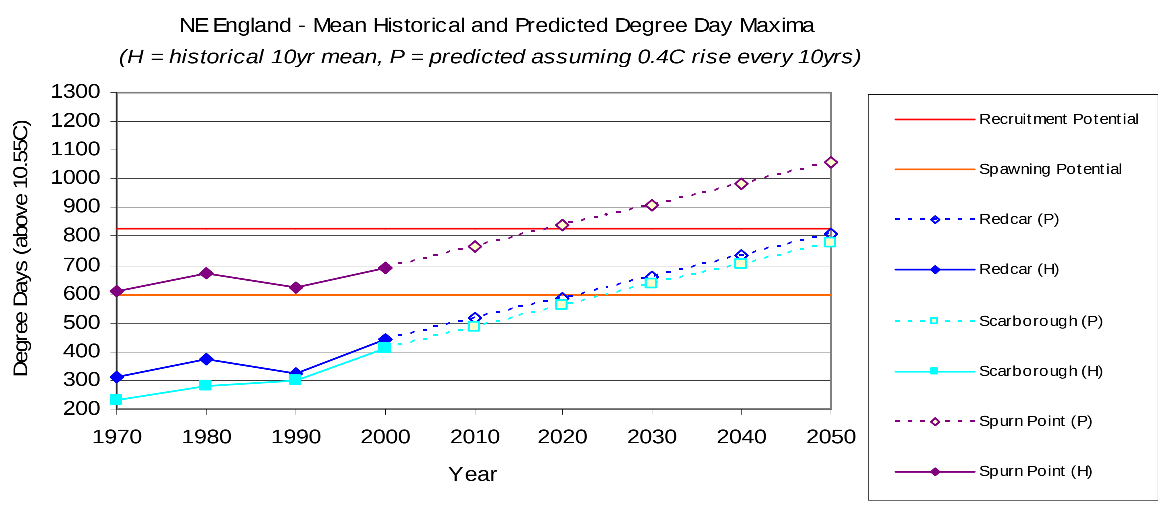


Figure 25. N.E. England hist. & predicted sea temp. regime with recruitment events



2.5 South Devon – Yealm Estuary Case Study (Temperature)

2.5.1 Introduction;

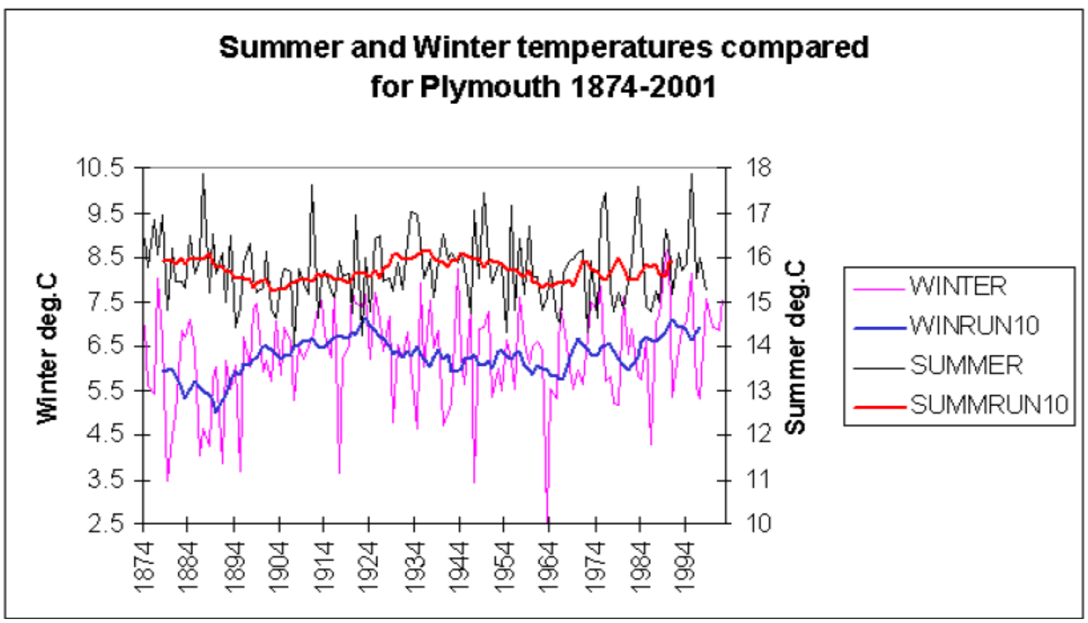
The temperature regime is a central control on the potential risk of spawning and subsequent recruitment. Couzens (2006b) working on the Pacific oyster spatfall in the Yealm suggested a link between the increased settlement potential and climate change, “since 1990 there has been a 1 ^{o}C increase in sea surface temperature in the Western English Channel off Plymouth (Mieszkowska *et al.,* 2006).”

Section 2.4 outlines a regional review of the temperature regime from long-term data sets and gives a broad indication of geographical and temporal variation in settlement risk. Inshore temperatures in the vicinity of oyster culture operations are strongly site specific and likely to be warmer than those obtained in deeper water measurement locations.

As inshore temperatures are strongly influenced by terrestrial conditions a good indication of the variability in summer and winter maxima and minima can be seen from Figure 26 below.

Notable are the extreme freeze of 1963 and the hot summers of 1976, 1983, 1989 and 1993. These episodic events are thought to correspond to warmer inshore waters and increased spawning potential.

Figure 26. Plymouth long-term temperatures (air) 1874 to 2001 (Source: SWCCIP, 2003)



This section aims to review local temperature measurements for the case study site for comparison against adjacent long-term data sets.

2.5.2 Yealm Estuary;

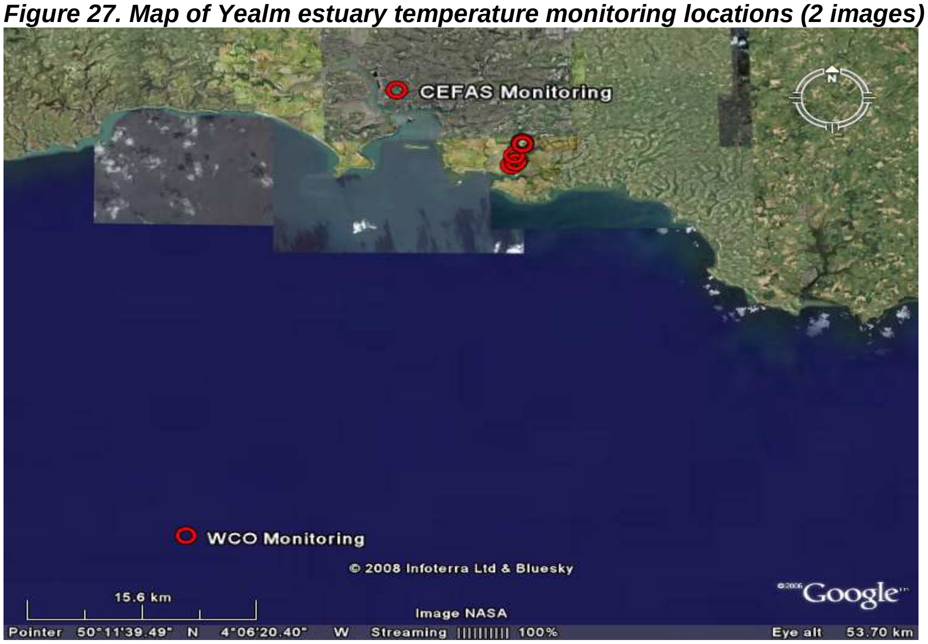
Data sources for the Yealm estuary and surrounding waters are summarised in Table 21 as follows and presented in Figure 27.

Table 21. Summary of Yealm temperature data availability

Source	Position	Period	Interval	Comments
Yealm (lower) (International Paints)	X3 points off paint rafts at 1' depth	1930-1990	Daily / fortnightly	Comprehensive data available for much of the period
Yealm (upper) (Environmental Health)	X2 points	1999-present	Fortnightly / monthly	Tidal bias with most measurements obtained around LW on spring tides
Plymouth Sound (CEFAS inshore network)	X1	1957-1993	Monthly (mean from unknown measurement Interval)	Uncertain knowledge of local bias (e.g. measurement depth)
Offshore Plymouth (WCO,2008)	X1	1903-present	CTD casts on period basis	Some years with reduced data collection
Yealm (lower) (MBA)	X2 (upper and lower intertidal)	Nov 2007-present	20 minutes	Ongoing study

Ideally all data sources would use a common measurement protocol allowing complete inter-comparability. In practice, all the data sets have their limitations with either data gaps, poor resolution or limited duration. However, the use of multiple sources does allow some appreciation of the variations which help with data interpretation.

Figure 27. Map of Yealm estuary temperature monitoring locations (2 images)



2.5.3 Offshore Data from Plymouth Sound and Western Channel Observatory (WCO);

It was hoped that data from these sources would provide a long-term data set free of inshore shallow water variations. The CEFAS Plymouth Sound data are generally good with relatively few data gaps although they only extend to 1993. The WCO data are still ongoing although resolution is poor with large data gaps (sometimes for years – e.g. 1985 to 2002) that prevent calculation of degree days. The WCO data do provide an interesting offshore truthing to the Plymouth data as they are obtained using a CTD cast at a deep water site (~80m) thereby providing water column data at a 10m interval. Measurement occasions with >1 ^{o}C difference between near-surface and 10m depth occurred from June to August suggesting a greater potential for thermal near surface stratification in the summer. Data from the WCO with its increased maritime influence would be expected to present a cooler summer maxima than for Plymouth.

However, comparison for July 1983 (a relatively warm year for both data sets) shows maxima temperatures at WCO of >19 ^{o}C at both near-surface and 10m depth in contrast to Plymouth with an average of 17.2 ^{o}C. A scatter-plot comparing summer maxima from the two sites also showed a higher temperature skew in the WCO data set. It should be noted that the WCO measurements are obtained from periodic CTD casts (maybe 1-2/month) which are unlikely to be completely representative of the whole month.

It is concluded that both of these data sources are subject to limitations to their accuracy to represent inshore waters adjacent to oyster culture areas. However, the Plymouth Sound CEFAS Coastal Temperature Monitoring station is one of the stations considered within Section 2.3 and is considered suitable for coarse scale regional and long-term trend analysis.

2.5.4 Environmental Health Monitoring Points;

Temperature data were obtained from the Environmental Health monitoring points adjacent to the shellfish harvest areas. Data were provided from 1999 to the present from two measurement points at 'Thorne' and 'Foxcove' as depicted in Figure 27. Data from this source showed that summer temperatures regularly exceed 18 ^{o}C and periodically exceed 20 ^{o}C with a maximum reading of 23.3 ^{o}C. Table 22 overleaf presents a summary of the temperature regime data and calculated degree days.

Calculation of degree days suggest that spawning and recruitment have occurred in all of the previous 9 years which is not supported by the physical observations. Closer inspection of the tidal phasing of the sampling shows that the majority of the Environmental Health monitoring data were obtained around LW primarily on a spring tide (i.e. around shellfish sampling times). As the shellfish sampling points are immediately downstream of a largely drying intertidal mudflat area the LW temperatures will have a strong terrestrial bias and are likely to be elevated above mean conditions throughout the tide.

Table 22. Temperature regime and Pacific oyster conditioning potential – Upper Yealm (Source: Plymouth City Council Environmental Health)

Mean Temperature (°C)

Year	Mar	Apr	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	mean
1999	10.0	9.9	13.4	16.0	14.0	19.0	18.0	15.0	11.8	8.3	13.5
2000	10.8	9.1	14.5	15.0	15.0	18.6	15.9	13.0	11.0	11.0	13.4
2001	11.5	10.0	15.0	13.0	16.0	18.8	16.6	14.8	11.5	10.8	13.8
2002	8.4	12.3	13.8	17.5	17.8	18.3	19.8	16.5	14.0	11.8	15.0
2003	9.8	11.5	14.7	18.0	20.7	23.3	18.2	13.0	11.3	7.9	14.8
2004	11.5	11.86	13.4	17.38	17.0	18.1	15.9	13.2	11.65	10.6	14.1
2005	9.1	10.8	13.2	20.0	19.5	18.2	17.7	16.6	10.4	10.2	14.6
2006	7.8	12.1	14.0	17.1	19.0	18.0	18.6	17.0	13.0	11.2	14.8
2007	9.1	15.0	13.2	17.6	18.0	19.0	18.9	15.2	12.8	10.5	14.9
mean	9.8	11.4	13.9	16.8	17.4	19.0	17.7	14.9	11.9	10.3	14.3

Monthly Degree Days (assuming 10.55 °C biological zero)

Year	Mar	Apr	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1999			88	164	107	262	224	138	38	
2000	8		122	134	138	250	161	76	14	14
2001	29		138	74	169	256	182	132	29	8
2002		53	101	209	225	240	278	184	104	39
2003		29	129	224	315	395	230	76	23	
2004	29	40	88	205	200	234	161	82	33	2
2005		8	82	284	277	237	215	188		
2006		47	107	197	262	231	242	200	74	20
2007		134	82	212	231	262	251	144	68	

Cumulative Annual Degree Days

Year	Mar	Apr	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	max	C?	S?	R?
1999			88	252	359	621	844	982	1020	1020	1020	y	y	y
2000	8	8	130	264	402	651	812	888	901	915	915	y	y	y
2001	29	29	167	241	410	666	847	979	1007	1015	1015	y	y	y
2002		53	153	362	587	827	1104	1289	1392	1431	1431	y	y	y
2003		29	157	381	695	1091	1320	1396	1419	1419	1419	y	y	y
2004	29	69	157	362	562	796	957	1039	1072	1073	1073	y	y	y
2005		8	90	373	651	888	1102	1290	1290	1290	1290	y	y	y
2006		47	153	350	612	843	1084	1284	1358	1378	1378	y	y	y
2007		134	216	427	658	920	1171	1315	1382	1382	1382	y	y	y

Key: ***>600*** *-degree days to achieve spawning*
>825 *-degree days to achieve metamorphosis of larvae*
(shaded) *-Summer months when spawning trigger temperature of >18 °C likely*

Notes: ***S?*** *-Spawning Potential (does not necessarily indicate widespread spawning which would be required to achieve fertilisation)*
R? *-Recruitment Potential (does not necessarily indicate recruitment as larvae could be retarded during 28 days of larval life stage)*
Note 1 - Temperatures likely to be an overestimate as measured around LW generally on spring tides

Data from the International Paint rafts (a short distance downstream) indicate a mean temperature difference of 2.8 ^{o}C between maximum and minimum daily measurements which are likely to be due to daily warming and diurnal phasing. If the Environmental Health monitoring temperature were 'normalised' by 1.4 ^{o}C (over the 8 summer months above 10.55 ^{o}C) then summer conditioning would be reduced by around 350 degree days moving many of the years below the theoretical High Recruitment Potential. In this case only 2003 would have yielded sufficient degree days to provide a High Recruitment Potential – this would fit site observations of a significant spatfall observed around 4 years ago. Unfortunately, a direct normalisation is not possible as the Environmental Monitoring and the International Paint data sets do not overlap in their measurement periods.

Even with a 'normalisation' allowance for a tidal bias to the measured temperature regime, the data would suggest a higher incidence of recruitment than appears to be occurring. It is a possibility that the nutritional regime in the Yealm estuary is not optimal therefore retarding larval development beyond the hatchery derived 825 degree day threshold. In consequence the temperature derived High Recruitment Potential may provide a useful tool for a conservative assessment of risk.

2.5.5 International Paint Monitoring Points;

A number of paint rafts are moored within the lower Yealm estuary by a private company in order to monitor fouling on test panels. Three points were monitored at different sites within the estuary which rarely showed more than a 1 ^{o}C separation between sites. These sites have received comprehensive monitoring of temperature, salinity and weather since 1930 on a daily basis with near surface and depth monitoring on a weekly basis. Unfortunately, the data collection stopped in 1990 and the resolution of collection was reduced in the latter years that are of interest to the current study.

As data are only available on paper records a limited period was transcribed for this study to assess inter-comparability with other data sources. The years 1988-1989 were selected for analysis as 1989 was a known 'hot' year (see Table 23). Elevated air temperatures in 1989 (up to 30 ^{o}C) were associated with increased water temperatures in July/August with a peak water temperature of 21 ^{o}C and an average of 19 ^{o}C in July as opposed to an average of 16 to 17 ^{o}C the previous year. However, this early summer rise in 1989 was not reflected in the degree days which were not greatly different from the previous year (which had been warmer in the autumn). Degree day calculations from these monitoring points indicate conditioning and spawning had probably occurred but that the recruitment potential was low. In both years assessments of degree day suggest that the 825 degree day recruitment threshold was reached but not until October when temperatures were already dropping below 15 ^{o}C reducing the potential for settlement.

Inter-comparison of maximum degree days between the Lower Yealm temperature monitoring points and the CEFAS Plymouth Sound monitoring point showed a generally poor match. Maxima of around 830 and 880 for the Lower Yealm compared with ~630 and 970 degree days obtained from Plymouth Sound for 1988 and 1989 respectively. In explanation it should be noted that the Lower Yealm exhibited a marked daily variation between maximum and minimum temperature of 3 to 4 ^{o}C. For the purposes of this study these temperatures were averaged to provide an overall mean.

In reality it is likely that peak temperatures in any one year within the estuary will be influenced by both freshwater run off, air temperatures and solar heating in addition to the underlying change in offshore temperatures. Without higher resolution data it is impossible to know whether these maxima temperatures may have been short term events and as such unrepresentative of the temperatures that would have been experienced throughout most of the tide. It is concluded that accurate representative degree day assessments can only be obtained using a high resolution data set for estuarine settings such as the Yealm.

Table 23. Temperature regime and Pacific oyster conditioning potential – Lower Yealm (Source: International Paints)

Mean Monthly Temperatures

Site	Year	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
R1 *(Note 1)*	**1988**	12.8	15.0	16.5	17.3	16.3	13.7	10.8	10.0
	1989	12.3	15.3	18.8	16.8	15.5	12.0	10.3	9.3
	mean	12.5	15.1	17.6	17.0	15.9	12.8	10.6	9.6
R2 *(Note 2)*	**1988**	12.8	15.3	16.3	16.9	16.8	14.0	10.7	10.0
	1989	12.3	14.8	19.0	17.0	16.0	11.5	10.0	9.0
	mean	12.5	15.0	17.7	16.9	16.4	12.8	10.3	9.5
R3 *(Note 3)*	**1988**	12.8	15.0	16.3	17.0	16.3	13.7	10.7	10.0
	1989	12.3	15.3	19.3	17.3	16.3	11.5	9.8	9.3
	mean	12.5	15.1	17.8	17.1	16.3	12.6	10.3	9.6

Monthly Degree Days

Site	Year	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
R1	**1988**	68	134	184	208	171	97	8	
	1989	53	141	254	192	149	45		
R2	**1988**	68	141	179	196	186	107	4	
	1989	53	126	262	200	164	29		
R3	**1988**	68	134	179	200	171	97	4	
	1989	53	141	270	208	171	29		

Cumulative Annual Degree Days

Site	Year	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	C?	S?	R?
R1	**1988**	68	202	386	594	765	861	870		y	y	y
	1989	53	194	448	640	789	834			y	y	y
R2	**1988**	68	209	388	585	771	878	881		y	y	y
	1989	53	179	441	641	804	834			y	y	y
R3	**1988**	68	202	381	581	752	849	852		y	y	y
	1989	53	194	463	671	842	872			y	y	y

***Note 1*: Raft 1- Kitley (upstream site)**
***Note 2*: Raft 2- Inner (off Newton Ferris site)**
***Note 3*: Raft 3- Outer (off Noss Mayo to Cellar Beach site)**

2.5.6 Yealm - MBA Minilog Monitoring;

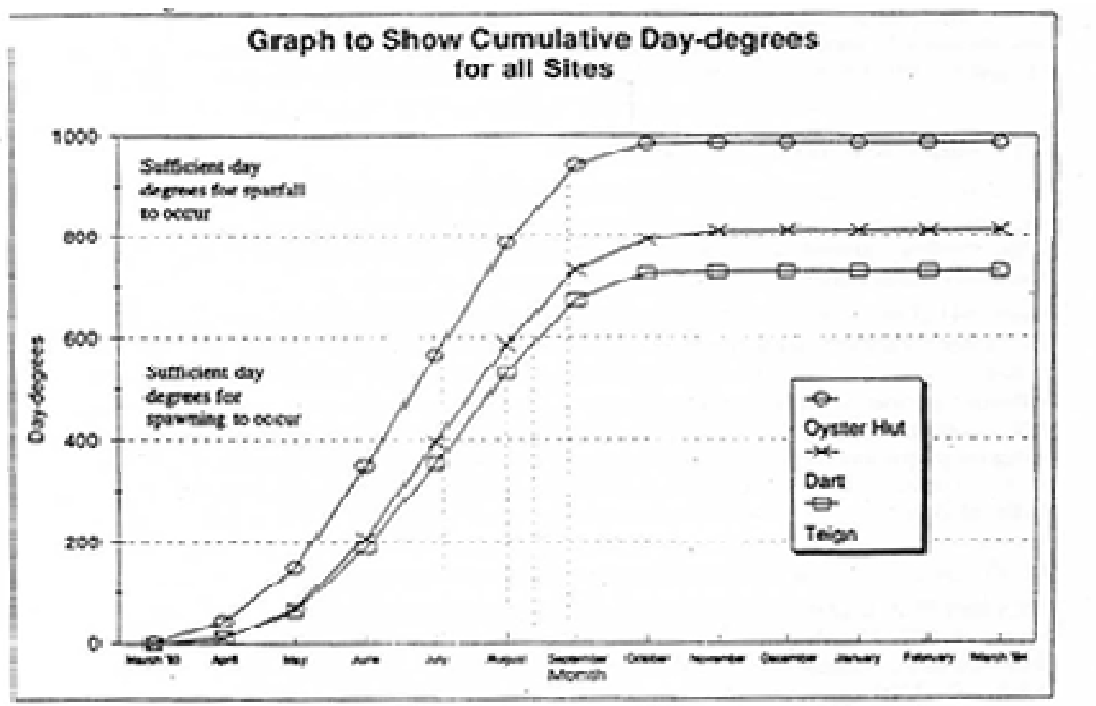
Two high resolution temperature loggers have been placed across the tidal profile within the Yealm as part of a Pacific oyster monitoring project which is described in Section 3.4.2 (Nova Mieszkowska, pers. comm.) Although this data set is very recent it will provide a definitive data set with a high level of confidence that is representative of the temperature regime experienced by the Pacific oysters. It is strongly recommended that the findings of this study are monitored closely and that this measurement approach be adopted for monitoring inshore waters representative of oyster culture.

The use of miniloggers adjacent to Pacific oyster culture areas provides a reliable, cost effective monitoring tool. Cornwall Sea Fisheries successfully used this technology to simultaneously monitor five offshore sites for 18 months using a duty/standby system of x2 loggers per site whereby local fishermen periodically swapped over the loggers and sent them through the post for central processing (FitzGerald, 2003).

2.5.7 South Devon;

Following the wild spatfall reported by Spencer *et al.* (1994) which was attributed to the warm summers of 1989, Eno (1994) measured the temperature regime in the Dart and Teign estuaries in 1993 and showed that both estuaries experienced sufficient degree days to allow conditioning with a high probability of spawning. Eno calculated that insufficient degree days had been attained to allow recruitment for the year of study with 813 and 732 degree days received for the Dart and Teign respectively. A plot of the cumulative degree days obtained from this study are presented in Figure 28 below. Measurements in the nearby Fleet Lagoon, Dorset, did demonstrate sufficient degree days for recruitment, although in the absence here of any observed spatfall, confounding factors are considered to be operating at a local level (see Section 2.2.2).

Figure 28. 1993 Cumulative degree days for the Fleet, Dart and Teign Estuaries (Source: Eno, 1994)



Data for nearby Plymouth and Weymouth showed that 1989 was warmer than both the long-term mean and the year 1993 when Eno's study was performed (see Table 24 below).

Table 24. Degree day assessments for 1989 and 1993 in South Devon / Dorset (Source: CEFAS Coastal Temperature Monitoring Network)

Year	Plymouth	Weymouth
Long-term mean (1966-1993)	710	896
1989	946	1161
1993	894	661
Difference	52	500

Note 1: Spawning Potential >600 degree days
Note 2: Recruitment Potential >825 degree days

However, the differential between 1989 and 1993 was highly variable between the two sites (52-500 degree days), probably as a function of each monitoring points site specific characteristics (see Table 25 below).

Table 25. Application of 1989-1993 degree day offset
(Source: CEFAS Coastal Temperature Monitoring Network)

Year	Plymouth	Weymouth
1993-1989 offset	52	500
Dart	865	1313
Teign	784	1232

Note 1: Spawning Potential >600 degree days
Note 2: Recruitment Potential >825 degree days

Although this variation makes it hard to estimate how much warmer 1989 was relative to 1993 it is highly probable that the Teign and Dart would have received sufficient additional degree days to exceed the 825 degree day recruitment potential. It is suggested that the use of degree days for assessing settlement risk is a good initial screening tool. However, the confidence in the data is strongly dependant on obtaining high resolution representative data from the site local to the Pacific oyster culture operation.

2.6 Temperature Influence on Other Commercial Species

Section 2.4 has demonstrated an underlying climatic shift that is associated with the change in the Pacific oyster population within the UK. This section reviews the possible implication of this temperature increase on other, potentially competing, commercial species such as the Native oyster (*Ostrea edulis*) and the blue mussel (*Mytilus edulis*) and considers whether the Pacific oyster presents a threat to these species within warming seas. It should be noted that the implications of seawater temperature increases with respect to Pacific oysters and other specific non-commercial species are outside the scope of this present study.

In essence the Pacific oyster, Native oyster and blue mussel have reproductive potentials linked to the temperature regime. An overview of the temperature regime for conditioning of the Pacific oyster, blue mussel and the Native oyster is provided in Table 26 below.

Table 26. Summary of the temperature requirements for conditioning of the Pacific oyster (Taken from: Helm and Bourne, 2004)

Species	Period (days)	Temperature (^{o}C)
Pacific oyster	28-42	20-24
Native oyster	28-56	18-22
Blue mussel	28-35	12-16

Table 26 shows that warmer waters favour the Pacific oyster over the other two species. Detailed consideration of temperature requirements and interactions are reviewed on a species specific basis in the following sub-sections.

2.6.1 Mussels;

The blue mussel is a cold water species and is therefore under threat from warming seas. Newell (1989) provides a good review of the physiological temperature requirements of the blue mussel. The blue mussel can operate at significantly lower temperatures than the Pacific oyster. Although the blue mussel will be killed by freezing at -10 ^{o}C to -15 °C they survive beneath sea ice (at ~ -1.5 ^{o}C) for several months off the east coast of the United States. The biological zero (threshold to undergo gametogenesis) is considered to be 5 ^{o}C for the blue mussel which is far below the 10.55 ^{o}C considered to be applicable to the Pacific oyster (see Section 2.2).

Similarly the growth rate of mussel larvae increases progressively above 5 ^{o}C to a maximum at around 16 ^{o}C. By comparison larval success for the Pacific oyster is reduced below 15 ^{o}C. The upper temperature limits are also accordingly lower for the blue mussel relative to the Pacific oyster with 27 ^{o}C suggested as an upper long-term temperature limit for the blue mussel. However, acclimation is critical as demonstrated by mussels acclimated at 20 ^{o}C which can survive at 25 ^{o}C, whilst those from 10 ^{o}C waters cannot. Mussels have been shown to tolerate warmer temperatures for short periods with associated mortality as demonstrated by Leblanc *et al.* (2005). This study showed ~75% mortality from a 6-h exposure to 33 °C water although highest survival t o these adverse conditions tended to be with larger mussels suggesting an increased susceptibility to high temperatures with mussel seed.

The relative mortality of the blue mussel and the Pacific oyster in high temperature conditions was explored by Rajagopal *et al.* (2005) who studied the upper temperature tolerance of Pacific oysters against the blue mussel in respect to periodic heat treatment to kill off fouling within power stations cooling water systems. The study showed that although current treatment regimes were effective against the blue mussel they were insufficient to kill the Pacific oyster therefore demonstrating a higher short term upper temperature tolerance.

Although it is convenient to define characteristic temperature ranges it is possible that this is too simplistic a tool to evaluate the relative performance of the two species. The response of different populations to a change in temperature is likely to be a complex balance between each population's thermal history, food availability and reproductive condition. In this way the blue mussel and Pacific oysters ability to acclimate (Section 2.2.3) and to resist summer mortality events (Section 2.2.4) is likely to be as important as their theoretical temperature range.

Conflicting reports have emerged regarding the potential impact of the Pacific oyster upon the blue mussel. Potential problems can be grouped into those related to a general ecosystem shift from blue mussel reefs to Pacific oyster reefs, or to those on a commercial basis where Pacific oyster settlement on cultured mussels may present a nuisance value.

In terms of the wider potential ecosystem impact there is a general perception amongst agency workers that appears to infer a link between the reported decline of the blue mussel and the growth of the Pacific oyster in the Wadden Sea. Natural England cited the recent Independent article and states "Where the invasion of Pacifics' has been rapid and widespread, areas which used to be sandflats and mussel beds are now being dominated by Pacific oysters" (Rob Blyth-Skyrme, pers. comm.). The response from CCW for this study stated that the Pacific oyster "can replace mussel reefs and while the associated fauna is less affected, it nonetheless changes the existing habitat," (Clare Eno, pers. comm.). The EHS (Northern Ireland) deferred their response on potential impacts pending the ongoing research work by Claire Guy from Queen's University. However, Guy (2007) points to research on the wild settlement of Pacific oysters in the Wadden Sea as an example of conflict with the blue mussel when stating "Warm summers triggered *C. gigas* to breed and the spat preferentially settled on the native mussel (*Mytilus edulis*) beds and smothered them thus out competing them for space." The rise of the Pacific oyster and the decline of the blue mussel would initially appear from a precautionary perspective to have a causal link.

However, the literature describing the status of the Pacific oyster and mussel interactions in the Wadden Sea indicates a far more complex relationship than Pacific oysters directly replacing blue mussels. Diederich (2005) and Diederich (2006) compares the relative settlement performance of the two species in terms of substrate, tidal position and other species associations. These studies show that whilst food resources are sufficient there is no direct conflict between the two species, but that the Pacific oyster performs significantly better. Nehls *et al.* (2005) and Nehls and Büttger (2007) go further in their assessment of the causal link between the decline of the blue mussel and the rise of the Pacific oyster. These studies show that the blue mussel population at a number of sites within the Wadden Sea plummeted <u>prior</u> to the expansion of the Pacific oyster. Climate change and differential predator interactions have been attributed for this shift. Although the increasingly warmer summers have been attributed to the Pacific oyster's success in the Wadden Sea the poorer performance of the blue mussel is a result of the warmer winters.

Historically, cold winters would favor the blue mussel which can survive and out perform the Pacific oyster in colder waters. However, mild winters are not effective in removing crabs from the Wadden Sea so leading to much higher predation in the early summer on the newly settled mussel seed, whereas the Pacific oyster spat is less susceptible to predation. In consequence, mild winters work against the mussel but not the Pacific oyster, allowing one species to decline and the other to thrive. This is not the direct ecological challenge of one native species being replaced by another non-native species. Furthermore, it also implies that the blue mussel and its associated epifauna would suffer this fate regardless of the presence of the Pacific oyster. This suggestion would tend to be supported by Nehls *et al.*

(2005) who estimated that dense oyster reefs only covered 10-20% of the blue mussel bed area of 1999.

Dare *et al.* (2004) considered mussel and cockle stocks in the Wash and also observed an inverse relationship between mussel recruitment and the severity of the preceding winter. These workers also stressed the importance of the green shore crab in predation upon both commercial species and also how cold winters reduced and retarded crab recruitment. This study also shows how since the late 1980s the mussel stock and fishery landings have dropped significantly following successive seed recruitment failures. The area represents many parallels with the Wadden Sea, which, coupled with reports of wild Pacific oyster settlement in the nearby Kings Lynn / Brancaster area (Section 3.3), suggest the potential to give rise to a similar pattern of species shift. There is concern that the temporary loss of a native commercial species could allow replacement by the Pacific oyster which would then prevent recolonisation by the original species in the future.

The commercial nuisance issue posed by unwanted Pacific oyster settlement on other stocks gives a varied picture. Industry reports of Pacific oyster settlement upon mussels within the UK for this study do not suggest a problem at this stage. The Fal estuary system has been identified as one area with a potential Pacific oyster settlement problem yet local mussel long-line operators currently report 20-30 cases of Pacific oyster settlement a year, with greater settlement from slipper limpets and vastly greater problems with sea squirts (both native and non-native)(Steve Kestin, pers. comm.). In other areas direct conflict may be going unnoticed. Brightlingsea for instance, an area reported to have extensive wild Pacific oyster settlement (Section 3.3), has a dual designation for Pacific oysters and blue mussel culture. However, despite oyster encroachment and some reduction in mussels (Joss Wiggins, pers. comm.) these beds are currently not worked and as such negative impact may be going unnoticed. Nehls and Büttger (2007) indicate co-settlement of blue mussel and Pacific oyster spat which can contaminate commercial beds and therefore have an economic impact upon commercial operations.

In summary, it would appear that although the Pacific oyster has been presented as a casual link with the demise of the blue mussel in the Wadden Sea more recent studies have shown this not to be the case and that climate change is the underlying association. It would however appear that with the shift in population dynamics and the growth of the Pacific oyster biomass it is possible that in a resource limited environment that Pacific oysters are likely to out compete the blue mussel. It is recommended that the potential impact of climate change on the major mussel producing areas of North Wales, Scotland and Eastern England should be assessed to establish whether a parallel threat exists to that described for the Wadden Sea.

In some settings indeed the blue mussel has been shown to out compete the Pacific oyster. Ruesink *et al.* (2005) described how mussels on wave-exposed western North American shores are known to be dominant competitors and reduce growth rates of the Pacific oyster by more than 30%.

It is concluded that although wild Pacific oyster settlement may not currently be a significant problem to the UK commercial mussel sector, a potential for nuisance fouling does exist if increased rates of settlement occur in the future. It is unknown what the impact of this fouling would be or how it compares with existing operational problems such as sea squirt settlement. It is recommended that further studies are performed to assess the status of blue mussel cultivation in the UK and the South East England in particular, in relation to decreasing performance through global warming and encroachment by Pacific oyster settlement.

2.6.2 Native Oyster;

The Pacific oyster was originally introduced in order to help support an industry that was struggling with the failing performance of the Native oyster. There are a number of differences between the two species in terms of disease resistance, reproductive strategy and growth rates.

Mann (1979) compared the growth rates and reproductive potential of both the Pacific and Native oyster at 12 ^{o}C, 15 ^{o}C, 18 ^{o}C and 21 ^{o}C. The growth rate for the Native oyster was notably slower at around half that of the rate of the Pacific oyster. However, Mann obtained a biological zero below which gametogenesis will not occur of 10.55 ^{o}C for the Pacific oyster and a tentative value of 6.75 ^{o}C for the Native oyster suggesting that the Native oyster will perform better in cooler waters.

Child and Laing (1998) compared the survival of juvenile Native and Pacific oysters at typical winter seawater temperatures for the British Isles. Two size groups of each species were maintained either unfed or with low algae rations at 3 ^{o}C, 6 ^{o}C and 9 ^{o}C for up to 11 weeks. The results showed that the majority of Native oysters survived for 11 weeks at all temperatures. However, whilst all the Pacific oyster spat survived at 9 ^{o}C and 6 ^{o}C, a mortality rate of over 95% mortality occurred after 3-7 weeks at 3 ^{o}C. This pattern with respect to differences in mortality levels was also reflected in better growth performance for the Native oyster at low temperatures.

Higher food cell consumption rates were obtained in the Native oyster at 9 ^{o}C than for the Pacific oyster and whilst fed Native oysters showed a small weight loss at 3 ^{o}C both fed and unfed Pacific oysters suffered a weight loss. Biochemical comparison showed that whilst the Native oyster metabolized glycogen at low temperatures the Pacific oysters metabolized protein as an energy source. In essence, Child and Laing (1998) demonstrated that the Native oyster is better suited to colder winter temperatures than the Pacific oyster.

As with the blue mussel, the Native oyster is a cold water species and is therefore under threat from warming seas. The Native oyster is protected within the UK Biodiversity Action Plan (UK BAP) and as such any potential species conflict with the Pacific oyster would have significant implications if a direct threat were demonstrated. Direct habitat competition between the two oyster species is somewhat limited as the Pacific oyster tends to inhabit the mid-lower intertidal range whilst the Native oyster is generally found sub-littorally in shallow estuarine environments (Fitter, 1984). As the Pacific oyster can be found in sub-littoral settings a potential for conflict could exist if settlement were widespread. Guy (2007) identified the need for a sub-littoral survey to study this relationship and is currently engaged in work within Strangford Lough in this respect (Claire Guy, pers. comm.).

Krassoi *et al.* (2008) studied the potential competition issues between the Pacific oyster and the native Sydney rock oyster and showed that at mid-low intertidal levels the Pacific oyster out grew the Sydney rock oyster with a 60% higher growth rate. In contrast, the Sydney rock oyster outperformed the Pacific oyster in the high intertidal zone owing to its greater resilience. The study concluded that there was scope for the two species to co-exist in their different ranges. It is uncertain whether a similar potential for coexistence can occur between the Pacific oyster and the Native oyster. Further work would be needed to investigate how wild Pacific settlement is likely to perform in a subtidal setting. It is recommended that a watching brief is maintained on the current scientific studies on this subject.

In summary, it is currently uncertain to what degree the two oyster species may compete in the natural environment. Climate change may well drive a shift in the less hardy Native oyster populations whilst the Pacific oyster may thrive. The future for the Native oyster in some regions could be uncertain, whilst the hope of strain selection to help overcome some of our Native species limitations may struggle due to limited research investment or insufficient time to act. It is recommended that the implications of climate change to the Native oyster should be considered further and incorporated within the UK BAP for this species.

2.6.3 Other Species;

In common with a number of bivalve species the common cockle (*Cerastoderma edule*) has been shown to suffer periodic massive losses in relation to summer mortality events. As with the blue mussel and the Native oyster it would appear as though the underlying population dynamics are more at threat from shifting environmental conditions due to climate change than the direct impact of the Pacific oyster.

Generally the Pacific oyster settles on hard substrates whilst the common cockle lives just below the surface within fine sandy mud environments (Fitter, 1984), therefore normally allowing little habitat overlap. However, the Pacific oyster has also been shown to settle on small particles in sandy or muddy sediments. Where this happens and if conditions are suitable, e.g. low energy environments, then individual oysters may eventually form clumps with other oysters thus stabilising the sediment below and allowing further recruitment. This settlement may therefore eventually lead to the formation of stable Pacific oyster reefs thus potentially excluding species such as the common cockle.

The presence of oysters close to cockle beds could have an impact upon commercial hydraulic dredge operations (Joss Wiggins, pers. comm.). Fortunately, the majority of the cockle beds occur on mobile sands within which the cockle is able to maintain its proximity to the sediment / water interface by active movement through the sediment. The Pacific oyster is less capable of such active movement in this environment and is therefore likely to be smothered so preventing establishment in these areas. It is concluded that although the potential for conflict may occur in some low energy environments the majority of commercial cockle beds will be unaffected by direct competition with the Pacific oyster.

The horse mussel *(Modiolus modiolus)* is a UK BAP listed species which has a more restricted range than the blue mussel. It is found mainly in northerly UK sites suggesting a requirement for a colder temperature regime. There are well documented deposits in the SAC protected waters of Strangford Lough. This site will be studied with respect to potential conflict with the Pacific oyster (Claire Guy, pers. comm.). As with the blue mussel the horse mussel is found in a subtidal environment and it unlikely to suffer direct conflict with intertidal Pacific oyster settlement although very little growth and reproduction data are available for this species to ascertain the extent of any potential threat.

2.7 Summary

Temperature profiles provide a good tool to assess risks and can help provide a tiered set of risk thresholds based on the reproductive stages of conditioning, spawning, recruitment and high level recruitment. These criteria based on degree days and whether the thresholds are attained within favorable summer conditions provide an easy guideline for spatfall 'potential'.

Confounding factors such as acclimation (which may allow recruitment more readily) or local hydrodynamic / food factors (which may retard recruitment) will influence conditioning, development and recruitment risk potential. A better understanding of these factors is required particularly for wild Pacific oyster populations operating at temperatures lower than the optimum conditions used within hatcheries. Ongoing research should be supported and monitored.

The use of temperature profiles in the UK on a regional and historical basis has been made possible by the use of national long-term temperature time series. Although these data sets are not directly representative of Pacific oyster culture areas they do provide a valuable illustration of trends and patterns.

Regional variation is dramatic. It is apparent from this study that some regions (such as Scotland and North East England) present a low risk. Other regions such as Northern Ireland, Wales and South West England present a moderate risk with episodic recruitment potential – particularly for inshore shallow areas. Southern England and South East England present a high level of risk for potential settlement on a regular basis.

Historical change is considerable. At the time of introduction the Pacific oyster presented little risk of recruitment to the wild. By the late 1980s only restricted shallow water areas in the South East of England presented a theoretical risk of recruitment. Global warming rates of 0.3 ^{o}C to 0.9 ^{o}C/10yrs have since been observed with a marked warming after 1989. The greatest warming has been observed in South East England – which was already the area of greatest risk.

Predicted change is also significant. Projections based on 0.4 ^{o}C/10yrs show that most moderate risk areas with intermittent recruitment potential are likely to suffer regular recruitment before 2040. The greatest predicted temperature rise is for the southern North Sea – yet again presenting a further risk increase to South East England. Further work is required to assess the risk more accurately and this could be achieved through the utilisation of the UKCIP08 predictions in autumn 2008.

Inter-comparison of inshore data sets for the Yealm and South Devon against reported spatfalls have shown an overall relationship suggesting episodic settlement associated with warmer years. Consideration of the local temperature regime in relation to cultured Pacific oyster stocks provides a straight forward baseline assessment of the potential for recruitment. However, there are a number of limitations to existing measurement regimes with either data gaps, bias or poor measurement resolution.

It is suggested that although the regional UK temperature profiles provided in this study give an overview of the regional risk, a definitive assessment of UK oyster conditioning will need to be supported by local high resolution temperature measurements. Temperature miniloggers are robust, relatively cheap and easy to maintain. A shellfish temperature monitoring programme could be cost effectively run in parallel with other site specific data requirements in accordance with the outline risk appraisal suggested for the POP.

The blue mussel and the Native oyster both perform better than the Pacific oyster in cooler waters. It is therefore likely that the temperature rise associated with global warming and demonstrated by the UK data in Section 2.4 will favor the Pacific oyster. Under an increased temperature regime the Pacific oyster is liable to out grow, out reproduce and out survive native species during extreme events.

The potential impact of the Pacific oyster upon other commercial species has been raised as a significant concern. The demise of the blue mussel in the Wadden Sea has been attributed by many to the spread of the Pacific oyster – however, the current scientific literature shows a more complex pattern with the blue mussel suffering losses before the Pacific oyster has spread. Mild winters have resulted in much greater crab predation upon newly settled mussel seed whilst favoring the Pacific oyster. This suggests that there is no simple direct relationship of two species competing for space and resources but instead suggests an underlying trend associated with climate change. Furthermore, it is possible that the Pacific oyster may fill an ecological niche left vacant by a native species in the face of global warming.

The Convention of Biological Diversity lists the five key threats to biodiversity as invasive alien species, climate change, nutrient loading/pollution, habitat change and overexploitation. The Global Invasive Species Network considers "Alien Species are 2nd only to habitat destruction as a threat to biodiversity" (see GISN website: http://www.gisp.org/index.asp). However, there is an increasing recognition that climate change is gaining in significance in its impact on both the environment and mankind.

Biello (2006) reviews the impact of global warming and points to climate change as rapidly becoming the most significant threat to biodiversity leading to catastrophic species loss. Mass extinctions are expected particularly for species with a narrow temperature tolerance such as within tropical or polar habitats. In August 2004 the European Commission described climate change as “one of the greatest environmental and economic threats facing the planet”.

The current study would seem to suggest that potential concerns raised by some invasive species issues have an underlying cause in climate change. It is recommended that further investigations are undertaken to more fully assess the potential conflict of the Pacific oyster with other commercial species and how these interactions are likely to develop in the face of global warming.

2.8 Recommendations for Future Work

Section	Work/Research Required	Action Taken During Current Study (where applicable)	Importance	Potential Organisation to Action or Participate	Possible Sources of Funding
2.8.1	Further industry monitoring of seawater temperature profiles is needed in order to provide accurate data for calculation of local degree day conditions. It is suggested that temperature data loggers are deployed at farm sites to obtain temperature profiles for comparison against inshore waters records.	30+ shellfish culture sites around the UK have been identified in the current study as potential areas for deployment of temperature loggers. Initial discussions with industry confirmed a willingness to become involved in this work.	Without adequate data the precautionary principle approach may be adopted with respect to commercial activities. This risks problems for industry when renewing leases/licenses, expanding or modifying operations or developing new sites. UKCIP08 will shortly provide high resolution marine & terrestrial grid climate change predictions for the UK. These could be applied on a local level if this type of site specific temperature data was available.	- Industry - SNCAs	- European Fisheries Fund - SNCAs - Seafish - Industry
2.8.2	The potential affects of climate change on commercial shellfish species requires assessment. Such work should evaluate the likely impacts of Pacific oysters on other commercial species in the future; implications for the Native oyster should be considered and incorporated in the BAP; potential for impact on blue mussel stocks and fisheries in the UK.	The complexity of interactions between species with respect to changes in seawater temperatures due to climate change has been highlighted in this study.	The example of the decline of blue mussel stocks and increase in Pacific oysters in the Wadden Sea is an example of the complex nature of the affects that climate change may play in the future with respect to commercial shellfish species. A UK evaluation of threats or opportunities should be considered.	- SNCAs - SAGB	- EFF

2.8.3	South East Case Study – significant settlement of wild Pacific oysters has been identified in the Brightlingsea and Southend areas. These areas would provide a good opportunity to assess large scale wild settlement in a UK context in terms of year classes, proximity to farms, local hydrographic data and local seawater temperature profiles etc.	Contact made with Kent and Essex SFC to discuss known areas of wild settlement.	Most literature reports for the UK have cited the South West as the 'hot spot' for wild settlement. Section 2 shows that the South East is in fact more at risk from wild settlement. Further in-depth analysis is needed of possible origins of wild settlement in this region e.g. local or European.	- Seafish - SNCAs - SAGB	- EFF - Seafish - SNCAs
2.8.4	National survey program of the distribution and abundance of Pacific oysters in UK waters. This work could incorporate a spatfall monitoring program.	Need for this work has been highlighted through the SAGB Mollusc Committee.	Without baseline data concerning levels of wild settlement of Pacific oysters it is impossible to monitor changes in numbers or dispersal over time. A national survey would also help with assessing the impacts of climate change. The addition of annual spatfall monitoring at selected regional sites would further help inform decision making.	- SAGB - SNCAs - Industry	- EFF
2.8.5	Analysis of the potential economic impact of Pacific oyster settlement on existing commercial beds for other species.	Competition with other wild species has been considered in this report.	If large scale wild settlement of Pacific oysters were to occur this may remove existing fisheries or exclude fishermen from undertaking harvesting e.g. by raking/hand gathering.	- Seafish - SAGB - Industry	- Seafish - SAGB - EFF

2.8.6	Refinement and updating of regional temperature profile risk assessments for historical and predicted temperatures: - UKCIP08 predictions are due to be released in autumn 2008 which will allow the temperature profiles to be updated in light of the latest predictions of likely changes due to climate changes. - More comprehensive historical temperature records covering the period since the 1980s could be obtained using available satellite data - Further work is needed to refine the 'biological zero' and spawning and settlement degree days that are relevant to Pacific oysters in UK environmental conditions.	- Routes to help increase the accuracy of the historical profiles and to update the future predictions have been identified. - Researchers active in the field of Pacific oyster acclimation have been identified.	- UKCIPO8 predictions will give industry, SNCAs and managers the latest predictions of likely seawater temperature changes due to climate change. - Satellite data has the advantage over the CEFAS Inshore Temperature Network used in this study that it can provide better spatial and temporal levels of resolution of offshore sites close to culture areas. - Refining the biological aspects (together with historical & predicted temperatures) of the prediction forecasts for likely spawning and settlement events will help increase the accuracy of the evaluation of risk on a regional basis.	- SNCAs - SAGB - Seafish	- EFF - Seafish - SNCAs

SECTION 3 – INFLUENCE OF FARM TYPE & REGION ON SETTLEMENT SUCCESS

3.1 Influence of Culture Type on Settlement Success

3.1.1 Introduction;

As part of this study a review was carried out of the literature surrounding the possible role that farm or culture type might have on the reproductive state and subsequent spawning and settlement of Pacific oysters. This literature review highlighted that whilst work has been carried out on the reproductive state and likely spawning events, little work seems to have been carried out to assess if the farm or culture type has an influence on success at settlement.

3.1.2 Parc Culture versus Bag and Trestle;

A comprehensive research program was carried out by IFREMER on the culture of the Pacific oyster in the Marennes-Oléron Basin which is described in Goulletquer *et al*. (1998). This study was primarily focussed on investigating the underlying factors of summer mortality in this growing region which mostly effects bottom or Parc cultured oysters within the intertidal zone. This research showed that loose spread 'on-bottom' cultured oysters had a higher total weight, dry meat weight and condition index (C.I. = 100 x fresh meat weight / total weight) compared to 'off-bottom' culture on trestles. On-bottom oysters also reached peak sexual maturation sooner than off-bottom oysters (early June vs. early July respectively). An analysis of the C.I. shows that on-bottom oysters experienced a rapid rise between early May and early July after which a slight downward trend develops followed by a steep decrease in C.I. after late July.

For off-bottom oysters the C.I. increases steeply after early June and continues to rise until late July although the rate of increase decreases through July itself. The C.I. then drops after late July as with the on-bottom oysters. Gagnaire *et al*. (2006) in similar work carried out in the Marennes-Oléron Basin described an active gametogenesis period as May to 20th June, ripe gamete period as 20th June to 8th August and a post-spawning period as 8th August to 11th September which would seem to roughly match the change in C.I. described by Goulletquer *et al*. (1998).

It appears therefore that on-bottom oysters in this region reach sexual maturity sooner than off-bottom oysters, attain a greater flesh weight and start spawning earlier than off-bottom oysters. Another factor shown by Goulletquer *et al*. (1998) is that the oysters placed on the sediment experience greater temperature changes in July and August than that experienced by oysters in the more stable environment of the trestles. This could well therefore provide a trigger mechanism for inducing the on-bottom oysters to spawn.

Taken together this research would seem to indicate that in the Marennes-Oléron Basin, Parc cultured oysters when compared to oysters grown on trestles are producing more gametes and that these gametes are released earlier than the trestle culture oysters. This therefore means that they are likely to have a better chance of successfully settling either on the spat collectors or as part of a wild population.

In trials carried out in a South West of England estuary by Robbins (2005) which compared growth rates of Pacific oysters in bags placed either on trestles or on the substrate no significant differences were found in size or weight over time between treatments although the oysters placed on the substrate were marginally larger than those on the trestles.

It is however difficult to directly compare the results from Goulletquer *et al*. (1998) and Robbins (2005) as in the former the oysters were spread loose on the substrate whereas in the latter the oysters were retained within the bags and so may have been subject to some form of density effect. Overall therefore it seems that Parc or bottom culture in the intertidal zone is likely to result in increased growth rates above that which will be exhibited by Pacific oysters held in bags on trestles and so may well result in a greater reproductive effort by those oysters.

3.1.3 Effects of Emersion Time on Likelihood of Spawning;

As part of the work by IFREMER in the Marennes-Oléron Basin described in Section 3.1.2, growth and reproduction of on-bottom cultured Pacific oysters were studied at three intertidal levels equating to 12%, 29% and 46% emersion (Goulletquer *et al*., 1987). They concluded that the seasonal changes in the ash-free dry weight showed correlations between the quantity of gametes released and the immersion times whereas somatic growth was less variable. Reproductive effort (gonadosomatic index) increased from 43% to 87% when immersion times of 13 hours to 21 hours per day were compared i.e. reproductive effort is proportional to the length of immersion time. They also found that when comparing oysters at the same level of exposure, the allocation of resources to reproduction was a priority in oysters older than 2 years, with that allocation increasing with age. Therefore in this example the degree of emersion or exposure was shown to have a significant effect on the level of spawning likely to occur.

Research by Spencer *et al*. (1978) carried out in the Menai Straits (North Wales) on the effects of exposure on the growth of Pacific oyster seed showed that live weight and dry meat weight were reduced with increased exposure to air. Whilst oysters cultured in trays and exposed for 0-10% of the time to air showed only small differences in live weight and dry meat weight, exposure over the range of 10-30% led to a significant reduction in growth rate. Research by Handley (2002) in New Zealand with Pacific oysters grown on sticks attached to racks also found that growth increased with decreasing aerial exposure from the top of the racks to extreme low water neap (ELWN). From this it might be inferred that in this North Wales location, oysters placed lower on the shore would have more chance of reaching spawning condition than those placed in a more exposed site.

For a site such as the Menai Straits where the degree day conditions necessary for settling are only experienced infrequently then this would have implications in terms of which type of site is more likely to have the potential to lead to wild settlement of Pacific oysters. However later work by King *et al*. (2006) at ‘high shore’ and ‘low shore’ sites on the Menai Straits reported findings that contradict this position. King *et al*. (2006) found that there were no significant differences in growth between the oysters held at the high and low shore sites although condition index (tissue dry weight / shell dry weight / x 100) was significantly higher at the high shore site than the low shore site.

Gonad development was limited but was significantly higher at the high shore site when compared to the low shore site. Whilst gonad development did not generally reach the ripe or spawning stage at the high shore site, and resorption was in evidence, the high shore site had significantly more sexually mature animals and fewer undifferentiated than expected. King *et al*. (2006) concluded that the differences between their study and the earlier work by Spencer *et al*. (1978) were probably due to higher infestation rates in the low shore oysters with *Polydora* sp. together with higher levels of fouling of the bags at this low shore site. In terms of bag and trestles versus Parc culture, the research carried out by King *et al*. (2006) using oyster bags when compared to the work of Goulletquer *et al*. (1987) with on-bottom oysters also highlights that the degree of fouling of the oyster bags may well influence the availability of food and consequently the amount of energy resources that can be dedicated to the reproductive effort.

The work by IFREMER suggests that in general the longer the immersion time where food availability and temperature are not limiting then the greater will be the availability of energy resources for reproduction and so the greater the levels of gametes produced. In a UK context in terms of the possible use of exposure as a management tool for preventing wild settlement of Pacific oysters where degree days may be limiting, it can be seen that the impact of the extent of exposure can however be either highly site specific or may vary over time. Therefore the use of exposure as a management measure is unlikely to provide an effective method for eliminating the risk of spawning events in Pacific oysters.

3.1.4 Subtidal and Suspended Culture versus Intertidal Culture;

The above summaries of research on Parc or bottom culture versus bag and trestles and the effects of exposure would logically seem to indicate that subtidal culture, where oysters are spread on the seabed, will result in higher growth rates and therefore greater reproductive effort than oysters reared in an intertidal location. However in research on *Crassostrea virginica* by Gillmor (1982) comparing growth rates subtidally and intertidally, the oysters cultured intertidally showed the greatest growth rate. This research reported that *C. virginica* showed abilities to supplement energy input such that growth per unit immersion time was better at certain intertidal levels than subtidally. Moroney and Walker (1999) also carried out research on the effects of differing tidal and bottom placements on the growth of *C. virginica*. This work showed that subtidal on-bottom oysters exhibited significantly lower growth than oysters cultured intertidally off-bottom.

Work by Handley (2002) in New Zealand found that Pacific oyster racks placed 0.5m below ELWN showed lower growth than those placed at the level of ELWN although this was not on-bottom culture. However, Sumner (1981) reports that Pacific oysters grown subtidally on longlines exhibited faster growth rates than intertidal oysters. As the Pacific oyster's natural settlement range can be both the lower littoral and shallow sublittoral zones then it seems possible that a degree of aerial exposure may in fact be required for optimal growth. However the scarcity of relevant research that was found with regards to the relative effect of subtidal versus intertidal culture makes it difficult to draw firm conclusions in this respect.

In terms of the suspended culture of Pacific oysters, differences in the levels of available food and differing temperatures between depths will have a major influence on the amount of energy available for allocating to the reproductive effort and the speed of development of that effort. The effect of culture depth on the reproductive effort of Pacific oysters has been studied by Ngo *et al*. (2006). They compared the reproductive output of oysters placed in the top 1 to 2m of seawater with oysters placed at 3 to 5m in depth as part of a suspended culture system. Water temperature in this bay in Korea was 2 to 3 ^{o}C higher at the surface oysters than at the 3 to 5m point during the early spring to mid-summer period. Phytoplankton levels were also higher at the surface during March and April due to a spring bloom in the bay.

Ngo *et al*. (2006) report that compared to the lower placed oysters the surface oysters produced more gametes during the spring to early summer spawning period and that the gonadosomatic index (GSI) was significantly higher. The deeper oysters had a higher GSI in late summer than the surface oysters which suggests that spawning at the lower depths is more extended. However no conclusions could be drawn as to whether or not these eggs produced in late summer would add significantly to larval recruitment in the bay.

3.1.5 Further Work;

As mentioned previously, little research appears to have been undertaken on the influence of farm or culture type on success at settlement and recruitment of the Pacific oyster. Francis O'Beirn (Marine Institute, Galway, pers. comm.) confirmed that in preparation for a recruitment and gametogenic study comparing intertidal and subtidal Pacific oysters they have been able to find little information about this subject. Their planned project that is due to commence in 2008 is summarised in the following abbreviated extract from the International Conference on Shellfish Restoration held in 2005 (O'Beirn *et al*., 2005);

"The Pacific oyster, *Crassostrea gigas*, has been cultured successfully in Ireland for approximately 30 years. Typically it has been cultured intertidally using conventional bag and trestle systems. More recently some licences have been issued permitting cultivation of oysters subtidally in plots directly on the seafloor. There are a number of advantages for the grower with this arrangement in that it makes considerably more space available for culture, the subtidal location may increase oyster growth rates and performance, and the infrastructural requirements and operational costs are considerably reduced. On the other hand, however, the practice of culturing oysters directly on the seabed could result in the uncontrolled expansion of naturalised populations of *C. gigas* in Ireland as has been documented in The Netherlands and Germany. Initial assurances that conditions in Ireland (i.e. low water temperatures) would not support successful reproduction of oysters have proven to be unfounded, with the documentation of full gametogenesis in *C. gigas* throughout Ireland and the discovery of newly settled oyster spat in the wild in Counties Donegal and Galway. A number of additional perceived risks have also been identified. These risks include, inter alia, competitive exclusion of populations of the Native oyster (*Ostrea edulis*), the risk of introduction of alien or nuisance species on seed oysters and the alteration of benthic communities by the addition of oysters that may influence the trophic status and structural complexity of the area. While some of the risks might be mitigated by the culture in areas where *O. edulis* do not occur, or the use of triploid oysters originating from hatchery sources, even these measures (along with any others) will require targeted research to fully evaluate their efficacy. [*The planned project will be*] a culture trial that will incorporate targeted research to address the concerns and evaluate the risks associated with the practice [*of bottom culture*]. The expected outcome will be a full risk evaluation of the culture of *C. gigas* on the seafloor in Ireland that will provide scientific based management advice to the licensing process."

This study, which it is understood will run for three years, should do much to help in understanding the role that the type of shellfish culture activity may play in the possible development of wild populations of Pacific oysters in European waters.

Some work is being undertaken in the UK in this respect (see Appendix 1) by the Marine Biological Association where an investigation is being undertaken of emersion and immersion times with temperature as it relates to gametogenesis of Pacific oysters in the Yealm Estuary in South West England. However this is only a pilot scale project for one site and so a wider geographic study in this respect would prove valuable in understanding the effect that UK environmental conditions have on the reproductive effort of the Pacific oyster. To be effective any such future work should target both oysters in wild populations and those held in differing culture conditions.

3.2 Questionnaire

3.2.1 Introduction;

When the Project proposal was drafted it was originally intended that following the literature review the interpretation in a UK context of the role of farm type and stocking regime in relation to wild settlement would be based upon responses from industry to a detailed questionnaire survey that would be distributed to all registered Pacific oyster shellfish farms. After concern from oyster growers on the level of detail requested (at SAGB Technology and Training Committee meeting), it was decided that a more basic questionnaire should be sent to industry to help guarantee a reasonable level of response (see Appendix 4). The primary aim was to establish whether industry was experiencing any wild settlement of Pacific oysters in their local area and if so whether this was then being used commercially.

The change in level of detail requested from industry has meant that it has not been possible to make any proper judgements about the relative influence that farm type or stocking regime may play with respect to levels of wild settlement. Investigations as part of this project have however established that the Irish Marine Institute is currently about to undertake a three year study looking at these aspects of wild settlement of Pacific oysters (see Section 3.1.5). Terence O'Carroll of Bord Iascaigh Mhara (BIM) confirmed that recently the Marine Institute had objected to the issue of licences to the Irish industry to undertake bottom culture of Pacific oysters based on the possibility of the increased potential for wild settlement. The Irish Shellfish Association's response was that there was no firm proof that this culture method encouraged wild settlement and so the Marine Institute agreed to withdraw their objections on this basis. This aspect of farm type and stocking density with respect to wild settlement of Pacific oysters is therefore one aspect of the study that the Marine Institute is undertaking as part of their research.

3.2.2 Methodology;

A questionnaire was agreed between the industry partners that requested information on general location of farm sites; main type of farming activity; standing stock; area in hectares; evidence of wild settlement and whether any commercial utilisation of wild settlement took place. In order to reach as many industry members as possible it was agreed that the questionnaire and covering explanatory letter would be sent out by Centre for Environment, Fisheries and Aquaculture Science (CEFAS) to all registered Pacific oyster farms. Replies from industry were sent back to the SAGB by way of a stamped addressed envelope. This gave excellent coverage of the industry but meant that due to Data Protection issues the project team were not able to review the list of farms to which the questionnaire had been sent. This obviously meant that it was also not possible to follow up on responses other than to those who replied to the questionnaire and indicated that they were happy to discuss further.

The questionnaire sent out by CEFAS covered all farms in England and Wales but not those of Northern Ireland. In order to cover the Pacific oyster producers in that region the Aquaculture Initiative were contacted to see if they could help in this respect. The Aquaculture Initiative agreed to undertake this role on behalf of the project and subsequently contacted all Northern Irish producers on their records. They then subsequently collated and returned the completed questionnaires to the project team. Once the questionnaire responses had been analysed each respondent was then contacted for a more detailed discussion of the answers that they had supplied. These questions included establishing more details about their type of culture operations, experiences with triploid oysters, previous work regarding temperature monitoring, willingness to participate in further research and general industry feedback on this subject area. Where these responses are available details of culture type are included in the Results Section 3.2.3 and more general comments are included in the regional review of the Discussion Section 3.2.4.

For the purposes of this research the South West of England was taken to include Cornwall, Devon and Somerset. Southern England was considered to be Dorset to West Sussex inclusive. The South East of England was classed as East Sussex to Kent inclusive. Eastern England was taken to include Suffolk and Lincolnshire. Where utilisation of wild seed was undertaken by industry this was assumed to be diploid in origin.

The questionnaire was sent out to 100 registered shellfish farms in England and Wales utilising the CEFAS records. Discussions with CEFAS have indicated that of the 100 registered farms it is unlikely that all would still be involved in actual production of Pacific oysters. Of the 100 questionnaires that were sent out 27 replies were received for England and Wales together with two written replies covering the broader issues surrounding the questionnaire. Of these replies 21 actual questionnaire responses, covering 27 farm sites, were deemed suitable for further analysis. Of the 27 sites, 9 were located in South West England; 1 in Southern England; 9 in South East England; 5 in Eastern England and 3 in North Wales. Six replies covering 6 sites were received for Northern Ireland. The total number of sites analysed therefore for the purposes of this study was 33. A percentage system has been used in the following Results Section 3.2.3 to describe a national overview and differences in findings between regions. The number of sites analysed is therefore stated for each section in order to indicate the level of confidence that can be ascribed to the results.

3.2.3 Results;

3.2.3.1 National overview (based on 33 sites): Of the replies received to the questionnaire covering 33 sites in total, 64% of farm sites were exclusively located in the intertidal area; 6% were exclusively subtidal and 30% were a combination of both intertidal and subtidal farming activity. Follow up to the questionnaire showed that most sites (64%) utilised the bag and trestle system of cultivation with approximately a quarter (27%) practising exclusively seabed culture. Only 9% of sites had both bag and trestle and seabed cultivation of Pacific oysters.

The majority of farms utilised diploid seed (67%) exclusively although for the purposes of this questionnaire this was also taken to include farms which relied on wild settlement of Pacific oysters. Against this only 12% of farm sites were based on exclusive use of triploid seed. Approximately a fifth (21%) of respondents however already used a combination of diploid and triploid seed in varying proportions.

In terms of standing stock of Pacific oysters on farm sites, 24% of sites had 0 to 10 tonnes stock and 27% had between 10 to 20 tonnes standing stock indicating that 51% of all farm sites had less than 20 tonnes standing stock at any one time. Only 12% of sites had between 20 to 40 tonnes of stock and 37% of sites had in excess of 40 tonnes standing stock giving a total of 49% of sites with in excess of 20 tonnes standing stock at any one time.

The majority (55%) of farm sites were less than 5 hectares in total size with 24% of sites covering between 5 to 10 hectares. This means that 79% of the farm sites analysed in England, Wales and Northern Ireland were less than 10 hectares in total size. With respect to the larger farms 9% were between 10 to 15 hectares and 12% were considered to be greater than 15 hectares in size.

In terms of settlement of Pacific oysters in the local area around the farm sites 55% of respondents reported that no wild settlement had been observed. Of those areas where settlement was in evidence over three-quarters of this settlement (77%) was of individual oysters rather than reefs. These individuals were generally reported to be a mixture of juvenile and adult oysters.

Where wild settlement did occur in the local area near farm sites then most (87%) of these wild populations were the subject of regular monitoring. Of these monitored areas 60% of respondents reported that they had observed regular settlement. It should be noted that these figures regarding regular settlement relate mainly to the South East of England which is considered in more detail in the Regional analysis. Indeed this was the only region where wild seed was utilised for on-growing or relaying.

One final point is that of the questionnaire replies that were received the respondents all indicated that they would be happy to discuss the matter of wild settlement of Pacific oysters in more detail.

3.2.3.2 South West of England (based on 9 sites): The majority (67%) of respondents from the South West had farm sites located in the intertidal zone. The other sites were all a mixture of intertidal and subtidal culture. This is reflected in the type of culture practised which is in proportion to the location of sites with two-thirds based on bag and trestle culture (see Figure 29) and one third on mainly subtidal seabed culture.

Of these sites 44% used only diploid seed whilst 12% used only triploid seed. However 44% of sites used both triploid and diploid seed although the use of triploid seed was generally a new practise. The standing stock of Pacific oysters was spread between the various tonnages at 12% in 0 to 10 tonnes; 22% in 10 to 20 tonnes; 22% in 20 to 40 tonnes and 44% at over 40 tonnes. The majority of farms (67%) were in the 0 to 5 hectare range with one-third (33%) in the 5 to 10 hectare range.

Figure 29*. South West of England intertidal Pacific oyster farm site*
Farm is situated in an estuary location using bag and trestle culture technique

In terms of wild settlement of Pacific oysters 45% of respondents reported no settlement in their local area. Of the remaining sites where settlement was observed this related mainly to individual settlement of both juvenile and adult oysters (44%). All sites where settlement occurred were monitored with the majority of replies (80%) indicating that settlement was irregular. As such there were no reports of any growers utilising wild seed settlement or deploying spat collectors.

3.2.3.3 Southern England (based on 1 site): Only one questionnaire response was received from farms in the South of England. The site for which information was obtained was however a large subtidal farm of over 15 hectares practising seabed culture with a standing stock of diploid oysters in excess of 40 tonnes. No wild settlement was reported for this farm site.

3.2.3.4 South East England (based on 9 sites): The farm sites for which questionnaires were received in the South East were dominated by sites where both intertidal and subtidal culture was practised. Only 22% of sites were wholly intertidal. Follow up to the questionnaire showed that these sites were all based around seabed culture of Pacific oysters i.e. both intertidally and subtidally.

The dominant seed type was diploid at 78% whilst 22% relied exclusively on triploid seed. There were no reports of the use of both diploid and triploid seed. The standing stock levels of oysters were predominantly over 40 tonnes (45%) whilst 22% of farm sites were in the 0 to 10 tonne range and 33% were of 10 to 20 tonnes standing stock. Most of the farm sites (56%) were in the 0 to 5 hectare size range with 11% each in the 5 to 10 and 10 to 15 hectare size whilst 22% of sites were over 15 hectares.

All respondents in the South East had observed wild settlement of Pacific oysters of which the majority were made up of both individual juvenile and adult settlement at 82%. There were also reports of reefs (18%) consisting of both juvenile and adult oysters. Most respondents (89%) monitored wild settlement of Pacific oysters. The importance of wild settlement and why it is closely monitored becomes obvious when looking at the level of wild seed utilisation. In total 67% of respondents utilised wild settlement for on-growing or relaying and there was one report of a site where spat collectors were actually deployed as a means of collection, an approach used widely in some of the Pacific oyster producing regions in France. The South East was in fact the only region in the UK that reported any commercial use of wild settlement.

3.2.3.5 Eastern England (based on 5 sites): All respondents in Eastern England reported that their farm sites were intertidal. This is reflected by the fact that all farm sites were undertaking bag and trestle culture. Of these sites there was a fairly even split between the use of diploid, triploid or both triploid and diploid seed at 40%, 10% and 40% respectively.

In terms of standing stock 60% were in the 0 to 10 tonne range and 40% were in the 10 to 20 tonne range i.e. there were no farm sites greater than 20 tonnes standing stock. The majority of these sites (80%) were of 0 to 5 hectares in size whilst 20% were 5 to 10 hectares. None of the respondents had observed any wild settlement of Pacific oysters in their local area.

3.2.3.6 North Wales (based on 3 sites): The farm sites covered by the questionnaire responses received were all located in North Wales. Of these, two sites were intertidal and one site was located subtidally. The predominant form of culture activity was the use of bag and trestles. All these sites currently use diploid oyster seed. Two of the three sites had 0 to 10 tonnes standing stock with the other site falling in the 10 to 20 tonne standing stock bracket. Of the three sites two were 0 to 5 hectares in size whilst the other was between 5 to 10 hectares. One site was noted as having had juvenile settlement although this was not noted as being a regular occurrence.

3.2.3.7 Northern Ireland (based on 6 sites): All of the Northern Irish sites covered in questionnaire replies were intertidally based with the majority (83%) of the sites using diploid seed whilst the remaining site utilised both triploids and diploids. The majority of sites (80%) were based on the use of the bag and trestle system whilst one site utilised seabed culture where the oysters are placed on plastic matting.

Standing stock was generally in the over 20 tonne category with only one site in the 10 to 20 tonne range. Of the larger standing stocks two sites (33%) were reported as holding 20 to 40 tonnes and three sites (50%) held over 40 tonnes of Pacific oysters. Production area was mainly in the 5 to 10 and 10 to 15 hectare range (33% each) with one site each in the 0 to 5 and 15+ hectares range. None of the respondents reported wild settlement of Pacific oysters in their local area on their questionnaire responses.

3.2.4 Discussion;

3.2.4.1 Introduction: As reviewed in Section 3.2.1 the level of detail requested in the questionnaire has limited the extent to which conclusions can be drawn about the role that farm/culture type or stocking density may play with respect to successful wild settlement of Pacific oysters in the UK. The basic level of detail requested regarding the farm locations also made it difficult to identify individual Marine Protected Areas (MPAs) that may possibly be impacted by wild settlement of Pacific oysters. This lack of detail combined with the scale of work required by other tasks within this project has meant that it has been beyond the scope of this short-term study to adequately explore this subject area. It has therefore been suggested that further work should be undertaken by way of collaboration between industry and the statutory nature conservation agencies to determine the main species of, and species in, MPAs in the UK that may possibly be affected by the culture of Pacific oysters.

The questionnaire responses showed that the Pacific oyster industry in England and Wales is, numerically at least, characterised by small producers. Most farms are located intertidally and utilise diploid seed. Standing stock levels over all questionnaire responses are split fairly evenly between the ranges with 51% of sites falling within the up to 20 tonne category and 49% in the over 20 tonne range. The majority of the sites were however less than 10 hectares in total size.

Where wild settlement did occur the majority of this was made up of individual juvenile and adult oysters. An analysis of the respondents' data regarding wild settlement shows that settlement only occurs in any significance at present in the South West and South East of England. Of these two regions the South West settlement tends to be only sporadic following very warm summers such as 1990 when settlement occurred for example in the Exe (David Jarrad, pers. comm.) and 2004 when settlement could be found on the Yealm (Martyn Oates, pers. comm.). The South East by comparison is experiencing regular settlements of wild Pacific oysters to the extent that this has become an integral part of the commercial operations of the growers in that region. When considering the different regions covered by the questionnaire it appears that the findings with respect to the wild settlement of Pacific oysters in England and Wales are very much in accordance with that predicted by the temperature profile analyses contained in Section 2.4 of this report. The final part of the questionnaire requested any other comments that industry may have which together with the detailed follow up interviews yielded more information about industry practises and experiences with respect to Pacific oysters:

3.2.4.2 South West of England: One respondent from the South West of England stated that their area had previously experienced a small settlement in 1990 but that genetic evaluation carried out on that settlement (Child *et al*., 1995) showed that these oysters were not of local origin and had genetic traits characteristic of hatchery-reared oysters from France. There does however appear to be uncertainty about how these Pacific oysters of possible French origin may have arrived in a South West of England estuary (JNCC, 2008). Other responses highlighted the sporadic nature of wild settlement of Pacific oysters in the South West. For instance on the Camal Estuary where Pacific oyster culture has been undertaken for 25 years there are no signs at present of any wild settlement.

Respondents were generally open to the idea of using triploid seed. Two farms were undertaking trials with triploids during 2008, one using seed from Guernsey Sea Farms and the other using half-ware oysters from Jersey. Two farms already use triploids, of which for one, triploids are their only type of oyster produced. There was however some concerns raised about whether triploids would grow too fast for current husbandry practises and with respect to ending up with an oversize product. One respondent did however state that they were not keen on 'GMOs' (see Section 4.7 for further discussion of this issue). There was some comment about dealings with the SNCAs in that there seemed to have been a general hardening of stance by SNCAs with respect to Pacific oyster cultivation activities in MPAs.

3.2.4.3 Southern England: The farm for which a questionnaire response was received on the South coast indicated in a follow up interview that they had previously tried triploid oysters but that "the last thing we need is an oyster that grows faster!" The respondent thought that their oysters probably would spawn in local conditions but that the lack of local wild settlement was probably due to predation by crabs.

3.2.4.4 South East England: The culture of Pacific oysters in the South East appears to be primarily centred around seabed culture both intertidal in Parcs and subtidal with more than two-thirds of the growers in this region utilising wild settlement of Pacific oysters as the source of seed in their operations. Chain harrowing is carried out by at least two respondents in order to help ensure marketable shaped oysters. Dredging was then commonly used to harvest both market size Pacific oysters and in some instances smaller oysters for on-growing on private beds. Wild Pacific oysters are now considered so abundant in many areas that the best oysters are "cherry picked" when dredging. In many ways this form of bottom culture is viewed by these growers as just a continuation of their traditional activities from when they were more intensively involved in harvesting Native oysters.

The availability of Native oysters has been severely impacted since the severe winter of 1963, and as such, industry in this region were early adopters of the use of Pacific oysters to replace the shortfall of Native oysters. There was a general feeling amongst respondents that it was better to "now have a resource in estuaries that had previously been barren" following the severe decline in Native oyster numbers. One respondent stated that they had "first noticed wild *gigas* 10 to 12 years ago but that it was only in the last 4 to 5 years that these wild populations had exploded". It was interesting to note that the use of the term 'wild *gigas*' was common amongst respondents from this region. The use of spat collectors had been tried by one respondent, who was due to carry out further trials in 2008.

One respondent stated that from 2009 their on-growing operations will be entirely based upon wild settlement of Pacific oyster seed i.e. with no reliance on hatchery produced stock. Their company had taken receipt of half-ware diploid oysters up until the end of 2007 but this was only as part of a winding down process with their current supplier. They are in fact the last grower in that area still to be utilising hatchery seed as "everyone else has been on natural *gigas* for the last 2 years". Their company is one of only two respondents who were still using triploid oyster seed although the other grower stated that hatchery produced seed did provide a better shaped oyster. However in the face of so much wild seed availability it seems very unlikely that these growers will resort to purchasing seed, either diploid or triploid, in the future.

One respondent offered some particularly detailed insights into the development of wild settlement of Pacific oysters over the last few decades. The respondent had been involved with farming first Portuguese and then later Pacific oysters for 40 years as well as fishing for Native oysters during this time. He stated that originally 'wild *gigas*' occurred as individual oysters which they harvested and on-grew themselves or sold to other growers. As numbers of these oysters have increased they have formed agglomerations that are difficult to separate into individual oysters and are uneconomic to break open for just the meats.

In the last 2 years whilst dredging for Native oysters he has witnessed large numbers of these subtidal Native oysters with Pacific oysters attached to them, which is something that he had not experienced in the last 30 years. He gave other examples of seeing Pacific oysters settled on shore crabs and detailed areas in the region where wild Pacific oysters could be found in very high densities. One such area was the Southend foreshore, where on following up this information, it appears from survey estimates (Wiggins, 2004) that as far back as 2004 there was in excess of 400 tonnes of oysters, which are reported to have now grown in numbers since this last survey.

Of interest also were general comments from South East growers who pointed out that regular working and harvesting of wild beds of Pacific oysters would stop reef building and thus would "turn what could be deemed as a pest into a marketable product". There were also calls for help with selling this product rather than restrictions being placed upon industry. When asked about the potential for halting this increase in wild settlement or removing these oysters none of the respondents believed that this would now be possible.

3.2.4.5 Eastern England: No wild settlement of Pacific oysters had been reported by respondents in Eastern England. These respondents in The Wash region stated that they thought this might be "due to the bottom being too muddy for Pacific oysters to colonise". This explanation was also given for a site in Suffolk which is just above the delineation used to describe the South East in this study. This site was unable to use the traditional bag and trestle system as these were prone to silting up and so were now using Australian oysters baskets suspended from wire between wooden posts. Further investigations of seawater temperatures on farm sites in this region would be useful in order to help try and explain the apparent differences between this area and the South East in terms of wild settlement.

3.2.4.6 North Wales: Welsh respondents stated that they have seen wild oysters up to 3 miles from farm sites but that settlement was only very sporadic. This would fit in with previous surveys of the Menai Straits area (Spencer *et al*., 1994) that described wild settlement as the result of warm summers in the late 1980s and early 1990s. One respondent stated that in 14 years of growing oysters in the Menai Straits they had only witnessed two spawning events, both in late summer and in each case they had not seen any settlement as a result of these. During 2008 both respondents in this region are scheduled to take part in trials utilising triploid seed. These trials are being funded by the Countryside Council for Wales (CCW) due to concerns they have about the potential for future wild settlement of Pacific oysters through aquaculture activities. Furthermore these trials are being linked to the decision regarding the renewal of current aquaculture activities as part of the Fishery Order for the western Menai Straits which expired in spring 2008.

3.2.4.7 Northern Ireland: None of the respondents had witnessed any wild settlement of Pacific oysters in their local area although there was comment that there had been some reports of limited wild settlement within Strangford Lough. Pacific oysters were introduced into Strangford Lough in 1970 by DANI (Guy, 2007; Roberts *et al*., 2004) and have been farmed there since 1971 (Industry, pers. comm.). One industry respondent stated that it was "only in the last 5 years that some individual live *gigas* have been found intertidally off Rainey and Reagh Islands… but numbers in this area were no more than 1-3 per year". Further investigation revealed that previous survey work by industry in connection with Native oyster regeneration efforts that had taken place up to 2 years ago had not shown up the presence of wild Pacific oysters, although one respondent believed that researchers may have found some settlement on the shores of the Lough. This was subsequently shown to be the case following discussions with Claire Guy at The Queen's University Belfast. Guy (2007) has shown that spat and adult Pacific oysters have been observed in several locations around the Lough and are therefore no longer confined to the areas where Pacific oysters were introduced as part of commercial on-growing. However an analysis of the size classes present showed that successful spawning events were intermittent.

With respect to triploids, one respondent already used them but only in limited quantities so as to be able to offer good condition oysters to customers at times of the year when diploid oysters are too milky. They stated that they felt that triploids "can be prone to mortalities if handled at the wrong time of the year". The potential for mortalities was even felt to apply when transporting triploid oysters to market. Other respondents who had not previously cultured triploid oysters also expressed these concerns regarding mortalities when handling triploids at certain times of the year.

3.2.5 Conclusions;

- Further work should be undertaken to determine the main species of, and species in, MPAs in the UK that may possibly be affected by the culture of Pacific oysters;

- An investigation should be carried out into the South East of England wild settlement to see if with modern genetic techniques whether a more accurate determination could be made of the origin of the wild settlement in that region. This has been included as a recommendation for further work (see Section 3.7 and Appendix 1 re. SEAFARE). Linked to this should be an investigation of the residual currents in the eastern English Channel to ascertain if this settlement could have originated through larval drift from the Continent;

- All respondents to the questionnaire who were contacted as part of the follow up interviews confirmed that they would be willing to consider participating in further work on this subject area. These respondents were asked specifically if they would consider deploying temperature data loggers on their farm sites as part of a national monitoring programme and all confirmed that they would. Such a national programme of temperature monitoring would help in obtaining a better understanding of the actual degree day conditions experienced where the oysters are actually cultured;

- From the replies received to the questionnaire it would appear that the Pacific oyster industry in England and Wales is predominantly made up of small producers. Most farms are located intertidally and utilise diploid seed;

- The questionnaire responses regarding wild settlement show that settlement only occurs in any significance at present in the South West and South East of England. Settlement in the South West is sporadic but occurs regularly in the South East;

- Intertidal bottom culture together with subtidal bottom culture are the dominant forms of Pacific oyster farming in the South East of England. The widespread practise of harvesting wild Pacific oysters in this region for on-growing or sale seems to have originated from their original traditional Native oyster fishing activities;

- By contrast to the South East of England, the South West and Northern Irish farms comprise sites mainly undertaking bag and trestle culture activities;

- The availability of wild Pacific oyster seed means that the UK market for hatchery seed is becoming increasingly limited;

- Husbandry practises for growing triploid Pacific oysters need highlighting to industry as there are instances where negative experiences are due to the culture of this type of oysters in sub-optimal conditions or by using inappropriate husbandry techniques. A better understanding of the characteristics of triploid Pacific oysters may well also lead to a more positive experience in this respect;

- Negative opinions of the role and use of triploid Pacific oysters are often expressed by growers that have not had first hand experience of growing this type of oyster i.e. these opinions may be influenced by discussions with other growers;

- The questionnaire did not provide enough detailed information in order to be able to investigate any possible relationships between farm type and successful settlement of Pacific oysters in the UK. A further more intensive study would be required to investigate this subject area in the detail required in order to draw any meaningful conclusions. It should also be noted that a three year study by the Irish Marine Institute is due to start in 2008 to investigate the basis of any such relationships.

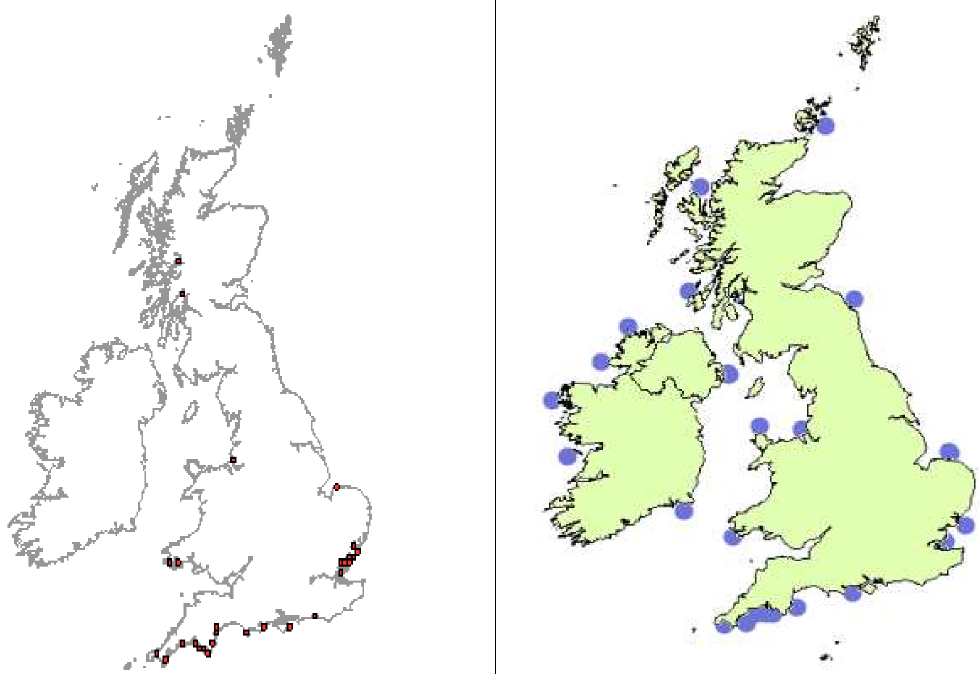
3.3 Regional Patterns of Settlement

3.3.1 Historical Records and Scientific Literature;

Wild Pacific oyster spatfall has been recorded around the coastline of the British Isles for a number of years and was first reviewed by Spencer *et al.* (1994). Figure 30 provides a map overview of previously reported sightings which are then considered on a regional basis.

Figure 30. Pacific oyster wild settlement records (NBN Gateway and MARLIN)

(Source: NBN Gateway) *(Source: MARLIN)*



3.3.1.1 Scotland: The NBN Gateway and MARLIN distribution maps (shown in Figure 30) also suggest an infrequent scattering of wild settlement observations with x2 and x4 records respectively. Spencer *et al*. (1994) also cited wild settlement at Loch Sween in 1969/1970 which was subsequently not reported in a 1991 survey. No further reports have been received.

3.3.1.2 Northern Ireland: The NBN Gateway and MARLIN distribution maps (shown in Figure 30) indicate settlement confined to Strangford Lough. Environment and Heritage Service (EHS) have also reported settlement in Strangford Lough following an extensive survey by Guy (2007) which was prompted by anecdotal reports of settlement since 2004. Guy (2007) showed the presence of wild settled Pacific oysters in 18 out of 30 studied sites. The highest incidence and density of settlement occurred in the northern basin of Strangford Lough which was attributed to its more restricted hydrodynamic regime. The size distribution of the wild stock suggested that the area does not yet suffer consistent annual settlement. Although located wild stocks were found to be intertidal there is concern that subtidal settlement may impact upon the Native oyster and the horse mussel both UKBAP protected species in this SAC area. Comprehensive work is ongoing (Claire Guy, pers. comm.) which should be monitored as the output will help inform management options.

3.3.1.3 North West England and North Wales (Irish Sea): The NBN Gateway and MARLIN distribution maps (shown in Figure 30) indicate a low number of settlement observations – although both sources reference settlement in the Liverpool area. Spencer *et al*. (1994) provided observations from 13 sites along the length of the Menai Straits. Five sites presented no oysters, whilst a further 5 sites exhibited low oyster levels although 3 sites around Beaumaris provided >10 oysters/man-hour search.

A recent survey of the New Zealand oyster *Tiostrea lutaria* distribution along the Menai Straits also noted the occurrence of the Pacific oyster (Morgan, 2007). This study mentioned the presence of dead Pacific oyster shells but only recorded a cluster of live Pacific oysters at one site. However, this survey did not visit the 'hotspots' at Beaumaris mentioned in Spencer *et al.* (1994). No more personal observations have been received during the current study to ascertain the current status of present observations.

3.3.1.4 South Wales and Bristol Channel: The NBN Gateway and MARLIN distribution maps (shown in Figure 30) show minimal settlement in this region other than in records for Milford Haven which have been mirrored in responses from Countryside Council for Wales (CCW) for this study. The continuing presence of wild spatfall remains unknown following the closure of the former Pacific oyster operation (Phil Coates, pers. comm.).

3.3.1.5 South West England: The NBN Gateway and MARLIN distribution maps (shown in Figure 30) both show extensive sites of observed settlement along the southern coastline of Cornwall and Devon. Settlement has also been reported in this study by Natural England in the Helford SAC which has been the cause of industry operational constraints. Local contacts in the area have anecdotally reported settlement in the nearby Percuil Estuary but with conflicting accounts of Pacific oyster settlement within the Helford Estuary itself.

Most of the South Devon estuaries have recorded observations of wild settlement at generally low levels. Spencer *et al.* (1994) provided observations from a number of sites along the South Devon coastline in the early 1990s. Over 100 wild settled Pacific oysters were observed on crab tiles within the Teign Estuary in both 1991 and 1992. The shift in the uni-modal size distribution from a mean of ~29mm to 66mm in the two successive years suggested a single settlement event which was attributed to the exceptionally warm summer of 1989. Recent revisits to the Teign and Exe sites have subsequently reported no observed settlement (Couzens, 2006b). Conversely, other sites which have previously not supported reported wild settlement have subsequently yielded new observations of Pacific oysters. The Yealm estuary has provided cases of abundant settlement and has formed the focus of recent UK scientific literature with studies continuing at present. For this reason the Yealm and associated South Devon estuaries have been considered in more detail as a case study in Section 3.4.

3.3.1.6 Southern England: The NBN Gateway and MARLIN distribution maps (shown in Figure 30) show a low level of settlement and would benefit from return site visits to assess whether there is a continued presence of wild stock. Natural England also report that some settlement has been identified on the Isle of Wight (via. Dr. Roger Herbert, University of Bournemouth, pers. comm.).

3.3.1.7 South East England: The NBN Gateway and MARLIN distribution maps (shown in Figure 30) show settlement in a number of Essex estuaries. Surprisingly no scientific literature studies appear to have been undertaken to record settlement for this coastal section.

Natural England report settlement as part of this study in the: "Wash, Blackwater Estuary, off the Essex coast." CCW reported for this study: "Anecdotal reports by recreational anglers suggest it is becoming an amenity issue at Southend on Sea in the Thames estuary, who have reported cutting their feet on the shore on wild settlements of *C. gigas*." This study has provided feedback from a number of other sources demonstrating extensive settlement in Essex (Brightlingsea and Southend) and North Kent. Kent and Essex Sea Fisheries Committee have provided a good initial assessment of hot spots in Essex. The Pacific oyster settlement in Brightlingsea (see Figure 31) is on an old oyster bed which was previously used mainly as a storage area many years ago when this was a major oyster handling centre (Joss Wiggins, pers. comm.). Extensive wild stocks have also been observed off Southend seafront with a biomass measured in 2004 of nearly 400 tonnes (Wiggins, 2004).

Figure 31. Pacific oyster reef on the foreshore at Brightlingsea in Essex

Dimensions of reef are estimated to be 250m by 20m (Image: Joss Wiggins)

Reports from Natural England for this study have shown that around North East Kent extensive Pacific oyster settlement has occurred and is reported to near ‘reef’ status. The majority of this settlement has been focused at the mid-intertidal level upon man-made structures such as groynes and retaining walls although individual settled oysters have been observed on the chalk cliff (Willie McKnight, pers. comm.). Mass mortalities have been observed although any potential reason for this occurrence has not yet been established. A baseline survey of Pacific oyster distribution is expected in September 2008.

The absence of a hard substrate does not appear to be a long-term barrier to recruitment in an otherwise favourable environment. Cognie *et al*. (2006) reports that in Bourgneuf Bay, France, 70% of Pacific oyster biomass is wild stock, of which 75% occurs on shallow tidal walls which sub-divide the mud-flats. A further 21% has settled upon cultured stock and equipment. The absence of hard rocky shores did not ultimately restrict Pacific oyster colonisation within the Wadden Sea and likewise does not appear to be a limitation at Brightlingsea and Southend-on-Sea. Once settlement has obtained a foothold future settlement can be focussed upon conspecifics to form a reef.

3.3.1.8 North East England: The NBN Gateway and MARLIN distribution maps (shown in Figure 30) do not show any recorded wild settlement of Pacific oysters.

3.3.2 Farm Distribution and Observations;

Figure 32 maps the distribution of production areas in England and Wales whilst Table 27 summarises the distribution of harvest beds throughout England, Wales and Scotland.

Figure 32. Pacific oyster culture in England and Wales (Taken from: Spencer, 1990)

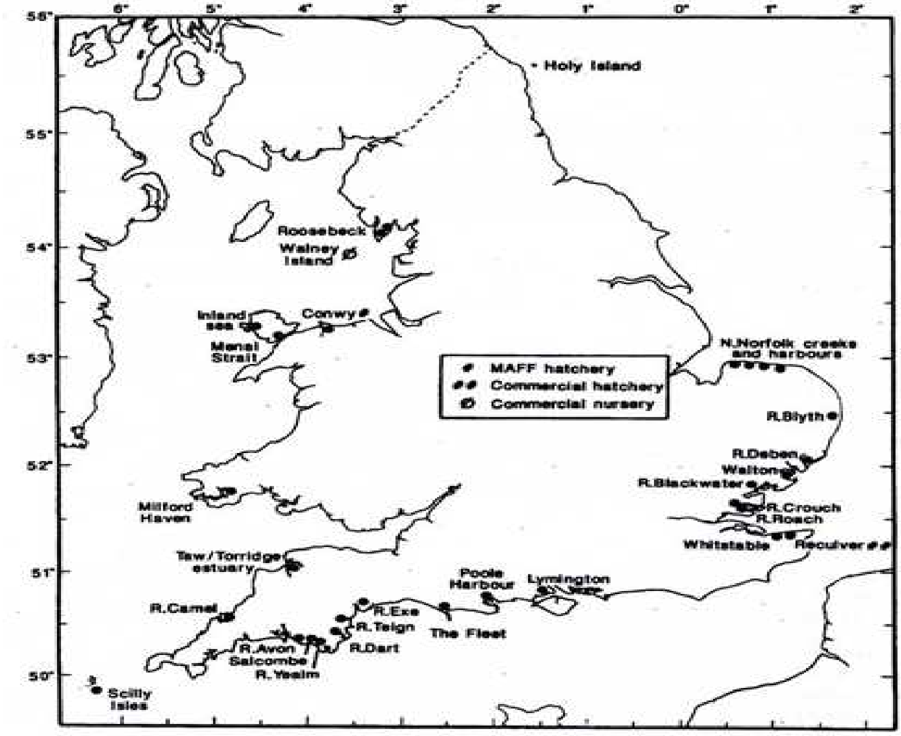


Table 27. Summary of Pacific oyster production areas in England, Wales and Scotland (Source: FSA, 2008)

Region	Production Areas	Beds
N.E. England	1	1
S.E. England	13	23
S. England	1	1
S.W. England *(Note 1)*	12	30
S. Wales	0	0
N. Wales & N.W. England	2	3
Argyll & Bute	21	23
Lewis & Harris	1	1
Lochaber	4	4
Ross & Cromarty	5	5
Sutherland	2	2
Ayrshire	1	1
Orkney	1	1
Shetlands	6	6
Total	**70**	**101**

Note 1: Includes Portland to Taw/Torridge

Table 28 as follows gives an overview of the relative productions levels between the different regions of the UK.

Table 28. UK production of farmed Pacific oysters in 2006
(Source: CEFAS Shellfish News, 2007)

Region	Scotland	England	Wales	N. Ireland	UK Total
Tonnage	251	680	12.5	346	1,290

Tables 27 and 28 indicate that the majority of UK Pacific oyster production is found in 4 regions: South East England, South West England, Northern Ireland and Argyll and Bute. It is of interest that of all these regions the highest density of beds is found in the South East region for the Thames approaches.

The high density of cultured beds in South East England would appear to correspond to some of the highest incidences of wild settlement (Section 3.3.1.7). However, some anomalies do occur where wild settlement has been observed in areas not associated with Pacific oyster culture. The South coast of England is believed to have just one registered Pacific oyster bed that is under commercial production. This bed is located in Poole Harbour and yet wild settlement has been recorded at two sites which are well away from this area.

Other anomalies may occur due to changes in the status of culture operations such as that for Milford Haven where two observations of wild settlement have been recorded in an area that has had no Pacific oyster cultivation since 1996. The current status of old commercial stock or any wild settlement in the Milford Haven area remains uncertain.

These ‘source’ and ‘sink’ factors and the increase in production of cultured Pacific oysters in recent years are considered further in Section 3.5.

3.4 South Devon - Yealm Estuary Case Study (Settlement)

3.4.1 Background;

The Yealm has long been at the vanguard of Pacific oyster culture in the UK. From the earliest days of introduction in 1967 Pacific oysters were cultured on the Yealm to replace the loss of production from the Native oyster fishery that was decimated following the extensive big freeze of 1963.

A hatchery was set up at Steer Point and operated by Tony Maskell who also trialled a number of innovative culture techniques. Following problems with TBT the fishery fell into demise for a period in the 1970s before being started up again by the current operators in the 1980s. At present intertidal trestles are deployed on two registered harvest beds near Thorne (see Figure 33, second image, top right corner) with a moderate stock level of under 50 tonne standing stock biomass.

The Yealm operators were contacted as part of the current study to obtain their views and observations of wild settlement of Pacific oysters. In their experience wild settlement is infrequent with the only notable incidence to impact their operation occurring around 4 years ago (possibly 2003 or 2004) with extensive wild spat settling on their stock and trestles.

Figure 33. Map of Yealm Estuary with culture locations & wild settlement observations (2 images shown; blues circles indicate culture sites; red circles indicate wild settlement; No.s next to circles indicate Study No. as per Sections 3.4.2.1 ; 3.4.2.2 ; 3.4.2.3 ; 3.4.2.4)

The Yealm case study helps to provide an indication of how temperature records can be used to predict Pacific oyster recruitment and illustrates the various debates on 'sources' and 'sinks' for larvae (Section 3.5).

The Yealm has formed the principal focus for research as the site is in close proximity to the Marine Biological Association (MBA) and the University of Plymouth. For this reason the area has been widely studied and is the subject of ongoing work. An outline of the studies undertaken in South Devon, and the Yealm in particular, is provided in the Section 3.4.2.

3.4.2 Yealm Studies;

3.4.2.1 Couzens (2006b) - The Distribution and Abundance of the Non-Native Pacific oyster, *Crassostrea gigas*, in West Devon - A Result of Climate Change? Couzens (2006b) investigated wild spatfall by revisiting a number of the South Devon estuaries studied by Spencer *et al.* in a 1994 study. Couzens' MSc thesis was summarised in Shellfish News (Couzens, 2006a) which reported a highly significant level of wild settlement in the Yealm that far outstripped the other South West estuaries.

Although Couzens work on the Yealm provides some useful additional information, her wider assessment of the South Devon sites and their implied link to the Yealm may require some further evaluation.

> *"C. gigas* was found to be abundant at Noss Mayo in the River Yealm where Pacific oyster farming has occurred since its introduction in 1965. Further along the estuary and at the open coast, the frequency of individuals decreased indicating that there is an attenuation of *C. gigas* from the local aquaculture site to the open coast……..If we suspect that the aquaculture site in the River Yealm is responsible for the recruitment of oysters at Noss Mayo, then we might also expect that Noss Mayo is in turn affecting the recruitment between Noss Mayo and Cellar Beach and at Cellar Beach. Populations at Cremyll, Cawsand and Queen Anne's Battery may originate from extensive recruitment and dispersion of oysters from established populations in the River Yealm."

The passage before suggests settlement abundance is expected to relate to proximity to potential spawning sites and a slow progression of oysters along the coast. This is inconsistent with the known extended larval life stage and the heterogeneous pattern of settlement found within the Yealm estuary. Couzens also relates the size of the oysters in the open coastal stock against the size of the Yealm stock as an indication of age and hence to proximity to a source population:

> "As the distance increased between study sites and Noss Mayo (closest site to aquaculture plot), the analogous oyster populations became younger containing more juveniles and fewer large individuals."

Couzens points out that the Pacific oysters in the Yealm had a mean length of 8cm with the majority above 4cm which was significantly different from most of the Plymouth Sound populations. Couzens compared shell sizes against Wadden Sea growth rates and assumed that the majority of the Yealm stock was 2 to 3 years old whereas the Plymouth Sound stock was younger. Cardoso *et al.* (2007) pointed out that: "in addition to the overall differences between areas, large differences in environmental conditions must also occur within an area, leading to the large variability in individual growth within each location." Cardoso's study showed a large difference in oyster weight and shell size between sites for oysters of similar age.

In the absence of growth analysis on the shell umbro there is no way to distinguish an old slow growing oyster at one site, from a young fast growing oyster at another. It is quite possible that all of the different size populations may have resulted from the same spawning event. Indeed the only other Plymouth Sound population of a comparable size to the Yealm oysters was found at Cremyll at the mouth of the Tamar estuary. It is possible that stock at Cremyll and the Yealm were growing under better salinity and food conditions and were therefore larger. Estuarine sites will be closer to the optimal salinity of 25 to 30ppt, whereas all of the other coastal Plymouth Sound sites are more likely to have been full salinity. It is therefore suggested that Couzens was not able to not substantiate the presence of a self-sustaining wild population and hence 'establishment'.

Although outline biomass assessments for this study indicate that the cultured biomass is still significantly larger than the wild biomass, both stocks will contribute to an increased recruitment potential. As such Couzens central assertion that settlement at various nearby Plymouth Sound sites is attributable to aquaculture in the Yealm is still of concern. A categorical link cannot be demonstrated at this stage as other Pacific oyster stocks will also be within a 30 day residual drift radius of the settlement sites. Furthermore, many large visiting vessels visit Plymouth Sound raising the potential for a vessel borne vector. Couzens concludes that DNA testing could help determine potential links between source populations and the new wild settlements in Plymouth Sound. Indeed an Atlantic Arc Interreg genetics based project has been proposed entitled SEAFARE to investigate these patterns of settlement (see Appendix 1).

Couzens discusses the link between a 1 ^{o}C rise in sea temperatures off Plymouth since the 1990s and the increased recruitment success of the Pacific oyster in the Yealm. Section 2 discusses regional degree day calculations and the potential implications of future global warming.

3.4.2.2 Alexander (2007) - The Introduced Pacific oyster, *Crassostrea gigas* - Population Biology and Consequences for Community Structure and Ecosystem Functioning: Alexander (2007) also considered the 'reef' area visited by Couzens but with a wider range of sampling points along a more extensive length of the southern Noss Mayo shoreline as shown in Figure 33. Alexander (2007) extended the size frequency distribution work undertaken by Couzens (2006b) to include study of the spatial distribution and potential ecosystem impact of the wild settlement.

Spatial distribution trends were studied by undertaking extensive profiles both horizontally and vertically between HW and LW at four sites along the southern Noss Mayo shoreline. This work showed that there was a clear vertical distribution pattern with clustered occurrence on the lower mid-shore but no clear horizontal trend. A study of the potential trophic impact of wild oyster filtration compared oyster densities and literature filtration rates against the tidal volume of the estuary. The results exhibited minimal utilisation of the available tidal volume.

Potential ecological impact was studied by recording species assemblages associated with the oysters in an attempt to see whether the surrounding biota may display changes in species diversity and abundance. Alexander highlights the potential for the cultivation of oysters at high densities to increase organic enrichment, reduce current velocity and enhance sedimentation. Environmental parameters such as sedimentation and current velocity are advocated as a causative force for the higher numbers of mobile invertebrates found in high density areas of oysters in the Yealm Estuary.

Alexander could find no negative loss of species diversity even in high density oyster areas. However, Alexander did find increased abundance of mobile invertebrates and therefore concluded that the wild oyster settlement was responsible for localised changes in the community structure.

3.4.2.3 Marine Biological Association and MECN Work: Ongoing survey transects of Pacific oyster settlement have been recorded by workers from MARLIN within MBA with further surveys conduced in 2007 along the Newton Ferris shoreline of the estuary where Pacific oysters have also been recorded (Jack Sewell, pers. comm.). The Yealm remains a key study site for other MBA workers working on the MECN programme (Section 2.3.2) (Matthew Frost, pers. comm.). Nova Mieslowska is currently working on a research project looking at the reproductive abilities of the Pacific oyster in the River Yealm as part of a collaborative project with the University of Florida.

Since December 2007 adult body temperatures have been measured continuously at a high resolution at mid and low water levels to determine the annual temperature cycle experienced by individual oysters during emersion and immersion. Tissue samples have also been obtained to look at links with the onset of gametogenesis, gonad condition, timing and duration of maturation and timing and duration of spawning events. Temperature loggers have been located at nearby open exposed coastal sites for comparison of thermal trends between the estuary and the open coast. This field work will help fill many of the gaps in information regarding Pacific oyster conditioning in the wild as opposed to that shown under hatchery conditions (Section 2.2).

3.4.2.4 Site Assessment: As part of this study, site investigations were conducted by members of the project team on all three shorelines of the Yealm system (Noss Mayo, Newton Ferris and Wembury Point) over two low water spring tide periods. In addition, the local Pacific oyster operator was contacted to obtain their feedback and observations. Anecdotal observations of wild oyster settlement were also sought from local boat operators and members of the public. Locally derived temperature data was sought from a number of sources which are described in Section 2.5 with respect to the potential for spawning and recruitment.

Outline biomass assessments were undertaken to provide a crude estimate of the relative cultured and wild biomass. Table 29 below provides a summary of the areas and densities found. Oyster data for the reef and hot spots were supplemented using the findings of Alexander (2007).

Table 29. Estimation of Yealm Estuary wild Pacific oyster biomass

Zone	Area	Oyster Density (Note 1)	Mean Mass (Note 2)	Density	Total Mass
(Units)	**m^2**	**No./m^2**	**kg**	**kg/m^2**	**kg**
Reef	50	20	0.20	4.00	200
Hot spots	2,000	5	0.15	0.75	1,500
Low density	25,000	1	0.15	0.15	3,750
				Total	**5,450**

Note 1: Approximation from Alexander (2007)
Note 2: Alexander (2007) obtained average mass of ~0.11kg/piece at the reef and ~0.08kg/piece elsewhere. Oyster mass has been approximately doubled for annual growth 2007-2008

The 'reef' section between Noss Mayo and Cellar Beach which has been widely reported and cited is in fact of very limited extent with a patch of 5 to 10m in diameter constituting an area of around 50m^2 in total. It should be noted that the reef is a virtually discreet body in a backwater area of a bend in the estuary which would appear to have offered a suitable hydrodynamic area for mass settlement. This strong zonation was identified in work by Alexander (2007) which undertook a duplicate transect adjacent to the reef and recorded minimal oyster occurrence. Alexander's (2007) reported oyster densities have been used to calculate a mass density with a conservative assumption for growth. Visual inspection indicated that most stock present in the reef is of the same size class which is supported by the size frequency analysis of both Alexander (2007) and Couzens (2006b) which showed a strong dominance of oysters ~8cm in length.

Other 'hot-spots' were encountered throughout the estuary system although in nothing like the density of the Noss Mayo 'reef'. Much of the rest of the estuary system had a low level of settlement with oyster densities of less than 1/m^2. As found by Alexander, settlement was confined to a narrow band of the mid to upper-intertidal zone as much of the intertidal area itself was muddy and therefore less well suited for settlement. The rocky foreshore and retaining walls therefore formed the majority of the settlement area. However, boulders and debris (particularly any iron chain) provided local clusters lower down the tidal profile. Occasionally 'free' specimens were observed frequently with the indentations of barnacles on their base suggesting settlement on an insecure substrate before breaking free. In one area, 'free' oysters had been washed high up on the foreshore where they had developed a smooth 'rumbled' appearance. These oysters had a very low meat yield suggesting growth in non-optimal conditions. As with the 'reef' site, most of intertidal stock found consisted of large older oysters of around 200g/piece. These specimens had a very good meat yield of ~15%. One large sub-tidal specimen of 600g was obtained yet this oyster had a surprisingly low meat yield of less than 10%.

Table 29 indicates a wild oyster biomass of around 5 tonnes as compared with a cultured biomass of 25 to 50 tonnes. The implications to settlement in surrounding waters are discussed in the following section.

3.4.3 Yealm Estuary Impact on the Wider South Devon Coast;

In common with Couzens (2006b) previous studies on wild Pacific oyster settlement have been performed on other South Devon estuaries by Eno (1994) and Spencer *et al*. (1994). Oyster production is common along this coast with a number of small production sites in adjacent estuaries.

Table 30 summarises the harvest beds registered for Pacific oysters and the recorded wild spat-fall in South Devon areas from recent studies.

Table 30. Reported wild settlement of Pacific oysters in South Devon estuaries

Area ***(Note 1)***	**No. Harvesting Beds** ***(Note 2)***	**Spencer *et al.* (1994)**	**Couzens (2006b)**	**MARLIN** ***(Note 7)***
Exe Estuary	X5	Yes *(Note 5)*	Not found *(Note 5)*	-
Teign Estuary	X3	Yes	Not found *(Note 6)*	-
Dart Estuary	X3	Yes	-	-
Salcombe (Kingsbridge ria)	X1 *(Note 3)*	No *(Note 3)*	-	-
Bigbury & Avon (Avon estuary)	X3	No	Yes (Rare – Bantham Occas. – Bigbury)	-
Mothercombe (Erme estuary)	-	-	-	Yes
Yealm Estuary	X2	-	Yes (Abundant - Frequent)	-
Jenny Cliff (Plymouth Sound)	-	-	-	Yes
Mount Batten (Plymouth Sound)	-	-	-	Yes
Queen Ann Battery Marina (Plymouth Sound)	-	-	Yes (Common)	-
Cremyll (Plymouth Sound)	-	-	Yes (Rare)	-
Cawsand (Plymouth Sound)	-	-	Yes (Occasional)	-
Fowey Estuary	X2	*(Note 4)*	-	-

Note 1: Areas arranged from East to West;
Note 2: Food Standards Agency (FSA) Listings;
Note 3: 'Geese Quarries' bed currently not managed yet wild settlement has been observed in the lower estuary to the North of Southpool Creek;
Note 4: Wild settlement has been observed in the mid estuary at Pont Pill;
Note 5: Couzens (2006b) visited Exe at the mouth of estuary (Maer Rocks + Great Bull Hill rocks) but not crab tiles at Dawlish Warren observed by Spencer et al. (1994);
Note 6: Couzens (2006b) visited Teign at the mouth of estuary (Shaldon + Ness Beach) but not mid-estuary sites observed by Spencer et al. (1994);
Note 7: MARLIN ongoing surveys in co-operation with local schools/colleges.

Table 30 shows that a large number of registered Pacific oyster beds are present to both the east and west of the Yealm estuary. The incidence of observed wild settlement from most areas has been spasmodic and of low density. The high incidence of reports from open coastal sites around Plymouth Sound demonstrated in Figure 33 tends to suggest a link to the Yealm estuary. However, caution should be exercised as Pacific oysters are known to favour lower energy sites (such as Plymouth Sound) for settlement and the widespread oyster culture sites along the coast could also be acting as 'sources'. Another area of reporting bias relates to the proximity of the Yealm to institutions and study groups actively seeking Pacific oysters. Other estuaries and areas are likely to support un-noticed settlement that if reported could suggest a different pattern of development. For example, the author has observed 'occasional' and 'frequent' settlement of large Pacific oysters in the Salcombe and Fowey systems that have not been reported previously.

Another significant feature of Pacific oyster settlement is that it tends to be very localised and heterogeneous. Couzens (2006b) did not find Pacific oysters on the Exe or Teign despite previous sightings by Spencer *et al.* (1994). Although this might suggest that the original settlement was ephemeral it should be noted that the exact same settlement sites were not revisited. Local hydrodynamics will also play a significant effect upon settlement. Eno (1994) studied the Fleet nearby in Dorset and noted that despite the presence of spawning oysters and sufficient degree days to allow recruitment – no settlement was observed. Couzens (2006b) surmises that the low incidence of Pacific oysters found adjacent to Bigbury and Avon may be due to the current direction or the fact that oyster culture has only been operating since the 1980s. It is unlikely that culture duration relates to settlement unless ongoing recruitment is occurring. Instead it is probable that the flushing regime in the Avon estuary is not conducive to maintain viable larvae within the estuarine system.

Considerations of wild settlement in open coastal waters have led to the supposition that the source larvae may have been derived from wild stock in the Yealm (Couzens, 2006b). Estimates of wild stock biomass suggest around 5 tonnes of wild oysters in the Yealm estuary system at present (this study). If a similar assessment could have been made in 2006 at the time of Couzens study it is probable that an even lower wild biomass may have been obtained. This compares to ~25 to 50 tonnes of cultured oysters therefore indicating x5 to x10 times less wild stock than cultured.

Although cultured stock outstrips wild stock it is possible that the wild stock provides a greater reproductive potential on a mass : mass basis. The majority of the wild stock is large mature stock in good condition, whilst the cultured stock is at various stages of growth with juvenile oysters and lower mass adults. In consequence, the wild stock will have a proportionally greater spawning potential than for the cultured stock. However, the majority of the cultured stock is likely to be sexually mature and even a 50% reduction in the viable biomass estimates will still indicate that the vast majority of viable larvae are currently derived from cultured stock. The future balance between stocks of wild and cultured biomass is hard to determine. On one hand continued growth of the current wild stock will generate increasing biomass, whilst any further settlement will compound increases. Conversely, wild biomass might decrease - anecdotal observations from local residents at Noss Mayo indicate that previous hotspots had come and gone. It is unclear whether wild stock losses may be from continued ongoing local gathering for consumption (which was observed during the site visit) or from 'summer mortality' a phenomena where large masses of oysters die in association with elevated temperatures. Nehring (2006) reviews:

> "reports of mass Pacific oyster deaths in a restricted area along the Dutch coast in August 2004 and in several harbour areas on the German Wadden Sea coast in September 2005. Up to 80% of oysters were found dead. There were no clear indications of the causes and there have been no indications of any disease or parasite. Possible explanations are high water temperatures, low water exchange and low plankton concentration during these periods (Wehrmann and Schmidt, 2005)."

It is possible that whilst continued global warming may increase the potential for recruitment it may also give rise to periodic stock destruction during particularly hot summers.

3.5 'Sources' and 'Sinks' of Larvae

3.5.1 Introduction;

This brief review of the 'sources' and 'sinks' of larvae will seek to highlight the complex nature of additions to and removals from larval numbers in bivalve shellfish and the role that larval dispersal can play in establishing populations of shellfish in areas outside that of the original spawning stock.

Sources and sinks will therefore be considered in the following <u>differing</u> terms:

1. In terms of an 'individual box model' where changes in larval numbers are considered as mass balance movements for one location i.e. <u>additions to or subtractions from larval numbers at one location</u>;
2. In terms of a 'global box model' where larval dispersal or transport moves larvae from one area to another i.e. <u>considers the potential interactions between different areas or populations</u>.

3.5.2 Individual Box Model;

The Pacific oyster is a protandrous hermaphrodite that exhibits external fertilisation of sperm and eggs through broadcast spawning. This biological strategy coupled with a long (up to 30 days) planktonic larval phase provides the Pacific oyster with a good distribution strategy. The nature of this reproductive strategy means that there are often a number of potential 'sources' and 'sinks' for viable larvae.

Population growth of any marine species will only be achieved if the 'source', or additions to, viable offspring exceeds the 'sinks,' or subtractions from, their numbers. Where this happens successful recruitment is achieved and the population size for future reproductive effort is increased.

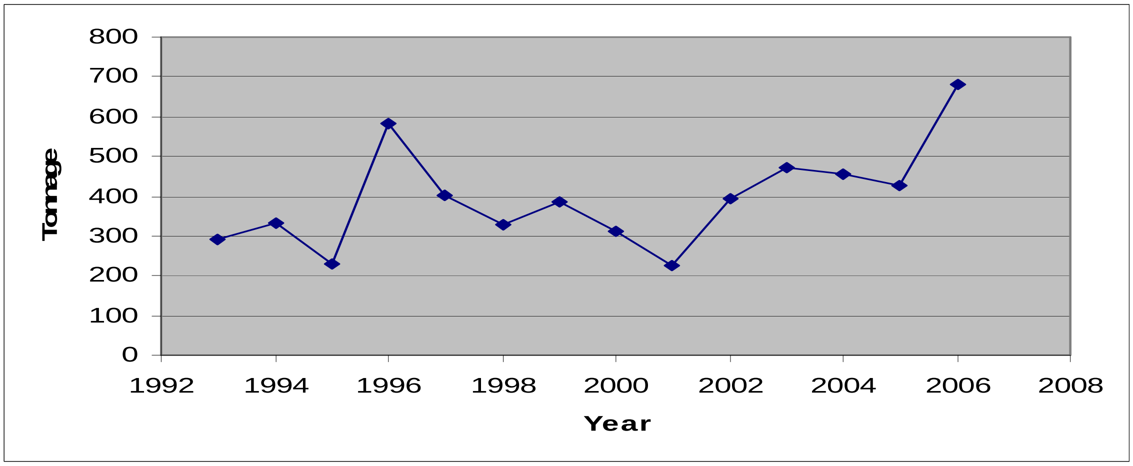
In the case of Pacific oysters the UK industry has historically relied on hatchery produced seed to maintain a cultured population suggesting that 'sinks' exceeded 'sources'. Currently successful wild settlement in some areas would suggest factors have changed allowing the 'source' to outstrip the 'sinks.' The question posed is whether this is because production has reached 'critical mass' or is it due to changes in underlying factors such as the temperature regime?

3.5.2.1 Review of 'sources': In the current situation in the UK 'sources' of larvae will include:

- Cultured stock;
- Wild stock;
- Introduced larvae from overseas (direct residual drift);
- Introduced larvae from overseas (vessel vector).

Cultured stock - There has been an underlying increase in Pacific oyster production within the UK as indicated in Figure 34 (for England and Wales) and Table 31 for the overall UK production. A regional breakdown of production is provided in Section 3.3.2.

Figure 34. Pacific oyster production for England and Wales (Source: CEFAS Shellfish News, 2006 and 2007)



Note: Does not include bed culture tonnage or output from other regions

Table 31. UK farmed production of Pacific oysters 2000 to 2006 (Source: CEFAS Shellfish News, 2006 and 2007)

Year	**2000**	**2002**	**2003**	**2004**	**2005**	**2006**
Tonnage	560	976	1,068	1,019	975	1,290

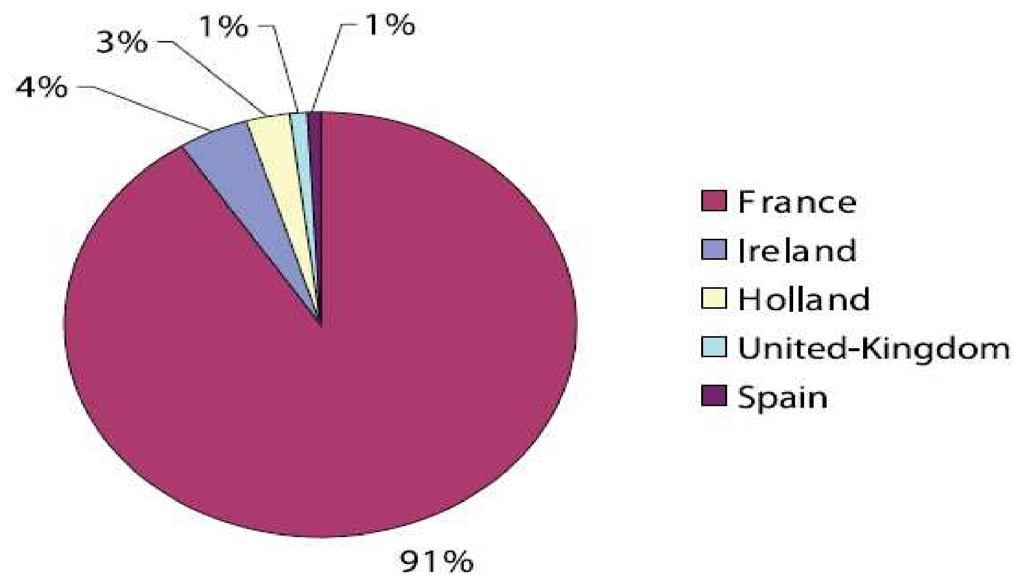
Production in recent years has increased markedly which will have amplified any underlying system changes.

Wild stock - The balance between cultured and wild breeding stock will vary on a site specific basis. The Yealm case study (Section 3.4) indicated a cultured : wild ratio of greater than 5:1, whereas with the widespread wild settlement in the Bay of Brest the balance tips towards the wild stock with a cultured : wild ratio of 1:7. The 2004 Southend fisheries survey (Wiggins, 2004) estimated that there was around ~400 tonnes of Pacific oysters on the foreshore which is nearly a half of all annual UK production.

This indicates that regardless of where the wild stock originated it is now likely to be a significant source of larvae in this area. A reassessment of the Southend stock would also give a good indication of the biomass growth rate over the last 4 years.

Introduced larvae (residual drift) - Many factors will influence the level of risk presented by the long distance introduction of larvae from overseas. Firstly, the level of Pacific oyster culture on the continent and France in particular far exceeds that of the UK by two orders of magnitude as shown in Figure 35 overleaf.

Figure 35. European production in 2004 of 120,000 tonnes of Pacific oysters (Taken from: FAO figures in Lapègue et al., 2007)



Coupled to the increase of continental wild stocks in recent years it is probable that the mass of viable larvae released has also increased accordingly. However, the English Channel presents a significant obstacle to transfer despite the short distance of just 33km (20miles) at its narrowest point.

Studies of the residual drift in the Western English Channel have shown that the predominant residual drift is to the South East towards France and away from the UK, whilst at the junction of the English Channel and the Southern North Sea the predominant residual drift is towards the ENE and the continent (Carruthers, 1921 and 1933). Cooper (1961) considered that although anomalies in current occurred (such as associated with shelf edge currents) overall 'drift' was associated with a current move to the right relative to the predominant wind direction.

These studies would suggest that for the majority of the time the dominant residual drift would prevent larval movement towards the UK. However, Carruthers (1921) showed that periods of strong easterly winds averaging 9.4mph did give rise to movement of drift bottles onto the beaches of Essex therefore indicating that periodic reversals of wind could result in water movement to the UK. Using a wind to water transfer rate of 5.5% (Carruthers, 1933) this would suggest that a strong easterly wind could provide passage across the channel in about two days. Although Carruthers' work suggested a low frequency of residual movement towards the UK (<10%) even this incidence could account for significant larval introduction to South East England from the continent.

Knowledge of the ocean-atmosphere interaction has vastly increased in recent years as better understanding has emerged of the North Atlantic Oscillation (NAO). It is uncertain what impact climate change and the intensity and frequency of a positive NAO will have on the incidence of prolonged easterly winds. It is recommended that specialist investigation is undertaken to better assess the potential for Pacific oyster transfer to the UK via residual currents.

Introduced larvae (vessel vector) - Contamination of vessel hulls or the discharge of ballast water has long been recognised as a significant vector for the transfer of non-native species. A number of shipping controls, such as the sterilisation of ballast water, are now placed upon commercial vessels in order to minimise transfer from this route. The current 'Marine Aliens' research project (Marine Biological Association/Scottish Association for Marine Science) is focusing on surveys to identify non-native species located in ports and harbours in order to further assess this source (Liz Cook, pers. comm.). It is suggested that although this vector may be significant in the introduction of new founding populations the mass transfer of larvae may be small relative to other sources.

3.5.2.2 Review of 'sinks': The extended larval distribution phase presents a series of challenges for oysters in establishing new populations and results in significant 'sinks' occurring for larvae:

- For external fertilisation to be successful oysters are required to allocate a significant amount of resources to producing large numbers of gametes. In this way the gametes produced will have a chance of achieving fertilisation within a short period after spawning (sperm having a short period of viability);

- In order to achieve success at settlement with a long planktonic phase a large number of progeny are required. As they develop these larvae are likely to undergo significant losses due to predation;

- Once fertilised, larvae require around 225 degree days before metamorphosis can occur (generally around 3 weeks at 20 ^{o}C). Whilst inshore shallow estuaries are warm and may have a temperature regime theoretically capable of supporting metamorphosis, the hydrodynamic regime of the spawning area may flush larvae into deeper cooler waters. Alternatively, if spawning occurs too late in the year temperatures may drop and the required degree days may not be achieved;

- If larvae manage to metamorphose and settle then the small oyster spat are still highly susceptible to predation, particularly by shore crabs;

- Upon reaching maturity, successful fertilisation by oysters is only likely to be achieved if they are located close to conspecifics. If they are not then any gametes produced are unlikely to result in the production of viable larvae.

3.5.2.3 Appraisal of shifting recruitment balance: The balance between 'source' and 'sinks' for viable larvae and the successful recruitment of breeding adults appears to have shifted within the UK. A number of factors are likely to be responsible for this phenomenon the significance of which are likely to vary on a regional and site specific basis.

The Yealm case study (Section 3.4) provides an illustration of potential sources and sinks. A cultured stock of Pacific oysters has been implicated in the occurrence of a pattern of local and open coastal settlement. Some uncertainty still exists about the causal link between aquaculture sources and the status of a self-sustaining established wild source. It is suggested that in this case the source of larvae may be intermittent and successful settlement may be episodic. However, continued growth of wild stock and periodic recruitment would indicate an increasing reproductive potential. Coupled with a greater chance of reaching the necessary temperature threshold for spawning and settlement it is possible that if the Yealm has reached its 'critical mass' then self-sustained population growth may become the norm.

In contrast, the reported Pacific oyster status in the South East of England indicates widespread and regular settlement beyond culture sites. In this case the source biomass of wild mature oysters is significantly greater than the South West of England and the hydrodynamics may well be conducive to local settlement.

It is uncertain to what degree continentally derived larvae may have on occasion contributed to the establishment of wild stocks although it is likely that the South East of England is subject to an increased threat relative to the rest of the country. Whatever the source however it is probable that the South East of England has exceeded its 'critical mass' and with increasing seawater temperatures will continue to have a self-sustaining population. It is recommended that a South East of England case study should be undertaken to include known areas of extensive settlement at Brightlingsea and Southend.

It is suggested that there is no set 'critical mass' for successful recruitment and that the interplay of gamete density, hydrodynamics and temperature regime will need to be considered on a case by case basis. It may be possible to develop guideline criteria using a multi-parameter approach. It is recommended that a systematic assessment of oyster culture, wild settlement, temperature and hydrodynamic regime is undertaken to help ongoing development of the Pacific Oyster Protocol.

3.5.3 Global Box Model;

Section 3.5.2 considered an individual area and identified potential means by which larval numbers can be introduced into an area or removed. What is also important to consider for larval dispersal studies is the impact that one population can have on another discrete area or population. In terms of this study the genetic or population structure implications of larval dispersal are not as important as the identification of risk factors for the possible establishment of new wild populations of the non-native Pacific oyster in the UK. As such only the geographic spread of shellfish larvae is considered in this brief overview of larval dispersal.

3.5.3.1 Origin and destination of larvae: Levin (2006) describes two key basic questions in the study of larval dispersal "Where do larvae go?" and "Where do settling larvae come from?" In terms of larval dispersal the factors to be considered are how far can larvae travel, what influences that transport and what traits of the species reproductive biology impact on dispersal? In terms of the origin of larvae the modern description for the spatial element of recruitment is the concept of connectivity of which knowledge about the sources and sinks within a metapopulation are vital. In terms of modelling connectivity the main methods used include physical modelling of larval dispersal (e.g. circulation models), geo-chemical tracers and genetic studies (Levin, 2006).

3.5.3.2 Role of dispersal studies: The use of dispersal studies and the role of metapopulation connectivity have already been used in attempts to restore the native Eastern oyster in the U.S.A (Lipcius *et al*., 2005). In this work they identified through the use of modelling that the spatial structure of oyster reefs was critical to ensure metapopulation recovery in such areas as Chesapeake Bay. In effect they identified that the prevailing hydrographic situation in their waterways meant that larvae released during spawning events were often removed from that area and deposited in another waterway.

In practical terms this meant that to try and achieve a long-term restoration of a reef population of oysters in a certain waterway it might be necessary to locate the corresponding waterway that was the source area in this respect and place broodstock oysters at that location. The placement of adult oysters directly in the target area would therefore not be self-sustaining.

In terms of managing the potential spread of Pacific oysters in UK waters this source-sink relationship has implications in terms of correctly identifying for a given wild population where the recruiting larvae originated from. An example of the potential difficulties in identifying sources of larvae in dispersal studies is shown in the work carried out as part of the SMILE (Sustainable Mariculture in Northern Irish Lough Ecosystems) project covering five loughs in Northern Ireland. As part of this project the hydrographic transport between loughs was identified using modelling tools.

An animation is shown on the SMILE website (www.ecowin.org/smile/A2.htm) describing the dispersal of tracers during a study in 1995 from Carlingford Lough into the surrounding waters. The animation shows that at differing times of the year tracers released into Carlingford Lough can either go north into Strangford Lough or south into Southern Irish waters. In practical terms this means for example that whilst wild settlement of Pacific oysters in an individual waterway may be the result of aquaculture activities in that area, the possibility remains that the recruiting larvae may have originated from another waterway and been carried there on prevailing currents.

In summary the increasing threat of the spread of non-native species on a global basis has led to a new genre of dispersal studies focusing on newly colonised, non-indigenous populations (Neubert and Caswell, 2000). If the sources of wild populations in the UK are to be correctly identified so that management measures can be put in place then dispersal studies based on local and regional hydrographics, physical models and genetic studies will be necessary to ensure that the correct source of the larval input is identified.

3.6 Summary

3.6.1 Influence of Culture Type on Settlement Success;

The available literature would seem to indicate that Pacific oysters held in Parc or bottom culture conditions in the intertidal zone may well exhibit greater reproductive effort than those oysters held in bags on trestles. The degree of exposure in intertidal culture seems to have a significant effect on reproductive effort with longer immersion times generally leading to a greater availability of energy resources for reproductive allocation. However culture type and degree of exposure will also be influenced at a site specific level by other factors such as the level of siltation that may be experienced (Robbins, 2005), local hydrographics and substrate type etc. in determining the allocation of energy resources for reproductive activities by Pacific oysters. For suspended culture there does appear to be a strong correlation between greater reproductive effort and shallower water depths due generally to increased water temperatures and greater food availability at critical times of the year. The effects on reproductive effort of on-bottom subtidal as opposed to intertidal culture seem less clear and more research work is needed in order to adequately describe the likely impacts that either culture type might have with respect to wild settlement of Pacific oysters.

Irrespective of the culture type or degree of exposure it seems certain that as shown by comparing the work by Spencer *et al*. (1978) and King *et al*. (2006) that the level of reproductive effort shown by Pacific oysters will be site specific and will vary over time. This would imply that it would be difficult to foresee how exposure time could be used as an effective tool in preventing wild settlement of Pacific oysters whilst still allowing growth rates that are sufficient to ensure the economic viability of a farm. What must be borne in mind in a UK context is that where the prevailing environmental conditions in terms of seawater temperature do not provide the necessary degree days for successful settlement of Pacific oysters then the culture type and exposure level etc. are of no relevance. Where the environmental conditions do currently, or might in the future, allow for settlement then thought must be given to the type of culture activity, husbandry and management practises that will be adopted in order to prevent wild settlement of Pacific oysters from occurring.

For the UK little research has been done to assess the effect that culture type may play in determining the reproductive effort of Pacific oysters. Further research is therefore needed to investigate the reproductive abilities of Pacific oysters in the UK including an analysis of the effect of the degree of exposure and temperature on wild populations and oysters held in culture conditions.

3.6.2 Culture Type by UK Region;

The analysis of different types of Pacific oyster culture methods (Section 3.1) indicates that intertidal Parc or loose bottom culture has a greater likelihood of increasing the energy available for allocation towards reproductive effort than intertidal bag and trestle culture. An analysis of the questionnaire survey responses indicates that intertidal bottom culture together with subtidal bottom culture are the dominant forms of Pacific oyster farming in the South East of England. The methodologies used are derived from the previous fishery for Native oysters in this region. With respect to the other regions only one site in Northern Ireland was identified as undertaking intertidal bottom culture of Pacific oysters.

An analysis of the historical seawater temperature regime and predicted regime for the South East of England (see Section 2.4) indicates that in the South East, degree days necessary for settlement are not currently limiting in most areas. The predictions indicate that after 2020 no areas are likely to experience a temperature regime that would not support successful settlement of Pacific oysters. The predicted temperature regime for South West England indicates that spawning events and successful settlement will be much more likely to occur in this region by 2020-30. Given that degree days are not limiting in the South East and that considerable wild settlement of Pacific oysters has already taken place in this area then it seems unlikely that changes to current or future husbandry and management practises will have any significant impact on the ability of Pacific oysters to continue successfully recruiting in this region. The other region for which degree days are not shown to be limiting is the Southern part of England. The respondent to the questionnaire from this region practises subtidal bottom culture and the shallow nature of their culture site and fast growth rates would indicate that spawning events must be common with their diploid stock. However there are no known reports of wild settlement surrounding the culture area indicating that larvae are either being removed from the area or that the spat may suffer high mortality rates due to factors such as predation.

Although it was not possible to obtain temperature profiles for Northern Ireland the questionnaire responses and a review of the surveys conducted in Strangford Lough indicate that the temperature regime in this region is such that occasional successful settlement of Pacific oysters does take place and that this occurrence has increased in frequency in recent years. By way of a crude approximation of likely future impacts of climate change on Northern Ireland an analysis of the historical and predicted temperature regimes for the North West of England shows that for that region settlement events are considered to be likely to occur more frequently by 2030-40. If this trend is applied to Northern Ireland then this raises the question that, where degree days are currently limiting for most if not all years, would a change in husbandry practise on the site practising intertidal bottom culture reduce the risk of spawning and settlement events in that locality in the future? However, without analysing accurate historical data for the actual culture site then it is impossible to draw firm conclusions in this respect.

By contrast to the South East of England the South West and Northern Irish farms comprise sites mainly undertaking bag and trestle culture activities. The degree of aerial exposure is believed to be the main factor in determining the energy available for allocation to reproductive activities with this type of culture activity although this tends to be site specific and can vary with time. Generally the trestles are placed as near to the main water channel as possible whilst still allowing access to service the bags or harvest. Market size stock may be stored in holding areas higher up the shore so as to allow a greater period of access over each tidal cycle.

Spencer *et al*. (1978) suggest that altering the position of the stock on the shore could be considered as a method of retarding growth of oysters so as to retain them in a form suitable for market i.e. to limit their period of immersion so as to reduce feeding time and therefore reduce the energy available for reproductive effort. However whilst limited amounts of stock may be held for market on the higher shore it seems unlikely that industry will feel that it is acceptable to move bags of oysters between tidal heights in order to limit the build up in spawning condition. The economic implications of the additional labour involved in moving the bags plus the extra trestles and growing area that would be needed would almost certainly prove unfeasible for a farm site where commercial quantities of oysters are grown. Also, the site specific nature of growth rates and variation between years would make the positioning of trestles on individual sites very difficult to estimate.

It is not believed that any suspended offshore culture of Pacific oysters takes place at present in the UK. There is however increasing interest generally in the possibilities that offshore culture may hold for both finfish and shellfish aquaculture. For shellfish culture, offshore sites offer the potential for greater space availability, reduced water quality issues and increased water flow with consequent increases in food availability for filter feeding bivalves. The placement offshore, whilst probably still within easy access of land, does mean that the chances of spawning events leading to wild settlement of Pacific oysters would be greatly reduced although this would depend on the prevailing hydrodynamics of each site. Whilst food availability would be unlikely to limit gametogenesis the cooler offshore seawater temperatures may slow development sufficiently to lessen or even eliminate spawning events. Also the more stable environmental conditions when compared to the extreme variations in exposure and temperature experienced in estuary environments make it less likely that Pacific oysters in suspended offshore culture would be subject to the type of shocks likely to induce spawning.

3.6.3 UK Industry Overview and Perspectives;

A questionnaire was used to investigate current industry practises and observations of wild settlement of Pacific oysters. This questionnaire was sent to all registered oysters farms in England, Wales and Northern Ireland of which responses were received for 33 culture sites. The need to obtain a good response rate on the questionnaire placed a limitation on the number of questions and level of detail that could be requested. This limitation on scope means that more work will be necessary in order to investigate the main species of, and species in, MPAs in the UK that may possibly be affected by the culture of Pacific oysters.

The majority of farm sites are located intertidally and utilise diploid seed. Respondents from the South West of England had the greatest experience in the cultivation of triploid oysters. Trials were also planned by other growers in the South West of England and North Wales in 2008 using triploid seed. There were however misgivings amongst some respondents about the effect that high growth rates may have with respect to current husbandry practises and with regard to perceived issues over mortalities associated with handling these triploid oysters in the summer months.

With regards to wild settlement of Pacific oysters this was only reported to be found to any significant extent in the South West and South East of England although incidences of settlement were also reported for North Wales and Northern Ireland. Settlement in the South West tends to be sporadic whereas the South East experiences regular settlement of oysters which are often used by growers in the region as a source of seed or as a marketable product. There was a general view amongst industry respondents in the South East that it was now too late to halt the impact of wild settlement in that region and that efforts should now be made to help them increase the sales and market for this product.

The majority of Eastern England respondents were based on the margins of The Wash. Although only approximately 80 miles due north of West Mersea, where significant wild settlement of Pacific oysters has been observed, this region reported no wild settlement of oysters. It is recommended that as part of a national program of monitoring, temperature loggers are deployed at farm sites in this region to investigate if these apparent differences in settlement are related to temperature or whether other factors such as local hydrodynamics or lack of suitable substrates may be involved. For Northern Ireland there is evidence from surveys and from industry observations that some sporadic settlement of Pacific oysters has occurred in the past and that these incidences although small scale may be increasing in frequency.

3.6.4 Wild Settlement Occurrence;

Generally, patterns of observed Pacific oyster spat settlement have correlated roughly with occurrence of cultured stock. Some settlement anomalies not apparently associated with local farm culture would benefit from revisiting as would some of the historical reported sightings of Pacific oysters in Wales and Scotland. There is no useful quantitative reporting of Pacific oyster settlement that will allow assessment of the relative threat level between reported spatfalls. Many of the most significant areas of settlement in South East England which have become apparent in this study and have not been previously reported through the MARLIN/NBN Gateway systems. There is a need for a better up to date audit of UK wild Pacific oyster stocks in order to inform further management options.

3.6.5 Yealm Estuary Case Study – Ecological Status;

A high level of research effort has been focused upon the Yealm Estuary which has made the site a focus for UK attention. Previous studies have indicated that the Yealm supports a self sustaining 'established' wild population which has influenced the surrounding biota. A stock assessment for this study has suggested that cultured stock still significantly outstrips wild biomass and is currently likely to dominate larval production in the area. The suggestion, based on the relative size frequency distribution, that the wild Pacific oyster stock in the Yealm is responsible for secondary settlement in surrounding coastal waters is inconclusive.

The current level of settlement in the Yealm is still relatively low with the well documented 'reef' contributing less than 0.5 tonnes biomass. Anecdotal and size distribution data indicate that significant regular spatfall and recruitment does not yet occur in the Yealm. The current level of impact remains minimal with the only biological indicator being an increase in mobile invertebrates attributed to the presence of the Pacific oysters. Although the Yealm remains an important site that would benefit from further research, other areas, particularly in South East England, should be considered for a similar level of investigation.

3.6.6 Yealm Estuary Case Study – Implications for Local Settlement;

The South Devon case study shows that wild spatfalls would benefit from periodic monitoring to establish the pattern and frequency of settlement events. Previous studies on the South Devon coast have not always been consistent in revisiting the same sites (e.g. Spencer *et al*., 1994 and Couzens, 2006b). A more systematic approach to assess spatfall in relation to all harvest areas and to obtain associated representative temperature data might provide a more balanced picture. Some settlement sites have not reported any settlement previously (e.g. Salcombe), whereas other sites have a large number of sightings that are possibly proportional to the number of studies rather than the significance of settlement (e.g. MARLIN at Mothercombe).

Settlement events would benefit from outline wild stock assessments in relation to the local temperature regime and against nearby cultured stock biomass. It is recommended that consideration should be given to undertaking a coherent spatfall monitoring program, possibly in association with other measurement and monitoring schemes.

3.6.7 Larval Sources and Sinks;

Sources of larvae would appear to be increasing with increased culture production and wild biomass. The potential for even limited larval input from France also remains a potentially significant source whilst the conventionally considered vector of ship transport would appear to be less important than other potential sources at this stage. Sinks rates remain dominated by the temperature related processes which govern development speed, predation and recruitment potential.

When considering management measures in specific areas of the UK to help limit the impact of wild settlement of Pacific oysters then dispersal studies should be undertaken to identify the source of the larvae wherever possible.

3.7 Recommendations for Future Work

Section	Work/Research Required	Action Taken During Current Study (where applicable)	Importance	Potential Organisation to Action or Participate	Possible Sources of Funding
3.7.1	Review of the potential for larval settlement in the South East of England from the Continent. Issues surrounding larval drift and dominant hydrographic movements would need to be investigated.	Suggestions made with respect to likely impact of larval drift from the Continent.	If the present wild settlement seen in South East England is derived from the Continent then this has major implications for what measures should be put in place for shellfish farms in the South East.	- SNCAs - SAGB - Seafish	- Seafish - SNCAs - EFF
3.7.2	Investigation of main features and species in Marine Protected Areas in the UK that may possibly be affected by the culture of Pacific oysters.	Potential industry contacts identified through the post-questionnaire interviews for collaborative work with SNCAs in this respect.	Required to identify any potential risks to designated areas.	- SNCAs	- SNCAs - SAGB - Seafish - EFF
3.7.3	Investigation of genetic profile of wild settlement of Pacific oysters in the South East of England.	See Appendix 1 re **SEAFARE.**	This would help to establish if larval drift from European Pacific oyster populations has contributed to present wild settlement in South East England. This has implications for management decisions for the region.	- Atlantic Arc Aquaculture Group	- EFF/EC
3.7.4	Research project to investigate the reproductive abilities of *Crassostrea gigas* in the UK including an analysis of the effect of the degree of exposure and temperature on wild populations and oysters held in culture conditions.	Meeting held with researcher at the MBA who is currently carrying out a pilot scale project in this respect based upon a South West of England estuary (see Appendix 1).	Little information is currently available about the effect that exposure and temperature may play with respect to the reproductive efforts of Pacific oysters in the UK. This research would help to inform both managers and industry as to the implications of different husbandry practises.	- Seafish - SAGB - SNCAs	- EFF - Esmée Fairburn Foundation

SECTION 4 – ORIGINS & DEVELOPMENT OF PACIFIC OYSTER BROODSTOCKS IN THE UK & USE OF TRIPLOIDS

4.1 Broodstock Introduction and Development

4.1.1 Introduction of the Pacific Oyster into the UK;

Before 1960 the ecological implications of importing and depositing non-native bivalves were disregarded. Since this time legislation, codes of practise and guidelines have helped to control the introduction, deposit and release of non-native bivalves into UK waters (Utting and Spencer, 1992). The Pacific oyster as a non-native species was originally introduced in June 1964 into the MAFF Shellfish Research Station in Conwy, North Wales under strict quarantine procedures. This original introduction was sourced from Pendrell Sound in British Columbia (Canada) and releases of eggs and sperm were obtained later that year. In order to increase the available gene pool a further introduction was made in 1972 from a very isolated population of Pacific oysters in Seymour inlet on the west coast of Vancouver Island (Walne, 1979). Utting and Spencer (1992) note that a further introduction of Pacific oysters was made from the U.S.A. in 1978.

These stocks that were released to commercial hatcheries from quarantine in the late 1970s (Neild, 1995) form the basis of the commercial production of Pacific oysters in the UK since that date. It should be noted that whilst there are no regulatory restrictions to stop further Pacific oyster stocks from being imported from other EU Member States, such as France (Ian Laing, CEFAS, pers. comm.), this practise has been largely resisted by the UK industry due to concerns over the potential for introducing new diseases or other non-native species with imports.

4.1.2 Development of UK Broodstock Pacific Oysters;

Commercial privately owned shellfish hatcheries were originally set up in the UK utilising research work, technology and techniques developed at the Conwy laboratory. Initial interest centred on the Native flat oyster (*Ostrea edulis*) (Spencer, 1990) but was expanded to include the Pacific oyster in the late 1970s after this species was released from quarantine conditions. In terms of the development of non-diploid broodstocks the only development work that seems to have been undertaken is that by Guernsey Sea Farms who have previously produced a small number of tetraploid broodstock. However Mark Dravers of Guernsey Sea Farms reports that their initial trials with producing triploid oysters proved to be disappointing due to poor growth rates for larvae and juveniles.

As part of this study discussions were undertaken with the two UK commercial hatcheries in order to try and ascertain what levels of selective breeding might have been undertaken since the original distribution of Pacific oysters from the Conwy laboratory in the late 1970s. From these discussions it would appear that very little selective breeding has been undertaken for targeted traits and there is no evidence of family based or mass selection programs having taken place. Selection of broodstock oysters has been based either around choosing the faster growers with slower growing oysters being discarded or alternatively larger oysters are selected at random from sites where the oysters are in spawning condition at the time they are required for hatchery production. One hatchery stated that they would not knowingly just select for faster growing stock specifically as they preferred stock which showed a range of positive characteristics e.g. shell shape, meat to shell ratio etc. This was based on the fact that they felt that it is the faster growing oysters that tend to suffer first in times of adverse environmental conditions that can be associated with husbandry practises during commercial culture operations.

The choice of faster growing oysters for use as broodstock and the general practise of culling slower growing larvae as part of normal hatchery procedures raises two questions as to the possible unintentional consequences of these actions:

1) Could the use of the faster growing oysters as broodstock lead to an unintended selection pressure for Pacific oysters that are more likely or able to spawn in UK waters?

2) Does the practise of culling slower growing larvae from these broodstock to help reduce and synchronise the length of time to achieve settlement lead to the production of oysters with a faster growth rate which over time may lead to an increased potential for spawning?

A review of the literature concerning the first question shows that Ernande *et al*. (2003) investigated genetic variability and genetic correlations in the early life-history (larval and juvenile stages) of Pacific oysters. They found that larval survival, development rate, size at settlement and metamorphosis success were strongly heritable traits, whereas larval growth rates and juvenile traits were not. Therefore where fast growing and developing larvae settle and metamorphose early there is a cost in terms of success at settlement and metamorphosis. Conversely slower growing larvae settle and metamorphose late and at a smaller size but have a higher success rate at metamorphosis as well as a higher post-metamorphic growth rate and survival. The end consequence of this is that size advantage at settlement disappears with time during the juvenile stage. Also, the lack of genetic correlations between larval and juvenile stages implies a genetic independence between the different life stages of these life-history traits.

With regard to the second question, recent research by Taris *et al*. (2006) has investigated the phenotypic and genetic consequences of size selection through culling of slower growing larvae during hatchery production. Their work measured larval growth, survival, time taken to attain pediveliger stage and settlement success of larvae subjected to progressive culling compared to a non-culled control. Their results showed that culling had the greatest effect on levels of variance of these larval traits rather than their means.

The practise of culling also lead to a loss of genetic diversity in the larval population. Later work by Taris *et al*. (2007) to assess the consequences of the hatchery practise of culling on larval characteristics, and in particular growth, showed a lower survival performance in the hatchery broodstock but which conversely had a higher proportion of success at metamorphosis. They conclude that the results suggest that these larvae suffered from inbreeding depression, but that this is counteracted by better success at metamorphosis. Therefore where inbreeding depression co-occurs with size selection through culling not only may there be selection for faster growing larvae but also a preservation of genetic diversity by further selecting heterozygous fast growing larvae.

The two questions posed have only been considered at a superficial level as it does not form a main objective of this present study. However, the literature reviewed would seem to indicate that it is unlikely that selection of faster growing oysters as broodstock would lead to the level of selective pressure needed in order to produce Pacific oysters that are more likely to spawn in UK waters (Pierre Boudry, IFREMER, pers. comm.). Neither does it seem likely that practises such as culling would lead to this effect. Furthermore there does not seem to be any research to date that would suggest a link between faster growing larvae and spawning temperature threshold (Andy Beaumont, School of Ocean Sciences, Bangor University, pers. comm.).

4.1.3 Selective Breeding of Pacific Oysters;

Discussions were undertaken with Pierre Boudry of IFREMER (formerly La Tremblade and now Brest) on this subject area. Boudry was previously part of the triploid and hatchery development work programs on Pacific oysters within IFREMER and now works on the projects related to the invasiveness of these oysters. The question was asked as to whether any work might be on-going within or outside Europe with respect to developing strains of Pacific oysters that are less likely to spawn in European environmental conditions or whether this was an area for which there might be potential for future research. Boudry stated that IFREMER in Brest and the University of Caen are dedicated to the physiology of reproduction of *C. gigas*, including endocrine control and gene expression studies (see Ernande *et al*., 2004; Fleury *et al*., 2008). They are looking at factors regulating gametogenesis in diploid and triploid oysters and have recently submitted a proposal to develop new tools (notably microarrays) to further investigate this question. The aim is to better understand how reproduction is controlled in oysters in order to address its consequences in terms of aquaculture and the environment. Andy Beaumont (School of Ocean Sciences, Bangor University) stated that whilst one could try to breed for higher spawning temperature thresholds, we do not as yet know how much of the variation in this trait is heritable and amenable to selection.

In terms of research outside of Europe, Boudry stated that to the best of his knowledge breeding programs outside of Europe are not directly targeting the development of strains that would not spawn under European conditions. It appears that in the last decade, family-based selective breeding programs have generally focused on improving yield (survival, growth) or quality traits (shell shape, meat/shell ratio). Examples of breeding programs that have been initiated in recent years include in the U.S.A. selection for yield (MBP and WRAC), Australia selection for growth (CSIRO and ASI) and New Zealand selection for growth (Cawthorn Institute) (Boudry and Haffray, 2006). The question of developing breeding programs such as this in a European context has previously been discussed with IFREMER by Syvret as part of a potential European Collective Research project that was discussed in 2004. It was recognized at that time that the significant investment and facilities that would be needed to develop Pacific oyster breeding programs when compared to the size of the UK industry meant that only an EC centrally funded project with European partners would have any chance of success in this respect. However certain difficulties became apparent in this approach at that time. These included the following:

- Selective breeding programs invariably raise issues with respect to ownership of the selected material and with respect to intellectual property rights (IPR);
- Breeding programs would involve movement and exchange of oysters between the UK and Europe which is something that has previously been resisted by parts of the UK industry due to concerns over possible importations of disease;
- The traits to be bred for would need to be agreed. At the time it was envisaged that this might be difficult to agree as for instance the French might be interested in breeding for disease resistance whereas the Irish would probably be more interested in improving condition and growth parameters.

In terms of the current situation in Europe it would seem likely that work on investigating the genetic variability and differentiation between European Pacific oyster stocks would still be of interest. However with the significant increase in recent years of wild settlement of Pacific oysters and significant problems being experienced with summer mortality (see http://www.ifremer.fr/morest-gigas/ ; Boudry and Haffray, 2006; Samain *et al.*, 2004 and 2007) it is unlikely that French research efforts would be targeted at producing non-spawning strains of oysters as it is in effect too late in France to undertake any remediation efforts in this respect. It is not believed that the facilities exist in the UK to undertake this type of long-term, large-scale research and breeding program development work and as such it must be concluded that efforts to improve the availability of non-spawning oysters for culture in the UK should be targeted at the use and further development of the triploid technology.

4.2 Production of Triploid Pacific Oysters

4.2.1 Introduction;

Triploidy refers to the condition of a cell or organism having three sets of chromosomes (3n). In bivalve molluscs triploids are fully viable and do not appear morphologically different from diploids (Guo and Allen, 1994a) where each cell of the organism contains a matching set of chromosomes. Oysters for instance have a diploid number (2n) of 20 chromosomes (10 pairs; haploid number, n = 10). In the last 10 years, triploids have become an important part of Pacific oyster aquaculture and now account for about one third of the hatchery produced seed on the US West Coast (Chew, 1994). Uptake of this technique has however been slower in Europe which can probably be attributed to the lower market share of hatchery produced spat compared to natural spat in Europe (Boudry *at al*., 1998).

There is a presumption that due to their 3n state that triploids will as a consequence be sterile. This is considered in more detail later in this Section. From a commercial viewpoint a sterile triploid oyster is desirable for three main reasons which are summarised as follows from a review by Beaumont and Fairbrother (1991):

1. Energy usually diverted to gamete production is available for somatic growth and therefore adult triploids should grow faster;

2. In oysters the gonad ramifies throughout the somatic tissue often rendering ripe animals unmarketable. In animals that have spawned the flesh is often severely depleted and watery in appearance. Triploid oysters therefore allow year–round production (Allen, 1988) and marketing of a saleable product;

3. The potential to produce sterile triploids of non-native species such as the Pacific oyster enables their use as aquaculture organisms in areas which might be sensitive to the accidental introduction of competitor species.

A further reason why triploids may be seen to outperform diploids is that triploidy potentially induces higher mean heterozygosity, a character which has been shown to be positively correlated with growth in many shellfish species (Boudry *et al*., 1998).

4.2.2 Triploid Production Methods;

Triploidy can be induced in Pacific oysters through the application of a shock treatment during the normal egg maturation process at either meiosis I (mI) or II (mII) followed by fertilisation by a haploid sperm. These methods generally exhibit varying rates of success in producing triploid oysters. Following the production of tetraploid Pacific oysters by Guo and Allen (1994b) a method of producing 100% triploids by crossing tetraploid (4n) males with diploid females (2n) has now been developed following further work by Guo *et al.* (1996). These differing methods are considered in more detail below:

4.2.2.1 Induction through shock:

Chemical shock – This is the most commonly used method of shock induced triploidy production in commercial hatcheries whereby inhibition is induced at meiosis II by inhibiting the second polar body with cytochalasin B (CB) (Allen *et al*., 1989) or more recently with 6-dimethylaminopurine (6-DMAP) which is less toxic than CB (Desrosiers *et al*., 1993). This is the technique that is employed by all UK or British hatcheries in producing triploid Pacific oysters for commercial purposes. The induction of triploidy at meiosis II is favoured as research has shown that viable mI triploids are more difficult to obtain than mII triploids with 6-DMAP and CB being equally efficient at producing mII triploids (~84±14% in work by Gérard *et al.* 1999). The use of these chemical methods is not however without its limitations. Foremost amongst these is the fact that the chemical methods cannot produce

100% triploidy with an average of around 80% being reported across the literature (Beaumont and Fairbrother, 1991). This has potential consequences in practical and economic terms for hatcheries and on-growers as well as environmental ramifications where triploids are being used to mitigate wild settlement of a non-native species.

The use of these chemicals in a hatchery environment also has health and safety issues as CB is highly toxic and may have implications in terms of consumer acceptance due to the use of chemicals in a food production process. Finally there is the possibility that for induction techniques that by blocking the second polar body there may be a negative impact on the survival and growth of these triploids (Eudeline *et al*., 2000).

Thermal shock - Both heat and cold shocks can be used to help induce triploidy at meiosis I or II or first cleavage. Effective heat shocks are generally between 25 ^{o}C to 38 ^{o}C and cold shocks from 0 ^{o}C to 5 ^{o}C (Beaumont and Fairbrother, 1991). Helm and Bourne (2004) describe a methodology in use in some hatcheries whereby fertilized eggs, normally held at 25 ^{o}C, are suddenly subjected to a temperature of 32 ^{o}C for two minutes and are then returned to 25 ^{o}C. The temperature shock is applied after the emission of the first polar body, about twenty minutes after fertilization. Helm and Bourne claim that this method has been perfected and that the success rate in producing triploids is now about the same as with the chemical method, i.e. averaging about 90%, which would be a significant improvement on previous research findings. The potential for further development of thermal shock treatment is considered further on in this Section.

Pressure shock - Hydrostatic pressure shock has been successfully used previously to induce triploidy in oysters. Shen *et al*. (1993) obtained 76% of triploid embryos when working with the pearl oyster, *Pinctada martensii* Dunker. Work on Pacific oysters by Chaiton and Allen (1985) obtained up to 57% of triploids using a pressure treatment of 6,000-8,000 psi administered 10 minutes after fertilization for a 10 minute duration. Allen *et al*. (1986) managed to achieve a best result of 60% by use of a pressure shock of 7,200 psi at 29 ^{o}C.

As with thermal shocks a drawback of this method, and a potential reason for the relatively low percentage induction rates when compared to chemical shocks, is that the timing of physical shocks is more critical (Beaumont and Fairbrother, 1991). Eggs have only a small window of vulnerability for applying these treatments when compared to chemical treatments and since physical shocks arrest all development, only those eggs at that vulnerable stage will be affected and go on to develop as triploids. The use of CB on the other hand does not arrest normal egg development and so the eggs go on to reach the vulnerable stage whilst still undergoing the treatment (Allen, 1987). A further drawback with this technique when compared to chemical or heat shocks is that it requires the use of specialist high-pressure treatment equipment. These drawbacks together with the relatively low success rates obtained so far in inducing triploids would suggest that this technique is not well suited to any allocation of funding resources in a UK context.

4.2.2.2 Use of tetraploids: As mentioned above the crossing of diploid females and tetraploid males is a technique that has been shown to be capable of producing 100% triploids (Guo *et al.*, 1996). The tetraploids themselves were first produced by Guo and Allen (1994b) by blocking the expulsion of the first polar body in eggs from a fertile triploid through the application of CB and crossing with a diploid male i.e. 3n x 2n + CB = 4n. Research by Eudeline *et al*. (2000) to try and optimise this technique ended up with an average tetraploid survival rate of 4.4% which was considered acceptable as these were to be used for broodstock purposes. A major advantage of this technique in addition to its ability to produce 100% triploids is that once tetraploids are produced then there is no further need for chemical treatments to produce triploids in a hatchery environment thus avoiding some of the health and safety concerns in this respect as well as possible consumer acceptance issues. This has therefore lead to the use of the terms ‘natural’ or ‘mated’ when describing triploids produced through this technique.

4.3 Patents and Triploid Seed Supply

4.3.1 Production of Tetraploid Pacific Oysters;

The original technique developed by Guo and Allen (1994b) for producing tetraploid males is a patented process. The patent itself, United States Patent 5824841, was filed in 1997 and has the Assignee stated as Rutgers, The State University of New Jersey (New Brunswick, NJ) with inventors as X. Guo and S.K. Allen Jr. The 'exclusive rights to market and sub-licence the tetraploid technology' are however held by 4Cs Breeding Technologies, Inc. (4Cs) who are based in New Jersey, U.S.A. The 4Cs web-site (www.4cshellfish.com) has Prof.s Allen and Guo noted as Scientific and Technical Advisors. The web-site now has contact details for sub-licence holders in Washington, Korea and Australia. It is assumed that in order to grant these sub-licences that the tetraploid technique must have been filed with the relevant patent office in each country as for instance the U.S. patent grants are effective only within the United States, U.S. territories, and U.S. possessions.

It appears that there is some dispute as to the legitimacy of this patent claim as it is believed that this technique was already either in use or under development in both the UK and France at the time the original patent was filed. However this patent is now in force and sub-licences are being issued in various parts of the world. A separate patent has been registered with the European Patent Office for this tetraploid technique. The European patent No. EP 0 752 814 B2 was filed in 1995 with Rutgers University as the Proprietor. This is therefore the effective patent covering both France and Great Britain. European patents have a 20 year duration provided that the on-going maintenance fees are paid. Therefore based on a filing date of the 20/01/1995 this would mean that the patent is due to expire on 20/01/2015. The effect that this has on the UK's ability to use this process is somewhat unclear and despite investigation remains so. Guernsey Sea Farms were in fact noted as a 'Partner in Europe' on the 4Cs web-site up until February 2008. This reference to Guernsey Sea Farms has as at May 2008 been removed with no contact point for Europe cited. Mark Dravers of Guernsey Sea Farms (pers. comm.) has stated that in 2003 they became a licensee of the patented method and from there went on to produce a small number of tetraploid stock. They then encountered problems with a claim from IFREMER and a commercial company that IFREMER were in fact the holders of the European patent with the result that IFREMER claim to control all triploid stock produced from tetraploids from any source. Dravers then states that this claim may be open to challenge but Guernsey Sea Farms do not have the necessary resources to undertake such an action with the result that their existing licence agreement is nullified with no contact with 4Cs since 2004. Guernsey Sea Farms therefore continue to produce triploids by the chemical induction method.

Indeed it appears that in 1997 IFREMER did perfect the tetraploid technique to produce what are termed 'natural triploids' or 'Four Seasons' oysters. However no mention is made of this arrangement with IFREMER on the 4Cs web-site. IFREMER (Abdellah Benabdelmouna, pers. comm.) in discussions with Syvret stated that their patent only covers French territory but that a French commercial hatchery, Grainocean S.A., have an agreement with Rutgers University in order to act as the European contact point. In practical terms what now happens is that IFREMER maintain and produce the tetraploid male Pacific oysters in their quarantine facilities at la Tremblade under an official agreement to maintain tetraploid oysters in such a way as to prevent any biosafety risk i.e. colonisation of the environment by polyploids. They then supply French hatcheries with the necessary male tetraploid sperm each year for use in their commercial hatchery work.

With regard to the patent issues what seems possible is that the actual ownership of the intellectual property rights surrounding the technique to produce tetraploid Pacific oysters for use in triploid production may in fact be open to challenge between, at the very least, IFREMER and 4Cs or Rutgers University. Although speculation, it may be that this has led to an understanding between 4Cs and IFREMER that IFREMER will be free to continue to use this technique within their own geographic boundaries and that some commercial use of the technology through French hatcheries can take place.

Certainly in discussions with Grainocean S.A. (Eric Marissal, pers. comm.) they seemed happy to discuss the possibilities of supplying French triploid seed produced through the tetraploid technique into the UK. Grainocean currently supply some Jersey oyster farmers with Natural Triploids as a mixture of triploids and diploids are currently farmed in Jersey. CEFAS have confirmed that there are no regulatory reasons why Pacific oyster seed (triploid or diploid) cannot be imported from France provided they are notified ahead of time of any shipments and that the correct declarations and paperwork accompany the seed shipment.

To date there has been reluctance by the UK industry to import any sort of French oysters due to concerns over the possible introduction of new diseases. However importations of French part-grown oysters into the UK have occurred although before any thoughts are given to importing French seed it would certainly seem preferable in the first instance to investigate if support can be given to UK/British hatcheries to use this technique if indeed tetraploid produced triploids prove to be an effective management tool in preventing environmental impacts in this respect (see also Section 4.10). The relative advantage of the tetraploid method in producing 100% triploids will also have to be assessed through some form of risk assessment against the still high success rate of the chemical induction method. A basis for the comparison of relative risk is considered in more detail in the 'Viability of Triploids' review in Section 4.4.

In summary it would appear that firstly any challenges to the patent regarding the right to use the tetraploid technique are likely to be costly and without any guarantees of a positive outcome. The question would also arise as to who would mount this challenge and pay for the legal expenses in this respect. The second possibility therefore is to revisit the issue of a UK or British hatchery obtaining a licence to use the patented tetraploid technique. In order to try and assess the possibilities in this respect Syvret as part of this study contacted 4Cs to discuss the future potential in this respect. The President of 4Cs, Tom Rossi, stated that they "would be willing to licence the tetraploid technology to a UK hatchery, and we would be interested in promoting the use of triploidy in the UK oyster culture industry". Rossi stated that he had previously had an arrangement with Guernsey Sea Farms and had held discussions with Seasalter Shellfish (Whitstable) Ltd. but that any use of the tetraploid technology had not progressed any further. Rossi then stated that perhaps it was time for discussions to be renewed between 4Cs and interested parties. It was then agreed that the position of 4Cs with respect to the possible licensing of a UK or British hatchery to use the tetraploid production technology would be communicated as part of this technical report. It would then be for industry to take this matter forward directly with 4Cs.

4.3.2 Use of Hydrostatic Pressure Shock to Induce Triploidy in Oysters;

United States Patent No. 4834024 was filed in 1984 with the Assignee stated as being the Board of Regents of the University of Washington (Seattle, WA). Inventors are S.K. Allen, J.A. Chaitin and S.L. Downing. In brief the invention is stated to relate to the production of polyploid animals in general, and more specifically, to a method of inducing polyploids in oysters through the use of hydrostatic pressure. A search on the European Patent Office web-site did not reveal an equivalent European patent. The only other similar patent found during this search related to a polyploid breeding method for inducing heterogeneous triploid scallops by physical means (in this case pressure).

4.3.3 Use of Thermal Shock to Induce Triploidy in Oysters;

A search of the European Patent Office web-site and of United States patents did not reveal any patents relating to the use of the thermal shock technique, either hot or cold, for inducing polyploidy or triploidy in shellfish.

4.4 Viability of Triploids

4.4.1 Introduction;

As mentioned in Section 4.2.1 there is a general assumption that the 3n state of triploids means that they must be sterile and therefore incapable of reproducing in the wild. This has led to the call in the UK for use of triploid Pacific oysters as a means of eliminating any possible environmental impact of this non-native species through wild settlement. This presumption of complete sterility is not in fact the case in triploid Pacific oysters as they are capable of producing viable eggs and sperm (Allen and Guo, 1996).

Gametes produced by triploid Pacific oysters are generally aneuploid and when fertilised, some of these can develop into viable offspring (Guo and Allen, 1994a). Whilst triploid oysters' potential for reproduction is greatly reduced when compared to diploid oysters, they do still have the potential to exhibit gonadic maturation (Gong *et al*., 2004).

4.4.2 Biological Containment and Type of Triploid;

This poses the question therefore of whether the use of triploids can in fact be offered as a means of ensuring biological containment of this non-native species when used in aquaculture activities in the UK. To appreciate the complexity of this issue and assess the risks involved one must first consider a scenario where triploids are crossed with other triploids and then a further scenario where triploids are crossed with diploid oysters.

Professors Allen and Guo of Rutgers University discuss this issue with respect to their earlier research (Guo and Allen, 1994a) in a paper considering the use of triploids for biological containment (Allen and Guo, 1996). They state that:

"When triploids are crossed with themselves, the ploidy of resulting embryos is 2.88n on average, that is hypo-triploid. Survival of fertilized eggs to metamorphosis and settlement was only about 0.0085% [*compared to 20.6% for diploids*]. Further work in 1996 showed that triploid males are about 1000 fold less fecund than diploid males; triploid females about 20 times less fecund. So, although triploid oysters are not sterile in terms of gamete production, their reproductive potential is extremely low, by all practical measures, 0."

Furthermore in other laboratory work at Rutgers University (Guo and Allen, 1994a) where triploid x triploid offspring were produced 90% of the survivors were triploid, although the chance of producing a diploid was not zero.

To understand the scenario where triploid oysters are crossed with diploids one should first consider the technique by which the triploids are produced. The methodology behind the work carried out by Guo and Allen in 1994(a), which provided an estimate of the reproductive potential and gamete chromosome numbers of triploids, was based on using triploids produced by chemical induction. This work estimated that the relative fecundity of triploid females produced by this technique was 2% of that of an equivalent diploid female. However, more recent work by Gong *et al*. (2004) using triploid females produced by a diploid female x tetraploid male (as per Guo *et al.*, 1996) showed that the relative fecundity was in this case 13.4%.

The difference in relative fecundity levels may be due to the fact that the tetraploids used were produced from selected triploid females with high fecundity. The mated triploids may then have inherited the genes that are responsible for high fecundity from their highly fecund triploid grandmothers.

This possible difference in relative fecundity rates between chemically induced and 'natural' or 'mated' triploids has led to claims that the 'natural' triploids are more fertile than those produced by chemical induction. However Pierre Boudry of IFREMER stated that these claims should be treated with great caution as there was no definitive published data supporting this opinion and also because intellectual property rights and patent issues tend to bias views about this question. Work has been carried out by IFREMER to further investigate this finding (Normand *et al*., 2007) and is still on-going through a PhD student under Pierre Boudry's supervision. One last point that should be remembered is of course that chemically induced triploids do not have the 100% level of triploid production achieved through the use of the tetraploid technique and so any risk analysis in this respect would have to take into account the ~10 to 20% difference normally found in triploid production between these two techniques.

Whatever the basis of claims about differences in fertility of types of triploids Gong *et al*. (2004) concluded that assuming that triploid males have about the same relative fecundity as triploid females then on average triploids have a relative reproductive potential of 0.1075% (about 1 in 1000) when mated with normal diploids. This reproductive potential is higher than the previous estimate by Guo and Allen (1994a) of 0.0046% or 1 in 22,000. This difference in findings with the earlier research is certainly partly to do with increased fecundity (~ seven fold) but is also partly due to increased larval survival. Larval survival can be highly variable and these estimates were provisional and for hatchery conditions only (survival in the wild would be expected to be lower) but could help to explain at least some of the differences in fecundity exhibited between these research findings.

These findings have implications for the use of triploids as a form of biological containment. A recent report by Guy and Roberts (2007) has advocated the use of triploids in Strangford Lough (Northern Ireland) as a means of limiting or reversing the spread of wild Pacific oysters. However it can be seen that as triploid Pacific oysters are not completely sterile then it cannot be claimed that they can offer a method of complete containment of cultured populations during aquaculture activities especially if diploid oysters are also present. Where diploid oysters are to be found then it would appear that the risks of some low level production of viable offspring are increased even if the risk of actual successful settlement remains very low.

4.4.3 Risk Assessment;

It seems therefore what can be reasonably claimed is that the reproductive potential of triploids when compared to diploids is greatly reduced.

It would seem that the best use of triploids for containment would be in cases where no diploid stock were in evidence whether that was on a farm site or through pre-existing wild settlement.

In order to fully understand the implications of these differences Syvret contacted Prof. Guo at Rutgers University to work through a relative risk assessment of the culture of triploid oysters versus the use of diploid oysters.

The results are summarised overleaf as worked examples where the calculation for chemically induced triploids is by Guo (pers. comm.) and for mated triploids is by Syvret as part of this study.

Basis of calculations;

- Relative Reproductive Potential is calculated as Relative Fecundity x Relative Survival i.e. diploids relative to triploids;
- Survival of triploids from a TxT cross (from Guo and Allen, 1994a) is 0.0085% whereas survival for diploids is 20.6%. This gives a relative survival of 20.6% ÷ 0.0085% = 0.04126%;
- Fecundity of a chemically induced triploid female is estimated to be 2% of that of a diploid female (Guo and Allen, 1994a);
- Fecundity of a mated triploid female (produced via the tetraploid technique) is estimated to be 13.4% of that of a diploid female (Gong *et al.*, 2004).

TxT cross using chemically induced triploids;

- Assuming sperm is not a limiting factor (a conservative assumption), the Relative Reproductive Potential of a TxT cross is 0.04126% x 2% = 0.000,008 or 1 in 125,000 i.e. for every 125,000 viable offspring that diploids produce, triploids will produce 1 or for every 1 million viable diploid offspring, triploids will produce 8;
- Next, assuming only 7% of the TxT progeny are fertile diploids, the Relative Reproductive Potential becomes 0.000,008 x 0.07 = 0.000,00056 or 1 in 2,000,000;
- If sperm is also limiting and the triploid male produces only 13.4% of diploids, then this is 0.000,00056 x 0.134 = 1 in 100,000,000.

TxT cross using mated triploids;

- Assuming sperm is not a limiting factor (a conservative assumption), the Relative Reproductive Potential of a TxT cross is 0.04126% x 13.4% = 0.000,0552 or 1 in 20,000 i.e. for every 20,000 viable offspring that diploids produce, triploids will produce 1 or for every 1 million viable diploid offspring, triploids will produce 50;
- Next, assuming only 7% of the TxT progeny are fertile diploids, the relative reproductive potential becomes 0.000,0552 x 0.07 = 0.000,0038 or 1 in 250,000;
- If sperm is also limiting and the triploid male produces only 13.4% of diploids, then this is 0.000,0038 x 0.134 = 0.000,0005 or 1 in 2 million.

4.5 Triploid Reversion

4.5.1 Heteroploid Mosaics;

Allen and Guo (1996) reported that in the production of induced Pacific oyster triploids in their laboratory a high proportion of heteroploid mosaics had been found suggesting that at least some triploids are unstable, i.e. that they can revert from triploidy to mosaics. This had serious consequences at that time for the use of triploids in population control of non-native marine animals.

Indeed an experiment in Chesapeake Bay in 1994 looking at whether triploid Pacific oysters were more resistant to the local oyster diseases of MSX and dermo was ended when it was discovered that around 20% of the triploids had both triploid and diploid cells i.e were mosaics (Blankenship, 1994). Prof. Allen commented at the time that it was the first instance they had seen of this reversion process to a diploid state and that it was to be investigated further.

Heteroploid mosaics had been seen in routine laboratory sampling work carried out at Rutgers University and this was not considered surprising in itself as the triploid induction process affects cytokinesis in newly developing embryos and so abnormal progeny might be expected occasionally. They were surprised however on further investigation to find that the frequency of mosaics in several triploid populations increased over time, suggesting that some triploids could have a tendency to lose chromosome sets.

4.5.2 Reversion by Tissue Type;

Research carried out to investigate this reversion (Allen and Guo, 1996) found no differences between frequencies of mosaics in embryos between chemically induced and mated triploids. In terms of assessing the reproductive potential of mosaics Guo and Allen looked at ploidy in 4-5 tissue types within the oysters, including the gonad. They found that with a few exceptions, mosaics had 2n and 3n cells in all tissues examined. In the exceptions, one tissue type would have either diploid or triploid cells. They did not however find any evidence of haploid gamete production at that time indicating that there was in fact no risk of these mosaics successfully reproducing.

A review of the scientific literature surrounding triploids has shown that reversion of triploids to a diploid state is a possibility, especially as the oysters age. As there is little current literature on this subject Syvret contacted Prof. Ximing Guo at Rutgers University to discuss this issue directly. Prof. Guo (pers. comm.) gave the following information “Some triploids can revert to diploid/triploid mosaics in gill and haemolymph tissues, but we have not seen any evidence that the reversion happens in the gonad”. Prof. Guo also confirmed that fertility of triploids was more of an issue than reversion when considering triploids for population control.

Abdellah Benabdelmouna of IFREMER (pers. comm.) confirmed that reversions can occur back to the diploid/triploid mosaic state and that both natural and chemical triploids exhibit this risk. However he stated that this is generally only when the polyploid oysters became older (more than 3 years of age). Benabdelmouna went on to state that when considered with the low reproductive potential of triploids then reversion is considered to be of minor importance.

Given these assurances it would seem reasonable to conclude that reversion of triploid Pacific oysters to a heteroploid mosaic state is not a risk factor when considering utilising triploids for biological containment.

4.6 Summer Mortality

4.6.1 Introduction;

It has been suggested that the use of triploid Pacific oysters may be one method of overcoming what appears to be an increasingly important issue of 'summer mortality' in Pacific oysters, especially in some regions of France. Reports of between 30% to 60% mortality levels in oysters mainly within their first two years of growth have not been uncommon since this problem emerged in France in the mid-1990s. Reports from France on summer mortality events during 2008 have even indicated that in some areas mortality rates have reached 100% in one to two year old oysters. Along the coasts of France, mortality events amongst adults generally occur during the spring, whilst mortality amongst juveniles is more prevalent during summer (Fleury *et al.,* 2001). However much of the underlying cause of summer mortality remains of 'unknown origin' despite intensive scientific investigations.

Previous studies indicate that in general summer mortalities cannot be wholly explained by any one single factor. It appears therefore that the problem of summer mortality is more likely to be caused by a combination of environmental (biotic and abiotic) and internal (genetic, physiological and immunological) parameters (Dégremont *et al*., 2005).

Indeed such was the concern over the impact that summer mortality was having on the French oyster industry that the MOREST program was launched in 2001 in France. This was a national multidisciplinary project with teams from IFREMER and other varying research institutes and organisations. Research under the MOREST program is still being published but an overview of its research with respect to the relationship between summer mortality and oyster genetics, reproduction, physiology, immunology and infection/pathogen pathways can be found in Le Roux *et al*. (2002); Dégremont *et al*. (2007); Delaporte *et al*. (2007); Samain *et al*. (2007).

4.6.2 Comparison of Diploid and Triploid Pacific Oysters;

Some previous research has found that diploid and triploid Pacific oysters are both affected by summer mortality problems (Calvo *et al*., 1999; Cheney *at al*., 2000). Nell and Perkins (2005) review some of the literature regarding differential levels of mortality between diploid and triploid Pacific oysters but do not draw any firm conclusions as the literature currently available shows conflicting reports. This therefore makes it very difficult to accurately assess for given conditions whether or not triploid oysters are more 'resistant' to summer mortality than diploid oysters or are in fact more likely to suffer mortalities. It also presents difficulties when comparing the literature on this subject as it is hard to assess whether research findings are describing comparable conditions or events.

Boudry and Haffray (2006) perhaps offer some insight into the problems involved in comparing triploids and diploids in this respect. Their overall conclusion is that generally triploid oysters resist summer mortality better than diploids. This is probably due to differences in energy allocation during reproduction which seems to be a key factor in causing the summer mortality phenomenon. However they point out that there can be variability between years in spat mortality levels. In their research spat mortality levels in 2002 were 24% for diploids and only 7% for triploids whereas in 2003 both types of oysters experienced spat mortality levels of 48%. Furthermore the relative resistance (R) or susceptibility (S) of family lines seems to also play a key role in relative mortality levels.

By way of an example, in their work using non-selected tetraploid males they found that when crossing these with high resistance diploid females they produced triploids with a summer mortality level of 36%. However when crossing the tetraploid with a highly susceptible diploid female they ended up with a mortality level of 58%. Normal non-selected diploid male and female crosses by comparison had a mortality level of 48% which was similar also to the mortality level of 50% found in a cross between the tetraploid and non-selected diploid female. Therefore in this example triploid oysters exhibited the lowest, worst and average mortality levels with respect to summer mortality depending on the relative resistance of the diploid females.

Further work by IFREMER (Gagnaire *et al*. 2006) which compared mortality levels between diploid and triploid Pacific oysters reared at two heights above sediment (15cm and 70cm) showed that trestles placed higher above the sediment exhibited lower mortality levels and that whatever the rearing height, mortality levels in triploid oysters were significantly lower. Work by Soletchnik *et al*. (2003) also concluded that triploids exhibited lower mortality rates than the diploids. In this work the triploids were again produced via the tetraploid technique but no mention is made of family traits. Obviously more work is needed with respect to trying to select high resistance tetraploids but this shows that family traits can be an important factor in determining the relative resistance of triploids to summer mortality.

One note of caution should be that this French research is based upon triploid production using tetraploids whereas the UK and British hatcheries are currently producing triploids through chemical induction. No literature could be found that confirmed whether there are likely to be survival differences between triploids produced by these different methods and so IFREMER were contacted directly to obtain an opinion in this respect. Pierre Boudry (pers. comm.) confirmed that whilst this is little published literature on this subject they felt that there was clear evidence that chemically induced triploids often show higher mortality rates than 'mated' triploids although this should be considered in light of making proper comparisons using oysters of the same genetic background (to account for the high heritability of summer mortality survival). This work has not to his knowledge been carried out so far but he was willing to state that "it is clear to me that mated triploids perform better than chemically induced triploids". Boudry felt that the mechanisms to cause this difference are not clear but thought that heterozygosity might be one factor and that almost certainly the process of chemical induction has a detrimental effect on the resulting embryo.

4.6.3 Incidences of Summer Mortality in the UK;

To date there have not been widespread reports of summer mortality occurrences in the UK. High temperatures are associated with summer mortality events in Pacific oysters (Goulletquer *et al*., 1998) and 19 ^{o}C has been stated as a critical threshold temperature for mortality events associated with reproduction (Soletchnik *et al*., 2003). It is possible that UK water temperatures have tended overall to buffer UK growers against the levels of mortality experienced in France. However there is now some evidence that summer mortality events may be starting to occur in the UK. One example was a widespread mortality of 1 year old Pacific oysters that was experienced by a South West grower in 2007 (Industry, pers. comm.). This has led the grower this year to purchase replacement half-ware triploids to try and overcome this issue. There have also been some unexplained diploid Pacific oyster mortalities previously in the Channel Islands. These mortalities may have been due to a combination of factors (presence of a herpes-type virus together with warm summer temperatures) in line with French summer mortality events. In this case diploid stocks were affected more than triploid oysters (Industry, pers. comm.).

Certainly climate change or global warming trends were reported by Soletchnik *et al*. (2003) to be thought to be partly responsible for the increase in summer mortality events with an example cited of the Marennes region where sea temperatures have risen by ~1 ^{o}C over the last 30 years. If seawater temperatures therefore continue to rise in the UK then it is possible that summer mortality events may become more widespread and frequent. This would therefore seem to indicate that in order to avoid these significant losses that industry might be advised to consider the use of triploid Pacific oysters in the future.

4.7 Market Acceptance of Triploid Oysters

4.7.1 Introduction;

Whilst not a core aspect of this study it is helpful when considering the use of triploids to look at the wider implications of their use in terms of marketability and consumer acceptance. Therefore some notes on these issues are included as follows.

4.7.2 Classification;

It appears that triploids are not considered to be 'GMOs' under the current ICES (2005) definition;

'Genetically modified organism (GMO)' - An organism in which the genetic material has been altered anthropogenically by means of recombinant DNA technologies. This definition includes transgenic organisms, i.e. an organism bearing within its genome one or more copies of novel genetic constructs produced by recombinant DNA technology, but excludes chromosome manipulated organisms (i.e. polyploids), where the number of chromosomes has been changed through cell manipulation techniques.

4.7.3 Organic Status;

To date there has been a resistance on the part of the shellfish farming industry to the adoption of the use of organic certification schemes. This is based on a general perception by industry that their product is by default an organic one and that to label one shellfish product as organic poses the question as to what constitutes a 'non-organic' shellfish. However, the use of organic certification is growing in other food production sectors and may in the future become of interest to the UK shellfish culture sector. The Soil Association were therefore contacted to obtain guidance on what status triploid shellfish have in terms of organic certification given that they may be one potential means of reducing possible environmental impacts of culturing Pacific oysters.

The Soil Association stated that triploid animals are not allowed in organic standards. It also appears that from discussions to date regarding the new European organic regulations that triploids would be prohibited. However, they are likely to be permitted in proposed US organic standards as long as the triploids are produced via the tetraploid technique, so that any chemical treatment is one step removed from the consumer.

In terms of organic standards and environmental impacts then the Soil Association stated that it is likely that where Pacific oysters were already well established on the South Coast then they would permit the use of diploid stock within their standards. Where wild settlement was not already well established then this would be considered on a case by case basis. Were for example Natural England to recommend using triploids in a specific area due to concerns about wild settlement then the Soil Association would choose not to certify the use of diploids in that area (Peter Bridson, Aquaculture Programme Manager, Soil Association, pers. comm.).

4.7.4 Consumer Perception;

The advantage of triploids, in that they are marketable when diploid oysters are either milky (in spawning condition) or spawned out, has led to the use of terms such as 'Summer Specials' or 'Four Seasons' being used to describe them. However as triploid shellfish are not considered to be GMOs then there is understood to be no regulatory need to label them as triploids. Even though triploids do in fact occur naturally within Pacific oyster populations there is still a perception, even within some parts of the shellfish industry itself, that a shellfish with three sets of chromosomes must be some form of GMO. Consequently there is reluctance by some growers to use triploid oysters on this basis. Whether or not the definition states that triploids are not GMOs there has been caution in the past from growers about whether this issue may cause consumer perception problems even if only through misunderstanding about the product. There have been no known consumer issues to date with respect to triploid Pacific oysters in the UK as far as can be ascertained in this study although there are reports of some consumer resistance in France to eating triploids. Were there however to be consumer perception issues following any shift by UK growers to triploid production then this would of course have serious economic implications for the industry.

Another potential consumer perception issue could arise with respect to the techniques used to induce triploidy. UK hatcheries currently use the chemical induction method e.g. CB or 6-DMAP. Of these two chemicals CB is recognised as being highly toxic and whilst only used at the larval stage it would appear to have the potential to raise consumer concerns in this respect.

4.7.5 Consumer Acceptance;

Nell (2002) reviews consumer acceptance in terms of sensory comparisons or taste tests. Overall it appears that when comparing triploids and diploids taste panels reported high consumer acceptance of triploid Pacific oysters. By way of an example in work by Allen and Downing (1991) consumers and oyster growers were asked to compare diploid and triploid Pacific oysters in terms of flavour, texture and overall preference. In their blind tests both panels favoured triploids in preference to diploid oysters for all test categories.

4.7.6 Market Acceptance;

There have been market acceptance issues with the use of triploid Pacific oysters due to the development by some of a brown discolouration on the meats which is not seen in diploid oysters. In research carried out in Tasmania, Nell (2002) reports that this was found to be primarily a problem in the summer months particularly in the post-spawning months of diploid oysters. Shellfish Culture Ltd. of Tasmania report (Shellfish Culture Newsletter, Spring 2007) that their selective breeding of triploid oysters is to be expanded to include the issue of what they describe as 'Tan Pigmentation' which they describe as a seasonal issue that can be influenced by local conditions of productivity. They are looking to develop breeding and farm management strategies to help combat this problem using their family lines of tetraploid (under licence from 4Cs Breeding Technologies, Inc.) and diploid oysters. In UK terms however it is not anticipated that this issue will cause significant difficulties with respect to market acceptance.

4.7.7 Economics of Production and Market Development;

4.7.7.1 Costs versus market prices: As discussed in Section 4.8 there may well be production cost implications associated with the adapting of husbandry techniques to successfully produce triploid Pacific oysters. Whilst triploid oysters can be successfully cultured using traditional bag and trestle methods some growers may obtain improved performance with this type of oyster if new culture systems such as the rigid baskets are utilised. This would obviously require investment in new equipment and infrastructure which must then be recouped through sales of the product. There may also be a need to reduce stocking densities during on-growing which may mean that bigger sites are required in order to maintain the same levels of production and that additional equipment will be required. Both of these will also have cost implications for the oyster grower. However in order to make these sorts of additional investments growers will have to be confident that they will obtain some sort of increased return on their investment.

A problem currently facing the UK growers with respect to prices received for their product is that the market price for Pacific oysters has remained static for a number of years whilst the costs of production in terms of labour etc. have risen. Another issue currently affecting the industry is competition for markets from an influx of cheap imports from Ireland and the continent, particularly France and the Netherlands with imported Irish and French oysters being delivered within the UK at 18 to 20p per shell. This has brought the first sale price down to 15p per shell (11 to 13p if sold unpurified) although prices of 20 to 25p per shell are still being achieved by some growers selling to niche markets (Syvret and Utting, 2004).

4.7.7.2 Quality schemes; It would appear therefore if growers are to be persuaded to undertake more production of triploid oysters then an adequate return on investment must be forthcoming. At present the lack of differentiation in terms of quality between oysters sold in the UK means that it is very difficult for growers to be able to achieve a higher price per shell for a superior quality product. It is recommended therefore that support be given to industry to help develop a quality grading system that could then be circulated to buyers of Pacific oysters. Through such a system of product quality promotion it may be possible for growers to obtain a better price for their product in comparison to poorer quality products.

Cooperative approach - An example of an industry cooperative approach to initiating a quality scheme can be seen in the Tasmanian Pacific oyster industry. Up until 15 years ago the industry in Tasmania was developing with little control or policing of standards. As a result outbreaks of sickness in consumers were common leading to poor consumer confidence which together with haphazard grading and poor quality products allowed the buyers to constantly push down prices.

As a result of this a group of Tasmanian growers instigated a quality standard guarantee for buyers which was run through a grower-owned company (TASEA Enterprises www.tasea.co.au). This company set a standard price for shareholder-growers based on a quality scheme (see Figure 36) with payment within 7 days of delivery once the customer had confirmed that they were happy with the quality of the consignment.

The company was responsible for finding the sales and the grower harvested to order. This approach meant a radical change in farming practices for many growers, especially with respect to stocking densities, more care in husbandry, selection, grading, packing and transport to market. However, the end result is that 15 years on 'Brand Tasmania' is now a sought after product mark and prices per oyster have more than doubled.

Figure 36. Grade 'A' Tasmanian Pacific oyster
(shown with the characteristic black mantle and shell rim - Image: Peter Hoare)

Certification - By way of a European example, in recent years the French industry has been active in adding value to its oyster production using a variety of marketing tools including market segmentation and certification. Oysters are now sold on a region of origin basis, an approach similar to segmentation in the wine industry.

Initiatives in the certification area include the "Label Rouge" quality brand covering selected oysters produced in the Marennes region in the South West of France. Label Rouge certification in this case covers various features including meat quality and the natural greening process which is found in certain oyster ponds in Marennes.

An indication of the premium generated by this label can be seen from a simple price comparison seen recently. A Label Rouge pack of two dozen number three grade 'Fine de Claires Vertes' (containing a natural green tinge) was retailing at €15/pack in one hypermarket chain in the Paris region. This price compares with €13.90 for a pack of three dozen oysters of the same size grade and from the same region in a competing chain (O'Sullivan, 2008). There has also recently been the development of a quality scheme for Pacific oysters in Ireland following an initiative between Bord Iascaigh Mhara, industry and a certification company.

Many producers in the UK are too small to undertake their own marketing and some have asked for assistance to encourage the idea of a healthy, natural and sustainable product. A new marketing initiative promoting a saleable oyster product is desperately needed to help increase home consumption. Local agricultural shows and seafood festivals are becoming increasingly popular for promoting sales (selling product, distributing leaflets etc.) but more help is required by industry if this interest in oysters is to yield a long-term increase in returns for growers.

4.8 Industry Experiences With Respect to Triploid Pacific Oysters

4.8.1 Introduction;

As part of this overall study, and the industry questionnaire in particular, contact was made with UK oyster farmers and shellfish hatcheries to try and gauge their experiences with respect to either the hatchery production of chemically induced triploid seed or the practical husbandry implications of using this type of oyster.

4.8.2 Regional Analysis;

In a regional context the results of the questionnaire would indicate that the South West of England has had the greatest experience of using triploid oysters as part of their commercial production methods. Almost half of questionnaire respondents in this region had undertaken some element of triploid production with one farm relying solely on triploid seed for their commercial production. South East growers have in the past used triploids and some continue to rely on this type of seed. However the availability of wild Pacific oyster seed through natural settlement has meant that many growers no longer rely on hatcheries for their sources of seed. Growers in the East of England did not seem to have tried triploid production and they commented that their oyster growth rates were already good in that region.

The Southern England respondent to the questionnaire had used triploids in the past but already experienced high growth rates on their sub-tidal site. In North Wales the two oyster growers contacted were about to commence trials with triploid Pacific oysters that were being funded by the Countryside Council for Wales in a joint initiative to investigate mitigation measures to prevent the possibility of wild settlement of oysters in the Menai Straits. In Northern Ireland only one grower reported having had any experience of growing triploid oysters and this was only as a small proportion of their production in order to maintain supply to customers when diploids were in advanced spawning condition i.e. milky.

4.8.3 UK Industry Experiences;

The various points raised by industry or arising out of these post-questionnaire discussions in this respect are summarised as follows:

4.8.3.1 Handling mortalities: There was a report by the one Northern Ireland grower who produced triploids of mortalities following handling, such as grading, in the warmer summer months. Interestingly concerns about mortality levels following grading in summer months and unmanageable growth rates for triploids were mentioned by most Northern Irish growers even though most had no experience of growing this type of oyster. It seems therefore that viewpoints amongst growers with no experience of using this type of seed are being strongly influenced by the minority of growers that have tried triploids.

Whether a fair assessment of the advantages and disadvantages of using this type of seed is being put forward is questionable. Indeed broad brush statements regarding triploid use seem to be common in the industry with similar views being aired by one speaker at the 2008 SAGB conference. However the evidence to back up these reports seems in some cases limited and so it is recommended that more detailed follow up of these reports of mortality issues should be undertaken to see if this is an inherent issue with the use of triploid seed or whether it is in fact related more to the need to alter husbandry or management practises when dealing with this different form of oyster.

4.8.3.2 Summer mortality: Whilst generally not considered to be an issue at present for UK growers, one South West grower did describe summer mortality problems with one year old diploid oysters in 2007. Because of this they were trialling triploid half-ware oysters for the first time in 2008.

4.8.3.3 Stocking densities and poor shell shape: It is often the case in commercial oyster production that the production of oysters with a poor shell shape is due to overstocking of the culture container. Where oysters are overstocked the crowding effect produces misshapen oysters and the competition for food leads to oysters growing through the mesh in an effort to reach food. One answer to this problem would be to reduce the stocking densities of oysters held in oyster bags. However this would of course lead to a requirement for a larger growing area to accommodate the same level of production, more oyster bags and more steel trestles. The latter is particularly important as current high commodity costs have pushed up the cost of steel considerably. The economic impact of such a change in practises would need to be assessed taking into consideration both the additional costs and potential savings in labour that might arise through a reduced need for handling and grading oysters.

4.8.3.4 Handling requirements and growth rates: There are several reports of triploid oysters growing too fast for growers to be able to accommodate using their current husbandry and management systems. The fast growth rates result in the need for regular handling, turning and grading. However as mentioned above a reduction in stocking densities in oyster bags should help to overcome this problem. Another possibility to help combat this problem might be a change in the culture equipment used. The rigid plastic basket-type systems such as the Australian Aquapurse, BST and SEPA systems or British ORTAC cylinder do not hold the oysters in place thus allowing movement with tide and wave action. The main advantages of this are that there is improved hydrodynamics allowing more water movement and therefore food through the growing volume as well as a reduced need and time spent turning the cylinders in order to ensure the oysters do not grow into each other and maintain a good conformation (Legg, 1998). Any change in culture systems would of course require expenditure on new rearing cylinders as well as the infrastructure to hold or mount them. Such purchases of new equipment would have economic consequences and impacts that would require further investigation.

4.8.3.5 Costs of seed: A comparison of chemically induced triploid seed costs from two suppliers to UK growers gave an average cost of £12.75 per 1,000 G7 seed (length 10-13mm) and £16.97 per 1,000 G10 seed (length 12-16mm). By way of a crude comparison one French hatchery who supply mated or natural triploids quoted a price of €7 (£5.60 @ 1.25 £ to €) per 1,000 G7's and €9 (£7.20 @ 1.25 £ to €) per 1,000 G10's although it is believed that the French hatchery quoted here are acknowledged as being considerably cheaper than even their own French counterparts. There has however been a reluctance on the part of the UK industry to import French oysters due to disease concerns although French stock has been brought into the South West of England and French seed is routinely used in commercial operations in the Channel Islands.

4.8.3.6 Variable triploidy rates: Discussions with industry and support organizations (Clive Askew, pers. comm.) have highlighted some concerns over the variable success rates of triploid production through chemical induction. Ben Wright (pers. comm.) of the Duchy of Cornwall Oyster Farm gave an example of a presentation issue that can arise in a restaurant environment. Wright acknowledged that triploids offered a good alternative to diploid oysters at times of the year when diploids would either be in poor condition post-spawning or considered too milky. However when opening at a table in a restaurant it was not considered acceptable to have an average of 3-4 oysters per dozen in poor condition for this niche high value market i.e. due to the presence of some diploids with the triploid oysters. This was not however during the course of this study highlighted as a problem by growers using triploids for supply to the bulk market although this problem may arise if variability is too high.

4.8.3.7 Market perception: The issue of whether triploids might be considered to be GMOs by consumers was only mentioned by one respondent as being a source of concern and as such they had avoided using this type of seed.

4.8.4 Irish Industry Experiences;

4.8.4.1 Introduction: Discussions with Kelsey Thompson of Seasalter (Walney) Ltd. (pers. comm.) yielded the following information regarding experiences that they have had reported to them with respect to the cultivation of triploid Pacific oysters in Ireland. Thompson's comments are summarised as follows:

4.8.4.2 Galway: Their client grows small diploid seed in bags on trestles up until around 10g in weight. These are then transferred to bottom lays, usually producing one of the better meat yields in Ireland. They report that triploids grew well in oyster bags but didn't achieve a good meat yield when grown on the bottom lays. As they cannot market oysters with poor meats they no longer grow triploids.

4.8.4.3 Waterford: Triploids experience very fast growth but this has resulted at times in poor shell shape. Poor shell shape results in this grower often having to sell at a lower price. Consequently when the market is bad, i.e. low demand, their sales are adversely affected sooner than other growers.

4.8.4.4 Donegal: At the first site described triploids show very fast growth but the grower was unable to maintain a good shell shape which has led them to moving the growing site further towards the shore i.e. higher ground and so more aerial exposure. This change in culture sites has proved effective but necessitated an application for a new licence. At a second site the triploids also show very fast growth but no licence could be obtained to move the culture area and so poor shell shape has been experienced at times. This grower continues to grow a proportion of triploids in order to be able to supply the French market when their oysters are milky.

4.8.4.5 Part-time oyster growers: Several part-time growers have commented that triploid oysters grow too fast and as such the nature of their operations means that they would be unable to cope with the grading requirements using their normal husbandry and stocking regimes.

4.8.4.6 Handling mortalities: Many growers have reported losses from trying to handle triploid oysters in warmer months, which is reported as being when they need attention to prevent clumping, misshapen growth and shells growing through the mesh bags. With respect to hatchery practises Thompson reports that seed transferred in warmer months from the hatchery to farms can suffer high mortalities, but producing seed in the winter is impossible thus leaving a very narrow window for producing seed. Some farmers will only therefore buy larger part-grown triploids in order to reduce the risk of mortalities. This is of course more costly for the grower but as a consequence places the burden of risk with respect to mortalities on the hatchery producer.

4.8.4.7 Market acceptance: Growers have reported that this is the strength of triploids. The positive aspects reported are good flavour with bigger meats without being milky. As such they are marketable when diploid oysters are still milky.

4.8.4.8 Summary for Ireland: Clients of Seasalter (Walney) Ltd. have reported that triploids grow well where food levels are good but struggle to achieve a good meat to shell ratio in areas where food levels are low. In these poorer growing conditions diploids are often said to still grow reasonably. There are also reports that triploids can grow too fast for some farms to manage leading to issues with poor shell shape. Mortalities have been experienced where triploid oysters are handled during the warmer months.

4.8.5 *Jersey Industry Experiences;*

In can be seen from the previous sections concerning UK and Irish experiences that there a number of mixed messages and differences of opinion between UK and Irish growers and hatchery producers regarding the issues and practicalities of utilising triploid oyster seed for commercial production. In order to try and clarify some of these points Christopher Le Masurier of the Jersey Oyster Company (Jersey, Channel Islands) was also interviewed to obtain an overview of their experiences of producing commercial quantities of both triploid and diploid Pacific oysters. Le Masurier (pers. comm.) gave the following overview of their experiences with triploid oysters:

4.8.5.1 Seed source: The Jersey Oyster Company sources their seed from a number of different French hatcheries. This enables them to avoid any one-off mortality problems that may be experienced occasionally due to problems within individual hatchery suppliers.

4.8.5.2 Growth rates: The triploids they produce are faster growing but as they already have good growth rates with their diploid oysters then they estimate that the triploids reach market size approximately one month earlier than the diploids given an 18 month growing cycle.

4.8.5.3 Grading requirements: Their triploid oysters are turned and shaken and graded regularly so as to ensure that shell shape is maintained and so that sufficient space is provided for the oyster to develop in the desired ‘cup’ shape. Failure to do this will result in misshapen or long oysters and growth through the bag mesh.

Contrary to some of the reports of mortalities following handling they regard the triploids as being generally hardier when compared to diploids in terms of summer handling and grading. It seems likely that the basis of their experience lies in the fact that triploid oysters and diploid oysters will be handled differently during the warmer summer months. Firstly, unnecessary handling during summer months is avoided as much as possible so as not to stress either type of oyster.

When grading is required for diploid oysters then this is only carried out if the oysters are not close to spawning. If the oysters are about to spawn then grading will not be undertaken. Experience has shown that if passed over mechanised graders when in spawning condition the shock tends to induce spawning which then together with exposure to air and high summer temperatures can lead to mortalities occurring. These mortalities therefore are as a result of the reproductive state of the diploid oysters at that time.

Triploids by comparison can be graded throughout the summer as they do not suffer mortalities in this way as no spawning event will occur through a shock such as grading. However, Jersey Oysters employ a different methodology when handling triploids as opposed to diploid oysters in the summer. This difference is based on the fact that triploids with their fast growth rates tend to have large amounts of frill and softer shells. Therefore two weeks prior to grading the oyster bags are turned in order to help harden the oysters; the trailer on to which the oyster bags are loaded is only filled to half the normal depth so as not to crush the shells of the oysters in the bottom bags; grading may either be carried out by hand or with the minimum amount of mechanisation possible. A grader using a water bath to soften impact is also about to be purchased in order to further reduce stress during grading for both diploid and triploid oysters. In this way the risks of causing shell damage and holes, thus allowing desiccation of the oyster, are minimised.

4.8.5.4 Dispatch to market: Prior to dispatching to market their oysters are placed in the upper intertidal zone for at least two weeks in order to ‘harden’ off i.e. in order for adductor muscles to strengthen and shells to harden. This ensures that the shell valves do not gape during transport and lose moisture. This method ensures that the oysters are transported under minimal stress conditions so ensuring a good shelf life and minimal mortality levels.

4.8.6 Overview of Industry Experiences;

In summary the author believes that further investigation of these issues highlighted by industry through site visits and detailed one to one interviews would help in obtaining a clearer picture of why such varying results are being obtained with triploid oysters. It may be that the experiences of oyster farmers who have successfully grown triploid oysters could where possible be documented and this information made available to other industry members.

Industry members growing triploid oysters should be encouraged as far as possible to share their experiences and dissemination routes that might be used could include invitations to those growers to attend and present at association and industry meetings or conferences. Other forms of training material and dissemination routes could be considered such as training DVDs or videos if the cost levels are practicable. Funding should be investigated to allow for this dissemination to take place whether through literature, site visits or presentations.

4.9 Recent Advances in Ploidy Manipulation

4.9.1 New Method for Producing Tetraploid Pacific Oysters;

A new or complementary method to produce tetraploid Pacific oysters has recently been described by McCombie *et al*. (2005). With this method cytochalasin B (a blocking agent) is used to inhibit the expulsion of polar body 2 in diploid females crossed with tetraploid males.

The process of producing tetraploids was described first by Guo and Allen (1994b) where cytochalasin B was used to treat the cross of a fertile triploid female with a diploid male. This can be represented as 3n x 2n + CB (where the female is shown first). This new method uses the normal cross used in hatcheries to produce triploids of 2n females with 4n males but with the added addition of cytochalasin B treatment to the fertilised eggs to inhibit the expulsion of the second polar body therefore adding an extra haploid genome and producing tetraploids (i.e. 2n x 4n + CB = 4n). This technique differs from that of Guo and Allen (1994b) in that no triploid oysters are used during the process.

This method gives a direct means of introgression of genetic characters from selected diploid to tetraploid lines. Selective breeding of tetraploids is known to be slower and more complex than in diploids (Boudry and Haffray, 2006) so this new method of producing tetraploids has the advantage that desirable traits can be selected in diploids working in normal laboratory conditions, i.e. outside of the quarantine conditions required for keeping tetraploids in some countries, and then introduced into tetraploids. Thus breeding of tetraploids lines can be undertaken more easily thus leading to the possibility of producing genetically improved triploids. McCombie *et al.* (2005) go on to state that future work will focus on increasing the percentage yield of tetraploids through this method by more precise timing of the cytochalasin B treatment of 2n x 4n + CB crosses.

4.9.2 Patent Issues;

One question that is raised about this method is that it appears to be a method of producing tetraploid males that is outside the scope of that described by the European Patent Specification (EP 0 752 814 B2) in the name of Rutgers University with Inventors stated as Guo, X. and Allen, S.K., Jr. Investigations have been undertaken as to whether this might offer a non-patented method of producing tetraploid males for triploid production. If this were the case then this might open up a possible avenue for UK hatcheries to consider this route of triploid production although a source of tetraploid males would still be needed at least initially.

This matter was discussed with Pierre Boudry at IFREMER as he was responsible for supervising this research. Boudry confirmed that this method requires that you have at least one male tetraploid oyster in order to produce more tetraploid progenies. It shows that diploid eggs can produce tetraploid offspring, so that the use of larger triploid eggs is not the only way to produce tetraploids (which is the basis of Guo and Allen patent). However Boudry was unable to confirm if this therefore fell "inside" or "outside" Patent EP 0 752 814 B2. It also appears that there are more Patents currently being processed regarding the production of tetraploid bivalves that will only make this issue more complex.

This patent issue added to the need to have at least some tetraploid males to begin with would seem to suggest that it is unlikely that this method described by McCombie *et al*. (2005) offers a solution to the development of triploid oysters for UK production at present.

4.10 Development Potential for Triploidy in the UK

4.10.1 Thermal Shock and Chemical Induction;

The level of wild settlement currently being experienced in the South East of England has meant a reduction in demand by industry for Pacific oyster seed. This has direct consequences for UK and British hatcheries in terms of the size of their customer base and future sales. There does however appear to be a strong demand in the French market at present for triploid Pacific oyster seed due to concerns over summer mortality problems.

John Bayes of Seasalter Shellfish (Whitstable) Ltd. (pers. comm.) has confirmed that UK hatcheries have the facilities and skills to undertake either of the non-chemical treatments, i.e. hydrostatic pressure and thermal shock, but require scientific research support in order to help them perfect these techniques. It seems reasonable to assume that given possible consumer awareness issues over the use of chemicals in food production that the refinement of these non-chemical methods would present the UK industry with a significant opportunity.

Andy Beaumont (School of Ocean Sciences, Bangor University) was contacted to discuss the potential for improving triploid induction techniques in the UK. His comments are summarised as follows:

- There is good scope for increasing the percentage of triploids oysters produced by temperature methods. This would require laboratory based trials to be carried out that could then be scaled up to hatchery production. A well organised collaborative approach between an R&D institution and a commercial hatchery would be essential;

- There is further scope for exploring the use of 6-DMAP as an induction agent as it is less toxic and so may be more acceptable in terms of perceived chemical ‘risks’. This could also be explored through a collaborative R&D and commercial arrangement;

- Developing these methods could well achieve triploid production rates of 95 to 100%.

4.10.2 Tetraploid Production and Other Methods;

In discussions about alternative methods of triploidy induction other than thermal or chemical means Andy Beaumont (pers. comm.) stated:

- There is at least one other non-patented method of producing tetraploids in other bivalves that produces 4n larvae but which is still in an early stage of development with respect to keeping these larvae alive through the juvenile stage to maturity. This method could be considered for Pacific oysters but would be considered more speculative;

- Beaumont was not aware of any other methods of producing sterile oysters other than triploidy. Other techniques used in aquaculture such as hormonal feminisation that is used on fish etc. (to make an all female population that is therefore not able to reproduce) have never been tried on oysters.

4.11 Summary

4.11.1 Development of UK Broodstock Pacific Oysters;

- The choice as to which broodstock oysters to use for spat production within UK hatcheries has been largely based around selection of the fastest growing oysters or those exhibiting a range of positive characteristics. As such there has been little selective breeding for targeted traits and there is no evidence of family based or mass selection programs having taken place;
- The available literature indicates that it is unlikely that the use of faster growing oysters as broodstock would lead to the level of selective pressure needed in order to produce Pacific oysters that are more likely to spawn in UK waters. It also seems unlikely that practises such as culling of slow growing larvae would have this effect.

4.11.2 Selective Breeding for Non-spawning Strains of Pacific Oysters;

- Given that in European terms the UK Pacific oyster industry is relatively small it seems unlikely that the significant investment required in terms of funding and facilities will be forthcoming in terms of trying to establish a national selective breeding programme for developing non-spawning strains of Pacific oysters;
- The main European producer of Pacific oysters is France. Their research efforts are currently targeted more at understanding the basis of the invasive nature of Pacific oysters and at developing solutions to the significant problem of summer mortality in the French oyster industry. As such it seems unlikely that a cross-European project to develop non-spawning oyster strains would be of interest to French researchers;
- There are no known breeding programs outside of Europe targeting the development of non-spawning strains of Pacific oysters. Breeding programs are instead focussing on yield, growth and other quality traits.

4.11.3 Triploid Production Methods;

- Triploid Pacific oyster seed can be produced by induction through shock (chemical, thermal or pressure) or through the use of a tetraploid male crossed with a diploid female. Of the induction methods, chemical induction generally has the highest success rate in producing triploid embryos at ~80 to 90%. Triploids produced via the tetraploid technique should theoretically produce 100% batches of triploid embryos;
- Triploid production is only undertaken in UK hatcheries by chemical induction.

4.11.4 Patent Issues and Triploid Seed Supply;

- The technique to produce tetraploid male Pacific oysters for use in hatchery production of triploid seed is a patented process;
- The current effective EU patent (EP 0 752 814 B2) for the technique to produce tetraploid male broodstock has a 20 year duration provided that the on-going maintenance fees are paid. This patent is due to expire in 2015;
- Whilst there may be some grounds for challenging the current patent regarding the rights to use the tetraploid technique any such legal action is likely to be costly with no guarantee of success;
- There appears to be scope for revisiting the issue of licensing of the patented tetraploid production technology for use by UK and British hatcheries. Given the advantages that this technology offers in terms of producing 100% batches of ‘mated’ triploids it is recommended that industry should contact 4Cs Breeding Technologies, Inc. to discuss this further;
- Triploid seed produced via a tetraploid male x diploid female cross is available from a French commercial hatchery. Under current movement regulations there are no restrictions on importing French seed as long as the correct import procedures are followed. There has however been reluctance in the past to import French Pacific oysters due to concerns over possible accidental disease or non-native introductions.

4.11.5 Viability of Triploids;

- Despite the general perception that triploid Pacific oysters are sterile this is not the case as they still produce some viable eggs and sperm albeit in greatly reduced numbers when compared to diploid oysters;
- Triploid Pacific oysters produced through chemical induction may have a lower relative fecundity rate when compared to 'mated' triploids but more research is needed to prove definitively that this is the case. However it should be remembered that the chemical induction technique will generally only be ~80 to 90% effective in producing triploids;
- Relative reproductive potential for both chemical and tetraploid produced triploids has been assessed based on fecundity values calculated in recent research. These calculations show that whilst triploid Pacific oysters are not absolutely sterile their reproductive potential when compared to diploids is greatly reduced;
- The most effective use of triploid Pacific oysters for biological containment is where those oysters are placed in areas free from diploids as the presence of diploid oysters increases the chances of the production of viable embryos from triploid x diploid crosses.

4.11.6 Triploid Reversion;

- Research has shown that a proportion of all triploids produced are unstable in that they can revert from triploids to a mosaic or diploid state. This effect appears to become more pronounced as the oysters age;
- Research has indicated that there are no differences in the frequency of heteroploid mosaics between chemically induced and mated triploids;
- Reversion is understood to generally affect only gill and haemolymph tissues but not gonadic tissue. The results of discussions with researchers have led the authors to conclude that reversion in triploid oysters is not considered to be a risk in terms of its affect on biological containment.

4.11.7 Summer Mortality;

- Despite intensive research investigations much of the underlying causes of summer mortality incidences remain unknown. What seems likely however is that the problem of summer mortality is caused by a combination of biotic and abiotic environmental factors as well as internal parameters;
- The potential combination of factors that may cause summer mortality makes it difficult to assess through comparison of literature results whether triploid or diploid Pacific oysters are more susceptible to summer mortality. However genetic predisposition or resistance to summer mortality in family lines does seem to play a key role in determining relative mortality levels;
- Recent work by IFREMER has indicated that triploid Pacific oysters are more resistant than diploid oysters to summer mortality. This work was based on the use of mated triploids which IFREMER believe show higher survival rates than chemically induced triploids, although this has yet to be proved by research;
- To date there have not been widespread reports of summer mortality events in the UK although there is some evidence that isolated incidences have taken place. With the predicted increase in sea temperatures predicted through climate change it is however possible that summer mortality events may become an issue for UK growers in the future.

4.11.8 Market Acceptance of Triploid Oysters;

- Triploid Pacific oysters provide a product that is marketable at all times of the year and which generally has high consumer acceptance in terms of sensory or taste tests;
- Although not by definition a GMO there are still concerns amongst some growers that misinformation about this product with consumers or in the media may cause consumer confidence issues. A positive message should be encouraged regarding the environmentally benign nature of triploid oyster farming activities;
- Prices paid for per shell for bulk sales in the UK are understood to have remained static for a number of years at around 15 to 20p per oyster. Cheap imports have also recently driven down prices being received by growers;
- If investment is to be undertaken by industry in the equipment and infrastructure that would be needed to successfully produce triploid oysters then either new markets will be needed that can provide a higher price or alternatively promotion and a raising of awareness is needed with buyers as to the attributes of a 'quality' oyster product. This would allow market differentiation to occur between differing quality grades of Pacific oysters. Through this a realistic and economic return may be achieved by industry. It is suggested therefore that the possibility of the adoption of a UK quality scheme for oysters be revisited and that promotion of oyster product quality be undertaken with wholesalers and retailers of Pacific oysters.

4.11.9 Industry Experiences With Respect to Triploid Oysters;

- In order to produce a 'quality' product, triploid oysters may require a better or more productive growing environment and/or lower stocking densities than diploid oysters. Method of culture may also be a factor in influencing condition. Some feedback from industry has indicated that growers may have experienced difficulties with on-growing triploids in the past where they have not altered either stocking densities or culture practises;
- Feedback from growers would seem to confirm the rule of thumb that triploid oysters outperform diploid oysters in areas of high productivity but tend to do less well when compared to diploid oysters in areas of marginal or poor productivity;
- Reports of mortality issues when handling or grading triploid oysters in the warmer summer months and poor shell shape need to be investigated in detail in order to ascertain if these issues described are an inherent problem with triploid seed or if husbandry and management practises on farms need addressing in order to make best use of the positive characteristics of triploid seed;
- The economic impact of reducing stocking densities of Pacific oysters in terms of the need for additional growing area, equipment and infrastructure versus a possible reduction in grading requirements needs further investigation. The potential for reducing handling and grading requirements through the use of alternative culture systems should also be considered in terms of its economic impact;
- If the use of triploids is to be considered as a management option for helping to eliminate any possible environmental impacts of Pacific oysters through wild settlement then industry in the UK would need advice and support in changing current husbandry practises in order to facilitate the successful use of triploids;
- Methods of funding the production of training/informational material or presentations by current triploid growers to other industry members requires investigation;
- Consideration should be given and funding sought for a fact finding trip for industry to France to demonstrate the economic implications of wild settlement of Pacific oysters in terms of factors such as overcatch or reduced carrying capacity.

4.11.10 Recent Advances in Ploidy Manipulation;

- Whilst a new method of producing tetraploid male Pacific oysters as described by McCombie *et al*. (2005) may open up the possibility of utilising this technique in UK hatcheries, the issues surrounding existing patents and patent applications currently being processed means that this is not thought to be a practical solution to the possible need of the UK industry for access to mated triploid production techniques.

4.11.11 Development Potential for Triploidy in the UK;

- Funding for further research into the development of triploid techniques should be sought. Research efforts to increase the availability of sterile oysters should be targeted at improving the effectiveness of current methods of inducing triploid production, especially through the use of non-chemical methods;
- Of the non-chemical induction methods it appears that thermal induction offers the most practical solution for triploid production in a commercial hatchery environment as it does not require the specialist equipment associated with the use of induction through pressure shocks.

4.12 Recommendations for Future Work

Section	Work/Research Required	Action Taken During Current Study (where applicable)	Importance	Potential Organisation to Action or Participate	Possible Sources of Funding
4.12.1	Industry in the UK needs further advice and support in changing current husbandry practises in order to facilitate the successful use of triploids. Negative issues experienced by UK growers require further investigation. Examples of the possible detrimental economic impacts of wild settlement of Pacific oysters need to be demonstrated to industry. This might be achieved by a fact finding trip for industry members to French growing regions.	The issues raised by some growers with respect to triploid oysters have been reviewed. Growers who are successfully producing triploid Pacific oysters have been identified.	If triploid production is to be encouraged as a route by which wild settlement can be avoided then practical advice on how to grow triploid oysters is vital to ensure uptake of this method. The possible economic impacts of such things as overcatch should be demonstrated.	- Seafish - SAGB - Industry	- Seafish - EFF - Industry
4.12.2	The economic impact of reducing stocking densities of Pacific oysters in terms of the need for additional growing area, equipment and infrastructure versus a possible reduction in labour for grading requires further investigation. The potential for reducing handling and grading requirements through the use of alternative culture systems should also be considered in terms of its economic impact. Also, the method by which industry will be helped to meet any additional costs as part of the implementation of new management, husbandry or monitoring strategies needs to be considered.	Outline costs have been identified in terms of seed prices through UK or European suppliers. Economic impacts have been identified and described.	The success or otherwise of the use of triploids will rely heavily on the development of good husbandry and management practises. As part of this development there may be a requirement for investment in additional or even new equipment and infrastructure. The economic impact of these changes requires investigation.	- Seafish - SAGB	- Seafish - EFF

4.12.3	Consideration should be given as to whether the adoption of a quality scheme for Pacific oysters in the UK would allow market differentiation to develop and thus help potentially increase returns to UK growers. Buyers and wholesalers need to be made aware of what constitutes a 'quality' product.	Quality schemes and certification in Europe and overseas have been highlighted and examples given of the possible increases in returns that might be achieved through this route.	If investment is to be undertaken by industry in the equipment and infrastructure that would be needed to successfully produce triploid oysters then either new markets will be needed that can provide a higher price or alternatively promotion and a raising of awareness is needed with buyers as to the attributes of a 'quality' oyster product. This would allow market differentiation to occur between differing quality grades of Pacific oysters. Through this a realistic and economic return may be achieved by industry.	- SAGB - Seafish - Industry	- Seafish - EFF - Industry
4.12.4	Research and development work is needed to refine and develop non-chemical induction methods for the production of triploid Pacific oysters.	Potential University research partner contacted to discuss the potential for developing thermal induction techniques. University confirmed that ~95% success rates in triploid production were a realistic target with a properly funded project.	Currently patent issues do not allow the use of the tetraploid technique in the UK for producing triploid Pacific oysters. Current chemical induction methods have the potential for problems with consumer/market acceptance.	- Industry - Seafish - SAGB	- Seafish - EFF - Industry

SECTION 5 – AUSTRALIAN & FRENCH CASE STUDIES

5.1 Overview of Case Studies

Section 5.2 presents a summary of the development of the culture of Pacific oysters in Australia from initial introduction through to the present time. The Australian case study is included in this report in order to provide an overview of another industry's experiences with wild settlement of Pacific oysters and gives some indications of how this issue has been addressed. The French case study covered in Section 5.3 focuses both on the impacts on industry of wild settlement and the environmental aspects of the increase in wild settlement of Pacific oysters in France.

5.2 Australia

5.2.1 Introduction of Pacific Oysters into Australia;

The Pacific oyster (*Crassostrea gigas*) was originally imported into Australia from Japan in the late 1940s and early 1950s (Ward *et al*., 2000). The importations were undertaken with a view to starting an oyster farming industry comparable to the well-established Sydney rock oyster industry *(Saccostrea glomerata*, formerly known as *Saccostrea commercialis*) of New South Wales which is based on natural spatfall. The hope was that it would provide employment for the many soldiers returning home after the end of World War 2. The Pacific oyster has been introduced into Tasmania, Victoria, South Australia and Western Australia with shipments taking place up until 1970. None of the oysters introduced into South Australia and Western Australia survived although those in Tasmania did survive. Today the major areas of oyster production in Australia are New South Wales (approximately 6,000 tonnes worth A$37.9 million - predominantly Sydney rock oysters), South Australia (4,382 tonnes worth A$21.2 million - almost all Pacific oysters) and Tasmania (3,243 tonnes worth A$12.30 million - almost all Pacific oysters) (Maguire and Nell, 2005).

5.2.2 Pacific Oyster Cultivation in Tasmania;

The introduced Pacific oyster spat from the 1940s and 1950s were mostly placed at sites in Pittwater Bay in South East Tasmania. The idea was to use these introductions as a broodstock that would start and encourage the natural production of wild Pacific oyster spat which could then be gathered by industry through the deployment of collectors. As with the rabbit, fox, cane toad, gorse and bramble before, no thought was given to the future consequences of the introduction of a non-native species. Whilst the oysters survived and grew well at Pittwater, spat production was limited and so in 1953 most of the oysters were transferred to Port Sorrell in the north of Tasmania where it was hoped that the longer warm summer temperatures would help encourage successful spawning and settlement. This movement of the oysters proved to be successful with regular spat production being recorded. Within a few years Pacific oysters were found in The Mersey and Tamar Rivers to the west and east of Port Sorrell through what was believed to be larval drift during their ~28 larval duration.

From the late 1950s until the mid-1960s the Pacific oyster population in the Tamar River increased dramatically and this led to farms being established utilising this natural settlement. At that time the recognised method of collecting spat was 'stick culture' (catching the spat on tarred sticks - as was done with the Sydney rock industry). As well as providing the juvenile stock for the growers, it also increased the wild colony that would form the broodstock in the future. However, several years later, a series of poor (natural) spatfalls proved to be a disaster for the embryonic industry. In 1979 a Pacific oyster hatchery was built using oysters from the Tamar River that then started to provide seed for growers. After this the use of stick culture gradually ceased and wild caught spat has never been used in Tasmania since. It was only when the first commercial hatchery began operating in 1981 that the culture of Pacific oysters became established as a viable industry (Ward *et al*., 2000). The Tasmanian oyster hatcheries produce almost exclusively "black" Pacific oysters, which have a black mantle and shell, but also maintain a line of 'golden' oysters which have an orange/bronze or 'golden' mantle and shell (Nell, 2001).

5.2.3 Pacific Oyster Cultivation in South Australia and New South Wales;

Pacific oysters are farmed in only two States, Tasmania and South Australia. In Victoria, and Western Australia they are labelled a noxious pest and are prohibited. The industry in South Australia developed in parallel with the Tasmanian one. It started in the 1970s with the importation of wild-caught spat from Tasmania and then developed rapidly during the 1980s with the import of hatchery-produced spat from Tasmania (Olsen, 1994). Oyster hatcheries were developed in South Australia in the 1990s which now also supply spat to the industry along with that from hatchery production in Tasmania (Nell, 2001).

New South Wales has had an oyster farming industry for more than a hundred years based on the Sydney rock oyster. These oysters are native to the Eastern seaboard of Australia from Brisbane (Queensland) in the north to Eden (New South Wales/Victoria border) in the south and across the Tasman Sea, at similar latitudes to New Zealand. There are wild populations of Sydney rock oysters in all the estuaries - covering rocks, wooden piles and other suitable substrates. However a deliberate and therefore illegal introduction of Pacific oysters into Port Stephens, NSW in 1984 (Holliday and Nell, 1985) has allowed a self-sustaining population of oysters to become established in this estuary.

5.2.4 Impacts Associated with Wild Settlement of Pacific Oysters;

5.2.4.1 Tasmania: Although Tasmania's climate is temperate, summer temperatures are high enough to permit spawning in all coastal inshore intertidal sites. With the increased number of farms at other sites around the State, other wild Pacific oyster populations have appeared and become naturalised. However it took some 50 years before wild settlement of Pacific oysters in Tasmania became an issue both in terms of the environment and public relations. A much publicised, State Government backed, proposed expansion of the Tasmanian Aquaculture industry in the early 1990s resulted in an increased public awareness of the issue of wild settlement of Pacific oyster populations around the State. This caused a subsequent adverse reaction during the planning process for new aquaculture sites.

Marine Farm Development Plans were developed by the State Government, in conjunction with industry and TAFI (Tasmanian Aquaculture and Fisheries Institute - equivalent to CEFAS in the UK), plus other stakeholders involved with the 'Planning Process' for all current and future planned growing areas. As part of this process areas of wild settlement of Pacific oysters were identified around the State and an investigation undertaken into the current extent of wild settlement and what possible remedial action could be taken. This investigation concluded the following:

- The wide range and extent of wild settlement of Pacific oysters meant that eradication was impossible;
- Populations were found to be confined to unusable and often inaccessible areas;
- Wild Pacific oyster populations were generally not found at farm sites;
- Wild Pacific oyster populations were not found on recreational areas of the foreshore.

The wild populations of Pacific oysters were in fact confined mainly to the northern introduction site of Port Sorrell. Here they were found in silted slack water or eddy areas of the tidal estuary, as well as other estuaries on the East coast with similar slack waters and suitable substrates. However no recreational areas such as beaches were affected. The presence of these wild populations of Pacific oysters was attributed to shellfish farming activities in the local vicinity. Wild Pacific oysters are not welcome by the shellfish farms if close to their leases, as they will compete for the available food resources.

As part of this study James Calvert, Chief Executive Officer of TAS Oyster Company, was contacted (pers. comm., April, 2008) in order to ascertain the current position with respect to wild settlement of Pacific oysters in Tasmania. Calvert stated that:

"To answer your questions on ferals, Tasmania's feral population has exploded which was obviously the result of the wild population reaching the critical mass required and, with the right weather conditions, have had an incredible settlement. Most mature oysters on farms are normally sold during the Christmas selling season pre-spawning which would lead to farms being stocked at less than 10% of normal stocking rates of oysters which are capable of spawning, not enough to increase the wild population by the size that it has. Parts of the Channel are now so heavily populated that it is nearly impossible to view the rocks and shoreline that they settled on, some patches are acres and acres across. Settlement in the River Derwent has increased significantly over the past 2 years and this will now increase at a faster rate of settlement over the coming years. Settlement in the Tasman Peninsular is increasing dramatically along with Fredrick Henry Bay, Pitt Water, Pipeclay etc. Whether global warming and longer spawning periods are having an impact or not is now up for debate. SA has a very few small pockets of overcatch (spat settlement on culture equipment or oysters themselves) and yes you are right about unsuitable substrate. The Freycinet Peninsular has absolutely no feral population due to the granite rocks which run from Bicheno to Coles Bay so the theory works. Farmers are finding it more important than ever to arrange annual clean up days of ferals to appease government and residents."

The Australian Native oyster (*Ostrea angasi* which is similar to *Ostrea edulis* found in UK waters) is found from southern Western Australia to South East Victoria and Tasmania. The Native oysters provided Tasmania with a substantial oyster industry 150 years ago which was certainly larger than the industry currently operating in Tasmania. Most Native oyster beds have now disappeared due to over fishing and disease. However a large native bed still exists in Georges Bay, on the east coast. Despite several Pacific oyster farms being situated in the bay, recruitment on the native beds is very limited.

5.2.4.2 New South Wales: Up until an illegal importation of Pacific oysters in 1984 oyster growers in Port Stephens collected Sydney rock oyster spat near the mouth of the estuary and then on-grew their oysters with only a minimal amount of overcatch being experienced in the upper half of the estuary. However as The Pacific oyster spat settle throughout the estuary farmers have learned to remove the growing baskets from the water if 'D' larvae are found in water samples. Where overcatch does occur it adds greatly to the production costs of producing the Sydney rock oyster.

Following the illegal introduction of Pacific oysters into the State new regulations were brought in during 1985 to control the number and spread of Pacific oysters in NSW. In Port Stephens itself it is accepted that it is too late to reverse the impact of the Pacific oyster and growers were given permission by the NSW government in 1991 to grow and market them. In estuaries other than Port Stephens however oyster farmers are legally required to remove Pacific oysters from their leases and therefore cultivation of this species remains prohibited.

These new regulations had serious implications for many of the Sydney rock oyster producers who practised "highway oyster farming" where oysters were transported by truck between growing areas to take advantage of the differing timing of periods of maximum food availability. This practise was widespread in Port Stephens where large quantities of Sydney rock oysters were taken to the northern rivers of NSW for winter 'fattening' before being returned to Port Stephens in the spring ready to go to market. These regulations effectively ended this practise. Despite these regulations the Pacific oyster has also spread to all oyster growing estuaries south of Port Stephens, although it has not been seen in virtually any estuaries to the north of Port Stephens (Nell, 2001).

Despite the complete reliance of the Australian Pacific oyster industry on hatchery produced spat no efforts have been made to selective breed for strains of oysters that would be less likely to breed in Australian marine environmental conditions. Pacific oyster growers in Tasmania when asked by the Tasmanian Oyster Research Council (TORC) about what characteristics they would see as being desirable in a breeding programme highlighted meat yield, growth rate and shell shape as being of most importance. This highlights that as far as is known by the author no mass breeding programme for minimising the environmental impact of wild settlement has ever been addressed by any oyster growing country.

The use of triploid Pacific oysters is widespread with Shellfish Culture Products having the rights to use the patented tetraploid technique for producing triploids. A review of their web-site shows that in addition to the advantages with respect to year round condition, growth rates and meat yields they also highlight the fact that these oysters will not produce 'feral' populations as an advantage in utilising this form of oyster.

5.2.4.3 New Zealand: As mentioned, unlike the French oyster industry, all Australian oyster farms (including pearl oysters) rely on hatchery produced spat. Stick culture and other forms of spat collection are banned and have long since disappeared. This however is not the case in New Zealand where stick culture continues. Originally the New Zealand oyster industry was based around the cultivation of their Rock oyster. However another species of oyster started to appear on their collector sticks in the early 1970s. Initially the growers tried to remove it from their collector sticks, but over the course of a few years the numbers of Pacific oyster spat settling increased dramatically until it proved impossible to try and remove it. This then led to the start of the commercial cultivation of Pacific oysters on a widespread basis. Pacific oyster culture takes place in the northern part of the North Island at Ninety Mile Beach and the Coromandel area, near Auckland.

The use of self-caught spat on sticks is still widespread, although suspended culture systems (such as Aquapurse and Aquatray) as used in Australia, with hatchery produced spat, are becoming more popular. Wild settlement of Pacific oysters has taken place at certain sites but is not considered a restriction to the expansion of the industry. Pacific oysters were successfully excluded from the mussel growing areas in Marlborough Sounds of South Island until they were discovered in Golden Bay near Nelson. The source was traced to the legs of a gas rig recently towed from Japan and moored in the Bay.

5.3 France

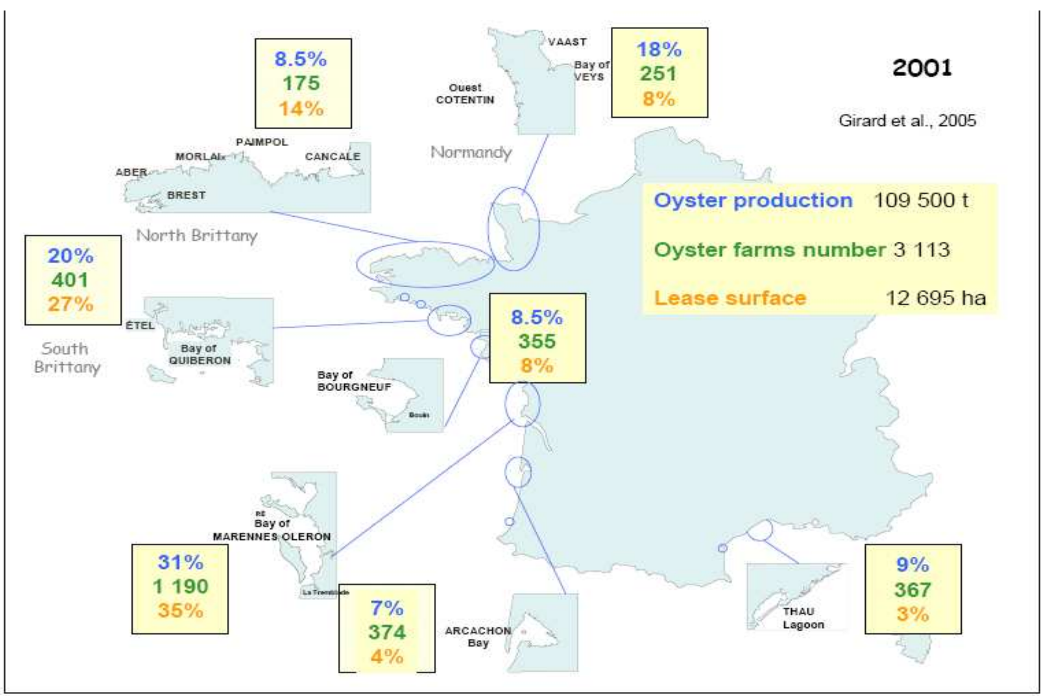
5.3.1 Introduction of Pacific Oysters into France;

The Pacific oyster was introduced into France as part of the 'Resur' campaign during the 1970s. In total 562 tonnes of adult oysters were imported from British Columbia (Canada) between 1971 and 1975 and over 5 billion spat were brought in from Japan between 1971 and 1977 (Miossec and Goulletquer, 2007). The Pacific oyster proved to be well suited to the prevailing marine environmental conditions on the west coast of France and within four years of the initial introductions levels of natural spatfall within the Arachon Bay and Bay of Marennes-Oléron were sufficient to sustain the French oyster production levels at that time.

5.3.2 Pacific Oyster Cultivation in France;

After the initial introductions, production levels of Pacific oysters increased quickly reaching 100,000 tonnes in 1979. Since the start of the 1980s the level of Pacific oyster production has stabilised at a level of between 100,000 and 140,000 tonnes of oysters per annum (Miossec and Goulletquer, 2007). A national census of shellfish culture activities was carried out in France in 2002 which gives an excellent overview of the status of the industry. An analysis of the census data by Girard *et al*. (2005) shows that in 2001 production levels reached 109,000 tonnes. The main areas of production were in the Poitou-Charentes region (South West coast of France), including the Marennes-Oléron Bay, followed by Normandy and then the culture regions of Southern Brittany. These main areas accounted for over 90% of total French Pacific oyster production (see Figure 37 below). On the Mediterranean coast of France the main culture area is the Basin de Thau where about 9% of French production takes place with oysters here grown on ropes. In 2000 it was estimated that about 4.6 billion spat were utilised through collection of wild settlement and hatchery production. Of this 4.6 billion spat, 84% were accounted for by the wild collection of seed whilst only 15% was the result of hatchery production. More than 60% of the spat obtained was moved the following year from the areas where they were obtained such as Charente Maritime and Arcachon Bay to new on-growing areas such as Normandy and Southern Brittany (Girard *et al*., 2005).

Figure 37. French Pacific oyster aquaculture industry in 2001
(overview of the status of regional production - Source: Girard et al., 2005)



Such has been the expansion in production in the Marennes-Oléron Bay that a reduction in growth performance has been seen in recent times. This is due primarily to production levels reaching the maximum carrying capacity for the Bay which is estimated to be 40,000 tonnes of bivalve shellfish. It was observed during work by IFREMER on the relative rearing efficiency of the different regions that the Bay was inefficiently managed. The problems lay mainly in large areas of wild abandoned oysters and the development of wild natural beds. These wild Pacific oysters were competitors for the finite food resource and also had the effect of reducing the current flows around the Bay thus further limiting the circulation of the phytoplankton. Therefore new management strategies were put in place and more use was made of transferring shellfish to other areas for on-growing at different stages of production.

Amongst the work carried out was a clearing and restructuring of the culture areas in the Bay including removing abandoned oyster racks, destroying wild oyster beds, gathering slipper limpets and oyster drills and the quarrying of stone, sand and mud. This work clearing 600 hectares of ground was carried out during 2004 at a cost of approximately €610,000 (~£490,000). For the Bay of Brest it is estimated that there is now approximately 15,000 tonnes of wild Pacific oysters compared to 2,000 tonnes of oysters under culture (Christian Hily, pers. comm.). This wild settlement is predominantly occurring in the intertidal rather than subtidal zone. Research is on-going to try and ascertain why this pattern of settlement is occurring and whether factors such as competitive exclusion by other species may be playing a role.

In some areas such as the more sheltered areas of the Brittany coast ‘overcatch’ is a recognised part of the growing process. This leads to a large input of labour into removing the unwanted oysters using a specialised ‘culling knife’. There are reports that overcatch is becoming such a problem in some areas that some oyster farmers are moving their stock offshore at certain times of the year so as to try and avoid this problem (Christian Hily, pers. comm.). It is interesting to note however that in the Mediterranean production area of L’Etang de Thau at Sete where oyster growth rates are very high it was originally thought there were no wild populations in this area. However on further investigation by Hoare it was found that small colonies of wild Pacific oysters do exist on some hard substrates. As there is little tidal movement in this region, these wild Pacific oysters were only found in a narrow band of about 30cm which is the tidal range in that area.

Several theories were given as to why there is not more evidence of infestation. These include too high a salinity, possible shortages of the correct phytoplankton types for larvae to feed on and possible pollution in the water column which will either kill the larvae or the phytoplankton the oyster larvae feed on. Another possibility is that as only one season is required to grow the oysters to market size and with a main harvest time of December most of the adult oysters are not on the farm sites during the summer months. In effect the majority of stock held during the summer are juveniles being on-grown for sale that Christmas and so the potential for large scale spawning is reduced.

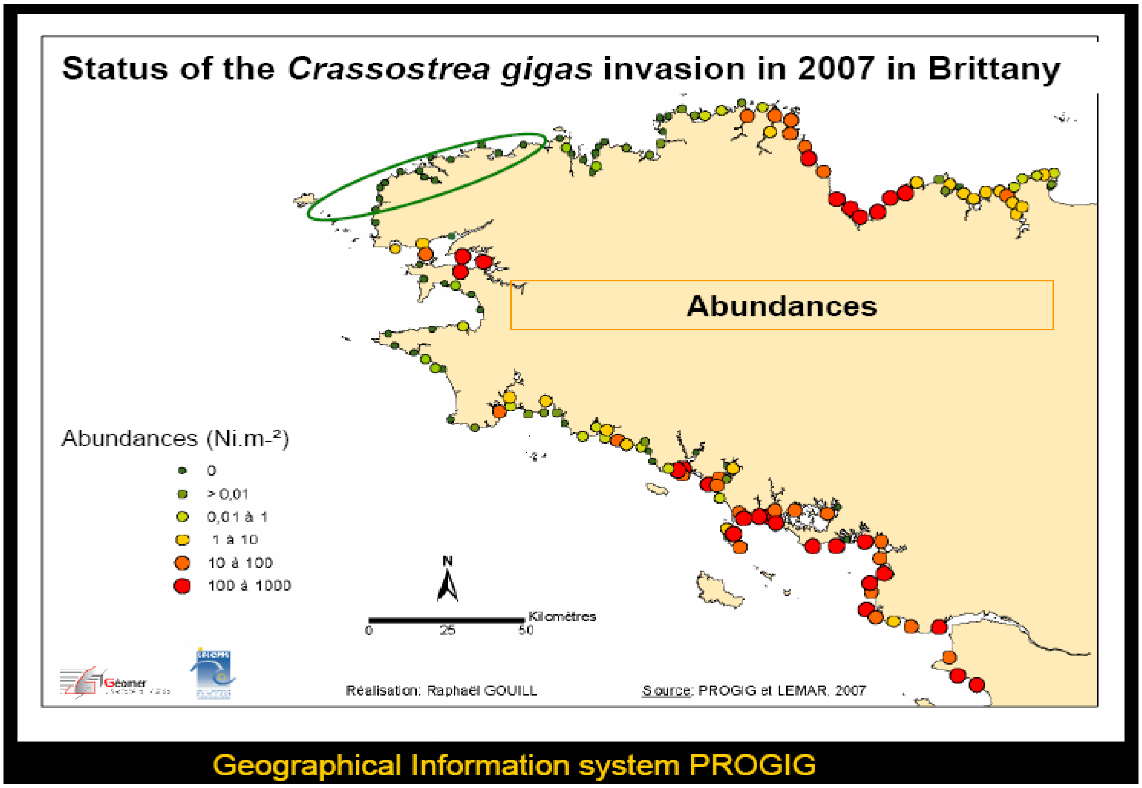
In their review of the introduction of the Pacific oyster into France, Miossec and Goulletquer (2007) conclude that the Pacific oyster has been a beneficial introduction for the French shellfish industry and has exhibited high natural spatfall levels and high growth capacity although this has consequences for management and culture practises in shellfish growing areas.

5.3.3 Ecological Consequences of Wild Settlement of Pacific Oysters in France;

The LEMAR institute in Brest is part of a research program entitled PROGIG (PROliferation GIGas) running from 2006 to 2008. A central theme in this multidisciplinary project is to better understand the ecological consequences of the increasing levels of wild settlement of Pacific oysters on the French coasts.

The Brittany coast was used as a reference region to study the ecological impacts of the wild settlement of Pacific oysters (see Figure 38) due to the highly diversified littoral environment found in that region (Hily and Lejart, 2007).

Figure 38. Levels of wild settled Pacific oysters in 2007 in Brittany (abundance shown in oysters per m^2 - Source: Hily and Lejart, 2007)



During a visit to the LEMAR Institute to discuss this current study Christian Hily (pers. comm.) outlined the complexity of the differing levels on which the Pacific oyster has impacted the biodiversity or species richness and abundance (no. of individuals per m^2) in the Brittany region. On the smaller scale where few other species are present then Pacific oysters increase biodiversity. Where substrates are covered by oysters or reefs are formed then micro-habitats are formed where soft-bottom species can colonise the muddy crevices leading to a high increase in biodiversity. These might be considered in some ways to be a positive impact of wild settlement of Pacific oysters.

On the larger or habitat scale Pacific oysters have become a key species in 17 EUNIS Littoral Rock and other hard substrata habitats and 5 Littoral sediment habitats (Hily and Lejart, 2007). Where this settlement of Pacific oysters becomes dominant then there could be said to be a reduction in overall habitat diversity. However there is a further argument that in Pacific oyster reefs for instance that new micro-habitats may also be formed. In terms of appearance where Pacific oysters are dominant then the impact is considered negative as all areas will look the same.

Hily and Lejart (2007) also question whether Pacific oyster reefs should now be considered as new habitats on European shores and propose two potential different scenarios for EUNIS classification as a Feature of littoral rock (Mediolittoral oyster reefs) and as a Littoral biogenic reef (Littoral oyster reef on sediment). In their 2007 report Hily and Lejart conclude that whilst Pacific oysters are an alien species with high invasive ecological potential they also provide, in ecological terms, an interesting model for study as they increase heterogeneity and the complexity of marine habitats.

5.3.4 Climate Change and Wild Settlement of Pacific Oysters in France;

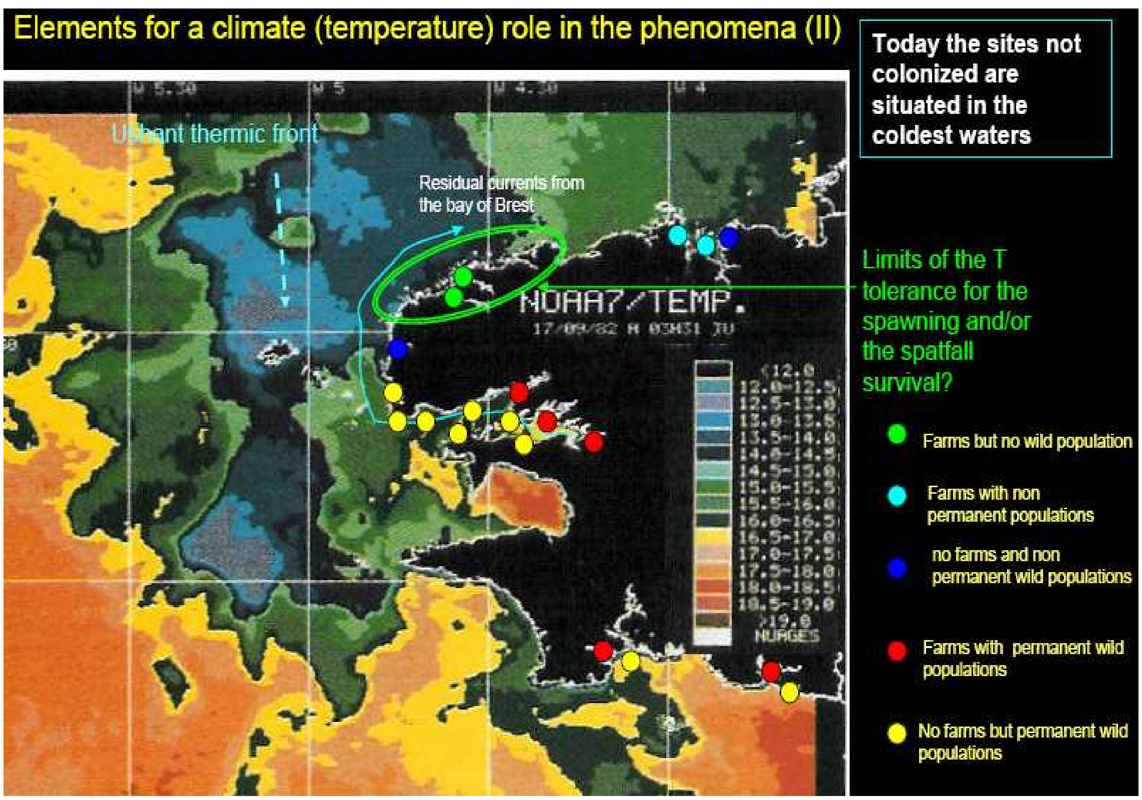
An important aspect of the PROGIG research program is to try and ascertain the extent to which climate change may have played a role in increasing the abundance and range of the wild settlement of Pacific oysters in France. The current range of the wild populations of Pacific oysters in France is from the Basque coast in the South West to the Bay des Veys in the north (situated close to the Seine Estuary). However, it was originally thought that the Pacific oyster would be incapable of spawning north of the Loire Estuary and so this expansion in range over recent years has formed a central part of the PROGIG work.

Whilst it is possible that such factors as high phenotypic plasticity, opportunistic characteristics and genetic adaptation (Hily and Lejart, 2006) may all have played a role in the spread of Pacific oysters it seems likely that climate change will also have been a key factor in recent years. The role that climate change may have played has been the subject of research by Hily and Lejart (2006) and is summarised as follows:

1976 to 1980s – The first observations of wild settlement were in the summer of 1976 in the South Loire region (Arachon basin, Marennes-Oléron basin, Bourgneuf basin) with the warmest sites being colonised first. Over time areas to the south of the Loire were the subject of increasing spawning and settlement events on an annual basis. However to the north of the Loire only occasional settlement of Pacific oysters was seen in the more sheltered and semi-enclosed sites of South and West Brittany (Bay of Brest and Morbihan Gulf).

1990 to date – The South Loire area and Southern Brittany have seen the Pacific oyster settling on even exposed coasts and are described at this stage as being invasive by Hily and Lejart. In the West and Northern Brittany as well as Normandy there has been an increasing number of reported incidences of small wild populations, generally where Pacific oyster farms are found. However this recruitment has been irregular (see Figure 39).

Figure 39. Water temperature & settlement of Pacific oysters - N.W. coast of France (overview of settlement on the North West coast of France - Source: Hily and Lejart, 2006)



Hily and Lejart (2006) report that between 1994 and 2004 there has been a substantial increase in seawater temperatures off the North West coast of France where the spread of the Pacific oyster has been most strongly noticed. The temperature increases they report are +1 ^{o}C increase in winter; +0.5 ^{o}C in spring; +0.7 ^{o}C in summer; +0.9 ^{o}C in autumn. There are multiple impacts of these temperature rises in terms of increasing the likelihood of more regular and more successful spawning and settlement events in this region. As part of their conclusions Hily and Lejart state that climate change has played a role in the increasing range and abundance of wild settlement of Pacific oysters in France and that this process is still ongoing with potentially major consequences for the environment and human activities in coastal areas.

5.3.5 Key Contacts for the Australian Case Study;

Peter Hoare	Oyster Farmer in Tasmania, 1991 - 2001 Director of the Tasmanian Oyster Growers Association Director of the Tasmanian Oyster Research Council Director of the Tasmanian Aquaculture Council Agent for TOOLTECH Pty Ltd. Brisbane Australia: Representative of AQUAPURSE to the French Oyster Industry
Barry Ryan	Chairman of ASI (Australian Seafood Industries Pty. Ltd.) Past Chairman of the Tasmanian Oyster Research Council Past Chairman of the Tasmanian Oyster Growers Association
Richard Pugh	General Manager of Shellfish Culture Ltd., Tasmania
James Calvert	Oyster farmer and Owner of the Tasmanian Oyster Co. Chairman of TAC (Tasmanian Aquaculture Council)

5.3.6 Key Contacts for the French Case Study;

Christian Hily	LEMAR (Laboratoire des Sciences de l'Environnement Marin)
Philippe Goulletquer	IFREMER (Prospective & Scientific Strategy Division in charge of the 'Biodiversity')

SECTION 6 – PACIFIC OYSTER PROTOCOL

6.1 Technical Report

The Technical Report produced during the first phase of this current study will be circulated to project partners for their review and comment. It is hoped that this will assist in generating discussion and clarifying positions with respect to the development of agreed management, husbandry and monitoring strategies with industry that will help where possible towards mitigating or eliminating any environmental impacts of Pacific oyster culture in the UK.

6.2 Pacific Oyster Protocol Framework

Following the review period by project partners, and once feedback is received on the contents of the Technical Report, the project will seek to define the objectives of and processes involved in formulating a protocol in this respect. The methodology and mechanics of producing a protocol that is agreeable to all parties will need to be identified as will key contacts and facilitators, timeframes etc.

6.3 Protocol Template

The final aim of the current study will be to produce a template that will be presented for consideration as a 'first draft' of a protocol. It is likely that this protocol template will be based primarily on a geographic risk assessment of the likelihood of Pacific oysters spawning and successfully recruiting in a given region based on current and future predicted seawater temperature profiles. Thereafter this relative risk will be analysed in terms of other factors such as the current level of wild settlement in that region, presence of other Pacific oyster culture activities, local hydrographics where known etc. This would then allow an application for any new Pacific oyster farming activity to be interpreted in light of these factors.

Wherever possible the protocol will look to identify a range of husbandry, management and monitoring strategies that will help mitigate or eliminate any possible environmental impacts through Pacific oyster culture activities. By way of an example, the use of triploids in commercial activities is one possible method of reducing possible impacts of Pacific oysters through wild settlement. The protocol would however seek to identify a range of possible management or husbandry techniques in this respect, of which the use of triploids may form one part.

The choice of methods suggested should therefore reflect the degree of 'risk' anticipated with individual farms in differing locations. The degree of risk will be strongly influenced by the prevailing environmental conditions in terms of seawater temperature both current and predicted. This is likely to mean that those farms located in areas with a higher potential for settlement events may have to consider a wider range and scope of methods and monitoring than those in areas where settlement is considered unlikely.

In conclusion it is hoped that the development of such a template will then serve to initiate further discussions between industry, Seafish, the SAGB, SNCAs and other relevant organisations.

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APPENDIX

List of Appendices

Appendix 1. Summary of On-going Work;
As identified during the course of the study with respect to the subject area.

Appendix 2. Contact Listing;
Details of key contacts who contributed to this study.

Appendix 3. Statutory Nature Conservation Agency Replies;
With respect to the information and data gathering exercise. Appendices ordered as follows:

3A Natural England;

3B Countryside Council for Wales;

3C Environment and Heritage Service (Northern Ireland).

Appendix 4. Industry Questionnaire;
A copy of the questionnaire that was circulated to industry as part of the data gathering element of this study.

APPENDIX 1 – Summary of On-going Work

On-going research and proposed work that will report after the Pacific Oyster Protocol project timeframe (Page 1 of 2)

Work/Research On-going	Methods	Organisation Undertaking Work/Research	Source of Funding	Timeframe for Reporting
SEAFARE Project Proposal – Atlantic Arc Aquaculture Group - preliminary work programme; - identify & quantify the extent of naturalisation of the PO along the Atlantic coasts of Europe - identify the impact of selected naturalised PO populations on habitat structure & native marine communities - establish the spatial extent of hybridisation between Pacific & Portuguese oysters. - estimate the relative contributions made by aquaculture activity & global warming to the northward spread of naturalised POs - provide information for the management of oyster aquaculture in Europe with respect to the economy and the environment	Methods of the preliminary work programme may include the following; • Surveying for oyster populations; • Estimation of ecological impact; • Microsatellite genetics on oysters; • Analysis of genetic data; • Genome scan of *C. gigas*;	(**SEAFARE**) a project consortium of European Institutes led by Bangor Uni. Partners; Andy Beaumont, Jon King, Shelagh Malham, John Turner & Steve Hawkins (BU, Wales); Gavin Burnell (UCC, Ireland); Pierre Boudry, Sylvie Lapègue, (IFREMER, France); Christian Hily (UBO, France); Liz Cook (SAMS, Scotland); Alexandra Leitao (IPIMAR, Portugal).	**EU project Proposal due to be submitted in June 2008. Budget €1 million** **Note;** Endorsement of project scope should be considered by project partners	Proposal to be submitted June 2008
PhD in Northern Ireland into impacts of Pacific oyster settlement on Northern Irish lough systems	Research including survey monitoring work of wild settlement around Northern Irish lough systems.	Claire Guy is undertaking the PhD in association with Queen's University Belfast & EHS (N.I.)	Unknown	3 year duration
Performance investigation and assessment of an Australian suspended culture system for Pacific oysters in the Solway Firth	Impacts of this oyster growing system on the environment will be assessed which will include any evidence of wild settlement of Pacific oysters.	- Seafish - Institute of Aquaculture, Stirling University	- Seafish	Starting in 2007 with a 3 year duration
Wild settlement of Pacific oysters in Ireland	Three year study into aspects of the potential for wild settlement of POs in Ireland. Aspects being investigated include seawater temperatures around Ireland and influence of farm type and stocking regimes on potential for successful settlement.	Irish Marine Institute. Contact Francis O'Beirn (francis.obeirn@marine.ie)	Irish Government	Three year project starting 2008

APPENDIX 1 – Summary of On-going Work

On-going research and proposed work that will report after the Pacific Oyster Protocol project timeframe (Page 2 of 2)

Work/Research On-going	Methods	Organisation Undertaking Work/Research	Source of Funding	Timeframe for Reporting
Status of the Pacific oyster in Strangford Lough: 2007	Management report on the spread of Pacific oysters in the SAC including recommendations for management options to reverse impact and eliminate any future possible impacts through culture activities.	Quercus (partnership between EHS (N.I.) & Queen's University, Belfast)		June 2008
Research project looking at the reproductive abilities of *Crassostrea gigas* in the River Yealm as part of a collaborative project with the University of Florida.	Since Dec. 2007 measurements have been taken of PO body temperatures experienced during emersion & immersion continuously with a 20 minute resolution factor for adult organisms at mid & low water levels to determine the annual temperature cycle experienced by these individuals. Tissue samples have also been taken to look at how this links to onset of gametogenesis, gonad condition, timing & duration of maturation and timing and duration of spawning events. Temperature loggers have been deployed at nearby open exposed coastal sites for comparison of thermal trends between the estuary & the open coast.	Dr. Nova Mieszkowska Postdoctoral Research Associate & MECN Research Coordinator Marine Biological Association of the UK The Laboratory Citadel Hill Plymouth PL1 2PB		Started December 2007
MARINE ALIENS II – Controlling marine invasive species by targeting vectors of dispersal	Marine surveys that will look to identify wild settlement of Pacific oysters in UK marinas and ports.	Liz Cook, Co-ordinator- (SAMS); G. Baker (MarLIN); J. Bishop (Uni. Of Plymouth); P. Clark & R. Huys (National History Museum); S. Jenkins (Bangor Uni.); C. Maggs (Queen's Uni.; N. Mieszkowska (MBA); T. McCollin (FRS, Aberdeen).	Esmée Fairburn Foundation	Three year project 2008 to 2011

APPENDIX 2 – Contact Listing

Page 1 of 2 (ordered by surname)

Contact Name	Organisation	Telephone No.	E-mail Address	Reason for contact
Andrews, Jim	AWJ Ltd.	0845 880 2540	jim@awjmarine.co.uk	Undertaking work on WFD for the SAGB
Askew, Clive	Shellfish Association of Great Britain	020 7283 8305	clive@sagb.freeserve.co.uk	Project Partner
Bayes, John	Seasalter Whitstable (Shellfish) Ltd.	01227 272003	seasalter@globalnet.co.uk	Commercial hatchery operator
Beaumont, Andy	Bangor University	01248 713808	a.r.beaumont@bangor.ac.uk	Non-native researcher – Pacific oyster genetics
Benebdelmouna, Abdellah	IFREMER, La Tremblade, France		Abdellah.Benabdelmouna@ifremer.fr	Cytogeneticist in charge of polyploid shellfish production
Blyth-Skyrme, Rob	Natural England	01733 455274	Rob.Blyth-Skyrme@naturalengland.org.uk	Project Partner
Boudry, Pierre	IFREMER, Brest	+ 33 02 98 224040	Pierre.Boudry@ifremer.fr	Genetics & invasive potential of Pacific oysters
Bridson, Peter	Soil Association	0131 6661205	PBridson@SoilAssociation.org	Aquaculture Programme Manager
Brown, Janet	Association of Scottish Shellfish Growers	01786 467874	jhb1@stir.ac.uk	Project Partner & Institute of Aquaculture, Stirling Uni.
Bunting, Ben	Environment Agency (S.W. region)	01392 352264		WFD implementation group
Cowden, Janet	UK TAG (Technical Advisory Group)	01315 249747	janet@sniffer.org.uk	WFD guidance
Dravers, Mark	Guernsey Sea Farms Ltd.	01481 247480	oyster@guernseyseafarms.com	Commercial hatchery operator
Dye, Stephen	CEFAS Lowestoft laboratory	01502 524508	stephen.dye@cefas.co.uk	MCCIP - Offshore Temp. Data / Marine Climate Predictions
Eno, Clare	Countryside Council for Wales	01248 385674	c.eno@ccw.gov.uk	Project Partner
Enquiries	UK TAG (Technical Advisory Group)		wfduktag@sniffer.org.uk	WFD guidance
Farrell, James	Environment Agency (S.E. region)	01903 832218		WFD implementation group
Frost, Matthew	MBA (Marine Biological Association)	01752 633242	matfr@mba.ac.uk	MECN (Marine Environmental Change Network)
Gaffney, Joanne	Aquaculture Initiative (EEIG)	+353 42 9385074	gaffney@aquacultureinitiative.eu	Project Partner
Goulletquer, Philippe	IFREMER, France	+33 02 40 374042	Philippe.Goulletquer@ifremer.fr	Prospective & Scientific Strategy Division - 'Biodiversity'
Gray, Mark	Sea Fish Industry Authority (Environ. Impacts)	01248 605038	m_gray@seafish.co.uk	Project Partner
Guo, Ximing	Haskin Shellfish Research Laboratory, USA	+ 856 785 0074	xguo@hsrl.rutgers.edu	Triploid information
Guy, Claire	Queen's University, Belfast	028 90 972066	cguy04@qub.ac.uk	Non-native researcher - Competition with Native oyster
Hily, Christian	LEMAR, Brest, France	+33 02 98 498644	Christian.Hily@univ-brest.fr	Researcher - Invasive potential of Pacific oysters
Horsfall, Sarah	Sea Fish Industry Authority (Legislation)	01482 327837	S_Mossman@Seafish.co.uk	Project Partner
Hunt, Peter	Shellfish Association of Great Britain	020 7283 8305	peterhunt@SAGB.fsnet.co.uk	Project Partner
Hutchson, Rory	Plymouth Marine Laboratory	01752 633100	rohu@pml.ac.uk	NEODAAS Support (satellite data)
Jarrad, David	SAGB / River Exe Shellfish Ltd.	020 7283 8305	david@shellfish.org.uk	Pacific oyster grower / SAGB (Project Partner)
Jones, Audrey	Natural England	01273 407938	audrey.jones@naturalengland.org.uk	Project Partner
Kestin, Steve	Cornish Mussels Ltd.	01326 341319	stevekestin@mac.com	Mussel growers (Cornwall)

APPENDIX 2 – Contact Listing

Page 2 of 2 (ordered by surname)

Contact Name	Organisation	Telephone No.	E-mail Address	Reason for contact
King, Jonathan	Bangor University	01248 713808	j.w.king@bangor.ac.uk	Non-native researcher – Pacific oyster culture
Laing, Ian	CEFAS Weymouth laboratory	01305 206600	i.laing@cefas.co.uk	CEFAS Inspectorate - Movement regulations
Le Masurier, Chris	Jersey Oyster Company	01534 852553	chris@jerseyoyster.com	Pacific oyster growers (Jersey, Channel Islands)
Leonard-Williams, Adam	Met Office	01392 884833	adam.leonard-williams@metoffice.gov.uk	Provision of historical + predicted temperature data
Liz, Cook	SAMS (Scottish Assoc. for Marine Science)	01631 559 243	ejc@sams.ac.uk	Non-native researcher - Port vectors + PO Acclimation
Marissal, Eric	Grainocean, France		graino@club-internet.fr	Commercial hatchery operator
McKeown, Renny	Environment & Heritage Service, N.I.	028 90 56 9631	renny.mckeown@doeni.gov.uk	Project Partner
McKnight, Willie	North East Kent Coast Scientific Adv. Group		willie.mcknight@btinternet.com	Surveys - North East Kent European Marine Sites
McLeod, Doug	Association of Scottish Shellfish Growers	01471 844 324	DouglasMcLeod@aol.com	Project Partner
Mieslowska, Nova	MBA (Marine Biological Association)	01752 633332	nova@mba.ac.uk	MECN Research Coordinator (PO Acclimation Project)
Miossec, Laurence	IFREMER, France	+33 02 40 374000	Laurence.Miossec@ifremer.fr	Researcher - Invasive potential of Pacific oysters
Moore, Niall	NNSS (Non-Native Species Secretariat)	01904 462000	niall.moore@csl.gov.uk	Great Britain Non-Native Strategy
Oates, Martyn	Limosa Farms Ltd.	01752 880937	limosafarmsltd@tiscali.co.uk	Pacific oyster growers (Devon)
O'Beirn, Francis	Marine Institute (Galway, Ireland)	+353 91 387250	francis.obeirn@marine.ie	Benthos Ecology - Environ. impacts of Pacific oysters
O'Carroll, Terence	Bord Iascaigh Mhara (BIM), Ireland	+353 12 144100	ocarroll@bim.ie	Aquaculture Development Division
Parker, Kenny	Dept. of Agriculture & Rural Development, N.I.	028 90 524980	kenny.parker@dardni.gov.uk	Project Partner
Pickerell, Tom	Shellfish Association of Great Britain	020 7283 8305	tom@shellfish.org.uk	Project Partner
Robbins, Tim	Devon Sea Fisheries Committee	01803 854648	trdsfc@btconnect.com	Mariculture Officer
Rossi, Tom	4Cs Breeding Technologies, Inc., N.J., USA	+1 609 425 2475	trossi08248@yahoo.com	Patent holder for PO tetraploid production technique
Selge, Sebastian	University of Aberdeen	01224 272256	s.selge@macaulay.ac.uk	Non-native researcher - Policy and perception
Service, Matthew	Fisheries & Aquatic Ecosystems Branch (N.I.)	028 90 255502	Matt.Service@afbini.gov.uk	N.I. moored buoy temperature data / SMILE
Sewell, Jack	MBA (Marine Biological Association)	01752 633336	jase@mba.ac.uk	MARLIN
Shucksmith, Richard	SAMS (Scottish Assoc. for Marine Science)	01631 559278	Richard.shucksmith@sams.ac.uk	Non-native researcher - Ecosystem functioning
Smith, Kate	Countryside Council for Wales	01248 672557	k.smith@ccw.gov.uk	Project Partner
Stevens, Helen	Natural England	023 80286416	Helen.Stevens@naturalengland.org.uk	Project Partner
Thompson, Kelsey	Seasalter (Walney) Ltd.	01229 474158	oysters@seasalter.org.uk	Commercial hatchery operator
Utting, Sue	Sea Fish Industry Authority (Aquaculture)	01492 650884	s_utting@seafish.co.uk	Project Partner
Van der Wal, Rene	University of Aberdeen	01224 272256	r.vanderwal@abdn.ac.uk	Non-native researcher - Policy and perception
Wiggins, Joss	Kent & Essex Sea Fisheries Committee	01206 303261	joss.wiggins@btconnect.com	S.E. England Pacific oyster Status
Wright, Ben	Duchy of Cornwall Oyster Farm & Fishery	01326 340210	ben@duchyoysterfarm.com	Pacific oyster growers (Cornwall) + restaurant (London)

APPENDIX 3 - Statutory Nature Conservation Agency Replies

APPENDIX 3A - Natural England

Answers to questions asked during FIFG funded project FGE 648- Development of a Pacific oyster aquaculture protocol for the UK

Literature Search and Data Collation:

1. *Do you have any relevant literature references or reports regarding Pacific oysters that would be of value within the current study?*

A. Couzens, G. (2006). The distribution and abundance of the non-native Pacific oyster, *Crassostrea gigas*, in west Devon- a result of climate change? MSc thesis. (Summary reported in Shellfish News- http://www.cefas.co.uk/media/26621/sfn_nov06webfinal.pdf)

B. Allen Jr., S.K. and Guo, X. Triploids for biological containment: the risk of heteroploid mosaics. Internet report: http://www.isb.vt.edu/brarg/brasym96/allen96.htm

C. Article in The Independent on 18th March 2008 – 'Invasion of the giant oysters'.

Dutch reports:

D. Fey, F., Dankers, N., Meijboom, A., de Jong, M., van Leeuwen, P-W., Dijkman, E. and Cremer, J. (2007). De ontwikkeling van de Japanese oester in de Nederlandse Waddenzee: Situatie 2006, Wageningen IMARES
Institute for Marine Resources & Ecosystem Studies, Internal report No. 07.003.

E. Dankers, N., Meijboom, A., de Jong, M., Dijkman, E., Cremer, J., Fey, F., Smaal, A., Craeymeersch, J., Brummelhuis, E., Steenbergen, J. and Baars D. (2006). De ontwikkeling van de Japanese oester in Nederland (Waddenzee en Oosterschelde). Wageningen IMARES Institute for Marine Resources & Ecosystem Studies, Report Number C040/06

2. *Do you hold any relevant data listings that could help with the current study (e.g. long-term temperature records for English inshore waters)?*

We do not hold long-term temperature records, but these should be available from the British Oceanographic Data Centre. Lesley Rikards is our normal contact. We also hold some habitat/species information available for European marine sites that is derived through specific reporting processes.

3. *Are there any other staff contacts within your organisation that should be contacted to obtain feedback regarding this Project?*

There are other relevant staff but for the time being it will be easier if you contact either Rob Blyth-Skyrme or myself and then we can co-ordinate Natural England responses.

Naturalisation and wild settlement:

4. *Could the Pacific oyster now be considered naturalised? Please explain the reasoning behind your answer.*

In answering this question Natural England has considered that 'naturalised' means the same as 'established' (**Established:** a non-native species in a new habitat successfully producing viable offspring with the likelihood of continued survival. Ref Review of non-native species policy, Defra 2003).

Established is the term used to consider species for Schedule 9 of the Wildlife and Countryside Act (as amended) 1981. (Schedule 9 contains measures for preventing the establishment of non-native species which may be detrimental to native wildlife).

JNCC use breeding in the wild and producing offspring which reach maturity as the criteria to determine if a species is established. Our understanding is that Pacific oysters in English waters are now doing this. So, we would consider that Pacific oysters are now naturalised or established in the wild.

However becoming 'established' or 'naturalised' in the wild does not imply that a species has therefore become native. The definition for non-native is: '**Non-native:** a species that does not originate in local waters and which has been introduced from other parts of the world by humans, either deliberately or accidentally'. (Ref Defra 2003).

Therefore using this definition in Natural England's opinion Pacific oysters are an established, non-native species.

5. *If deemed non-native, do you feel that the Pacific oyster should be considered 'non-invasive' or 'invasive'? Please explain the reasoning behind your answer.*

Natural England considers Pacific Oyster to be a non-native, invasive species in English waters.

The Review of non-native species policy, Defra 2003, states that: 'Invasive species are those whose introduction and/or spread threatens UK biological diversity. Broadly interpreted this includes threats to the entire ecosystem including human interests (e.g. including threats to public health and financial damage)'

In our opinion Pacific Oysters fit this description as they have the potential to transform ecosystems, and threaten native and endangered species resulting in the loss of distinctive UK biodiversity. The recent cases in the Wadden Sea and Denmark demonstrate how invasive Pacific oysters can be, leading to the loss of mud and sand flats as well as competing with local indigenous fauna such as native mussels.

6. *What are the specific concerns that your organisation has about wild settlement of Pacific oysters in UK waters?*

A. Uncontrolled spread that will change existing habitat types
B. No/few natural predators so once established will potentially out-compete and dominate marine habitats
C. Will colonise bare mud as well as rock habitats, potentially forming a reef monoculture which transforms estuarine and marine environments.
D. This has the potential to effect bird feeding areas which could have a significant effect on our estuaries, of which a large proportion are protected for the nationally and internationally important bird populations that they support.
E. They also have the potential to effect fish nursery areas, through the smothering of muddy and sandy areas which provide an essential food source.
F. There is a real risk that once established that it will not be possible to control them, or extremely invasive methods such as dredging will be required. Rocky substrates are likely to be particularly difficult to clear.
G. All the above will have the effect of permanently damaging internationally and nationally important conservation sites meaning that they will always be in unfavourable condition and will not meet good ecological status under the Water Framework Directive.
H. Access to the coastal/estuarine environment will also be impacted as Pacific Oysters have razor sharp edges which make walking on them extremely hazardous, has been demonstrated in Sylt, Germany, Wadden Sea, Holland and Denmark.

7. *Does your organisation have any evidence of wild settlement of Pacific oysters in areas for which you have responsibility?*

Couzens reported the wild settlement of Pacific Oysters in areas around Plymouth, even though the Plym and Tamar estuaries do not contain any commercial Pacific oyster farms. It also showed the reef which has now formed in the River Yealm, and reported the sporadic spatfall of Pacific oysters near areas of cultivation in the Exe, Yealm and Dart estuaries, but this was in 1994 prior to the warm summers and mild winters experienced over the last 10years.

We also have anecdotal evidence through personal comments from various sources that Pacific oysters are beginning to form reefs or settle in the wild in: the Wash, Blackwater Estuary, off the Essex coast and within the Helford.

8. *Is there any evidence of wild Pacific oysters having an adverse environmental effect on designated areas in UK waters and elsewhere in Europe? If protected habitats or fauna and flora (e.g. within Special Areas of Conservation and Sites of Special Scientific Interest) are being affected, where have these effects been noted and what are the specific impacts?*

This information is essentially contained within the answer to the question above on wild settlement. However, we currently have not reported Pacific oysters causing adverse effects within designated conservation sites within England. However this may in part be due to the timetable for assessing site condition being on a 6 yearly cycle, which means that the areas like the Yealm may not have been condition assessed since the development of the Pacific oyster reef.

An article in The Independent on 8th March 2008 reported on the spread of Pacific Oysters on Sylt Island, Germany. Where the invasion of Pacifics has been rapid and widespread, with areas which used to be sandflats and mussel beds now being dominated by Pacific oysters. This was reported to have lead to the reduction in eider and other birds that used to feed on the sandflats and mussel beds.

The issues in the Dutch and Danish Wadden Sea have also been well documented.

9. *In addition to designated areas does your organisation have any evidence of Pacific oysters having a significant effect on other specific natural habitats, native fauna and flora or the wider ecosystem of non-designated areas in the UK?*

No, apart from the Couzens report. However, although the focus is likely to be on protected sites, the issues are likely to be generic to inshore waters around England.

Legislation:

10. *What marine conservation legislation protects natural habitats & native flora and fauna from non-native species and in what capacity (e.g. Wildlife & Countryside Act, Habitat Regulations etc.)?*

The review of non-native species policy by Defra (2003), provides a useful summary of the relevant legislation, the following is taken from this document:

1. Convention on Biological Diversity:
Perhaps the most important international instrument is the Convention on Biological Diversity (CBD). This Convention requires contracting parties (of which there are 184), as far as possible and as appropriate, to prevent the introduction of, to control or eradicate, those alien (*i.e.* non-native) species which threaten ecosystems, habitats or species.

2. Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention)
Resolution VII.14 on invasive species and wetlands calls upon Contracting Parties to wherever possible address the environmental, economic and social impact of invasive species on wetlands within their jurisdictions.

3. Bern Convention on Conservation of European Wildlife and Natural Habitats
Article 11(2) of this convention requires each contracting party to "*strictly control the introduction of non-native species*". Further to this Article, the Committee of Ministers to Member States issued Recommendation R(84)14 (adopted on 21st June 1984), stating that the introduction of non-native species into the environment should be prohibited. Exceptions to this prohibition may be authorised on the condition that the potential consequences of such introductions are assessed beforehand.

4. The Wildlife and Countryside Act 1981 (amended)

This is the main piece of legislation regulating the release of non-natives in Great Britain. Under Section 14(1) of this Act, it is an offence to "*release or cause to escape into the wild*" any animal which:

a) is of a kind which is not ordinarily resident in and is not a regular visitor to Great Britain in the wild state; or

b) is included in Schedule 9 part I.

5. Countryside and Rights of Way Act 2000 (CRoW Act)

Article 74 of the CROW Act stipulates that it is the duty of all Ministers of the Crown, government departments and NAW, in carrying out their functions, to have regard (as far as is consistent with the proper exercise of these functions) to the purpose of conserving biological diversity in accordance with the CBD. This therefore implies that the implementation of Article 8(h) of the CBD concerning non-native species should be considered by all Ministers and government departments.

6. EC Habitats Directive 92/43/EEC

Article 22 of this Directive requires Member States to regulate deliberate introductions of non-native species so as not to prejudice natural habitats or wild native fauna and flora, where necessary prohibiting such introductions. In Great Britain, this is transposed into domestic legislation by Section 14 of the Wildlife and Countryside Act 1981.

Designated sites:

Habitats and species which are included within Sites of Special Scientific Interest (SSSIs), Special Areas of Conservation (SACs), Special Protection Areas (SPAs) and Ramsar sites are also protected under the Wildlife and Countryside Act 1981 (as amended) and the Habitats Regulations 1994.

Through the Habitats Regulations, the UK has a duty in maintaining or restoring natural habitats and species of wild fauna and flora to a favourable conservation status within European marine sites (Special Areas of Conservation, Special Protection Areas and Ramsar sites). For more information, please refer to the Habitats Regulations Guidance notes, available online: http://enintranet/default_pages/default_37796.html

In addition, the Wildlife and Countryside Act 1981 (as amended) requires that all SSSIs are protected from damage or disturbance. For more information on SSSIs, please refer to http://tenis:8008/special/sssi/.

11. *How is and could the Pacific oyster farm industry be affected by such legislation?*

Under Article 6(3) of the Habitats Directive, 'plans or projects' that are proposed within sites of international importance e.g. SAC, SPA or Ramsar sites have to pass a number of tests in order to determine whether it can proceed or not. These are referred to as the Appropriate Assessment. In the event that a new farm site, or an expansion to a farm site that required a consent, licence, or other permission, was proposed within an EMS, we consider that the proposal would be a plan or project under this legislation.

Existing farm sites may also be covered under the provisions of the Habitats Regulations. Article 6(2) of the Habitats Directive states that 'Member States shall take appropriate steps to avoid, in the special areas of conservation, the deterioration of natural habitats and the habitats of species as well as disturbances of the species for which the areas have been designated, in so far as such disturbance could be significant in relation to the objectives of this directive.'

For more information on the provisions of Article 6 of the Directive, please see: http://ec.europa.eu/environment/nature/natura2000/management/docs/art6/provision_of_art6_en.pdf

It is likely also to be particularly relevant in the case of Pacific oysters that the plan or project does not have to be located within the designated area. Significant effects may occur even if the plan or project is some distance away [from the protected site]. The effects may be direct or indirect, temporary or permanent, beneficial or harmful to the site, or a combination of these.

For sites which are only designated as a SSSI it is an offence under the WCA for anybody to ‘release into a SSSI any wild, feral or domestic animal, plant or seed’ without prior consultation and agreement from Natural England.

Applications for new farms or modifications to existing activities:

Our answers to the following questions relate to new applications or modifications to existing licences that are not within Regulating or Several Orders.

12. *In the last 5 years how many applications have you been asked to comment on for new proposed Pacific oyster farms or modifications to existing operations?*

From the responses we have received back from our regional officers it appears that we have commented on 6 applications in the past 5 years. However this may not be a complete figure as we have not been able to get responses from all the relevant people within the short timescale of this part of the project. Those applications we have received are from a wide geographical area of the English coast.

13. *In general terms what were your recommendations in this respect and what was the eventual outcome of the applications?*

In general terms our recommendations have been: limits on the size and locations of operations, the use of triploid stock, the need to go through an appropriate assessment under Regulation 48 of the Habitats Regulations and the need to monitor the effects of the activities.

14. *Without reference to specific individuals what is the current status of applications that you have been asked to comment on?*

The current situation is that 2 of the applications have gone ahead, 1 was given permission but abandoned due to the infrastructure washing away, 1 is still in discussions with the competent authority over the impacts, 1 has gone ahead against our advice and the other is considering the possibility of undertaking an appropriate assessment.

APPENDIX 3B – Countryside Council for Wales

Literature Search and Data Collation:

- Do you have any relevant literature references or reports regarding Pacific oysters that would be of value within the current study?

Yes – have passed various papers over to you in person regarding Pacific oyster potential spawning and spat settlement associated with temperature monitoring.

- Do you hold any relevant data listings that could help with the current study (e.g. long-term temperature records for Welsh inshore waters)?

CCW grant aid the University of Bangor School of Ocean Science to undertake turbidity monitoring in the Menai Straits – the University have done parallel temperature monitoring. You should contact Jonathan King in this respect – he is also involved with the oyster industry quite heavily from an academic and practitioners perspective.

- Are there any other staff contacts within your organisation that should be contacted to obtain feedback regarding this Project?

Other than Kate Smith, you should contact Gabrielle Wyn (g.wyn@ccw.gov.uk).

Naturalisation and wild settlement:

- Could the Pacific oyster now be considered naturalised? Please explain the reasoning behind your answer.

No the Pacific oyster should not be considered naturalized. The few species we consider naturalized include species such as the rabbit, the garden snail etc which have been present for hundreds of years, not cultivated for 30 years and only settling in the wild over the last 10. We do not consider the term 'naturalized' as synonymous to 'established'.

- If deemed non-native, do you feel that the Pacific oyster should be considered 'non-invasive' or 'invasive'? Please explain the reasoning behind your answer.

Non-native species have the potential to become invasive. Sometimes they may not or sometimes this move is delayed (e.g. Zebra mussels *Dreiseina polymorpha* which is invasive in North America has been present in Britain for over a century and has only recently started to cause problems here). In Europe it has taken a couple of hot summers which seems to have triggered the Pacific oyster into taking on invasive properties especially in France and the Wadden Sea. At present in Britain there is only one example of a wild settlement of *Crassostrea gigas* forming a reef as such, in the Yealm estuary in Devon despite quite extensive settlements. Anecdotal reports by recreational anglers suggest it is becoming an amenity issue at Southend on Sea in the Thames estuary, who have reported cutting their feet on the shore on wild settlements of *C. gigas*. It is therefore on the verge of becoming invasive.

- What are the specific concerns that your organisation has about wild settlement of Pacific oysters in UK waters?

On the continent, the status of the Pacific oyster, *Crassostrea gigas*, has changed from non-native to invasive. This has been brought about by recent warm summers which have resulted in an explosion of the species in some warmer areas including the Wadden Sea. It is causing a nuisance in several countries – namely France, Holland, Germany and Denmark. It has also been found to be settling in the wild further north into Scandinavia (it recently settled in Sweden at densities of up to 300/m^2). The nuisance value comes from it forming dense reefs and aggregations that can comprise a very large proportion of the biomass. It can replace mussel reefs and while the associated fauna is less affected, it nonetheless changes the existing habitat. In the intertidal and shallow subtidal there is an amenity issue as the shells are razor sharp. These effects are both of concern to CCW on account of our wildlife and countryside remit.

In Britain, this species is a non-native and has been settling in the wild for over 10 years. As with records from elsewhere in Europe, it was initially found as individual shells attached to hard substrates. CCW is concerned that it will become invasive as it has on the continent and by that time it will be too late to control its effects.

The cause of the spread lies in the cultivation of Pacific oysters on aquaculture lays. Initially its settlement in the wild in south coast estuaries was blamed on larvae being transported in gyres from France, however, their wider appearance soon showed that local recruitment was occurring.

The oysters have no natural predators.

There are a range of habitats which could be colonized and changed by the settlement of Pacific oysters. Our greatest concern lies within site of nature conservation importance, however, any establishment in the wild would degrade its naturalness.

- Does your organisation have any evidence of wild settlement of Pacific oysters in areas for which you have responsibility?

There has been sparse but widespread settlement in the Menai Straits since the 1990s. There are subtidal settlements in the Milford Haven.

- Is there any evidence of wild Pacific oysters having an adverse environmental effect on designated areas in UK waters and elsewhere in Europe? If protected habitats or fauna and flora (e.g. within Special Areas of Conservation and Sites of Special Scientific Interest) are being affected, where have these effects been noted and what are the specific impacts?

Not yet

- In addition to designated areas does your organisation have any evidence of Pacific oysters having a significant effect on other specific natural habitats, native fauna and flora or the wider ecosystem of non-designated areas in the UK?

Not yet

Legislation:

- What marine conservation legislation protects natural habitats & native flora and fauna from non-native species and in what capacity (e.g. Wildlife & Countryside Act, Habitat Regulations etc.)?

In relation to the wildlife and Countryside Act 1981: From the 1960s the fisheries laboratories have maintained there was no likelihood of this species spreading in the wild, since it requires a water temperature of 20ºC to complete its life cycle, and actively promoted its use in aquaculture. It was supposedly put on general licence (under section 14 of the Wildlife and Countryside Act 1981), although we have not been able to obtain any record of recent licences being issued.

There is a current consultation on the review of schedule 9 of the W&CA (first in 15- 20 years) which lists species established in the wild but that continue to pose a conservation threat to native biodiversity and habitats, such that further releases should be regulated. The Pacific oyster is not one of the species proposed by Defra at this stage.

The classification of aquatic alien species found in the UK in terms of their impact on native habitats and biota on the Water Framework Directive is currently being revised and it is being considered whether the Pacific oyster is listed as 'high impact'. If it were, its presence would be of sufficient concern to trigger failure of good ecological status in Water Framework Directive assessments and by implication this would be likely to lead to measures being taken to control them.

- How is and could the Pacific oyster farm industry be affected by such legislation?

Quite considerably if they came into force.

Applications for new farms or modifications to existing activities:

- In the last 5 years how many applications have you been asked to comment on for new proposed Pacific oyster farms or modifications to existing operations?

Three at least.

- In general terms what were your recommendations in this respect and what was the eventual outcome of the applications?

Undertake Appropriate Assessments.

- Without reference to specific individuals what is the current status of applications that you have been asked to comment on?

Part of the process of preparing Appropriate Assessments has been the commencement of trials using triploid stock.

In April Kate Smith will be available to discuss further the situation regarding leases in the western Menai Straits.

APPENDIX 3C – Environment and Heritage Service (Northern Ireland)

Literature Search and Data Collation

- **Do you have any relevant literature references or reports regarding Pacific Oysters that would be of value within the current study?**

DARDNI have sponsored a PhD entitled "Potential threats of Crassostrea gigas to the commercial and ecological sustainability of the Native oyster (Ostrea edulis) in Strangford Lough: Informing Management". The student is Claire Guy who is based at C-MAR (Centre for Marine Resources & Mariculture) and is due to report in October 2010. Her contact details are E-mail: cguy04@qub.ac.uk

- **Do you hold any relevant data listings that could help with the current study (e.g. long-term temperature records for Northern Irish inshore waters)?**

Coastal water quality parameters are being remotely measured across a network of sites by the North of Ireland Joint Agency Coastal Monitoring Programme. This is a collaborative project between Environment and Heritage Service (EHS), the Department of Agriculture and Rural Development (DARD), The Loughs Agency and Queen's University Belfast. Instruments have now been installed in over ten sites including many of the sea-loughs in the north of Ireland. Sites have been selected that are suitable for monitoring whilst important for conservation and aquaculture. Up-to-date data on coastal water quality can be obtained on the AFBI Website

http://www.afbini.gov.uk/index/services/specialist-advice/coastal-monitoring/services-coastal-monitoring-data-archive.htm

EHS Water Management Unit also hold relevant data from their Estuarine Monitoring Programme

- **Are there any other staff contacts within your organisation that should be contacted to obtain feedback regarding this project?**

Mr Bob Bleakley – bob.bleakley@doeni.gov.uk 028 9056 9582
Mr Joe Breen – joe.breen@doeni.gov.uk 028 9056 9634

You may also wish to contact Dr Dai Roberts, Director of CMAR (Centre for Marine Resources & Mariculture)
d.roberts@qub.ac.uk or Tel: 028 9097 2249

Naturalisation and Wild Settlement

- **Could the Pacific oyster now be considered naturalised? Please explain the reasoning behind your answer.**

A naturalised species can be defined as an alien species that can form populations that endure (maintain a reproductive population) for at least 10 years without direct intervention by people. Until Claire Guy reports the results of her PhD, EHS cannot be definitive as to whether Pacific Oyster can be considered "naturalised".

- **If deemed non-native, do you feel that the Pacific oyster should be considered 'non-invasive' or 'invasive'? Please explain the reasoning behind your answer.**

Pacific Oysters are not native to Northern Ireland – however, for a species to be defined as invasive, it must successfully out-compete native organisms, spread through its new environment, increase in population density and harm ecosystems in its introduced range. This being the case, there is currently no evidence to support these impacts in Northern Ireland, but we consider that Pacific Oyster would be an undesirable addition to the wild marine environment particularly in Strangford Lough where there is concern for similar bivalves, Ostrea edulis and Modiolus modiolus. However, until the *results of the PhD referred to above are reported, we cannot be definitive on whether Pacific Oyster is spreading and increasing in population density. In the absence of relevant research at this stage, it would be difficult to determine if Pacific Oyster is harming the ecosystem in Northern Ireland.*

- **What are the specific concerns that your organisation has about wild settlement of Pacific oysters in UK waters?**

The following are the main concerns that EHS as about wild settlement of Pacific Oysters (in no particular order)

1. Establishment of a non-native species as a functional population.

2. Disease Transmission

3. Effect on Ecology of Designated Sites

- **Does your organisation have any evidence of wild settlement of Pacific oysters in areas for which you have responsibility?**

Distribution data will be contained with Claire Guy's PhD, referred to above.

- **Is there any evidence of wild Pacific oysters having an adverse environmental effect on designated areas in UK waters and elsewhere in Europe? If protected habitats or fauna and flora (e.g. within Special Areas of Conservation and Sites of Special Scientific Interest) are being affected, where have these effects been noted and what are the specific impacts?**

EHS has not carried out any research into the effect (if any) that Pacific Oysters are having on Designated Sites in Northern Ireland.

- **In addition to designated areas does your organisation have any evidence of Pacific oysters having a significant effect on other specific natural habitats, native fauna and flora or the wider ecosystem of non-designated areas in the UK?**

EHS has not carried out any research into the effect (if any) that Pacific Oysters are having on natural habitats, native flora and fauna or the wider eco-system of non-designated areas in Northern Ireland.

Legislation

- **What marine conservation legislation protects natural habitats & native flora and fauna from non-native species and in what capacity (e.g. Wildlife & Countryside Act, Habitat Regulations etc.)?**

The Wildlife (Northern Ireland) Order 1985
The Nature Conservation and Amenity Lands (Northern Ireland) Order 1985
The Conservation (Natural Habitats, etc.) Regulations (Northern Ireland) 1995

Environment (Northern Ireland) Order 2002

- **How is and could the Pacific oyster farm industry be affected by such legislation?**

All sea loughs in Northern Ireland have been designated as Natura 2000 sites (either as SAC or SPA or both) – as such, any application for a Pacific Oyster farm in these areas will be subject to a Test of Likely Significance and Appropriate Assessment as required by The Conservation (Natural Habitats, etc.) Regulations (Northern Ireland) 1995 (The Habitats Regulations).

Applications for new farms or modifications to existing activities

- **In the last 5 years how many applications have you been asked to comment on for new proposed Pacific oyster farms or modifications to existing operations?**

Fisheries Division, of the Department of Agriculture and Rural Development (DARD) are responsible for the licensing of fish and shellfish farms in Northern Ireland. Under the provisions of the Fisheries Act (Northern Ireland) 1966, as amended, it is an offence to operate a fish or shellfish farm without a fish culture licence. Licences are granted following a public consultation exercise which includes consultation with EHS. No new fish culture licences for Pacific Oysters farms have been granted in the last 5 years. Under the provisions of the 1966 Act, DARD may amend a fish culture licence either on its own motion or on the application of the holder of the licence. You may also wish to note that DARD is considering the usefulness of stocking currently licensed Pacific oyster farms with triploid oysters.

It has been agreed that aquaculture licensing functions in respect of the Foyle and Carlingford Areas will transfer to the Loughs Agency of the Foyle and Carlingford Irish Lights Commission. The transfer will come into operation as soon as the mechanisms necessary to deliver an effective aquaculture regulatory system have been established by the Loughs Agency. Pending the transfer of functions you may wish to formally consult with the relevant licensing authorities in the Republic of Ireland in light of their aquaculture responsibilities in the border sea loughs i.e. Lough Foyle and Carlingford Lough.

- **In general terms what were your recommendations in this respect and what was the eventual outcome of the applications?**

N/A

- **Without reference to specific individuals what is the current status of applications that you have been asked to comment on?**

N/A

APPENDIX 4 – Industry Questionnaire

Once completed please return to the SAGB using the enclosed SAE.

Where you have more than 1 site please list the information separately.

1) Contact details:

Business name:	
Contact phone numbers:	
E-mail address:	

2) Please describe your location e.g. South West, Southern or Eastern England, Wales, Northern Ireland:

Site 1)	
2)	
3)	

3) What are the main type(s) of farming activities undertaken at each site (please circle)?

	Farming activity (circle both if each are undertaken)		Seed type (circle both if each are used)	
Site 1)	**Intertidal**	**Subtidal**	**Diploid**	**Triploid**
2)	**Intertidal**	**Subtidal**	**Diploid**	**Triploid**
3)	**Intertidal**	**Subtidal**	**Diploid**	**Triploid**

4) What is the approximate standing stock of Pacific oysters on each site (please circle)?

Site 1)	**0 - 10 tonnes**	**10 - 20 tonnes**	**20 - 40 tonnes**	**40+ tonnes**
2)	**0 - 10 tonnes**	**10 - 20 tonnes**	**20 - 40 tonnes**	**40+ tonnes**
3)	**0 - 10 tonnes**	**10 - 20 tonnes**	**20 - 40 tonnes**	**40+ tonnes**

5) What is the area in hectares (10,000 m^2 or 2.5 acres) covered by each site (please circle):

Site 1)	**0 - 5 hectares**	**5 - 10 hectares**	**10 - 15 hectares**	**15+ hectares**
2)	**0 - 5 hectares**	**5 - 10 hectares**	**10 - 15 hectares**	**15+ hectares**
3)	**0 - 5 hectares**	**5 - 10 hectares**	**10 - 15 hectares**	**15+ hectares**

6) Is there any evidence of wild Pacific oysters in the local area (please tick)?

	No wild settlement	Individual oyster settlement (tick each box if both are present)		Evidence of reef building (tick each box if both are present)	
		Juveniles	Adults	Juveniles	Adults
Site 1)					
2)					
3)					

7) If there are wild Pacific oysters in the local area please indicate the following:

	Do you monitor levels of settlement (please circle)?		Do you harvest or utilise seed oysters for on-growing/relaying (please tick)?		Do you deploy spat collection devices (please tick)?	
	YES	NO				
	If YES, is settlement REGULAR (occurs most years) or IRREGULAR (please circle)?		YES	NO	YES	NO
Site 1)	Regular	Irregular				
2)	Regular	Irregular				
3)	Regular	Irregular				

8) Would you be happy to discuss this information in more detail (please circle YES or NO)?

YES –	NO –
I am happy to discuss by phone or E-mail	Please limit my contribution to this Questionnaire

9) Please add any other information or comments you may have. We are particularly interested in industry experiences with respect to the application process for new sites or modifications to existing activities (continue overleaf if required):

Thank you for your help!