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A feasibility study of native oyster (*Ostrea edulis*) stock regeneration in the United Kingdom

CARD Project FC1016
Native Oyster Stock Regeneration -
A Review of Biological, Technical and Economic Feasibility

for
Defra and Seafish

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EXECUTIVE SUMMARY

1. Throughout much of the UK, the native oyster remains in a severely depleted state in the wild, having suffered for two centuries with over-exploitation, pests, disease, pollution and harsh winters.
2. The native oyster is a Biodiversity Action Plan Species. Native oyster beds can form a flourishing part of the ecosystem, with many associated species. **A significant driver for restoration of native oyster beds should therefore be re-creating and conserving an ecological resource** in order to re-establish a biotope that was once common and covered wide areas of the UK inshore seabed.
3. **Various restoration efforts and associated studies have shown the potential for success of native oyster stock regeneration** and valuable information on the factors affecting success has been gathered that can inform initiatives in the UK. There is a great deal of other biological data on the species available to assist this process.
4. **There is provision within existing legislation to allow for the protection and management of restoration programmes**. Any provisions for conservation of habitats in the proposed new Marine Bill should include native oyster beds.
5. The major limits to restoration are disease, pests, lack of suitable substrate and limited broodstock numbers (critical mass).
6. **Areas free from diseases and major pests should be selected, in the first instance, for attempts at restoration**. Areas where residual concentrations of TBT remain at potentially harmful levels should be avoided.
7. **Stocking selected sites with strategically located broodstock is an effective strategy for oyster restoration and should form an important component of the overall process. The best options in economical terms to carry out a native oyster restoration program would be to either import half-grown native oysters from an area free of disease or encourage natural regeneration, following an initial seeding. Use of hatchery and pond-reared stock can also be cost effective.**
8. For enhancement with wild stock, either directly or through hatchery production of seed for enhancement, there should be sufficient disease-free broodstock available from existing Approved Zone areas in the UK. There is also the possibility of introducing stock from Approved Zones in Norway and Denmark. **A basic genetic similarity of wild European** *O. edulis* **populations means that the geographical source of stock is not critical** although it would be advisable to use stock that is physiologically adapted to the local conditions.
9. When rearing stock for replanting, there is a need to be fully aware of the functional value of conserving genetic variability. The question of genetic management of broodstock must be addressed and measures must be taken to avoid the danger of inbreeding.
10. Targeted hatchery-based selection programmes are not recommended as they represent too high a risk in respect of the probable success in relation to the costs. There are also inherent difficulties in the problems associated with the lack of a fully reliable method for rearing native oysters in the hatchery.
11. **Relaying considerable quantities of cultch to encourage settlement is an essential part of a native oyster stock restoration programme**.
12. The use of sanctuary areas, where broodstock will provide for recruitment over a larger area, should be considered for appropriate sites.
13. **Recovery to significant stock levels is likely to be slow even within or from established populations**. Stocks will probably need a lot of time to build up. A time frame of 25 years or more is not unrealistic.
14. **Management must go alongside restoration**. Management plans must involve all stakeholders in the area.

15. Some exploitation of restored stocks may be possible but this would need to be strictly controlled and set at a level that does not exceed biological production above an agreed level of stock that is needed to sustain a viable biotope.
16. Market forces are unlikely to drive restoration and funding will need to be identified. Costs could be supported by favourable results from a Contingent Valuation study for the UK, carried out to give an estimation of Willingness To Pay and so elicit the Total Economic Value of the programme.
17. Currently exploited native oyster stocks are predominantly in areas affected by diseases and major pests and here the feasibility of restoration is much less certain. Studies into the dynamics of oyster recruitment in these areas are needed before attempts at stock restoration on any significant scale can be made.
18. There is evidence to show that disease-resistant stocks can be developed, through techniques such as rearing from stressed survivors, kept at high density and, where available, using older and larger broodstock as these will be the hardier, more disease-resistant oysters.
19. Use of such disease-resistant oysters together with careful management can bring about an increase in currently exploited stocks and any initiatives along these lines should be encouraged as contributing to the overall maintenance of the species in its natural habitat.

CONCLUSIONS

Biological factors

1. The biology and ecology of *Ostrea edulis* has generally been well studied over many years and there is a considerable body of data available on the species to inform restoration projects.
2. Site selection criteria are known and it should be possible to predict growth performance at specific sites. Temperature is the major factor influencing performance of oyster stocks at different sites.
3. There is a lack of data on the importance of depth on oyster biology.
4. Information on sites where native oyster beds have existed historically is available from recent reports.
5. Fully saline areas would afford a degree of protection against the risk of introduction of *Marteilia refringens*, which favours reduced salinity.
6. Oyster larvae abundance in the water column can be measured and molecular tools are available to facilitate this. It must be recognised that this measurement will not necessarily be an indication of quality and success at spatfall.
7. Genetic mixing of populations through larval interchange, but more probably through human interventions during the last 2000 years, has maintained a basic genetic similarity of wild European *O. edulis* populations, although some minor differences can be detected by molecular techniques.
8. The continued introduction of hatchery oysters into wild populations over several years has inherent risks for the fitness of the populations, especially if the same broodstock are used repeatedly, and particularly if the broodstock is maintained without periodic replenishment of genome variability through the introduction of wild individuals.
9. The importance of genetic management of broodstock in aquaculture is frequently underestimated and the number of breeders used is frequently too small, resulting in inbreeding.
10. Genetic improvement programmes are ambitious and costly with no guarantee of a successful result.
11. For enhancement with wild stock, either directly or through hatchery production of seed for enhancement, there should be sufficient disease-free broodstock available from existing Approved Zone areas in the UK. There is also the possibility of introducing stock from Approved Zones in Norway and Denmark.
12. As a species *Ostrea edulis* is much less hardy than the Pacific oyster. Mortality is observed in the hatchery with some batches and this could inhibit any programme to breed for or from selected lines, as success cannot be guaranteed with all hatchery batches, so limiting the potential of this approach. It might be possible in the future to sequence these successful batches and perhaps identify what makes them so, in relation to French genetic studies of the oyster genome.
13. Disease is a major factor. *Bonamia* is probably the biggest biological factor limiting the potential for stock restoration. It is unlikely that affected areas will ever recover to previous population densities.
14. Disease resistance can be achieved by breeding from selected stock and has possibly arisen by natural selection at some sites. This has only been to an extent that will allow oysters to live for one or two years longer in the presence of disease. They will still succumb eventually.
15. For *Bonamia*, further studies on the life cycle of the parasite and the immune mechanisms of the host would assist in understanding the potential for developing strains of oysters resistant to this disease. The recent development of molecular probes for detecting the presence of the disease should allow for better progress into these aspects than has been achieved to date.

16. Global warming may increase the risk of Marteiliosis becoming introduced, particularly in the south of England.

17. Dominance of competitor species such as slipper limpets (*Crepidula fornicata*) following loss of the oyster population can prevent re-establishment, through changes to the environment and competition. This, together with introduced and native predators has probably inhibited recovery of natural populations.

18. There is also some evidence that the immunocompetence of native oysters is compromised in the vicinity of slipper limpets.

19. TBT has documented deleterious effects on native oysters to the extent that recovery of populations may be inhibited where residual levels are still relatively high.

20. Proposals might arise for introducing a non-native flat oyster species similar to *Ostrea edulis*, should one be identified, particularly if it was found to be resistant to disease.

21. The potential for restoration is compromised in areas affected by tingles. While these might be a manageable problem this would incur an additional cost.

22. Overall, for the biological considerations, prospects for restoration are better away from areas affected by pests and diseases except that these will tend to be the more northern sites where seawater temperatures are lower and so growth rates are slower and spawning is less frequent and reliable.

Technical requirements

23. The technical aspects of hatchery rearing of stocks to enhance natural populations follow standard procedures.

24. There are nevertheless some problems associated with the hatchery process and not all batches are successful.

25. There is no requirement to set hatchery-reared oysters onto cultch as there is no advantage of greater immunocompetence by this method.

26. A successful method of producing relatively large numbers of oysters in breeding ponds has been developed in Ireland. Oysters from this source exhibit some degree of resistance to *Bonamia*. It could provide a source of oysters for restocking in the UK, but only in areas affected by *Bonamia*.

27. There is no difference in immunocompetence between hatchery and wild stocks, so either would be suitable as a source of seed for restoration projects in this respect.

28. Year on year variations in the success of recruitment in wild populations make it difficult to predict spatfall from surveys of broodstock abundance. A similar lack of correlation is found with other species.

29. It has been shown that heavier dredges are detrimental to oyster beds, especially causing damage to spat.

30. There are significant risks associated with restoration of offshore beds where security will be less, monitoring and management will be more difficult and the sites may be subject to damage from fishing or periodic natural storm events.

31. Current knowledge suggests that there is the potential to increase production in areas affected by disease provided that stocks are maintained at low density on sub-tidal beds. If these stocks were left to increase by natural recruitment then the expectation would be that as density increased so would mortality. Some oysters would survive however and it is feasible that over a protracted period some natural resistance would develop but it is not known to what extent this would allow significant regeneration of stocks.

32. The habitat can be restored through relaying of cultch. Many studies view this as an essential component of a successful oyster restoration programme. Old oyster or scallop shell is the preferred type.

33. There is some evidence that there is a small risk of transferring disease with the relaying of cultch from affected areas.

34. There is adequate area available to increase existing exploited stocks. If grounds will support a modest production of 5 tonnes per hectare then an area of just 20,000 ha, would be needed to give a yield of 4,000 tonnes per annum. This is less than 3% of the areas already designated for oysters. It should however be noted in this calculation that not all areas are suitable and many are now occupied by other commercially valuable species, particularly mussels.

35. The use of sanctuaries is generally beneficial, particularly in disease-free areas.

36. Hydrographical information, particularly in respect of placing broodstock, as a nucleus for further recruitment, may be available. There is no central depository of such information and background data for regeneration plans would have to be sought from a variety of sources at local and national levels. Configuration and use of these models will probably require the allocation of significant resources.

37. Gravel dredging operations are perceived as potentially harmful to stocks although there are not any specific scientific studies to fully substantiate this.

38. Careful monitoring of oyster restoration projects is essential such that lessons learned in some areas can be applied in others. Various methods are available although this is expensive to do thoroughly.

Regulatory framework

39. There is a very strong element of re-creating and conserving an ecological resource in native oyster stock restoration, in order to re-establish a biotope that was once common and covered wide areas of the UK inshore seabed. Various reports have identified native oyster beds as a nationally important marine feature in decline and under threat of further significant decline. Where there is an environmental imperative to restore and sustain stocks this could be achieved in areas designated as such under existing conservation legislation.

40. Depending on the provisions, the proposed new Marine Bill could assist the potential for oyster stock restoration.

41. The regulatory framework exists for allowing for an increase in production of managed stocks of native oysters. The system of Several and Regulating Orders would allow for designation of new areas for oyster stock regeneration. In this situation the main driver would have be to for sustainable exploitation.

42. Conflicts of interest occur between some native oyster fisheries and other concerns such as the use of grounds for recreational activities. The increased demand for and value of moorings within these areas have contributed to an increase in their numbers and significant encroachment upon some fisheries with resultant damage. Other problems include poor water quality and those associated with illegal fishing practices.

43. It is apparent that dealing with conflicts of interest and other factors which reduce the effectiveness of any management strategies, will become increasingly important in any future conservation efforts for the native oyster.

44. It should be noted that a restored resource sustaining a fishery at the historical harvest level is unrealistic, because: (1) harvest probably exceeded biological production for much of the recorded history of exploitation; and (2) maximum production, a desired end for fishery support, occurs at approximately half the maximum (virgin, unexploited) biomass, and, thus, can only be achieved with disruption of the virgin complex community structure.

45. Control of disease to protect restored stocks is crucial. There are controls in place and the UK is well protected by Approved Zone status.

46. Disease controls (Molluscan Shellfish (Control of Deposit) Order 1974) in force at the time failed to prevent the introduction of *Bonamia* through the illegal movements of oysters and so there is potentially a risk of introduction of *Marteilia* through illegal movements of oysters that may be deliberate or accidental. There is the question of how well this could be controlled and prevented from spreading if it were to appear in the UK.

47. The re-introduction of Control of Deposit legislation might help to prevent further spread of pest species. Such legislation is highly unlikely but there could be voluntary controls for restoration sites.

48. Algal toxins are not an important issue. In fisheries, closures are not common for oysters and the animals themselves are rarely affected.

49. While there is a theoretical risk of accidental introduction of an alien species through, for example, transfers by shipping, this is considered a low risk, which should become less as new regulations designed to limit shipping mediated introductions come into force.

50. Native oysters are well protected from the effects of deliberate introductions of non-native species that might compete with or replace them by Conservation legislation and the ICES Code of Practice.

51. The various separate pieces of legislation on coastal water quality have led to improvements over the last few years that are set to continue, particularly under the Water Framework Directive.

Economic analysis

52. The Cost Benefit Analysis (CBA) considered the benefits and costs that can be measured through market transactions. In order to provide a complete a picture as possible, all the important benefits and costs including environmental benefits should be reasonably quantified. In order to provide an idea of what these benefits may mean this study provides figures of a similar restoration program conducted in the US, which shows that non-marketable costs and benefits can be estimated. Although results from the study in the US cannot be extrapolated to the UK they provide an idea of the high value that may be behind non-marketable goods (e.g. biodiversity, environmental services).

53. Nevertheless, this study shows that there are reasons for stock restoration on an economical basis if prices and yields are sufficiently high. Results of the CBA show that the best options in economical terms to carry out a native oyster restoration program would be to either import half-grown native oysters from an area free of disease or encourage natural regeneration. The latter option assumes priming a site where there are residual stocks of native oysters with seed in the first year. Maintenance and surveillance would then be carried out during the whole life of the project.

54. The profitability estimation derived from the CBA is highly dependent on native oyster market price and yield. The sensitivity analysis conducted shows that under low costs a stock restoration program would be “worth” if the methods of production are the use of half-grown native oysters or the introduction of native oyster seed in the wild, followed by natural regeneration, even if the price is as low as £1,000/tonne and the yield were 3 tonnes/ha. The same profitability would be obtained if the yield is as low as 2 tonnes/ha and the price is £1,500/tonne.

55. With regards to the direct and indirect impacts on the oyster sector and related sectors in the whole economy, a restoration program where restoration is successful at 10 sites will have a positive impact on the oyster sector by increasing native oyster production in 20 years time between 2,500-5,000 tonnes per year, which could imply between 150-300 people directly employed. The indirect effects on the fishery industry and the whole economy will not be

significant due to the small niche that the native oyster industry represents.

56. With the aim of achieving a better understanding and therefore more accurate results further research on the species dynamics in the UK is required.

57. There is the need to take into account finding markets if stocks and therefore landings increase. Export markets are a possibility.

58. Native oysters currently command a relatively low market price. Although they have niche acceptance in the UK they would need to have convenience and added-value components if they were to achieve a wider market. Given this situation it is very unlikely that market forces will drive restoration. If this were possible it would have happened already.

59. Currently the industry is focussed mainly on mussels and pacific oysters. The latter have shown some signs of spawning in the wild and if this were to continue and increase it could present a threat to native oyster restoration. Although the two species of oyster generally occupy separate habitats the industry has become more familiar with the Pacific oyster market.

Current status and attempts at restoration

60. Throughout much of the UK, the native oyster remains in a severely depleted state in the wild, having suffered for two centuries with over-exploitation, pests, disease, pollution and harsh winters.

61. The loss of the standing stock is a limiting factor to restoration in that there are insufficient broodstock available for replenishment of grounds. The habitat has also become degraded and is less suitable for recruitment.

62. There does now appear to be the start of a small recovery, with natural stocks being supplemented in some areas with spat settlement from farmed stocks and other oyster grounds being actively managed to ensure the conservation of stocks. In some cases there is no obvious explanation for any recovery but more favourable water temperatures may play a part.

63. Where there is recovery it is very small and experience from previous slight recoveries suggests that it is unlikely to persist without significant management intervention.

64. From surveys in Wales it has been concluded that native oysters form a flourishing part of the ecosystem, with many associated species.

65. Of sixteen “flagship” species and habitats investigated as potentially worthy of conservation, native oyster stocks are relatively stable and perceived to be much less at risk than thirteen other species and habitats.

66. Restoration efforts and associated studies in disease-free areas in Northern Ireland have shown the potential for success of native oyster stock regeneration and valuable information on the factors affecting success has been gathered that can inform initiatives elsewhere.

67. There is a considerable body of historical literature relevant to stock regeneration from studies carried out in Essex in the 1960s and 1970s.

68. In France the focus has been on genetic studies and in particular on developing a disease-resistant strain of native oysters. It appears that this approach has had only very limited success.

69. In Spain, a program to develop a *Bonamia ostreae* resistant strain has failed to produce any published results to date.

70. During the last decades there have been numerous attempts to increase the stock of native oyster in Spain, none of which have persisted long enough to produce tangible improvements.

71. Results from studies in Denmark indicate that recovery is likely to be slow even within or from established populations. Stocks will probably need a lot of time to build up. A time frame of

25 years or more is not unrealistic. At more northern sites the oysters may not spawn every year. Another factor here is the lack of suitable hard substrate for settlement, where the adult population has been removed, and especially where shell debris has also been removed.

72. In the Netherlands attempts to eradicate *Bonamia* have not been successful. Currently, although there is still considerable pathogenic pressure on the oyster population by *Bonamia*, the population seems to be coping and it seems possible that the oysters have developed some natural resistance over time.

73. In New Zealand, relaying considerable quantities of cultch to encourage settlement is seen as an essential part of a native oyster stock restoration programme.

74. There are valuable lessons to be learned from the practical experience of an extensive native oyster restoration programme in Chesapeake Bay. In particular:

- The primary goal for oyster restoration should be to restore and manage oyster populations for their ecological value. This should be done in such a way that a sustainable fishery could exist.
- Stocking strategically located broodstock reefs with hatchery-produced oysters can be an effective strategy for oyster restoration.
- Permanent reef sanctuaries permit the long-term growth and protection of large oysters that provide increased fecundity and may lead to development of disease resistant oysters.
- Transplantation of large wild-caught oysters is followed by greatly increased abundance of juvenile oysters throughout that river.
- All stakeholders, including the federal government, academia, environmental organizations and the oyster industry can and must work together to develop an effective Oyster Management Plan.
- Disease is a major limiting factor to oyster restoration projects. Recent advances in producing oyster strains that have some resistance to disease hold promise for the future. Nevertheless, exploitable stocks of adult oysters have been very slow to recover, due to losses through disease, and so restoration in affected areas will inevitably be a very long-term process.

RECOMMENDATIONS

1. The native oyster is a Biodiversity Action Plan Species and a significant driver for restoration of native oyster beds should be re-creating and conserving an ecological resource in order to re-establish a biotope that was once common and covered wide areas of the UK inshore seabed.
2. Any provisions for conservation of habitats in the proposed new Marine Bill should include native oysters beds, by establishing a system of marine spatial planning. A Marine Act should include provision for the designation and protection of Nationally Important Marine Sites so that locations where the native oyster occurs now or have occurred in the past can be protected from potentially damaging activities.
3. In the case of an oyster restoration project there are components in the benefits derived from it that cannot be estimated through market prices (i.e. benefits to the environment and society in general and the rural economy in particular). The study in the USA provides an idea of the high value that may be behind such non-marketable components, although this cannot easily be extrapolated to the UK. For this reason it would be useful to conduct a Contingent Valuation study for the UK. This would give an estimation of willingness to pay and so elicit the Total Economic Value of the programme.
4. While recovery of natural stocks has been noted in some areas, including those affected by disease, it is clear that real progress with restoration can only be made through an active programme. Restoration efforts and associated studies elsewhere have shown the potential for success of such an approach and the valuable information available from these studies should be consulted.
5. Restoration of offshore beds where security will be less, monitoring and management will be more difficult and the sites may be subject to damage from legitimate fishing activities or periodic natural storm events should not be attempted.
6. Careful consideration needs to be made of security of inshore restoration sites, to prevent accidental damage or deliberate poaching of stock.
7. Disease and, to a certain extent, pests, particularly slipper limpets, are major barriers to native oyster stock restoration and areas free from these should be selected, in the first instance, for attempts at restoration. Areas where residual concentrations of TBT remain at potentially harmful levels should be avoided.
8. Stocking selected sites with strategically located broodstock by using pond or hatchery-produced oysters or half-grown stocks is an effective strategy for oyster restoration and should form an important component of the overall process.
9. While legislation will only allow stocks from disease-free areas there should also be a presumption against introducing pest species, where these are absent.
10. Selection of broodstock should be an important consideration when rearing stock for replanting. It may be advantageous to rear from stock from stressed survivors, kept at high density, to simulate reef conditions. Where available, older and larger broodstock oysters should be used, as these will be the hardier, more disease-resistant oysters. It is recognised that such stock may not currently exist, having been fished out long ago.
11. In addition to the above, broodstock from a similar physical environment should be used to allow for the fact that these oysters may be physiologically adapted to the local conditions. For example, oysters of a more northern origin may be adapted to spawn at lower temperatures.
12. Cultchless oysters should be the stock of choice in hatcheries and controlled outdoor rearing ponds with low velocity bottom flows.
13. Further work is necessary to determine if attachment to cultch confers any benefits in coastal waters, where bottom currents are sufficient to re-suspend spat, especially if not attached to a piece of heavier material.

14. The availability of background data on water movements should be investigated with a view to modelling larval distribution and thus strategic placement of introduced broodstock or re-location of local stock.

15. There is a need to be fully aware of the functional value of conserving genetic variability. The question of genetic management of broodstock must be addressed and measures must be taken to avoid the danger of inbreeding. Management policies that favour supportive breeding for replenishment of exhausted oyster beds should be planned carefully and must maintain pedigree records to avoid crossing even distantly related lines, and monitor donor (hatchery) and recipient (wild) populations to avoid damage to genetic resources. At least 50 per lot, and preferably 100, broodstock should be used to produce *O. edulis* larvae, in order to maintain genetic diversity.

16. Targeted hatchery-based selection programmes are not recommended as they represent too high a risk in respect of the probable success in relation to the costs. There are also inherent difficulties in the problems associated with the lack of a fully reliable method for rearing native oysters in the hatchery.

17. Some consideration should be given to establishing oyster breeding ponds in a disease free area as a source of seed for restocking in similar areas.

18. The habitat should be restored through relaying of cultch. Some care should be taken in selection of the source of shell for cultch in order to eliminate the risk of transferring disease. Ideally it should come from disease-free areas otherwise it is recommended that it be stored in air for at least one month prior to use.

19. Management must go alongside restoration. Management plans must involve all stakeholders in the area.

20. Management measures should ensure the return of larger, and therefore older and presumably hardier oysters so that these will remain as brood stock. These oysters will then also produce more larvae.

21. Exploitation of restored stocks must be strictly controlled and set at a level that does not exceed biological production above an agreed level of stock that is needed to sustain a viable biotope.

22. The use of sanctuary areas, where broodstock will provide for recruitment over a larger area, should be considered for appropriate sites.

23. Studies into the dynamics of oyster recruitment in areas affected by *Bonamia* are needed before attempts at stock restoration on any significant scale can be made in these areas.

24. Current initiatives to increase stocks in areas affected by disease, such as development of disease-resistant strains, should be encouraged to continue.

25. For *Bonamia*, further studies on the life cycle of the parasite and the immune mechanisms of the host would assist in understanding the potential for developing strains of oysters resistant to this disease.

26. There should be a presumption against deliberately introducing an alternative non-native species, to prevent it becoming established and replacing *Ostrea edulis*, as supported by the current legislative framework.

INTRODUCTION

Compared to the late 1800s stocks of the native oyster in UK waters are at a very low level. In order to address and potentially to reverse this situation the native oyster was designated as a named species in the UK Biodiversity Action Plan, which is part of a national commitment to the International Convention on Biodiversity. The action plan is reproduced as Appendix A.

A steering group was formed to agree and progress the objectives of the Native Oyster Species Action Plan (NOSAP). The lead agency for this is the Shellfish Association of Great Britain.

The two objectives in the Action Plan relevant to this report are:

- Expand the existing geographical distribution of the native oyster within UK inshore waters, where biologically feasible.
- Increase the abundance of the native oyster within UK inshore waters, where biologically feasible.

To address these points, a feasibility study has been carried out to evaluate all the factors, including an economic assessment, relative to achieving these objectives.

There is a considerable body of literature on the biology of the native oyster (*Ostrea edulis*), accumulated over many years. Some of the early studies, relevant to the cultivation of this species, were carried out by CEFAS (then MAFF) at the Conwy laboratory. Lack of consistent success with the commercial rearing of this species, compounded by the introduction and spread of the disease Bonamiasis into the major oyster growing areas in England has led to oyster production in the UK concentrating on the Pacific oyster (*Crassostrea gigas*). Consequently, there are fewer recent studies of relevance. Nevertheless, the native oyster remains a valuable commodity and exploitation of managed wild stocks has continued. These stocks, particularly the main ones in the Solent Fishery Order areas, have been surveyed regularly by CEFAS. The prevalence of disease and, in particular, the status of Bonamiasis in both wild and cultivated stocks is also kept under constant review through monitoring and testing carried out by CEFAS. Data from both these programmes are considered in this report.

Economic modelling, developed by Seafish, has been applied to cultivation of native oysters, as an aid to farmers. Much less information is available on the potential costs and benefits of stock restoration programmes at various scales.

The Cost-Benefit Analysis is based on market and research literature information. Market information serves to estimate the benefits and costs derived from practical uses of the programme (i.e. use value) whereas by doing a literature review on research of estimation of non-use values for similar programmes (i.e. benefit transfer) social benefits and costs will be assessed.

The dramatic reduction in native oyster stock abundance seen in the middle of the nineteenth century is attributed mainly to over-exploitation and this was also the experience in other European countries with *Ostrea edulis* fisheries. The species is rapidly fished out because it is relatively long-lived and reproduces sporadically. The demise of flat oyster fisheries around the British Isles was not caused solely by over-fishing pressure. The decline in many former fisheries was due in part to a series of unusually cold winters in the 1930s and 1940s, which resulted in severe oyster mortalities, especially on North Sea coasts. Declining water quality due to municipal and industrial pollution also had a detrimental impact on oyster stocks. The introduction of exotic pests created additional problems in many oyster-producing regions. The slipper limpet (*Crepidula fornicata*) was particularly harmful on oyster grounds on the East Coast of England, the invader competing voraciously with the indigenous oysters for space and planktonic food.

Native oyster beds form a biotope, with many associated epifaunal and infaunal species. Loss of this habitat has therefore resulted in a major decline in species richness in the coastal environment.

A report on the current status of native oyster stocks in the UK was commissioned under the NOSAP programme (Gardner and Elliott, 2002), and further surveys have been undertaken in Wales and Scotland. The results from these are analysed within this study. Other recent initiatives being carried out in support of NOSAP objectives have also been considered.

Various attempts have been made in other countries to restore or regenerate *Ostrea edulis* stocks where this oyster is native and where in the past it has supported an important fishery. This experience is also considered in this study. Also relevant are the attempts elsewhere to restore stocks of the local native oyster species where the constraints (e.g. disease) are similar. An example is the restoration programme for *Crassostrea virginica* in Chesapeake Bay.

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SECTION 1 - BIOLOGICAL CONSIDERATIONS

1.1. Introduction

There is a considerable body of literature on the biology of the native oyster (*Ostrea edulis*), accumulated over many years. It is not the purpose of this report to repeat the detailed information on the various aspects of the biology, ecology and life cycle that are well described in various scientific journals and many standard texts (see, for example, Gosling, 2003). Summary data on the species is also available on-line (Tyler-Walters, 2001; Jackson, 2003) or in electronic media format (Seafish, 2002). However, consideration needs to be given to the biological factors relevant to the feasibility of successful stock regeneration and a brief description of the oyster life cycle is outlined below.

Native oysters are described as protandrous alternating hermaphrodites. This means that when they reach maturity, the adults function first as a male and then they go into alternate cycles of female and male stages for the rest of their life. The number of cycles each year depends on the length of the breeding season, so in the UK native oysters may spawn twice during the summer, once as a male and once as a female. A minimum water temperature of 16°C is required before they spawn. The males release sperm into the surrounding seawater, which is taken in through the inhalant siphon of the female. The eggs produced by the female are fertilised inside the parent's shell and the larvae are brooded within the mantle cavity until they have a fully formed shell (at around 0.170 mm). This usually takes about 10 days. The parent oyster releases the larvae into the seawater where they drift in the plankton and feed on natural phytoplankton. The number of larvae released is related to the size (and age) of the parent oyster (see Table 1.1., after Walne, 1974).

Table 1.1. Fertility (number of larvae) of native oysters in relation to approximate age and size

Age (years)	Mean shell diameter (mm)	Number of larvae
1	40	100,000
2	60	540,000
3	70	840,000
4	80	1,100,000
7	90	1,500,000

After 2 to 3 weeks, depending on local environmental conditions, the larvae are mature and they develop a foot. At this stage, they are called pediveligers. They sink to the seabed and explore the sediment surface with their foot until they find a suitable surface on which to settle and attach permanently, by cementation. Next, they go through a series of morphological and physiological changes, a process known as metamorphosis (which takes 3 to 4 days), to become 'immature' adults. These are called juveniles, spat or seed.

Growth is quite rapid for the first year and a half. It then remains constant at around 20 grams (fresh or live weight) per year before slowing down after five years. Oysters can take 4 to 5 years to reach a marketable size, depending on local environmental conditions, particularly temperature.

1.2. Site selection

1.2.1. Introduction

While efforts in other areas, such as developing disease-tolerant brood stock (see below) may contribute to restoration efforts, suitable site selection in restoration is absolutely crucial to success.

A range of physical, biological and chemical factors will influence survival and growth of oysters, including substrate type, sea water temperature and salinity, water turbidity, flow rate and nutrient content and exposure to air and wind. Other factors, which may also be site-specific, such as pollutants, pests, predators and competitors are dealt with separately later in this Section. Many of these factors are subject to seasonal and annual variation.

For cultivation of this species, prospective farmers are usually advised to monitor the conditions at their prospective site for at least a year before any commercial culture begins and carry out a pilot study to see how well oysters grow and survive.

Ostrea edulis has a large geographic range so it can be seen as an adaptable species, although this adaptation will have taken a considerable period of time, leading to physiological races, possibly with small but significant genetic differences.

1.2.2. Substrate and depth

The native oyster may inhabit the lower inter-tidal area of the foreshore but is more usually found in the sub-littoral zone where it is associated with highly productive estuarine and shallow coastal water habitats, most commonly in depths down to 30 m. Inter-tidal populations are less common probably due to competition and predation. Oysters can also be found at greater depths, of up to 80 m but there is very little information to show if there is a preferred depth. Lama and Montes (1993) found that mortality from *Bonamia* was greater in oysters suspended at 8-9 m than at 1-2 m although Diaz *et al*., (2001) found no difference in growth performance of oysters suspended at different depths. Native oysters occur on a range of firm bottom substrates, including mud, rocks, muddy sand, muddy gravel with shells and hard silt.

1.2.3. Temperature

Temperature is the most important factor limiting growth rate. In the UK, oysters start to grow in the spring when sea water temperatures reach 8-9°C. Growth rate reaches a maximum in July or August when temperatures peak (usually 16-18°C) and then falls off again as the temperature drops to below 8-9°C in November or December. Native oysters are tolerant of higher temperatures. As they occur from the Mediterranean to the Norwegian coast they are unlikely to be adversely affected by long-term changes in temperatures in Britain and Ireland. However, Spärck (1951) has suggested that temperature is an important factor in recruitment of *Ostrea edulis*, especially at the northern extremes of its range with warm summers resulting in good recruitment. Spawning is initiated once the temperature has risen to 15-16°C, although local adaptation is likely. Larvae will grow faster with increasing temperature and that should reduce the time in the pelagic phase, provided sufficient food is available, and thus increase survival. Therefore, recruitment and the long-term survival of an oyster bed may benefit from both short and long term increases in temperature.

Hutchinson & Hawkins (1992) suggested that native oysters switched to a reduced, winter metabolic state below 10°C that enabled it to survive low temperatures and low salinities encountered in shallow coastal waters around Britain. Korringa (1952) reported that British, Dutch and Danish oysters could withstand 1.5°C for several weeks. However, oysters will die in very cold winters if exposed to chill winds and air temperatures close to freezing. Heavy mortalities of native oysters were reported after the severe winters of 1939/40 and 1962/63.

1.2.4. Salinity

Oyster stocks extend into estuaries, where they can tolerate salinities down to around 23 psu, although *Ostrea edulis* has a preference for more fully saline conditions (> 30 parts per thousand). However, Hutchinson & Hawkins (1992) showed that 19 -16 psu could be tolerated if the temperature did not exceed 20°C. They noted that at low temperatures (10°C or less) the metabolic rate was minimal, which would help *Ostrea edulis* survive in the low salinities associated with storm runoff in the winter months. Low salinity may result in marked mortality if in combination with high temperature. For example, no oysters survived more than 7 days at 16 psu and 25°C; although these combined conditions rarely occurred in nature.

1.2.5. Exposure

When exposed to the air, during the tidal cycle, oysters close tightly to prevent desiccation of the internal tissues. They can respire anaerobically (i.e. without oxygen) when out of water but have to expel toxic metabolites when re-immersed as the tide comes in. They are known to be able to survive for long periods out of water at low temperatures such as those used for storage after collection, but growth will cease when animals are emersed for more than 35% of the time.

1.2.6. Turbidity

Yonge (1960) considered *Ostrea edulis* to be intolerant of turbid (silt laden) environments. However, oyster beds are found in relatively turbid estuarine environments. Oysters respond to an increase in suspended sediment by increasing pseudofaeces production with occasional rapid closure of their valves to expel accumulated silt, both of which exert an energetic cost. Korringa (1952) and Hutchinson & Hawkins (1992) both reported that an increase in suspended sediment decreased the filtration rate in oysters. Suspended sediment was also shown to reduce the growth rate of adult *Ostrea edulis* and to result in some shell thickening (Moore, 1977). Reduced growth probably results from increased shell deposition and an inability to feed efficiently. Nevertheless, short periods where the suspended sediment level is relatively high will probably result in only sub-lethal effects.

While the normal functioning of oysters is not seriously upset in the presence of occasional elevated loads of suspended sediment in the water they will be sensitive to smothering. Yonge (1960) reported death of populations of *Ostrea edulis* due to smothering of oyster beds by sediment and debris from the land as a result of flooding. Moore (1977) reported that variation in suspended sediment and silted substratum and resultant scour was an important factor restricting oyster spatfall. Therefore, an increase in suspended sediment may have longer-term effects of the population by inhibiting recruitment, especially if the increase coincided with the peak settlement period in summer. A layer of settled material of 1-2 mm in depth will prevent satisfactory oyster settlement. Sites where there are tidal current flows of 1–2 knots (50-100 cm sec^{-1}) will help to prevent these problems. A flow of water should also help to ensure a continuous supply of fresh phytoplankton food cells to the animals. More exposed sites are not generally suitable for oysters as the animals may be swept away by strong tidal flow and a proportion of the oyster bed may be lost.

1.2.7. Nutrients and algae blooms

Moderate nutrient enrichment, especially in the form of organic particulates and dissolved organic material, is likely to promote primary production and therefore increase food availability for all suspension feeders, including oysters.

However, long term or high levels of organic enrichment may result in eutrophication and have indirect adverse effects, such as increased turbidity, increased suspended sediment, increased risk of de-oxygenation through microbial activity and the risk of algal blooms. The subsequent decline of these algal blooms may result in large numbers of dead algal cells collecting on the sea bottom, resulting in local de-oxygenation as the algal decompose, especially in sheltered areas with little water movement where native oysters are most likely to be found. However, *Ostrea edulis* may be relatively tolerant of low oxygen concentrations, although other species within the community may be more intolerant.

In the presence of algae species that produce toxins harmful to human health (ASP, DSP, PSP) oysters tend, in general, to accumulate lower concentrations of these toxins than, for example, mussels, when simultaneously exposed to toxic algae blooms. There is also some indication that oysters can rid themselves of the toxins more quickly than many other species of molluscs (Shumway, *et al.*, 1990). Other species of algae may be toxic to the shellfish themselves. There is little evidence for *Ostrea edulis* being affected to any great degree although certain species e.g. blooms of *Gonyaulax* sp. and *Gymnodinium* sp. have been reported to cause physiological effects and some mortality (Shumway, 1990).

1.3. Genetics

1.3.1. Introduction

Analysis of genetic diversity within and between populations of *O. edulis* can assist with two aspects of stock regeneration:

1. Identifying whether or not there exists any natural genetic diversity between stocks, which may confer the unique local characteristics of a stock that allow it to thrive in a particular environment.
2. To guard against the loss of genetic diversity, through inbreeding in hatchery stocks used for restoration programmes.

Analyses of genetic variations in enzymes (allozymes) and, more recently, at the DNA level (microsatellites) has provided scientists/managers with the tools to address both these aspects.

1.3.2. Genetic diversity amongst wild populations

Populations of *O. edulis* have lower levels of genetic variation than other oyster species (Saavedra *et al.*, 1993). A lack of extensive genetic variation is to be expected for this species, since a prolonged planktonic larval phase of 10 to 14 days facilitates dispersal over large distances and extended gene flow. In addition, however, the restocking of heavily exploited Atlantic oyster beds during the last century with oysters of non-native origin has probably resulted in a high degree of mixing of natural oyster stocks from throughout Atlantic Europe, and reduced the original levels of geographic differentiation (Saavedra *et al.*, 1993). This is supported by evidence from the relatively limited number of studies of inter-population genetic variation, although variation is greater between populations from Atlantic and Mediterranean waters.

Saavedra *et al.*, (1993) detected only slight genetic differentiation of allozyme loci among populations of *O. edulis* from the Atlantic and Mediterranean coasts of Europe, although increased differentiation was apparent from NW Spain to the Mediterranean. The authors suggested that the unidirectional marine surface circulation southwards along the Iberian Peninsula and into the Mediterranean probably acts as a barrier to gene flow outwards from the Mediterranean: alleles originating in the Mediterranean are prevented from spreading to the Atlantic populations, while those of Atlantic origin spread readily into the Mediterranean. Furthermore, Lucic (1999) reported that levels of microsatellite variation amongst *O. edulis* populations along the eastern coast of the Adriatic Sea are higher than those among populations from the Mediterranean and Atlantic coasts.

Scandinavian oyster populations are somewhat different to populations from Spain, France, Ireland and Maine, USA (originating from the Netherlands) but this is mainly due to the loss of genetic variation in the former, suggesting a fairly close relationship between the Scandinavian and European Atlantic populations, with the former being more inbred (Johannesson *et al.*, 1989). At the most northerly range of *O. edulis*, in Norwegian and Swedish waters, low summer water temperatures prevent breeding in most years (Rodstrom, pers. comm. cited in Johannesson *et al.*, 1989). Population bottlenecks in this area are likely to be followed by a prolonged recovery phase, and therefore, there are likely to have been substantial losses of genetic variation during periods of low population numbers, as indicated by relatively low levels of intra-population variability (Johannesson *et al*., 1989; Saavedra *et al*., 1995). Rödström (1989) however did find some small genetic differences between Swedish and Norwegian stocks and also some physiological differences. For example, Swedish oysters showed relatively higher activity under low temperature and salinity conditions.

More recently, a study by Beaumont and Sobolewska (2002) to examine genetic variability and population structuring at the DNA level using microsatellite loci (Sobolewska *et al*., 2001) showed that there was little difference between nine stocks of oysters sampled from a wide area, including France, Scotland and Ireland (North and South). The microsatellite data therefore reinforce the story provided by earlier genetic studies that there has been considerable gene flow between most northern European populations of *O. edulis*. Genetic mixing of populations through larval interchange, but more probably through human interventions during the last 2000 years, has maintained a basic genetic similarity of European *O. edulis* populations. This study also found that the Norwegian population was distinct from the others examined. There has probably been much less exchange with stocks here. Results from enquiries made in Norway suggest that there have probably not been introductions of flat oysters into Norway since 1934, with the exception of a single introduction to one site in 1964 and a possible illegal introduction of post-larvae in 1999.

Growth rates of *O. edulis* seed from broodstock from geographically different source populations produced in an Orkney hatchery transplanted to various grow-out sites grew at rates that were specific to the on-growing site, with no differences between the stocks. It appeared that temperature was the main factor influencing oyster growth in these trials (Beaumont and Gowland, 2002).

1.3.3. Genetic diversity within hatchery stocks

Saavedra *et al*., (1993) detected deficiencies of heterozygote allozymes genotypes in several *O. edulis* populations along the Atlantic and Mediterranean coasts of Europe. The lower levels of genetic variation within populations of *O. edulis* compared to other oyster species may be related, in part, to its brooding habit as fecundation occurs inside the pallial cavity, which favours mating between nearest-neighbours, and larvae are brooded for eight to 10 days before becoming planktonic (Saavedra *et al*., 1993, and references therein). However, reduced variability may also be as a consequence of supportive breeding programmes using hatchery-origin broodstock.

Genetic drift is likely to be stronger within hatchery populations, as they are characterised by relatively small numbers of spawners (relative to the wild), and this will lead to a reduction in genetic variability, and an increase of inbreeding in successive generations (Saavedra, 1997). Genetic variability exists amongst wild populations of *O. edulis* for economically important traits such as growth rates and resistance to parasites (Newkirk & Haley, 1983; Naciri, 1994), but could be diminished or even lost within restricted hatchery broodstock populations. Relatively high rates of inbreeding result in a relatively low effective population sizes (N_e: the theoretical minimum number of individuals required to produce the genomic variation evident in the next generation). Saavedra (1997) reported a value for N_e for a wild population of *O. edulis* (248) that was much lower than the estimated number of adults in the population (~10 000), and that the N_e for hatchery populations were even lower. Saavedra and Guerra (1996) found that although a study population was obtained from a mass-spawning of 120 oysters, analysis of the genetic structure suggested the N_e of the founder population was an order of magnitude smaller, and perhaps as low as 3.5. Low N_e could result in inbreeding depression, as indicated by significant reductions in yield and individual growth rate at harvest in Pacific oysters (*Crassostrea gigas*) after two generations of crossing between 1st cousins, and significant depression in survival after crossings between siblings (Evans *et al*., 2004). The authors reported linear relationships between relatedness and the reduced body weight and survival, and suggested that a 10% increase in relatedness would result in an 8.8% reduction in average body weight and a 4.26% decrease in survival.

Saavedra (1997) also reported that hatchery populations of *O. edulis* showed a marked decrease in heterozygosity. The existence of a positive correlation between the number of allozyme loci for which an individual is heterozygous and quantitative traits related to fitness has been demonstrated in many species of organisms including several species of oysters, mussels, scallops and clams (see citations in Saavedra & Guerra, 1996).

Two allozyme loci, AP-2 and ARK, showed a relative increase of heterozygotes with age, resulting in heterozygote advantage in viability on *O. edulis* (Saavedra & Guerra, 1996) and microsatellite analyses indicated a strong selection during the larval stage, and through settlement, with a mortality differential, expressed as the percentage of homozygotes dying for genetic reasons, of the order of 25-50%, indicating that heterozygotes may have an advantage in larval life (Bierne *et al*., 1998). Furthermore, significant positive microsatellite heterozygosity-growth correlations were recorded for full-sib *O. edulis* crossings (Bierne *et al*., 1998) and a positive correlation between growth rate and multilocus allozyme heterozygosity was detected in 18 month and 30 month old *O. edulis*, the heterozygosity explaining about 2% of the variability in growth rate among individuals (Alvarez *et al*., 1989).

In contrast to the above, Alvarez *et al*., (1989) reported a strong negative correlation between heterozygosity and viability: 57% of individuals died at between ages 18 and 30 months old. However, they suggested this might be due to a positive association between weight and infestation by the haemolymph parasite *Bonamia ostreae*, since mortality was greatest amongst the heavier oysters, which appear most susceptible to infestation. Similarly, the lack of significant correlations between the number of heterozygous loci per individual and viability or growth rate of a hatchery population of *O. edulis*, was probably related to a founder effect, since the N_e was perhaps as low as 3.5 (Saavedra & Guerra, 1996). The authors suggested, therefore, that *O. edulis* is relatively sensitive to founder effects, perhaps because the life cycle favours fecundation by near neighbours, and proterandric hermaphroditism which may deviate the sex ratio towards an excess of males, and that hatchery operators should make efforts to increase the number of spawnings used to obtain and maintain a population.

Where hatchery-reared oysters are used to seed wild beds that have been overexploited, individuals of hatchery origin may contribute disproportionately to the genome of the mixed population, and assuming that the wild population had a larger effective size than the hatchery stock, the consequence for the mixed population could be a reduction in N_e (Saavedra, 1997). Based on the wild and hatchery reared populations studied, Saavedra (1997) estimated that N_e could be reduced by 80% and inbreeding increased fivefold within one generation of supportive breeding.

Inbreeding of stocks is clearly to be avoided. It is suspected of weakening the immune system, rendering animals more susceptible to infection. Results from studies with fruit flies (Spielman *et al*., 2004) imply that some genetically depleted species risk being trapped in a downward spiral of inbreeding: inbred animals would succumb more frequently to infection, leaving fewer individuals with which to breed, leading to even more inbred and susceptible animals and so on. Recent studies with a stock of scallops originating from a small initial introduction and kept in culture in China for over 20 years has shown that they have a very low heritability and did not respond to selection for growth rate.

Supportive breeding often results in a trade-off between economic gain and loss of genetic variability (Ryman, 1991). While increased production usually supersedes concerns about the loss of genetic diversity, the continued introduction of hatchery oysters into wild populations over several years has inherent risks for the fitness of the populations, especially if the same broodstock are used repeatedly (Saavedra, 1997), and particularly if the broodstock is maintained without periodic replenishment of genome variability through the introduction of wild individuals. Therefore, management policies that favour supportive breeding for replenishment of exhausted oyster beds should be planned carefully and must maintain pedigree records to avoid crossing even distantly related lines (Evans *et al*., 2004), and monitor donor (hatchery) and recipient (wild) populations to avoid damage to genetic resources (Saavedra, 1997). To this end, Vercaemer *et al*., (2003) noted that the genetic diversity and heterozygosity of native oyster stocks in Nova Scotia were still relatively high, after 30 years in cultivation and recommended that at least 50 per lot, and preferably 100, broodstock are used to produce *O. edulis* larvae in hatcheries, in order to maintain genetic diversity.

1.4. Disease

1.4.1. Bonamiasis

This is the one major disease of significance present in oyster stocks in the UK. Where present, it is perhaps the most important factor limiting production in the managed wild and cultivated stocks of native oysters in the UK. It has had a significant negative impact on *O. edulis* production throughout its distribution range in Europe. Mortality rates in excess of 80% have been noted. The effect this can have on yields can be seen in the drastic (93%) drop in recorded production in France, from 20,000 t per year in the early 1970's to 1,400 t in 1982 (FAO data).

In the UK, the prevalence of this disease is relatively low (less than 1%) in the native oyster stocks in the Solent. This allows a small cultivation industry to survive in the Essex creeks and estuaries of relaying part-grown oysters taken from this fishery for growing on to market size in a single growing season. The measured prevalence of *Bonamia* reaches typically 10-20% in these oysters in this time, with usually relatively low levels of mortality. Experience from studies in Spain (Cigarria *et al*., 1995) suggest that holding the oysters into another year gives very little additional growth as mortality increases to 75-90%.

The disease is caused by the parasitic organism *Bonamia ostreae*. It was first recognised in Europe in Brittany in 1979 and first diagnosed in England in October 1982, following an investigation into an unexplained mortality in the creeks of the rivers Fal and Helford in Cornwall (Bucke and Feist, 1985).

The disease spread through movement of infected stock and it now occurs in most of the major oyster producing areas of the south and east coast of England. Restrictions on movements of infected oysters (see Section 3.4.2) help to prevent this disease spreading further and regular sampling and testing are undertaken to confirm that these controls are effective. Bonamiasis remains absent in Scotland, Wales and Northern Ireland.

In the rest of Europe, Bonamiasis is known to be also present in parts of France, Spain, The Netherlands and Ireland. Norway and Denmark have areas that are declared free of this disease (2005/104/EC - Commission Decision of 3 February 2005 amending Decision 2002/300/EC establishing the list of approved zones with regard to *Bonamia ostreae* and/or *Marteilia refringens*).

Bonamiasis has attracted a lot of attention from the scientific community. Around 1 in 5 of the almost 600 papers and reports on *Ostrea edulis* published in the last 20 years have dealt with some aspect of it. However, we currently still know very little about the biology and life cycle, including mode of infection, of *Bonamia ostreae*. Studies have shown that direct transmission of the parasite can occur from oyster to oyster (Culloty *et al*., 1999) and there is some evidence to suggest that entry of the parasite may be initially through the gills (Montes *et al*., 1994). Van Banning (1990) suggested a presumptive life cycle in which an infectious phase might be involved in the ovarian tissue of *O. edulis*. However, the possibility of other life cycle stages such as a spore stage or an intermediate or secondary host being involved cannot, at present, be discounted. To date, a spore stage has not been observed in infected oysters and no secondary hosts have been identified.

Further studies on the life cycle of the parasite and the immune mechanisms of the host would assist in understanding the potential for developing strains of oysters resistant to this disease. The recent development of molecular probes for detecting the presence of the disease (Carnegie *et al*., 2000; Cohennec *et al*., 2000) would allow further progress into these aspects. These methods can give a more rapid assessment compared with the traditional histological techniques although there is still the problem that animals have to be sacrificed for individual assessment of infection.

Infected oysters can appear normal, although others may have yellow discolouration and/or extensive lesions in the connective tissues of the gills, mantle and digestive gland. Actual pathology appears correlated to haemocyte destruction and diapedesis (the passage of blood cells into surrounding body tissue) due to proliferation of B. *ostreae* (Balouet *et al*., 1983). Infection was demonstrated to result in the increase in the number of tissue infiltrating haemocytes (Cochennec-Laureau *et al*., 2003). Although some flat oysters die with light infections, others succumb only under much heavier infections.

Culloty and Mulchy (1996) found that the critical age for disease development in *O. edulis* in the Bay of Arcachon, France and on the south coast of Ireland was two years, although later experience has shown that juvenile oysters can become infected only a few months after planting out (Hoare, 2004). There is a well documented link between stress and susceptibility to disease (see below) and in the above case it is assumed that *Bonamia* developed under the very stressful conditions of containment of the oysters in bags and a sudden rise in temperature and caused high mortality even in these small (less than 5 cm shell height) oysters.

Studies at Southampton University have shown that there is a link between disease susceptibility and physiological stress caused by handling and overcrowding. Results from experimental trials in an area affected by *Bonamia* showed that at low density the cellular defence mechanisms of the oysters was able to cope with an acute pathogen challenge without difficulty but this capability was diminished by increasing stock densities, and by bag culture combined with tidal exposure (Hawkins *et al*., 2000).

Attempts at control and eradication of Bonamiasis have been largely unsuccessful. Nevertheless, experience from various research investigations has led to a number of modified husbandry techniques that have been successfully employed to minimise disease effects and allow the animals to grow to market size before mortalities have become unsustainable (see Appendix B).

1.4.2. Marteiliosis

The only other serious disease affecting native oysters in Europe is Marteiliosis, as caused by the paramyxean parasite *Marteilia refringens*. This brings about serious recurring mortalities with a significant negative impact on the local industry. For example, it has been associated with the dramatic decrease in *O. edulis* production from the Gulf of Thermailos in northern Greece between 1994 and 1998. Infection causes a poor condition index with glycogen loss (emaciation), discolouration of the digestive gland, cessation of growth, tissue necrosis, and mortalities. However, *Marteilia* can occur in some oysters without causing disease. The factors triggering a pathogenic host response are not clearly established, but may be related to environmental stresses or stock differences in disease resistance. Mortality appears to be related to sporulation of the parasite, which occurs in the epithelial cells of the digestive tubules.

There is no evidence for direct horizontal transmission of *M. refringens*, rather intermediate or alternate host or hosts appear to be essential in the life cycle of this parasite. Recent developments in the DNA-based diagnosis of *M. refringens* make it possible to detect the parasite in other hosts. However, the large number of other species living in the vicinity of oyster beds hampers any screening programme. However, attempts to identify these alternative hosts have identified the copepod *Paracartia* (*Acartia*) *grani* (Audemard, 2002). Not only was DNA of *M. refringens* consistently detected in this copepod but the presence of the parasite in the ovarian tissues was also demonstrated, using a technique known as In-Situ Hybridisation. Finally, successful experimental transmissions provided evidence that *P. grani* can be infected from diseased flat oysters.

Marteiliosis does not occur in the UK and controls associated with Approved Zone status for this disease (see Section 3.4.2) are designed to prevent it being introduced. It favours reduced salinity and it is of interest to note that a closely related species, *Marteilia maurini*, has recently been identified in mussels near the docks in Southampton Water. It is not clear if this is endemic or has arrived as a shipping associated introduction, for example in ships' ballast water. Marteiliosis was not detected in samples of native oysters from a nearby bed and *M. maurini* does not affect native oysters.

The appearance of these diseases in Europe and the serious affect that they had on native oyster fisheries prompted some initiatives to introduce similar flat oyster species as replacements for native oysters. Trials were carried out with the New Zealand dredge oyster (*Tiostrea lutaria*) in the UK and with flat oysters of the same species but from Chile and another species from Argentina (*Ostrea puelchana*) in France. All of these species proved to be susceptible to these diseases but had they not been we might well have seen the demise of *Ostrea edulis* in many areas, as they were supplanted by these alien species.

1.4.3. Other diseases

There are other diseases not present in Europe to which *Ostrea edulis* is susceptible. Of these, Denman Island Disease, caused by *Mikrocytos mackini*, is of greatest concern. This disease affects and can be transmitted by the Pacific oyster (*Crassostrea gigas*), a species that is widely cultivated in the UK. Current import controls protect against introducing *C. gigas* from areas where this disease is found but as it has only a relatively minor effect on these oysters there are proposals to relax the controls that prevent movements of infected stock. There is strong circumstantial evidence that commercial stocks of another ostreid species, *Ostrea concaphila*, in British Columbia became drastically reduced through infection with *M. mackini* from Pacific oysters introduced for cultivation.

1.5. Resistance to disease

Some early studies on the susceptibility of native oysters from different geographical sources to Bonamiasis were carried out in Cornwall, where the disease was first identified in the UK. Three samples, each of 300 oysters of approximately the same age, originating from two separate hatchery-reared stocks (Conwy, Wales, and Loch Sween, Scotland), and a natural stock, dredged from the Solent, were laid down on a bed in the River Helford that was known to be infected by *Bonamia ostreae* (Hawkins *et al.*, 1992).

Oysters from each group were sampled at regular intervals over a period of 18 months in order to investigate and compare seasonal trends in infection. Results revealed that *Bonamia* infection was slow to develop, but led to mortalities in the Solent oysters. Ultimately all the Solent oysters became infected, compared with 74% for Conwy oysters, and 52% for Loch Sween oysters. Pathological changes in the 3 groups followed the same pattern of severity. Any apparent resistance of the Loch Sween oysters was at least partially attributable to their ability to sustain an effective and active generalised immune response to pathogen challenge. However, it would appear that the different groups of oysters were physiological races rather than genetically distinct populations. The poorer physiological state of the Solent oysters was most likely due to the fact that they are adapted for faster growth and earlier maturity compared with the Scottish stocks. This project could also be seen as an indicator that stocks of *O. edulis*, for whatever reason, could vary in their immune response to *Bonamia* infection.

The results of a recent study (Culloty *et al.*, 2004) suggest that differences exist between European populations of *O. edulis* in susceptibility to infection with *B. ostreae*. The study investigated the susceptibility of a number of European populations of *Ostrea edulis* to the protistan parasite *Bonamia ostreae*. The study was carried out at oyster-growing regions in three European countries where *Bonamia* is endemic. The oyster populations screened during the trial were either: naive populations, which had never previously been exposed to the parasite; populations of oysters, which had been exposed to the parasite for a number of years and where no management of the population to try to reduce infection had occurred; and an infected population, where selective breeding has taken place to try to reduce susceptibility to the parasite. The field trials indicated that Rossmore oysters, from Cork Harbour, Ireland, showed some tolerance to infection with *Bonamia* compared to other populations. The Rossmore oysters had been exposed to the parasite throughout life, having been selectively bred in an area where the parasite has been present for over 16 years. When comparing prevalence and intensity of infection in the different populations over the 22 months of the trial, lower levels were observed in the Rossmore group, and significant differences in prevalence of infection were found between the Rossmore oysters and the other populations tested. However, when comparing mortality, the picture was not as clear, with the Lake Grevelingen population performing better in one trial.

Studies at Southampton University have shown that there is a link between disease susceptibility and physiological stress caused by handling and overcrowding (Hawkins *et al*., 2000). Hatchery-produced native oyster spat were laid sub-tidally directly on the bed of the river Blackwater at three densities (10, 20 and 30 oysters per square metre). As an additional comparison spat were also placed in bags on racks on the mid and low shore. Both the traditional laying and the bag culture groups of oysters were sampled every two months and their disease susceptibility, health and growth assessed. The success of the low intensity approach to the cultivation of native oysters was unambiguous. Growth was quite clearly inversely proportional to laying densities in the sub-tidal groups and in bag and rack culture groups on the mid and low shore, where the degree of tidal exposure markedly affected growth. All groups reached, or were approaching minimum legal sizes in the third year of growth on the ground, and the oysters were of a marketable quality. This is a relatively short growing period for this species. There was no indication of infection by *Bonamia* using histological examination and there has been no evidence of increased disease-related mortality. This is particularly significant, as monitoring of the trial beds continued through the reproductive phase when mortality might have been expected. In the previous 10 years this species had not grown well using more intensive culture methods and had not exceeded 32 mm shell size before significant mortalities had intervened. Greater differences between groups were detected when measures of immunocompetence were used. At low density the cellular defence mechanisms of the oysters was able to cope with an acute pathogen challenge without difficulty but this capability was diminished by increasing stock densities, and by bag culture combined with tidal exposure. Studies in Spain (Conchas *et al*., 2003) have also shown a higher prevalence of disease in inter-tidal culture. Results from these studies also indicated that prevalence of disease varied between sites, reinforcing the importance of suitable site selection.

A further project has recently been completed at Southampton, in which the effects of post-settlement culture of native oysters on and off a range of cultch materials (broken and suspended scallop shells, cockle shells and weathered slipper limpet shells) at different oyster densities and in the presence of slipper limpets, also at a range of densities, has been evaluated. In addition, comparisons were made between a hatchery-reared stock and juveniles collected from wild stock in the Solent. A range of metabolic indicators was used to quantify the stress response of oysters to the experimental conditions (Hawkins, L.E., Defra project FC 0926 final report, April 2005).

Overall, no differences were detected in immunological functions between hatchery-reared and wild stocks, indicating that the former would be suitable for stock restoration. Cultchless groups appeared to out-perform oysters settled onto shell cultch. For both of these groups there was generally an increased stress response with an increase in overall density of live animals, irrespective of whether this consisted of oysters, slipper limpets or both organisms. With one of the tests, Neutral Red retention time, which is an indicator of lysomomal membrane stability and reflects the viability of haemocytes (and other tissues) in response to stressors, there was a response related specifically to the density of slipper limpets. This effect of increasing density was more pronounced for oysters settled onto cockle or slipper limpet shell than for oysters settled onto scallop shells. This may be related to the interactions between curved shells and benthic boundary layer microflows.

Selective breeding for strains resistant to disease can be achieved as described above, where older survivors from areas where *Bonamia* is endemic are used as broodstock, with the view that the natural processes of selection will favour resistant oysters, or by developing resistant strains through careful management of family lines selected following challenge with the disease in the field or the laboratory. This latter approach has been attempted in France (Naciri-Graven *et al*., 1998).

Two selected strains were obtained, one in 1985 (S85) and the other in 1989 (S89). Survival in the third generation of S85 oysters was more than 4-times higher than in the control group after a 20-month experiment in the wild. Significant differences in parasite prevalence were also recorded. However, no significant differences were observed between the second generation of the S89 oysters and the control group for either survival or parasite prevalence. The percentage survival of the cross between the two strains was more than twice as high as the control group and significant differences were recorded for parasite prevalence here. The selected strains showed a tendency toward higher weights and higher weight variances when compared to controls. These populations are suspected to have undergone bottlenecks, which would explain the increase in phenotypic variance. Improved resistance seems to be related to the delayed mortality of selected oysters.

A problem with this approach is that the low level of genetic variation in *Ostrea edulis* means that artificial selection for desirable traits such as disease resistance may not be particularly successful with this species (Johannesson *et al*., 1989) and a consequence of the French trials has been a loss of genetic variability (Launey *et al*., 2001).

1.6. Pests

1.6.1. Tingles

The main pests directly affecting native oysters are the drills or tingles. These are marine snails, which eat bivalves by rasping a hole through the shell to gain access to the flesh. There are two species in the UK, the American whelk tingle (Urosalpinx cinerea) and the European rough tingle (*Ocenebra erinacea*). The former was an associated unintentional introduction with American oysters (*Crassostrea virginica*) and was first recorded from the Essex oyster grounds in 1927. Its distribution is limited to the estuaries in Essex and Kent. The European rough tingle occurs predominantly on west and southwest coasts of Britain, being found in some of the important oyster grounds of the Fal, Helford River and Solent and it is also present in Ireland. Over half of the oyster spatfall in the River Crouch was devoured by the American whelk tingle in 1954, and in Southampton Water in 1978 *Ocenebra* killed about 10% of 30-45 mm (shell length) flat oysters in plastic mesh containers. Tingle abundance in some areas was reduced by the presence of tributyl tin (TBT) from marine anti-fouling paints. In populations subject to high TBT pollution, female tingles exhibit a characteristic malformation of the oviduct as an effect of advanced imposex. Following the introduction of restrictions on the use of TBT, the concentration of this contaminant in the environment has diminished and it is possible that tingles may re-emerge as serious predators in the future. There is already some evidence of this from ad hoc observations in the Solent. In the Fal the concerns are such that a Code of Practice has been developed to help to deal with the problem. This involves fishermen collecting any eggs or adults in their catch and disposing of them. The eggs will die if left to dehydrate in air but it is recommended that the adults be removed to landfill.

1.6.2. Slipper limpets

Native oysters face serious competition from slipper limpets, *Crepidula fornicata*. This species was brought over from the United States, probably associated with introductions of American oysters, and can occur in very high densities, competing for space and food. They are relatively fast growing, often individuals remain attached to each other forming chains and mats, with a wide tolerance to temperature and salinity and no natural predator. The slipper limpet deposits pseudo faeces, which forms ‘mussel mud’ changing the substratum and hindering settlement. The adults are capable of ingesting oyster larvae.

This species is also a problem in France, where slipper limpets have proliferated around the coast of Brittany during the last thirty years. The most significant quantities are to be found in the Normand-Breton gulf, where they amount to thousands of tons. It is now a significant component of the coastal ecosystems in these areas. In order to try to control this problem, a local restoration programme has been initiated. This should allow the harvest and the treatment of approximately 40-50,000 tonnes of slipper limpets per year. The aim is to appreciably reduce stocks. It is hoped this will lead to increased recruitment of scallops and oysters. The harvested slipper limpets are taken to a factory where they are drained, introduced into a rotary drier and then transferred towards a crusher where the whole animals (shell and flesh) are transformed into powder. They are treated in this way within 48 hours following harvest, in order to avoid bacterial degradation. The product obtained, called “ biocarbonate marin “ has all the qualities of a traditional calcareous fertiliser.

It is recognised that it is unlikely to be possible to completely eradicate slipper limpets. In order to sustain and justify initial investment into an industry producing fertiliser from this source the future level of exploitation would need to be set to meet the requirements of both this industry and the fishermen and the oyster cultivators. Uncertainties relating to the ecological impact of such levels of exploitation also require further scientific study.

It is interesting to note that the tradition of mining seaweed deposits from the Fal estuary in Cornwall to use as fertiliser has recently been stopped in order to save rare calcified seaweed called maerl. Licences that resulted in the annual extraction of between 20,000 and 30,000 tons of dead maerl will no longer be issued and the company harvesting the product will shut. Slipper limpets might provide an alternative raw material in such a case.

1.6.3. Other species

There are a few other species found in the coastal environment that may affect oysters, although their impact is considerably less than the species dealt with above.

A small red-orange copepod, *Mytilicola orientalis*, can infest the guts of the oyster. In large numbers they can cause a partial blockage and lead to a loss of condition.

Infestation of the shell by marine worms of the genus *Polydora* can cause unsightly brown blemishes on the inner surface and decrease marketability of the stock.

‘Dutch shell disease’ is a fungal infection that can affect oysters. The adductor muscle of infected oysters is weakened with the result that the oyster cannot close its shell properly. In extreme cases, oysters lose condition and die.

A summary of pests and diseases is given in the Table below.

Table 1.6. Pests and diseases affecting native oysters

Problem	Description	Relevance
Bonamia	Parasitic disease	A major limiting factor. Can cause high mortality in stocks. Controls on oyster movements available.
Marteilia	Parasitic disease	Not present in the UK but there is a risk that it could be introduced, with potentially devastating consequences. Controls on oyster movements available.
Tingles	Boring marine snails	Of concern as they are lethal to oysters. Some evidence that numbers are increasing but some management is possible in order to cope with the problem. Control of deposit restrictions to prevent spread no longer apply but the American tingle would be controlled as a non-native species.
Slipper limpets	Mollusc	A major competitor for space and food. Can be managed but only effectively as a large-scale undertaking. Control of deposit restrictions no longer apply but as it is a non-native species this allows some control to prevent spread.
Mytilicola	Copepod	Can lead to loss of condition in heavy infections. Control of deposit restrictions no longer apply as it is not considered to be a serious problem.
Polydora	Worm	Large infestations erupt occasionally, causing problems with marketing the stock.
Shell Disease	Fungus	Can weaken the oysters but rarely causes mortality. Not considered to be a serious problem.

1.7. Chemical contaminants

Suspension feeding organisms process large volumes of seawater and remove organic and inorganic particulates from the water column. Therefore, they are vulnerable to both water-soluble contaminants and contaminants adsorbed onto particulates. The effect of pollutants on oysters has been extensively studied and, as expected, they are sensitive to anthropogenic chemical contaminants in seawater.

For example, it was found that the immunocompetence (resistance to infection – a measure of stress) of flat oysters after exposure to petroleum hydrocarbons (oil) and a contemporary chemical dispersant, used to tackle oil spills was reduced. Animals exposed to either the oil or dispersant separately were more affected than animals exposed to these two substances in combination, suggesting that where oil is present, use of dispersants is beneficial (Byford, 1998).

Molluscan shellfish, as particulate filter feeders, may accumulate chemical contaminants from polluted environments. Monitoring of a range of species, including native oysters, has shown that concentrations of metals are below existing standards/guidelines for shellfish in England and Wales and over 95% of samples are below new EU limits for lead and cadmium in molluscs. (Jones *et al*., 1998) Likewise, recorded concentrations of pesticide residues and chlorinated biphenyls in all samples are very low, with the majority at or below the limit of detection (Jones *et al*., 2000).

There is a slight concern over levels of polycyclic aromatic hydrocarbons (PAH), particularly in oysters and mussels. Relatively high concentrations (>400 µg kg^{-1}) were recorded in approximately 15% of the samples (Jones *et al*., 1999). The ranges of concentration for a sum of the PAH determined in the various shellfish tested were very wide, at 63 to 1,592 µg kg^{-1} wet weight in native oysters. As might reasonably be expected, some of the highest concentrations were recorded in areas associated with oil refineries/terminals, petrochemical industries, heavy shipping, power stations and other major sources of PAH inputs. The results indicate that the concentrations of PAH in bivalve molluscs around England and Wales are sufficiently high that shellfish may be an important dietary source of PAH for those who consume large quantities of them (Jones *et al*., 1999).

1.7.1. TBT

The deleterious effects of TBT on bivalve molluscs are well documented, including from some studies carried out with *Ostrea edulis*. Axiak *et al.* (1995, 2000) collected native oysters from coastal sites exposed to antifoulant containing TBT and found that they exhibited shell thickening as indicated by a particular shell thickness index. It was suggested that this effect was qualitatively different from that reported for other bivalves where it was known to be specifically caused by TBT. Nonetheless, laboratory exposure experiments (Axiak *et al.,* 1995) showed that nominal levels of 10 ng per l of TBT in seawater led to digestive cell atrophy, with a significant reduction in digestive cell volume in this species, and this may have led to reduced somatic growth and thus to shell abnormalities

Reproductive performance was measured in *Ostrea edulis* exposed to TBT-based antifouling paint leachates for 75 days by Thain *et al*., 1986. Larval production was inhibited, compared with values for oysters in clean water. Histological examination of the gonad showed normal development in the control animals, a predominance of maleness in the low concentration TBT-treated animals and little or no gonadal differentiation at the high TBT concentration. Lee (1991) also demonstrated breakdown of sexual differentiation, oogenesis and egg production in *Ostrea edulis*.
In the United Kingdom, the use of TBT-based anti-fouling paints on small vessels was banned in 1987, and a biological study of the Crouch Estuary, a yachting centre on the south-eastern English coastline, was initiated in order to monitor any associated changes (Rees *et al*., 2001). From this study it was reported that the population of native oysters in the Crouch estuary was increasing (between 1992 -1997) since the reduction in TBT concentration in the water column.

SECTION 2: TECHNICAL REQUIREMENTS

2.1. Introduction

Native oysters are not cultivated as commonly as Pacific oysters, since their growth rate is slower, their survival rate is often lower and seed tends to be slightly more expensive. The main reason that hatchery-reared flat oysters attract relatively little attention as a cultivated species at present is almost certainly because of their susceptibility to the disease organism, *Bonamia*, which was first recorded in the UK in 1982. However, they do generally fetch a higher market price.

Nevertheless, relaying of hatchery-produced oysters might be a means of replenishing stocks in order to assist with the build up a population. There is then the opportunity of selecting particular stocks that might be suited to specific locations or selectively breeding from existing stocks to obtain, for example, oysters resistant to disease.

A viable alternative to hatchery production for replenishing stocks might be to rear the oysters in ponds. An advantage of this is that a much larger broodstock are used, helping to eliminate the problems associated with genetic bottlenecks and allowing for selective breeding programmes, for example for disease resistance, on a much larger scale.

Other technical aspects, associated with native oyster restoration through management of exploited wild stocks and stock monitoring, are also considered in this section.

2.2. Hatcheries

Although hatchery rearing of native oysters has never been as reliable as that for Pacific oysters it can be achieved with care. Survival rates of up to 90% through to metamorphosis are possible with some batches of larvae, although this figure can be much lower than 50% with others. Much seems to depend on the fatty acid content of the newly released larvae and this can be influenced to a certain extent by selection of the appropriate broodstock conditioning diet. (Berntsson *et al.*, 1997; Millican and Helm, 1994). Techniques for hatchery rearing follow well-established procedures and these are described in both the scientific literature and in standard texts and guides (e.g. Utting and Millican, 1997; Seafish, 2002; Spencer, 2002).

It is generally accepted that fewer larvae are released from hatchery-conditioned broodstock and that these larvae tend to be lower in total lipid and perform less well compared with those from the wild (Millican and Helm, 1994).

Reasons for the losses of batches of native oyster larvae in the hatchery are not well understood.

There are reports of infections in hatchery-reared native oyster larvae by a herpes-like virus. Similar infections are associated with sporadic mortality of Pacific oyster larvae, particularly in France, and it is likely that transmission of the disease can occur between these two species of oyster. In the Pacific oyster, virus particles and lesions in the tissues were found at 25-26°C. At lower temperatures, 22-23°C, lesions were found but no viral particles (Le Deuff *et al.*, 1996).

Vibrio bacteria are also associated with larval mortality in hatcheries. These produce ciliostatic toxins, which effectively paralyse the cilia on the velum of the larvae. As a result, the larvae are unable to swim or feed and they sink to the bottom of the rearing vessel where they die. They can be controlled by improved hygiene. An example would be treatment of the incoming water with ultra-violet light. Although usually an effective method of controlling bacteria levels, this can sometimes have the opposite effect where harmful bacteria get into the rearing vessel with the microalgae food. In such a sterile environment, the harmful bacteria can quickly flourish and affect the larvae. Other methods of bacterial control include the use of antibiotics such as oxolinic acid. The ban on the use of many antibiotics, because it can potentially lead to the development of disease-resistant strains of bacteria, has meant that alternative rearing methods are being investigated. Using through-flow systems or partially through-flow recirculation systems is an option.

Native oyster juveniles from hatchery-reared larvae perform well in standard pumped upwelling systems and survival is usually good, although some early losses may occur immediately following metamorphosis. Studies have been carried out to determine the most suitable procedures for maintaining these systems. Diet, ration, stocking density and water flow rate are all important (Spencer *et al.*, 1986; Spencer, 1988, Laing and Millican, 1992). These systems are only suitable for initial rearing of small seed. As the spat grow food is increasingly likely to become limiting in these systems and they must be transferred to the sea for on-growing.

In the late 1990s UK hatcheries produced from 1.5 to 2 million native oyster juveniles per annum for on growing. This represents less than one and a half percent of the production of Pacific oysters and reflects lack of demand rather than any limit to capacity for this species. This demand has fallen away to virtually nothing in the last few years throughout the UK. Thus, although native oyster production in the UK is currently based predominantly on management of wild stocks, production of seed to assist in restoration projects is not a technical limiting factor.

One means to obtain stocks resistant to disease is by selective breeding programmes. In the earlier years of hatchery cultivation such programmes were attempted to select for faster growing oysters (e.g. see Newkirk and Haley, 1982). The problem with such programmes is that they require substantial resources. There are considerable logistic implications due to the need to keep families separate over an extended time period, until the oysters reach an adult size, as larval growth rate is not necessarily a good indicator of performance (Newkirk, 1981). Careful monitoring of all the families must be carried out and at the end of the day it can easily be discovered that there have been no significant gains.

Seed native oysters are usually made available from commercial hatcheries at a range of sizes (from 4-5 mm shell length up to 25-30 mm). The larger the seed, the more expensive they are but this is offset by the higher survival rate of larger seed. Larger seed should also be more tolerant to handling.

2.3. Ponds

Pond culture was the method that was originally developed in early attempts to stimulate production following the decline of native oyster stocks in the late nineteenth century. Ponds of 1 to 10 hectares in area and 1 to 3 m deep were built near to high water spring tides, filled with seawater and then isolated for the period of time during which the oysters are breeding naturally, usually May to July. Collectors put into the ponds encourage and collect the settlement of juvenile oysters. There is an inherent limited amount of control over the process and success is very variable. Spat production from ponds built at that time was insufficiently regular to provide a reliable supply of seed to the industry and the method was largely abandoned in favour of the more controlled conditions available in hatcheries. However, it has since been successfully adopted by the oyster industry in Cork Harbour, Ireland where the approach has been based on a relatively large number (22) of smaller, butyl-lined ponds, each holding 1000 m^3 of seawater. These ponds are stocked with up to 700 - 800 oysters and from them about 20-50 million seed oyster survive to 4 mm for on-growing. This system has allowed for some selective breeding for disease resistance, as discussed above.

2.4. On-growing

Various standard methods are available for on-growing of hatchery-reared seed (see, for example, Spencer, 2002). Oysters smaller than 10 g will need to be held in trays or bags attached to metal trestles on the foreshore until they are large enough to be put directly on to the substrate and be safe from predators, strong tidal and wave action, or siltation. The mesh size can be increased as the oysters grow, to improve the flow of water and food through the animals. Holding seed oysters in trays suspended from rafts and long-lines may be an alternative method in locations where current speed will allow. The oysters should grow more quickly because they are permanently submerged but the shell may be thinner and therefore more susceptible to damage. The additional costs associated with rafts and long-line systems are an important consideration and may be prohibitive. In all cases, early stages of predator species such as crabs and starfish can settle inside containers, where they can cause significant damage unless containers are opened and checked on a regular (monthly) basis. In the longer term the oysters will perform better on the seabed. Here, oysters perform best at low density. Trials in Essex showed densities of 10 oysters m-2 were better than 20 or 30 m^{-2} and those animals grown on the seabed were better than those held in oyster bags on racks, even when trestles were sited low on the shore.

Protective fences can be put up around ground plots to give some degree of protection to smaller oysters from shore crabs. The walls of the fences can be made from 10 mm plastic netting and are about 50 cm high with another 15 cm buried into the substrate. An overhang at the top made of a smooth material such as metal or fibreglass, points outwards at a 45 or 90-degree angle to the vertical. Potting crabs in the area of the lays is another method of control.

Recently, experiments funded under the NOSAP programme have been carried out at Southampton University to see if the performance of hatchery-reared native oysters, including their immunocompetence, can be increased if the spat are settled onto different types of shell cultch (broken and suspended scallop shells, cockle shells and weathered slipper limpet shells, at different oyster densities) (Hawkins, L.E., Defra project FC 0926 final report, April 2005). Cultchless groups appeared to out-perform animals associated with shell cultch. Deleterious changes were principally associated with high levels of live tissue densities, irrespective of whether this was oysters or limpets or both. Animals settled onto cockle or slipper limpet were more susceptible to these density-related effects than those settled onto scallop shells. This may be related to the interactions between curved shells and benthic boundary layer microflows. Two sources of oyster seed were tested in this programme. These were obtained from parental hatchery brood stock, of known origin and genetic relationship, and from spat obtained from a random assortment of reproductive adults collected from the Solent during the peak spawning phase in May/June. It is interesting to note that no differences were detected in immunological functions between the two stocks.

Harvesting of mature native oysters begins after 4-5 years (depending on where in the UK the cultivation site is located) when they have reached a minimum size of around 70 g. Oysters are graded, purified where necessary and packaged before sale to wholesalers, retailers or catering outlets in the UK. There is also an export market, mainly to France and Spain. In 2003 over 97% of UK live oyster exports were sent to France (557 tonnes), Spain (353 tonnes) and the Irish Republic (60 tonnes).

2.5. Management of beds

2.5.1. Introduction

Recovery of natural oyster beds will be dependant on larval recruitment, since adult *Ostrea edulis* are permanently attached and incapable of migration. Recruitment of *Ostrea edulis* is sporadic and dependant on the local environmental conditions, hydrographical regime and the presence of suitable substratum, especially adult shells or shell debris, and has probably been inhibited by the presence of competition from non-native pest species.

The lipid quality of larvae released in the wild can vary throughout the year, presumably through differences in food quality, and this probably affects performance and subsequent success at and through metamorphosis (Helm *et al.*, 1991).

Natural beds can be managed to encourage the settlement of juvenile oysters and sustain the fishery. Beds can be raked and tilled on a regular basis to remove silt and ensure that suitable substrates are available for the attachment of the juvenile stages. Adding settlement material (cultch) is also beneficial.

2.5.2. Stocks

Some of the natural fisheries that are not self-sustaining continue to produce because half-grown oysters are relayed for one growing season from other natural beds. There are strict controls over the areas for fishing and relaying to reduce the risk of high mortalities from Bonamiasis. Guidelines have been developed to assist the industry in making this activity as successful as possible (see Appendix B).

2.5.3. Water movements

Shelbourne (1957) related hydrographical observations to the distribution of oysters on beds in Essex rivers. There is similar observational data on water movements in some UK waters where a regeneration of oyster stocks might be undertaken. Unfortunately there is no central depository of such information and background data for regeneration plans would have to be sought from a variety of sources at local and national levels.

Water movements have been widely modelled mathematically in the last two decades. However, there has been little application to date of the techniques to aid the understanding of molluscan shellfish distributions. Dare *et al.* (1993) utilised a shelf seawater flow simulation model (NORSWAP) to investigate potential larval dispersal pathways in the scallop in the English Channel and Celtic Sea. Young *et al.* (1998) modelled the environmental influences on cockle and mussel settlement in the Wash.

Although there is a wide variety of models available their configuration and use in individual locations requires the allocation of significant time resources. In many locations where regeneration schemes might be considered, it is doubtful if adequate base level observational data is available. Before modelling could be attempted a scheme of local data acquisition would have to be undertaken.

2.5.4. Cultch

Various studies have been made using both natural and artificial materials to assess the preferred type of substrate for use as cultch to encourage settlement of native oysters. Results have been variable but in general natural shell has performed well, although crushed concrete and limestone have also been used successfully in the restoration programme for American oysters in Chesapeake Bay (see Section on Current Status and Attempts at Restoration). The most commonly used cultch in the UK is old bivalve shells. There are sources of this available but costs associated with transporting and depositing it can be high. There is some indication that disease organisms can persist on unwashed shucked shell (Bushek *et al.,* 2004) and so it is recommended that shell from an area where disease is endemic (or the disease status is unknown) should be left exposed to the air for one month.

Some investigations into settlement of native oysters in ponds (Gathorne-Hardy and Hugh-Jones, 2004) have yielded useful data on the most successful strategies for collecting seed in these systems.

2.5.5. Effects of fishing (dredging)

Although abrasion may cause damage to the shell of *Ostrea edulis*, particularly to the growing edge, regeneration and repair abilities of the oyster are quite good. Oysters were often harvested by dredging in the past and their shells apparently survived relatively intact. On mixed sediments, the dredge may remove the underlying sediment, and cobbles and shell material with effects similar to loss of substratum. Dredging may also damage some of the associated fauna in the biotope. It has been reported that polychaetes and other segmented worms are badly affected by physical disturbance from oyster dredging (Gubbay & Knapman, 1999).

2.6. Management methods

Fisheries management is generally framed around two concepts. The first is that there should be limits, which define the acceptable range of conditions for the fishery (any measure of the performance of the fishery or the target stock). Limits could apply to catch quantities, fishing effort, stock abundance and many other fishery and stock quantities, but they all have in common the idea of stock conservation – maintaining the stock in a condition that allows it to replace itself and to provide sufficient production to sustain a future fishery. The second concept for fishery management is the definition of targets. In contrast with limits, which define conditions that are to be avoided, targets define desirable outcomes of fishery management. Targets for a fishery depend very much on defining explicit management objectives. For example, different targets would be adopted depending on whether the management was for maximum fishery yield, maximum profit or maximum long-term employment.

There is a well-developed body of theory relating to the definition of targets and limits for finfish fisheries, and for the measurement of management outcomes against these quantities. Targets, and more particularly limits, are often referred to as Biological Reference Points (BRPs). For limits, modern fishery management also takes into account the statistical uncertainty associated with the estimation of appropriate BRPs alongside the risks that managers consider acceptable – this is the so-called ‘Precautionary Approach’ to fishery management. There has been much less development of BRPs for invertebrate fisheries than for finfish. For shallow water and inter-tidal bivalve molluscs in UK waters, including oysters, fishery management has generally not defined clear objectives. Instead, management has evolved in an *ad hoc* fashion, based on experience rather than an explicit conceptual framework.

Management of oyster fisheries in England and Wales have concentrated on maintaining adequate spawning stocks, using a suite of byelaws and regulations. These regulatory measures developed empirically over time to meet local needs and may vary significantly between neighbouring areas. However, more recent regulation has increasingly taken account of environmental and diversity issues. Table 2.5 summarises the measures employed in managing the oyster fisheries of England and Wales.

At present there are no fisheries regulations or management measures in place in relation to native oyster harvesting in N. Ireland. Similarly, as there are no active consents to fish oysters in Scotland, there is no active management of native oyster stocks.

Table 2.5. Summary of management measures employed in oyster fisheries in England and Wales.

	Limit effort	Eliminate unlicensed effort	Conserve spat	Conserve juveniles	Conserve spawning stock	Protect environment	Provide management advice
Licence entry to fishery	*						*
Vessel restrictions	*					*	
Gear restrictions	*		*	*	*	*	
Bed closure			*	*		*	
Closed periods	*				*		
Carriage restrictions		*	*	*	*		
Total catch limit					*		
Minimum landing size					*		
Prohibit cultch removal			*			*	
Return undersize to beds				*		*	
Return by-catch to beds						*	
Detailed monitoring							*

2.7. Monitoring

Monitoring the progress of stock restoration to evaluate the effectiveness of management strategies is highly desirable if not essential for a creditable programme.

The degree of monitoring can range from a simple assessment of numbers size and density of oysters on the ground to a full ecological survey to include changes in the composition and abundance of other species in the ecosystem and effects on nutrients and primary productivity in the water column. As the level of complexity increases then so will the cost. Ideally, a baseline survey should be conducted before initiation of any restoration programme.

There are various sampling and survey methods available, depending on the level of detail of information required. For exploited stocks valuable information can be obtained from standard tows with standard dredges, then sorting examining and quantifying the oysters in the catch. Non-destructive methods are more desirable where restoration is primarily for ecological reasons. This can involve diver surveys and sampling, together with the use of remote controlled video equipment where appropriate.

Enhanced recruitment is an important yardstick in evaluating the success of a restoration programme and this can be monitored both by deploying spat collectors at selected sites at appropriate times and by estimating the numbers of larvae in the water column.

The identification of larval marine invertebrates to species or even higher taxonomic levels by morphological examination is notoriously difficult. Many diagnostic features are absent or poorly formed at early stages in development. This is particularly true for the larvae of bivalve molluscs, for which a routine and accurate method of identification would prove valuable to both ecologists and fishery managers. A simple molecular genetic method to identify specifically *Ostrea edulis* larvae has been developed (Morgans and Rogers, 2001). The test is based on PCR amplification of highly species-specific microsatellite loci and is sensitive enough to register the presence of a single larval individual of 200 µm width in a mixed sample of 20 mg wet weight plankton (approximately 250 larval animals).

Similar techniques using genetic tags developed for *Crassostrea virginica* have been used to confirm the survival and reproduction of oysters planted out to enhance stocks in the Chesapeake Bay restoration programme (Milbury *et al.*, 2004). In this example the techniques are sensitive enough to distinguish between different stocks, from different sources, of the same species.

SECTION 3: REGULATORY FRAMEWORK

3.1. Introduction

There are various legal aspects relevant to oyster stock regeneration. Primarily, there must be a high measure of protection of and control over restored stocks to prevent inappropriate exploitation. Other controls are designed to prevent the introduction and spread of disease and alien species that may predate on or compete with and displace native species. Water quality is also important and there is a raft of legislation surrounding this issue. The conservation status of sites should also to be taken into account and this may provide a means of protecting stocks where there is no intention to exploit them commercially.

3.2. Authorities

Several government, public and other bodies have responsibilities for legislation in the marine and coastal environment relevant to native oyster stock regeneration. These are listed below, together with the abbreviations where these are used in the text.

Department for Environment, Food and Rural Affairs (Defra)
Welsh Assembly Government (WAG)
Scottish Executive Environment and Rural Affairs Department (SEERAD)
Crown Estates (CE)
Local Authority (LA)
Environmental Health Department (EHD)
Port Health Authority (PHA)
Sea Fisheries Committee (SFC)
Centre for Environment, Fisheries and Aquaculture Science (CEFAS)
Fish Health Inspectorate (FHI)
Fisheries Research Services (FRS)
Food Standards Agency (FSA)
International Maritime Organisation (IMO)
European Community (EC)
Environment Agency (EA)
Scottish Environment Protection Agency (SEPA)
Environment and Heritage Service (EHS)
Joint Nature Conservation Committee (JNCC)
English Nature (EN)
Scottish Natural Heritage (SNH)
Countryside Council for Wales (CCW)

3.3. Rights And Fishery Orders

3.3.1. Introduction

The legal status of the native oyster varies under different jurisdictions in the UK. In England, Wales and Northern Ireland it is a 'fish' in common with any other indigenous marine fish. Anyone who holds a Category 'C' fishing vessel licence can take oysters unless the right to fish has been removed by designation of a Several Orders or otherwise restricted by, for example a Regulating Order (see below). In Northern Ireland a system of Fishery Licences is operated, whereby ownership of the stock is effectively given to the licence holder. Conditions can be applied to Fishery Licence Holders to ensure that their activities are carried out in an environmentally sensitive manner.

In Scottish waters the native oyster is Crown (Crown Estates, CE) property, except where the right of ownership has been sold or passed to named individuals or organisations. Thus, to fish for and retain native oysters in Scottish waters is theft unless consent to fish has been granted by the CE.

The CE will not issue consent until they have considered the sustainability of the stock and its implications for nature conservation interests. At present there are no consents to fish in Scottish waters, the only production comes from small private fisheries or cultivation sites. Historically, Several and Regulating Orders have not been instruments for fisheries management in Scottish waters but that position has changed in recent years. There has been a growing move to apply for (and issue) Regulating Orders (see below) covering very extensive sea areas around the Northern and Western isles. Where these applications are successful, the CE intends to surrender their rights of native oyster ownership to the holders for the duration of the Regulating Order.

In England and Wales, Sea Fisheries Committees are empowered to make byelaws for the regulation, protection and development of fisheries for shellfish. The management methods available are described in Section 2.6.

3.3.2. Regulating Orders

A Regulating Order may be granted in England by Defra or in Wales or Scotland respectively by WAG or SEERAD to a responsible body such as a Harbour Board, LA, or (in England and Wales only) SFC, to enable it to regulate the fishery of a natural stock. The stock may then be fished by the public in accordance with the terms of the order, subject to the observance of any by-laws or regulations made by the controlling body, and on payment of any tolls or royalties which may be charged by it. By-laws control, for example, gear specifications, minimum-landing size, fishing season, quotas etc., while fishing effort is controlled by a licensing system. New by-laws may be introduced or old ones deleted to meet current management needs, but only with the approval of Defra.

3.3.3. Hybrid Orders

Hybrid orders are Regulating Orders with powers to grant leases of Several rights

3.3.4. Several Orders

A cultivator who wants to have additional protection for stock kept in public waters may apply for a right of Several fishery. Orders establishing these are granted in England by Defra or in Wales or Scotland respectively by WAG or SEERAD. They are granted for a fixed period, to an individual, a co-operative, or a responsible body, to enable the grantee to cultivate the sea bed within a designated area of water and to conserve, develop and enhance the specified stocks of shellfish thereon. The Several fishery concept is designed to give the lessee a much greater management control of the stocks. Several rights may also be granted to a SFC, which cannot cultivate stocks in its own right but may lease rights of Several fishery, subject to the consent of the Fisheries Departments. The applicant must provide a management plan, and this must satisfy the Minister that the fishery will benefit from cultivation. The driving philosophy is that the productivity of the fishery must be enhanced. Where natural stocks are concerned, enhancement may require encouraging spatfall by the placement of collecting material (cultch), or relaying with partly grown stock from elsewhere, for on-growing to market size. The Several fishery rights may be terminated if the grantee fails to meet the terms of the order.

There are 16 fishery order areas, covering 3,297 hectares (Several Orders), 618,296 (Regulating Orders), and 72,085 (Hybrid Orders) for protection of oyster stocks. This is a substantial area, although it must be remembered that not all grounds within these areas will be suitable for flat oyster cultivation and many are already being used for cultivation of other species. Also, many of these current areas are in sites affected by *Bonamia*. It is possible to apply for new areas, but the processes for application for and granting of a Several fishery right can be a time-consuming process, which may take up to 3 years. If there are any objections to the application then this can force a public enquiry, the cost of which falls to the applicant.

Table 3.3. Current Fishery Order areas in the UK. Those in bold have native oysters included as a named species for cultivation

England	Wales	Scotland
Several Orders		
Blakeney Harbour	**Menai Strait (East)**	Broadford Bay andLoch Ainort
Brancaster Staithe	**Menai Strait (West)**	Little Loch Broom
Calshot	Deepdock	**Camus an Lighe, Loch Ceann Traigh**
Emsworth Channel	Penrhos Point	Loch Caolisport
Horsey Island	Swansea Bay	Loch Crinan
Hunstanton (Le Strange)		Loch Ewe, West Ross
Portland Harbour		Loch Moidart
River Roach		Scalpay Island
Stanswood Bay		Loch Sligachan
River Taw		
Tollesbury & Mersea (Blackwater)		
Waddeton		
Regulating Orders		
Morecambe Bay	Burry Inlet	**Shetland**
The Solent	Conwy	
Thames Estuary		
River Teign		
Truro Port		
Hybrid Orders		
Poole Harbour		
The Wash		

3.3.5. Private ownership

Private property rights prevent public fishing in some tidal waters. These rights may have been acquired in various ways, including: granting of rights of a fishery to individuals by the Crown before the Magna Carta (1215); private Acts of Parliament (up to 1868) conferring Several Rights on boroughs such as Rochester and Colchester or private companies such as the Seasalter and Ham Oyster Fishery Company Ltd, Whitstable, and the Whitstable Oyster Company. Beaulieu Estate is a private fishery with rights of cultivation granted by the estate.

3.4. Disease

3.4.1. Registration of shellfish farms

The Fish Farming and Shellfish Farming Business Order 1985 obliges shellfish farmers in England, Wales or Scotland to register his or her business with Defra or SEERAD. The purpose of registration is to assist the Departments in dealing with outbreaks of disease if these should occur. Registered businesses are required to keep a record of the stock movements on and off site and to submit a simple summary of movements each year. Rules are designed to quickly identify and prevent the spread of new diseases. This legislation also allows for an early warning system in the event of an outbreak of a new or emerging disease and it also assists in tracking the spread of diseases. The legislation in Northern Ireland has a similar purpose except that The Fisheries Act (Northern Ireland) 1966 requires farmers to be licensed to farm fish and shellfish and it is an offence to operate without a licence.

3.4.2. Movement controls

There are certain restrictions on the deposit of bivalves around the coast of Great Britain, to prevent the introduction and spread of diseases. January 1993 saw the introduction of the Single European Market, which was accompanied in many areas of trade with the removal of internal border controls between Member States. However, movements of shellfish into Great Britain, from both within and outside of the EU, continued to be controlled because of the risk such trade poses to the health of established disease-free stocks.

The controls apply to movements to Great Britain of all live molluscan shellfish and their eggs and gametes, from other parts of the EU; from non-EU countries and to deposits within and between coastal zones of Great Britain. The controls operate through a system of approved zones and approved farms that have a high shellfish health status because they are free from the notifiable shellfish diseases, *Bonamia* and *Marteilia*. For these, it is necessary to complete movement documents to accompany the consignment. These are completed by the official fish health protection service where the shellfish are produced. Also, it is necessary to give pre-notification of movements, which entails written 24 h notice to the fisheries department of the arrival of the consignment.

Shellfish from non-EU countries may only be deposited within the EU waters so long as they are certified free from disease by a testing programme as stringent as that which applies in the EU and comply with the other conditions of import.

Great Britain has been granted approved zone status for the whole coastline for *Marteilia* and approved zone status for the whole coastline for *Bonamia* except in the three restricted areas where the disease is found. These areas are (1) from the Lizard to Start Point; (2) from Portland Bill to Selsey Bill and (3) from Shoeburyness to Felixstowe. Movements within the UK are controlled according to the health status of these areas. Anyone wishing to deposit or relay molluscan shellfish taken from the controlled (restricted) areas listed above must apply for permission to the FHI at the CEFAS Weymouth Laboratory (for England and Wales) or the FRS at the Marine Laboratory, Aberdeen (in Scotland).

In the UK Approved Zones have also been recognised for Northern Ireland, Guernsey and Herm, the States of Jersey and the Isle of Man. Elsewhere in the EU there are Approved Zones in Ireland (parts of the coast only for *Bonamia*), Norway and Denmark (2005/104/EC Commission Decision of 3 February 2005 amending Decision 2002/300/EC establishing the list of approved zones with regard to *Bonamia ostreae* and/or *Marteilia refringens*).

3.5. Introduced species

3.5.1. ICES Code of Practice

All introductions and transfers of marine organisms carry risks associated with target and non-target species (including disease agents). Once established, introduced species can spread from foci of introductions and have undesirable ecological, genetic, economic, and human health impacts. Introductions of marine organisms occur in the course of many human activities, including but not limited to aquaculture, stocking, live trade (e.g., species used for aquaria, ornamentals, bait, and food), research, bio-control, and the use of genetically modified organisms. Even species introduced intentionally into closed systems can be released accidentally. Thus, introductions can result whenever live organisms are moved, regardless of the original intent. As a result, a risk of introduction and subsequent impacts exists with any movement and should be considered explicitly. This Code of Practice provides a framework to evaluate new intentional introductions, and also recommends procedures for species that are part of current commercial practices to reduce the risk of unwanted introductions, and adverse effects that can arise from species movement.

The ICES Code of Practice sets forth recommended procedures and practices to diminish the risks of detrimental effects from the intentional introduction and transfer of marine (including brackish water) organisms. The Code is aimed at a broad audience since it applies to both public (commercial and governmental) and private (including scientific) interests. In short, any persons engaged in activities that could lead to the intentional or accidental release of exotic species should be aware of the procedures covered by the Code of Practice.

The Code is divided into seven sections of recommendations relating to: (I) a strategy for implementation, (II) the steps to take prior to introducing a new species, (III) the steps to take after deciding to proceed with an introduction, (IV) policies for ongoing introductions or transfers which have been an established part of commercial practice, and (V-VI1) the steps to take prior to releasing genetically modified organisms.

Although the COP is not legally binding, it is recommended as a precautionary approach, particularly where in countries where stricter regulations do not apply.

3.5.2. Wildlife and Countryside Act

The Wildlife and Countryside Act 1981 is the principle mechanism for the legislative protection of wildlife in Great Britain. It does not extend to Northern Ireland, where equivalent provisions are contained within the Wildlife (Northern Ireland) Order 1985. This legislation prohibits the release of non-native species into the wild (Section 14). This is to prevent the release of exotic species that could threaten our native wildlife. This legislation therefore gives some protection to native oysters by not allowing the deliberate introduction of pest and competitor species such as Slipper limpets and American tingles into new areas in which restoration attempts might be made. Defra has issued a general licence authorising the release of, among other species, Pacific oysters (*Crassostrea gigas*) for cultivation. The release into the wild of all other kinds of non-native fish and shellfish currently requires a specific licence for each individual release.

3.5.3. Shipping

In recent years the release of exotic organisms via ship's ballast water has become a pressing issue, with profound implications for fisheries resources, mariculture, and other activities. Introduction of alien organisms through discharge of ships' ballast water is seen as the second greatest threat to world biodiversity, after habitat loss. As well as considerable economic loss, introductions (of which around 50 have been identified in the UK) reduce bio-diversity by supplanting indigenous species and interfering with natural ecosystems and have caused human health risks via the transfer of toxic algae that can be taken up by commercially valuable shellfish.

The IMO held a Diplomatic Conference in February 2004 at which the text of a Convention on Management of Ships' Ballast Water was agreed. In the short term the Convention will require ships that undertake deep-sea voyages to exchange their coastal ballast water for cleaner offshore water. This will provide some measure of protection using a currently practised technique that has a low cost for the shipping industry. It is recognised that this approach is limited by conventional ship design and route. Also, the method may not be fully effective as exchange of water may only serve to revive any residual organisms.

For the longer term, water quality standards (maximum permitted discharge concentrations for different groups of viable organisms) are proposed that will guide technological development. To meet these standards various treatment methods are under development.

Protocols for validating and therefore enabling certification of treatment systems are also needed and these are currently under development. For implementation and enforcement within the UK there is also some discussion, particularly within OSPAR, on the usefulness of a regional ballast water management area comprising of several neighbouring port states.

3.6. Water quality

There should be a presumption in favour of oyster stock restoration at sites where the seawater is clean (unpolluted). This is imperative at sites where the stocks are to be exploited but also an ideal where they are managed for conservation reasons, to help ensure a balanced ecosystem.

3.6.1. Classification

It is a statutory requirement [Food Safety (Live Bivalve Molluscs and Other Shellfish) Regulations, 1992] that shellfish beds must be classified according to the faecal coliform (or *Escherichia coli*) levels of the bivalve flesh. Treatment of shellfish before marketing is dependent on that classification. In harvesting areas with a 'B' classification oysters must be purified of any faecal bacterial content in cleansing (depuration) tanks before sale for consumption.

The local EHD or PHA may be able to provide information on shellfish hygiene and water classifications if the site is already a shellfish harvesting area.
New sites must be graded. Samples must be collected from the selected area or oysters (contained in a tray) placed in the area for testing. If the EHD/PHA can be involved and the sampling is done every 2 weeks for 3 to 4 months according to strict protocols it may be possible to get a provisional classification almost immediately thereafter. If the sampling is done independently, the results will not count towards a provisional classification. Full classification may be achieved after a year of continuing sampling at monthly intervals. It may be possible to shorten the sampling period if additional information is available for the same species on nearby beds, from other species in the same area, of from historical monitoring.

3.6.2. Algal toxins

The risks to consumers from shellfish poisoning due to the presence of algal toxins in the tissues are minimised by a statutory requirement for sampling. The monitoring programme for algal biotoxins is a requirement of the Shellfish Hygiene Directive 91/492/EEC, which is implemented in the UK by the Food Safety (Fishery Products and Live Shellfish Hygiene) Regulations 1998 as amended. The monitoring programmes are undertaken on behalf of the FSA, FSA (Scotland) and FSA (Northern Ireland). Farmers may be required to provide samples. If the amount of toxin exceeds a certain threshold, the collection of shellfish for consumption is prohibited until the amount falls to a safe level, giving a temporary closure of the fishery. Sampling frequency is increased if toxins are detected. Samples of seawater from selected sites are also examined routinely for the presence of the phytoplankton species that produce these toxins, as an early warning system.

In areas where the strategy for restoration includes management of exploited stocks then there will need to be Classification to Grade A or B, ideally with no history of algal toxins. Where restoration is undertaken purely for conservation purposes then there may be some advantage in selecting areas with no Classification as harvesting would not be allowed from such areas.

3.6.3. Contaminants

When marketed for consumption live molluscan shellfish must, in addition to the bacteriological and algal toxin requirements detailed above, meet a number of "end product" standards. These include a requirement that the shellfish should not contain toxic or objectionable compounds such as, trace metals, organochlorine compounds, hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) in such quantities that the calculated dietary intake exceeds the permissible daily intake. Since 91/492/EEC additional legislation has come into force in which the EU has set limits for a number of contaminants in food stuffs, including bivalve molluscs (EC 466/2001). Limits for Mercury, Cadmium and Lead are 0.5, 1.0 and 1.0 mg/kg (wet wt), respectively and for dioxins 4pg WHO-PCDD/F-TEQ/g fresh weight. A study of commercial molluscs in the UK was carried out and a considerable body of data on levels of these contaminants obtained (Jones *et al.*, 1998, 1999, 2000). This information can assist in identifying areas where industrial and other activities would make restoration a less attractive prospect.

3.6.4. Shellfish Waters

Oysters and mussels, because they are filter-feeders, draw water across their sieve-like gills. These gills can rapidly accumulate microorganisms, heavy metals and organic contaminants. Good water quality in areas where shellfish live is therefore essential to their wellbeing.

The EC Shellfish Waters Directive (79/923/EEC) aims to protect shellfish populations by setting water quality standards in areas where shellfish grow and reproduce. The Directive requires that certain substances, which can threaten the survival of shellfish or inhibit their growth, be monitored in the water in which the shellfish live. These substances are grouped into metals, organohalogens and other 'substances' including salinity and dissolved oxygen. For each substance, the Directive specifies the minimum number of samples to be taken, the standards to be met and the percentage of samples that must meet these standards. The standards can either be a numeric limit or a descriptive standard. There must also be no evidence of harm to the shellfish from organohalogenated compounds.

The Shellfish Waters Directive is administered in England by Defra and in the rest of the UK by the relevant Devolved Administration. This Directive has been transcribed into UK legislation under the Surface Waters (Shellfish) (Classification) Regulations 1997 and The Surface Waters (Shellfish) Directions 1997. It is implemented in the UK by the EA (England and Wales), SEPA (Scotland) and EHS (Northern Ireland).

There are currently 98 designated shellfish waters in England, 104 in Scotland, 26 in Wales and 9 in Northern Ireland constituting 237 designated shellfish waters in the UK as a whole extending over 4000 km^2. Waters designated under this Directive are formally designated through the issue of a Notice and Schedule. These are largely based on areas where there are currently stocks of commercially exploited species. The location of these sites is taken into consideration in drawing up the National Environment Programme, which is the water companies' five-yearly environmental improvement programme. This programme has an overall objective to reduce the impact of abstractions and discharges on the environment, including internationally and nationally important nature conservation sites.

The Water Framework Directive (2000/60/EC) will eventually rationalise and update existing water legislation and introduce an integrated and co-ordinated approach to water management in the whole of Europe based on the concept of river basin planning. The overall requirement of the Directive is to achieve "good ecological and good chemical status" by 2015 unless there are grounds for derogation. There is also a general "no deterioration" provision to prevent deterioration in status. These will require the management of the quality, quantity and structure of aquatic environments. The Directive also requires the reduction and ultimate elimination of priority hazardous substances and the reduction of priority substances to below set quality standards.

The overall effect of the above legislation is that coastal water quality has improved over the last few years and this improvement is set to continue.

3.7. Conservation

3.7.1. Introduction

Marine habitats are protected under various legislative frameworks such as the EC Habitats Directive (92/43/EEC), Ramsar Convention, Birds Directive (79/409/EEC), Wildlife and Countryside Act 1981 and through OSPAR's Biodiversity Committee. These include Sites of Special Scientific Interest (SSSIs), Marine Nature Reserves (MNRs), Special Areas of Conservation (SACs), Special

Protection Areas (SPAs), Ramsar sites and Marine Protected Areas (MPAs). Designated areas can, and are encouraged, to include estuaries, shallow bays and coastal waters. Within such areas, cultivation of oysters is likely to be subject to local management plans.

3.7.2. SSSIs

SSSIs are designated under the Wildlife and Countryside Act 1981. In Northern Ireland equivalent status is held by Areas of Special Scientific Interest (ASSI), designated under Northern Ireland Habitats legislation. These extend only as far as the mean low water mark (England and Wales) or the mean low water spring mark (Scotland) and, as they only cover the inter-tidal interests of the site, are of limited interest to this review.

3.7.3. Marine Nature Reserves

Marine Nature Reserves have been designated to conserve inter-tidal and shallow-sea ecosystems and coastal features. There are relatively few of these designated. They have been established at Lundy Island, Skomer Island and Strangford Lough.

3.7.4. Habitats Directive

The EC Habitats Directive (92/43/EEC) states a range of measures for Special Areas of Conservation (SACs) to avoid the deterioration of habitats and species for which the areas have been designated from damage, destruction or over-exploitation. Identified in Annexes I and II of the Directive are habitat types and species considered to be most in need of conservation at a European level because they are considered to be particularly vulnerable and are mainly, or exclusively, found within the European Union. Protection requires member states to designate areas containing good examples of those habitats and species as Special Areas of Conservation (SACs). These SACs, along with Special Protection Areas (SPAs), classified under the EC Birds Directive are known as the Natura 2000 network of important high-quality conservation sites. In September 2004, the European Court of Justice ruled that certain fishing activities would only be authorised in a Natura 2000 site when it is certain that they would not negatively affect the environment. The Court ruling makes clear that, at least where an assessment is undertaken as a basis for annual licences, an assessment under Article 6(3) of the Habitats Directive is required.

Special Protection Areas, designated under the EC Directive on the Conservation of Wild Birds, commonly known as the EC Birds Directive (79/409/EEC), provide for the protection, management and control of all species of naturally occurring wild birds in the European territory of Member States. In particular it requires Member States to identify areas to be given special protection for listed rare or vulnerable species and for regularly occurring migratory species and for the protection of wetlands, especially wetlands of international importance.

Ramsar sites are designated under the ‘Convention on Wetlands of International Importance especially as Waterfowl Habitat’ (commonly known as the Ramsar Convention). This convention ensures the conservation of wetlands and their flora and fauna by combining far-sighted national policies with coordinated international action. For the purpose of this Convention wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.

There is clearly the potential for conflict of interest between fishery and conservation interests in the inter-tidal area in designated wetlands. This has led to the closure of the cockle fishery and a curtailment of the mussel fishery in the Netherlands, in favour of ecological considerations.

The OSPAR Commission has agreed an international programme of work to implement the OSPAR Convention, a long term strategy being the protection of ecosystems and biological diversity, and, promoting the establishment and management of a system of marine protected areas (OSPAR MPA Programme). A Marine Protected Area, as per the definition developed by the World Conservation Union is “any area of the inter-tidal or sub-tidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment” MPAs are used as management tools to protect, maintain, or restore, natural and cultural resources in coastal and marine waters. The establishment and management of a system of Marine Protected Areas, is an aim of the OSPAR MPA programme. Marine Protected Areas provide a range of benefits to coastal communities and the public by enhancing fisheries, safeguarding marine habitats and increasing economic opportunities.

3.7.5. Control of slipper limpets

Recently, a proposal was received that an area of Poole Harbour was to be dredged to remove slipper limpets to facilitate oyster cultivation. The dredged animals were to be taken out of the harbour and dumped. The proposer identified an area in Swanage Bay that is used to accept dredged sediments from Poole Bay and suggested that the animals be dumped at this site. However, disposal at sea is regulated both by international conventions and domestic legislation. Under the Food and Environment Protection Act 1985, Part II a licence is needed “for the deposit of substances or articles within United Kingdom waters, either in the sea or under the sea-bed”.

The proposer had not applied for a licence and was thus advised through consultation with the local Sea Fisheries Inspectorate Fisheries Offficer and CEFAS that any disposal without licence would be illegal. However, there is an associated statutory instrument, Deposits in the Sea (Exemptions) Order 1985, which contains a schedule of operations not requiring a licence. This was taken into consideration during the consultation period and it was opined that none of the exemptions rightfully apply in this case, particularly since the dredged animal material would be purely a waste. By reference to the international London Convention Protocol 1996, Article 4 states
“1 Contracting Parties shall prohibit the dumping of any wastes or other matter with the exception of those listed in Annex 1.
2 The dumping of wastes or other matter listed in Annex 1 shall require a permit. Contracting Parties shall adopt administrative or legislative measures to ensure that issuance of permits and permit conditions comply with provisions of Annex 2.”

Annex I includes “organic material of natural origin“.

Should the proposer have applied for a licence, further considerations would have needed to be applied. Since the species is non-native, it would need to be determined if the phrase “natural origin” applies, as the animals are outside of their original natural geographic area. The disposal site is currently characterised for the deposit of dredged sediments, not this differing waste type, so a full environmental impact assessment may be required prior to the licensing authorities being satisfied that the operation would have no significant detrimental environmental impact. Until such time as a licence application is received, the legality of such an operation is unresolved.

In addition to the above legislation, the release of non-native animals into the sea falls within the scope of the Wildlife and Countryside Act 1981. This is, again, a somewhat grey area, as the south coast has established local breeding populations of this species in locally high densities.

It should be noted here that relaying of shell as cultch to encourage settlement of oyster spat is a listed exemption in The Deposits in the Sea (Exemptions) Order 1985, and so is not subject to the provisions of The Food and Environment Protection Act 1985.

3.8. Future legislation and other initiatives

A review of Marine Nature Conservation was established in 1999, by Defra, to examine how effectively the UK system for protecting nature conservation in the marine environment is working and make proposals for improvements. A cross-sectoral Working Group, to which the JNCC and the country agencies (EN, CCW, SNH) contribute, was convened to undertake the Review. The Working Group has a wide membership drawn from statutory and non-statutory organisations, industry and user groups with a particular interest in the marine environment.

A key recommendation of the final report was a proposal for a pilot scheme to test ways of integrating nature conservation into key sectors at the regional seas scale in order to make an effective contribution to sustainable development on a regional basis. Following this, the Irish Sea pilot was initiated. A report was delivered in 2004 (Vincent *et al*., 2004).

This report advocates the marine landscapes approach, using data that are currently available to enable management strategies for the marine environment to be developed and implemented. As new survey information becomes available over time, marine landscape maps could be refined.

The Water Framework Directive requires the achievement of good ecological status in transitional and coastal waters. In coastal and estuarine waters it is suggested that the marine landscapes approach should seek to complement that taken under the Water Framework Directive (in relation to typology and reference conditions) at a more detailed level.

The report further recommended that a list of internationally agreed marine landscapes for the northeast Atlantic should be developed. The list identified for the Irish Sea could be expanded and further refined as necessary to achieve this. Native oyster beds were identified in the report as one of 16, out of 25 examined, nationally important marine features in decline and under threat of further significant decline. The report has also developed a clear rationale and justification for a series of nationally important areas for biodiversity in the marine environment, and a suite of agreed criteria for selecting them. The value of identifying areas of particular importance for biodiversity is based on the principle that these areas make such an essential contribution to meeting the objective of maintaining the range and scale of biodiversity present in the country, that, unless they are enabled to maintain this contribution in perpetuity, this objective will not be met.

The means of management of Inshore Fisheries is currently under review. It is not presently clear how this would affect management of native oyster stocks although it is probably unlikely to have any effect on restoration programmes. The government is committed to bringing about changes in this area. Various conservation bodies have been advocating a more holistic approach to management of the marine environment for some time and in September 2004 the Prime Minister said in a speech “on the marine environment, I believe there are strong arguments for a new approach to managing our seas, including a new Marine Bill”.

The report commissioned by the World Wide Fund for Nature UK (Hiscock *et al*., 2005) advocates the preparation of a Marine Bill to further good stewardship of the marine environment. In a section specific to the native oyster it concludes “Establishing a system of marine spatial planning will allow for the identification of special features for protection, which can include oyster beds. A Marine Act should include provision for the designation and protection of Nationally Important Marine Sites so that locations where the native oyster occur now or have occurred in the past can be protected from potentially damaging activities. An integrated management regime implemented by a Marine Act could aid measures to reduce the arrival and spread of non-native species and diseases.”

Finally, in a recent (December 2004) report (Turning the Tide – Addressing the Impact of Fisheries on the Marine Environment. The Royal Commission on Environmental Pollution 25th Report. 480 pp.) the creation of national marine parks, which would be closed to commercial trawlers in order to protect stocks is proposed. The report recommends that about 30% of the UK's exclusive economic zone should be closed to commercial fishing for at least a time. It is generally accepted that there are arguments for restricting access to some areas for fishing, at least for certain periods, particularly in order to protect spawning stock.

SECTION 4: ECONOMIC ANALYSIS

4.1. Introduction

Cost-Benefit Analysis (CBA) is a widely used information support tool for decision–making on competing priorities. In this section a CBA of a native oyster stock regeneration program in the UK is presented. This analysis determines a framework for summarising the estimated benefits and costs associated with the implementation of a native oyster restoration program in the UK. Furthermore, it provides a judgment about whether a native oyster stock restoration program is "worth" undertaking as a public investment. Projects for which benefits exceed costs provide a net economic improvement so that, in principle (if not in practice), those who gain could fully compensate losers and still be better off.

In the case of a native oyster restoration program there are components within both benefits and costs that can be estimated through market prices. For instance, native oyster market prices can be used to estimate the value of the expected increase in oyster population due to the implementation of the restoration program. However, there are other components (i.e. externalities such as biodiversity support) that markets do not specify a value for and therefore a non-market valuation procedure is required to account for the non-marketable goods and services linked to the program. Time and resource restrictions constrained this study to focus on the marketable costs and benefits of the project. Consequently, an estimation of the monetary value of the externalities through an environmental valuation procedure could not be conducted. In order to account for non-market values benefits derived from a similar native oyster regeneration program conducted in the US are determined and non-use values of this experience are reported.

Due to the specific geographical characteristics of the UK's coastline, the use of existing natural beds combined with the placement of shell (cultch) is thought to be the only suitable technique to conduct a restoration program in the UK. This can be achieved by applying different methods such as growing oysters in the wild, on-growing cultivation (i.e. hatcheries, ponds) or placing half grown native oysters on the ground.

A native oyster restoration program will have direct and indirect impacts on the oyster sector and related sectors in the whole economy. In addition to the direct benefits to the industry derived from the restoration program (i.e. an oyster fishery can be exploited once the restoration program is completed), flows to other sectors in the economy in monetary and employment terms should be taken into account.

Information about the native oyster natural dynamics and the economic agents' (i.e. native oyster cultivation managers, fishermen) behaviour is crucial to determine the potential economic outcomes of any restoration program. Therefore, a good understanding of both social and environmental aspects associated with oyster cultivation are decisive to undertake this study. Conversely, little is known about wild oyster population dynamics (e.g. oyster growth rate, density dependence issues and interaction with other species) in the UK.

Time is particularly important when programs take many years to materialise, since future benefits and costs derived from the implementation of the programme have to be discounted. This study assumes a time-scale of 20 years to develop the native oyster restoration program. In addition, inflation is taken into account since monetary flows related to operational costs change through time. Therefore, the present value of a stream of future revenues and costs is provided.

It is worth noting that no detailed costing for native oyster restoration schemes was found in the literature. Only a study for the Spanish case of the oyster culture enterprises where the productive system and the profitability are analysed was found.

Nevertheless, the study shows different outcomes depending on the expected market price and whether or not non-market values are taken into account. If non-market prices are not included the import of half-grown oysters method appears to be "worth" implementing even if native oysters prices are £1,000/tonne during the period studied and a yield of 3 tonnes/ha is achieved. A similar result is obtained for the introduction of native oyster seed in the wild, followed by natural regeneration. Other methods such as hatcheries and the use of ponds may be worth implementing if high yields can be achieved and prices are sufficiently high. Conversely, native oyster production is not economically profitable if prices are as low as £1,500/tonne for these two methods. However, there is a considerable level of uncertainty about the success of the program and the right amount of seed required. If non-market values are taken into account the implementation of a restoration program is likely to be "worth" independently of the program used from a social point of view.

4.2. Native oyster dynamics

Before discussing the detailed costs and benefits of the restoration program it is important to review what is known about the native oyster dynamics in the UK. Information on the dynamics of the species is relevant to obtain estimates of the expected population in future and therefore estimate the costs and benefits of the program. Unfortunately, there is very little relevant information on wild oyster dynamics in the literature. On the other hand experience from oyster on-growing cultivation provides valuable insights into variables such as seed survival rates under on-growing conditions.

Only a percentage of the larvae brooded will survive and form part of the collectable biomass. The survival rate will depend on the circumstances (e.g. wild seed or on-growing) (Guerra, 2002). Korringa and Marteil estimated the survival of the native oyster in the wild in each life stage until the oyster is 1 year old (Table 4.2.). Obviously, this estimation may vary depending on factors such as site characteristics (e.g. predators, diseases, temperature, quality of the cultch) and time. Table 4.2. shows that each female of approximately 4 years old places one million larvae and usually only 2 larvae survive after 1 year. Estimation of the oyster total biomass available in a specific site is crucial to discern the availability of a resource and therefore assess the success of a restoration program. The biomass that can be collected is explained by three essential factors: recruitment, growth and mortality. More research is needed to investigate these factors for native oysters in the wild.

Table 4.2. Native oyster survival rates for each life cycle stage

Life cycle stages of the native oyster	Units	Survival rate (%)
Larvae emitted to the environment	1,000,000	
Larvae surviving metamorphosis	250	0.025
Spat surviving first winter	14	0.0014
1 year old oysters	2	0.0002

Source: Guerra (2002)

Apart from the number of individuals the total biomass depends on individual size. Oyster's growth depends on factors such as temperature, food supply and shell length or mass. Conversely, mortality can reduce the biomass. Mortality rates depend on factors such as diseases, resources available, competitors, predators and human exploitation. The aim of renewable resource exploitation such as oysters is to find the population equilibrium through time. This will happen when the amount of oysters collected equalises the natural growth of the renewable resource.

4.3. Brief description of the restoration methods

There are three processes involved in native oyster production: seed production, nursery and on-growing. As described below, not all the restoration systems studied require every production process.

As noted previously a set of alternative methods can be applied in order to regenerate native oyster stocks in the UK. Oyster cultivation depends on the availability of seed and their survival rate. The oldest method of oyster cultivation is the management of natural oyster beds. On the other hand, oyster restoration by hatcheries implies that sufficient seed can be produced in this system.

This study analyses the costs and benefits associated with each of the following alternative methods of native oyster restoration.

1) Native oyster production in the wild
2) Native oyster cultivation in hatcheries
3) Alternatives to hatcheries: the use of ponds.
4) Putting down half grown imported native oysters (18 months).

1) Oysters in their natural state are attached on an appropriate substratum on the seabed. Seed from larvae setting on a suitable substratum create oyster populations. The oldest method to grow oysters involves the use of clean oyster shells as the substratum. Other materials that can be used are roof tiles, plastic, mussel shells and cellulose plates. Whereas roof tiles are still used as substrate in other parts of the world such as France and Holland they have not been used for approximately 50 years in the UK. The abandonment of this technique may be due to a cost inefficiency of this technique in the UK. In this study, this method consists of creating an appropriate substratum in an area with a residual oyster population, together with priming with a large seed input during the first year, subsequently leaving the population to regenerate naturally.

2) Hatcheries allow the supply of large quantities of seed and half grown oysters, since the seed production process is continually controlled step-by-step (e.g. appropriate conditions for the reproduction of oysters, larvae cultivation). This system guarantees a stable oyster supply.

   Three phases can be identified in the oyster productive process by hatcheries:

   - Conditioning and spawning of broodstock
   - Larvae cultivation
   - Seed or spat cultivation

3) The use of ponds is an alternative production method to hatcheries. It is a simple and versatile low cost system. It consists of a set of interconnected spatting ponds where once the oysters reach a suitable size they can be placed on the ground.

4) This method is the simplest of all. Native oyster seed need to be purchased from disease free areas, such as Denmark, and introduced into the environment (e.g. into the wild or a controlled environment such as a hatchery). This stage is not required for the restoration option where half grown native oysters are used.

Usually, there are 4 variables that determine profitability of the nursery and on-growing stages.

- Variety of the oyster used (e.g. *Ostrea edulis*) which determines growth and survival parameters as well as market prices.
- The ecosystem where the oyster population is located. This dictates survival and growth rates.
- Type of installation and technology used.
- Density and size of the seed.

Therefore, the productivity in any type of installation is conditioned by biological factors such as ecological features of the location, size and weight of the seed.

(Luna, 2002) identifies five stages in the nursery and on-growing process. These are:

- Infrastructure acquisition and preparation. Installation costs and legal permission costs are included in this stage.
- Acquisition of oyster seed and transport to the production site.
- Growth. Costs are related to the growth and survival rate. Other factors that may influence the cost are the complexity of the process and labour costs.
- Oyster harvesting and sale. This study does not include these costs since it accounts for a 20 years period without resource exploitation.

Native oysters grown in the wild do not pass through a hatchery or nursery stage. They are continually exposed to environmental conditions such as temperature changes, high-densities of predators and diseases. Conversely, native oyster production in hatcheries have a hatchery and nursery stage which requires capital investment to obtain a more stabilised oyster production through time by controlling environmental conditions. However, hatcheries contribution to wild stock remains a major issue. A lower cost alternative to this process is the use of restricted areas to grow native oysters such as ponds.

Once the native oysters kept in hatcheries, or in alternative production systems such as ponds reach a given size they will be placed on the ground where natural beds already exist and where cultch was placed previously. In the case of the half grown imported oysters, they would be placed on the ground without any previous process apart from relaying of cultch.

It is worth noting that the uncertainty of success is very large where native oysters are allowed to regenerate naturally in the wild: putting down shell is unlikely to achieve production unless there is already substantial native oyster broodstock nearby. On the other hand, hatcheries have produced relatively very few native oysters due to the problems of low survival. Therefore, the use of ponds for seed production or importing half grown oysters from e.g. Denmark seem to be the best and most viable alternatives.

In order to reduce the risks of diseases and predator effects, it is assumed that a feasibility study will be conducted to select a suitable site to implement the program. The study is costed on the assumption that it will be done within a set of sites where native oyster populations are known to exist. The selection of the suitable sites will be on the basis of existing native oyster disease free beds, as illustrated in the Section on Current Status and Attempts at Restoration.

4.4. Identification of the costs of restoration

As noted previously this study assumes a time-scale of 20 years to develop the native oyster restoration program. Therefore, costs associated with exploitation of the native oysters after the restoration program is completed are not contemplated.

The main economic cost components associated with the oyster restoration program are split into capital and operational costs. These costs can vary significantly depending on the nature of the restoration strategy and the site characteristics. This study examines a restoration program based on the use of shells as substrate for oysters.

4.4.1. Capital costs

Capital costs are divided into pre-construction and construction costs. Pre-construction costs include the initial feasibility studies and site surveys to identify the most suitable sites to conduct the restoration program as well as the objective setting, planning and design of the program, and any required permissions for using the site. On the other hand, construction costs include substrate preparation, equipment, labour, materials, stock and transport. In addition, building and equipment such as tanks and water cleaning systems are included for the hatcheries.

a) Pre-construction costs. Case studies would be needed for each of the four alternatives. They serve to identify the most suitable areas to conduct the restoration program (i.e. where the program is most likely to succeed). This generally entails areas free of disease and with low numbers of pests or predators. Estimation of the costs and benefits derived from the program is based on restoration attempts in areas where no pests or diseases have been recorded.

The case studies will include a report, which provides a general description of the area and the identification of relevant site selection factors as well as an estimation of the current oyster population in order to evaluate the success of the restoration project. In addition, basic indicators of the quality of environmental resources such as water quality and biodiversity are also included in the report. The costs associated with this preliminary feasibility study are on the assumption that the study will be conducted by a professional high quality survey organisation. It is assumed that the task will begin in 2005/2006 for an oyster restoration programme of 10 sites across the UK, including some that are known from past studies. The study will require:

- 2 scientific staff involved
- 3 days report preparation (3 md)
- 2 days travelling to the sites (6 md)
- Subsistence costs (e.g. meals)
- Accommodation (4 nights)
- 3 days vehicle hired (approx. 600 miles)
- Boat hired with crew
- 1 day survey (2md)

- Therefore, 11 man-days would be needed per site for the feasibility study of 10 sites across the UK. Travel costs should be added to these costs.

Survey costs are variable depending on the site. For instance, larger prospective areas would need more time to be surveyed. An estimate of 1-3 days is considered in this report.

b) Construction costs. Once the site case studies are conducted a set of suitable sites where natural native oysters populations exist and the site is disease free can be selected. It is worth noting that although the case studies would be conducted in areas where no disease problems have been recorded, this does not assure that such problems do not appear when the study is carried out.

The rehabilitation of natural beds requires the establishment of cultch. The cost of cultch creation must be included in the capital costs. It is worth noting that geography deters from using other oyster cultivation techniques such as the use of rafts. Rafts are used in deep areas such as the north-western area of the Spanish coast. In the UK such a technique may be used in the south west of England. Costs associated with cultch are transport costs of the substrate (e.g. shells), which can vary between £500-1,500 depending on the distance. The price for scallop shells vary from £500-£600 for a lorry load of 30 tonnes. It is assumed that price for mussel shells are not significantly different and between 300 and 400 tonnes would be required for an area of approximately 130 ha. In addition a boat would be required for this process and for tasks such as placing the seed/oysters on the ground and cleaning the ground. It is assumed that the boat is bought and its costs would be between £75,000-£150,000.

The oyster cultivation in hatcheries involves conditioning the oyster to spawn by providing cultured algal food and holding them in warm (20°C) water. The larvae, when released by the brooding oysters are grown in rearing tanks where they settle after a time on black plastic mats suspended within the tanks. After the spat reach 2-5 mm they are removed from the surface and placed in upwelling systems to grow on. Capital costs such as building, tanks, water-cleaning system, and nursery to build the spat must therefore be taken into account. A total estimate for these elements (building is not included) is approximately €72,500-135,000 (£50,000-95,000) for the whole program (Luna, 2002). Capital costs are higher in this system which has lower survival rates when the oysters are placed on the ground, and therefore more spat are required. This study assumes a yield of 4-5 tonnes/ha. In addition, operational costs including between 3-5 people would be needed.

The use of ponds is a simple and versatile low cost system. This study considers the use of a set of 30 interconnected spatting ponds that require approximately 5ha of land and 20ha. of sea ground. This system implies capital costs on the ponds, which is approximately £10,000 per 1M litre pond (i.e. 25 m^2 and 2 metres deep). Yields achieved using this system in good years have been approximately 8 tonnes/ha (personal communication with David Hugh-Jones, Atlantic Shellfish Ltd.). In this study we assume a more conservative estimate of 4-5 tonnes/ha.

4.4.2. Operational costs

Operational costs include maintenance and monitoring, which comprise costs such as materials, equipment, staff wages, expenses and general administrations and seed costs. Maintenance and monitoring are essential to assess the success of the restoration scheme. The ground would have to be constantly managed to ensure predators such as starfish and oyster drills are not a problem. Furthermore, in order to protect the native oyster beds 24-hour surveillance is required. The surveillance would be conducted during the project's life span and it would involve the use of a boat and between 3-6 staff.

Monitoring would be carried out by 2 scientific staff using between 2-5 days per year depending on the size of the site whereas cleaning the ground of potential predators is necessary and it would be done by two staff during the summer (when spawning occurs) using relatively cheap methods such as mops or lines.

For production of native oysters in the wild, native oyster seed needs to be introduced during the first year of the program. In order to place these seed, or half grown oysters, on the ground, two people and a boat would be required. It is estimated that for an area of 100 ha. 2½ hours per day would be needed during two consecutive days. It is worth noting that the seeding process needs calm waters to allow the seed to attach to the substrate.

Price for seed is £2 per thousand per mm sieve size. So for example, if 5-12 mm oysters were bought, the cost would be £10-£24 per thousand. For an area of 100 ha. it is assumed that approximately 10,000,000 seed (£100,000-240,000) would be required and a harvest of 3-5 tonnes/ha can be achieved (this may vary depending on the system used and the site's characteristics) for production in the wild. On the other hand for the case of hatcheries approximately 300,000 seed are required per year for an area of 30 ha.

Alternatively, half grown native oyster could be imported from a *Bonamia* free area e.g. Denmark for a cost of approximately £2.90-£4.10 /100 seed, The oyster unit cost varies depending on the number of seed which could vary from 60 to 80 per kg, and their quality.

Table 4.4 1. Survival rates in the seeding phase using hatchery techniques

Phases of the native oyster seed	Units	Survival rate (%)
Larvae	12,000,000	
Fixation/post-larvae	3,000,000	25.0
Seed (5mm)	1,000,000	8.3

Source: Guerra (1998)

These phases require different installations and biotechnology

Table 4.4 2. Seed production. Hatchery vs. natural bed

Hatchery and alternative methods	Natural bed
Seed is obtained regularly	Seed is obtained randomly
Installations on land required (costly)	Seed is well adapted to environmental conditions
Seed input required	In order to obtain regular seed important stocks are needed in the environment
Possibility of progenitor selection	Progenitor selection is not possible
Qualified personnel are required	This method is simple, economical and qualified labour is not needed
	Large surface required

Source: Guerra (2002)

4.5. Benefits

Benefits of the implementation of the program are estimated as the value of the stock at market prices. Therefore, market native oyster prices and expected yields are used in order to estimate the "use benefits" of the program. It is assumed that the program will produce its benefits from its 7th year. Although this CBA only accounts for the project life span it is worth noting that once the program is completed fishermen may exploit the resource, which would mean (if the resource is not overexploited and diseases do not affect it) future income to fishermen. These benefits are shown in Table 4.9.7.

4.6. Non-use benefits

The total economic value of an environmental public good such as a native oyster restoration program comprises not only the use value (i.e. production value) but primarily the non-use values (i.e. conservation value). Use values can be divided into actual use (direct or indirect) and option value whereas non-use values refer to existence value of the native oyster. Use values may be direct (e.g. visiting a site for recreation) or indirect (e.g. by securing some benefit from the good). The public willingness to pay (WTP) for a public good (such as the native oysters) existence in the UK reflects the existence value; the public's WTP for future availability of the resource (for future generations) is known as bequest value. This includes also their WTP to avoid an irreversible loss of the resource. Finally, the public's WTP for a good, even though he or she makes no direct use of it, may not benefit indirectly from it and may not plan any future use for themselves or others is known as existence value (Pearce *et al.*, 2002). There are a variety of techniques available to assess the total economic value of environmental public goods (Freeman, 1993). The basis for estimating benefits is the public's willingness to pay for the improvements.

Total economic value:

TEV= Use Value + Non-Use Value
UV= Current use + Option Value
NUV= Existence Value

The implementation of a native oyster regeneration program would bring more benefits apart from those purely marketable. Native oysters provide environmental services such as water quality and habitat improvement for the overall health of the ecosystem (Hicks *et al.*, 2004). In 2004 a report prepared for the Chesapeake Bay Foundation investigated the economic benefits of oyster reef restoration in the Chesapeake Bay. This report focused on two groups, recreational fishermen and general public, who will benefit from such program.

Oysters in the Bay studied have been reported as a keystone species that provides ecological services, which benefit other species and overall ecosystem functioning. These functions include filtering of algae and sediment resulting in increased water clarity. With an increase in clarity, other aquatic species, such as seagrasses, can flourish. This synergistic effect can lead to suitable habitat for many species of fish and birds. Oysters, and in particular, oyster reefs provide important services leading to a healthy and valuable Bay ecosystem.

With regards to the costs associated with an oyster reef restoration the Virginia Marine Resources Commission has concluded that reef creation in the lower Rappahannock River costs, on average, \$14,800 (£7,800; exchange rate at 4/01/2005 1\$=£0.53) per acre or \$27.97 M (£14.82 M) for a creation of a reserve area of one acre of three dimensional reefs surrounded with 25 acres of hard bottom created using oyster shells. The reserve area is designated as off limits to commercial oyster harvest, while the surrounded areas were open to commercial harvest once established oysters are present on them. Costs per site estimates are based on the creation and seeding of a one acre 3 dimensional reefs (\$103,125; £54,656), labour contracts (\$31,200; £16,536), and the creation of 2 dimensional hard bottom of oyster shell on surrounding 25 acres (\$250,000; £132,500) (Virginia Oyster Reef Heritage Foundation).

In the Chesapeake Bay's study 77% of respondents from the general public in five US states (Delaware, Maryland, New Jersey, North Carolina and Virginia) ranked the environmental role of oysters as the most important factor of a regeneration program followed by fish habitat. It was found that the willingness to pay for a 10,000 acre oyster sanctuary with 1,000 acres of constructed oyster reef to be at least \$14.91 (£7.90) per household per year. Aggregating to the general population, it was estimated the non-use value of a ten year oyster reef project, consisting of 10,000 acres of oyster sanctuary and 1,000 acres of artificial reef to be at least \$114.95 M (£60.92 M).

The total number of households in the UK is approximately 24.5 million (National Statistics, 2001 Census). Assuming that the people's willingness to pay for this restoration program in the UK was similar to the US study (£ 7.90) the total economic value of an oyster restoration program would be approximately £49M per year.

4.7. Profitability indicators

Cost-effectiveness means adoption of the least-cost way of achieving a given objective. The cost effectiveness of a project can be analysed by using economic indicators such as the Net Present Value (NPV). The NPV is calculated from the following equation, in discrete time, and assuming the interest rate is kept constant during the period studied.

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1 + r - i)^t}$$

where B_t are the benefits in the year t, C_t are the costs in the same year t, r is the interest rate, i inflation rate and T is the life span of the project.

An alternative cost effectiveness indicator is the Internal Rate of Return (IRR):

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1 + IRR - i)^t} = 0$$

IRR is the interest rate that would equalise benefits and costs. Therefore an *IRR* higher than the interest rate show that the investment is "worthy". In this study *IRR* higher than 2.25% are considered as a profitable investment.

The Benefit/Cost ratio shows the coverage of costs by the expected benefits and, like the NPV, is an indicator of the social viability of the proposed project. For instance, if the ratio of benefits to costs is 3.0 meaning that the benefits are three time the costs.

4.8. Risk and uncertainty aspects

Risk and uncertainty aspects are introduced in the analysis by the use of different scenarios (i.e. sensitivity analysis) that represent optimistic and pessimistic results.

4.8.1. Diseases

As noted previously there are risk factors that may affect oyster stock populations such as predators (e.g. oyster drills or tingles, starfish, sea urchins and crabs), diseases (*Bonamia ostreae* and *Marteilia*) and competitors. The diseases are particularly important, *Bonamia ostreae* commonly causes over 90% mortalities in infected populations and while *Marteilia* is currently absent the possibility that it may spread to the UK cannot be ignored.

4.8.2. Predators

The impact of predators on native oyster populations is an aspect to take into account when oysters are introduced into an ecosystem. It has been reported that the greatest impact on oysters by predators occurs in the younger stages as larvae or spat. At this stage between 21 and 91% of oyster larvae could be lost. Starfish are also considered to be an important predator of oysters.

The relative fertility of the native oyster varies with age. Therefore the age of the introduced oysters will produce different outcomes in terms of the cost-benefit analysis. The greater the spat the more expensive it is and the greater the survival rate.

Very little is known about the oyster's population dynamics. Population dynamics are influenced by density as a function of the mortality rate; the individual growth rate, which depends on environmental factors such as temperature and salinity; and the inter-individual variability. On the other hand the daily growth rate depends on the local conditions of temperature and food and individual weight. The management strategy of the producers defined by the timetable of seeding and harvesting is also important.

Obviously, growing native oysters in natural beds is not a method as controlled as cultivating oysters in hatcheries. This means that oysters may be at higher risk of diseases, predators and competitors. In order to reduce the impact of predation cultivation requires regular maintenance (i.e. maintenance costs) of beds to remove those predators together with weed and sediment. This is time consuming would need the use of a boat provided with sonar to locate the starfish and two people cleaning the ground during the summer. Cleaning costs vary according to the method used. Low cost options include the use of ropes or baits to catch starfish. The use of mop rollers, on the other hand, is more expensive.

4.9. Cost-benefit analysis results

Due to the uncertainty about the possibility of the occurrence of a disease and how this would affect the oyster population, estimation of the benefits and costs associated with the program may be inaccurate. However, this CBA can help to identify the best options *a priori* under "normal" circumstances.

This study assumes that a stable level of production will be reached at the end of the sixth year of the program. Consequently, benefits derived from an increase in the native oyster population are taken into account from the seventh year to the end of the project.

The major costs and benefits attached to an oyster regeneration program are enumerated in Table 4.9.1. In order to obtain the NPV constant interest (Treasury base rate of 4.75%) and expected inflation (2.50%) rates per year were assumed. Therefore a real interest rate of 2.25% is applied to the analysis.

The largest costs for all the production methods are the operational cost, which account for approximately 90% of the total costs of the project. However the structure of these costs varies depending on the production method used. In the case of native oyster production in the wild seed costs for priming the site in the first year account for approximately 2-18% of the operational cost. Staff wages are crucial costs for the hatcheries and the use of ponds for native oyster production where these costs represent between 67-75% of the total operational costs. A much lower percentage (1%) is attributed to the production methods where half-grown oysters are used and for production in the wild. Surveillance is also a significant cost for the hatcheries and ponds (20-27% of the total operational cost). Due mainly to the low importance of other costs associated with the method of production in the wild and introduction of half-grown native oysters, surveillance costs are approximately 70-80%. This is based on a 24 hr surveillance programme to give complete assurance of the security of the stocks. The costs would be reduced pro-rata for a lower level of surveillance. There should be scope for this without a significant increase in risk of loss of the restored stocks but the actual level would depend on local factors, including the position of the site.

Results based on market prices show that it is "worth" undertaking the restoration program using any production method if variables such as price and yield behave positively. Nevertheless, the best options seem to be the introduction of 1,000,000 imported half-grown oysters per year during the whole project in an area of 100 ha or priming a site of a similar size where there is a residual population and allowing natural regeneration. It is worth noting again that success of this latter option is highly uncertain.

More favourable results for the implementation of a native oyster restoration program are likely to appear when non-use values are taken into account. Assuming that the general public in the UK have similar preferences for native oysters than the general public in the US and that the programs were similar in both countries the implementation of a restoration program would be "worthy" from a social point of view. Even if the general public in the UK valued native oysters 100 times less than the American public the implementation of the program would be worthy. This highlights that non-market values are clearly the most important element within the TEV.

The results shown in Table 4.9.1 are based on a programme conducted in a site. The production in the wild and introduction of half grown oysters methods can be implemented in larger areas than is possible with the finite production available from hatcheries and ponds. For a program at a regional or national level and under the assumption that economies of scale are not relevant the outcome in terms of benefits costs ratio would be similar to those obtained in the one site case.

Table 4.9.1. Costs Benefit Analysis. Summary of results.

	Wild (100 ha)		Hatcheries (30 ha)		Ponds (30 ha)		Half-grown oysters (100 ha)	
COSTS	Min	Max	Min	Max	Min	Max	Min	Max
Feasibility study; survey	60,000	100,000	60,000	100,000	60,000	100,000	100,000	100,000
Objective setting, planning+design, license	5,000	10,000	5,000	10,000	5,000	10,000	5,000	10,000
Preconstruction costs(£)	65,000	110,000	65,000	110,000	65,000	110,000	105,000	110,000
Building			100,000	200,000				
Substrate preparation (cultch)	10,000	21,000	3,000	7,000	3,000	7,000	10,000	21,000
Equip. (tanks, water cleaning syst., nursery)			50,000	95,000	30,000	30,000		
Boat	75,000	150,000	75,000	150,000	75,000	150,000	75,000	150,000
Substrate Preparation (Labour)	548	1,096	183	365	183	365	548	1,096
Construction costs(£)	85,548	172,096	228,183	452,365	108,183	187,365	85,548	172,096
Capital costs (£)	**150,548**	**282,096**	**293,183**	**562,365**	**173,183**	**297,365**	**190,548**	**282,096**
Seed cost £	100,000	240,000	38,449	38,449	38,449	38,449	353,957	500,422
Reg. Maintenance+ survey	375,147	375,147	125,049	125,049	125,049	125,049	375,147	375,147
Staff wages	500	500	1,596,371	2,394,557	1,596,371	2,394,557	3,499	3,499
24 h. surveillance (3-6 people)	1,915,645	1,915,645	638,548	638,548	638,548	638,548	1,915,645	1,915,645
Operational costs (£)	**2,391,292**	**2,531,292**	**2,398,417**	**3,196,603**	**2,398,418**	**3,196,603**	**2,648,249**	**2,794,713**
TOTAL COST (£)	**2,541,840**	**2,813,388**	**2,691,600**	**3,718,968**	**2,571,600**	**3,453,968**	**2,798,796**	**3,036,809**
BENEFITS								
Native oyster market price (£/tonne)	1,000	2,500	1,000	2,500	1,000	2,500	1,000	2,500
Expected net quantity produced (tonnes/ha)	4	5	4	5	4	5	4	5
BENEFITS (at market prices) (£)	4,163,694	13,011,544	1,249,108	3,903,463	1,249,108	3,903,463	4,163,694	13,011,544
WTP (£)	782,221,906	782,221,906	782,221,906	782,221,906	782,221,906	782,221,906	782,221,906	782,221,906

Table 4.9.2. Profitability indicators

Profitability indicators	Wild (100 ha)		Hatcheries (30 ha)		Ponds (30 ha)		Half-grown oysters (100 ha)	
	Min	Max	Min	Max	Min	Max	Min	Max
NPV (market prices) ('000)	1,620	10,468	-1,442	184	-1,322	449	1,340	9,925
IRR (market prices)	13.0%	31.0%	Non-prof.	3.2%	Non-prof.	5.1%	10.0%	26.7%
BENEFITS/COSTS RATIO	1.6	4.6	0.5	1.0	0.5	1.1	1.5	4.2
BENEFITS (TEV) /COSTS RATIO	307.7	278.0	290.6	208.1	304.2	223.9	275.5	254.2

Tables 4.9.3-4.9.6 show results for a sensitivity analysis for yield and price assuming the stock restoration program incurs low costs and high costs.

Hatcheries and the use of ponds can be economically profitable provided high yields and prices prevail. At 4 tonnes/ha and prices under £2500/tonne the implementation of the program could be profitable if the program is carried out for a longer period of time. However, the implementation of a native oyster stock restoration program is more likely to be economically profitable using half-grown native oysters or with native oyster stock regeneration in the wild.

The shaded cells show those cases when the investment is economically profitable.
n.p. indicates those options that are not profitable to be carried out.

Table 4.9.3. Sensitivity analysis for production in the wild (IRR)

Price	Low cost Yield				High cost Yield			
	5 tonnes/ha	4 tonens/ha	3 tonnes/ha	2 tonnes/ha	5 tonnes/ha	4 tonnes/ha	3 tonnes/ha	2 tonnes/ha
£2,500	34%	30%	25%	17%	31%	27%	22%	15%
£2,000	30%	26%	20%	13%	27%	23%	18%	11%
£1,500	25%	20%	15%	7%	22%	18%	13%	5%
£1,000	17%	13%	7%	-3%	15%	11	5%	-4%

Table 4.9.4. Sensitivity analysis for production in hatcheries (IRR)

Price	Low cost Yield				High cost Yield			
	5 tonnes/ha	4 tonnes/ha	3 tonnes/ha	2 tonnes/ha	5 tonnes/ha	4 tonnes/ha	3 tonnes/ha	2 tonnes/ha
£2,500	10%	6%	-1%	n.p.	3%	-2%	n.p	n.p.
£2,000	6%	0%	-9%	n.p.	-2%	-10%	n.p	n.p.
£1,500	-1%	-9%	n.p	n.p.	n.p	n.p.	n.p	n.p.
£1,000	n.p	n.p.	n.p	n.p.	n.p	n.p.	n.p	n.p.

Table 4.9.5. Sensitivity analysis for production using ponds (IRR)

Price	Low cost Yield				High cost Yield			
	5 tonnes/ha	4 tonnes/ha	3 tonnes/ha	2 tonnes/ha	5 tonnes/ha	4 tonnes/ha	3 tonnes/ha	2 tonnes/ha
£2,500	12%	7%	0%	n.p.	5%	0%	-12%	n.p.
£2,000	7%	1%	-8%	n.p.	0%	-9%	n.p.	n.p.
£1,500	0%	-8%	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
£1,000	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.

Table 4.9.6. Sensitivity analysis for production using half-grown native oysters (IRR)

Price	Low cost Yield				High cost Yield			
	5 tonnes/ha	4 tonnes/ha	3 tonnes/ha	2 tonnes/ha	5 tonnes/ha	4 tonnes/ha	3 tonnes/ha	2 tonnes/ha
£2,500	34%	30%	24%	15%	31%	27%	21%	13%
£2,000	30%	25%	19%	11%	27%	22%	17%	8%
£1,500	24%	19%	13%	4	21%	17%	11%	2%
£1,000	15%	11%	4%	-10%	13%	8%	2%	n.p.

4.9.1. Oyster sector analysis

The UK has a substantial fish processing industry of around 563 businesses, which employ some 18,480 people. At the retail level there were approximately 1.4 thousand fishmongers in the year 2003. 87.3% in volume and 88.2% in value, excluding canned produce was sold through supermarkets. Fish is also consumed in restaurants and in take away form, from fish and chip shops. A small proportion of the catch is used to make fish oils and animal feeds. Some of the species caught by UK fishing vessels find a better market abroad and these species are usually exported or landed directly abroad. In 2003, UK vessels landed directly into non-UK ports 187,000 tonnes of sea fish with a value of £129 million (DEFRA).

Seafood can be divided into three separate categories:

- **Demersal** – whitefish including cod, haddock, plaice, whiting, pollack, saithe (coley), hake, monk/anglerfish, dover sole, lemon sole, megrim, witches, brill, turbot, halibut, dogfish, skates, rays, John Dory, bass, ling, catfish, redfish etc.
- **Pelagic** – oily fish including herring, mackerel, pilchard, sprat, horse mackerel, whitebait, tuna etc.
- **Shellfish**
  - Molluscs including scallops, oysters, cockles, mussels, winkles etc.
  - Crustacea including nephrops (scampi, langoustines), crabs, lobsters, crawfish, shrimps etc.
  - Cephalopods including octopus, squid, cuttlefish etc

Seafood processes are classed as:

- **Primary** (processes include cutting, filleting, pickling, peeling, washing, chilling, packaging, heading and gutting); or
- **Secondary** (processes include brining, smoking, cooking, freezing, canning, de-boning, breading, battering, vacuum & controlled packaging and the production of ready meals).

Employment in firms carrying out only primary processing has declined by 42% since 1995 (SEAFISH).

The oyster's sector represents a very small segment in both the shellfish and the fishery industry as a whole in the UK. The oyster industry can be divided into two different groups: wild oyster production and oyster cultivation in hatcheries.

Wild native oyster production is a niche market in the UK. Thus, in 2003 the share of the landings of wild oysters with respect to the total shellfish and the total fishing industry were 1.0% and 0.5% respectively in terms of market value (Defra Fisheries statistics unit). The landings of oyster in 2003 at Major Ports in the UK by the UK Fleet were 748 tonnes, which were valued at the market at £815,000, which shows that oysters are a high valued good.

Data for Scotland show that prices for native oysters were £0.50 per shell in 2001. This meant 0.75% and 2% of the total value of shellfish value in 2001 and 2002, respectively.

As an example of the small size of the oysters sector plays in the fishing sector Scottish native oysters production are entirely located in the region of Strathclyde and they are all for the table. With regards to employment allocated to shellfish production only 2 out of 58 companies in 2001 and 53 in 2002 produced native oysters in Strathclyde (Scotland). Total employment in shellfish companies in Strathclyde was 143 in both 2001 and 2002 including full-time, part-time and casual workers.

Native oyster production depends on its demand. Oysters demand is usually highly influenced by the proximity of production areas. In addition a set of factors such as volumes landed, quality, size, availability of alternative supplies, consumer demand and prices at other ports drive oyster prices. With regards to the quality, studies in France and Spain (Polanco *et al*., 2002) (where consumer attitudes to oyster consumption were investigated show that aesthetic (e.g. the oyster should come to the market place clean and it is highly valued if its shape is round) is a major characteristic of quality as well as taste.

Costs of exploitation should be estimated and compared with the expected benefits in order to examine the profitability of fishing the oysters. Table 4.9.7. shows the market benefits expected from oyster's exploitation.

Table 4.9.7. Market benefits after the stock restoration is completed

Year	5 tonnes/ha			
	30 ha		100 ha	
	£1000/tonne	£2500/tonne	£1000/tonne	£2500/tonne
21	30,000	75,000	100,000	250,000
22	30,000	75,000	100,000	250,000
23	30,000	75,000	100,000	250,000
24	30,000	75,000	100,000	250,000
25	30,000	75,000	100,000	250,000
26	30,000	75,000	100,000	250,000
27	30,000	75,000	100,000	250,000
28	30,000	75,000	100,000	250,000
29	30,000	75,000	100,000	250,000
30	30,000	75,000	100,000	250,000
NPV (£'000)	**£266**	**£665**	**£887**	**£2,217**

A restoration program where restoration is successful at 10 sites will have a positive impact on the oyster sector by increasing native oyster production in 20 years time between 2,500-5,000 tonnes per year, which could imply between 150-300 people directly employed. The indirect effects on the fishery industry and the whole economy will not be significant due to the small niche that the native oyster industry represents.

SECTION 5: CURRENT STATUS AND ATTEMPTS AT RESTORATION

5.1. Introduction

Ostrea edulis has a wide geographical range which extends from latitude 65°N in Norway, along the west coast of Europe as far as Spain, and further south along the Atlantic coast of Morocco. It extends into the Mediterranean, primarily along the north coast and penetrates into the Black Sea as far as the Crimea. It once formed extensive beds all around the UK coast, but these natural populations have declined considerably.

Landings of native oysters in Europe have been in decline since the early 1990s and are currently at relatively very low levels (see Figure 5.1.1.). The fall during this period is party explained by unsustainable exploitation of stocks in Greece and Turkey and figures for oyster landings in earlier periods show a similar pattern for other countries, together with a decline following the introduction of *Bonamia*.

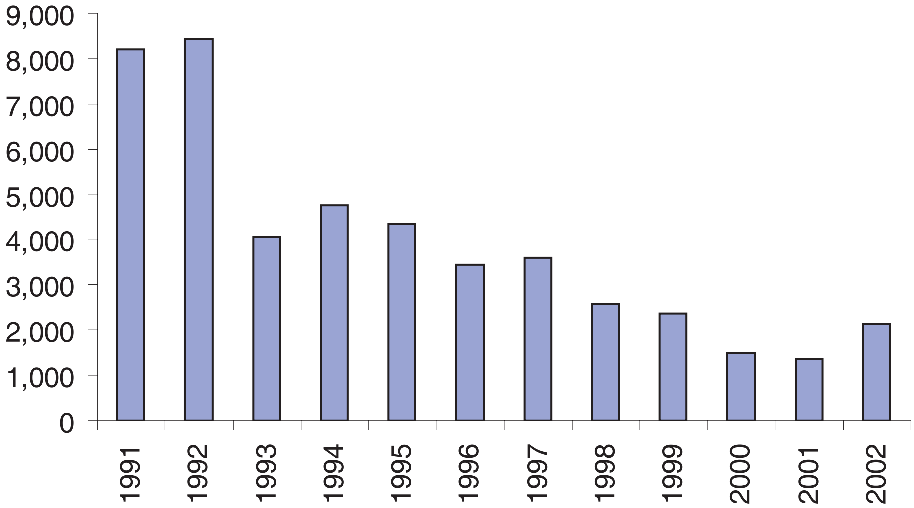

Figure 5.1.1. Native oyster landings (tonnes) in Europe 1991-2002 (FAO data)

As a cultivated species, native oyster production in Europe is currently mainly from Spain and France (see Figure 5.1.2.). Care should be taken in interpretation of the data however as it is sometimes uncertain to what extent cultivation has been distinguished from landings from wild fisheries where the beds are actively managed. Cultivation has shown a small but sustained increase over the previous nine years, although it should be noted that these totals represent less than one percent of all mollusc production in Europe, making native oysters a very minor species in this respect.

We can make many assumptions on the feasibility of native oyster stock regeneration from the knowledge gained from previous scientific studies related to the biological and technical aspects of native oyster stock restoration. However, these studies invariably examine at most a few aspects in isolation and there is no substitute for the lessons learned during practical experience. Various attempts at *Ostrea edulis* stock restoration have been made and these are examined below, together with the experience in New Zealand with the native flat oyster (*Tiostria lutaria*) and an extensive restoration project in the USA with the local native oyster *Crassostrea virginica*.

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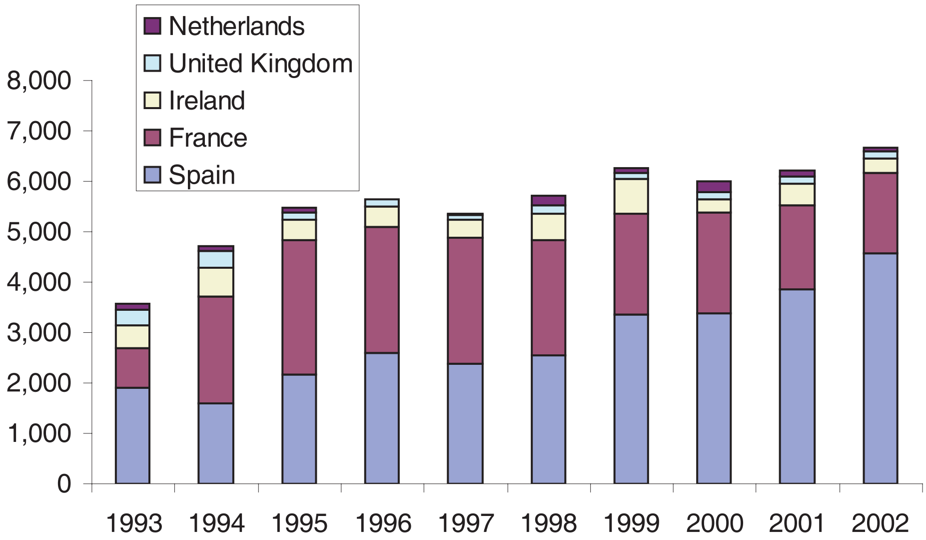

Figure 5.1.2. Cultivated native oyster production (tonnes) in Europe 1993-2002 (FAO data)

5.2. United Kingdom

Historically, annual production of flat oysters fell from more than 2,000 tonnes in the 1920s to a few hundred tonnes by the early 1990's (Figure 5.2.1). There are many peaks and troughs in this figure and this may have been due to periodic exploitation of beds until they were exhausted followed by the development of fisheries following a similar pattern elsewhere. If this is the case then the maximum yields achieved during these years are almost certainly not sustainable. Recently, there appears to have been some slight improvement in yields (see Figure 5.2.1), although it would be dangerous to read too much into this as the figures relate mainly to the Solent Regulated fishery where there are problems in obtaining reliable data for fully accurate year on year comparisons.

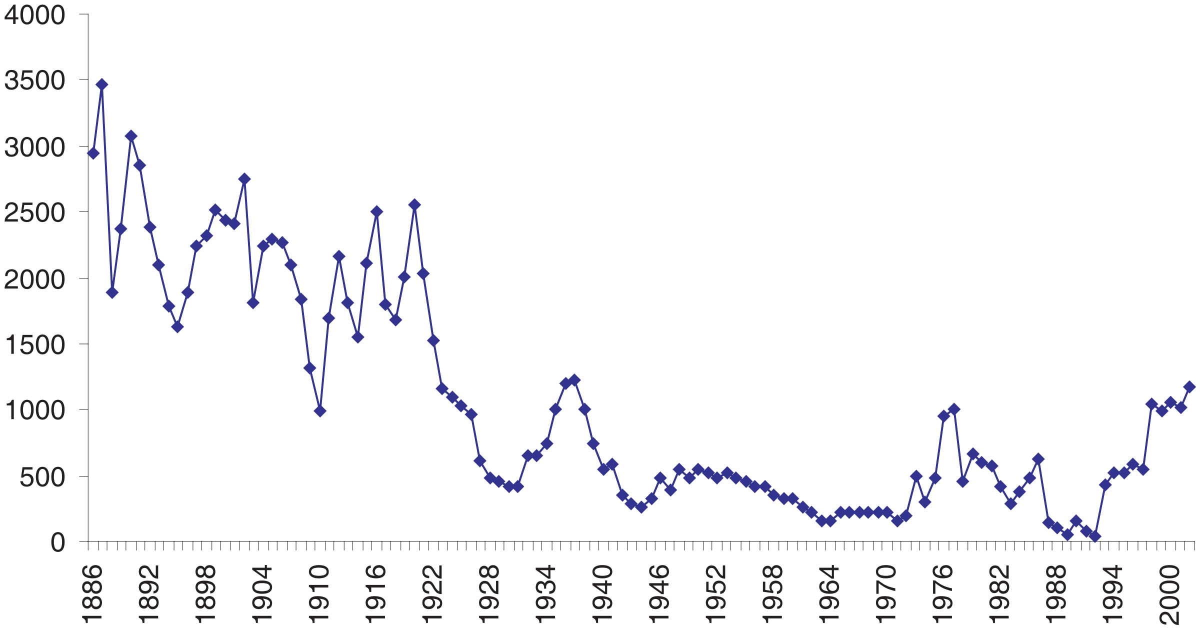

Figure 5.2.1. Native oyster landings (tonnes) in England and Wales (1886-2002)

A detailed assessment of the distribution, abundance (insofar as it is known) and fisheries of the native oyster in UK estuarial, coastal and territorial waters from the mid 19th century to the present day was undertaken by Gardner and Elliott (2002). It is not the intention to reproduce verbatim that information here, but brief summaries are presented below, together with further data from other sources, particularly the Countryside Council for Wales and Scottish Natural Heritage.

A recent report commissioned by the World Wide Fund for Nature UK (Hiscock *et al.*, 2005) looked into the status of sixteen "flagship" species and habitats. It concludes that although thirteen of these species are in decline that despite the historical (previous 100 years) severe decline in native oyster stocks that the current status of this species in the UK is relatively stable, with some inter-annual variation in recruitment.

5.2.1. England

In England, flat oysters are still fished commercially from natural beds, mainly from the Solent but also some of the Cornish estuaries, particularly the River Fal estuary, and from the Thames and Essex estuaries.

Since the 1960s there has been a general change in the type of native oyster exploitation undertaken within the country. Natural wild populations other than those noted are now generally too small and dispersed to be exploited commercially, such that there has been a move to the farming of oysters, with areas once noted for their large natural beds, particularly the Essex estuaries, now being used for cultivation, mainly by fattening of part grown stock from the Solent or other grounds.

The former large native oyster populations in the Wash and the large offshore native oyster beds (e.g. Dogger Bank and the mid English Channel beds) have been lost. The distribution throughout much of the rest of the British Isles appears to be little changed. Comparisons by geographical distribution are somewhat limited however as they do not indicate the size of the oyster populations within areas where their presence is recorded. In general, with the possible exception of the Fal and the Solent, where populations are recorded as occurring both pre and post 1950s, the pre-1950s populations consisted of large, densely populated oyster beds, which were naturally self-sustaining. The post-1950s records indicate a different trend, with many of the natural beds surveyed consisting of very sparse populations, in some cases with only a few individuals recorded. There have been relatively few attempts to restore these natural populations to historic levels.

Since the appearance of *Bonamia* the industry for wild stocks has focussed on management to mitigate the effects of this disease, with the cultivation sector developing with Pacific oysters. Designation of *Ostrea edulis* as a UK Biodiversity Action Plan Species has re-kindled some industry interest in restoring stocks and studies to take this forward have been commissioned although with limited funds these have been restricted to the surveys of the current status of stocks reviewed in this Section and the stress-resistance work carried out at Southampton University and summarised in Section 1.5.

5.2.1.1. Rivers Crouch and Roach

At the end of the Second World War there was little activity on the Essex oyster beds as a result of repeated poor spatfalls, high adult mortalities from unknown causes, the effects of severe winters and the presence of pests such as the slipper limpet *Crepidula fornicata* and the American tingle *Urosalpinx cinerea*.

In 1947 the Ministry of Agriculture, Fisheries and Food established a Shellfish Research Station at Burnham on Crouch with the aims of elucidating the causes of the decline of the east coast oyster fisheries and in establishing the conditions necessary for the revival and restoration of oyster beds. Derelict oyster lays were purchased, restocked and cultivated by Ministry vessels. A scientific programme was begun to study the biology of the oyster, extend cultivation and expand stocks. For the next two decades considerable effort was expended by the Burnham Laboratory on a wide range of oyster related studies.

Amongst the work carried out were studies on factors effecting the spawning and settlement of oysters, growth of settled spat, adult distributions, the effects of cultivation practices, pests, diseases and competitors. Much of the work undertaken at the Burnham Laboratory is relatively unknown, but it forms an extensive knowledge base on which any future regeneration projects could be based. The table below lists, in chronological order, reports of the key work undertaken at the Burnham Laboratory from 1947 to 1981.

Reference	Areas of work encompassed
Mistakidis 1951	Quantitative studies of the fauna of derelict Essex oyster beds
Knight Jones 1952	Conditions required for survival and successful settlement of oyster larvae
Hancock 1955	Feeding of starfish on oyster beds
Walne 1956	Biology and distribution of slipper limpets
Waugh 1957	Growth-rate, abundance and survival of oyster larvae
Shelbourne 1957	Oyster stocks: influence of currents and scour on distribution patterns
Howell 1969	Oyster stocks in the Crouch and Roach
Waugh 1972	Oyster settlement in relation to cultivation practises
Davidson 1974	Oyster stocks in the Crouch and Roach 1974
Davidson 1976	Oyster stocks in the Crouch and Roach 1976

There were some serious natural setbacks during the lifetime of the programme. After the floods of 1953 some 40% of oysters were lost in the River Roach (Waugh, 1954). The large-scale mortalities (70–95%, Crisp, 1964) during the winter of 1962-3 were followed by an unexplained failure of stocks to recover. Although stock surveys were carried out until 1981, the importance of the programme declined steadily from the mid 1960s. Recruitment failure in the 1970s is now believed to be linked to the increasing use at this time of tributyl tin in antifouling paints (Thain and Waldock, 1986). Recent surveys in the Crouch show that by 1997 stocks were again on the increase (Rees *et al.,* 2001). There is currently limited cultivation in the rivers, one site on the Crouch and two on the Roach.

5.2.1.2. Solent

The annual CEFAS surveys have shown a decline in stocks in the Western Solent, including the Stanswood and Calshot Several Order areas. In the former, catches have declined from 224 tonnes in 1995 to 24 tonnes in 2003 and zero in 2004. This has been mainly attributed to clearance of *Bonamia*-infected stock in the Beaulieu River in the 1990's, removing the source of stock for future recruitment. There is also a perception locally that extensive dredging operations in 1996 contributed to a tube worm epidemic and that the sharper gradient from the Several Order boundaries into the deep Thorn Channel, to accommodate the approach of larger vessels into Southampton Port, has led to a falling away of both cultch and stock. The concern over this extends to a belief that further research is required on the effects of greater depth on performance of oyster beds. Another observation is that the discharge of nutrient enriched water at elevated temperatures from the Fawley Power Station benefited productivity in the fishery in the past and that the run-down of operations here has contributed to the decline.

Some measures have been taken in both Several Order areas in an attempt to restore the fishery. At Stanswood, a nursery bed was set up in 1999. This is an area of no fishing in which cultch, both scallop and whelk shell, have been placed, together with a limited quantity of seed oysters, in 2003 and 2004. The oysters have performed well. With care and changes of sacks in a penned environment the 2003 oysters grew from 5 mm to almost 7 cm in 6 months. It is anticipated that future improvements would be an extension of the above initiatives, together with a clearance programme to remove dumpy oysters, tingle and tube worm, provided funding could be secured. At Calshot considerable quantities of cultch have been deployed, although there is a concern that much of this may have been washed away.

The current Several Orders in the Solent end this year (2005) and this lends an area of uncertainty to the prospects for restoration in this area.

5.2.1.3. Thames estuary

Following an apparent natural increase in native oyster abundance in the Kent and Essex Sea Fisheries District a questionnaire on proposals for future management of the stock was sent out to the local fishermen. Responses to this survey indicate that while it is not universally accepted that recruitment is increasing it is widely recognised that fishing effort may well in any case increase and that this will lead to depletion of the stocks. There was a majority view in favour of an Oyster Fishery Management Plan being produced. The most favoured management methods were seasonal closures and an increase in the minimum size. Laying and cleaning of cultch on the beds was also seen as highly beneficial.

Table 5.2.1. Summary of native oyster sites in England. An asterisk denotes sites where survey data are known. Shaded areas are those infected with* Bonamia*. FO = Fishery Order

Location	Status	Data
Holy Island	Cultivated residual	
Humber	Wild residual – various beds	
Wash	FO. No known stocks.	
Wells	Determined FO – no known stocks	
Blyth	Cultivated residual	
Alde	Cultivated residual	*
Ore	Cultivated residual	*
Deben	Determined FO - wild residual.	*
Orwell	Wild residual	
Stour	Wild residual	*
Walton Backwaters	FO - cultivated	*
Colne	Cultivated	*
Blackwater	FO and culitvated.	*
Crouch	Cultivated	*
Roach	FO - cultivated	
Thames	Public and private fisheries	
Shoreham and Selsey	Extinct offshore beds	
Emsworth Harbour	FO - managed wild stocks	*
Langstone Harbour	Wild residual	*
Portsmouth Harbour	Determined FO - Wild residual.	*
Solent	Various beds. Regulating Order and two Several Orders	*
Poole Harbour	FO - cultivated and managed wild stocks	
Poole Bay	Residual Wild stocks	*
Portland Harbour	FO. Residual wild stocks. Cultivation in Fleet.	
Exe	No known stocks	
Teign	No known stocks	
Dart	FO - no known stocks	*
Salcombe	Cultivated residual	*
Yealm	Cultivated residual	
Plymouth	Wild Residual - various beds, some polluted.	*
Fowey	Cultivated residual	
Fal	FO - managed wild and cultivated stocks	*
Helford	Wild residual	*
Morecambe Bay	No known stocks	

5.2.2. Wales

In Wales, the native oyster industry thrived up until the end of the 19th century, where it was an important economic activity in Swansea Bay and the Gower, Milford Haven, Tenby, Stackpole, Cardigan Bay and the Menai Strait. A rapid increase in demand then boosted the fishing industry and quickly brought heavy pressure on the oyster grounds in Wales, as was the case elsewhere around the British coast. The native oyster fishery in Wales declined rapidly due to this intense exploitation, combined with poor recruitment.

Significant oyster beds are now restricted to Milford Haven, Swansea Bay and Porthcawl, although these remaining beds are at a much-reduced scale.

The Countryside Council for Wales commissioned research into the remaining known oyster beds in Wales - in Swansea Bay and in Milford Haven, Pembrokeshire. Dive surveys were employed to gather information on oyster abundance at selected sites and also the marine biodiversity associated with oyster beds (Cooke, 2003). Oysters were successfully located in Milford Haven, but none were recorded in Swansea Bay. However, it is known that oysters occur inter-tidally in Swansea Bay and Swansea Port Authority carries out positive dredge sampling. Low numbers of oysters and the few dives undertaken are the most likely reasons for not finding oysters in Swansea Bay. In Milford Haven, the abundance at most sites was < 0.2 oysters/m^2. All observed oysters in dive transects were collected and sent to the University of Wales, Bangor for age analysis A single individual was aged at 34 years of age. Otherwise, it was found that 21% were between 10 and 20 years old, and 76% were between 0 and 10 years old. Most of the oyster populations at the sites in Milford Haven contained a cohort of small oysters (<15 mm) attached to the shell surfaces of the larger individuals. However, there was no evidence of spat settlement on oysters from some sites in the upper sections of the estuary. Data on the marine biodiversity associated with native oyster beds indicate that they form a flourishing part of the ecosystem. Over a hundred species were recorded from native oyster beds, including anemones, sponges, brittle stars and various crustaceans. The non-native slipper limpet *Crepidula fornicata* was recorded in all of the native oyster beds surveyed.

Table 5.2.2. Summary of native oyster sites in Wales. An asterisk denotes sites where survey data are known. FO = Fishery Order

Location	Status	Data
Porthcawl	Wild Residual	
Swansea	Wild Residual	
Milford Haven	Wild Residual	*
Cardigan	Extinct offshore beds	
Menai Strait	FO (mussels) No known stocks. Ostrea lutaria present.	

5.2.3. Scotland

Scottish Natural Heritage (SNH) commissioned a study of coastal areas around Scotland to investigate the current population of native oysters, which have declined significantly in Scottish waters during the 20th century. The survey, which is part of the drive by SNH to boost biodiversity in Scotland, aims to provide a clearer picture of the abundance, distribution and reproductive biology of native oysters in Scotland and help to develop appropriate advice for conservation management.

The native oyster once supported a significant fishery in the Firth of Forth but although dead shells can commonly be seen, no live animals have been found in recent surveys. It is not entirely clear as to how much the species has suffered elsewhere, although scattered populations can be found in sea lochs on the West coast of Scotland, which probably represent a UK stronghold. However, there has been concern in the last two years about the level of illegal fishing experienced at a number of isolated oyster populations in Argyll. The native oyster is vulnerable to exploitation pressure and even though prosecutions were obtained over this recent spate of illegal fishing in Argyll it is likely that significant damage has been done to stocks and there is a continuing risk whenever their price is high.

The Firth of Clyde still has small native oyster populations. However, these are only a fraction of their size in the 19th century and they consist primarily of old individuals with few young actively reproducing oysters present in the population.

5.2.3.1. Loch Ryan

The information in this section is extracted from Hugh-Jones (2003).

By far the largest fishery for native oysters in Scotland is situated in the southwest of the country, in Loch Ryan, near Stranraer. In around 1910 it was producing about 130 tonnes of *Ostrea edulis* supporting up to 30 boats. This level of production was sustained for only about 10 years before the catches fell to about 20 tonnes per year and these quickly fell to 10 tonnes from 1930. It was not viable to fish from about 1957. In the late 1970s up to 61 tonnes per year were harvested, using 4 boats. Since 1987 the catch has been restricted to about 15 tonnes per year, mostly harvesting the larger oysters for the London market and relaying the small ones. At one time hatchery seed were produced for relaying in the Loch, but this was discontinued with the introduction of the Pacific oyster and the rise in interest in the cultivation of this species.

Studies were undertaken in the late 1990s to assess the level of spatfall in the loch. It was found that there was good recruitment in some areas and that greatest spatfall can occur in markedly different parts of the Loch in different years. The overall level of spatfall also varied between years. Oyster shell was best for settlement, followed by whelks. No spat were caught on scallop shells. The oysters in Loch Ryan grow slowly, averaging about 11 g per year. The one advantage of this is that each oyster that remains on the bottom provides a perfect surface for the settlement of larvae, whilst it grows to a marketable size. The future of Loch Ryan is dependent on the size of the spatfall and how the spat are captured. There is a huge lack of any shell in the loch, and if the loch is to be brought back to its former peak of production, the natural spatfall must be used to the greatest extent.

There is a body, The Loch Ryan Forum (LRF), established under the Scottish Coastal Forum/ ICZM initiative, to provide an open, non-statutory assembly at which those interested in the area can raise issues which may or may not fall within the functions of one particular body. Potentially, this group could develop further initiatives associated with native oyster stock restoration in the Loch. However, the Forum is purely an advisory body with no formal constitution, nor finances, nor officers. It is staffed through a secretariat provided by Dumfries and Galloway Council, and joint projects are funded collaboratively by member organisations. LRF is currently chaired by the representative from the local National Farmers Union (Scotland) and has a membership of some 40 bodies. These range from the sea-angling federation to the multinational companies STENA-Line, and P&O, and also include all tiers of local government and the community.

Improvements in water quality in the Loch are likely. Loch Ryan has the distinction of being one of the first oyster beds in the UK to be designated as a Shellfish Water and significant improvements of the discharge from Stranraer Waste Water Treatment Works are planned.

Table 5.2.3. Summary of native oyster sites in Scotland. An asterisk denotes sites where survey data are known

Location	Status	Data
Loch Ryan	Managed wild stocks	*
Firth of Clyde	Wild Residual	
West Coast, including Islands.	Around 30 cultivation and isolated wild stock sites scattered throughout the region.	
Orkney and Shetland	Cultivated and residual wild stocks	
Dornoch and Moray Firths	Extinct and residual offshore beds	
Firth of Forth	Extinct offshore beds	

5.2.4. Northern Ireland

In Northern Ireland, the distribution of the native oyster is concentrated in the sea loughs. Belfast Lough once had numerous large beds of oysters occurring throughout but these now appear to have all disappeared. The rest of Northern Ireland appears to follow a similar trend to that of western Scotland, with natural native populations occurring in the same areas now as in the 19th century but in smaller, more sparsely populated beds. Oyster farming has also become important within the loughs of Northern Ireland, with natural native stocks again being supplemented from spatfalls originating from farmed native oysters.

5.2.4.1. Lough Foyle

The Lough Foyle oyster fishery in Co. Donegal is based exclusively on self-propagating spat production on natural beds. These were replenished in 1970 when 250,000 *O. edulis* spat were introduced by the Department of Agriculture for Northern Ireland. The Foyle system presently enjoys a disease-free status, with an annual yield of 80–200 tons from five major beds on the western side of the Lough (McKelvey *et al,*. 1996), although the fishery has experienced a decline in landings over recent seasons and this has been blamed on lack of a suitable management strategy (including legislation) and monitoring.

The strategy here is now for regeneration of indigenous oyster beds with the subsequent maintenance of a sustainable fishery. It is believed that this can provide a natural means to facilitate flat oyster production. Thus, one of the current major philosophies behind this is to avoid importation of seed foreign to the area so as to alleviate the danger of importing disease. Oyster movement is effectively a one-way process from the beds to the market.

5.2.4.2. Strangford Lough

The information in this section is extracted from Kennedy and Roberts (1999, 2001).

Historically, Strangford Lough in Co. Down had a productive oyster fishery supporting up to 20 oyster dredgers. This fishery, first documented in 1752, was already in a state of decline in 1877, when fishermen complained of falling catches. By 1903, oyster fishing in Strangford Lough had effectively ceased. In more recent times live specimens of *Ostrea edulis* have been recorded both inter-tidally and sub-tidally at various locations around the Lough. Both native and Pacific oyster spat showed favourable growth in trials conducted in the Lough in the 1970s but since then commercial production has focused primarily on Pacific oysters.

The Lough is a fully saline enclosed area in an Approved Zone for mollusc diseases, that is, it is free from the *Bonamia ostreae* and *Marteilia refringens*. These observations suggest that there is great potential for flat-oyster production in Strangford Lough.

Between 1997 and 1999 a local Co-operative embarked on a EU funded project aimed at re-establishing oyster beds to support a sustainable oyster fishery in the Lough. Oyster-bed re-establishment involved laying cultch and seed and re-laying native adults at selected sites. During the same period, a baseline survey was initiated to establish the status of *O. edulis*, and monitor larval production and spatfall patterns in the northern part of the Lough (Kennedy and Roberts, 1999). Oyster and cultch densities were estimated using random 0.25 m^2 quadrants along 100 m transects at 16 sub-tidal and 11 inter-tidal sites. Plankton samples were taken in summer and autumn to monitor oyster larval densities at 8 sites, and subsequently spatfall was monitored on slate spat collectors at 11 sites. Cultch was deployed sequentially over the study period at 9 sites to monitor fouling levels.

Field surveys revealed natural cultch cover at between 0 and 70% and extremely low densities of oysters (1-2 per 1000 square metres) in the areas surveyed. By contrast, densities of *O. edulis* on commercial oyster mats ranged between 66 and 100 individuals m^{-2}. In 1997 plankton surveys revealed larval densities from less than 1 m^{-3} to 17 m^{-3}. Densities peaked in August and September and were highest in the outflows from embayments where large commercial stocks of *O. edulis* (over 100,000 individuals) are over-summered by Cuan Sea Fisheries. Spatfall was evident at 6 of the 11 sampling sites in 1997 and is probably attributable to larval production by over-summered commercial oysters.

It was concluded that wild flat oyster populations in Strangford Lough appear to be relatively insignificant. No living specimens of *O. edulis* were detected at any of the sixteen sub-littoral survey sites monitored during the survey. Live flat oysters were discovered at five out of the eleven inter-tidal stations. The population is composed of relatively few, often-isolated individuals attached to rocks and stones.

As oysters were discovered in only two survey regions, population estimates could only be attempted for two out of the six designated survey regions. The total wild oyster population estimate for the whole of the northern half of Strangford Lough is 110,000, at a mean density of about 0.0011 per square metre. This figure is insignificant when compared to figures reported for other wild oyster populations. An area of a similar size might easily support over 100 million flat oysters.

Dead oyster shell was discovered in relatively small quantities at 22 of the 27 survey sites. The percentage cultch cover varied from 0.08% to 8.76%. The quantity of cultch at most of the survey stations was low. Two exceptions to this general situation were sub-tidal sites that exhibited percentage cultch cover of 73.61% and 67.33%. The majority of this material was composed of queen scallop (*Aequipecten opercularis*) shell.

Live oyster spat were detected at only three sub-tidal sites during a preliminary survey conducted in April 1997. These spat resulted from the 1996-spawning season. Spatfall resulting from the 1997-breeding season was evident at five out of the nine sampling stations. The density of setting was not particularly high at any site; peak spat numbers were two spat per 100 cultch shells. Across all the survey stations, mean setting density of 0.0017 oysters per cultch shell was calculated during April 1997 and a mean density of 0.0052 oysters per shell was found during October 1997.

A commercial stock of flat oysters is held over summer in Strangford Lough and this population was estimated at 125,280 individuals. This transient population may actually represent a more significant broodstock than the wild population within the Lough.

Following termination of commercial fishing pressure on the Strangford Lough oyster resource it is unclear why a recovery in stocks did not ensue. A general revival may be unattainable by a natural population following a protracted period of overexploitation for a variety of reasons. Once the population falls beneath a certain threshold level the total reproductive effort in terms of larval production may not be heavy enough to offset the ‘normal’ losses associated with a planktonic recruitment phase. In addition, fertilisation rates have been shown to decrease as the oyster population falls.

Large quantities of old oyster shell still carpet the seabed locally in certain areas along the west coast of Strangford Lough but, as with many other Irish flat oyster fishery regions, no recruitment has been observed on this material for a considerable length of time. Although cultch deposits may indicate areas that were inhabited by oysters, they provide no indication of former productivity levels. Many oyster populations exhibited low productivity and were incapable of tolerating the increased pressures caused by fishing, disease, pollution and competitors, thus leading to the virtual extinction of the flat oyster from many coastal areas as optimum recruitment needs a fairly high density of resident oysters. Also, the removal of too many mature oysters makes population revival difficult due to the lack of optimum settling substratum.

It is not clear if the low settlement rates of oysters in Strangford Lough are due to a naturally reproducing wild oyster population or from the commercial oyster stocks. Even with the benefit of this limited spatfall, it is unlikely that Strangford Lough oyster stocks could be restored without intervention. Derelict oyster beds rarely develop if left unattended (Millar 1968 – see Loch Ryan). The deposition of fresh, unfouled cultch onto areas experiencing consistent spatfall has been shown to enhance recruitment in oyster fisheries as the number of larvae that can set is directly proportional to the available area of clean shell surface. Supplemental shell planting cannot generate increased yields in fisheries where spatfall is too slight due to inadequate broodstock density. To achieve the reclamation of Strangford Lough oyster beds, it may prove necessary to import large quantities of seed oysters in order to build up a large enough central spawning stock.

Korringa (1946) stated that at least 10 million mother oysters were required to produce an adequate spatfall during an ‘average’ summer spawning season in the Dutch Oosterschelde, an area of similar size to Strangford Lough.

No descriptive relationship between broodstock size and setting intensity has ever been established. Oyster spatfall success fluctuates widely between seasons. Low spatfall will often accompany a large adult biomass, whereas heavy setting can occasionally result from a small spawning stock. The lack of correlation between broodstock size and spatfall success implies that larval survival is at least as important as adult abundance in determining the viability of a localised oyster population

A revival of the native oyster beds in Strangford Lough may also be attainable through a large-scale reclamation process. The hydrographical conditions in the Northern Strangford basin are ideal for such a project. A high degree of water retention is experienced over each tidal cycle, ensuring a restricted dispersal of oyster larvae from the local system. The establishment of a large broodstock should be a major focus for any proposed reclamation programme. However millions of broodstock may be required to produce satisfactory spatfall levels. A great deal of work is required to discern the potential amount of supplementary stock required to stimulate revival and the subsequent influence of hydrodynamics on any resultant progeny. In addition, large quantities of fresh cultch would need to be planted at various locations on the sea bed, determined by the local hydrodynamics, to provide suitable substratum for the larvae to colonise. The impact of fouling organisms on the effectiveness of planted cultch for oyster setting also needs to be addressed.

In summary, spatfall on natural cultch occurred at low levels in 1997. Natural recruitment of oysters in Strangford Lough may be limited by the availability of suitable substratum. Although the hydrographical conditions in the north of Strangford Lough are ideal for oyster bed reclamation, any development programme would require a large-scale accumulation of broodstock and suitable substratum. Nevertheless, efforts at restoration have been reasonably successful with significant levels of natural recruitment having taken place over the past five years as a result of the increased densities achieved by replanting in strategic areas. Unregulated harvesting (from non-designated shellfish harvesting areas) has become a problem since people became aware of the increase in stocks and the industry are of the view that fishing regulations need to be introduced and enforced to allow proper management of stocks and prevent them being exploited illegally. The issue has become complicated by the fact that he use of mobile gear, including the dredges the fishermen were using to harvest oysters, was banned in the Lough in December 2003, to promote the conservation of horse mussels.

Table 5.2.4. Summary of native oyster sites in Northern Ireland. An asterisk denotes sites where survey data are known

Location	Status	Data
Lough Foyle	Managed wild fishery	*
Larne Lough	Cultivated and Residual wild stocks	
Strangford Lough	Cultivated and Residual wild stocks	*
Dundrum Bay	Cultivated and Residual wild stocks	
Carlingford Lough	Residual wild stocks	

5.3. Channel Islands

Historically there were extensive stocks around the coast of Jersey that were over-fished in the late 19th century and have never recovered. There have been no studies to determine the causes for the lack of recovery but it is perceived locally that this is due to either a lack of broodstock or a change in habitat and possibly a combination of the two. The Channel Islands have Approved Zone status for the diseases *Bonamia* and *Marteilia* based on the absence of the susceptible species (*Ostrea edulis*). A few wild set native oysters are occasionally found.

5.4. Ireland

A Native Oyster Workshop meeting of industry stakeholders and other interested parties was held at Westport, Co Mayo on 16 October 2004. There is an annual production from the oyster beds of about 350 tonnes and continuing interest in developing native oyster fisheries in disease free areas by utilising measures to manage the stock. Prospects in areas affected by *Bonamia* are seen to be very limited, although there is an ongoing initiative for the development of disease resistant oysters in Cork. This is described further in Section 1.5.

5.5. France

The information in this section was provided by Sylvie Lapègue (IFREMER).

There has not been any programme in France to conserve stocks of native oysters. However several studies on population genetics at the European scale have been carried out in order to better understand the genetic structure of this species in its range. These are reported in Section 1.3.2. In parallel, a program has been running on selecting strains that are disease-tolerant to *Bonamia ostreae*. Selected lines have been produced that show improved survival to Bonamiosis (see Section 1.5). Attempts were made in 2003-2004 to transfer these improved lines to the industry (Project OFFISTREA). However, no restocking with any lines has been realised to date, due to difficulties with hatchery production of flat oysters.

On the research side, the French are now working at the establishment of a genetic map (INTERREG project) in order to help towards markers assisted selection. They are also beginning to work on functional genes to try to better determine possible differences between populations. Finally, a project proposal was put forward to the EUROdiversity programme. The aim of this was to characterize the diversity of the European flat populations on the level of phenotype (growth, mortality, physiology), as well as neutral and functional molecular markers in order to better consider the conservation and use of the genetic resource of this indigenous species. This proposal has recently been rejected, but it shows that there is interest in France in following research along these lines.

5.6. Spain

The information in this section was provided by Alejandro Guerra (CIMA).

Here, hatchery produced native oyster are cultivated using rafts, most commonly in Galicia. Each raft can support from 200,000 to 300,000 oysters.

Historically, stocks of native oysters in Spain were first seen to be in decline as early as 1778, as recorded by Cornide (Pazó, 1987). Due to a lack of interest and an oyster growing tradition, as well as absence of any official action nothing was done to remedy the situation. In 1867 a new report again drew attention to the oyster stock reduction. As a result of this publication two oyster culture establishments were formed but due to the lack of experience of the personnel these failed. During the twentieth century new studies reporting on oyster populations and production of oysters in Spain have been published (Perez Camacho, 1987; Guerra, 1998).

During the 1930s the first attempt to regenerate native oyster stocks in Galicia was attempted, although this was eventually terminated for non-technical reasons. In the 1950's a regeneration program using roof tiles as an attachment substrate was conducted. Although the outcomes were promising there was little interest from the growers who were by now more concerned with exploitation of clams.

In 1960 the exploitation of native oysters was no longer profitable due to the lack of the resource. New attempts to regenerate the native oyster population were carried out in the 60's by introducing oysters imported from France. Unfortunately this resulted in the introduction of the diseases *Bonamia* and *Marteilia* that negatively affected the oyster stocks. The oyster population in Spain decreased by 80% from 1974 to 1987 with the spread of these diseases. In order to halt and reverse this trend a number of projects were started to obtain oyster seed either from natural oyster beds or using hatcheries.

During 1978-1981 some studies were carried out with an existing oyster stock. The aim of the first year of the project was to locate the most suitable areas for oyster settlement. During the following two years containers, each with 8 collector plates were put in the sea (203 in 1979 and 289 in 1980). There was a mean settlement of 43 oysters/plate in 1979 and 89.3 in 1980 (78.7% of these survived after they were taken off the plate). From these trials the factors important for the success of growing oysters in natural beds were identified. These were considered to be:

- Hydrographical conditions such as temperature, currents and coastal configuration
- Number of native oysters already living in the area
- Collector type used (shells, roof tiles, plastic surfaces)

Recently, the economical potential of the species in Galicia is being considered, as a possible alternative to mussel production. National and regional administrations have promoted initiatives and research to investigate the factors that are preventing the general development of the native oyster.

A program to develop a *Bonamia ostreae* resistant strain is currently underway. Oysters from different populations have been used as broodstock, including animals from bonamiosis-free areas in Ireland and Greece, and two areas in Galicia with different prevalence of this disease. Results from this do not appear to be published yet and it has been suggested that the lack of evidence points to the failure so far to identify or develop a strain for which disease resistance is genetically inherited.

Other studies (Conchas *et al.*, 2003) have looked at the prevalence of the disease at various sites using different methods of cultivation over several years. Results confirm that inter-tidal cultivation is not particularly suitable and also indicate that there is an effect of site, with lower prevalence of the disease in certain areas. This study also showed a decline in prevalence with time at cultivated sites but not in wild stocks, suggesting that by introducing appropriate husbandry measures farmers can learn to live with the disease.

5.7. Denmark

The information in this section was provided by Per Dolmer (Danmarks Fiskeriundersøgelser).

All fishing of the European flat oyster is located in Limfjorden.

Spärck, (1951) conducted some early studies on oyster fisheries recruitment, in relation to stock regeneration, in Limfjorden. He reported marked changes in population size due to recruitment failure. In unfavourable year stocks declined naturally (in the absence of fishing pressure) and the population in Limfjorden became restricted to the most favourable sites. In favourable years the stock increased and the population slowly spread from the most favoured locations. He concluded that a long series of favourable years was required for recovery. For example, after closure of the oyster fishery in 1925, stocks did not recovery their fishery potential until 1947/48, over 20 years. However, the Limfjord population of *Ostrea edulis* is at the northern most extent of its range where recruitment may be more reliant on summer temperatures than more southerly temperate populations.

Stocks of flat oysters have increased significantly In Limfjorden during the last 5 years. The figure shows the landings from the fishery. Up until summer 2004, two different types of dredges were used in the fishery for oysters: a heavy 250 kg 2 m wide dredge and a 12 kg dredge. Investigations conducted by the Danish Institute for Fisheries Research showed that due to a high mortality of oyster spat in the fishery while using the heavy dredge, the landings could, in a longer-term, be doubled if the fishery used only the light dredge. Consequently, use of the heavy dredge has banned by the authorities. A report, in Danish, has been published on this study (Dolmer and Hoffmann, 2004). The major UK fisheries commonly already use lighter dredges.

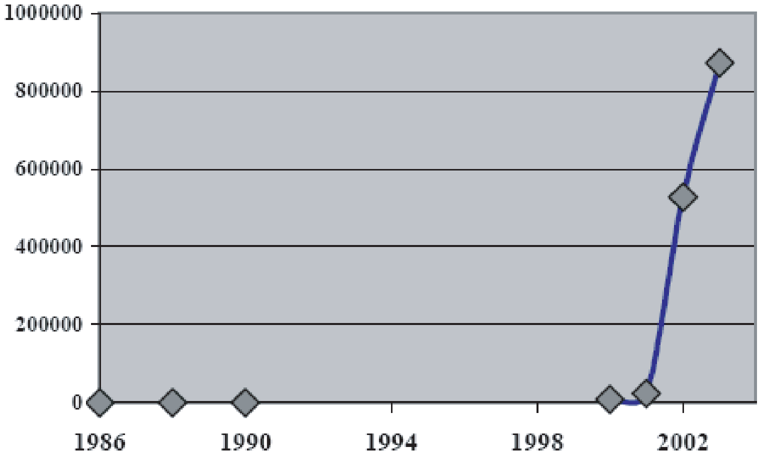

Figure 5.7.1. Oyster landings (kg) in the Limfjorden, Denmark (1986-2003)

In addition, there is currently (until March 1st 2005) also a limit for the maximum catch. The oyster fishery is also regulated by weekly quotas, minimum sizes and by periods when no fishing is allowed.

Finally, the Danes intend to help conserve oyster stocks in Limfjorden by gaining Approved Zone status for the diseases Bonamiosis and Marteiliosis. The Danish Food and Veterinary Administration sent an application to the EU in August 2004 based on results of sampling and histological examination of oysters for *Bonamia ostreae* and *Marteilia refringens* since 1996. Approved Zone status has since been agreed, allowing for export of native oysters to other Approved Zones, including the UK.

5.8. The Netherlands

The information in this section was provided by Marc Engelsma (CIDC-Lelystad).

Oyster stocks in the Netherlands are located in an estuary on 2 sites, Yerseke Bank and Grevelingen. The Yerseke Bank became infected with the protozoan oyster pathogen *Bonamia ostreae* in 1980, as a result of importations of infected oysters from France. The oyster stock of the Grevelingen was free of Bonamiasis until 1988. In 1989 maximum prevalence levels of *Bonamia* of 48% and mortality levels of dead oysters of up to 80% were reached. Recorded landings from the fishery fell by 50% from an average annual production of around 1,200 tonnes in this period. Subsequent studies of prevalence of *Bonamia* have shown that levels vary from just one or two percent up to around 35%.

There have been no attempts specifically directed to conserve or regenerate stocks other than normal management for commercial native oyster culture. This is itself favours the species to some extent, although neither the Fisheries Research Institute or the Producers Organisation for Oysters have been involved in any programmes to conserve or regenerate the stocks. After the initial outbreak of *Bonamia* in 1980 there have been some attempts to eradicate the pathogen as is described in a number of articles from Van Banning. However these were not successful.

At the moment, although there is still considerable pathogenic pressure on the oyster population by *Bonamia*, the population seems to be coping with it. It seems possible that the oysters have developed some resistance to *Bonamia* over time. Introducing naive oysters from other sources in the area results in heavy losses compared to mortality rates in the local stocks.

5.9. Norway

The information in this section was provided by Stein Mortensen (IMR).

The Norwegian oyster industry is relatively very small. Although there has not been any programme on the conservation of native flat oysters in Norway, as a background for various R&D work, as well as the disease surveillance programme run by the Veterinary Institute, a lot of data on oyster production, trade, and movements has been collected from various sources. There is therefore a fairly good overview of the distribution of the native stocks and their origin. There have not been any systematic introductions of flat oysters into Norway since 1934, with the exception of one introduction into a single site in 1964 and a possible illegal introduction of post-larvae in 1999. Several stocks have been identified that are presumably native.

Norway has Approved Zone status and hatchery and on-growing capacity for rearing native oysters for on-growing or restoration of beds and can export to other Approved Zones, including the UK.

5.10. New Zealand

The information in this section was provided by Bob Hickman (NIWA).

The collapse of the Foveaux Strait dredge oyster (*Tiostrea chilensis* (=*Tiostrea lutaria*)) fishery in the mid to late 1980s, which was caused by *Bonamia* and resulted in upwards of 90% reduction in the oyster population, led to lots of disease surveys and population studies, as well as generating interest in the potential for enhancement as a means of rejuvenating the fishery. There has been a Bluff Oyster Management (formerly Enhancement) Company project carrying out enhancement trials in Foveaux Strait since the mid 1990s. Relatively little in the way of published results has come out of the project, even though initial observations on growth and survival of spat that were settled onto old shell, held suspended in mesh bags until about 25 mm in size, and then returned to selected areas of oyster bed, were promising (Street 1995, 1997).

Earlier attempts at enhancement by returning recently opened oyster shell (from the oyster factories) to areas of the beds with low oyster populations were unsuccessful, probably because of lack of stability of the beds and the small volumes of returned shell (Street *et al.*,1973). However there is a new proposal to undertake more extensive return of shell on a much larger scale, using all the opened shell from all the local factories.

The Challenger Oyster Management Company, which operates the Tasman Bay/Golden Bay dredge oyster fishery, where *Bonamia* has had much less impact, is currently developing a proposal for enhancement by increasing natural settlement and recruitment, or by hatchery seed production, or both, to increase the size of its fishery.

The extensive disease studies, since the mid 1980s, have focussed on the effect of *Bonamia* on the fishery and on the oyster itself (see summaries in Hine 1991, Hine and Jones 1994) with no work yet done on developing disease resistant strains and only anecdotal observations on the possible existence of naturally resistant populations.

5.11. USA

5.11.1. Chesapeake Bay

It is relevant to examine the considerable efforts at restoration of stocks of the oyster native to Chesapeake Bay in the USA (*Crassostrea virginica*) following a massive decline in the population due to over exploitation and disease (Brumbaugh *et al.*, 2000; Mann, 2000; Mann and Evans, 2004).

Overfishing in the late 1800s and early 1900s reduced Chesapeake Bay market oyster landings from a peak of about 24 million bushels in 1887 to a more-or-less steady state of about 5 million bushels by 1930. This high harvest pressure also mined the oyster reefs themselves, greatly reducing the reef habitat in the Bay. In the last four decades two protozoan diseases (MSX disease caused by *Haplosporidium nelsoni* and Dermo disease caused by *Perkinsus marinus*) have combined to further reduce oyster populations throughout Chesapeake Bay to about 1% of historical levels.

The Chesapeake Bay Program is committed to the restoration and creation of aquatic reefs. In The Chesapeake 2000 agreement, Bay Program signatories committed to “by 2010, achieve, at a minimum, a tenfold increase in native oysters in the Chesapeake Bay.” This commitment has created an unprecedented level of cooperation among multiple agencies including state, federal, non-profit and academic entities to restore oysters. As a result, the oyster restoration partners have developed the Comprehensive Oyster Management Plan (COMP) to provide guidance and coordination for a bay-wide approach to oyster restoration and fishery management. Oyster restoration is viewed as a long-term, multi-generation effort and a challenge of immense proportions but the potential ecological and economic benefits are seen to be well worthwhile.

A key component of the strategy to restore oysters is to designate sanctuaries, that is, areas where shellfish cannot be harvested. Since much of the historic oyster grounds in the Bay have degraded to soft mud, it is often necessary within a sanctuary to rehabilitate the bottom to make it a suitable oyster habitat. Within sanctuaries aquatic reefs are created primarily with oyster shell, the preferred substrate of spat. Alternative materials including concrete and porcelain are also used.

Permanent sanctuaries are seen to be critical for a number of reasons. Permanent sanctuaries will allow for the development and protection of large oysters. It is well documented that fecundity in oysters increases exponentially with length. Thus, a small number of very large oysters can produce many more eggs than a large number of small oysters. In addition, large oysters in disease-endemic areas have a demonstrated ability to survive diseases, a characteristic that is, at least in part, inherited by their offspring. Natural disease resistance has not developed in Chesapeake Bay for two reasons. First, there has been historically a large unselected gene pool in low salinity that diluted any selected gene pool. Second, the fishery harvested all the large oysters that were surviving in disease-endemic areas and that may have been disease resistant. It cannot be guaranteed that disease resistant oysters will become widespread in the Bay with the protection of large oysters, but certainly disease resistance will never become widespread without the protection of large oysters.

Maryland and Virginia have been creating aquatic reefs since the mid 1990's. To date, sanctuaries have been created on historically productive oyster ground, which serves as the "footprint" for potential reef projects. Virginia has created over 35 aquatic reefs ranging in size from one to five acres and Maryland has created over 15 aquatic reefs ranging in size from 2 to 40 acres. Success of these projects is still being evaluated, however in recent years success has been hampered by the increased presence of diseases that affect oysters.

Furthermore, attempts have been made at seeding with hatchery disease-free oysters Over 55 million oysters were planted in 2001 and an additional 164 million in 2003.

The philosophy behind restoration and proper management of oyster populations in the Chesapeake Bay is not solely the concept of restoring and managing oysters strictly to support an industry, although this is seen to be important. In fact, the primary impetus for oyster restoration is because their filter-feeding lifestyle is an important ecological component in the Bay ecosystem and because their reef-building nature provides valuable habitat for oysters themselves and for other organisms. Oysters can improve water quality because they consume phytoplankton that contribute to anoxia in bottom waters and they also reduce suspended particulate matter, thereby improving water clarity and light penetration critical for aquatic plants. Oyster reefs support a diverse macrofaunal community that provides shelter and food for crabs and fish. An increase in oyster reefs will increase habitat and food for other important species in the Bay.

However, it is recognized that restoration of oyster populations for their ecological value must be in such a way that a sustainable fishery can exist, through management on a regional basis with regional quotas established for a fishing season based on stock assessments.

Optimal size of reef sanctuaries has not been determined and will likely be dictated by funding constraints. In Virginia, reefs as small as one acre have substantially increased spat set in the surrounding area.

It is critical that reef sanctuaries be protected from poaching. They should be sited such that enforcement of the sanctuary will be feasible.

It is also expected to be necessary to add adult oysters to some restored reefs to enhance recruitment to the reef and to the surrounding area. Large natural oysters can be harvested and aggregated on reefs to enhance fertilization success. This strategy worked successfully in Virginia where large, but scattered, oysters were aggregated on a reef. Spatfall on and around the reef increased dramatically the following year. Where possible and when available, progeny from genetically selected oysters could be stocked on reefs. There are a number of programs underway to select oysters for a variety of traits including growth in low salinity, fast growth, or disease resistance. These strains will require evaluation for their effectiveness for use on reef sanctuaries.

Another important component of the restoration strategy is to plant shell around reef sanctuaries to enhance spatfall, although the need for shell planting will likely be site specific. Circulation models may help determine current patterns and where best to plant shell.

The state of Virginia has also been studying the possibility of using non-native oysters, and began conducting field trials with the Suminoe oyster (*Crassostrea ariakensis*) in 1996. While not directly relevant to this study it is worth examining briefly some of the issues associated with this approach. A National Research Council report was commissioned arising out of the differing opinions among states and federal agencies about the environmental risks involved.

The Suminoe oyster, which is native to coastal China and other Asian countries, is an appealing alternative to the native oyster because it is resistant to the two diseases that have reduced oyster populations up and down the East Coast. It grows quickly and compares favourably to the native oyster in taste tests.

However, it was noted that potential harmful effects of the Suminoe oyster on the ecology of the bay need investigation. Past introductions of foreign oysters in other parts of the world have brought diseases, parasites, and predators that have decimated native oyster populations. The report also notes that the Pacific oyster, another species from Asia, which has been introduced around the world, has become invasive in parts of Australia and New Zealand, displacing the native rock oyster in some areas.

Several issues requiring further research were identified, including the potential introduction of a new disease, competition with native oysters, dispersal of non-native oysters outside the Chesapeake Bay, and market demand for non-native oysters. This additional research is needed before scientists can reassess the environmental risks of wider aquaculture of sterile non-native oysters or the introduction of reproductive ones.

5.11.2. Gulf States

Hurricane Ivan caused significant damage to oyster populations in the southern states of the USA. At one site in Alabama, divers had staked out yard-length grids to measure the reefs for productivity in August, then again after Ivan struck. The concluded that losses of about 80 percent occurred at this site. Alabama has a total of 4,000 acres of reefs, supporting an industry worth $4 million and giving employment to 200 oystermen who work the reefs in winter. Florida was also severely affected, with smaller losses in Louisiana and Mississippi.

The National Oceanic and Atmospheric Administration (NOAA) will allocate a total of $9 million federal grant for oyster bed reseeding and rehabilitation to restore affected areas in the above States.

Alabama will receive $4.3 million to restore its oyster populations. Some of his grant money will fund scientists studying the effects of the hurricane. Florida will receive $1.7 million to restore oyster reefs in seven bays. This will fund restoration by deploying cultch material on selected reefs and these will be monitored to assess oyster populations, settlement growth, survival rates and the stability of the restored reefs. Large-scale deployment of cultch will be by distributing shells from barges with high-powered hoses. Fishermen might assist by reseeding shallower areas. Planting out of fingernail-size oysters is also being tried on a small scale in one area. It is expected that the combined efforts of the State Departments of Conservation and Natural Resources, NOAA, and academic and scientific communities will be integrated to ensure a cooperative conservation programme.

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APPENDIX 1. NATIVE OYSTER (*OSTREA EDULIS*) SPECIES ACTION PLAN

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Web: http://www.ukbap.org.uk/UKPlans.aspx?ID=495

Current status

The native or flat oyster (*Ostrea edulis* L.) is a sessile, filter-feeding, bivalve mollusc. It is associated with highly productive estuarine and shallow coastal water habitats with sediments ranging from mud to gravel. *Ostrea edulis* is widely distributed around the British Isles, the North Sea, Mediterranean and Black Sea. Along with other oyster species, it is also cultivated in North America, Australasia and Japan. Stock abundance was probably greatest in the 18th and 19th centuries, when there were large offshore oyster grounds in the southern North Sea and the Channel producing up to 100 times more than today's 100-200 tonnes. During the 20th century its abundance declined significantly in European waters. The main UK stocks are now located in the rivers and flats bordering the Thames Estuary, The Solent, River Fal, the west coast of Scotland and Lough Foyle.

Native oyster fisheries are subject primarily to UK shellfisheries conservation legislation; the species is not named in any national or international nature conservation legislation or conventions.

Current factors causing loss or decline

The dramatic reduction in stock abundance seen in the middle of the last century is attributed mainly to over-exploitation following the increased demand that accompanied improved rail transport.

The American oyster drill *Urosalpinx cinerea* and the slipper limpet *Crepidula fornicata* were introduced with *Crassostrea virginica* from North America around 1900. *Urosalpinx* is a predator alongside indigenous species such as crabs, starfish, dog whelks, shell boring worms and sponges. *Crepidula* is a filter feeder that deposits pseudofaeces and creates `mussel mud`. This mud degrades the grounds and hinders recruitment, but dead *Crepidula* shell provides culch upon which oyster settle.

Severe winters, such as those experienced in 1947 and 1963, caused high mortalities in the UK, particularly on the east coast where stock levels have not recovered to the pre-1963 levels.

The parasitic protozoan *Bonamia ostreae* has caused massive mortalities in France, from whence it was introduced, and in the Netherlands, Spain, Iceland and England. Another protozoan parasite, *Marteilia refringens*, has also been found in French stocks but hitherto it has not affected UK stocks.

TBT (tri-butyl tin) anti-fouling paints used on ships and leisure craft in the early 1980s caused stunted growth and probably affected reproductive capacity.

There are many other factors that affect oyster stock abundance, most contributing to the high variability of recruitment: temperature, food supply, hydrodynamic containment in a favourable environment, anthropogenic effects (eg coastal development, waste disposal). Also spawning stock density or biomass may be too low in many areas to ensure synchronous spawning or sufficient larval production for successful settlement.

Current action

Native oyster fisheries in the UK are managed by a mixture of national legislation (eg in Great Britain by the Sea Fisheries (Shellfish) Act 1967) and, in England and Wales, local Sea Fisheries Committees (SFC) bye-laws. Almost all naturally occurring oysters in Scotland belong to the Crown Estate, except where the rights have been specifically granted to others. Many of the principal oyster fisheries in England and Wales are managed through Regulating or Several Orders (the latter extinguish the public right to fish). There are also some private oyster fisheries based on historic rights. There is a national closed season (14 May to 4 August) to protect native oysters during the spawning season, though a dispensation exists for cultivated stocks.

The EC Directive 95/70/EC, which forms part of the EU fish and shellfish health regime, sets Community-wide rules to prevent the introduction and spread of the most serious diseases affecting bivalve molluscs. This is implemented in Great Britain through the Fish Health Regulations 1997 (SI 1997 No. 1881).

The use of TBT-based paints on vessels less than 25 m in length was banned in 1987 (Food and Environment Protection Act 1985, Part III). Oyster growers believe this ban is helping to reduce the adverse effects on oysters.

The Shellfish Hygiene Directive (91/492/EEC), implemented through the Food Safety (Fishery Products and Live Shellfish) (Hygiene) Regulations 1998, requires that all production areas must be classified according to the degree to which samples of shellfish from those areas are contaminated by coliform bacteria. The classification is a public health measure and determines whether the shellfish can go directly for human consumption or need to be treated beforehand by relaying in cleaner water or by depuration.

Shellfish are monitored for marine biotoxins so that if Diarrhetic Shellfish Poison (DSP) is detected or if Paralytic Shellfish Poison (PSP) exceeds the maximum permitted level considered safe for human consumption, affected fisheries can be closed.

Action plan objectives and targets

Maintain the existing geographical distribution of the native oyster within UK inshore waters.

Expand the existing geographical distribution of the native oyster within UK inshore waters, where biologically feasible.

Maintain the existing abundance of the native oyster within UK inshore waters.

Increase the abundance of the native oyster within UK inshore waters, where biologically feasible.

Proposed actions with lead agencies

Policy and legislation

Assess whether the existing EU Directives and UK legislation provide sufficient controls to minimise the risk of introducing new diseases and pests into the UK. (ACTION: DANI, DEFRA, NAW, SE)

Recognising that EU legislation only covers disease controls, consider re-establishing pest controls equivalent to the Molluscan Shellfish (Control of Deposit) order 1974 which could aid pest control by prohibiting the movement of shellfish. If considered necessary to prevent recontamination or the introduction of alien species, UK fisheries ministers should encourage new controls on the use of seaweed and other natural products used as packing for live transport. (ACTION: DANI, DEFRA, NAW, SE)

Site safeguard and management

Oyster grounds, and hence oyster abundance, require suitable surfaces for spat settlement. Slipper limpets have degraded some and made them difficult to re-establish. Consider whether appropriate mechanisms are available to encourage oyster farmers to carry out an environmental impact assessment and, if appropriate and feasible, to rework derelict areas to increase both oyster distribution and abundance and benthos diversity. (ACTION: DANI, DEFRA, NAW, SE)

Integrate oyster habitat safeguards into Marine Nature Reserves, Special Areas of Conservation and estuary management plans where relevant to the site's conservation objectives. (ACTION: All relevant authorities)

Species management and protection

Define clearer, tighter objectives, and apply specialist advice, in managing the UK regulated fisheries. (ACTION: Carrick District Council, DANI, DEFRA, NAW, NIO, SE, Southern SFC)

Maintain the existing stock abundance in the main self-regenerating fisheries. (ACTION: DANI, DEFRA, SE, SFCs, NAW)

Ensure adequate recruitment to maintain stock abundance. Target to be defined following a review. (ACTION: DANI, DEFRA, NAW, SE, SFCs)

Endeavour to stop the spread of the introduced pests *Urosalpinx cinerea* and *Crepidula fornicata* beyond their existing distribution. (ACTION: DANI, DEFRA, NAW, SE, SFCs)

Control stock density to reduce the risk of transmission of disease. (ACTION: DANI, DEFRA, NAW, SE, SFCs)

Endeavour to prevent the introduction of the oyster disease marteiliosis, limit the spread of bonamiosis. (ACTION: DANI, DEFRA, NAW, SE, SFCs)

Maintain genetic variability. Target to be defined. (ACTION: DANI, DEFRA, NAW, SE, SFCs)

Advisory

Produce guidance notes and a code of practice on habitat restoration and species protection. (ACTION: CCW, DANI, EHS, EN, DEFRA, NAW, SE, SNH)

Future Research and Monitoring

Review the evidence of a relationship between spawning stock biomass and recruitment, and define safe biological reference points. (ACTION: DANI, EN, DEFRA, NAW, SE)

Provide managers of several and regulated fisheries with guidelines and code of practice for habitat protection, stock management and species protection. (ACTION: DANI, DEFRA, NAW, SE)

Continue and extend surveys of all wild stocks and fisheries to establish stock biomass, distribution and spatfall variability including assessments of any recovery in areas previously contaminated by TBT. (ACTION: DANI, DEFRA, NAW, SE, SFCs)

Assess and report on the implications for genetic variability and biodiversity of using hatchery brood stock to produce seed for stock replenishment. (ACTION: CCW, DANI, EHS, EN, DEFRA, NAW, SE, SNH)

Communications and Publicity

To raise awareness and provide information about the Biodiversity Action Plan, write articles on progress with the plans for appropriate trade journals (eg Fishing News, Fish Farming International) explaining the action plan. (ACTION: CCW, DANI, EN, DEFRA, NAW, SE, SNH)

APPENDIX 2. GUIDELINES FOR THE CULTIVATION OF FLAT OYSTERS IN AREAS AT RISK FROM THE DISEASE *BONAMIA*

These 11 guidelines are mostly common sense. Their implementation, in full or in part, will help to reduce the impact of *Bonamia* disease.

(1) Do not relay obviously diseased oysters

(2) Do not accept undocumented batches of oysters for deposit.

The implications of these 2 guidelines are that oysters for relaying should ideally come from wild stocks in unaffected areas. Oysters may also be taken from stocks in areas experiencing a low level of infection. There is now evidence that surviving oysters from infected areas may have developed some natural resistance to the disease.

(3) Only relay oysters for one growing season

(4) Do not return undersized oysters to your lays

Long-term lays in infected areas should be avoided. Any re-laid seed should be of such a size that one season of growth will take most to marketable size. During subsequent harvesting, undersized oysters should not be returned to the lay since they, more than the larger oysters, are likely to carry the disease.

(5) Reduce the density of lays

Laying should be as sparse as possible, consistent with commercial viability. This should reduce the passage of the disease from oyster to oyster and may also enhance growth rates. Experiments have shown that oysters cultivated at 10 per square metre grow better and are more resistant to *Bonamia* than oysters at 30 per square metre.

(6) Destroy unwanted oysters on land away from water

Great attention should be placed on the destruction of all unwanted oysters from lays, even small spat. With most disease, it is almost always the case that infected animals are predominant amongst discards.

(7) Avoid putting oysters under unnecessary stress

Move oysters as little as possible and with care. Handling of any sort stresses animals, reduces their capacity for growth and enhances susceptibility to disease.

(8) Do not deposit in areas free from disease

Oysters from disease-risk locations must be depurated, if it is necessary, within those localities or at places already affected by *Bonamia*.

Oysters *en route* to market should only be deposited if necessary in tanks or ponds that can be sterilised and cleansed after use.

(9) Cleanse depuration plants regularly

Even though ultra-violet radiation of the water for normal purposes might kill *Bonamia* spores, contaminated faeces could remain infected. The plant should be shut down, settlement permitted followed by run-off of clean water. The last 5 cm of water, plus sediment, should be sterilised with 1% caustic soda which should be then flushed away. Proper care should also be given to the efficiency of ultra-violet lamps.

(10) Clear infected lays

Heavily infected beds of oysters should be cleared as soon as possible. At lower levels of infestation it is acceptable to dispose of oysters more gradually via normal sales for consumption.

(11) Cleanse all gear before returning to base

Fishing gear and decks should be cleared of all oysters and cleaned thoroughly by hosing down whenever work on a bed in an infected area is finished. They should not be washed down back at base.

Further advice may be obtained from CEFAS Weymouth Laboratory, The Fish Health Inspectorate, Barrack Road, The Nothe, Weymouth, Dorset, DT4 8UB
(Telephone: 01305 206673/74).

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