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The Pacific Oyster (*Crassostrea gigas*) in the UK: Economic, Legal and Environmental Issues Associated with its Cultivation, Wild Establishment and Exploitation

Report for the Shellfish Association of Great Britain

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Summary

Introduction and Methods

1. This paper presents an independent review of current economic, legal and environmental issues pertaining to the Pacific oyster (*Crassostrea gigas*) industry in the UK. The study was commissioned by the Shellfish Association of Great Britain (SAGB) and a steering group consisting of industry members and regulatory agencies. The study draws on evidence from comparable temperate regions around the world where Pacific oysters are grown and from UK and European stakeholders, industry, growers and regulators.

2. Although legally cultivated, wild Pacific oysters are classified as an invasive non-native species in the UK and the impetus for this study has been the ecological risk associated with the growth of wild populations of Pacific oysters as a result of rising sea temperatures caused by climate change. On the continent, the recent growth of wild populations has resulted in 'reef' formation which has displaced or modified habitat protected under EU Habitats legislation. There are concerns that this could also happen in the UK, resulting in protected areas not meeting favourable ecological condition status. Currently the UK Technical Advisory Group (UKTAG) has classified the species on the Water Framework Directive (WFD) 'high impact list', although a proposal has recently been made by UKTAG to move the species to a 'moderate impact list'. An independent risk assessment commissioned by the GB Non Native Species Secretariat (NNSS) concluded that the species presents a 'medium risk'.

3. These environmental concerns have created uncertainty over the future of UK Pacific oyster cultivation. Appropriate Assessments related to new Pacific oyster aquaculture licences have repeatedly failed to satisfy regulators that measures and mitigation have been put in place to reduce the ecological risks associated with wild settlement. Yet UK marine policy now includes a presumption in favour of sustainable development and there is a desire amongst stakeholders and regulators to promote the sustainable development of the industry.

4. A systematic (i.e. repeatable) review of evidence in the literature pertaining to all aspects of the study was conducted. In addition, a questionnaire was sent to all members of the SAGB and to all Mollusc Aquaculture Production Businesses (APBs) within England and Wales, Scotland and Northern Ireland. A separate questionnaire was sent to the Inshore Fisheries and Conservation Authorities (IFCAs) to gather up-to-date information on wild settlement and management measures. Information on the cultivation and production processes was obtained during site visits, as were figures used to estimate the economic contribution of the species. Expert opinion was also sought from a wide range of other institutions and organisations.

Cultivation and Economic Value

1. The risk of industry decline in the wake of uncertainty has prompted this review to provide a broad estimate of the economic value of the Pacific oyster industry in the UK and to review the beneficial ecosystem processes and services, including food production that wild settlement of Pacific oysters might provide.

2. The distinct cultivation and purification stages in the production of Pacific oysters suitable for consumption are reflected in a market structure in which individual companies may be involved in one or more of these processes. While some aquaculture and fishing companies also have depuration

operations, others sell on to companies that combine depuration and wholesale functions in the value chain. In some cases single companies (or groups with common or overlapping ownership) combine aquaculture and depuration with wholesale operations and even restaurants, thereby retaining most, or even all, of the value chain components within a single enterprise.

3. Around 1,200 tonnes of Pacific oysters are produced each year in the UK of which it is estimated that 67% is exported across the globe from France to south-east Asia. Based on 2011/12 prices and an analysis of the value chain, the total economic contribution as GVA (Gross Value Added), including indirect and induced effects, is estimated at £10.137 million. This value does not include seed production.

4. In addition to economic benefits, the case for long term growth in UK production is supported by strategic considerations including both food security and public health, particularly in the context of growing populations and the over- exploitation and plateauing of wild fisheries production.

5. With a large worldwide market, international demand will remain the key driver for British oyster production in the foreseeable future, and in this respect the comparatively low level of current UK production in comparison to neighbouring countries suggests that increasing market share, rather than just meeting growing demand, might provide a plausible component of business plans. Yet the fact that the 19th century British oyster boom was fuelled mainly by British consumption, along with hints from retail sales patterns, suggest significant growth in home consumption is feasible given appropriate marketing.

6. An extensive literature review provided evidence that wild Pacific oysters might provide beneficial ecosystem processes and services, in addition to food production via aquaculture, although these benefits are most likely to be associated with 'reef' formation that would only develop if wild settlement was particularly high. Relatively few studies have been carried out on wild Pacific oyster reefs, however some evidence was found for *Crassostrea* species (including *C. gigas*), although the beneficial characteristics and attributes of particular oyster species are likely to differ.

7. Collectively the beneficial ecosystem processes include biological control, formation of species habitat, formation of physical barriers (that attenuate the energy of water flow), erosion control, climate regulation and water purification. Biogeochemical cycling is an assumed beneficial ecosystem process based on the species' water filtration function. Beneficial ecosystem services include fisheries, other wild harvesting, aquaculture, cultch materials (shells) and construction materials (shells). Other inferred beneficial ecosystem services are natural hazard protection, environmental resilience and pollution regulation.

8. With respect to the societal benefit of food provision, it is clear that on the south-east coast of England, the colonisation of *C. gigas* has enabled the survival of the oyster industry from income arising from the management of this additional resource. However, no other ecological or societal benefits that may arise from the development of *C. gigas* reefs or the use of *C. gigas* individuals (in the case of research and education) were found to be unique and these services are already being provided to some extent by other habitats.

Origins of Larval Settlement

1. The first introduction of *Crassostrea gigas* to British waters can reliably be dated to 1890 or before and commercial importation of the Pacific oyster seed continued from 1926 until 1962. Although by 1965 the species was thought to have died out, it was known to be capable of "limited breeding" in the creeks of Essex and Kent and may have persisted in the Blackwater at least until 1970.

2. Although it has long been known that the species could episodically spawn in British waters, even as recently as 2002, the Pacific oyster was considered unlikely to be able to establish self-sustaining populations in the UK. However, although there is still a high level of uncertainty, current sea temperature projections are thought likely to result in certain non-native species, including *C. gigas*, recruiting every year in south-west England, Wales and Northern Ireland by 2040. An analysis of the effect of rising temperatures, under a medium emissions scenario, on the distribution of *C. gigas* and eight other marine invasive non-native species, showed that they would all theoretically be able to expand their range by the 2080s to encompass the entire UK.

3. The species current UK distribution mainly extends from southern England to Northern Ireland, with highest densities and some reefs developing in south-east England where it has not been harvested. There is also a scatter of individual records in Scotland. Although recruitment is still infrequent in most areas, populations are growing rapidly in some localities.

4. Wild settlement is not confined to the proximity of Pacific oyster farms, APBs or other wild settlements; isolated outbreaks are now occurring in areas that are distant (more than 50km away) suggesting other pathways of introduction, such as boat traffic.

5. Although no survey or modelling studies were carried out in this study, a review of the literature and expert opinion suggests that significant larval drift from continental oyster farms or wild populations across to the UK is highly unlikely. Of greater likelihood is transportation of adults and/or entrained larvae with boat traffic. Ballast water discharges were considered to be another possible source of larval introduction.

Impacts on Biodiversity and Protected Areas

1 The evidence suggests that the risk to biodiversity from wild settlement of Pacific oysters relates not so much to local changes in species diversity *per se* but to the extent of habitat transformation. On the continent, large areas of mudflats and rocky shore have been transformed to oyster reefs. Studies have mostly shown that species diversity is greater on Pacific oyster reefs than within the habitat on which the oysters settle. There is, so far, no evidence for total displacement of any species of national (UK) conservation interest, although small intertidal areas of *Sabellaria spinulosa* reef are being smothered by Pacific oysters on the shores of Kent.

2 Little evidence has so far been found for significant settlement in subtidal areas and habitats at most risk of significant transformation are intertidal. These include mudflats, rocky reefs and biogenic reefs, such as mussel beds and *Sabellaria* reefs.

3 Should the current warming trend continue and if left unchecked, there is a risk that extensive and broad-scale wild settlement could significantly affect the integrity of intertidal protected sites, including designated European Marine Sites (EMS). However, the evidence base for regional scale

impact of wild settlement on biodiversity and conservation interests is weak. It is possible that natural disturbances combined with managed interventions, including some fisheries, could maintain site integrity and functionality in some designated areas.

4 The physical removal of wild settlement on rocky shores is more problematic than on sediment shores, although small feasibility trials are currently underway.

Legal Issues

1. Although Pacific oysters are legally cultivated in the UK, wild Pacific oysters are classified as an invasive non-native species and are subject to an independent assessment of the risk they pose to the environment. In the UK, the assessment has concluded that the species currently presents a ‘medium’ risk to the environment.

2. EU legal instruments that are relevant to invasive non-native species such as the Pacific oyster include the Water Framework Directive (2000/60/EC); Habitats Directive (92/43/EEC); Marine Strategy Framework Directive (2008/56/EC) and the Council Regulation concerning use of alien and locally absent species in aquaculture (Regulation No. 708/2007). Although Pacific oysters are classified as an invasive non-native species in the UK, the current EU legislation does not prohibit aquaculture activities for this species. Instead, it attempts to ensure the sustainable management of the resource.

3. In view of the current EU legislative framework, competent authorities have some leeway on how to implement the legislation relating to the harvesting and aquaculture of the Pacific oyster and management of wild settlement. The wording of the directives and regulations aims to give Member States the ability to adapt the requirements of the legislation to the particular conditions present in their waters and, in particular, the demonstrable impact and risk that Pacific oysters are seen to pose in the environment.

4. Decisions related to aquaculture restrictions need to be fully justified and based on available data and a realistic assessment of the risk that the Pacific oyster poses to biodiversity and the environmental status of coastal areas.

Management Recommendations

1. It is important that any measures are proportionate to the level of risk that exists in a specific area at a specific time. However, as with any population invasion, it is also important not to be complacent due the rapidity of population growth. The feasibility of removing small developing populations that might cause a negative environmental impact should be considered seriously.

2. The environmental impact of wild settlement in the UK varies with locality and is currently absent or low in most regions. However, in the south-east of England, colonisation of Pacific oysters has now reached the stage that total eradication is considered economically impractical and environmentally undesirable due to the destructive measures that would be required.

3. Based on the evidence collected in this study and stakeholder engagement, it is concluded that a regional approach to the management of wild Pacific oyster settlement in the UK is likely to be the most effective, as opposed to broad-scale measures, that in some areas may be unnecessary or may already be irrelevant.

4. Specific measures that might be applied to the aquaculture industry include a consideration of the number of regional licences and the size and intensity of operations. The decision making process will need to take account of local hydrography and other physical characteristics of the water body. Applications for new licences should be considered in the context of a strategy for risk mitigation; this might involve producers in the implementation of mitigation measures such as harvesting wild settlement in more sensitive habitats.

5. There is evidence that triploid oysters are not completely sterile, and may revert to the diploid state over time, and as such cannot provide complete biological containment and prevent wild settlement. Furthermore, it has become clear from the industry consultation that experience of triploids varies between localities and individual growers, with good growth in some areas but not in others. The cultivation of triploid oysters may be considered on a regional or a local basis, where local producers say it works for them. Yet in the south-east of England, where wild settlement is already highly advanced, the introduction of triploids is unlikely to have any significant impact on wild settlement as the diploid population is already large. Wild settlement appears also to be occurring as a result of boat traffic, which will further increase the diploid population.

6. Constructive regional or local partnerships involving growers, regulators, statutory agencies, port authorities and other stakeholders, informed by locally relevant evidence and an assumption of sustainable development, represent the optimal approach to containing and mitigating negative ecological impacts of the Pacific oyster in the UK. The success and continuity of these partnerships will be best served by a vibrant but engaged industry, and there are incipient examples to draw from, which suggest that the achievement of both commercial and conservation objectives are not necessarily inconsistent.

7. In both areas where there is extensive wild settlement and in areas where the species is currently absent, it may be possible to provide financial incentives to support and develop a sustainable industry. For example, in harbours and port areas where wild settlement may be occurring as a result of boat traffic, harvesting and marketing the produce may be the only viable way of managing the stock. Business start-up schemes and fisheries and aquaculture support schemes could be appropriate avenues for support. However it is in northern areas, where there is currently minimal risk of wild settlement due to lower sea temperatures, that new growth and development of the industry might be most widely supported. In these regions, monitoring must still be rigorously applied, yet the life of the licence although conditional should not be too precautionary to inhibit long-term investment.

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1. Introduction

1.1 Project Background

There is a tension between the continued production of the Pacific oyster (*Crassostrea gigas*) in British waters and risk to biodiversity associated with the growth of wild populations as a result of rising sea temperatures caused by climate change. On the continent, large wild populations have resulted in 'reef' formation that has displaced or modified habitat protected under the EU Habitats Directive legislation. There are concerns that this could also happen in the UK, resulting in protected areas not meeting favourable ecological condition status and consequential fines (infractions) from Europe; both regulators and the shellfish industry in the UK fear that it will be held responsible for any such infractions. Yet, there is a perception amongst some stakeholders that the evidence base for negative ecological impact caused by growth of wild populations of *C. gigas* in the UK is weak, and that any necessary control and mitigation costs will be disproportionately prohibitive considering economic drivers for industry expansion.

Of prime concern to the industry is uncertainty relating to the legality of continued and increased production both within and in the vicinity of protected and designated sites. However, there is a desire amongst stakeholders and regulators that solutions for sustainable aquaculture and coastal management be sought and this report aims to provide an evidence base and suggestions for management options. An important part of the study has been an analysis of the socio-economic impact of the industry in different regions as this will have management implications.

1.2 Project Overview

This paper aims to present a review of the evidence base related to the economic, legal and environmental issues pertaining to the growth of the Pacific oyster industry in the UK. The study draws on evidence from comparable temperate regions around the world where Pacific oysters are grown and from UK and European stakeholders, industry, growers, and regulators. Many of these stakeholders are represented by individuals and organisations listed in the Acknowledgements section and members of the project Steering Group that included Natural England, the Countryside Council for Wales (CCW) Scottish Natural Heritage (SNH), Joint Nature Conservation Committee (JNCC), Defra Shellfish team, Defra Non-Native Species Secretariat, Defra Non-native Species policy team, Department of Agriculture and Rural Development (DARD), Shellfish Association of Great Britain (SAGB), Association of Scottish Shellfish Growers (ASSG) and the Seafish Industry Authority.

The report provides an overview of the drivers for expansion of the industry and the demand, markets and the process of cultivation and harvesting of Pacific oysters. A measure of the direct economic contribution of the UK Pacific oyster industry has been undertaken together with a review of the ecosystem services provided by Pacific oysters, including wild settlement and oyster 'reefs'. There is an analysis of the legal issues regarding the species status in the UK and that of other EU Member States and the implications of various environmental regulations and Directives. The ecological evidence for impact of wild settlement of Pacific oysters on biodiversity is discussed together with a literature review of the evidence that relates to the origins of wild settlement in the UK and the likelihood of larval dispersal and/or introduction from sources in the UK and continental shores. A particular focus has been the implication for maintaining favourable condition of different Annex 1 Habitats listed in the EU Habitats Directive e.g. rocky reefs and mudflats. Field studies and experimental studies that might aid this analysis have been sourced from the literature and from professional networks. The initiation of new studies has been outside the scope of this study.

The report aims to present evidence for any existing or potential positive or negative impact of wild settlement of Pacific oysters on biodiversity caused by dispersal from UK oyster farms that might have an impact on designated sites. Measures that may be implemented to mitigate any negative impacts are also reviewed and discussed. The feasibility, likely effectiveness and financial impact of these measures will be addressed as far as is practicable.

1.3 Report Structure

Following an Introduction (this Section) that provides the project overview and describes aims and methodology, with definitions and notes on synonymy, the report is divided into sections that begin with an analysis of the economic value of Pacific oyster cultivation in the UK (Section 2). The origins for wild settlement in the UK, together with evidence for larval dispersal from continental sources is covered in Section 3, with a review of evidence relating to the impact of wild settlement on biodiversity and habitats in Section 4. There then follows a review of ecosystem services provided by Pacific oysters in Section 5, including that provided by wild settlement. Legal implications for continued production within designated sites are discussed in Section 6. There then follows a section on management approaches and measures that might be implemented to address any negative impacts of wild settlement and to mitigate against risk of new settlement (Section 7). Case studies that help to demonstrate the nature and complexity of the issue in different areas are provided in Appendix A. Supplementary information and a copy of the questionnaire used within the stakeholder engagement exercise is provided in Appendix B.

1.4 Definitions

Some key definitions of terms used in this report are given below. Others are presented in the text when they first appear.

Non-native Species

In this report we refer to non-native and invasive species according to the definitions used by the GB Non-native Species Secretariat (NNSS, 2012).

The term 'non-native species' is equivalent to that of non-indigenous, foreign, exotic, and 'alien species' as used by the Convention on Biological Diversity (CBD). It refers to a species, subspecies or lower taxon, introduced (i.e. by human action) outside its natural past or present distribution; includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce. Non-native species include all fauna and flora with the exception of genetically modified organisms (GMOs), bacteria and viruses. Man first arrived in Britain about 8,000 years ago and virtually all new land animals and plants that have become established since this date have been brought here by man. These are all non-native species.

An *invasive* non-native species is any non-native animal or plant that has the ability to spread causing damage to the environment, the economy, our health and the way we live.

Establishment

This definition is used by the EU Water Framework Directive UK Technical Advisory Group (UKTAG, 2004).

The process of a species in a new habitat successfully reproducing at a level sufficient to ensure continued survival without infusion of new genetic material from outside the UK.

Wild Settlement

Pacific oysters have a larval stage to their life cycle that swims and drifts in the water for between 2-4 weeks. The final larval stage will settle on the shore or seabed and develop a hard shell that in time will be recognisable as a juvenile oyster. In this report, wild settlement refers to the point when the oysters are first observed on the shore. This may be at the juvenile or adult stages (the life-history of the Pacific oyster is illustrated in Image 3.1, Section 3). It is often the case that much larger quantities of larvae settle on the shore prior to observation, however most of these succumb to mortality from predators and unfavourable environment.

Oyster Reef

A reef is formed when wild oyster densities on the shore are so high that little space exists for subsequent oyster settlements or other species on the substrate surface (e.g. rock or mud). Densities of oysters will vary but would usually be in excess of 200 per m^2. Subsequent oyster settlements will therefore often be on existing oysters, and over time a hard concretion of live and dead oysters will develop. This is called an 'oyster reef'. It is often the case that groups of two or more oysters will merge and form a 'clump' and that 'clumps' of oysters will merge and eventually form a 'reef'. The area, height and thickness of the reef will vary and be dependent on the larval supply and settlement success in different parts of the site. No formal measure of oyster 'reefiness' was found by this review. Pacific oyster (*C. gigas)* reefs are illustrated in Images 4.1-4.3 (Section 4). Reefs formed by other oyster species do differ with respect to rugosity and topography.

1.5 Methodology

1.5.1 Evidence Base

A systematic (i.e. repeatable) review of literature pertaining to all aspects of this Issues Paper was conducted using the search terms shown in Appendix C. Information was obtained from areas with warm or cold temperate climate and within 'Biogeographical Realms' (Spalding *et al.* 2007) that have marine habitats similar to that of the UK; these are: *Temperate North Atlantic*, *Temperate North Pacific*, *Temperate South America, Temperate Southern Africa* and *Temperate Australasia*. This was primarily undertaken through searching relevant online research databases and catalogues (ISI Web of Science, JSTOR, ScienceDirect, Scopus, Google Scholar). To ensure that relevant 'grey literature' was incorporated, an internet search using the same search terms was conducted and professional networks and organisations likely to hold grey literature, and information on unpublished and on-going studies, were contacted. These organisations included CCW, Centre for Environment, Fisheries and Aquaculture Science (Cefas), Defra, DARD NI, Department of Environment (Northern Ireland; DoE NI), Marine Scotland, MarLIN, Natural England, JNCC, the Scottish Executive, SNH, ASSG and the Wildlife Trusts Partnership. Scientific experts with specific knowledge about the Pacific oyster and stakeholders professionally engaged in aquaculture were consulted either by email, phone or face-to-face interviews and field visits (listed in Acknowledgements). In addition, a questionnaire was sent to all members of the SAGB and to all Mollusc Aquaculture Production Businesses (APBs) within England and Wales via Cefas and within Northern Ireland via the Aquaculture Initiative (EEIG, Downpatrick). A separate questionnaire was sent to the Inshore Fisheries and Conservation Authorities (IFCAs) to gather up-to-date information on wild settlement and management measures. Copies of the questionnaires may be found in Appendix B.

1.5.2 Pacific Oyster Distribution in the UK

Data on the distribution of wild Pacific oyster settlement around the UK, and the location of current authorised Pacific oyster Aquaculture Production Businesses[1] (APBs) was used to create Geographical Information system (GIS) resource layers to help examine the origin of wild Pacific oyster settlement in the UK (presented in Section 3 and Appendix A).

Data on the current distribution of Pacific oyster APBs in England and Wales, Scotland and Northern Ireland was sourced from Cefas, Marine Scotland and the Loughs Agency and the Aquaculture Initiative (EEIG) respectively.

The current distribution of wild Pacific oysters in the UK was primarily sourced from Higgs *et al.* (2010). This data was supplemented by new records provided by expert individuals, organizations and information provided by IFCA surveys, and was used to create GIS data layers. For the purposes of this review, a ‘record’ relates to any wild Pacific oyster presence recorded within 10km x 10km grid cells around the UK coastline during surveys conducted between 1978 and 2012. In three locations around the UK it was known (from experts and/or the review authors) that dense aggregation/reefs of Pacific oysters existed, and that these reefs were not represented within the spatially referenced records described above. In these instances, the presence of these known dense aggregations/reefs were represented in the GIS data layers as non-spatial data (a symbol placed in the middle of a 10km^2 grid cell). The UK distribution maps are shown in Figures 3.1a and 3.1b in Section 3.

The distribution of wild Pacific oyster settlement around the Thanet coast (Kent) and Blackwater Estuary, is shown in greater detail in Appendix A, based on data provided by Natural England and Essex Wildlife Trust respectively. The broad-scale intertidal habitats on which wild settlement has occurred (shown in the Thanet coast case study) was sourced from Frost *et al.* (2010).

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1 Molluscan Aquaculture Production Businesses (APBs) will include Mollusc shellfish farms, hatcheries, importers, quarantine and depuration facilities and installations where animals are reared or held prior to market.

1.6 Note on Species Synonymy

As early as the 1960's, similarities of anatomy and habitat between *Crassostrea gigas* and *C. angulata* were taken to suggest that they may be the same species (Yonge, 1966). Since the 1970's, on the basis of such evidence as indistinguishable larval and adult shells and ease of hybridization between the two (Menzel, 1974; Mathers *et al.* 1974; Buroker *et al.* 1979), it has become accepted that *C. angulata* and *C. gigas* are the same. Consequently while some literature refers back to distinct British introductions of *C. angulata* and *C. gigas* (Cole, 1956; Davidson, 1976; Utting and Spencer, 1992), definitive taxonomic authorities such as the UK Natural History Museum, London, now regard *C. angulata* as a synonym for *C. gigas. C. angulata* is now globally an accepted synonym of *C. gigas* (WORMS, 2005).

The erroneous distinction between the two may have been the result of an assumed independence of populations in Portugal (*C angulata* being referred to as the Portuguese Oyster) and Japan/west coast America (*C gigas* being the Japanese or Pacific oyster) caused by high phenotypic plasticity and consequent variation in appearance in response to both the nature of the seabed and the degree of crowding (Quayle 1969). It can be postulated that the Tagus estuary, Lisbon was the site of an old introduction from the Pacific (CIESM, 2003), possibly attached to ships hulls (Yonge, 1966), from which stock was introduced into Britain as the "Portuguese Oyster" in 1926 (Utting and Spencer, 1992). On the west coast of America, populations of *C. gigas* from Japan, (initially known as Japanese Oysters) were introduced into Washington State in 1902 (Loosanoff and Davis, 1963). Subsequently they were regularly imported as spat to both US and Canadian Pacific coasts, gradually becoming sold as "Pacific oysters" by the trade (Ricketts and Calvin, 1962), possibly as a marketing response to Japan's involvement in WW2. The existence of three "races" of *C.gigas* with markedly different appearance in Japan (Quayle, 1969), suggests the possibility that genetically distinct Portuguese and north American populations came to exist through founder effects (the limited gene pools of small initial inoculums) and/or by differential allopatric selection. In any event by 1947 naturalised populations existed in British Columbia, from which specimens were taken to the UK in 1964 (Walne, 1979) to replace diseased "Portuguese oyster" populations (Davidson, 1976).

As summarized by Miossec *et al.* (2009), genetic studies indicate that *C. gigas* and *C. angulata* are a single species (e.g. Biocca and Matta, 1982; Gaffney and Allen, 1993; Huvet *et al.* 2002). Similarly nuclear and mitochondrial DNA studies have shown a close genetic relationship between the two (Lopez-Flores *et al.* 2004; Reece *et al.* 2008). Although some other studies have demonstrated genetic differences, on the basis of conventional species definitions relating to the viability and fertility of hybrids and supported by taxonomic authorities such as the Natural History Museum, for this review we consider them a single species: *Crassostrea gigas* (Thunberg 1793), NBN ID code NBNSYS0000174740.

Synonymy: *Crassostrea gigas; Crassostrea angulata; Gryphaea angulata*.

Although the National Biodiversity Network and the UK Natural History Museum, London, recommend the common name Portuguese Oyster (NBN ID code NHMSYS0020735281), in line with the more familiar terminology within the UK industry we will use Pacific oyster.

English Vernacular Names: Pacific oyster**;** Portuguese Oyster**;** Rock Oyster**;** Japanese Oyster**;** Pacific cupped oyster.

In this review, references to *Crassostrea angulata* in older sources will be interpreted as referring to *Crassostrea gigas*, except where stated otherwise in the text.

2. Pacific Oyster Cultivation in the UK

2.1 Origins of Commercial Exploitation

2.1.1 The British Oyster Tradition

The commercial exploitation of oysters in Britain has a history at least as ancient as the Roman occupation (Winder, 1992). During the medieval period the value of native flat oyster (*Ostrea edulis*) grounds were such that, in 12th century Essex, fishing rights were protected by Royal Charter and by the 16th century various forms of fishery regulation are known to have applied to Whitstable dredging operations (Yonge,1966). By 1683, landings on Essex grounds were limited to “1000 barrels” per week (Laver, 1916).

Probably commencing in the 1830’s, a boom in British oyster production was attributed by Mayhew (1851) to the provision of rapid transport via a growing railway system. However it also coincided with population growth, poverty and the consequent availability of labour (Neild, 1995). Official oyster landings were first recorded in 1886 with production of 40 million oysters reported for that year (Neild, 1995 p55, also reported by Spencer, 2002 p12 as 3,500 tonnes) However these figures are almost certainly a significant underestimate of total landings and, in any event, do not represent peak landings, as a precipitous fall in production between the 1860’s and the 1890’s is known to have occurred. Unreliable figures (reviewed by Neild, 1995) include an estimate (by Mayhew, 1851) of 500 million oysters passing through Billingsgate Market in 1850 and, in contrast to the first official statistics, a total British annual consumption of 1.5 billion oysters reported by the *Times* newspaper as late as 1867 (The Times 15th October 1867).

While figures for the 19th century British oyster boom are unreliable, the fact remains that mid century Britain was thought to contain the richest natural oyster beds in Europe: A resource which, along with deeper off-shore beds, generated much socio-economic benefit, as is indicated by various contemporary sources reporting hundreds of oyster boats and thousands of oystermen in each of a number of traditional oyster centres (See Neild, 1995).

The heyday of British oyster fisheries was followed by a “catastrophic fall which came gradually” (Yonge, 1966). A Royal Commission on Sea Fisheries, reporting a decline as early as 1866, rejected over-fishing as an explanation. However 10 years later the problem was such that Parliament established a Select Committee specifically to inquire into the continuing scarcity of oysters. This body rejected the opinion of the Royal Commission, finding the principle cause of the decline to be over dredging. Modern authors also consider this to be the main cause of the initial (i.e.19th Century) decline (Yonge, 1966; Neild, 1995).

In any event, the decline in native oysters (*Ostrea edulis*) provided a strong economic rationale for the importation of seed oysters for fattening in UK estuaries. In addition to *Ostrea edulis*, from 1870 these imports included the non-indigenous American oyster *Crassostrea angulata* (Spencer *et al*. 1994).

2.1.2 The Introduction of the Pacific Oyster

Prior to the discovery that the Portuguese and Pacific oysters were the same species (see Section 1.6), the first British introduction of *C.gigas* was sometimes reported to be in 1965 (Utting and Spencer, 1992; Spencer, 2002 p11), initially into the Blackwater Estuary in Essex (Eno *et al.* 1997). However the same sources when interpreted in light of the modern consensus on the synonomic relationship between these oysters, suggest the first introduction of *C gigas* to have been in 1926, as a response to a further and sharp decline of British oyster fisheries earlier in that decade. An alternative earliest UK introduction date of 1901 has been suggested by Spencer *et al*. (1994) who report *C. angulata* (= *C. gigas*) to have been imported for fattening and sale in the summer when the native flat oyster was breeding and therefore unmarketable. However since none of the above cited publications are primarily about the history of introductions, they do not provide primary source references for the dates asserted.

In light of the known 19th century connections between UK and French oyster fishers (e.g. Neild, 1995), the fact that *C.gigas* was introduced into France from Portugal as early as 1860, and within 20 years was cultivated on the Brittany coast (Spencer, 2002; Goulletquer & Heral, 1997), has led us to examine primary source material to check the possibility of earlier introduction into the UK. This work has revealed explicit references to Portuguese oysters and Tagus oysters (elsewhere in the same source being identified as *Gryphae angulata*) being fattened in Poole beds by the Poole Oyster Company in 1890 (Philpots, 1890 p105). The first introduction of *C. gigas* to British waters can therefore reliably be dated to 1890 or before.

Despite such efforts continued industry decline after 1926 was attributed to pollution, American pests introduced with imported stock, unusually severe winters (1939/40 and 1946/47), and occasional unexplained large scale mortalities (Cole, 1956). In fact late 19th century oyster production levels have never subsequently been restored or even approached (Utting and Spencer, 1992).

Commercial importation of the Pacific oyster continued until stopped in 1962 as a consequence of disease in source populations (Utting and Spencer, 1992). Although by 1965 the species was thought to have died out, it was known to be capable of "limited breeding" in the creeks of Essex and Kent (Cole, 1956) and it has been suggested that wild Pacific oysters persisted in the Blackwater at least until 1970 (Eno *et al.* 1997). However by then a second phase of British introduction was under way.

In 1965 a new and more stringent legislative regime was introduced, informed by increasing concern about the inadvertent introduction of alien pests and diseases. Various "control of deposit" orders regulated the movement and introduction of molluscan shellfish and provided a strong rationale for the development of techniques for the hatchery production of Pacific oysters from quarantined broodstock lines, as a safe alternative to importing seed oysters. This work was conducted by the government Fisheries Laboratory at Conwy, which had been investigating the culture of Oysters since 1918. In 1964, a consignment of *C gigas* was imported to Conwy from British Columbia (Walne, 1979). A promising field trial on the Menai Strait was followed in 1967 by successful experimental (pathogen free) introductions at 10 UK sites (Walne, 1979). By this time also, hatchery production techniques were sufficiently developed to be applied on a commercial scale.

As in the 1920's, the 1960's re-introduction of *C. gigas* was motivated by decline in established oyster fisheries. Even in the context of a steady decline in native oyster landings since the 1820's, the Ministry of Agriculture, Fisheries and Food's (MAFF; former Government department, now Defra) preferred solution involved the native species. Consequently work in the 1950's at Conwy had focussed on investigating the artificial enhancement of natural spat settlement by native oysters. Only after the failure of this work due to low numbers of adults on the fisheries and irregularity of spawning, did attention turn to using fully controlled hatchery techniques. While hatchery development also focussed initially on the native oyster, it later became clear that the more resilient nature of *C. gigas* made it a more suitable species for hatchery production and artificial rearing (Davidson, 1976). Further consignments of Pacific oysters from Canada and the USA were imported in 1972 and 1978 respectively, to enrich the UK gene pool (Utting and Spencer, 1992).

The history of British introductions of *C. gigas* is relevant as part of the evidence for understanding aspects of the ecology of the species in British waters. However in addition to its scientific relevance, such knowledge has also had policy implications: In 1982 a general licence to "release or allow to escape into the wild" *C. gigas* was issued (*London Gazette* 30th November 1982) under the terms of the Wildlife and Countryside Act 1981. The Act could have prevented such release if the species was considered "not ordinarily resident", however the rationale for the general licence for the species was that it was considered "already resident". In fact it has long been known that the species could from time to time spawn in British waters (e.g. Cole, 1956; Yonge, 1966) and this has, in the absence of perceived risk, sometimes been taken to imply that the species be considered as part of the British marine fauna (Yonge, 1966 p84). As recently as 2002 however, the Pacific oyster was considered unlikely to be able to establish self sustaining populations here (Spencer, 2002), and indeed there is little evidence that for the greater period of its presence in UK waters it did so.

While the bulk of this report is focussed on the nature and extent of the risks that the Pacific oyster represents today, the fact that it has been introduced into UK waters on a number of occasions since 1890 suggests that the general effects of climate change may have at least as much analytical power as invasive species theory for elucidating the causes of, and establishing appropriate responses to, recently established wild populations. Moreover, although the European flat oyster can thrive in warmer waters than currently surround Britain, its long standing decline indicates that it cannot be assumed that the native species will in the future provide the socio-economic benefits and ecological services that it once did, and which may alternatively be provided by the Pacific oyster.

2.2 Methods of Cultivation, Harvesting and Purification

2.2.1 Hatcheries and Seed Oyster Supply

In warmer waters small Pacific oysters for culture have traditionally been obtained using devices designed to encourage the settlement of wild pelagic larvae. In Britain however natural spatfalls of *C. gigas* are unreliable and inadequate as a basis for commercial seed capture. Consequently during the early phase of introduction in the 1920's, consignments of oysters were regularly imported for culture, bringing with them alien predators and diseases (see Section 4.1).

By the 1960's however, an understanding of these risks and the resulting regulatory regime required a new solution to seed oyster supply. In response, the Conwy fisheries laboratory developed methods for hatchery production. This technology was subsequently spun out, initially to a commercial hatchery in Reculver, Kent. Today broodstock for hatcheries can be sourced from designated shellfish areas which, on the basis of regular monitoring, are known to be clear of disease.

The costs of hatchery production derive mostly from the control of conditions for broodstock, larvae and spat. In addition to providing pathogen free, relatively warm seawater, UK hatcheries include facilities for the culture of specific species of phytoplankton, as an enriched food supply for the optimisation of fecundity and larval/juvenile growth in high density cultures. Large scale micro-algal production such as at the Reculver, Morecombe Bay and Guernsey hatcheries employ bag culture methods involving heavy but transparent polyethylene tubes arranged vertically in such a way as to allow continuous flows of the required algal species. In such conditions, relatively small numbers of broodstock suffice: one ripe female (70-100g wet weight) being capable of producing 50-80 million eggs (FAO, 2005). About 24 hours after fertilization the larvae reach the "D-larva" stage (fully shelled prodissoconch I) with metamorphosis and settlement after 14-18 days.

Spat are kept in the hatchery in an upwelling flow system until reaching around 3-5mm after which they may be sold or on-grown further in a nursery, in order to meet the varying requirements of different aquaculture operations. Hatcheries supply both diploid and triploid seed oysters, typically inducing triploidy through chemical treatment. Triploidy impedes reproductive success and constrains reproductive effort leaving more resources for flesh production. Triploidy and its significance for conservation is discussed in Section 7.

2.2.2 Nursery Operations

Further growth of the spat (typically up to 15mm) is achieved outdoors in nurseries involving upwelling systems on floating (e.g. Morecombe Bay) or fixed (e.g. Reculver) structures supplied by networks of outdoor salt water ponds. These pond systems are extensive outdoor equivalents to the intensive bag cultures used within the hatchery for algal food culture. As such they are designed to promote algal blooms and to this end are enriched with inorganic nutrients sufficient to achieve the required oyster growth rates. Since individual growth rates in any one batch of spat varies, grading and sorting by size occurs at various stages.

In response to orders, hatchery/nursery operators grow and sort seed oysters of the required size for transport to client aquaculture locations. For clients requiring larger seed oysters than are produced in the nursery, oysters may be brought to size in bags fixed to trestles positioned on the seabed and sold on as "part-grown".

2.2.3 Aquaculture and Harvesting

The size at which different oyster farms buy hatchery stock varies according to local conditions and methods employed. A not atypical practice might involve buying 6mm hatchery spat in the spring and growing them on for two summer seasons before selling at about 100g.

Pacific oysters smaller than about 15mm length (perhaps 10g wet weight) are vulnerable to severe predation, not least from crabs, and are therefore invariably protected until this size is reached (Spencer, 2002). Although in some circumstances the protection of ground plots can be effective, in the UK, small Pacific oysters are normally laid in trays and/or protected within mesh bags. These may be arranged on trestles, typically 0.3-0.5m above the seabed, or on a floating structure as in Poole Harbour. Regular servicing of these juveniles involves sorting by size and transferring stock to larger mesh gauge bags to maximize flow through of algae-laden water. In the UK this may be necessary twice in the first summer and ensures densities and growth rates remain as required. Inevitably growers build up expertise on the arrangements and husbandry practices best attuned to their localities. Consequently some operators may continue to grow their stock to market size on trestles or in baskets (such as in The Fleet). Alternatively they may be laid directly onto areas of seabed. In Poole Harbour, for example oysters, are moved to the seabed at about 30mm.

Techniques for harvesting oysters from the seabed range from hand picking at low water, through various conventional oyster dredge arrangements (Image 2.1a), to specially developed harvesting craft combining a pump-scoop dredge with mechanised conveyer to deck level (Image 2.1b). The technique employed by an operator relates to local conditions, the degree of specialisation of the operation and its capacity for investment.

Photo: J Humphreys

Image 2.1a West Mersea Oyster Boat on the Blackwater, Showing Dredge Gear

Photo: J Humphreys

Image 2.1b Othneil Oysters Harvester with (Submerged) Pump-Scoop Dredge and Conveyor at Poole Harbour

2.2.4 Shellfish Waters and Depuration

Hazards associated with the consumption of bivalve molluscs arise most commonly from the contamination of waters in which they grow, especially when, as with oysters, they may be eaten raw or only lightly cooked. As filter feeders, oysters accumulate pathogenic micro-organisms in concentrations higher than that of the surrounding seawater. Consequently waters polluted with human sewage or animal faeces (such as from farmland) have been the basis of outbreaks of various enteric diseases and other food poisonings. Statutory approaches for ensuring bivalve products are suitable for human consumption include the designation of shellfish harvesting areas which are monitored for various contaminants. A key measure is the degree of microbial contamination and in this respect designated shellfish waters are classified in line with international standards (EC Regulation 854/2004). For these purposes, levels of *Escherichia coli* are routinely monitored as an indicator of faecal contamination. While prohibition on harvesting occasionally results from this monitoring, in the great majority of UK cases, areas are classified, on an A – C scale, which in turn determines the regime that the oysters must experience prior to sale for consumption. Oysters from Class A areas can be marketed without treatment. Hazards associated with B and C class areas must be removed either by relaying in a less-contaminated area or an approved treatment process. In 2009 the majority (64%) of UK designated shellfish waters were Class B sites, for which purification without the need for relaying is sufficient (Cefas, 2011a). This is commonly achieved through "depuration", which involves allowing oysters to clear out their pathogens to safe levels in a closed seawater system in which water, after passing over the oysters, is sterilized with UV light before re-circulation. Lee *et al.* (2008) provide a detailed review of the theory and practice of depuration.

In terms of both monitoring and research on shellfish hygiene, the UK benefits from the technical expertise of the European Community Reference Laboratory for bacteriological and viral contamination of bivalve molluscs, which is located at Cefas in Weymouth.

2.3 The Economics of the Pacific Oyster

An appreciation of the societal benefits of production from the marine environment, such as those derived from fisheries and aquaculture, is increasingly recognised as a fundamental component of marine planning processes (e.g. Marine Management Organisation (MMO), 2011). UK marine policy now includes a presumption in favour of sustainable development and the value of shellfisheries and aquaculture, especially for coastal communities, is recognized (HM Government, 2011). In this context some assessment of the economic value of the Pacific oyster should provide a complement to information on its status in UK ecosystems. In the absence of published analyses of the full economic value of UK Pacific oyster production, it is difficult to appreciate the societal implications of regulatory and management recommendations and decisions. Although production and “value at first sale” (VFS) data reported annually by the Government provides essential information, these statistics do not seek to represent the full contribution of the species to the UK economy, and if taken as such, would be a substantial underestimate.

A calculation from first principles of the contribution of UK Pacific oyster production to the national economy is beyond the scope of this study, nevertheless, in the absence of such information in the literature, we have sought to acquire a greater insight into the economic significance of the species than value-at-first-sale information can alone provide.

2.3.1 UK Production

Estimates of UK shellfish production have suffered from significant uncertainties. Causes include variations across the UK between fishery administrations, and uncertainties in the validity of landings reports (ONS/MMO, 2011). Problems with the reliability of Pacific oyster landing statistics relate also to the possibility in recent years of data overlaps between farmed and fished production and uncertainties in the comprehensiveness of landings reports, especially from vessels under 10m, for which there has been no statutory obligation to complete a fishing logbook or landing declaration. Recent improvements including the mandatory reporting of first sales, new European regulations (EC 762/2008) and a UK code of practice designed to increase public confidence in official statistics, will continue to improve the situation for the future. Nevertheless useful Pacific oyster production and VFS data are collected and reported on an annual basis.

Tables 2.1a and b provide information on landings derived from government fisheries statistics reported annually in the Cefas publication *Shellfish News*. Further information on UK production, shown in Table 2.5 (see Section 2.3.8), is provided by the Global Fishery Statistics database of the UN Fisheries and Agriculture Organisation (FAO) (2012a). While there are discrepancies between the differently sourced UK figures in Tables 2.1a and Table 2.5, they are at least broadly compatible.

Figures for UK native oyster (*Ostrea edulis*) landings indicate the relative importance of the Pacific oyster. For example while in 2010, 1,150 tonnes of Pacific oyster production is reported by the FAO (Table 2.5), the equivalent figure for the native flat oyster is 117 tonnes, and although a further 200 tonnes was landed from natural beds, in recent years the native oyster has often provided well under 10% of UK oyster tonnage. Despite efforts to restore UK native oyster populations the fact remains that without *Crassostrea gigas*, the UK oyster industry would be decimated.

Table 2.1a Total UK farmed Pacific oyster production (tonnes) 2004-2009

Year	2004	2005	2006	2007	2008	2009
tonnes	1,019	975	1,290	1,169	1,061	1,356

(Sources: Cefas, 2005, 2006, 2007, 2008, 2009, 2011b)

Table 2.1b 2009 UK farmed Pacific oyster production (tonnes) by home nation

Species	England	Northern Ireland	Scotland	Wales	UK Total
Crassostrea gigas	811	309	232	4	1,356

(Source: Cefas, 2011b)

2.3.2 International Oyster Trade

From 2007 to 2010, combined Pacific and native oyster exports from the UK ranged between 916 and 1,051 tonnes per annum. Typically over 60% of exported oysters go to France and Spain with (in 2008) a further 7 countries taking more than 5 tonnes and 19 countries taking less than that quantity (Cefas, 2010). Over the same period oyster imports ranged from 292 to 450 tonnes per annum with Ireland, France, South Korea and USA being significant suppliers. (Cefas, 2009, 2010, 2011c).The balance of trade for oysters is therefore consistently in favour of export.

In 2010, total FAO (2012a) reported UK farmed oyster landings (Pacific and native oysters) was 1,267 tonnes. That year UK oyster imports amounted to 292 tonnes, giving a total UK oyster "stock" of 1,559 tonnes. Of this 1,051 tonnes was exported. Since Pacific oyster production is about an order of magnitude higher than that of the native oyster, we can reasonably assume that these ratios approximate well to those of the Pacific oyster in particular. If exports are equally likely to be taken from UK production and imported stock then we can estimate that 67% of UK Pacific oyster production is exported. In practice since oysters are generally traded as live animals it is probable that UK produced oysters are more likely to be exported from the UK than imported product. However the speed of chilled transport and extent of trade between the UK and its immediate neighbours Ireland and France makes this uncertain and in the absence of evidence to the contrary we will, for the purposes of the economic calculations below, assume that 67% of UK Pacific oyster production is exported.

2.3.3 Estimating Economic Contribution

Our approach for quantifying the economic contribution of UK Pacific oyster production is based on methods applied widely for analyses of the contributions made by particular firms, industries and geographical localities in regional and national economies. After elucidating market structure we have applied production and prices information to calculate gross output at each stage of the value chain. Direct GVA (Gross Value Added) for each stage is then calculated using published UK value added factors. To add indirect and induced economic effects we have applied published Type 2 GVA multipliers (see Appendix D for definitions) to predict the total GVA contribution of UK Pacific Oyster production to the national economy. Information on these concepts, and the assumptions and sensitivities in our estimations are provided in Appendix D.

Much of our information on the market and prices has been collected during our visits to companies directly involved in the production and marketing process. In order to capture the full value of UK Pacific oyster production our analysis encompasses all stages in the value chain from initial production to either export or sale for consumption. As such it ranges across distinct industry sectors from aquaculture at one end to hospitality at the other.

Our analysis excludes seed production (see Section 2.3.7) and therefore begins with published production reports and VFS figures. We have assumed an annual UK production of 1,200 tonnes per year, this probably being a conservative figure recognizing the annual fluctuations shown in Table 2.1a and uncertainties in landings data. It is also the ball-park figure for 2010 total UK Pacific oyster production reported by SAGB to the UK national press.

2.3.4 Value at First Sale

From official estimates (Anon, 2011) we can determine that VFS for Pacific oysters in 2009 was £1,815 per tonne. Since prices in parts of the value chain are quoted per oyster it is necessary for our purposes to estimate VFS per oyster (often referred to as “per shell”). Anon (2011) equates 1 tonne of Pacific oysters to 12,500 shells at a mean live mass per shell of 80g. These relationships in official industry figures correspond reasonably well with information we have direct from the industry indicating a typical range of 10,000 -12,000 Pacific oysters per tonne and mean live mass range from 83 -100g per oyster. For our calculations we assume a mean Pacific oyster live mass of 90g, and a standard number of 11,110 shells per tonne. Combining these figures gives a 2009 Pacific oyster VFS of 16p per shell. Although this figure contrasts noticeably with a 22-30p per shell figure which has been quoted for 2007 first sales in Scotland (UKMMAS, 2010), allowing for the time interval it fits better with our observed 2011/12 industry figure of 15 to 25p per shell, with 20p as the most commonly quoted figure from producers.

Therefore as our basis for estimating the economic contribution of the Pacific oyster we will use the following standard quantities:

- Standard no of shells per tonne = 11,110; and
- Standard value at first sale, per shell = 20p (2011/12 prices).

2.3.5 Market Structure and Prices

The distinct cultivation and purification stages in the production of Pacific oysters suitable for consumption (described in Section 2.2) are reflected in a market structure in which individual companies may be involved in one or more of these processes. For example, while some aquaculture and fishing companies also have depuration operations, others sell on to companies that combine depuration and wholesale functions in the value chain. In some cases single companies (or groups with common or overlapping ownership) combine aquaculture and depuration with wholesale operations and even restaurants, thereby retaining most or even all of the value chain components within a single organisation. The Scottish Shellfish Marketing Group, which is owned by a number of producers, provides a sophisticated example of overlapping ownership across components of the value chain. Image 2.2 provides a diagrammatic representation of the market structure including value chains connecting production with consumption.

The diagram shows two wholesale stages in supply chains. The first of these, referred to as Stage 1 wholesale, typically combines depuration with selling-on to Stage 2 wholesalers or directly into local retail operations such as restaurants. The diagram serves as our model for economic estimates. As such it simplifies some transaction patterns, particularly those connecting to boxes 9 and 10. For example, the model neglects the probability that, in response to immediate patterns of demand, oysters follow a more complex supply chain involving a third wholesale stage, or that some production enters the preserved or processed food markets. However in terms of world production at least, such products represent only a very small proportion of total production (FAO, 2012b). Although for completeness the model includes hatchery supply we have not included this activity in our GVA calculation as the value of this production is not published. However information on annual hatchery production rates is provided in Section 2.3.7.to indicate the scale of operations.

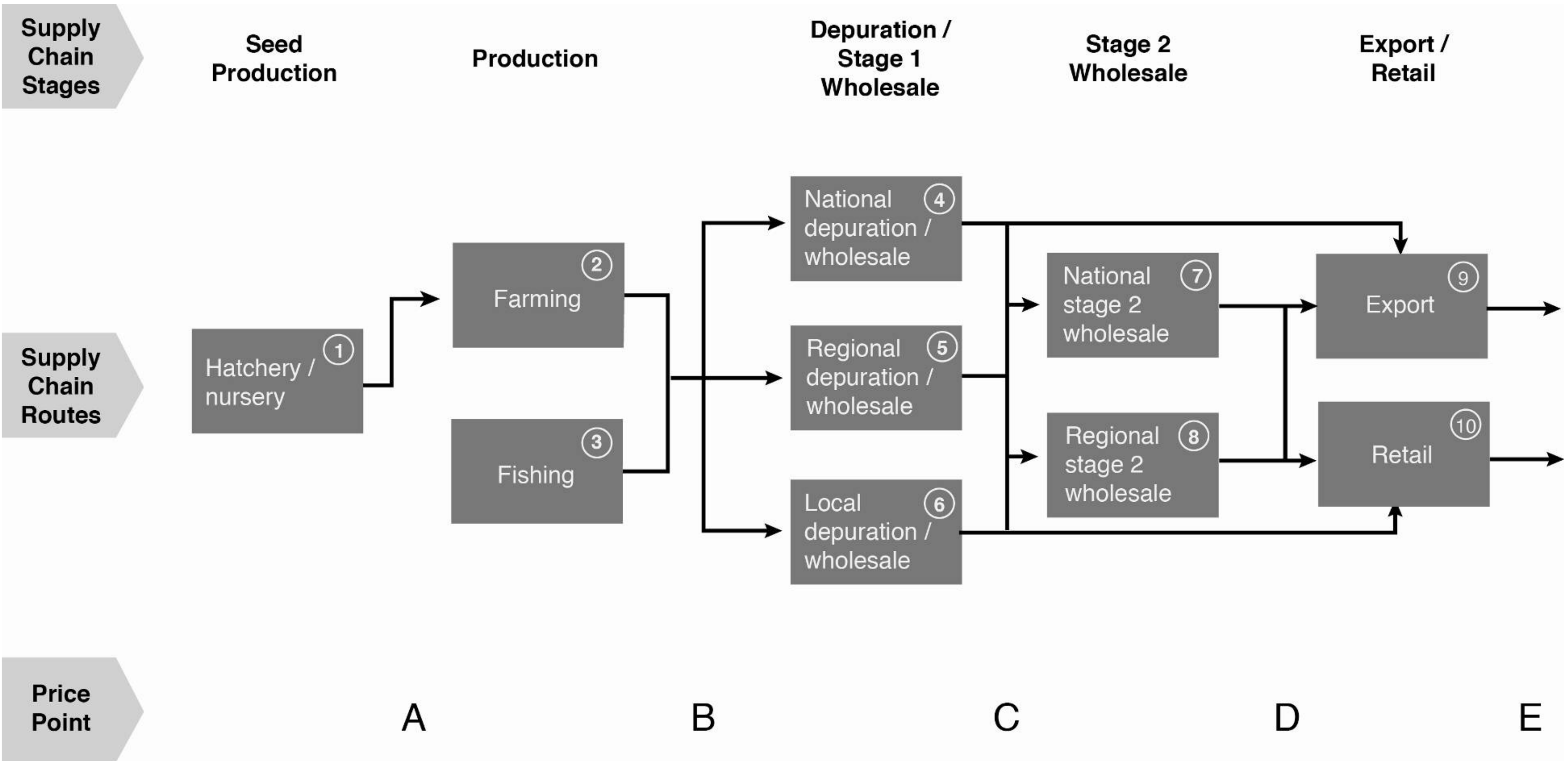
Prices per shell at different stages of the chain, are shown in Table 2.2. Price at first sale has been calculated from national estimates and corroborated during industry visits. Other prices are derived from industry visits combined with phone and web research. At price points C and D (Image 2.2, Table 2.2) prices vary with size, volume, quality and market conditions. Standard prices (used below for GVA calculations) are estimated on the basis of information obtained from wholesale organisations on "typical" or "average" buying and selling prices.

Table 2.2 Prices per Pacific oyster at different value chain stages, 2011/12

Value Chain Price Point (See Image 2.2)	Price Range (Pence)	Standard Price (Pence)
B	15-25	20
C	26-40	36
C/D (Export)	38-48	40
D	38-52	45
E (UK Retail)	60-200	95

Once oysters have been exported any further value added is outside the UK economy. However since the same companies both import and export oysters in response to demand, imported oysters will compensate for the loss of exported oysters in the UK value chain. However since this study relates to UK coastal habitats we have only taken into account UK landings and there is therefore no import box in Image 2.2. Consequently our economic estimates will be lower than the total value of the Pacific oyster in the UK economy.

For Pacific oysters entering the UK retail sector the range of final prices to consumers is large as they span both sales of fresh oysters at fishmongers/supermarkets and sale in the hospitality industry. Our industry evidence indicates that the great majority of UK Pacific oysters are consumed in restaurants. In this respect the London market dominates and we consider our standard price to be a conservative estimate.



(Arrows indicate the movement of oysters)

Image 2.2 Market Structure for UK Pacific Oyster Production Showing Value Chains and Price Points

2.3.6 Contribution to the National Economy

Although there appear to be no published analyses of the intermediate costs of bivalve production specifically, a number of multiplier studies for fisheries and aquaculture in the UK and elsewhere have been published (e.g. Gibbs, 1990; Grieg, 1999; Virtanen *et al.* 2003; Pugh and Skinner, 2002). The Seafish (2007) report represents the most recent comprehensive multiplier study of the UK sea fishery sector as a whole. Pugh and Skinner (2002) in examining marine activities in the UK economy have used a value added factor of 0.55 for fish farming (i.e. intermediate consumption for fish farming is 0.55 of gross output). For the purpose of this review, other factors including those used for the calculation of total GVA (i.e. including indirect and induced effects) are based on multipliers from a multi-sector catalogue of factors published by the Scottish Government (2007). Table 2.3 shows the application of these multipliers to the various data, assuming a 3% loss of saleable oysters at each stage of the value chain.

In summary, Table 2.3 predicts the economic contribution of UK Pacific oyster production (based on 2011/12 prices applied to an annual production of 1,200 tonnes), as follows:

- Direct national GVA = £6.721 million; and
- Total national GVA (including indirect and induced effects) = £10.137 million.

Given the volatility of oyster production and markets, whose parameters vary significantly year-on-year, combined with uncertainties in the reporting of information, and the conservatism in some of our estimates we postulate that these figures should be taken as minima (see Appendix D).

In reflecting on the relationship between total Pacific oyster GVA as reported here, and superficially comparable GVA figures for, e.g., total UK shellfish GVA (Charting Progress2[2]) or total fishery GVA contribution to particular UK coastal localities, it should be borne in mind that such other estimations, while equally valid, are often confined to only the first stage in the value chain or, at most, those parts of it that they define variously as the “principal production process” (UKMMAS, 2010) or “core businesses” of “the industry” (Sandberg, 2006). The fact that this report is focussed on a single species has allowed us, in contrast, to track the UK value of the product through to the ultimate consumer.

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2 http://chartingprogress.defra.gov.uk/aquaculture

Table 2.3 Multiplier based predictions of Annual Gross Output, Direct Gross Value Added (GVA) and Total GVA of UK Pacific oyster production (excluding UK hatchery production)

Oyster Value Chain	Production at Stage (Tonnes)	Production at Stage (Million Oysters)	Price per Oyster at Sale (£)	Gross Output (£Million)	Value Added Factor	Direct GVA (£Million)	GVA Type 2 Multiplier	Total GVA Contribution (£Million)
Production	1200	13.332	0.20	2.666	0.55	1.466	1.52	2.228
Wholesale for export	1164x67% = 779.9	12.932x67% = 8.665	0.40	3.466	0.55	1.906	1.63	3.017
Wholesale 1 for UK	1164x33% = 384.1	12.932x33% = 4.268	0.38	1.622	0.55	0.892	1.63	1.454
Wholesale 2 for UK 2	372.6	4.139	0.45	1.862	0.50	0.931	1.63	1.149
UK retail	361.4	4.015	0.95	3.814	0.40	1.526	1.50	2.289 `
Totals				**13.430**		**6.721**		**10.137**

2.3.7 Hatcheries and Technology Transfer

Although the above economic estimates do not include the hatchery production of seed oysters, published production figures for England and Wales (Table 2.4), which presumably exclude the Guernsey hatchery, indicate this type of production to be significant. Much of this seed production is for export and the volatility in these figures, particularly between 2005 and 2007, is at least in part due to varying demand. However there is also a reported tendency to order less seed but of larger size (Cefas, 2008), which would suggest that the economic impact of the drop in production in 2007 may be much less than the figures alone indicate. In the period since 2007, Pacific oyster losses due to disease have resulted in significantly increased orders for seed from France.

Table 2.4 Farmed juvenile (seed) Pacific oyster production in England and Wales

Year	2000	2001	2002	2003	2004	2005	2006	2007
Seed production (1,000's)	63,230	318,211	178,142	316,130	329,000	260,045	708,083	110,777

(Source: Cefas, 2008)

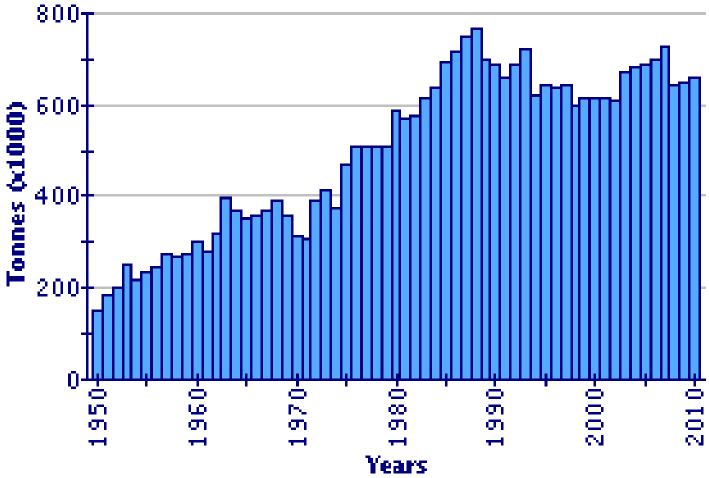
Finally, the British tradition and technical expertise is recognised internationally and generates spin-off economic benefits in the form of technology transfer and training. Such activities relate both to hatcheries (e.g. continuous harvest micro-algal systems and customised hatchery designs) and production (e.g. pump-scoop conveyor harvesters). Such expertise has been deployed in at least 16 other countries.

2.3.8 The Potential and Rationale for Growth

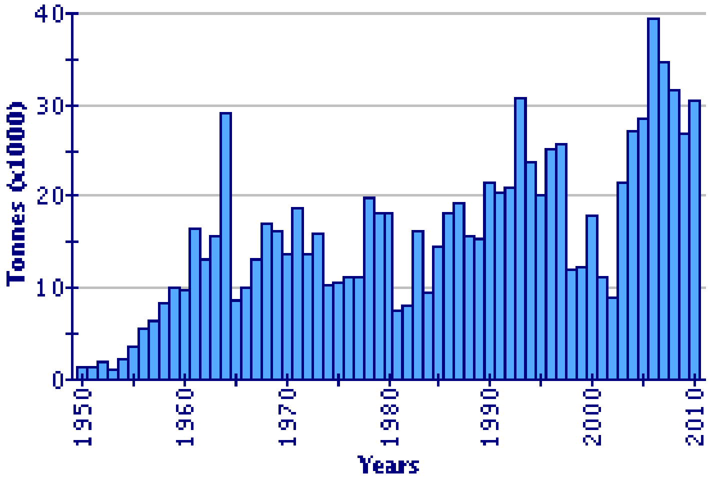
The long term costs to the UK economy of constraining Pacific oyster production for environmental reasons is not confined to current production, but includes also the opportunity cost of any lost future growth in production. The prospects for growth in production will be dependent on a number of factors, such as the relationship between supply and demand, the potential for growth in demand, and the motivation of governments and the industry to invest to increase production.

Since the greater part of UK Pacific oyster production reaches international consumers, from France to south east Asia, the magnitude of total world-wide demand (resulting in global production of 662,513 tonnes from aquaculture in 2010, Image 2.3) provides the basis of a feasible argument for growth in UK production. In fact, market indications of significant growth potential exists at many levels, from the anecdotal comments of individual oyster fishers and wholesalers that they cannot meet demand, to detailed analyses and aspirations contained within UK shellfish development and strategy documents (e.g. Lake and Utting, 2007; James and Slaski, 2009; Scottish Executive, 2003 etc).

a)



b)



(Source: FAO, 2012b)

Image 2.3 Worldwide Pacific Oyster Production From (a) Aquaculture and (b) Fisheries

Notwithstanding the world-wide market and the case for growth, our economic analysis shows that concomitant increases in UK consumption, although obviously more limited in terms of growth potential, would be disproportionately beneficial in terms of GVA contribution from the species. The fact that the 19th century British oyster boom was fuelled mainly by British consumption, along with hints from retail sales patterns (Waitrose, 2011) suggest significant growth in home consumption is feasible given appropriate marketing.

Nevertheless with such a large worldwide market, international demand will remain the key driver for British oyster production in the foreseeable future, and in this respect the comparatively low level of current UK production in comparison to neighbouring countries (Table 2.5) suggests that increasing market share, rather than just meeting growing demand, might provide a plausible component of business plans.

Table 2.5 Pacific oyster aquaculture production in the UK and its neighbours (tonnes)

Country	Year					
	2005	2006	2007	2008	2009	2010
France	118,120	110,706	110,800	103,799	103,467	95,000*
Ireland	5,811	6,511	7,661	6,188	6,488	6,942
UK	922	1,376	1,329	#	#	1,150
Channel Islands	592	600*	737	835	911	924

Note: The (estimated) drop in French landings in 2010 is likely to relate to acute spat mortality events since 2008 which are thought to be caused by ostreid herpes virus (Schikorski *et al.* 2011).
* Indicates FAO estimates
\# Indicates where clearly anomalous FAO figures have not been included

(Source: FAO Global Fishery Statistics, 2012a)

In any event the case for growth in UK production has been supported by other strategic considerations including both food security and public health, particularly in the context of growing populations and the over- exploitation and plateauing of wild fisheries. In a review of the potential for aquaculture in the UK, James and Slaski (2009) for example characterise an underlying strategic driver for continued growth as the requirement for aquaculture to: “Continue bridging the gap between maximum sustainable wild seafood harvests and the requirements of a growing and more nutritionally aspirational world population”.

Recognition of these various strategic drivers is implicit in support for innovation and development of shellfish aquaculture through various UK and European funding streams. However although the potential of Pacific oyster production has been established, against a backdrop of environmental challenges, the future contribution of the species in the UK is thought of in the industry as uncertain and the appetite for investment is consequently muted.

In light of the extent and nature of the UK coastline, all else being equal, the Pacific oyster presents an economic opportunity for the UK by virtue of the size of the global market and the comparatively low level of current UK production. Ironically, increasing sea surface temperatures, while raising conservation concerns about the species, are likely also to further enhance existing growth opportunities and consequent socio-economic benefits. As one producer put it, “They were introduced by MAFF to reverse the situation with the failing fortunes of the flat oyster beds in the 1960’s, well it’s working at last”.

2.3.9 Further Work

Suggested priorities for further work in this area are as follows:

- Developing bivalve specific industry derived multipliers. These would be a useful asset to apply in future decision processes;
- Honing our market model particularly in terms of retail, and final consumption parameters;
- Examining bivalve hatchery production and markets in such a way as to also establish GVA contribution, export value and potential;
- Investigating the parameters of imported bivalves in the value chain; and
- Applying similar approaches to other bivalve shellfish species and/or the bivalve aquaculture industry as a whole.

3. Wild *Crassostrea gigas* in the UK: Origins of Settlement

The aims of this section are to i) present the known current distribution of *Crassostrea gigas* in the UK and ii) to review the evidence for possible origins of wild settlement of *C.gigas* in the UK, including potential larval dispersal from oyster farms and other pathways of introduction. The probability of larval dispersal from the continent is also discussed.

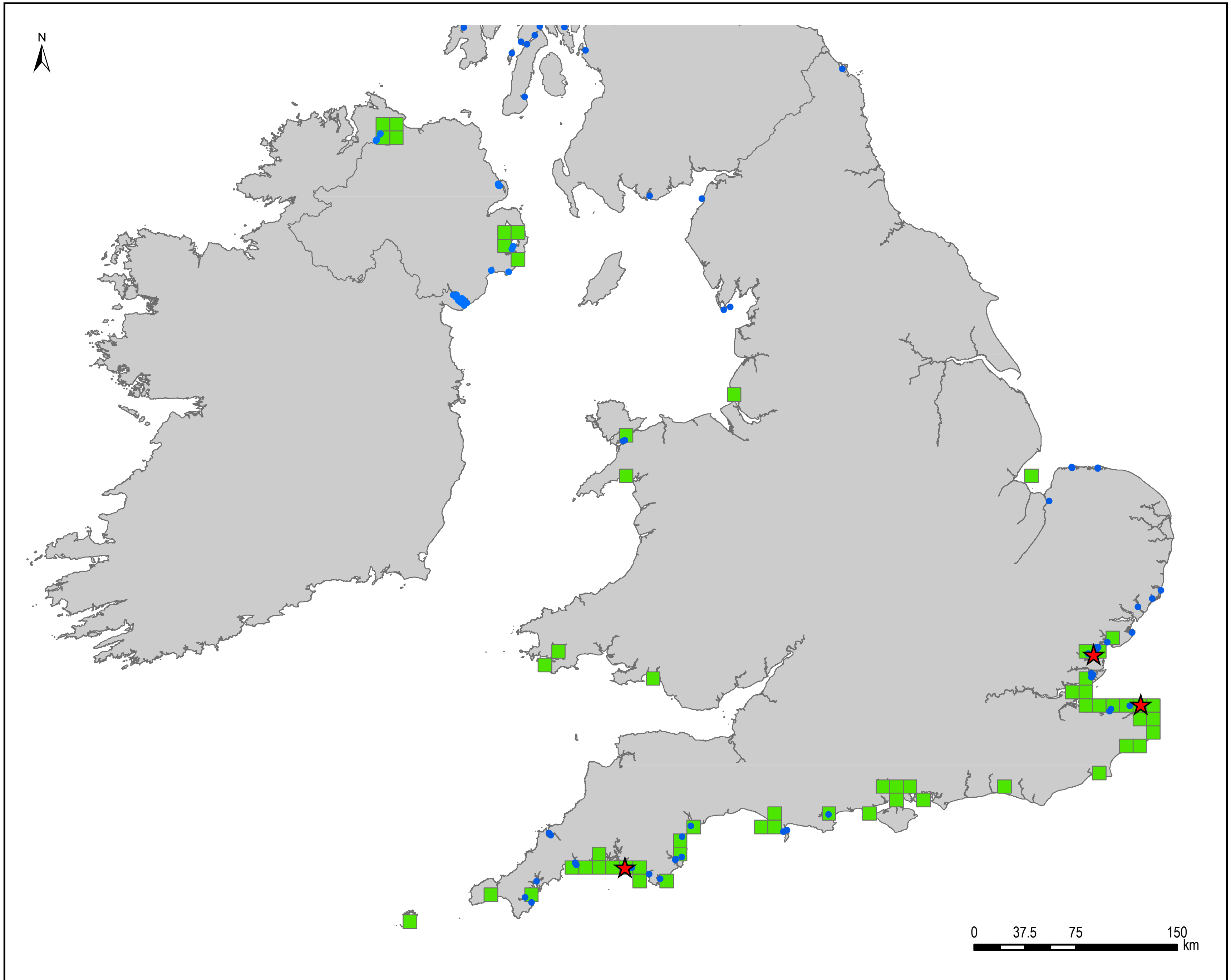
3.1 Distribution of Wild Settlement in the UK (April 2012)

Prior to quarantine legislation on the importation of overseas oysters, Portuguese oysters *(C. angulata = C. gigas*) were deposited on beds in the east of England from 1901 to 1962 and light natural spatfalls occurred in the Blackwater estuary (Essex) over this period (Spencer *et al.* 1994). To diversify the range of potentially harvestable shellfish species, further oysters, which were quarantined, were introduced on a trial basis at several sites in the south and west of England, Wales, north-west England and south-west Scotland (Spencer *et al.* 1994). In the 1970s, light natural spatfall was recorded on the south coast of England in Poole Harbour, Emsworth Harbour (where there had been trials) and Loch Sween, Scotland. Following the warm summers of 1989 and 1990, natural spatfall was first recorded in the River Teign and other estuaries, in south-west England, and in the Menai Straits, where Pacific oysters were cultivated. At the time, spat was not seen in other local estuaries where there was no cultivation (Spencer *et al.* 1994).

In subsequent decades, wild settlement of *C. gigas* has continued to be reported and the species is now found extensively on the Essex and Kent coast (Kent and Essex Inshore Fisheries and Conservation Authorities (IFCA) pers. comm.; McKnight, 2012), and more sporadically in the south and south-west England (Figure 3.1a). The settlement of Pacific oysters has been so great in the Mersea region of Essex, which includes the Blackwater and Swale estuaries, wild-harvesting and fisheries are now commercially viable. Small *C. gigas* 'reefs' are now forming on shores of Essex and Kent. A small 'dense aggregation/reef' in the River Yealm, Devon, has also developed over this period. New populations are now becoming established in Loughs in Northern Ireland with recruitment occurring in favourable years (Loughs Agency pers. comm.; Maggs *et al.* 2010).

The origin and subsequent development of wild settlement is largely in the vicinity of licensed UK Pacific oyster farms and other APBs. However, in the vicinity of some oyster farms, there is little or no settlement e.g. The Fleet, Dorset. Conversely, wild Pacific oysters are now increasingly also found on both hard substrata and soft sediments around ports and marinas (e.g. the Solent) that are at some distance away from oyster farms and, although there is no direct evidence, it is suspected that introductions from ballast water discharges and/or fouling may have occurred, perhaps via merchant shipping, continental ferries or leisure boats.

To date, there has been no systematic survey of wild *C. gigas* around the UK. However, qualitative records of the presence of wild *C. gigas* around the UK coastline are shown in Figures 3.1a and 3.1b. This data is primarily based on Higgs *et al*. (2010) and updated with new records (from 2004-2012) provided by IFCAs, the Loughs Agency, Wildlife Trusts, other individuals and experts for the purpose of this review (refer to Section 1.5 for the methodology).



Known Dense Aggregations/ Reefs of Pacific Oysters

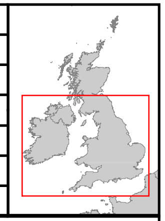
Pacific Oyster APB

Areas (10km² grid cells) Within Which Wild Pacific Oyster Have Been Recorded

Note: APB site locations in Northern Ireland and cross border areas have been aggregated and hence locations of individual farm sites are not shown. APB sites and wild settlement are not shown for the Republic of Ireland, except in border areas.

Aquaculture Production Business (APB)

Date	By	Size	Version
May 12	MCE	A4	1
Projection		OSGB 1936	
Scale		1:4,000,000	
QA		JDB	
4047-Fig1_Wild_PO_Density.mxd			
Produced by ABPmer Ltd			

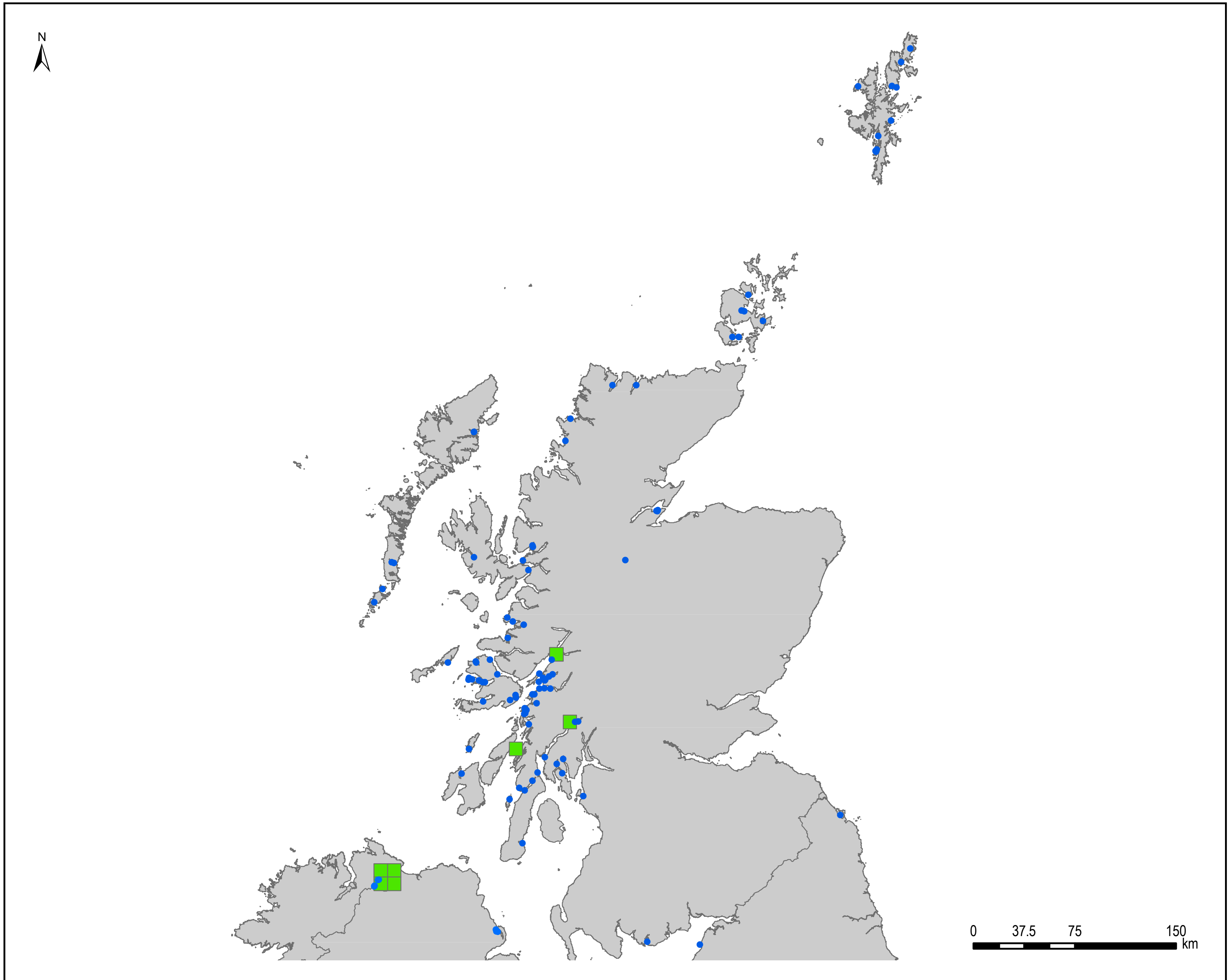


Data Sources: Marine Scotland, Bournemouth University, Defra, Loughs Agency, Cefas
NOT TO BE USED FOR NAVIGATION

ABP mer
marine environmental research

Distribution of Wild Pacific Oyster and Pacific Oyster Aquaculture Production Businesses - Southern UK

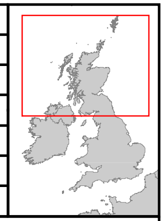
Figure 3.1a



- Pacific Oyster APB
- Areas (10km² grid cells) Within Which Wild Pacific Oyster Have Been Recorded

Note: APB site locations in Northern Ireland and cross border areas have been aggregated and hence locations of individual farm sites are not shown. APB sites and wild settlement are not shown for the Republic of Ireland, except in border areas.

Date	By	Size	Version
May 12	MCE	A4	1
Projection	OSGB 1936		
Scale	1:4,000,000		
QA	JDB		
4047-Fig1_Wild_PO_Density_N.mxd			
Produced by ABPmer Ltd			



Data Sources: Marine Scotland, Bournemouth University,Defra,Loughs Agency,Cefas
NOT TO BE USED FOR NAVIGATION

marine environmental research

Distribution of Wild Pacific Oyster and Pacific Oyster Aquaculture Production Businesses - Northern UK

Figure 3.1b

3.2 General Distribution

Overall the main centre of current distribution of wild *C.gigas* in the UK is in the south-east of England with the largest populations in the Essex estuaries and north Thanet coast of Kent. Scattered groups and individuals may be found in estuaries and harbours along the coast of southern England. While some wild settlement is in close proximity to oyster farms this is not always the case and settlement is occurring at distance (>50km) from oyster farms, for example, in the Solent region. Currently there is very little settlement in Wales, and very few reports in the north of England and Scotland. However in Northern Ireland, observations of wild settlement since 2004 appear to have become more widespread (Loughs Agency pers. comm.).

3.2.1 East and South-east England

Intense monitoring of *C.gigas* along the north Thanet coast of Kent (McKnight, 2010, 2011, 2012) has revealed some of the highest densities of wild *C.gigas* so far recorded in the UK, with up to 200 per m^2 found locally, although more generally 10-100 per m^2. Recruitment in parts of the region is now occurring annually, although this varies between shores and years. The last high level of recruitment on the Thanet coast occurred in 2006 and some of these individuals are now large. A small 'reef' has occurred near Birchington on a *Sabellaria spinulosa* bed upon chalk bed rock. At Ramsgate, south of Forelands, there has been a high frequency of settlement in recent years and this has resulted in low-moderate densities on parts of the chalk foreshore and on walls and other structures.

In Essex, there are high densities on intertidal sediment habitats in parts of the Blackwater estuary, Swale and other estuaries and sheltered harbours. At Brightlingsea Creek, Blackwater, the Crouch and Southend foreshore there are 'Pacific oyster reefs' present at low water (Essex & Kent IFCA, pers. comm.). Important fisheries and cultivation of wild Pacific oysters now occurs in parts of the Thames estuary and Essex region.

Further north, wild Pacific oyster settlement has been recorded in the Stour estuary (Suffolk/Essex border) (Eastern IFCA, pers. comm.) and in The Wash (Norfolk/Lincolnshire border). A survey of the Gat Sand mussel bed in the Wash in 2009 confirmed the presence of wild Pacific oysters across most of the area at mean densities of 0.03 per m^2. Most oysters were found on muddy-sand and on the mussel beds. Pacific oyster cultivation ceased in the Wash in 2000.

3.2.2 Southern England

Along the Sussex and Hampshire and Isle of Wight coast there are currently no registered Pacific oyster farms or APBs. Yet since mid 2000's, there has been increasing settlement on the shores of Southampton Water and other Solent harbours and at East Cowes on the Isle of Wight. Densities are still low and mostly from a single year class, although there is evidence of spawning of wild Pacific oysters in the Solent (K. Collins, pers. comm.).Informal hand-collection of Pacific oysters is occurring in parts of Southampton Water.

3.2.3 South-west England

Pacific oysters are cultivated in several harbours and estuaries between Poole Harbour and Falmouth. Although the presence of wild settlement has been confirmed at several localities, the frequency of settlement appears to be very variable. In the Dart there is some wild settlement on the wild mussel beds and on mudflats, and wild Pacific oysters are also present in the Salcombe estuary and the Yealm (Devon & Severn IFCA, pers. comm.; N. Miezkowska, (MBA) pers. comm.) with dense aggregations/reefs reported. Although there are no Pacific oyster farms in Plymouth Sound, there are large numbers of wild oysters on walls and structures at Millbay docks at Plymouth.

3.2.4 Northern England

There have been very few reports of wild *C.gigas* in north-east and north-west England.

3.2.5 Wales

Very occasionally, scattered individuals have been found in localities in the Menai Straits and at Milford Haven.

3.2.6 Northern Ireland

Since 2006, in Lough Foyle, wild settlement has been reported on intertidal areas, subtidal areas and on mussel beds (up to approx. 20 per m^2). In neighbouring Lough Swilly (Republic of Ireland) there is increasing fishing for subtidal Pacific oysters, though it is uncertain whether these are collected from intertidal areas and re-laid (Loughs Agency, pers. comm.). Pacific oysters have also been recorded in Strangford Lough where there is cultivation. However in Carlingford Lough, there have been no reports of wild settlement despite large-scale cultivation of oysters (Loughs Agency pers. comm.).

3.2.7 Scotland

There have been very few recent reports of wild *C.gigas* in Scotland.

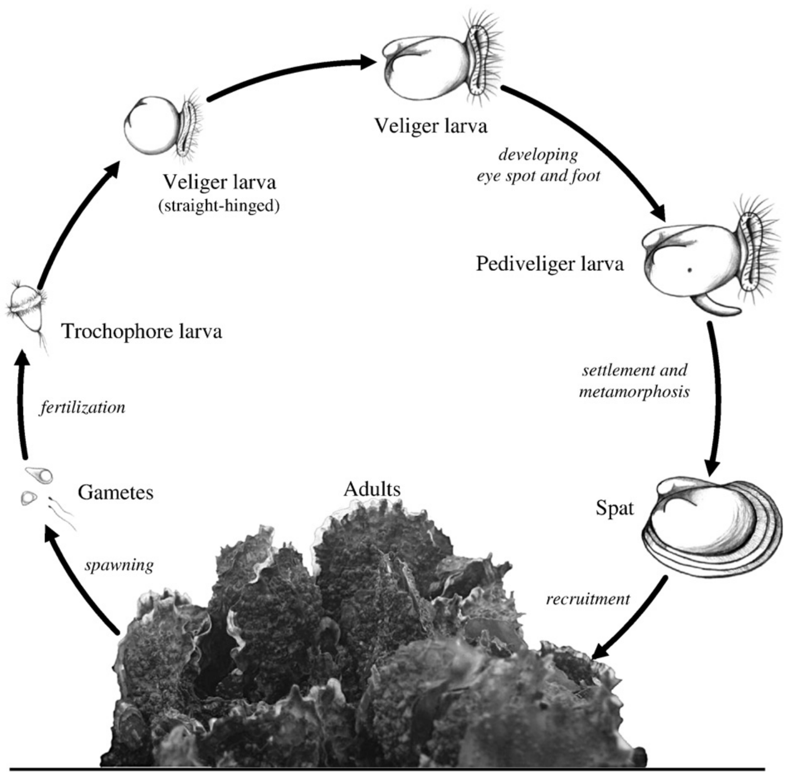
3.3 Effects of Climate Change on Distribution

Although there is still a high level of uncertainty, current sea temperature projections are thought likely to result in certain non-native species, including *C. gigas*, recruiting every year in south-west England, Wales and Northern Ireland by 2040 (Maggs *et al.* 2010). Under a medium emissions scenario, an analysis of the effect of rising temperatures on the distribution of *C. gigas* and eight other marine invasive species, showed that they would all theoretically be able to expand their range by the 2080s to encompass the entire UK (Pinnegar *et al*. 2012). Warm-temperate native species of rocky shores have spread in response to warming over the past fifteen years (reviewed in Hawkins *et al.* 2009) and it is therefore probable that *C. gigas* would spread outwards from areas of established settlement and oyster reefs. In France, dense wild settlement of Pacific oysters has progressed north and eastwards along the Brittany and Normandy coast from large centres of oyster production in southern Brittany. The main front is now close to Caen, east of Contenin. The spread is thought to be due to a combination of increased reproductive output due to rising temperatures and movements of oysters between regions (P. Goulletquer, (IFREMER), pers. comm.).

3.4 Origins of Wild Pacific Oyster Settlement in the UK

3.4.1 Dispersal and Recruitment

It is generally considered that the most important factor responsible for the spread and invasion of *C. gigas* on to intertidal habitats in the UK and elsewhere in Europe is the attainment of threshold temperatures that have enabled reproduction and spawning. Yet for completion of the life-cycle (Image 3.1), there must also be environmental conditions suitable for larval development, survival and settlement on to a substratum, and juvenile survival and growth to maturity. Larval mortality is considered to be extremely high for most marine invertebrates (Rumril,1990) as tidal currents sweep larvae away from potential settlement sites and planktonic predators and fish take their share. Post-settlement survival will be dependent on the harshness of the physical environment and on the resilience of the receiving ecosystem; crabs and fish are known predators on bivalve spat and there is likely to be considerable larvaephagy amongst existing filter and suspension feeders, including oysters (Troost *et al.* 2009).



From Troost (2010) Life cycle of oviparous bivalve filter-feeders (*C. gigas* as example; not drawn to scale). Adults release millions of eggs and sperm into the water column where fertilisation takes place. Fertilised eggs usually develop via the trochophore stage into veliger larvae within approximately 2 days. The veliger larvae, about 70 to 300 µm in length, swim and forage with their velum. The first veliger stage is called the D-veliger or straight-hinged veliger. Veligers continue to develop through the veliconcha stage into the pediveliger stage, in which the larvae have developed a foot and eye spot. At this stage the velum begins to degenerate, resulting in reduced swimming abilities. The larvae are now competent to settle on a suitable substrate and to metamorphose into the benthic juvenile stage, approximately 3 weeks after fertilisation. The benthic juveniles grow and recruit into sexually mature adults. (Taken from Troost (2010) and references therein).

Image 3.1 Life Cycle of Oviparous Bivalve Filter-feeders (*C. gigas* as example)

Apart from licensed importation of seed Pacific oysters to aquaculture farms, *C. gigas* might enter a new UK locality from one or more of the following sources:

- As larvae that drift on currents from spawning stock at UK oyster farms;
- As larvae that drift on currents from spawning UK wild stock;
- As larvae that drift on currents from spawning continental oyster farms;
- As larvae that drift on currents from spawning continental wild stock;
- As larval drift from ship ballast-water discharges;
- As fouling adults or juveniles on boats and ships or their larval progeny;
- Illegally imported seed or adults transplanted in suitable habitat in the hope that they survive, settle and can be fished;
- As contaminated 'seed' amongst other imported shellfish species e.g. mussels; and
- Deposition of mature stock from restaurants or from yachts and ships while in port.

These possibilities will be dealt with in turn with an assessment of the risk and probability arising from:

- Larval drift;
- Fouling; and
- Seed.

3.4.2 Larval Dispersal in UK Waters

Should successful spawning, egg and larval production occur, larvae from spawning adult populations will drift on tidal and wind-driven currents. The pelagic larval duration (PLD) for *C. gigas*, the time larvae are swimming in the water, is between 2-4 weeks, depending on temperature (see review in Syvret *et al.* 2008). At warmer temperatures, larval development is faster and settlement occurs earlier (O'Connor, *et al.* 2007). Yet larvae have also been known to survive for 50 days in hatchery tanks at low temperatures (P. Goulletquer, pers. comm.). The role of water movement and circulation (hydrodynamics) and larval transport and supply in determining the distribution of adult benthic invertebrates has been emphasised by several authors (Roughgarden *et al.* 1988; Underwood and Fairweather, 1989; Gaylord and Gaines, 2000). Yet the small size and low concentrations of larvae in the sea present considerable difficulties for empirical and direct methods of estimating the spatial and temporal variability of larval dispersal and population connectivity (Gawarkiewicz *et al.* 2007; Pineda *et al.* 2007; Watson *et al.* 2010).

Particle-tracking hydrodynamic computer models[3] are now used to predict larval dispersal in coastal and oceanic systems. These models have built-in tidal information at a resolution of at least 1km. It is possible to incorporate additional environmental variables such as salinity, wind speed and direction that might affect larval retention and transport. Some more recent models have also incorporated larval behavioural traits (Individual Based Models) such as vertical migration within the water column or responses to salinity. For example North *et al.* (2008) used these coupled bio-physical models to investigate transport and settlement of *Crassostrea* spp. on to oyster reefs in Chesapeake Bay, in the USA.

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3 Ssee http://www.estuary-guide.net/pdfs/particle_tracking.pdf

Mortality of marine invertebrate larvae is considered to be very high (Rumrill, 1990); and for US *Crassostrea* spp. in Chesapeake Bay is between 95-99% (North *et al.* 2008). Though from experimental studies, Moran and Manahan (2004) showed that *C. gigas* larvae could keep swimming for at least 33 days without feeding or losing their ability to capture and digest algal cells, enabling them to survive typically patchy distribution of phytoplankton. However, in the natural environment, it is likely that predation will significantly reduce survival.

Using a 2-D particle tracking model Brandt *et al.* (2008) attempted to model larval dispersal and subsequent colonisation of *C. gigas* on to mussel beds in the East Frisian Wadden Sea. The model did not incorporate behavioural traits and therefore larval transport distances may be overestimated (Shanks, 2009). Neither did the model incorporate wind-effects, although it did compare two years of data (2003-5). With few exceptions, drift distances varied between 0-50km, and the vast majority of 'model larvae' travelled less than 25km from sources, with a median distance of 10km. Although inter-annual differences were high, the findings generally supported limited dispersal and local recruitment of many marine organisms (Cowen *et al.* 2006; Levin, 2006; Todd, 1998). North *et al.* (2008) found that the median dispersal distance for modelled *Crassostrea* spp. larvae in Chesapeake Bay was between 7-9 km, though a maximum distance of 226 km was also recorded. Generally, a mean larval transport of 20-40 km can be expected with a PLD ranging between 20 and 30 days (Shanks, 2009; Eric Thiebaut, pers. comm.).

In the English Channel, tidal residual currents and wind-induced currents are key factors controlling larval dispersal (Thiebaut *et al.* 1994; Ellien *et al.* 2000, 2004). Ayata *et al.* (2010) investigated the transport of 'model larvae' with a PLD of 2 and 4 weeks from southern Brittany to the western approaches of the English Channel. In this study, self-retention rates were high within the main regions - western English Channel, southern Brittany and Bay of Biscay, however connectivity between the Bay of Biscay and English Channel was low and only occurred for species with a long (4 week) PLD during particular environmental conditions of high river run-off and strong SW winds. It is suspected that a front at Ushant presents a semi-permeable barrier to the north and then eastward transport along the Brittany coast.

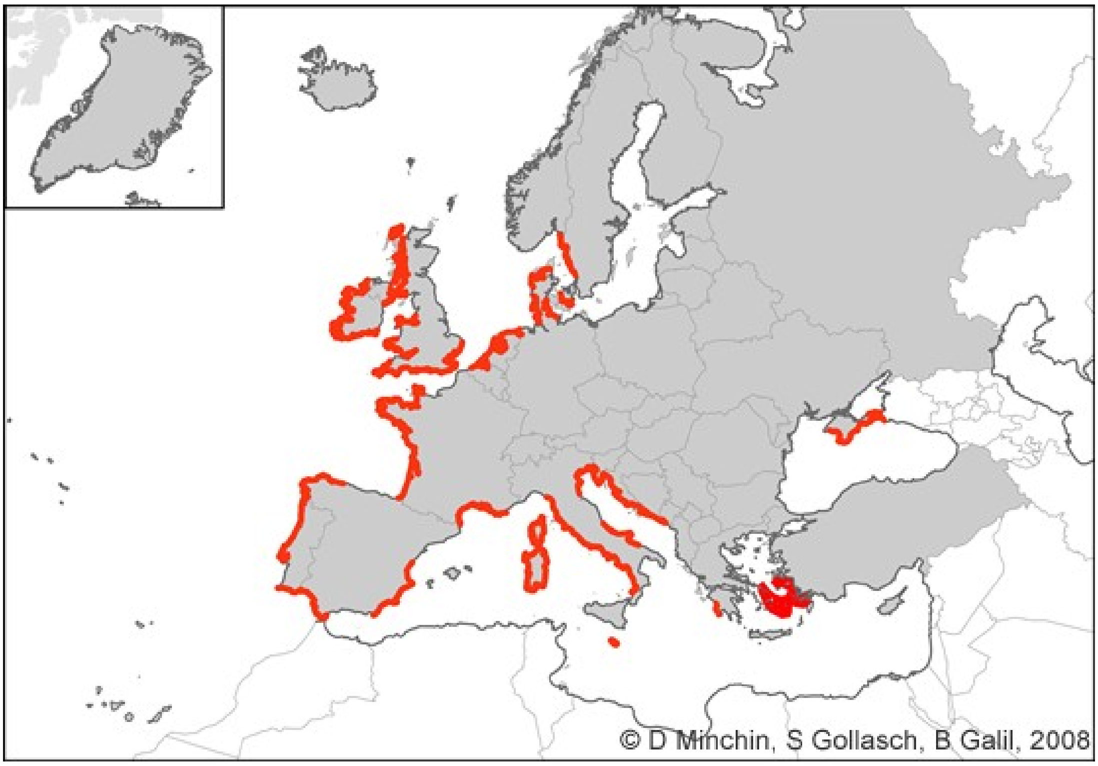
Within the Bay of Morlaix on the north Brittany coast, using a particle-tracking model, Rigal *et al.* (2010) demonstrated that the interaction between spawning location and hydrodynamics limited the proliferation of *Crepidula fornicata* within the Bay.

In the Gulf of St Malo, high levels of retention and self-recruitment were determined by Viard *et al.* (2006) who used a 2-D particle tracking model and wind data to investigate dispersal of the non-native gastropod *Crepidula fornicata*, which has a PLD of 21 days. The vast majority of larvae were retained close to the point of release, although under certain conditions, low numbers of 'model larvae' released from St Malo in the south, were found to theoretically reach the tip of the Contentin Peninsula, but no further east.

In the UK, a coupled bio-physical model has been used to investigate the dispersal and colonisation of the Manila clam (*Ruditapes philippinarum)* in Poole Harbour (Herbert *et al.* 2012). The model, which incorporated larval response to salinity, accurately predicted the distribution of adult clams in areas of low salinity in the harbour. However the model also indicated that large numbers of larvae could theoretically escape from the harbour and just about reach new habitat 40km east within their PLD of 15 days.

3.4.2.1 Could larvae drift from continental oyster farms and wild *C. gigas* reefs to the UK?

There is now considerable *C. gigas* aquaculture and high densities of wild oysters along the continental coast from southern Brittany, north Brittany and east along the English Channel to the Belgian, Dutch and German coast (Image 3.2). There is therefore extremely high potential for larval production on this coast once threshold temperatures for spawning are attained.



Broad-scale distribution of wild *C.gigas* on North European coast in 2008 (shown in red) plotted in Common European Chorological Grid Reference System (CGRS) grid squares (DAISE). For large-scale UK distribution see Figures 3.1a and b. For information on recent settlement in Scandanavia see Wrange *et al*. (2010). (Source: DAISIE European Invasive Alien Species Gateway, 2. *Crassostrea gigas*[4]**)**.

Image 3.2 Broad-scale Distribution of Wild C.gigas on North European Coast in 2008

Finding a genetic association between wild *C. gigas* in the Teign estuary, SW England and hatchery broodstock at Guernsey Oyster farm and French oysters, Child *et al.* (1995) discussed the possibility that larvae could have drifted from oysters on the Cherbourg Peninsula or Gulf of St Malo to Guernsey, where they could have entered the seawater intake at the Guernsey hatchery, survived, developed and been incorporated in to the broodstock at the hatchery which supplied oyster farms in the Teign. However it was concluded that the absence of such a genetic link in wild oysters in the nearby Dart estuary suggested that cross-channel drift was not happening regularly from the French coast and, together with analysis of hydrographic information, was probably unlikely.

4 Available from: http://www.europealiens.org/speciesFactsheet.do?speciesId=50156 (accessed July 2012))

From studies using particle tracking models, local larval retention appears to be the norm and the most likely location for cross-Channel drift is between Dover and Calais across the 40km-wide Dover Straits., Yet, the predominant flow through the Dover Strait is from west to east and the water flowing out of the English Channel in to the North Sea follows the Belgian and Dutch coasts up to Denmark (Breton and Salomon, 1995; Bailly du Bois and Dumas, 2005). Moderate south-westerly winds cause dispersal of organisms in a north-easterly direction, although a light north-easterly wind causes a reversal (Belgrano *et al.* 1995). These observations are also supported by coupled bio-physical hydrodynamic models of the dispersal of larvae of the polychaete worm (*Owenia fusiformis*) with a PLD of 2 weeks (Barnay *et al.* 2003). At this location, fronts promote alongshore transport and cross-channel exchanges are limited (Belgrano *et al.* 1995; E. Thiebaut pers. comm.). In a study combining 2D-hydrodynamic modelling and genetics on the current and historical patterns of larval dispersal of the polychaete worm *Pectinaria koreni* (PLD 4 weeks) around the British Isles (Jolly *et al.*. 2009), most populations in the eastern English Channel were found to be well connected through larval dispersal along the English and French coastlines, however cross-channel exchanges were restricted to the vicinity of the Dover Strait, but were generally infrequent and weak. However, there was a strong indication that populations in the southern North Sea (possibly in the Thames estuary) might be genetically connected to populations in the eastern English Channel. Strong variability of the water circulation at the entrance of the English Channel makes it possible for North Sea water to enter the English Channel (Jolly *et al.* 2009 and references therein).

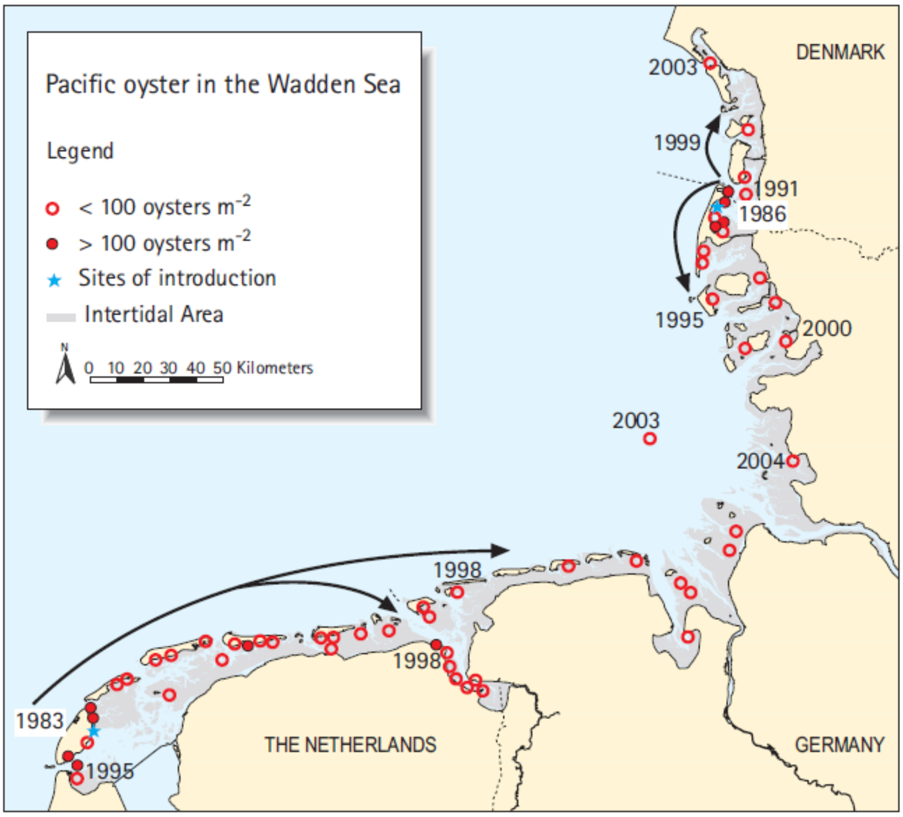
In summary, from the above evidence it appears that although it may be theoretically possible for *C.gigas* larvae to drift across the Channel in exceptional circumstances, it is unlikely that the dense wild settlement in the south east of the UK has originated entirely from larval drift from continental farms or wild populations. It appears much more likely that the species spread has been from establishing wild populations along the Kent and Essex coast as a result of the cultivation of *C.gigas* in the region and/or from fouled boats and larvae within ballast water discharges. Successful invasions that result in establishment usually occur as a result of repeated or frequent inoculations of larvae, sometimes from multiple and different sources, and not as a result of one-off events. The invasion of the Wadden Sea (Image 3.3) originated from at least two sources of introduction, though both likely from oyster farms (Reise *et al.* 2005).

Over the past decade, in response to rising sea temperatures, there has been spread of rocky shore species in an easterly direction along the south coast of England towards the Dover Straits (Herbert *et al.* 2003; Hawkins *et al.* 2009), in the direction of residual water flow. Colonisation of *C. gigas* from Kent, westwards along the south coast of England along the Sussex coast may therefore be slow, and possibly dependent on secondary introductions.

3.4.3 Fouling

Pacific oysters have often been found attached to the hulls of ships (Miossec *et al.* 2009), however there is very little evidence for the introduction of juvenile or adult *C. gigas* in to the UK on the hulls of boats and ships, although it is strongly suspected. A fouled yacht has been seen in the Wadden Sea (K. Reise, pers. comm.) and a fishing boat, with about 50 Pacific oysters fouled on the underside of the hull, was brought up on the beach at Brightlingsea, Essex; oysters also foul the waterline of pontoons in this area (Kent and Essex IFCA, pers. comm.). In 2002, a yacht in the island of Helgoland marina (Wadden Sea - 50km from the

German mainland, Image 3.3) was seen with a net bag of live oysters over its stern, having sailed across from the continental mainland coast. In 2003, Pacific oysters were recorded on the island for the first time, although it is unlikely that this was the only introduction (K Reise, pers. comm.).



Asterisks indicate sites and years (boxed) of introduction (Texel in Netherlands and Sylt in Germany). Other years indicate first records of wild settlement by larval dispersal for selected sites. Circles show mean abundance in 2003. The black arrows show likely direction of spread. From Reise *et al.* (2005). The island of Helgoland is shown approximately 50 km off the German coast, where oysters were first recorded in 2003.

Image 3.3 Colonisation history of the Pacific oyster *Crassostrea gigas* in the Wadden Sea

There is considerable ferry traffic and trade between the UK and continental North Sea ports and the French ports. It is possible that these ships are also fouled with Pacific oysters or entrain larvae within underwater structures and other fouling. Yet most yachts and leisure craft spend more time in quiet warm marinas and harbours, where there are often good breeding and settlement conditions, than motoring or sailing. Leisure craft, if fouled, may therefore present a higher risk of transporting *C. gigas* and other non-native species than commercial vessels. The presence of Pacific oysters within ports and harbours that are of some distance from nearest aquaculture (e.g. Southampton) may indicate that *C. gigas* is also being brought in by vessels from regions where there is considerable larval production, such as the continental coast.

3.4.4 Unlicensed Movements of Seed and Adults

In the UK there is little direct evidence that *C. gigas* seed or adults have been distributed to areas that are not licensed aquaculture businesses.

3.4.5 Further Work

Suggested priorities for further work in this area are as follows:

- The undertaking of a systematic survey of the colonisation of *C. gigas* around the UK, perhaps organised on a regional basis and following a survey protocol;
- Development of a individual based model for *C. gigas* larva to investigate dispersal patterns around the coast, that when integrated within hydrodynamic models will aid risk assessment; and
- Undertake a genetic analysis of populations to determine origins of new colonists.

4. Impact of Wild *Crassostrea gigas* on Biodiversity

The aim of this section is review evidence for the ecological impact of wild settlement and establishment of *Crassostrea gigas* on native biodiversity. Information on ecological impacts has been obtained from temperate regions around the world where *C.gigas* is cultivated and where habitats are broadly similar. The review first concerns the impact of *C.gigas* imports on the introduction of other invasive non-native species and parasites and then considers evidence for the impact of *C.gigas* on habitats and species of conservation importance.

4.1 Introduction of Other Invasive Non-native Species and Parasites

The potential consequences of the introduction of invasive non-native species around the globe are considered one of the most important biosecurity concerns of our modern age (IUCN, 2000). Yet, to date and to the best of knowledge, no marine species has become extinct as a result of the introduction of non-native species (Rilov, 2009). However marine native species have suffered some heavy losses when they interact directly or indirectly with non-native species - some have declined considerably and there have been local species extirpations as a result of competition (Byers, 2009).

The initial arrival of a new invasive species will often be followed by a 'lag phase' during which period the species remains at a low density and may be unknown for a considerable period of time. This is followed by rapid colonisation and population growth during which period the species may start to have a significant impact on the receiving environment. The establishment phase may be far from stable, yet the population will be successfully reproducing at a level sufficient to ensure continued survival without need for new migrants and the species may spread from its initial source of introduction at any point during its colonisation.

Harbours, estuaries and ports are hot-spots for the introduction and establishment of non-native species. The importation of a non-native species could happen repeatedly over time and thus increase the probability of successful establishment. This 'invasion (or propagule) pressure', is an important variable. It is also thought that non-native and potentially invasive species appear to be able to take advantage of disturbed habitat within these areas because ports and harbours already suffer from anthropogenic disturbances, such as dredging and pollutants (Olyarnik *et al.* 2009).

Pacific oysters have been introduced to 66 countries outside of their native range (Ruesink *et al.* 2005) and are now one of the most 'globalised' marine invertebrates. More than 20 non-native species have been introduced by *C. gigas* imports in to France alone, however only 4 of these have spread and become established (Grizel and Heral, 1991); the authors also report the introduction of two kelp species (*Undaria pinnatifida* and *Laminaria japonica*) in to a Mediterranean lagoon through *C. gigas* imports. Parasitic copepods *Mytilicola orientalis* and *Myicola ostrea* and the brown invasive alga *Sargassum muticum* have also been introduced through *C. gigas* aquaculture to both North America and Europe (Andrews, 1980; Wolff and Reise, 2002).

In spite of protests, half-grown Pacific oysters were imported in to Ireland from France in 1993. The parasitic copepods *Mytilicola orientalis* and *Myicola ostrea* were found in imports and *M. orientalis* subsequently became established. Although potentially circumstantial, following these imports, summer mortality events of Pacific oysters were recorded for the first time (Miossec *et al.* 2009). It is strongly suspected that the invasive alga *Sargassum muticum* was introduced to Strangford Lough in Northern Ireland with imports of Pacific oysters from the Channel Islands (Davison, 1999 in Miossec *et al.* 2009).

New molecular techniques have revealed the presence of the parasitic protozoan *Bonamia ostreae* DNA in a variety of marine invertebrates, including *C. gigas*, and zooplankton (Lynch *et al.* 2007, 2010). However, experimental studies (Renault *et al.* 1995; Culloty *et al.* 1999) and current risk analysis (European Food Safety Authority (EFSA), 2007) consider that *C.gigas* is not a vector of *B. ostreae,* that has devastated populations of the native oyster *Ostrea edulis* (Minchin and Rosenthal, 2002).

4.2 Impacts of *C. gigas* on Habitats and Species

4.2.1 Is the Species 'Invasive' in the UK ?

An 'invasive non-native species' is one that is considered to be a nuisance and can cause negative socio-economic and environmental impacts.

In continental Europe and in temperate regions elsewhere, the proliferation of wild *C. gigas* is regarded as an invasion (Drinkwaard 1999; Diederich *et al.* 2005; Ruesink *et al.* 2005; Smaal *et al.* 2005; Cognie *et al.* 2006; Lejart and Hily, 2005; see Image 3.3 showing spread of *C. gigas* in the Wadden Sea).

Some 'invasive' species are considered to be 'ecosystem engineers' that affect biota via alterations to the abiotic environment. These species create, destroy or modify habitats and therefore modify resources or stressors (Crooks, 2009; Padilla, 2010). The organisms in the receiving environment respond to these changes in a variety of ways. The extent of 'engineering' will be dependent on the stage of invasion; early colonists may have little or no impact. The nature and scale of the impact is also dependent on the type of habitat that is colonised (Padilla, 2010).

Determination of whether *C. gigas* is an invasive 'ecosystem engineer' in the UK and the extent to which it already has or may have the potential to modify habitats in the future is of crucial concern to regulators, irrespective of whether the colonisation of the species may result in a higher diversity than native habitats.

This review considers the impacts of wild *C. gigas* on intertidal and subtidal habitats listed under Annex 1 of the EU Habitats Directive and species features of conservation importance (FOCI) identified by Natural England and JNCC that are likely to be protected by Marine Conservation Zones (MCZs) in the UK (JNCC and Natural England, 2010 - English Network Guidance).The MCZs are likely to include European Marine Sites (EMS) and some Sites of Special Scientific Interest (SSSIs). Impacts have been included ***where there is a body of evidence***. The exclusion of some habitats does not necessarily infer that the species will have no impact, although deep sea habitats are beyond the species range. Evidence has been drawn from around the globe in comparable warm and cold temperate habitats and within biogeographical realms (Spalding *et al.* 2007) that have similar habitats to the UK.

4.2.2 Littoral Rock (EUNIS Code A1.1-1.3)

Rocky reefs (rocky shores) with assemblages of organisms are listed under Annex 1 of the EU Habitats Directive. This section combines the EUNIS level 3 habitats of ***high energy littoral rock***, ***moderate energy littoral rock***, and ***low energy littoral rock***. It also includes ***littoral chalk habitats***, **estuarine rocky habitats** and ***intertidal under-boulder communities***.

In Brittany, the Pacific oyster has been found to colonise all intertidal levels from Mean High Water (MHW) to Mean Low Water (MLW) on sheltered (low energy), moderately exposed (moderate energy) and high energy rocky shores (Lejart and Hily, 2005, 2011; R Herbert, personal observation). In the NW Pacific, where *C. gigas* was repeatedly introduced for aquaculture in the early 1900s, *C. gigas* is common on sheltered rocky shores (low energy littoral rock) and rare (<10% cover) on exposed shores (high energy littoral rock) (Ruesink, 2007). Reef formation is not reported in these habitats from British Columbia, though higher densities are present in other areas where warmer waters cause more frequent settlement (Ruesink, pers. comm.). Yet *C. gigas* reefs have formed in low/moderate energy rocky shores in southern Brittany (Lejart and Hily, 2011) (see Image 4.1).

(Photo: RJH Herbert.)

Image 4.1 Formation of *C.gigas* Reef on Rocky Reef at Ile d'Oleron, Atlantic Coast of France, September 2011

To our knowledge, *C. gigas* has not been recorded at extreme low water (ELWS) or subtidally below rocky habitats, as it has been in soft sediment areas. It can colonise artificial substrata including concrete and stone sea walls, groynes and other structures, as observed in parts of southern England. In Kent, SE England, it has colonised the chalk platforms along the Thanet coast, and small reefs have now formed on some of these shores (McKnight, 2012; Image 4.2; see also Thanet Coast case study in Appendix A). There are fewer studies on the impacts of *C. gigas* on rocky shores compared to mussel beds and soft sediment habitats, although work is currently underway in the Yealm estuary in Devon (N. Miezkowska, Marine Biological Association (MBA), pers. comm.). There is also intensive monitoring of settlement and distribution on the Kent coast (McKnight, 2010, 2011, 2012).

(Photo: W McKnight)

Image 4.2 Pacific Oyster Reef on the Chalk Shore at Epple Bay, North East Kent European Marine Site, January 2011

In the Strait of Georgia, Canada, wild *C. gigas* settles within the barnacle zone of rocky shores where they may provide a greater surface area for settlement of different organisms (Ruesink *et al.* 2005). In experimental manipulations, rocky intertidal predators such as seastars and crabs reduced monthly survival rates of *C. gigas* by 25% relative to caged oysters (Ruseink *et al.* 2005; Ruesink, 2007). It was concluded that some neighbouring species on exposed rocky sites might actually contribute to (facilitate) survival of *C. gigas* by reducing physical stresses.

On shores consisting of dark rock in British Columbia, Canada, experimental evidence showed that *C. gigas* in low to moderate densities were able to cool areas of rock in their immediate vicinity due to high solar reflectance of their shells (Padilla, 2010). This enabled the survival of higher numbers of limpets which are important grazers on the shore. This demonstrated that *C.gigas* was able to modify the thermal regime of its habitat and provide refugia for those species that might otherwise suffer from desiccation.

In Argentina *C. gigas* was introduced in 1982 and occurs in rocky habitats (Escapa *et al.* 2004), among eight epifaunal species, three occurred at higher densities within oyster beds and three were more abundant outside these areas. Foraging by shore birds was greater within the oyster beds.

In the Bay of Brest, France, a study was carried out to determine the impact of *C. gigas* reef formation on a sheltered/moderately exposed rocky shore (Lejart and Hily, 2011). Samples were taken from areas where *C. gigas* had formed a reef on the shore and in areas where it had not colonized. The results are as follows: (the study also considered impacts of *C. gigas* reefs on soft sediment, which are covered in Section 4.2.3).

- Ten species were found on adjacent rock whereas 55 species were found on the *C. gigas* reef that had colonised the rock, though the proportions of different species groups were different. Barnacles, normally important occupiers of space on rocky shores, were at considerably higher density on the reef and limpets (*Patella* spp.) were overall at higher densities on the reefs; numbers of *P. depressa* were less on the reef though *P. ulyssiponensis* were only found on the reef;
- Biomass was significantly higher on *C. gigas* reefs compared to adjacent rock; proportions of feeding groups were very similar and dominated by micrograzers. Deposit and detritus feeders occurred only on oyster reefs and not on the adjacent rock; and
- *C. gigas* reefs create a complex habitat and 3D structure that increases, by a factor of four, the surface area available for the attachment of animals and algae.

4.2.3 Intertidal Sediments (EUNIS Code A2.2, A2.3 and A.4)

These habitats include mudflats and sandflats occurring within Estuaries and Shallow inlets and bays listed under Annex 1 of the EU Habitats Directive. The section combines the EUNIS level 3 broad-scale habitat that comprises *intertidal mud*, *intertidal sand*, *intertidal muddy sand*, *intertidal mixed sediments* and *intertidal coarse sediments.*

In parts of the Dutch and German Wadden Sea, and in Brittany, settlement and growth of *C. gigas* has formed extensive oyster reefs over former littoral muddy and sandy habitats (Reise, 1998; Lejart and Hily, 2005). This has transformed these areas, effectively creating a hard substratum and markedly changed the nature of associated benthic communities (Lejart and Hily, 2011). These oyster reefs have formed predominantly at lower tidal levels, from approximately MLW into the shallow subtidal. Above MLW, mudflat and sandy habitats still remain.

The rate of *C. gigas* reef formation on soft substrates appears to be dependent on the availability and quantity of hard substrate for oyster settlement and growth. In the Wadden Sea, initial colonisation of *C. gigas* was on former mussel beds and cockle shell ridges, from which it has spread (Dankers *et al.* 2006; Nehls *et al.* 2006). Single valves of shells on a sandy shore can provide suitable substrate for oysters, which then begin to settle gregariously on conspecifics to form a small oyster clump. These clumps then merge with other clusters, and further settlement causes cementation of these structures to form a 'reef' (Nehring *et al.* 2009; R Herbert, personal observation) (Image 4.3).

(Photo: RJH Herbert)

Single oysters settle on shell; individuals merge to form clumps; clumps merge to form an oyster reef, seen in background. (See also Images A1 and A2 in Appendix A)

Image 4.3 *C. gigas* **reef development at Sylt, Wadden Sea, Germany, September 2008**

The expansion of the oyster reef might be expected to have a negative impact on the diversity and abundance of other soft-sediment species, and there is certainly some overlap in distribution of native bivalve species such as the Baltic tellin *Macoma balthica*, *Scrobicularia plana* and cockle *Cerastoderma edule.* These and other species, would however be expected to also occur above the level of *C. gigas* reef development, although the extent of habitat overlap is likely to depend on locality. In the Wadden Sea, densities of cockles and *Macoma* are apparently greater above the level of *C. gigas,* perhaps due to the impact of predation at lower levels (Troost, 2010).

A comparative study of the fauna associated with *C. gigas* reefs that had formed on mudflats and in control areas on adjacent mudflats where it had not colonized was carried out in France in the Bay of Brest (Lejart and Hily, 2011). Samples were taken from the mud beneath reefs, the reef structure and from adjacent mudflats. The results were as follows (the study also considered impacts of *C. gigas* reefs on rocky shores, which are covered in Section 4.2.2).

- Mud beneath oyster reefs had on average double the species richness of adjacent mudflats;
- Of the 37 species found in mud beneath reefs and in adjacent mudflats, 5 species were found only in adjacent mudflats. These included 3 polychaete species, one unidentified anemone and the non-native Manila clam (*Ruditapes philippinarum*). As far as it is known, the populations of the polychaete and anemone species are not 'at risk' from *C.gigas* colonisation. The non-native Manila clam provides important fisheries and wild harvesting services yet is unlikely to be excluded from the site as a result of *C.gigas* colonisation as it can occupy subtidal habitats.
- Mud beneath the oyster reefs contained a larger number of taxonomic groups than adjacent mudflats though proportions of molluscs, crustacean and annelids remained unchanged;
- Abundance and biomass in mud beneath reefs was double that in adjacent mudflats and dominated by carnivores, compared to suspension feeders in mudflats;
- On the *C. gigas* reefs, the proportion of main taxa were different from those on the adjacent mudflat; and
- Analysis of the pollution sensitivity of ecological groups showed that, although sensitive species were present, mud beneath reefs had on average slightly more tolerant species, which is indicative of organic enrichment.

4.2.4 Saltmarshes and Saline Reed Beds

These vegetated areas are Annex 1 habitats listed under the EU Habitats Directive and include 'Glasswort and other annuals colonizing mud and sand', Cord grass swards and Atlantic salt meadows'. These habitats occur in sheltered parts of estuaries and embayments at levels normally above Mean Tide Level (MTL). No *C. gigas* settlement has been observed amongst saltmarsh habitats in the Wadden Sea and any oysters that drifted from the mudflats below tend to die of air exposure (K. Reise pers. comm.). As oysters appear to occupy a lower tidal level, it is unlikely that the species would have a direct negative impact on saltmarsh habitat. However, in Argentina, Escapa *et al.* (2004) noted colonisation of *C.gigas* on the stems of the saltmarsh cord grass *Spartina alterniflora*.

Patches of the non-native and invasive cord grass *Spartina anglica* have increased on the shore on the Thanet coast of Kent and sand, gravel and Pacific oyster shell debris is accumulating around these clumps (McKnight, 2012). Although no settlement of Pacific oysters has been observed in these patches (McKnight, 2012), the stabilization of sediment by oyster shells may both facilitate further colonisation of *Spartina* and potentially create firm habitat for oyster settlement, although there is no evidence for this to date

4.2.5 Saline Lagoons

Lagoons are listed under Annex 1 of the EU Habitats Directive. Saline lagoons are one of the most uncommon habitats in the UK. They can accommodate a specialized assemblage of organisms that appear particularly tolerant of changeable and reduced salinity. Some form naturally behind beaches, whereas others are man-made habitats. Most of the lagoon might be regarded as a shallow subtidal habitat. However at some sites where water levels are managed for breeding bird populations, mudflats and sandflats do appear seasonally. As a relatively closed habitat, water temperatures can rise considerably in summer months and thus this habitat could be vulnerable to *C. gigas* settlement.

There is very little information on the impact of *C. gigas* in lagoons. However, it is within the Fleet lagoon National Nature Reserve behind Chesil Beach in Dorset that Pacific oysters have been cultivated since 1988 and for which there is hardly any recorded wild settlement (Seaward, 1992; R Herbert, personal observation[5]). This anomaly is of considerable interest and the special flushing characteristics of the Fleet and crab predation may provide resilience to wild settlement in this particular lagoon (Eno, 1994). Most of the lagoon species for which the site is designated are subtidal and may therefore not be as vulnerable as intertidal habitat, as there have been fewer observations of subtidal settlement of Pacific oysters. Yet on the Mediterranean coast, *C. gigas* is cultivated in micro-tidal lagoons and has established wild populations in some areas (Miossec *et al.* 2009).

4.2.6 Intertidal Biogenic Reefs (EUNIS Code A2.7)

These biogenic reef habitats are created by the organisms themselves growing in high density and are listed under Annex 1 of the EU Habitats Directive[6]. The impact of *C. gigas* on key intertidal biogenic reefs formed by Blue mussels (*Mytilus edulis*) beds, Honeycomb worm (*Sabellaria* spp.) beds and Sandmason worm (*Lanice conchilega*) beds are reviewed separately below.

4.2.6.1 Blue mussel (*Mytilus edulis*) beds

Blue mussels are bivalve molluscs that are found on shores and in shallow water. They are particularly prevalent on some high-low energy rocky shores and also on soft sediment shores where they form a hard surface in otherwise muddy or sandy areas. This attracts a range of other species that would not be found in the surrounding habitat. Mussel beds are subject to wide variation in recruitment. Mussel beds also provide an important food source for waterfowl.

Most of the research in to the effects of Pacific oysters on Blue mussel beds has been carried out in the Wadden Sea, where extensive intertidal Blue mussel beds once existed and have been cultivated (Reise, 1998; Diederich *et al.* 2005; Nehls *et al.* 2006). Mussel beds, and even empty shell valves, provide hard substrate for attachment of *C. gigas*. Mussel beds extend from just below MTL to the shallow subtidal, a region which overlaps considerably with the preferred habitat of *C. gigas*. Oyster larvae settle and attach to mussels and the oysters grow rapidly

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5 A few wild Pacific oysters were observed during a thorough survey between the Narrows and Ferry Bridge in March 2012 (Herbert & Short, personal observation).

6 *C.gigas* reefs are also biogenic reefs but are not protected under the EU Habitats Directive.

over and above the mussel bed. Yet although many *Mytilus*-beds have changed to reefs dominated by 95% *C. gigas* (Nehls and Buttger, 2007), mussels are still present, recruit frequently and settle amongst the oysters, migrating to lower regions in the interspaces between the oysters to evade predators, such as shore crabs and birds (Fey *et al*. 2010; Eschweiler and Christensen, 2011). These mussels remain small, and low growth is presumed to be due to food competition with *C. gigas.* Oysters settle preferentially on other oysters (conspecifics) and oyster reefs have now developed on large areas of former mussel beds. Clusters of oysters can form around small patches of mussels and also break away from reefs, serving as nuclei for new oyster reefs where mudflats had previously existed. Within and between mussel beds, abundances of oysters are variable, and it is uncertain whether *C. gigas* will exclude mussels entirely; the area of mussel beds in the Dutch Wadden Sea has remained relatively stable over the last few years while oyster reefs and mixed beds are increasing (Nehring *et al.* 2009).

Most Pacific oyster beds in Dutch and German coastal areas do not cover 100% of the substrate and contain many bare patches where soft-sediment communities are still present and where shrimps and small fish may be found in shallow pools (see Figure 5 in Troost, 2010). This resembles the habitat of former intertidal Blue mussel beds.

It is thought that climatic factors (specifically mild winters that result in high predator survival) have influenced the density of mussels. High levels of predator survival may have caused decline of mussel beds (Nehls *et al.* 2006). Yet, although mussel beds appear to be still declining in the north Wadden Sea, they are increasing in other areas. The last two to three winters have been more severe, yet an expected reduction in predator densities and recovery of mussel recruitment has not occurred (K. Reise pers. comm.). It now appears that variability in mussel survival is more complex but likely to be related to regional levels of invertebrate predation. It is uncertain to what extent *C. gigas* has had an influence on the decline of intertidal mussel beds. It is also possible that *C. gigas* has colonized shell debris associated with former mussel beds and interfered with their re-colonisation through occupation of their former habitat, although there is no experimental evidence for this.

In parts of the Dutch Wadden Sea and Oosterschelde estuary, which has not seen natural intertidal mussel beds for several decades, and where mussel culture plots were moved to subtidal areas in the 1990s, *C. gigas* reefs may compensate for the loss of ecological function of mussel beds in the intertidal Wadden Sea (Markert *et al.* 2010; Troost, 2010). There is an overall similarity in the structure of species assemblages associated with *C. gigas* reefs and mussel beds. Markert *et al.* (2010) also found that, due to a sediment-free upper part of the reef and more turbulent current flow, species richness was significantly greater amongst the oyster beds compared to mussels and that some faunal species were exclusively found on oyster beds, particularly anemones and suspension feeders. Higher species survival amongst the more complex oyster reef structure and biodeposition of sediments was also thought to explain differences in species richness (Kochmann *et al.* 2008).

In the UK, a survey conducted in 2004 on the Southend foreshore by Kent and Essex Sea Fisheries Committee (now IFCA) showed a significant stock of *C. gigas* present on the mussel beds. Currently (2012) there are few mussels remaining in the area with *C. gigas* being very much the dominant species. Whether the decline in mussels has been as a direct result of the encroachment by Pacific oysters or as result of other influences is uncertain (Kent and Essex IFCA pers. comm.).

4.2.6.2 *Sabellaria alveolata* reefs

Sabellaria alveolata is a gregarious segmented worm that builds tubes from sand or shell fragments which may form large reefs up to several metres across and a metre deep, mostly in intertidal areas.

In the Bay of Mont-Saint Michel, France, extensive *C. gigas* aquaculture has resulted in wild oysters colonising *S. alveolata* reefs (Dubois *et al.* 2006) (Images 4.4 and 4.5). Not all *S. alveolata* reefs were colonised by oysters, however oyster densities of >100 per m^2 were recorded on some of the *S. alveolata* reefs. In a study of associated macrofauna on *S. alveolata* reefs colonised by oysters and green algae (Desroy *et al.* 2011), higher species richness was recorded on those reefs that had been colonised with oysters (and with oysters and algae). It is thought that the greater complexity of the oyster matrix and presence of sediments within the interspaces was responsible for further increasing the richness of this already diverse habitat.

(Photo: N Desroy)

Image 4.4 Light Settlement of *C. gigas* on Honeycomb Worm Reef (*Sabellaria alveolata*) in Bay Mont St Michel, France, April 2011

(Photo: N. Desroy)

Image 4.5 Dense Settlement of *C. gigas* on Honeycomb Worm Reef (*Sabellaria alveolata*) in Bay Mont St- Michel, France, April 2011

However the colonisation of the *S. alveolata* reefs by oysters in the Bay of Mont-Saint Michel has led to their damage by recreational oyster harvesters who are able to obtain these oysters relatively easily. Increased competition for food due to higher levels of water filtration by wild oysters and bivalve aquaculture is also considered to have contributed to the habitat deterioration (Desroy *et al.* 2011).

No *C. gigas* was seen growing on lower shore *S. alveolata* reefs during observations in southern Brittany in autumn 2011 (R Herbert, personal observation), although very high densities of oysters were seen on adjacent rock and competition for food cannot be excluded. However Cognie *et al.* (2006) indicates that in Bourgneuf Bay, southern Brittany, the growth and settlement of wild *C. gigas* has now transformed areas where former *S. alveolata* beds had previously been recorded. It is possible that any new colonisation will now be prevented due to occupation by *C. gigas*.

4.2.6.3 *Sabellaria spinulosa* reefs

S. spinulosa is a small tube-building polychaete worm found primarily in subtidal habitat and on the extreme lower shore. It can be solitary or clustered in small groups, however dense aggregations may be found forming reefs up to 60cm high and extending over several hectares and raised above the surrounding sea bed.

At Epple Bay near Birchington, Kent, an area of *S. spinulosa* in reef formation is being displaced by *C. gigas* at ELWS (McKnight, 2012). *C. gigas* is also 'occasional' on an adjacent intertidal area of *S. spinulosa reef* that possibly represents the best example of the habitat within the North-east Kent EMS. Areas of intertidal *S. spinulosa* habitat are therefore at risk from *C.gigas* settlement within the designated site, although the subtidal areas may be at less risk as there is no evidence for subtidal colonisation in this locality.

4.2.6.4 *Lanice conchilega* reefs

L. conchilega (the sandmason worm) is a polychaete worm that can form dense beds within intertidal areas and the shallow subtidal.

At Ramsgate, Kent, an area of chalk reef 1000 m^2 covered in silt and colonised by 50% cover of *Lanice* worm reef is now being displaced by oysters, where maximum densities are currently 14 per m^2 (McKnight, 2012). It is uncertain how extensive dense aggregations of the species are within the North-east Kent EMS.

4.2.7 Seagrass Beds

Seagrass beds develop on intertidal sandflats and mudflats along sheltered coasts and within estuaries. They may also colonise subtidal sediments within shallow inlets and bays, in lagoons and channels sheltered from significant wave action. These habitats are listed under Annex 1 of the EU Habitats Directive. In the UK, two main species are found - *Zostera noltii,* which is primarily recorded on intertidal muddy sediments, and *Zostera marina,* which is found from MLW to subtidal depths of usually 3-4m, though it can be deeper. *Z. angustifolia* may be a variety of *Z. marina* (Foden and Brazier, 2007).

As burrowing, filter-feeding organisms, there are different mechanisms whereby Pacific oysters could interact with seagrass, including alteration of sediment biogeochemistry (Kelly and Volpe, 2007) and structure and space occupation (Heck *et al.* 2000; Gutierrez *et al.* 2003). The ability of oysters to reduce water turbidity is also likely to be beneficial to seagrass photosynthesis and production (Nelson *et al.* 2004). In the Thau lagoon on the north Mediterranean coast, increased water clarity caused by the uptake of particulate material and phytoplankton by *C. gigas* and mussel aquaculture, is thought to have enabled *Zostera* to grow in deeper areas of the lagoon (Deslous-Paoli *et al.* 1998).

However, there is a general pattern of reduced density and shoot size of the native seagrass *Z. marina* on cultured oyster beds (Tallis *et al.* 2009). It has been suggested that the hard surfaces of shells or aquaculture structures could abrade seagrass shoots or catch them in a way that increases desiccation stress at low tide (Simenstad and Fresh, 1995).

In Wallapa Bay, British Columbia, intertidal *C. gigas* reefs are generally above extensive areas of *Z. marina,* which have colonised previous native *Ostrea lurida* beds at elevations of -1.0 to +0.6 m relative to MLW (Image 4.6). *Z. marina* shoot density is typically 100 per m^2 in these areas and the leaves are large. Yet there is potential overlap in habitat of *C. gigas* and seagrass *Z. marina* at lower tidal levels (Dumbauld *et al.* 2011). An experimental approach was used to investigate the effects of *C. gigas* on beds of the seagrass *Z. marina* (Wagner *et al.* in prep). Oysters were laid upon a *Z. marina* bed at a range of densities and the response of the seagrass and associated sediment chemistry was monitored. In a second experiment, to mimic the cultivation cycle, oyster cultch (juvenile oysters growing on shell) was added to *Z. marina* beds which were monitored over several years. Overall, seagrass shoot density and cover declined with the increase in oyster density, which was attributed to space competition; this can exceed the footprint of oysters and generate strong impacts above thresholds of 20% oyster cover. At low densities, *C. gigas* has little impact, however oyster cover >50% is essentially impenetrable to seagrass.

A comparison between the benthic fauna, fish and swimming invertebrates immediately seaward of the *C. gigas* zone and amongst adjacent *Z. marina* beds, found that benthic diversity was greatest below the *C. gigas* beds, yet fish and swimming invertebrates were much more abundant within the seagrass (Kelly *et al.* 2008).

Disturbances associated with bed maintenance and harvest may additionally reduce seagrass density. Within oyster aquaculture in Willapa Bay, the proportional area occupied by *Z. marina* is similar to outside (Dumbauld *et al.* 2009), but the density and production per area may be 30-70% lower (Tallis *et al.* 2009). The distribution of *Z. marina* in Wallapa Bay reflects aquaculture practice and relative impact of space competition, disturbance and recovery. Recovery from pulse-disturbances can take between two to five years (Dumbauld *et al.* 2009).

(Photo: J Ruesink)

Image 4.6 Seagrass Bed (*Zostera marina*) and Wild C.gigas Reef. Willapa Bay, Washington State, USA

4.2.8 Subtidal – Habitats

Although *C. gigas* does occupy subtidal areas in its native habitat (Padilla, 2010), there is little evidence for the colonisation of subtidal habitats by non-native *C. gigas*, and published or anecdotal evidence on rocky habitats or below ELWS on rocky shores has not been found.

In the Oosterschelde (Holland), settlement has been observed in cultivated Pacific oyster beds in subtidal areas within 2-3m of water and fishermen report settlement on adult oysters at 10m depth (J. Wijsman, pers. comm.). Using side-scan sonar, sublittoral stocks were estimated as occupying 700 ha (Kater *et al.* 2002 cited in Smaal *et al.* 2005).

In the Essex and Kent area, including the Thames estuary, *C. gigas* have been seen at least 2-3m below Chart Datum on ***subtidal sediments*** and are believed to be in deeper water (Essex and Kent IFCA, pers. comm.). Subtidal oysters have also been recorded in Lough Foyle and Lough Swilly (Republic of Ireland) (Loughs Agency, pers. comm.). In the Wadden Sea, *C. gigas* can found at 10m below low water on subtidal sediments, however no juveniles or recruitment have been observed (K. Reise, pers. comm.). Subtidal oysters in the Wadden Sea are often large individuals or clusters that have most likely broken off intertidal reef structures (K. Reise, pers. comm.). Oysters are at low densities and heavily colonised by algae, such as the invasive Japanese seaweed *Sargassum muticum* and a variety of non-native epifauna. The oyster thus forms a novel hard substratum habitat amongst soft sediment and, in the Wadden Sea at least, is particularly attractive to non-native species.

4.2.9 Native Oyster *Ostrea edulis* Beds

The native oyster *Ostrea edulis* is protected within the UK Biodiversity Action Plan (UK BAP) and there is a specific action plan for the species (Native Oyster Species Action Plan: NOSAP). It has also been identified as a Northern Ireland Priority Species.

Pacific oyster was introduced by the UK government primarily as a substitute for dwindling stocks of *O. edulis* that had declined due to overfishing, pollution and disease. As a cold-water (Boreal) species, *O. edulis* is thought to be less capable of adapting to climate warming compared to the Pacific oyster *C. gigas.* Although *C. gigas* is known to survive subtidally down to 10m, its direct impact on *O. edulis* populations is unknown. Although there is no direct evidence, declining stocks of *O. edulis* in areas where *C. gigas* are harvested (e.g. Blackwater) may be as a result of overfishing and not due to competition. Interestingly, in South Africa, non-native *Ostrea edulis*, originally introduced in the 1940s but thought extinct, has been re-discovered as established and growing amongst adult and juvenile *C. gigas* at aquaculture sites (Haupt *et al.* 2010). *O. edulis* has been found to settle on shells of *C. gigas* and also live farmed *C*. *gigas* in Poole Harbour, UK (J Humphreys and R Herbert, personal observation).

4.2.10 Impacts on Fish

It is likely that the direct impacts of wild *C. gigas* on fish largely relate to species that feed or breed within intertidal areas that the oyster could occupy. In the UK, these would include gobies, shanny, rockling, pipefish, sand smelt and flatfish in addition to juveniles of other species that migrate to deeper waters when adult. Indirectly, there could also be competition for planktonic food and cascades down through the food web are possible. However, as yet, there is no evidence for this. In Wallapa Bay, NW Canada, a comparison between the benthic fauna, nekton and swimming invertebrates immediately seaward of the *C. gigas* zone and amongst adjacent *Z. marina* beds found that benthic diversity was greatest below the *C. gigas* beds, yet fish and swimming invertebrates were much more abundant within the seagrass (Kelly *et al.* 2008).

In the Netherlands, fish species that are reported to feed on bivalve spat are the gobies *Pomatoschistus microps* and *P. minutus*, and juvenile plaice (*Pleuronectes platessa)*, flounder (*Platichthys flesus)* and sole (*Solea solea*), though it is uncertain whether *C. gigas* features in the diet of these species (Hiddink *et al.* 2002 and references therein). In Japan, Pacific oyster spat is reportedly predated by the black sea bream *Acanthopagrus schlegelii* and the fine-patterned puffer *Takifugu poecilonotus* (Saito *et al.* 2008 cited in Troost, 2010). In the USA, many species utilize oyster reefs (species not specified) as recruitment sites, nursery areas and foraging areas (Ruseink *et al.* 2005).

4.2.11 Impacts on Birds

Pacific oysters accommodate high densities of invertebrates amongst the interspaces between shells and on their surfaces. However birds that might commonly feed on mussels (including Eider), may not be able to penetrate oysters due to their size, shell thickness and cementation (Nehring *et al.* 2009). In the Wadden Sea, Herring gulls (*Larus argentatus*) and oystercatchers (*Haematopus ostralegus*) are the only bird species reported to feed on *C. gigas* (Troost, 2010). In the Oosterschelde estuary, since the replacement of intertidal mussel plots with subtidal culture, more intertidal mussels may now be available to foraging birds because of their increasing presence amongst *C. gigas* reefs (Troost, 2010).

In Argentina, studies on bird foraging within non-native *C.gigas* beds and in control areas nearby found that the number of birds (two gulls and four wading bird species) was greater amongst the *C.gigas* (Escapa *et al.* 2004). The authors also found that although there was no difference in the foraging rate of American Oystercatcher and Two Banded Plover, the foraging rate of Red Knot and American Golden Plover was greater amongst the oysters compared to control areas.

No studies have been carried out on possible trophic cascading effects due to increased water filtration and plankton consumption through increases in oyster abundance, and subsequent impact on birds and fish. In the Wadden Sea and in Kent, *C. gigas* reefs on soft-sediment habitats have formed at around mean low tide level and there remain mudflats with dense invertebrate populations at higher tidal levels that can be exploited by shorebirds.

Wetland bird surveys for the Blackwater estuary, Essex, where there are extensive wild *C. gigas* reefs and species commercial exploitation do not specifically attribute any decline in bird abundance to wild settlement, aquaculture or fisheries (British Trust for Ornithology, 2012).

Birds act as final hosts for parasites, including trematodes. *C. gigas* and the non-native slipper limpet *Crepidula fornicata* have both been found to act as a decoy for parasites that would normally infect mussels. If birds don’t consume oysters then parasite loads may be reduced (Krackau *et al.* 2006) and bird fitness may increase.

4.3 Other Ecological Impacts of *C. gigas* Production and Wild-harvesting

Part of the production process may involve the importation or movement of 'seed' or juvenile oysters with associated risk of accidentally introducing non-native and potentially invasive species. This risk also extends to any transportation and re-laying of oysters more locally between sites in the region. The impact of non-native species introduction through these processes is largely dealt with in Section 4.1.

Many oyster farms on the continent where Pacific oysters have become naturalised, now collect their own seed from these wild stocks. If these juvenile oysters have become colonised or fouled with non-native species and these are subsequently moved, then there is risk of secondary introductions of these species.

There are different impacts associated with varied means of cultivation - oysters may be laid on the intertidal seabed where they will grow and are later collected (on-bottom cultivation), grown in bags on trestles that are placed within intertidal areas, or grown in bags suspended in the water column in subtidal areas, where access is usually by boat. The impacts of these different forms of cultivation are described in Section 4.3.1 below.

In addition, wild Pacific oysters are also fished; being either dredged from fishing vessels or collected by hand at low-tide. Pacific oysters are mostly known from intertidal areas, so fishing vessels attempting to exploit these beds must do so at high tide. The distribution of *C. gigas* in subtidal areas is not fully understood, although some inshore areas may have oysters that have broken off reefs and can be harvested. It is also possible that oysters dredged from intertidal areas might be re-laid in subtidal regions to grow and develop a more marketable shape. Impacts of wild harvesting are described in Section 4.3.2 below.

4.3.1 Direct Impacts of Cultivation – Aquaculture

The construction and maintenance of on-bottom aquaculture beds will undoubtedly cause some measure of disturbance to habitats in the immediate proximity. As many of these oyster aquaculture sites are within estuaries, lagoons and other sheltered waters, foot or vehicular access, particularly during winter months, may cause some localised disturbance to migratory water fowl. Some species, however, will tolerate disturbances of this kind and become habituated to noise and visual disturbances.

As with any marine industrial operation there is always risk of hydrocarbon leakage and waste water pollution from such sites. There is also risk of pollution from use of antifouling paints on boats and other structures.

A major cause of concern at aquaculture sites is the enrichment of water and sediments from such large quantities of oysters. Although minor changes in sedimentation and organic deposition have been recorded at off-bottom bag-on-trestle sites, the impact is thought to be severe in areas of large-scale (hectares) cultivation (Kaiser *et al.* 1996).

4.3.2 Wild Harvesting

The harvesting of wild *C. gigas* within intertidal areas is by hand or from fishing boats close inshore at high tide. Disturbances to over-wintering birds are a potential issue, yet currently only a small number of harvesters are present at any time and these are confined to the dense beds that have formed in parts of SE England. There have been reports of recreational harvesting of wild oysters off sea walls and other structures on the Kent coast and in the Solent region. Harvesting may also remove limpets and barnacles in the process (Thanet Coast Project, pers. comm.).

The use of boats to fish for wild oysters may have a larger impact if intertidal or subtidal sediments are also dredged in the process. The extent of the disturbance impact will depend on the scale of operations. Recovery of intertidal soft-sediment fauna from mobile demersal fishing gear may take between several weeks to several years depending on sediment type and intensity of disturbance and gear (Herbert *et al.* 2012).

Pollution from hydrocarbons and antifouling paints is also a concern although the size of the industry is relatively small. There is also the potential to spread oysters to other coastal areas if oysters foul the hulls of fishing vessels.

4.4 Impact on Protected Areas

From the evidence on ecological impacts presented above, dense wild settlement *of C. gigas* can transform some habitats in protected areas from a functional state in which they were originally designated, to a new functional state. For example, there is a significant possibility that a 'rocky reef' that is dominated by seaweeds, limpets, barnacles and mussels might be transformed in to an extensive 'non-native oyster reef' dominated by *C. gigas*. The spatial dominance of large filter feeding organisms and higher filtration capacity of the oyster reef differs considerably to the dominance of algae, grazers (e.g. limpets) and other filter feeders (e.g. barnacles) on a rocky reef. Although the species diversity of the non-native oyster reef might be greater than the native habitat, and include higher densities of limpets and barnacles, it is the fundamental alteration in type and variety of habitats or biotopes that is important, particularly in regard to the EU Habitats Directive. The threshold level of impact whereby a site might be considered to have changed or transformed has not been quantitatively determined. However, as far as the EU Habitats Directive is concerned, of critical importance is whether the *integrity* of the *whole* designated site is transformed. Changes in biotopes of at least EUNIS Level 3 (European Environment Agency, 2012) might be expected in such cases (e.g. Pacific oysters would dominate a rocky shore previously characterised by algae (*Fucus* spp.) limpets, barnacles and/or mussels).

The integrity of the site is '*the coherence of its ecological structure and function, across its whole area, that enables it to sustain the habitat, complex of habitats and/or the levels of populations of the species for which it was classified*'[7].

7 EC, 2000, Managing Natura 2000 Sites, Section 4.6.3.

In many cases, competent authorities have concluded that even the loss of considerably less than 1% of designated sites would be likely to be significant and in some cases could adversely affect site integrity[8] .

Although the functional state of a rocky shore might be significantly transformed through the colonisation of *C.gigas*, the same may not necessarily be true for habitats consisting primarily of filter-feeders, such as mussel beds. They may simply be replaced by an equivalent filter-feeding species that can accommodate a similar associated fauna.

A plan to develop a new Pacific oyster farm within or in the vicinity of an EU Natura 2000 site (Special Area of Conservation; SAC or Special Protection Area; SPA) may need to satisfy competent authorities that the proposal will not have an adverse effect on the site. There are various stages in the Appropriate Assessment process; importantly however, the *Likelihood of Significance of the Impact* and the *Impact on the Integrity of the Site* will need to be determined. With increased warming due to climate changes, in some regions, the risk that wild settlement of Pacific oysters might occur and spread across designated habitats could be assessed as high. This will not necessarily happen in the short or medium term, yet if uncontrolled, significant impacts may occur if sea temperatures remain high enough for spawning. Although the level of impact will vary between regions and sites, from the evidence presented above, there is good reason to apply the precautionary principle to address any uncertainty over the level of impact on certain habitats.

Examples of 'significant impacts' provided by Natural England[9] (formerly English Nature) and the European Commission[10] include:

- Alteration of community structure;
- Reduction in area of habitat/biotope or species for which the site was originally notified;
- Causes on-going disturbance to species or habitats;
- Presents a barrier between isolated fragments of native habitats, or reduces the ability of the site to act as a source of new native colonisers;
- Causes direct or indirect change to the physical quality of the environment (including the hydrology) or habitat within the site;
- Causes direct or indirect damage to the size, characteristics or reproductive ability of populations on the site; and
- Alter the vulnerability of populations/habitats to other impacts.

All of the above could conceivably be caused by dense wild settlement of Pacific oysters.

In the SE of the UK, in traditional oyster growing areas, it is clear that large areas of dense wild settlement of *C.gigas* now exist within designated sites. However, it is also obvious that large areas of habitat within these sites have either yet to be colonised or will never be colonised.

8 Hoskin, R., & Tyldesley, D. 2006. How the scale of effects on internationally designated nature conservation sites in Britain has been considered in decision making: A review of authoritative decisions. English Nature Research Reports, No. 704

9 English Nature, The Determination of Likely Significant Effect under The Conservation (Natural Habitats, &c.) Regulations 1994 HRGN3 English Nature 1999. [English Nature is now part of Natural England].

10 European Commission Environment DG, Assessment of plans and projects significantly affecting Natura 2000 sites. Methodological guidance on the provisions of Article 6(3) and (4) of the Habitats Directive 92/43/EEC.

Moreover, some areas are being managed or fished to reduce the level of impact on the site – and other areas are being cleared by wild harvesters. Any large scale clearance of Pacific oysters from the site may have a long-term adverse effect on the features of conservation interest.

The extent to which an individual Pacific oyster farm could have an adverse effect on the integrity of a site will ultimately depend on local and regional characteristics, the size of the operation, husbandry and the presence of other oyster farms and vectors (e.g. shipping and boating) that in combination will determine the overall magnitude of oyster 'propagule pressure' on the environment and invasion risk.

The legal aspects of this issue are explored further in Section 6 and possible options to mitigate negative impacts on biodiversity and the condition of designated sites are discussed further in Section 7.

4.4.1 Further Work

Suggested priorities for further work in this area are as follows:

- Investigate evidence for subtidal settlement and growth and interaction with subtidal species and communities, especially the native oyster *Ostrea edulis*;
- Establish regional impacts of wild settlement on biodiversity, including bird and fish populations; and
- Investigate habitat resilience to settlement, especially the relative impact of hydrography and biodiversity.

5. Beneficial Ecosystem Processes and Services

The objective of this section is to review the available evidence base relating to any beneficial ecosystem processes and services provided by *C. gigas* individuals and reefs, thereby highlighting ecological and societal benefits that may be provided by *C. gigas*. Where available, evidence was sought relating to the beneficial ecosystem processes and services arising from wild populations of *C. gigas*, however, information relating to cultivated *C. gigas* (i.e. from aquaculture) was included where it helped to provide further information about the beneficial processes and services that may be provided by dense aggregations of this species. The classification system followed in this report for beneficial marine ecosystem processes and services, has been taken from Fletcher *et al.* (2011) and Herbert *et al.* (2012) as described in Section 5.1.

Oysters have a strong influence on ecosystem processes (such as water filtration, biogeochemical cycling) when they occur in dense aggregations and reefs. The ecosystem level services, provided by reef forming oyster species, have been documented in numerous reviews and papers (e.g. Fletcher *et al.* 2011; Beck *et al.* 2011; Coen *et al.* 2007; Peterson *et al.* 2003). This section will present the evidence of the provision of beneficial ecosystem processes and services by *C. gigas* reefs. Evidence in the literature referred to both *C. gigas* 'reefs' and *C. gigas* 'beds' and for the purposes of this review, it has been assumed that both 'reefs' and 'beds' refer to dense aggregations of *C. gigas* and no further distinction between these terms has been made. Detail of the density of *C. gigas* oysters within reefs and/or beds has been provided where the information was available. Where evidence of ecosystem services was found that related to individuals of *C. gigas* rather than reefs, this is highlighted in the text.

Where no evidence was found of the provision of beneficial ecosystem processes or services specifically by *C. gigas*, this is highlighted in the text and in the summary tables in Section 5.4. In these instances, any evidence of beneficial processes and services arising from reefs formed from other oyster species of the genus *Crassostrea* (in all instances *C. virginica*), was included, based on the assumption that *C. gigas* may also provide these benefits, albeit with low confidence. It should be noted that *C. virginica* is a native species within all of the study areas described and hence this evidence does not reflect the potential ecological and societal benefits arising from reefs of a non-native *Crassostrea* species. In addition, Padilla (2010) notes that, in general, *C. gigas* does not build reefs such as those produced by other engineering species such as *C. virginica* (although no detail is given of the differences). If the structural characteristics of oyster reefs vary between species, caution must be applied in assuming that services provided by one species can be inferred for others.

A summary of the evidence-base and of the quality of the evidence is presented in Section 5.4. It should be noted that the beneficial ecosystem processes and services described are not necessarily uniquely provided by Pacific oysters (unless otherwise stated in the text) and other habitats and/or native species which are known to provide the same processes and services are listed in the summary tables in Section 5.4, based on the findings of Fletcher *et al.* (2011) and Herbert *et al.* (2012).

A qualitative assessment of the 'value' of these services has been undertaken. This assessment has primarily focussed on direct use values of the beneficial services provided, although some aspects of the psychological and social wellbeing encompass elements of non-use values (see Section 5.5).

Finally the likely impact of *C. gigas* reefs on the beneficial ecosystem processes and services provided by the habitats of conservation importance described in Section 4, is discussed in Section 5.6.

5.1 Ecosystem Processes and Services

The processes occurring in coastal and marine ecosystems provide ecological functions that directly or indirectly translate to a variety of services of economic value to society. As outlined by Fletcher *et al.* (2011) ecosystem services have been defined in a variety of ways, but fundamentally can be described as "the benefits human populations derive, directly or indirectly, from ecosystem functions" (Costanza *et al.* 1997).

Balmford *et al.* (2008) defined three elements of ecosystems, that deliver ecological functions and services (these overlap in some instances):

- Core ecosystem processes: these describe the basic ecosystem functions (e.g. nutrient cycling, water cycling) supporting the processes that provide benefits to people;
- Beneficial ecosystem processes: these are the specific ecosystem processes that directly underpin benefits to people (e.g. waste assimilation, water purification); and
- Beneficial ecosystem services (referred to as 'benefits' in Balmford *et al.* 2008): these are the end products of ecosystem processes that directly impact human wellbeing (e.g. food, raw materials).

Fletcher *et al.* (2011) modified the classification of Balmford *et al.* (2008) to make it more appropriate to the marine environment. Their classification system has been adopted in this report to structure the evidence of the beneficial ecosystem processes and services provided by *C. gigas* reefs and/or *C. gigas* individuals (see Image 5.1).

It should be noted that for the purposes of this paper, the classification system has been modified from Fletcher *et al.* (2011) to include two additional beneficial ecosystem services under the category of raw materials: cultch material and construction material, to accommodate evidence found by this review.

BENEFICIAL ECOSYSTEM PROCESSES
Primary production
Secondary production
Larval/Gamete supply
Biological control
Food web dynamics
Species diversification
Genetic diversification
Waste assimilation
Erosion control
Formation of species habitat
Formation of physical barriers
Formation of pleasant scenery
Climate regulation
Biogeochemical cycling
Water cycling (regulation)
Water purification (quality)

BENEFICIAL ECOSYSTEM SERVICES	
Fisheries	Food
Other wild harvesting	
Aquaculture	
Fertiliser / Feed	
Salt	Raw materials
Ornamental materials (shells)	
Cultch material (shells)	
Construction material (shells)	
Biofuels	Energy
Medicines	Physical wellbeing
Natural hazard protection	
Environmental resilience	
Regulation of pollution	
Tourism	Psychological/social wellbeing
Recreation / sport	
Spiritual/cultural wellbeing	
Aesthetic benefits	
Nature watching	
Aquaria	
Research and Education	Knowledge

(Source: Adapted from Fletcher *et al.* 2011)

Image 5.1 Definition of the Classification System Applied to the Ecosystem Services Provided by Marine Species and Habitats

5.2 Beneficial Ecosystem Processes

Fletcher *et al.* (2011) and Herbert *et al.* (2012) identified evidence of native oyster beds (*Ostrea edulis*) providing the following beneficial ecosystem processes and services:

- **Ecosystem Processes:**
  - Secondary production;
  - Food web dynamics;
  - Erosion control;
  - Formation of species habitat;
  - Formation of physical barriers;
  - Climate regulation;
  - Biogeochemical cycling, and
  - Water purification.

Evidence relating to the provision of these processes by oyster reefs in general, and *C. gigas* reefs (or reefs formed by a *Crassostrea* species) where available, is reviewed below.

Four additional beneficial ecosystem processes are assumed to be universally provided by all habitats (Fletcher *et al.* 2011):

- Larval / gamete supply;
- Biological control;
- Species diversification; and
- Genetic diversification.

For the purpose of this paper, the above four processes have been 'assumed' for all oyster reef habitats (including *C. gigas* reefs) and have not been described further, except biological control, for which specific evidence relating to *C. gigas* was found.

5.2.1 Secondary Production

Through the conversion of food and nutrients in the water column into biomass, all oyster species provide the beneficial ecosystem process of secondary production. The evidence below has been included to enable comparison of production rates of cultivated *C. gigas* with other cultivated oyster species.

A study in Willapa Bay, USA, compared the annual production of the native oyster (*Ostreola conchaphila*) and the non-native species *C. gigas*, which had been introduced to compensate for the decline in the native oyster species (Ruesink *et al.* 2006). Comparison of the annual production of the two oyster species, using over 150 years of harvested biomass records, showed that the native oysters used to generate about 92 tonnes of dry matter (excluding shells) annually, whereas *C. gigas* was generating 330 tonnes annually. Hence the results indicated that the annual yields of the introduced *C. gigas* at the end of the 20th century were almost four times higher then annual yields of the native oyster at the end of the 19th century.

5.2.2 Food Web Dynamics

The evidence below relates to the provision of this service specifically by *C. gigas* reefs. However, it should be noted that the evidence relating to whether *C. gigas* reefs have beneficial effects on food web dynamics, and in-particular, on the provision of food for higher trophic levels appears contradictory (see also Section 4.2).

Miossec *et al.* (2009) stated that *C. gigas* is predated by a variety of organisms including starfish, boring gastropods (molluscs that 'bore' through the shells of their prey), some polychaetes, crabs, benthic feeding fish, ducks and wading birds. However, Troost, (2010) concluded that lack of predators in receiving communities in continental NW European estuaries was considered to have played a role in the fast proliferation of *C. gigas*. While laboratory experiments showed that the shore crab *Carcinus maenas* and the starfish *Asterias rubens* predated on *C. gigas* (Diederich, 2005a, cited in Troost, 2010), both of these predators showed a preference for the native *Mytilus edulis* over *C. gigas*. It is not known whether fish species which typically feed on bivalve spat (e.g. gobies and juvenile flatfish) predate on *C. gigas* (Troost, 2010).

In the UK, the responses to the shellfish industry questionnaire (Appendix B) provided anecdotal evidence of cultivated Pacific oysters (adult, spat and damaged individuals) being predated upon by birds (including Oystercatchers and gulls), crabs, prawns and starfish, whilst birds had also been observed foraging on the invertebrates found amongst the cultivated Pacific oysters.

5.2.3 Erosion Control

Shellfish, including oysters, act as natural coastal buffers, absorbing wave energy directed at shorelines and reducing erosion caused by boat wakes, sea level rise and storms (Beck *et al.* 2011).

Due to the ability of mature *C. gigas* reefs to firmly consolidate sediment (Reise and Van Beusekom, 2008, cited in Troost, 2010), it has been suggested that *C. gigas* reefs could be valuable in preventing erosion of intertidal flats in the Oosterschelde estuary (the Netherlands), where coastal engineering projects (such as the construction of a storm surge barrier and dams) have reduced sediment deposition, causing tidal flats to slowly submerge as erosion continues. Borsje *et al.* (2011) described how a pilot study in the Oosterschelde Estuary had shown that the creation of mussel beds and *C. gigas* beds to stabilize intertidal flats in front of dikes was "promising", as the reefs clearly attenuated hydrodynamic energy and accumulated muddy sediment (De Vries *et al.* 2007, summarised in Borsje *et al.* 2011).

More recently, the project 'Building with Nature' in the Netherlands was established to investigate whether *C. gigas* could be used to reduce or prevent erosion in the lower intertidal zone of the Oosterschelde Estuary. Pilot studies were undertaken in 2009 (small scale) and 2010 (larger scale) to assess whether artificial reefs of *C. gigas* (constructed using empty oyster shells which provide suitable substrate for natural oyster settlement) could become self-sustainable structures which would stabilize tidal flats. In a presentation given by Walles *et al.* (2011)[11] at the International Conference on Shellfish Restoration, it was stated that the results of pilot studies have shown that the artificial reefs provided suitable substrate for oyster larvae, with settled oysters growing "fast" at the reef locations and that local sedimentation and reduced erosion was observed behind the reefs, in contrast to the surrounding tidal flat where further erosion had occurred.

However, the Conclusions and Recommendation from the Trilateral Workshop on Pacific oyster invasion in the Wadden Sea (March 2007)[12] stated that the positive effects of developing oyster reefs on coastal protection issues were not considered to be of significance, although the reasons or evidence underlying this statement was not expanded upon in the document.

5.2.4 Formation of Species Habitat

In general, oyster reefs serve as important biogenic habitat for benthic invertebrates as well as fishes and mobile crustaceans (Peterson *et al.* 2003 and references therein). This biogenic habitat is a consequence of the structural complexity that the oyster shells create. Studies in the USA, comparing invertebrate abundance and diversity between restored and non-restored oyster reefs, between oyster reefs and soft bottom habitats, and among oyster reefs of varying complexity, consistently found higher abundances, biomass and species richness on the structurally more complex reef habitats (Coen *et al.* 2007 and references therein).

In a bay in Washington USA, the introduction of *C. gigas* (to compensate for declining populations of the native oyster *Ostreola conchaphila*) resulted in a shift in oyster habitat from

[11] http://www.aqua.stir.ac.uk/public/shellfish2011/presentations/walles.pdf
[12] http://www.waddensea-secretariat.org/news/symposia/oyster2007/oyster2007.html

sub-tidal areas (where the native oyster had occurred) to intertidal areas where *C. gigas* formed 'hummocks' (Ruesink *et al.* 2006). The *C. gigas* reefs and aquaculture sites on the previously unstructured mudflats provided an extensive, otherwise unavailable hard substrate for fish, invertebrates and macroalgal species (such as *Ulva* spp.), the latter of which had become abundant in intertidal zones where *C. gigas* culture or hummocks were present (Ruesink *et al.* 2006). Although the *C. gigas* expansion had occurred at the expense of burrowing shrimp and other infauna (by changing their natural habitat), the oyster habitat was thought to be partly responsible for the increased richness and biodiversity recorded locally (Ruesink *et al.* 2006, cited in Miossec *et al.* 2009).

5.2.5 Formation of Physical Barriers

As noted in Section 5.2.3, oyster reefs, can act as natural coastal buffers, absorbing wave energy directed at shorelines (Beck *et al.* 2011). For example, in the United States it has been reported that the physical structure of a fringing oyster reef (species not stated) can protect salt marsh habitat by dissipating erosive wave energy (Meyer, *et al.* 1996 cited in Peterson *et al.* 2003).

In a review of the successful implementation of ecosystem engineering species[13] in coastal protection, Borsje *et al.* (2011) stated that, in addition to modifying their local hydrodynamic and sedimentary surroundings, *C. gigas* beds have a clear wave attenuation effect. In recent wave flume experiments, *C. gigas* beds, consisting of 148 oysters per m^2 (reported to reflect densities of *C. gigas* beds occurring in the field), with an average height of 7.1cm and 3.1m length, reduced the height of waves generated within the flume by about 50% (wave height reduction estimated from graphs reproduced by Borsje *et al.* 2011). The study also showed that the *C. gigas* beds were more effective in wave attenuation than mussel (*Mytilus edulis*) beds (consisting of 1400 mussels per m^2 with an average height of 7cm).

5.2.6 Climate Regulation

In general, oyster reefs sequester carbon in the form of calcium carbonate within the accumulating shell matrix and thus contribute to global carbon budgets (Peterson *et al.* 2003).

Hickey (2008) investigated the carbon uptake (biosequestration) potential of cultivated *C. gigas* in South Australia and compared the result to those of forestry activities (afforestation or reforestation). Biosequestration is measured in tonnes of carbon per hectare per year (tC ha^{-1} yr^{-1}) and was calculated for five oyster farms in South Australia using two methodologies i) based on the stocking density of plate oysters (size 60-70mm) per hectare (which varied between farms) and ii) based on the projected number of plate oysters produced from the spat stocking density for one hectare. The results estimated an average carbon sequestration of 0.83 tC ha^{-1} yr^{-1} (range 0.7 to 1.26 tC ha^{-1} yr^{-1}) based on plate oyster stocking densities of between 168,000 to 302,000 per hectare. The second approach estimated an average of 9.03 tC ha^{-1} yr^{-1} based on spat stocking densities of 1.5 to 6.6 million per hectare with a spat survival rate of between 60-70%. The author noted that while the sequestration rate calculated using the first (plate oyster stocking density) approach was perhaps the more realistic figure, it had to be noted that one hectare could not sustain such large densities of oysters and in reality the

13 Organisms that change the abiotic environment by physically altering structure

hectare would constitute a mix of oyster sizes from spat to ready-to harvest oysters. The second methodology started with a 'hectare' of spat but would result in several hectares of plate oysters and hence the tonnes of carbon per hectare per year unit of measurement was not entirely accurate. However, it was concluded that the sequestration rate, based on plate oyster stocking density, was comparable with that of some plant species (e.g. *Eucalyptus porosa*, predicted above-ground carbon sequestration rate between 0.94-1.57 tC ha^{-1} yr^{-1} at a density of 1000 plants per hectare; Table 11, Hickey, 2008) but was eclipsed by other species (e.g. *Eucalyptus socialis*, which can absorb between 2.5 and 4.2 tC ha^{-1} yr^{-1} (Hickey, 2008 and references therein).

5.2.7 Biogeochemical Cycling

Dense beds of suspension feeding bivalves, such as oysters, are important for the cycling of nutrients between the bottom sediments and overlying water column, resulting in increased rates of nutrient and organic carbon turnover and an overall increase in the productivity of the ecosystem (Dame, 1996). In Chesapeake Bay (United States) it was suggested that the destruction of *C. virginica* oyster reefs resulted in reduced grazing of the phytoplankton in the water column, resulting in spring algal blooms that increased turbidity and the risk of anoxia, and an increase in summer zooplankton and pelagic predators such as jelly fish (Newell 1988; cited in Dame, 1996).

In a review of the ecosystem impacts of non-native oyster introductions, Ruesink *et al.* (2005) stated that little evidence on biogeochemical impacts of introduced oyster species was available. Most data was from cultivated oysters and should be applied tentatively to the impacts of naturalized populations. In terms of impacts, when cultivated at high densities, *C. gigas* generates biodeposits (faeces and pseudofaeces), which lead to reduced particle size and increased organic content in sediment (Castel *et al.* 1989, cited in Ruesink *et al.* 2005). These impacts are avoided at lower oyster densities or higher flow rates (Crawford *et al.* 2003, cited in Ruesink *et al.* 2005).

5.2.8 Water Purification

Suspension-feeding bivalves, such as oysters, are very effective at filtering vast amounts of water; thus, they can have large effects on the water columns in which they occur (Padilla, 2010). Feeding oysters remove suspended inorganic matter, phytoplankton, zooplankton and detrital particles, thereby reducing turbidity and improving water quality/clarity (Dame *et al.* 1996 cited in Peterson *et al.* 2003; Troost, 2010). For example, Hicks *et al.* (2004) and Cohen *et al.* (1999) have noted that the native oyster (*C. virginica*) in Chesapeake Bay, USA exerts control over water clarity (through filtering algae and sediment), which enables other species, such as seagrass, to flourish and hence can lead to increased areas of suitable habitat for many species of fish and birds.

An experimental study in the USA showed that two transplanted reefs (3 x 4m reefs constructed by relocating live oysters from adjacent areas) of the native oyster *C. virginica* reduced levels of suspended sediment and chlorophyll a concentrations (an indicator of phytoplankton biomass) downstream of the reefs in two small tidal creeks (Nelson *et al.* 2004). Grizzle *et al.* (2006) showed that *C. virginica* reefs removed up to 37% of particulate matter as water flowed over the reefs. A further study by Grizzle *et al.* (2008) indicated that restored oyster reefs (constructed of oyster shell with subsequent development from natural spat settlement of which *C. virginica* was the dominant bivalve species) should provide water-quality improvements soon after construction.

C. gigas has a large filtration capacity and filters on average 5 l/g/h although values up to 25 l/g/h have been recorded (Ren *et al.* 2000, New Zealand, cited in Nehring, 2006). A study in the USA, used published filtration rates to estimate the filtration capacity of three harvested bivalve species, including *C. gigas*, in Willapa Bay, Washington. Scaling up the annual yields of the bivalves, it was estimated that the native oysters (*Ostreola conchaphila*), which occurred historically in the bay, could have filtered $6x10^9$ l /day prior to exploitation and the two introduced bivalve species (*C. gigas* and *Ruditapes philippinarum*) were estimated to filter at least 9.7 $x10^9$ l /day (Ruesink *et al.* 2006). In Dutch estuaries, individual *C. gigas* have been shown to process larger volumes of water per unit time compared to other bivalve species (*Mytilus edulis*, *Cerastoderma edule* and *Ostrea edulis*) (Troost, 2010 and references therein). *C. gigas* is now the most dominant bivalve in the Oosterschelde estuary in the Netherlands (Troost, 2010) and expansion of *C. gigas* reefs in this estuary has increased the total 'stock' of filter feeding bivalves in the estuary and decreased the 'bivalve clearance time' (the time that is theoretically needed for the total filter-feeding bivalve biomass to filter particles from a volume of water equivalent to the total system volume) in the estuary from roughly 10 days in 1990 to 7 days in 2000 (Geurts van Kessel *et al.* 2003, cited in Troost, 2010).

Evidence was also found of the potential beneficial use of *C. gigas* for water purification of effluents from finfish farms. It has been proposed that suspension feeding organisms, such as oysters, can be used as 'biomechanical filters' in intensive fish or shrimp aquaculture, as an inexpensive option to improve water quality by removing particulate organic matter and dissolved nutrients from effluent waste water (Shpigel and Blaylock, 1991; Shpigel *et al.* 1993; Shpigel *et al.* 1997). Such biomechanical filters could reduce the impact of facilities on the surrounding ecosystem and the fish-farm itself (Lefebvre *et al.* 2000).

Studies have indicated that *C. gigas* is a suitable species for such biofiltration. For example, a study in Israel demonstrated that when *C. gigas* cultivation was integrated with an intensive fish pond aquaculture system, *C. gigas* functioned as a biological filter, removing excessive and dangerous levels of phytoplankton from the pond water. In addition, *C. gigas* growth was rapid, producing another commercial product within 14 to 18 months (although it must be noted that water temperature was 27ºC and hence not comparable to temperate regions) (Shpigel and Blaylock, 1991).

Perhaps more relevant to the UK, laboratory studies in France indicated that *C. gigas* are capable of filtering most of the faecal particles in effluents from land-based fish farms and that detrital waste from intensive fish-farming can contribute to the growth of the oysters (Lefebvre *et al.* 2000). Hence, such results support the concept of using oysters, including *C. gigas*, as biomechanical filters for treating fish-farm effluents in land-based or offshore aquaculture facilities (Lefebvre *et al.* 2000).

In addition, there is anecdotal evidence that individuals of *C. gigas* are used in tropical aquaria for 'natural water filtration'[14].

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14 E.g. http://www.marksfish.me.uk/index.php/Tips/Natural-Filtering-with-Oysters.html

5.2.9 Biological Control

Although this beneficial ecosystem process is 'assumed' to be universally provided by all habitats (Fletcher *et al.* 2011), the evidence below relates to the provision of this service specifically by *C. gigas* individuals (in laboratory experiments) and by *C. gigas* beds in the field.

A study in Denmark has shown that *C. gigas* can act as an alternate host, and a 'sink', for parasites of the mussel *Mytilus edulis* (Thieltges *et al.* 2009). Laboratory experiments showed that the presence of *C. gigas* (up to four individuals) acted as a decoy for the parasites, reducing the parasite load in the native mussel. The reduced infection rate and load of parasites in the native mussel was greatest at high densities of *C. gigas*. A field experiment, using constructed *C. gigas* beds, suggested that this density-dependant effect of reducing parasite load in *M. edulis*, was also relevant in the field. At present it is not known if, at very high densities, *C. gigas* could increase the overall parasite population, making it more persistent in the system (Thieltges *et al.* 2009).

5.3 Beneficial Ecosystem Services

Fletcher *et al.* (2011) and Herbert *et al.* (2012) identified evidence of native oyster beds (*Ostrea edulis*) providing the following beneficial ecosystem services:

- **Ecosystem Services**:
  - Food provision - Fisheries;
  - Food provision - Aquaculture;
  - Physical wellbeing - Natural hazard protection; and
  - Physical wellbeing - Environmental resilience.

Evidence relating to the provision of these services by oyster reefs in general, and *C. gigas* reefs (or reefs formed by a *Crassostrea* species) where available, is reviewed below.

Two additional beneficial ecosystem services are assumed to be universally provided by all habitats (Fletcher *et al.* 2011):

- Psychological / social wellbeing - Spiritual/cultural wellbeing; and
- Knowledge - Research and education.

For the purpose of this paper, these services have also been 'assumed' for all oyster reef habitats (including *C. gigas* reefs). However, specific evidence relating to the provision of knowledge through research on *C. gigas* was found and this information is presented below.

In addition to the beneficial ecosystem services described by Fletcher *et al.* (2011), this paper found evidence relating to the provision of additional beneficial services provided by *C. gigas* and this evidence is presented in the text below:

- Raw Materials - cultch material;
- Raw Materials - construction (shell material); and
- Psychological / social wellbeing - aquaria.

An additional beneficial service, Physical wellbeing - Regulation of pollution could also be inferred from evidence relating to the water purification processes provided by *C. gigas* (described in Section 5.2.8).

5.3.1 Food Provision - Fisheries (Wild Capture Fish and Shellfish)

Studies from the USA have shown that the abundance, biomass and species richness of finfish are higher at oyster reefs than in unstructured estuarine habitats (reviewed in Coen *et al.* 1999; Atlantic States Marine Fisheries Commission (ASMFC; 2007) both cited in Coen *et al.* 2007). For example, ASMFC (2007) documented the evidence showing that fourteen out of the twenty two ASMFC[15] managed fishery species utilised oyster habitat (including *C. virginica*) as a nursery ground, foraging ground and/or for shelter at some point in their life histories.

A recent study in the USA, indicated that breakwater reefs, constructed of oyster shell to protect eroding shorelines, provided substrate for oyster recruitment and harboured a more diverse community of fishes and mobile invertebrates than control areas without reefs (Scyphers *et al.* 2011). Among the fish and invertebrate species enhanced were several economically valuable crab and fish species. It should be noted that this evidence relates to constructed 'shell reefs', which subsequently supported oyster settlement and survival, rather than an existing biogenic reef.

Peterson *et al.* (2003) stated that oyster introductions may enhance production of other economically valuable fishery species. Based on empirical studies of natural and restored oyster reef habitat and unstructured sedimentary habitats in the USA, the authors estimated that 10 m^2 of restored oyster reef is expected to yield an additional 2.6 kg per year of production of fish and large mobile crustaceans (e.g. shrimp and crab) for the functional lifetime of the reef. A reef lasting 20 to 30 years would be expected to augment fish and crustacean production by a cumulative amount of 38 to 50 kg per 10 m^2. Although these production estimates were made for "oyster reef habitat", several of the studies on which the analysis was based, were conducted on *C. virginica* reefs. The authors stated that this positive effect on fisheries would only occur where the oyster introduction involved a reef building species and local species of fish responded positively to the habitat through enhanced recruitment and/or use of the substrate for refuge and foraging. The study also indicated that the beneficial effect of restored oyster reefs on fish and crustacean abundance was virtually complete within a year for reefs constructed in the summer. However, any inference that this service may also be provided by *C. gigas* reefs (i.e. by another reef forming oyster species of the Genus *Crassostrea*) must be made with caution. *C. gigas* forms predominantly intertidal reefs, and this may potentially reduce the value to fishery species because of the need for organisms to find alternative submerged refuge at low tide. Furthermore, it must be noted that structural differences between *C. gigas* and *C. virginica* reefs were highlighted by Padilla (2010), which may also influence the value of habitat (with respect to recruitment, refuge and foraging) provided to fishery species. Hence the inference about the potential provision of this service by *C. gigas* reefs is made with low confidence.

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15 The body that coordinates the conservation and management of nearshore fishery resources on the Atlantic coast in the USA.

5.3.2 Food Provision - Other Wild Harvesting

Multiple responses to the industry questionnaire sent to commercial oyster cultivators around the UK provided anecdotal information that 'recreational' harvesting of wild Pacific oysters had been observed in their locality.

5.3.3 Food provision - Aquaculture

C. gigas is a commercially cultivated species in the UK. The provision of this service through the aquaculture of *C. gigas* is covered in detail in Section 2 of this paper. One negative aspect of wild *C. gigas* on aquaculture was provided by Hily (2009) who stated that oyster farmers in France had to spend a lot of time and money clearing their farm structures and their cultivated oysters of wild settlement, with the farmers considering the proliferation of the wild populations as a threat to their industry. However, in some areas of France, wild settlement is a source of spat and beneficial to the industry (see Section 6.4.1).

5.3.4 Physical Wellbeing - Natural Hazard Protection

Fletcher *et al.* (2011) assumed that the beneficial erosion control process provided by oyster reefs would provide benefits for natural hazard protection. From the evidence presented in Section 5.2.3 (erosion control) it can be inferred that *C. gigas* reefs would also provide the beneficial ecosystem service of natural hazard protection.

5.3.5 Physical Wellbeing - Environmental Resilience

Fletcher *et al.* (2011) assumed that the beneficial climate regulation processes provided by native oyster reefs (*Ostrea edulis*), would improve environmental resilience. From the evidence presented in Section 5.2.6 (climate regulation) it can be inferred that *C. gigas* reefs, or cultivated stocks of *C. gigas,* would also provide the beneficial service of improving environmental resilience by reducing the impacts of climate change.

5.3.6 Physical Wellbeing - Regulation of Pollution

No direct evidence was found relating to the provision of this service by *C. gigas*, however, from the evidence presented in Section 5.2.8 (water purification), it can be inferred that *C. gigas* reefs, or cultivated stocks of *C. gigas* (e.g. when integrated with finfish farming), would provide the beneficial ecosystem service of regulation of pollution.

5.3.7 Psychological/Social Wellbeing – Tourism, Recreation and Sport

In a study of the effect of the proliferation of wild *C. gigas* on the Atlantic and Channel coastlines in France, and the interaction with human activities, Hily (2009) noted that the increase in oysters had a positive effect on non-professional hand-fishing (although no further detail was provided in the abstract of the Conference Proceedings). However, the author noted that there were negative effects for beach visitors and bathers because the oysters caused many cuts. Similarly in the Netherlands, Pacific oysters have been reported to interfere with the recreational use of the Oosterschelde estuary (Wolff and Reise, 2002, cited in Nehring, 2011) where the sharp shells have been reported to pose a risk of cut injuries to walkers and swimmers (Nehring, 2011). In the UK, anecdotal evidence was obtained that Pacific oyster reefs in the Blackwater estuary, and specifically their sharp shells, were affecting access to intertidal areas and damaging the bottom of boats (Sarah Allison, Essex Wildlife Trust, pers. comm.).

5.3.8 Psychological/Social Wellbeing - Aquaria

There is a small trade in Pacific oysters for placement in tropical aquaria (David Jarrad, SAGB, pers. comm.).

5.3.9 Knowledge - Research and Education

Although it has previously been assumed that all marine habitats and species provide the opportunity for research and education and hence the provision of knowledge that is of value to human society, the following areas of scientific research which specifically utilise *C. gigas* were identified. It should be noted that this evidence relates to the use of individuals of *C. gigas* and not *C. gigas* reefs:

- The use of *C. gigas* embryos in direct toxicity assessments of environmental water samples (Environment Agency, 2007). The 'embryo-larval development test' can be used in effluent screening and characterisation, monitoring effluent toxicity against limits, assessing impact of point source discharges on receiving waters and providing a general quality assessment of receiving waters (e.g. within monitoring programmes). The embryos used are produced from the sperm and eggs of conditioned adult male and female oysters. It should be noted that the larvae of other bivalve species can be used for toxicity assessments.
- The use of biological compounds extracted from *C. gigas* in studies investigating an 'environmentally friendly' biomimetic[16] approach to CO_2 sequestration (e.g. Lee *et al.* 2011).

5.3.10 Raw Materials - Cultch Material

A beneficial use of *C. gigas* in the aquaculture of other species was reported by the OSPAR Commission (2009) which stated that *C. gigas* shells are often used as cultch in the maintenance of *O. edulis* beds in Ireland. It should be noted that this is a beneficial service associated with the use of *C. gigas* shells and not *C. gigas* reefs or individuals and that it is assumed that the shell of other bivalve or mollusc species could also be used. However, it has been suggested that clean *C. gigas* shell may be the only realistic source of suitable settlement surfaces (cultch) for native oysters in most sedimentary estuaries. It has been suggested (expert opinion) that Pacific oysters are less susceptible to many oyster diseases compared to native oysters and as such their shells present a lower risk of being a disease vector (e.g. for Dutch shell disease) when used as cultch.

5.3.11 Raw Materials – Construction (Shell Material)

The following evidence relates to the use of oyster shell being used for the construction of 'artificial reefs' for the protection of shorelines. This evidence has not been included under 'natural hazard protection' because on deployment, the reefs were shell and not a biogenic

[16] The study of structure and function of biological systems as models for the design and engineering of materials.

(living) reef structure. However, over time, if oyster spat settlement, survival and growth were sufficient, these structures would become living reefs, potentially providing the beneficial process of erosion control (see Section 5.2.3) and the service of natural hazard protection (see Section 5.3.4). Hence, there is some 'overlap' between this service (raw materials for shell reef construction) and natural hazard protection (if oyster settlement and growth results in a sustainable living structure).

In the USA, experimentally constructed *C. virginica* reefs (25m x 1m x 0.7m shell reefs constructed in the intertidal) were shown to reduce shoreline retreat on low-energy shorelines, but not high-energy shorelines (Piazza *et al.* 2005). Oyster spat settled on the shell reef (at a peak rate of 9.5 $\pm$ 0.4 spat per shell) and spat grew at a rate of 0.5mm per day during the study. The authors concluded that the recruitment and growth rates of oyster spat on the shell reefs suggested the reefs were potentially sustainable over time and as such small fringing reefs may be a useful tool in protecting shorelines in low-energy environments. Another study in the USA, showed that shallow subtidal breakwater reefs (5m x 25m, constructed of oyster shell, species not stated), mitigated shoreline retreat by more than 40% at one study site (Scyphers *et al.* 2011). Again, oyster settlement and survival were observed on the shell reefs, with adult densities reaching more than 80 oysters per m^2 at one site.

It should be noted that while the evidence above relates to shell reefs constructed of a *Crassostrea* oyster species (leading to live oyster settlement), it is acknowledged that it is likely that shell from other bivalve or molluscs species could be used for artificial reef construction, for example, for the purpose of erosion control. However, while field trials have shown that oyster larvae will settle on virtually all hard substrate, significant differences exist in the setting density and subsequent survival of oyster spat on different substrates[17]. Hence, the extent to which the use of other shell may lead to a living (biogenic) reef and therefore provide the benefit of natural hazard protection is not clear and beyond the scope of this review.

In the UK, one industry questionnaire respondent indicated that there was a demand for Pacific oyster shell to use in the production of lime mortar. Lime is produced by burning a naturally occurring source of calcium carbonate (e.g. limestone, chalk or shells) to form quick lime which can then be mixed with water to form lime mortar which has a long history of being used in traditional buildings in Scotland (Historic Scotland, 2007). Anecdotal evidence suggests that oyster shell is one of the better materials to use in this process.

5.4 Summary of Beneficial Ecosystem Processes and Services Provided By *C. gigas*

Table 5.1a and b provides a summary of the beneficial ecosystem processes and services provided by oyster reefs in general, *C. gigas* reefs and/or *C. gigas* individuals. An indication of the quality of the evidence base is also provided. Other broad scale habitats and habitats of conservation importance which provide the same beneficial processes and services are also shown to highlight whether any of the benefits identified are unique to the Pacific oyster.

17 http://chesapeakebay.noaa.gov/oysters/oyster-restoration

Table 5.1a Summary of beneficial ecosystem processes provided by oysters in general and oysters of the genus *Crassostrea*

Beneficial Ecosystem Processes	Evidence Found for 'Oyster Reefs'	Evidence Found for *Crassostrea* sp.	Evidence Source and Quality.	Other Habitats* Which Provide the Same Benefit (Sources: Fletcher *et al.* 2011; Herbert *et al.* 2012)
Primary production	Indirect influence	*C. virginica*	Newell, 1988 (A3, USA)	n/a
Secondary production	✓	*C. gigas* (cultivated)	Ruesink *et al.* 2006 (A2, USA)	Assumed universal to all habitats
Larval/gamete supply	Assumed	Assumed	Assumed	Assumed universal to all habitats
Biological control	✓	*C. gigas* (beds)	Thieltges *et al.* 2009 (A2, Denmark)	Seagrass beds
Food web dynamics	✓	*C. gigas* (beds and cultivated)	Positive: Miossec *et al.* 2009 (A2, Europe), Diederich *et al.* 2005a (A2, Europe), Anecdotal (B1, UK) Negative: Troost, 2010 (A2, Europe);	Assumed universal to all habitats
Species diversification	Assumed	Assumed	Assumed	Assumed universal to all habitats
Genetic diversification	Assumed	Assumed	Assumed	Assumed universal to all habitats
Waste assimilation	x	x	n/a	n/a
Erosion control	✓	*C. gigas* (beds and constructed reefs)	De Vries *et al.* 2007 (B2), Borsje *et al.* 2011 (A2), Walles *et al.* 2011 (A2) (all Netherlands).	A2.1; A2.2; A2.3, A2.4; A2.5; A2.6; A2.7; A5.1; A5.2; A5.3; A5.4; A5.5; Blue mussel beds; File shell beds; Native oyster beds; Seagrass beds
Formation of species habitat	✓	*C. gigas* (reefs and cultivated)	Ruesink *et al.* 2006 (A2, USA)	All broad scale habitats and habitats of conservation interest
Formation of physical barriers	✓	*C. gigas* (beds)	Borsje *et al.* 2011 (A2)	A2.5, A3.1, A3.2, A3.3, Intertidal underboulder communities
Formation of pleasant scenery	x	x	n/a	n/a
Climate regulation	✓	*C. gigas* (cultivated)	Hickey, 2008 (A2, Australia)	A1.1; A1.2; A1.3; A2.3; A2.5; A5.6; Native oyster beds; sheltered muddy gravels

Beneficial Ecosystem Processes	Evidence Found for 'Oyster Reefs'	Evidence Found for *Crassostrea* sp.	Evidence Source and Quality.	Other Habitats* Which Provide the Same Benefit (Sources: Fletcher *et al.* 2011; Herbert *et al.* 2012)
Biogeochemical cycling	✓	Inferred	Inferred based on provision of this process by oyster reefs of other species (e.g. Dame, 1996; Fletcher *et al.* 2011) (B3)	A1.1; A1.2; A1.3; A2.2; A2.3; A2.4; A2.6; A2.7; A5.1; A5.2; A5.3; A5.4; A5.5; A5.6; Saline lagoons; blue mussel beds; File shell beds; Maerl beds; Native oyster beds; Seagrass; sheltered muddy gravels; Subtidal sands and gravels
Water cycling (regulation)	x	x	n/a	n/a
Water purification	✓	*C. virginica* (reefs) *C. gigas* (cultivated) *C. gigas* (individuals)	*C. virginica*: Nelson *et al.* 2004 Grizzle *et al.* 2006, 2008 (all A3, USA); *C. gigas*: Ren *et al.* 2000 (A2), Ruesink *et al.* 2006 (A2, USA); Geurts van Kessel *et al.* 2003, (B2, Netherlands); Shpigel and Blaylock, 1991; Shpigel *et al*. 1993; Shpigel *et al*. 1997, (all A2, Israel); Lefebvre *et al.* 2000 (A2, France) *C. gigas* (individuals): Anecdotal (B1, UK)	A2.5; A2.6; A2.7; A5.6; Blue mussel beds; Native oyster beds; Seagrass beds

Evidence quality: A1 = *C. gigas*, UK evidence, peer-reviewed; A2 = *C. gigas*, overseas evidence. peer-reviewed; A3 = *Crassostrea* species, overseas evidence, peer-reviewed.
B1 = *C. gigas*, UK evidence, non peer-reviewed; B2 = *C. gigas*, overseas evidence, non peer-reviewed; B3 = Crassostrea species, overseas evidence, non peer-reviewed.

* Habitats which provide the same beneficial processes and services are based on Fletcher *et al.* (2011) and Herbert *et al.* (2012). Only habitats which occupy a similar ecological position to *C. gigas* (i.e. intertidal and/or shallow subtidal, but not circalittoral or deep sea) are shown. For the evidence quality relating to these habitats please refer to the source documents. Broad scale habitats are represented as EUNIS Codes: A1.1 = high energy intertidal rock; A1.2 = moderate energy intertidal rock; A1.3 = low energy intertidal rock; A2.1 = Intertidal coarse sediment; A2.2 = intertidal sand and muddy sand; A2.3 = intertidal mud; A2.4 = intertidal mixed sediments; A2.5 = coastal saltmarsh and saline reedbeds; A2.6 = intertidal sediment dominated by aquatic angiosperm; A2.7 = intertidal biogenic reefs; A3.1 = High Energy infralittoral rock; A3.2 = Moderate energy infralittoral rock; A3.3 = Low energy infralittoral rock; A5.1 = subtidal coarse sediment; A5.2 = subtidal sand; A5.3 = subtidal mud; A5.4 subtidal mixed sediments; A5.5 = subtidal sediment dominated by aquatic angiosperm; A5.6 = sublittoral biogenic reefs.

Table 5.1b Summary of beneficial ecosystem services provided by oysters in general and oysters of the genus *Crassostrea*

Beneficial Ecosystem Services	Evidence Found for 'Oyster Reefs'	Evidence Found for *Crassostrea* sp.	Evidence Source	Other Habitats* Which Provide the Same Benefit (Sources: Fletcher *et al.* 2011; Herbert *et al.* 2012
Fisheries	✓	*C. virginica* (reefs)	Scyphers *et al.* 2011 (A3, USA); Peterson *et al.* 2003 (A3, USA)	All broad scale habitats; saline lagoons; blue mussel beds; estuarine rocky habitats; file shell beds; maerl beds; horse mussel beds; native oyster beds; seagrass beds; sheltered muddy gravels; subtidal sands and gravels
Other wild harvesting	✓	*C. gigas* (individuals)	Anecdotal (B1, UK)	A1.1; A1.2; A1.3; ; A2.2; A2.4; A2.6; A5.6; Fragile sponge and anthozoan communities; Intertidal underboulder communities; Sheltered muddy gravels; Subtidal sands and gravels
Aquaculture	✓	*C. gigas*	See Section 2	A2.7; A5.6; Saline lagoons; Blue mussel beds; Seagrass beds;
Fertiliser / Feed	x	x	n/a	n/a
Salt	x	x	n/a	n/a
Ornamental materials (shells)	x	x	n/a	n/a
Cultch material (shells)	✓	*C. gigas* (shell)	OSPAR, 2009 (A1, Ireland)	Assumed not unique to *C. gigas*
Construction material (shells)	✓	*C. virginica* (shells used for artificial reefs) *C. gigas* (shells used for lime mortar)	*C. virginica*: Piazza *et al.* 2005 (A3, USA); Scyphers *et al.* 2011 (A3, USA); *C. gigas*: Anecdotal (B1, UK)	Assumed not unique to *C. gigas*
Biofuels	x	x	n/a	n/a
Medicines	x	x	n/a	n/a
Natural hazard protection	Inferred	Inferred	Inferred based on provision of erosion control by *C. gigas* beds and constructed reefs in Europe	A2.1; A2.2; A2.4; A2.5; A2.7; A5.1; A5.2; A5.3; A5.4; A5.6; Blue mussel beds; Estuarine rocky habitats; file shell beds; intertidal underboulder communities; native oyster beds; seagrass beds

Beneficial Ecosystem Services	Evidence Found for 'Oyster Reefs'	Evidence Found for *Crassostrea* sp.	Evidence Source	Other Habitats* Which Provide the Same Benefit (Sources: Fletcher *et al.* 2011; Herbert *et al.* 2012
Environmental resilience	Inferred	Inferred	Inferred based on provision of climate regulation by cultivated *C. gigas* in Australia	A1.1; A1.2; A1.3; A2.6; A2.7; A3.1; A3.2; A3.3: A5.1; A5.2; A5.3; A5.4; A5.6; Native oyster beds; Sheltered muddy gravels; Subtidal sands and gravels
Regulation of pollution	Inferred	Inferred	Inferred based on provision of water purification by transplanted *C. gigas* reefs (USA), wild reefs (Europe), cultivated *C. gigas* (Israel and France) and individuals (UK)	A2.3; A2.5; A5.1; A5.2; A5.3; A5.4; A5.5; Blue mussel beds; Seagrass beds; Sheltered muddy gravels; Subtidal sands and gravels
Tourism / Recreation	x	*C. gigas* (reefs)	Positive impacts:Hily, 2009 (A2); Negative impacts: Hily, 2009 (A2), Wolff and Reise, 2002 (A2); Anecdotal (B1)	n/a
Spiritual/cultural wellbeing	Assumed	Assumed	Assumed	Assumed universal to all habitats
Aesthetic benefits	x	x	n/a	n/a
Nature watching	x	x	n/a	n/a
Aquaria	x	*C. gigas* (individuals)	Anecdotal (B1, UK)	A5.6
Research and Education	Assumed	*C. gigas* (embryos, compounds extracted from individuals)	Environment Agency, 2007 (A1, UK); Lee *et al.* 2011 (A2, Korea).	Assumed universal to all habitats. Other bivalve larvae can be used in toxicity testing.

Evidence quality: A1 = *C. gigas*, UK evidence, peer-reviewed; A2 = *C. gigas*, overseas evidence. peer-reviewed; A3 = Crassostrea spp., overseas evidence, peer-reviewed.
B1 = *C. gigas*, UK evidence, non peer-reviewed; B2 = *C. gigas*, overseas evidence, non peer-reviewed; B3 – Crassostrea spp., overseas evidence, non peer-reviewed.

* Habitats which provide the same beneficial processes and services are based on Fletcher et al. 2011 and Herbert et al. 2012. Only habitats which occupy a similar ecological position to *C. gigas* (i.e. intertidal and/or shallow subtidal, but not circalittoral or deep sea) are shown. For the evidence quality relating to these habitats please refer to the source documents. Broad scale habitats are represented as EUNIS Codes: A1.1 = high energy intertidal rock; A1.2 = moderate energy intertidal rock; A1.3 = low energy intertidal rock; A2.1 = Intertidal coarse sediment; A2.2 = intertidal sand and muddy sand; A2.3 = intertidal mud; A2.4 = intertidal mixed sediments; A2.5 = coastal saltmarsh and saline reedbeds; A2.6 = intertidal sediment dominated by aquatic angiosperm; A2.7 = intertidal biogenic reefs; A5.1 = subtidal coarse sediment; A5.2 = subtidal sand; A5.3 = subtidal mud; A5.4 subtidal mixed sediments; A5.5 = subtidal sediment dominated by aquatic angiosperm; A5.6 = sublittoral biogenic reefs. Note – the confidence level

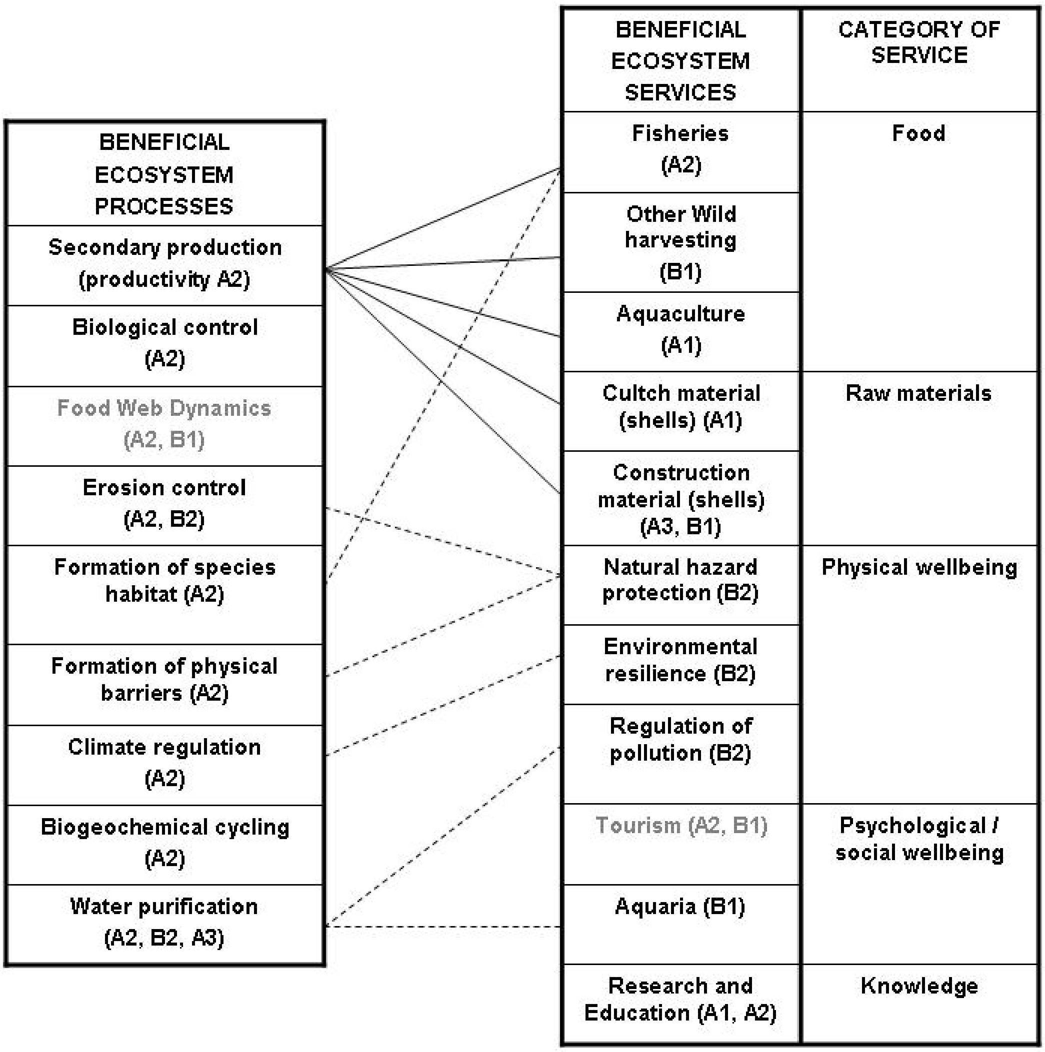
The summary tables show that, in general, oyster reefs provide nearly all of the categories of beneficial ecosystem processes provided by marine species and habitats (as categorised by Fletcher *et al.* 2011), except primary production, waste assimilation, formation of pleasant scenery and water cycling. However, through biogeochemical cycling, oyster reefs can increase the productivity of an ecosystem and therefore do indirectly influence primary production (see Section 5.2.7). Evidence was found of the provision of all of these beneficial processes by *C. gigas* reefs, except for biogeochemical cycling. As this process is a function of the feeding guild (filter feeder), filtration rate and the physiology of oysters, it can be assumed that this beneficial process would also be provided by high densities of *C. gigas* forming reefs. In all instances, evidence of the provision of beneficial processes relates to either constructed or wild reefs, or cultivated (and therefore relatively high densities) *C. gigas*, as opposed to individuals of *C. gigas*.

With respect to the provision of beneficial ecosystem services by *C. gigas*, there is evidence of provision of food from *C. gigas* reefs, via wild harvesting and aquaculture and the provision of raw materials from *C. gigas* shells (for cultch in the aquaculture of other species). Anecdotal evidence was found of the use of *C. gigas* shells in the production of lime mortar for use in traditional buildings in Scotland.

Additional evidence was found of the provision of raw material from *C. virginica* shells for the construction of artificial reefs (for coastal protection) and of enhancement of fisheries by 'generic' oyster reefs in the USA. Given that *C. gigas* reefs provide the same beneficial processes as oyster reefs, and in-particular the provision of structurally complex habitat and food web dynamics, it is likely that *C. gigas* reefs would also provide this beneficial service. However, Padilla (2010) noted that in general that *C. gigas* did not build reefs like *C. virginica* (although the differences between the reef structures were not described) and hence this assumption must be made in low confidence. In addition, as *C. gigas* forms predominantly intertidal reefs, this may potentially reduce the value to fishery species because of the need for organisms to find alternative submerged refuge at low tide. However, most of the studies on which Peterson *et al.* (2003) based their fish production estimates were intertidal, hence presumably this does not exclude the provision of this service by intertidal *C. gigas* reefs.

The only evidence of beneficial ecosystem services provided by individuals of *C. gigas* that was found was the provision of knowledge through research and education. In addition, anecdotal evidence was provided of *C. gigas* individuals providing the beneficial ecosystem service of psychological and social wellbeing through use in the aquaria trade.

It can be seen from the summary tables that all of the beneficial ecosystem processes and services identified as being provided by *C. gigas* reefs, or other *Crassostrea* oyster species, are also provided by a range of other broad-scale habitats and habitats of conservation importance that occur intertidally and subtidally. Hence none of the ecological or societal benefits that may arise from the development of *C. gigas* reefs or the use *C. gigas* individuals (in the case of research and education) are unique and are services that are already being provided to some extent. Whether the benefits from *C. gigas* reefs or cultivation would 'add' to existing benefits or 'replace' existing benefits to a greater or lesser degree depends on whether *C. gigas* displaces other habitats/species already providing these services. The likely impact of *C. gigas* on the beneficial ecosystem processes and services provided by other habitats is discussed in Section 5.6, based on the evidence presented in Section 4. The likelihood of any of the above beneficial processes or services being provided *C. gigas*, also depends on whether management measures are aimed at preventing the establishment of wild *C. gigas* reefs and this is discussed further in Section 7. This summary information is represented visually in Image 5.2.

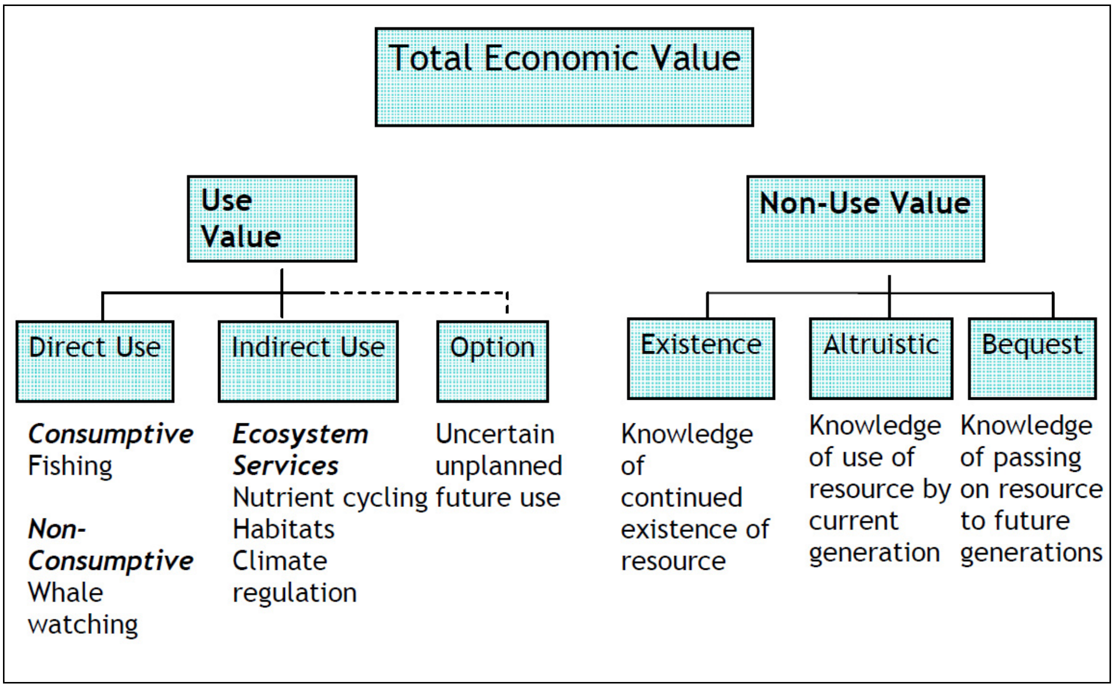


This summary is based on the information presented in Tables 5.1a and 5.1b and shows the relevance and reliability of the evidence indicating the provision of the processes and services (Evidence quality: A1 = *C. gigas*, UK evidence, peer-reviewed; A2 = *C. gigas*, overseas evidence. peer-reviewed; A3 = Crassostrea spp., overseas evidence, peer-reviewed. B1 = *C. gigas*, UK evidence, non peer-reviewed; B2 = *C. gigas*, overseas evidence, non peer-reviewed; B3 = *Crassostrea* spp., overseas evidence, non peer-reviewed). Processes or services shown in grey indicate where there is evidence of both positive and negative effects). The lines between the processes and services indicate that the process underpins the beneficial service. Solid lines indicate that it is known that the process underpins the beneficial service e.g. secondary production underpins all food related services; dashed lines indicate that the evidence relates to overseas paper, anecdotal evidence or an inferred linkage (based on Fletcher *et al.* 2011 and Herbert *et al.* 2012). Note, the linkages shown are not exhaustive but representative of the evidence sourced within this review.

Image 5.2 Summary of Beneficial Ecosystem Process and Services Provided by *C. gigas* Reefs and Individuals

5.5 Value of the Beneficial Ecosystem Services Provided by C. *gigas*

In order to provide a qualitative assessment of the beneficial ecosystem services provided by *C. gigas* reef / *C. gigas* individuals, the Total Economic Value (TEV) framework (shown in Image 5.3) has been used to classify the different types of economic value provided by ecosystem services.



(Source: Adapted from Defra, 2007)

Image 5.3 Total Economic Value Framework

Use value involves some interaction with the resource, either directly or indirectly (Saunders *et al.* 2010):

- Direct use value: Activities in the marine environment make direct use of an ecosystem service. These include consumptive uses (i.e. services extracted from the ecosystem such as fish and shellfish) and non-consumptive uses (i.e. the use of services without extracting any elements from the ecosystem such as recreation);
- Indirect use value: These are the values gained where individuals benefit from other ecosystem services or socio-economic activities supported by a resource rather than directly using it (Defra, 2007). Some supporting and regulating functions may be considered under indirect use. For example, it is possible to consider the role of the marine environment in slowing climate change as an indirect use; and
- Option value: The value that people place on having the option to use an ecosystem service in the future, when such use is not currently planned. A marine example is that of marine pharmaceuticals where species possessing currently unknown medicinal properties might be lost irreversibly through anthropogenic and/or natural processes, i.e. it is worth giving something up now in order to maintain the future option associated with potentially discovering useful medicine. There is debate over whether this is a true component of TEV.

Non-use value is associated with benefits derived simply from the knowledge that the natural resources and aspects of the natural environment are maintained. It is not associated with any personal use of a resource. For example, individuals may value knowing that specific ship-wreck sites would be protected, even though they have no intention to make any use of the site. Non-use value can be split into three parts:

- Altruistic value: Derived from knowing that contemporaries in the current generation can enjoy the goods and services related to the sea;
- Bequest value: Associated with the knowledge that marine resources will be passed on to future generations; and
- Existence value: Derived simply from the satisfaction of knowing that the sea, or specific bits of it, continue to exist, regardless of use made of it by oneself or others now or in the future.

The link between ecosystem services and TEV is that all services give rise to one or more (or all) components of TEV. The extent to which the contribution of each service to TEV can be valued separately depends on the type of evidence that is available. Economic value evidence comes from actual markets for the use values, or from non-market valuation methods. Valuation, in turn, depends on the information available on the ecosystem and qualitative and quantitative assessment of the services.

For each of the ecosystem services identified or assumed for *C. gigas* reefs or individuals, the relative potential for benefit (assessed qualitatively through judgement) and any existing data on value is summarised in Table 5.2. At the time of writing, the only beneficial ecosystem service for which valuation information is available from the literature and industry liaison, is the production of food via the aquaculture of *C. gigas* and the economic value of this service has been described in detail in Section 2.

Table 5.2 Qualitative assessment of the value of benefits provided by *C. gigas* reefs/individuals

Ecosystem Service	Relative Potential for Benefit	Value and Evidence
Fisheries	High	No data on the economic value of this service. However, restoration of oyster reef habitat (including *C. virginica*) lasting 20-30 years is expected to augment fish and crustacean production by 38-50 kg/10m^2 (Peterson *et al.* 2003).
Other wild harvesting	Medium	No data on the value of this service.
Aquaculture	High	Value at First Sale data. An estimate of GVA, calculated from landings data and industry liaison regarding production and supply chain prices is provided in Section 2.
Fertiliser / Feed	n/a	-
Salt	n/a	-
Ornamental materials (shells)	n/a	-
Cultch material (shells)	Medium	No data on the value of this service. Value may be derived from the market value of *O. edulis* oysters harvested from the cultched areas.
Construction material (shells)	Medium	No data on the value of this service. This value of this service will be encompassed by the ‘value’ of natural hazard protection if reefs become biogenic structures.

Ecosystem Service	Relative Potential for Benefit	Value and Evidence
Biofuels	n/a	-
Medicines	n/a	-
Natural hazard protection	High	No market value. Borjse *et al.* (2011) noted that a positive side effect of using oyster reefs for coastal protection may be a reduction of costs compared to traditional engineering solutions.
Environmental resilience	High	No market value. Value will be related to the option / bequest value of the service arising from biosequestration of CO_2 by oysters.
Regulation of pollution	High	No data. Value will be related to avoidance costs of current water treatment. *C. gigas* is a suitable biofiltration species for treating fish-farm effluents in land-based or offshore aquaculture facilities (Shpigel and Blaylock, 1991; Shpigel *et al.* 2007; Lefebvre *et al.* 2000). No evidence relating to the economic value of this service found.
Tourism, recreation and sport	Low	No data. Value could be derived from 'willingness to pay' studies*. In France, an increase in oysters was reported to have had a positive effect on non-professional hand-fishing (Hily, 2009). However, negative effects reported on beach tourism. May interfere with traditional uses of beaches (if major reefs develop).
Spiritual/cultural wellbeing	Low	No data. Value could be derived from 'willingness to pay' studies*.
Aesthetic benefits	n/a	
Nature watching	n/a	-
Aquaria	Low	No data. Value may be derived from the market value of C.gigas–individuals sold within the aquaria industry.
Research and Education	Medium	No data. However, value could be assessed from expenditure.

Grey Rows Represent beneficial services not identified as being provided by *C. gigas* reefs or individuals;
* Willingness to Pay can be estimated through economic analysis of actual market data, of behavioural data from revealed preference studies, or of data from stated preference surveys.

5.6 Impacts of *C. gigas* on Beneficial Ecosystem Processes and Services of Other Habitats

Where a body of evidence exists for potential impact of *C. gigas* on beneficial ecosystem processes and services of habitats of conservation importance (see Section 4), this is discussed in the following section.

5.6.1 Littoral Rock (EUNIS Code A1.1, A1.2, A1.3)

Following Fletcher *et al.* (2011), Beneficial ecosystem processes identified for these habitats are: *Primary production, secondary production, larval/gamete supply, food web dynamics, formation of habitat, species diversification, biogeochemical cycling and climate regulation*.

Beneficial ecosystem services identified are: *fisheries, wild harvesting, environmental resilience, recreation, research and education*.

Impacts on Beneficial Ecosystem Processes

Wild settlement of *C. gigas* and formation of reefs will clearly increase secondary production, through rapid growth. The impact on primary production and interaction with seaweeds is unclear, however high water filtration capacity will consume large quantities of phytoplankton that may be locally significant, though evidence for this is weak. There are clear competitive and facilitative interactions with other species, and feeding interactions. At high levels of settlement and reef formation, the rocky habitat and ecosystem is transformed. Impacts on biogeochemical cycling and climate regulation are inferred from linkages in Fletcher *et al.* (2011).

Impacts on Beneficial Ecosystem Services

Wild harvesting for *C. gigas* on rocky shores is not as commonly observed or recorded as it is on sediment shores, although oysters have been removed from hard artificial substrata, presumably for human consumption. Seed oysters from rocky habitats may be collected for use in aquaculture. Recreational use of rocky shores may be negatively affected, due to sharp shells causing access problems and/or cutting feet.

5.6.2 Intertidal Sediments (EUNIS Code A2.2, A2.3, A2.4)

Following Fletcher *et al.* (2011), beneficial ecosystem processes identified for these habitats are: *primary production, secondary production, larval/gamete supply, food web dynamics, formation of habitat, species diversification, erosion control, biogeochemical cycling and climate regulation*.

Beneficial ecosystem services identified are: *fisheries, wild harvesting, regulation of pollution, nature watching and natural hazard protection, research and education*.

Impacts on Beneficial Ecosystem Processes

At high levels of settlement and reef formation, there is evidence for competitive interactions with mussels including exclusion and reduced growth (see Section 4.2.6.1 for detailed review) However, although there is little evidence for food web dynamics, *C. gigas* appears to facilitate settlement of other species and increase species diversity. There is as yet little evidence however that erosion control of sediments may be improved as a result of colonisation by oysters. At lower tidal levels, the habitat is transformed by high levels of settlement and reef formation. In a similar way to mussel beds, in the Wadden Sea, Pacific oysters appear to locally raise the sediment surface and their persistent nature may contribute to the long-term stabilisation of the beds (Wolff and Reise, 2002; Commito *et al.*, 2008) and reduce erosion. In the Wadden Sea, oyster reefs may thus locally protect the intertidal habitat of native bivalves and other invertebrate fauna, and the intertidal foraging grounds of species at higher trophic levels such as shorebirds (Troost, 2010).

Impacts on Beneficial Ecosystem Services

Wild harvesting for bait and other bivalves may be negatively affected although there is little evidence for this. However, high settlement and reef formation does provide income for recreational harvesters and fishermen in Essex and the Thames estuary. Bird watching may be negatively affected locally, both through displacement of bird feeding habitat by formation of oyster reefs and by disturbances from harvesting, although there is no evidence for this. High settlement and reef formation, if continuous and over a significant area, may protect mudflats from erosion. There are negative impacts with beach tourism and recreation. For example, in the Netherlands, Pacific oysters have been reported to interfere with the recreational use of the Oosterschelde estuary (Wolff and Reise, 2002, cited in Nehring, 2011), where the sharp shells have been reported to pose a risk of cut injuries to walkers and swimmers (Nehring, 2011). Similar negative effects for beach visitors and bathers have been reported in France (Hily, 2009) Enhanced regulation of pollution is strongly inferred from the evidence presented for native oysters (*O. edulis*) linkages in Fletcher *et al.* (2011).

5.6.3 Blue Mussel (*Mytilus edulis*) Beds

Beneficial ecosystem processes provided by Blue mussel beds are (Fletcher *et al.* 2011): *primary production, secondary production, larval/gamete supply, food web dynamics, formation of species habitat, species diversification, erosion control, biogeochemical cycling and water purification*.

Beneficial ecosystem services provided by Blue mussel beds are: *fisheries, aquaculture, fertiliser/food, natural hazard protection, environmental resilience and regulation of pollution*.

Evidence for Impact on Beneficial Ecosystem Processes

There is evidence that high *C. gigas* settlement and reef formation will displace native Blue mussel beds, either by direct competition or by pre-emption - by preventing them from re-establishment on former mussel beds which may have declined due to other factors. However *C. gigas* reefs can also facilitate settlement of mussels in areas where they have previously declined; these mussels tend not to grow large due to competition and remain deep in the interspaces between oysters. Functionally, there is high similarity in the types of ecosystem processes provided by oysters and Blue mussels, although direct quantitative comparison has not been found; it could be inferred that more complex food web dynamics and other species interactions might be associated with oyster beds due to greater species richness, although there is no direct evidence for this.

Evidence for Impact on Beneficial Ecosystem Services

Where *C. gigas* has replaced or colonised Blue mussel beds, there is likely to be direct impact of *C. gigas* on ecosystem services provided by Blue mussel beds, especially to fisheries, wild harvesting and aquaculture (Wijsman *et al.* 2008). Where *C. gigas* competes with Blue mussel beds, then productivity of Blue mussels will be reduced, at least on a local if not a landscape scale. However, other ecosystem services provided by Blue mussels, such as environmental resilience, regulation of pollution and natural hazard protection are also provided by *C. gigas* and therefore, functionally there may not be a net loss of these services should *C. gigas* totally replace Blue mussels, in fact these services may increase to some degree, although so far there is little evidence for this.

5.6.4 *Sabellaria alveolata* Reefs

Beneficial ecosystem processes provided by *S. alveolata* reefs (Fletcher *et al.* 2011) are *secondary production, formation of species habitat, formation of physical barriers*.

Beneficial ecosystem service provided by *S. alveolata* reefs is *wild harvesting*.

Evidence of Impact on Beneficial Ecosystem Processes

There is evidence of impact on habitat formation of *S. alveolata* through the colonisation and overgrowth by *C. gigas*. The evidence for impacts on food web dynamics and species interactions between the fauna of *S. alveolata* reefs and that associated with *C. gigas* settlement is suspected, but so far unproven.

Evidence for Impact on Beneficial Ecosystem Services

Ironically, the settlement of accessible and easily extracted *C. gigas* on *S. alveolata* reefs have made the structures more attractive to wild harvesting (for oysters) than previously, and this is causing habitat damage (Desroy *et al.* 2011).

5.6.5 Seagrass Beds

The beneficial ecosystem processes provided by seagrass beds (Fletcher *et al.* 2011) are *primary and secondary production, food web dynamics, larval/gamete/seed supply, formation of habitat, erosion control, biogeochemical cycling and water purification*.

The beneficial ecosystem services provided are *fisheries, fertiliser and feed, natural hazard protection, regulation of pollution, climate regulation, tourism and nature watching*.

Evidence for Impacts on Beneficial Ecosystem Processes

In the UK, the seagrass *Zostera noltii* can grow at higher tidal levels than *Z. marina* and *C. gigas* could potentially overlap more with this species, should it begin to colonise these areas. The evidence for impact of *C. gigas* on beneficial ecosystem processes of *Zostera* is variable. While high filtration rates of *C. gigas* have been shown to improve water clarity and seagrass primary production and habitat formation at moderate to high densities of *C. gigas*, there is suppression of growth and production. There is also evidence of impact on biogeochemical processes of *Zostera*, however *C. gigas* colonisation will also have an impact on these processes through high water filtration rates. In the UK, it is likely that there will be a greater impact on *Z. noltii* beds. Impacts on other ecosystem processes are inferred from linkages in Fletcher *et al.* (2011).

Evidence for Impacts on Beneficial Ecosystem Services

There is no direct evidence of impact of *C. gigas* on ecosystem services provided by *Zostera* beds, however it can be inferred from Fletcher *et al.* (2011) that there will be impacts on fisheries, regulation of pollution (which may however be more productive and greater with *C. gigas* than seagrass), climate regulation, tourism, research and education and nature watching.

5.6.6 Summary of Impacts of *C. gigas* on Beneficial Ecosystem Processes and Services Provided by Other Habitats

Table 5.3 provides a summary of the impact of *C. gigas* on the habitats of conservation importance (described in Section 4). Impacts have only been summarised where a sufficient evidence base exists. Inferred impacts, from evidence presented in Section 4 and Fletcher *et al.* (2011, in relation to native oyster beds) has not been included.

Table 5.3 Potential impacts of wild *C. gigas* settlement at high densities on ecosystem services provided by habitats.

Habitat	Beneficial ES	Impact	Reason	Evidence
Littoral rock	Tourism and recreation	Negative	Sharp shells	Inferred from impacts on soft sediment shores
	Aquaculture and other wild harvesting	Positive	Collection of seed oyster	Expert opinion
Littoral sediment	Tourism and recreation	Negative	Sharp shells;	Wolff and Reise (2002; Europe), Hily (2009; France)
	Fisheries and other wild harvesting	Positive	Fishing and wild harvesting	See Section 5.3.1 and Appendix A, Blackwater Estuary Case Study.
Blue mussel beds	Aquaculture, fisheries and other wild harvesting	Negative	Trophic competition, displacement	Wijsman *et al.* 2008
Sabellaria alveolata reefs	Wild harvesting	Negative	Trampling and use of tools to collect oysters	Desroy *et al.* 2011

ES Ecosystem Service

6. Legal Issues Concerning the Status of the Pacific Oyster in the United Kingdom

6.1 Background

In the UK, policy-making in areas such as food production, food safety and the environment is a shared competence with the European Commission and, as a result, much of the legislation originates from the Commission and applies equally to all Member States. Under European Law the protection of the seas and its resources around the coast of the UK puts obligations on both competent authorities and operators.

The Pacific oyster *Crassostrea gigas* is a non-native species in Europe and yet both its wild status and the assessment of risk to native ecosystems posed by its rapid colonisation as an invasive species varies between EU Member States. As the main pathway of entry is from the cultivation of Pacific oysters for food, this review has a focus on legislation that applies to the aquaculture industry. However, most of the legislation applies to all pathways of introduction including translocation via shipping and boat movements.

In terms of food production, operators wishing to harvest live bivalve molluscs from either an aquaculture facility or wild stock must meet the requirements of hygiene legislation[18]. In addition, when setting up an aquaculture facility or renewing an existing license, harvesters and competent authorities must consider any environmental implications of the proposed activity; competent authorities must be satisfied that all potential risks to the environment have been considered and risks minimized.

These requirements apply equally to all commercially exploited bivalve molluscs. However, when the exploitation of Pacific oyster is being considered, the legislative requirements become more complex. The harvesting of Pacific oyster in Member States is complicated by the fact that this species is non-native to EU waters and has also been classed as an invasive species[19]. As such, a series of legislative instruments aiming to address the issue of non-native species and intending to control and reduce the impact of these organisms in the environment becomes relevant and must be considered before any activity is established or renewed.

There are two potential commercial activities involving harvesting of Pacific oysters: the harvesting of wild settlements and the harvesting of Pacific oysters maintained in aquaculture. The status of Pacific oyster as an invasive species will mainly impact operators wishing to establish or renew licences for aquaculture sites rather than the harvesting of wild settlements, unless the intention is to re-lay for on-growing[20]. The impact of the current legislative framework in the use of non-native species in aquaculture is discussed in the following sections, together with an analysis of whether the provisions may affect the culture of Pacific oysters in the UK. Some legislation also has an impact on the harvesting of wild stocks, for example the Habitats Directive, and this is highlighted when relevant.

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18 Regulation (EC) No 852/2004, 853/2004 and 854/2004 (as amended)

19 DAISIE European Invasive Alien Species Gateway, 2.Crassostrea gigas . Available from: http://www.europe-aliens.org/speciesFactsheet.do?speciesId=50156 (accessed July 2012)

20 In Northern Ireland, licences issued under the provisions of the Fisheries Act (NI) 1966, as amended, are not time limited or renewed. They may however be amended, suspended or revoked

This chapter of the report begins with a review of relevant European legislation and policy. Where European legislation has been transposed into UK law, this is noted. The report then outlines relevant legislation and policy in the UK. A key issue for the Pacific oyster is its differing legal status in other European Member States, discussed in Section 6.4, with the main focus upon interpretation in France. The importance of the precautionary principle emerges strongly through the European and UK sections of the Chapter, therefore the manner in which the EU recommends the precautionary principle to be applied is discussed. Clear conclusions that arise from this evaluation are identified at the end of this section.

6.2 European Legislation and Policy

The issue of invasive non-native species has been high on the European Commission agenda for some time. Due to the wide ranging impact of non-native species, provisions for these are included in many EU policies, in particular legislation aimed at the protection of ecosystems and sustainable use of natural resources. Specifically, several EU legislative instruments are in place to ensure the protection of the marine environment against the impact of non-native species. Those most important to Pacific oyster are:

- Water Framework Directive (2000/60/EC);
- Habitats Directive (92/43/EEC);
- Marine Strategy Framework Directive (2008/56/EC); and
- Council Regulation concerning use of alien and locally absent species in aquaculture (Regulation No. 708/2007).

In addition to the legislation listed above, the forthcoming EU Strategy on Invasive Species is discussed as it will form an important component of the policy framework affecting the Pacific oyster. The Ballast Water Regulations, which although not just applicable to the EU, are also discussed briefly. Whilst consideration of European legislation and policy relevant to the Pacific oyster is important, it should be noted that European legislation is binding on Member States not operators. Operators are only obliged to operate under the terms of the licence issued by the Member State (or their representative). If an operator is operating within the terms of their licence they are not liable for the state failing to meet its obligations under European law. However, the conditions of licences are shaped by Member State interpretation of EU legislation and it is possible that in the future, Member States may wish to further renegotiate the terms of the licence with individual operators to reflect revisions to the interpretation of European law. Any renegotiation of the terms of a licence driven by changes to European legislation is likely to have an impact on the industry - for example, the industry might experience a cost implication. It is important therefore that any measures are proportionate to the level of risk that exists in a specific area at a specific time.

6.2.1 Water Framework Directive

The Water Framework Directive[21] has synergies with the Marine Strategy Framework Directive (reviewed in Section 6.2.3) as both share goals related to the status of aquatic ecosystems. Transposition into national law in the UK occurred through The Water Environment (Water

[21] Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy

Framework Directive) (England and Wales) Regulations 2003 (Statutory Instrument 2003 No. 3242) for England and Wales; the Water Environment and Water Services (Scotland) Act 2003 (WEWS Act) for Scotland and The Water Environment (Water Framework Directive) Regulations (Northern Ireland) 2003 (Statutory Rule 2003 No. 544) for Northern Ireland.

The Water Framework Directive (WFD) aims to improve and protect the chemical and biological status of surface waters throughout a river basin catchment from rivers, lakes and groundwaters through to estuaries (transitional) and coastal waters to one nautical mile out to sea (three nautical miles in Scotland). The Directive requires Member States to achieve good ecological and chemical status of their water bodies by 2015, and sets out a process for Member States to follow to achieve this target. A key part of the implementation of the Directive is the production of River Basin Management Plans which (amongst other things) will contain measures to achieve good ecological and chemical status. As a result, the Directive has important implications for shellfisheries, both in terms of advantageous environmental protection measures and in terms of regulation of detrimental impacts arising from shellfisheries. Indeed, the WFD will replace the Shellfish Waters Directive, which is being repealed at the end of 2013.

Invasive species are generally recognized as posing a risk to achieving good ecological status under the WFD. Invasive species are not specifically mentioned in the text of the WFD, but are implied in Annex V as a potential anthropogenic impact on the environment. This view has been taken by the competent authority in the UK[22] and this interpretation is supported by the fact that invasive species are clearly identified in guidance developed by the Commission to support Member States in implementing the WFD in a harmonized fashion across Europe[23]. The presence and impact of invasive species has indeed been taken into consideration in all current river basin management plans in the UK[24]. It should be noted that this interpretation of the Directive has been taken in the UK but not necessarily in other Member States.

In practice, an interpretation of the WFD is that the presence of an invasive species such as Pacific oyster in a site may preclude the area from attaining a high status water body designation. A general definition of ‘high’, ‘good’, and ‘moderate’ ecological status of water bodies is presented in Table 1.2 in Annex V of the WFD, in which ‘high status’ describes the best attainable status. Waters achieving a status below moderate are defined as “poor or bad” (Annex V, Section 1.2). The definition applied to a specific water body is determined by the level of alteration of the water body arising from anthropogenic activity. ‘High status’ is defined where there are “no, or only very minor, anthropogenic alterations” whereas ‘good status’ is defined where “low levels of distortion resulting from human activity” are evident in undisturbed water bodies (Annex V, Table 1.2). Given these constraints, a competent authority may prohibit the transfer of oysters to an area in order to maintain or improve the status of a particular site. It should be noted, however, that the presence of Pacific oysters *per se* does not necessarily mean that action will be taken, as it is the impact of the species on the habitat and not the presence that is a concern.

22 RLTC_Alien Species_T_v2.0, Environment Agency. Technical assessment method
23 Common Implementation Strategy for the WFD: Guidance document no. 3, Analysis of Pressures and Impacts.
24 http://www.environment-agency.gov.uk/research/planning/33106.aspx

At present, the UK Technical Advisory Group (UKTAG) has classified Pacific oyster as a high impact species on the WFD 'high impact list'[25] (formerly known as the 'red list'[26]). However, a proposal has been made to move Pacific oyster from the UKTAG high-impact list to a proposed 'moderate impact' list. The proposal to establish a moderate impact list has been made in order to improve consistency between (some of) the results of the GB Non-Native Species Secretariat (NNSS) risk assessment[27], which has a 'moderate impact' category and the classifications presented in UKTAG lists. The proposal for a moderate impact list was included in the public consultation on the revised WFD environmental standards which closed on 8 June 2012. Assuming there are no issues arising from the consultation, it is expected that UKTAG will approve the movement of the Pacific oyster from the high impact to the moderate impact list.

The implications of this reclassification of the Pacific oyster for the application of the WFD are potentially significant, as the UKTAG guidance on WFD classification describes the way that the presence of established non-native species should be used to determine the ecological classification of water bodies. However, this procedure only relates to species on the high-impact list. Thus, taking Pacific oyster off the high-impact list means that it will no longer be used to downgrade the classification of water bodies. A further implication is that the 2013 round of WFD risk assessments to determine which water bodies are at risk of failing their WFD environmental objectives (for example, by failing to reach good ecological status by 2015) will not feature the Pacific oyster as they will only examine species on the high-impact list. In contrast, a single all-Ireland 'high impact' invasive species list exists (the amber list)[28]. The Pacific oyster is included on this list. This means that the presence of Pacific oyster in a WFD waterbody in Ireland could lead to the downgrading in ecological status of the site if they were shown to be impacting on the site.

Finally, there is provision within Article 4(5) of the WFD that allows Member States to achieve less stringent environmental objectives for specific bodies of water when:

> "they are so affected by human activity, as determined in accordance with Article 5(1)[29], or their natural condition is such that the achievement of these objectives would be infeasible or disproportionately expensive, and all the following conditions are met:
>
> (a) the environmental and socio-economic needs served by such human activity cannot be achieved by other means, which are a significantly better environmental option not entailing disproportionate costs;
>
> (b) Member States ensure:
>
> - for surface water, the highest ecological and chemical status possible is achieved, given impacts that could not reasonably have been avoided due to the nature of the human activity or pollution;

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25 http://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/Classification%20of%20Alien%20species_Final_010709.pdf

26 This is no longer referred to as the 'red list' to avoid confusion with red lists for conservation purposes.

27 The risk assessments are commissioned by the GBNNSS but are conducted by an independent expert.

28 See: http://invasivespeciesireland.com/toolkit/risk-assessment/amber-list-established-species/

29 Article 5(1) describes states that members states should produce, for each river basin district, an analysis of its characteristics, a review of the impact of human activity on the status of surface waters and on groundwater, and an economic analysis of water use.

- for groundwater, the least possible changes to good groundwater status, given impacts that could not reasonably have been avoided due to the nature of the human activity or pollution.

(c) no further deterioration occurs in the status of the affected body of water;

(d) the establishment of less stringent environmental objectives, and the reasons for it, are specifically mentioned in the river basin management plan required under Article 13 and those objectives are reviewed every six years."

Article 4(5) states that where conditions (a)-(d) are satisfied, Member States may argue that it would not be feasible, or would be too expensive to achieve the standards of the WFD due to the existing human activity or natural condition of a water body. However, it is debateable whether or not this would apply to locations containing a Pacific oyster population and has not yet been legally tested.

6.2.2 Habitats and Birds Directive (Natura 2000 Network)

The aim of the Habitats Directive (92/43/EEC) is to "contribute towards ensuring biodiversity through the conservation of natural habitats and of wild fauna and flora in the European territory of the Member States to which the Treaty applies". In the UK the Directive has been transposed into national laws by means of the Conservation (Natural Habitats, & c.) Regulations 1994, the Conservation (Natural Habitats, & c.) Regulations (Northern Ireland) 1995[30], Offshore Regulations 2007, and most latterly the Conservation of Habitats and Species Regulations 2010. These are known as the Habitats Regulations. Under the Habitats Directive, within Special Areas of Conservation (SACs), Member States are required to draw up conservation objectives. These apply to all the natural habitat types of Annex I and the species of Annex II present on the sites and may involve "management plans and statutory, administrative or contractual measures, which aim to achieve the general objective of the Directive" and should "take account of economic, social and cultural requirements and regional and local characteristics".

The aim of the Habitats Directive is related to that of the Birds Directive (92/43/EEC), as a result of which, there has been a gradual fusing of selected measures within both Directives. This alignment reflects the establishment of the Natura 2000 network, which is a single network of protected sites made up of SACs designated under the Habitats Directive and Special Protection Areas (SPAs) designated under the Birds Directive. Article 6 of the Habitats Directive is particularly important and has replaced measures within the Birds Directive, therefore articles 6.2, 6.3, and 6.4 of the Habitats Directive apply to all Natura 2000 sites.

Article 6.2 of the Directive states "Member States shall take appropriate steps to avoid, in [Natura 2000 sites], the deterioration of natural habitats and the habitats of species as well as disturbances of the species for which the areas have been designated, in so far as such disturbance could be significant in relation to the objectives of this directive". The Habitats Directive Article 6 Guidance Note (European Commission, 2000) stresses that this article

30 It should be noted that the Department of the Environment are planning to bring forward amendments to address deficiencies in the NI Regulations, as regulations 43 and 44 do not currently apply to fishing or aquaculture activities.

requires an anticipatory approach to conservation meaning that it is not acceptable to wait until disturbance or deterioration has occurred before acting. Therefore the article "should be interpreted as requiring Member States to take all the appropriate actions which it may reasonably be expected to take, to ensure that no significant deterioration or disturbance occurs" (European Commission, 2000, p. 25). For example, as a result of Pacific oyster colonization a transformation of habitat may occur from 'rocky reef' to 'non-native oyster reef'. This is likely to be interpreted as significant impact and change to 'unfavourable condition' as the original feature and associated biotopes has been replaced by a species that is classified as non-native and not naturalized in the UK.

Measures to address existing activities that are likely to cause a deterioration or disturbance to the habitats or species listed under Annex I and II in the Directive, should, if necessary, be contained within a site-specific management plan. These measures are intended to address the predictable ongoing impacts on a site. Where a new project or plan is proposed, this must be subjected to an 'Appropriate Assessment' of its likely implications on the relevant site's conservation objectives. A definition of plan and project is not provided in the Directive, and has been subjected to considerable debate. However, the Habitats Directive Article 6 guidance note (p.33) states that:

- "The term 'project' should be given a broad interpretation to include both construction works and other interventions in the natural environment";
- "The term 'plan' also has a broad meaning, including land-use plans and sectoral plans or programmes but leaving out general policy statements.

In advice to CCW on assessing projects under the Habitats Directive, Tyldesley (2011) comments that "projects are not limited to activities that only involve physical construction. Changes of use of land or water, or variations in the way in which things are done, can comprise 'projects' in this context". This interpretation is supported by the Waddenzee judgement[31] in which the European Court of Justice (ECJ) ruled that the granting of a licence for the mechanical dredging of cockles in the Waddenzee was a 'plan or project' in the meaning of the Directive (Tyldesley, 2011). Upon completion of an Appropriate Assessment, a plan or project can only proceed if it has been ascertained that it will not adversely affect the integrity of the site or if a series of further stringent tests are met. In the Waddenzee judgement, the ECJ ruled that the degree of certainty was satisfied "where no reasonable scientific doubt remained as to the absence of such effects".

This raises the question over whether aquaculture activities are considered to be a plan or project. In accordance with the Waddenzee judgement, any activity that has the potential to give rise to significant effects (or for which the possibility of significant effects cannot be excluded) could constitute a plan or project. This tends to only be triggered when consent is required for a new or revised activity, but could theoretically be triggered by a statutory nature conservation agency at any time. Accordingly, where new or modified aquaculture activity is proposed, it is normally considered to be a plan or project, which triggers an Appropriate

31 The National Association for the Conservation of the Waddenzee and the Netherlands Association for the Protection of Birds v The Secretary of State for Agriculture, Nature Conservation and Fisheries and the Cooperative Producers' Association of Netherlands Cockle Fisheries, ECJ Case C-127/02, 7th September 2004, the Waddenzee ruling.

Assessment. The outcome of the assessment will determine if an aquaculture licence is granted for a new or revised aquaculture activity and if so, the specific terms of the licence.

As the Pacific oyster is an non-native species in Europe it is subject to Article 22(b) of this Directive which requires Member States to "ensure that the deliberate introduction into the wild of any species which is not native to their territory is regulated so as not to prejudice natural habitats within their natural range or the wild native fauna and flora and, if they consider it necessary, prohibit such introduction". Given the medium level of risk currently assessed as associated with the introduction of the Pacific oyster (Sewell *et al.* 2010), combined with the application of the precautionary principle, the Habitats Directive plays a significant role in the governance of Pacific oyster in the UK.

Where wild settlement of a non-native species occurs on a site protected under the Natura 2000 network, such as following successful spawning as a result of climate change, the Directive does not offer guidance on the legal response. At present, no cases have been heard to clarify this situation concerning the burdens this places on relevant authorities. Measures to control the impact of Pacific oyster colonisation from specific sites are discussed in Section 7, however, the potential for the long term ecological success of such approaches is currently uncertain. There are also considerations related to the economic impact of any such measures where wild settlement is being commercially exploited.

6.2.3 The Marine Strategy Framework Directive

The Marine Strategy Framework Directive (MSFD) came into force in 2008 and was transposed into UK legislation in July 2010[32]. Although not seeking identical outcomes, the MSFD and WFD have comparable objectives, with the MSFD focused on the achievement of Good Environmental Status in marine waters, and the WFD aiming to achieve Good Ecological and Good Chemical Status in river basins from MHW (Springs) out to 1nm in England, Wales and Northern Ireland, and 3nm in Scotland. The range of the MSFD is broader than the WFD as it covers more components of biodiversity and pressures not included in the WFD, including noise, litter, most commercial fish species and some other aspects of biodiversity (e.g. marine mammals) (HM Government, 2012).

In order to overcome the spatial and objective overlap between the two directives, the MSFD explicitly makes it clear that in coastal waters, MSFD is only intended to apply to those aspects of Good Environmental Status which are not already covered by the WFD (HM Government, 2012)[33]. Effectively therefore, for the purposes of Pacific oyster cultivation, the MSFD has no practical relevance as it has no implications within 1nm in England, Wales and Northern Ireland, and 3nm in Scotland, which are the areas which currently contain all Pacific oyster sites. This approach assumes that Pacific oyster cultivation has no impact on offshore ecosystem function and there is no evidence that is does. It is conceivable that at some point in the future, Pacific oyster cultivation may take place beyond 1nm, at which point the MSFD will apply.

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32 2010 No. 1627Environmental Protection Marine Management The Marine Strategy Regulations 2010

33 It should be noted that it is possible that the MSFD may set more ambitious targets under Descriptor 2 (non-indigenous species) which could impose additional obligations compared to the WFD.

6.2.4 Council Regulation Concerning Use of Alien and Locally Absent Species in Aquaculture

Regulation (EC) No 708/2007[34] [35] came into force in October 2011 and is directly relevant to the issue of introduction and movement of Pacific oysters. Article 4 of the Regulation confers a general obligation for Member States to implement measures to avoid adverse effects to biodiversity "which may be expected to arise from the introduction or translocation of aquatic organisms and non-target species in aquaculture and from the spreading of these species into the wild" (EC708/2007). This regulation is also linked to the MSFD, in particular to Descriptor 2, concerning non-native species.

The regulation makes provisions for the introduction of non-native species and translocation of locally absent species in the European Community. In the text of the Regulation, the Commission recognises the economic benefit that species such as Pacific oysters have provided for the aquaculture industry and aims to optimise the benefits of such activities while protecting the environment. Aquaculture species for which special provisions are made are listed in Annex IV. As such, the administrative burden is reduced by exempting operators wishing to introduce oysters for use in aquaculture from most of the requirements of the regulation, in particular, the need for a risk assessment. However, the regulation allows individual Member States to still restrict the use of this species, but places the burden on the competent authority instead of the operator to justify the restrictions by means of an environmental risk assessment. Interestingly, the Regulation does not cover translocations of non-native species within a Member State unless there is a risk to the environment.

Taken together, the wording of the regulation allows the competent authority, in each Member State, discretion on whether to impose additional restrictions on the use of Pacific oysters in aquaculture by requiring risk assessments to decide on the need for restrictions. In other words, for species in Annex IV, individual Member States can determine how measures within the regulations are to be implemented. On the other hand, allowing the translocation of Pacific oysters to and within the UK without considering potential risks can put the UK at risk of infraction proceedings and the individual operator may also be financially liable[36].

6.2.5 EU Strategy on Invasive Species

In December 2008, the EU adopted a Communication outlining policy options to better address the problems caused by invasive species. The text of the European Communication noted that although existing legislation provides part of the solution to the invasive species problem, "at present there are no mechanisms to support harmonisation or consistency of approaches between neighbouring countries or countries in the same sub-region" and that "the fragmented measures in place are unlikely to make a substantial contribution to lowering the risks which invasive species pose to European ecosystems" (Commission of the European Communities, 2008, p3). The policy options ranged from business as usual to dedicated new legislation.

34 Council Regulation (EC) No 708/2007 of 11 June 2007 concerning use of alien and locally absent species in aquaculture (OJ L 168, 28.6.2007, p. 1)

35 Statutory Instruments 2011 No. 2292 Aquaculture, England And Wales The Alien and Locally Absent Species in Aquaculture (England and Wales) Regulations.

36 It should be noted that in early 2012 a stakeholder consultation on the Alien and Locally Absent Species in Aquaculture Regulations (Northern Ireland) 2012 was conducted. The final Regulations are due to be published in mid 2012.

Following a consultation process, the favoured option was to introduce a 'dedicated legislative instrument on invasive alien species'. Consultation on the detailed measures included in the new legislative instrument closed on 12 April 2012. The final form of the legal instrument and its implications for Pacific oyster cultivation and harvesting is therefore unclear at this time. However, the emphasis on harmonisation and consistency of approach to invasive species may address national-level inconsistencies between Member States with respect to the Pacific oyster.

6.2.6 International Convention for the Control and Management of Ships Ballast Water and Sediments, 2004

Although not restricted to Europe, the Convention is potentially important as ballast water is a credible route for the spread of Pacific oyster to the UK, therefore the effective control of ballast water discharge is relevant to Pacific oyster settlement. Within the International Convention for the Control and Management of Ships Ballast Water and Sediments, Ballast Exchange Regulations require ships to conduct all ballast water exchanges at least 50 nm and whenever possible 200 nm from land and at least 200m depth. The Convention will enter force 12 months after ratification by 30 States. To date 28 States representing 25-43% of world merchant tonnage have ratified the Convention.

6.3 National Policy And Legislation

6.3.1 Assessment of Risk Arising From Non-native Species in the UK

The NNSS manage the production of risk assessments to support the national-level response to invasive species under the terms of the Invasive Non-native Species Strategy, 2008. NNSS risk assessments are "carried out by independent experts and these are reviewed by one peer reviewer and the risk analysis panel of experts. Following this process risk assessments are available for comment before being finalised" (NNSS, online[37]). A NNSS risk assessment of the Pacific oyster published in 2010 concluded that it posed a 'medium' risk level[38]. The risk assessment outcome is important as it identifies Pacific oyster as a potentially problematic species in meeting commitments to 'good ecological status' under the WFD and 'good environmental status' under the MSFD. A discussion of the environmental risk presented by invasive Pacific oysters in included within Section 4 of this report.

It is noted by NNSS that the "completed risk assessments are not final and absolute" but that they are "an assessment based on the evidence available at that time. Substantive new scientific evidence may prompt a re-evaluation of the risks and/or a change of policy" (NNSS, online). The mechanism to trigger such a re-evaluation is the presentation of significant new evidence to the Non-native Risk Analysis Panel[39], who would then determine if the risk assessment should be revised. If the risk assessment was revised, this could be used as the evidence base for making a case to revise the status and treatment of the Pacific oyster under existing policy and legislation. It should be noted that the current designation of the Pacific oyster as 'high impact' on the WFD 'red list' (see earlier discussion on WFD in Section 6.2.1) is

37 https://secure.fera.defra.gov.uk/nonnativespecies/home/index.cfm
38 A definition of 'Medium risk' was unavailable.
39 The (NNRAP) is a core group of risk assessment experts who provide advice on risk associated with non-native species.

unrelated to its designation of 'medium' by the NNNS, as the two assessment procedures are unrelated.

6.3.2 National Nature Conservation Legislation

Within the UK the treatment of non-native species issues is being taken forward on a bio-geographic basis, in which the administrations in England, Scotland and Wales work together and Northern Ireland work with the Republic of Ireland. The Wildlife and Countryside Act 1981 (as amended) is the main piece of legislation concerning nature conservation in England, Wales and Scotland. In Northern Ireland equivalent provisions are contained in the Wildlife (Northern Ireland) Order 1985 (as amended) and Nature Conservation and Amenity Lands (Northern Ireland) Order 1985.

Sites of Special Scientific Interest (SSSI) are designated and protected through the Wildlife and Countryside Act 1981 (as amended) in England, Wales and Scotland, while in Northern Ireland, Areas of Special Scientific Interest (ASSI) are designated under the Environment Order (NI) 2002. It is the responsibility of statutory nature conservation agencies to designate an SSSI or ASSI. The arrangements for the designation of a SSSI or ASSI are broadly the same in England, Wales, Scotland and Northern Ireland (although in the latter case, specific wording of arrangements differs), with implementation undertaken by the relevant statutory body. For example in England, Natural England has a duty to designate (notify) a SSSI when it is "of the opinion that an area of land is of special interest by reason of its flora, fauna or geological or physiographical features" (Natural England, online). When a SSSI is notified, a SSSI notification package is produced that includes a list of operations requiring Natural England's consent[40]. If a new operation is proposed within a SSSI (either by the owner or a third party) a 'written notice' must be submitted to Natural England that describes the proposed operation(s) and applies for consent to undertake the activity. Natural England then assesses the notice by considering the likely impact of the operation(s) on the special features of the SSSI concerned. The possible responses to the written notice are: 1) to issue consent; 2) to issue consent with conditions; or 3) to refuse consent. Where consent is refused, the operation may not legally be undertaken.

If, following the award of consent, it is subsequently discovered that a consented activity is causing unacceptable harm to the special interest of a site, a voluntary agreement will be sought with the consent holder to re-negotiate the terms of the consent or site management scheme. Where this approach is unsuccessful, Natural England may give notice that it is withdrawing or modifying consent for the damaging operation. Any Natural England decisions concerning consenting of operations within an SSSI may be subjected to appeal to the Secretary of State. It should be noted that SSSIs are only de-notified in exceptional cases, and sites that have been illegally damaged, mismanaged, or neglected, will not be de-notified.

Section 14 of the Wildlife and Countryside Act 1981 directly relates to non-native species and seeks to prevent the release into the wild of certain plants and animals which may cause ecological, environmental, or socio-economic harm. Specifically, Section 14 prohibits the introduction into the wild of any animal of a kind which is not ordinarily resident in, and is not a regular visitor to, Great Britain in a wild state, or any species of animal or plant listed in

40 Or the consent of another public body provided that the other body has formally consulted Natural England

Schedule 9 to the Act. Although untested, Defra and Welsh Assembly Government (2010) guidelines on the interpretation of the Act present the view that a species should be considered 'ordinarily resident' when:

> "the population should have been present in the wild for a significant number of generations and should be considered to be viable in the long term".

As this definition applies to the Pacific oyster (furthermore the Pacific oyster is not listed in Schedule 9 of the Act), Section 14 of the Act does not apply to the Pacific oyster therefore it is not an offence to release Pacific oyster in Great Britain under this Act as interpreted by the Defra and Welsh Assembly Government (2010). The Act also notes in Section 16(4) that any provisions related to the release of a species "do not apply to anything done under and in accordance with the terms of a licence granted by the appropriate authority" thereby further supporting the view that as long as an operator operates within licence terms, there is little or no likelihood of prosecution.

In Northern Ireland, Article 15 of The Wildlife (Northern Ireland) Order 1985 (as amended by the Wildlife and Natural Environment Act (Northern-Ireland) 2011) states that:

> "if any person releases or allows to escape into the wild any animal which:
>
> (a) is of a kind which is not ordinarily resident in and is not a regular visitor to Northern Ireland in a wild state or is a hybrid of any animal of that kind; or
>
> (b) is included in Part I of Schedule 9,
>
> he shall be guilty of an offence".

The Pacific oyster is not included in Part I of Schedule 9 in either the original or amended (2011) form, therefore it is excluded from this legislation.

6.4 Interpretation of Legislation and Policy in Other Member States

Some information is available that indicates that other Member States which are large producers of Pacific oysters (e.g. France, Ireland and Netherlands) take a different stance in terms of the legislative controls that apply to this invasive species[41]. There appears to be different interpretations of the provisions of the regulations, different methodologies used and different perceptions of risk when it relates to the farming of Pacific oysters in the different Member States.

Generally, the issue of harmonisation between Member States has been touched on several times by the Commission and is the subject of a substantial programme of work within the EU, leading to the formation of working groups and issuing of guidance documents which, although having no legal standing, attempt to harmonise how Member States deal with common issues. The handling of invasive species such as the Pacific oyster within the Member States appears

41 M Syvret, A Fitzgerald and P Hoare. 2008. Development of a Pacific oyster aquaculture protocol for the UK – technical report. Seafish.

to be a case where harmonisation of approach between the different Member States is yet to be achieved[42].

A substantial body of work is already being undertaken by the Commission and Member States to attempt to harmonise the handling of invasive species within the WFD. The first step recognised that the way Member States deal with non-native species within the WFD is not always a coherent approach. All Member States recognise and agree that non-native species constitute an important pressure and alter the composition of biological communities. Therefore Member States are in agreement that invasive species must be taken into account when implementing the WFD. However, the current procedures used by Member States to take into account invasive species data in ecological status classification are extremely varied. Although in some states, the presence of a non-native species such as Pacific oyster in a site may preclude the site from attaining a high status water body, other Member States are of the opinion that high status water bodies could be allowed to have established non-native species provided no impacts on the biological community are detected[43]. A search of the literature revealed three different approaches currently in use in Member States: (i) water body classified using pressure-based classification tools: classification then modified in an additional step based on invasive species; (ii) water body classified, then modified depending on the abundance or percentage coverage of invasive species; or (iii) a separate risk assessment for invasive species is undertaken: biopollution indices published alongside water classification, but not affecting classification. These different approaches lead to different practical outcomes and will determine very different decisions on whether the farming of Pacific oysters would be allowed in a site.

It appears that the UK has been the main driver in identifying the risk invasive non-native species pose under the WFD while other Member States seem to take the view that no additional assessment of invasive species are necessary, on the assumption that impacts of invasive species are detected in existing instruments (ECOSTAT 2008). Overall, it appears clear that the implementation of the WFD is yet to be fully harmonized across all Member States, including the degree to which monitoring requirements from other directives are integrated during the implementation of the requirements of the WFD[44].

The Commission also recognises the need for consistency and comparability in the implementation of the MSFD by all Member States, having set up a working group to address this issue[45]. Meetings of this group have indicated that there are differences between Member States on the monitoring for non-native species under the WFD and efforts should be made to obtain a coherent approach under the two Directives. In reality, even if harmonization guidelines are agreed and adhered to, it is not unexpected that different Member States come to different conclusions regarding the same species as the physical environment, habitats and species assemblages in different regions can be different. Unfortunately the evaluation of risk

42 Shine, C., Kettunen, M., Genovesi, P., Essl, F., Gollasch, S., Rabitsch, W., Scalera, R., Starfinger, U. and ten Brink, P. 2010. *Assessment to support continued development of the EU Strategy to combat invasive alien species*. Final Report for the European Commission. Institute for European Environmental Policy (IEEP), Brussels, Belgium.

43 ECOSTAT workshop on alien species and the EC Water Framework Directive. 2-3 April 2008, Bordeaux, France.

44 Report from the commission to the European parliament and the council

45 Working group on good environmental status of the MSFD common implementation strategy.

to the environment is at times a subjective issue as it relies on expert evaluation of available evidence.

6.4.1 Case Study: Legal Status of Pacific Oyster in France

In France, a reproductive population of Pacific oyster was observed in the late 1990s in the southern Loire estuary (southwest Atlantic coastline of France). The more recent colonization by the species on the Brittany coast is therefore a new manifestation of a pre-existing condition. In the southwest Atlantic coast of France, management practices have been applied to Pacific oyster since the 1980s aimed at reducing wild populations which were competing with cultivated oysters and therefore limiting growth. These practices included the destruction of wild oyster beds in the Bay of Marennes Oleron, Arcachon Bay and Bay of Bourgneuf. In the southwest Atlantic areas, local decrees were enacted to regulate the quantity of oyster harvested by the public to limit market competition and to manage 'sanctuaries' for spat settlement for the oyster industry (P Goulletquer, (IFREMER), pers. comm.). In Brittany, the growing incidence of Pacific oyster has prompted similar management practices, aimed at:

1) regulating the new sources of spat in the Bay of Brest (north Brittany) which is displacing commercial spat supply from the Marennes Oleron; and

2) managing the impacts of wild populations on recreational and tourism activities.

The decree is enacted by the local Maritime Affairs administration on behalf of the relevant Départment or group of Départments, although any such decree must be consistent with State or European regulations. In effect, this is similar to a regional scale by-law in UK. An important difference between the southwest Atlantic and the Brittany areas is that Brittany has a greater incidence of rocky shores, making management measures considerably more difficult to implement. The rocky habitats are likely to include protected rocky reef sites designated as SACs or SPAs, yet it is thought that no management action is currently being taken to address the impact on these features.

As pointed out by Syvret *et al.* (2008), France has no plans to include a non-native component to the WFD, has adopted the Pacific oyster as a naturalised species and has applied the Aquaculture Alien Species regulation to 'long used' non-native species. In summary, the interpretation of existing EU legislation in France relevant to the Pacific oyster is considerably different from that in UK, as in this context France adopts an approach that is less prescriptive than the UK, which enables it to overcome many of the legislative problems experienced in UK.

6.5 The Precautionary Principle

The precautionary principle is the context in which scientific uncertainty about the environment and consequent implications for its management should be considered. This is specifically the case for the environmental impact of the Pacific oyster, about which considerable scientific uncertainties exist. Decisions and legal interpretations regarding the control and licensing of the Pacific oyster should therefore be considered with reference to the precautionary principle. In broad terms, the precautionary principle describes a way of approaching policy and decision making in the absence of full scientific certainty. It is discussed in both the Rio Declaration and CBD. The Rio Declaration Principle 15 notes that:

> "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".

The CBD preamble states that:

> "where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat".

In 2000, the European Commission issued a Communication on the precautionary principle intended to discuss the application of the principle in decisions related to the containment of risk (Commission of the European Communities, 2000). This includes, but is not restricted to, decisions related to the environment. The Communication states that:

> "Recourse to the precautionary principle presupposes that potentially dangerous effects deriving from a phenomenon, product or process have been identified, and that scientific evaluation does not allow the risk to be determined with sufficient certainty".

Article 5.1 of the Communication describes the factors triggering recourse to the precautionary principle. It is noted that:

> "the precautionary principle is relevant only in the event of a potential risk, even if this risk cannot be fully demonstrated or quantified or its effects determined because of the insufficiency or inclusive nature of the scientific data. It should however be noted that the precautionary principle can under no circumstances be used to justify the adoption of arbitrary decisions".

It is further noted in Article 5.1.1 that:

> "Before the precautionary principle is invoked, the scientific data relevant to the risks must first be evaluated. However, one factor logically and chronologically precedes the decision to act, namely identification of the potentially negative effects of a phenomenon. To understand these effects more thoroughly it is necessary to conduct a scientific examination".

The Communication further asserts that:

> "A scientific evaluation of the potential adverse effects should be undertaken based on the available data when considering whether measures are necessary to protect the environment, the human, animal or plant health (Article 5.1.2).

In Article 6.2, the Commission discusses the factors that trigger the application of the precautionary principle. It states that:

> "An assessment of the potential consequences of inaction and of the uncertainties of the scientific evaluation should be considered by decision makers when determining whether

> to trigger action based on the precautionary principle. All interested parties should be involved to the fullest extent possible in the study of various risk management options that may be envisaged once the results of the scientific evaluation and/or risk assessment are available and the procedure be as transparent as possible".

The Commission note that where action is deemed necessary, measures based on the precautionary principle should be, *inter alia* proportional to the chosen level of protection, non-discriminatory in their application, consistent with similar measures already taken, based on an examination of the potential benefits and costs of action or lack of action, subject to review, in the light of new scientific data, and capable of assigning responsibility for producing the scientific evidence necessary for a more comprehensive risk assessment. The proportionality of the action is stressed by the Commission as particularly important.

6.6 Proportionality

Proportionality is defined as "tailoring measures to the chosen level of protection" (Commission of the European Communities, 2000, p.3).

Article 6.3.1 of the Communication states that:

> "Measures based on the precautionary principle must not be disproportionate to the desired level of protection and must not aim at zero risk, something which rarely exists".

Continuing:

> "Risk reduction measures should include less restrictive alternatives which make it possible to achieve an equivalent level of protection, such as appropriate treatment, reduction of exposure, tightening of controls, adoption of provisional limits, recommendations for populations at risk, etc".

There is a clear socio-economic risk associated with the disproportionate application of the precautionary principle, which can result in 'gold-plating'. The Commission defines gold-plating as "exceeding the requirements of EU legislation when transposing Directives into national law"[46]. Gold-plating can take many forms including extending the scope of a Directive, setting standards that are higher than those required by the regulation (for example, aiming at zero risk) or not utilizing derogations which, for example, reduce burdens upon businesses. It is possible that because the UK species risk assessment is comparatively high, relative to other EU Member States, any imposition of severe measures applied to the aquaculture industry to limit production may be considered by the Commission and stakeholders as gold-plating.

6.7 Conclusion

In view of the current EU legislative framework, competent authorities have some leeway on how to implement the legislation relating to the harvesting and aquaculture of the Pacific oyster and management of wild settlement. The wording of the Directives and Regulations aims to

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46 Commission Communication: Review of the "Small Business Act" for Europe, COM(2011) 78 final, 23 February 2011

give Member States the ability to adapt the requirements of the legislation to the particular conditions present in their waters and in particular, the demonstrable impact and risk that Pacific oysters are seen to pose in the environment. In other words, most of the provisions of the regulations in particular are obligatory and must be adopted by Member States but some measures are left to individual Member States who can choose whether to impose additional restrictions. However, all decisions related to the imposition of additional measures to be fully justified and based on available data and a proportionate assessment of the risk that the Pacific oyster poses to biodiversity and the good environmental status of coastal areas.

In the UK, allowing the aquaculture of Pacific oysters in all sites that can support the species is unlikely to be considered a viable option as there is a risk that wild settlement may have a significant impact on sites designated for their nature conservation interest. However, following local risk assessment and adoption of agreed measures, allowing aquaculture activities on a site may be possible should the risk be considered low.

It is likely that in some designated sites, perhaps where management is considered too costly, inappropriate or has failed, wild settlement of Pacific oysters may have a negative impact on site integrity and potentially lead to the loss of, or prevent achievement of, favourable condition for features within a site. This would put both the UK at risk of infraction proceedings and operators at risk of facing legal proceedings, if deemed to have contravened the conditions of their licence.

Where Pacific oyster cultivation is shown to cause negative impacts that threaten biodiversity and where it can be demonstrated that control or eradication would not be practical, cost-effective or successful, competent authorities of Member States can argue that it need not be undertaken. There is however no legal precedent for this. Taking the most protective approach and completely restricting the aquaculture of Pacific oysters in the UK, although reducing the risk of downgrade of environmental status due to invasive species, may be considered ‘gold plating’ of the legislation if limited evidence is available on which to base this approach. Furthermore, it will also have negative economic consequences for a potentially valuable resource. The way the legislation is interpreted and implemented will most certainly depend on the evidence for impact of the Pacific oyster on UK ecosystems and whether their presence is a threat to obtaining or maintaining favourable conditions within designated sites. Despite the agreement that Pacific oysters are an invasive non-native species, the current EU legislation does not prohibit further aquaculture activities for this species. Instead, it attempts to ensure the resource is used in a sustainable fashion.

7. Mitigation for Negative Impacts of Wild Settlement in the UK

7.1 Measures

The risk assessment for *Crassostrea gigas* (Sewell *et al.* 2010) states that the species could be invasive and have an impact on sensitive habitats and species in the UK. From the evidence reviewed in Section 4, dense intertidal 'reef' aggregations can certainly have an impact on the habitat and, although higher species diversity has been recorded within reefs that have colonised both sediment and rocky shores (e.g. Brittany), the habitat has been either locally or regionally transformed. Biogenic reef habitats, particularly mussels and *Sabellaria* species, appear vulnerable to displacement and damage at high settlement densities (e.g. Gulf of St Malo). Yet there is little evidence that subtidal habitats have been impacted directly by *C.gigas* colonisation, although, as with use of mobile gears for harvesting other species, disturbance to subtidal habitats may occur through dredging the seabed for oysters. Impact on seagrass habitats is more uncertain; some studies show that reduced water turbidity as a result of high filtration stimulates growth, whereas other investigations show evidence of displacement and reduced shoot density.

The impact on species and biotopes in any region or designated site is likely to be determined by:

- the density of *C.gigas* settlement;
- the frequency of settlement;
- the geographical extent of settlement;
- the types of habitats present; and
- the magnitude of other natural and anthropogenic disturbances, such as wild harvesting, that might result in patchy, less homogenous settlement.

Although Pacific oysters appear vulnerable to invertebrate predators (Syvret *et al.* 2008; Troost, 2010), parasites (Troost, 2010), cold winters (Buettger *et al.* 2011) disease (Cotter *et al.* 2010; EFSA, 2010; J Bayes, SeaSalter Oysters, pers. comm.) and smothering by estuarine sediments (N. Miezkowska, pers. comm.), mitigation measures may still be considered necessary to manage environmental risks to species and habitats, as a result of increased settlement caused by rising temperatures and climate change. In the Wadden Sea, in spite of high mortality in recent cold winters (Buettger *et al.* 2011), settlement continues to occur on shells and reef structures, which are highly persistent and will last for years (K. Reise, pers. comm.).

As with all invasive non-native species, 'prevention', 'eradication' and 'control' are the three main types of measures aimed at limiting species negative impacts. This section outlines the evidence base for the impact of practical measures and options available to the industry and regulating bodies to reduce risk of adverse effects of wild settlement. Although the discussion broadly follows options for 'prevention', 'eradication' and 'control', issues concerning the use of triploid oysters, which has been a concern for the industry for some time, are discussed as a separate sub-section.

7.1.1 Temperature Risk Thresholds

It is generally accepted that wild settlement is dependent on the attainment of critical water temperature thresholds for oyster gametogenesis and spawning (Miossec *et al.* 2009; Duterte *et al.* 2010). The frequency at which temperature thresholds are now reached has increased within the past two decades (Duterte *et al.* 2010). The UK is committed to reducing global warming and emissions by 2020 and is a signatory of the Kyoto Protocol. However, temperatures are predicted to remain above thresholds for spawning with wild settlement likely to be frequent in Wales and Northern Ireland by 2040 (Maggs *et al.* 2010 - confidence low).

Based on an extensive review of the effect of temperature on *C. gigas* reproduction, together with historical and predicted trends in UK sea and air temperatures, Syvret *et al.* (2008) undertook a detailed regional analysis of likely reproductive periods of Pacific oysters around the UK. They concluded that the use of *'degree days'* (the annual number of days when temperatures meet thresholds for conditioning (gametogenesis), spawning[47] and recruitment[48]), for assessing 'wild settlement risk' is a useful initial screening tool when planning for, or re-licensing, *C. gigas* aquaculture developments. However, the authors point out that such a tool would only be operable and acceptable should high-resolution temperature data be available on-site, due to extremely local variation in temperature profiles. Uncertainty with respect to acclimation to local temperatures, physiological adaptation and duration of the larval development phase in response to available nutrition is highlighted and reviewed. Nevertheless, calculations of available degree-days over a time-series of several years were shown to accurately predict that wild settlement would be more prevalent in the south-east of England, as the temperature thresholds were more frequently met and exceeded in this region. Similarly, the north of England and Scotland were currently unlikely to have high risk of wild settlement due to lower temperatures.

The authors argue that this risk-based management might be incorporated in to a protocol that would be acceptable to industry and regulators.

The authors state that for southern and south-east England the degree-days necessary for settlement are not currently limiting and that it is *unlikely that changes to current or future husbandry and management practises will have any significant impact on the ability of Pacific oysters to continue successfully recruiting in this region.*

However, it was also pointed out that there were notable anomalies with the observed data; although, based on temperature data and calculations of degree-days, settlement and recruitment are predicted to occur regularly at some sites in southern England, wild settlement is seldom seen. These areas include Poole Harbour and the Fleet in Dorset. It is possible that these localities are particularly resilient due to local hydrodynamic flushing characteristics or biotic interactions, preventing spat survival.

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47 600 degree days for conditioning and spawning (>18^{o}C assumed trigger for spawning).
48 825 degree days required to achieve larval metamorphosis.

7.1.2 Marine Planning and Husbandry

The rate and extent to which a potentially invasive species might become established within a water body system will depend on the 'invasion pressure', i.e. the frequency of introduction, the size and fecundity of introduced breeding stock, abiotic characteristics of the water body, especially hydrodynamics, and the biotic resilience of the receiving system.

It might be possible to manage the scale of aquaculture operations and introduce husbandry restrictions within each water body to ensure that, should temperature thresholds for gametogenesis and larval growth be exceeded, the majority of any larvae produced succumb to predators and/or are flushed out in the open sea, where there will be further mortality and the probability of establishment considerably lower.

The flushing characteristics, water residence time and temperature regime of associated water bodies would need to be assessed before consideration of how to manage the operation. The SMILE project (Sustainable Mariculture in Northern Irish Lough Ecosystems) utilised hydrodynamic models and data on plankton food availability and cultivated shellfish biomass to model the aquaculture carrying capacity of five Irish Loughs. With known water residence times of UK estuaries and harbours, these models could be adapted to investigate larval transport and dispersal[49] and identify water bodies that, due to their physical characteristics, might be particularly vulnerable to wild settlement should cultivated (reproductively active) biomass exceed a particular threshold.

Options open to growers and regulators could be to:

- Limit the number of licensed operators within a region or water body;
- Limit the area of seabed that could be licensed for on-bottom (parc) production;
- Consider whether off-bottom (bag and trestle) or suspended culture significantly reduced risk of gametogenesis and would therefore be preferred to on-bottom cultivation;
- Limit the density of adult stock grown on- bottom;
- Control the numbers of bags or trays (off-bottom) permitted within the water body;
- Manage the size at harvest (larger oysters produce more gametes); and
- Consider harvest prior to spawning (in high risk areas currently mostly August and September).

There is very little evidence in the literature concerning how different husbandry of Pacific oysters might affect the reproductive activity of the stock. A review by Syvret *et al.* (2008) concluded that 'parc' or on-bottom culture in the intertidal zone might result in a greater level of reproductive effort in Pacific oysters, compared to off-bottom cultivation in bags on trestles, although evidence for this is weak. The tidal level at which the oysters are cultivated might also affect the reproductive effort, with longer immersion times (lower shore cultivation) leading to a higher availability of energy resources for reproduction. There are likely to be local influences and perhaps seasonal and annual variations depending on food availability in the water column. Experimental studies (Chavez-Villalba *et al.* 2003) showed that *C. gigas* had flexible reproductive patterns depending on food variability.

[49] see tracer study at www.ecowin.org/smile/A2.htm

7.1.3 Antifouling

The use of tributyltin (TBT) antifouling paints was banned in 1987 in the UK for use on leisure boats <25m. The antifoulant was extremely effective, yet had a devastating impact on non-target species in the marine environment and the oyster industry throughout Europe (Alzieu, 2000). Although there are now safer alternative products, it is suspected that the importation of *C. gigas* as fouling could be a problem on some vessels. Education programmes such as the 'Green Blue'[50], a joint initiative between the British Marine Federation and Royal Yachting Association, could perhaps help to address this, in addition to wider initiatives throughout the shipping industry.

There is also a problem of *C. gigas* settlement and fouling within power station cooling water pipes. A study found that to due cementation to the substrate, oysters are more difficult to remove than other fouling species such as mussels, yet 100% mortality of all size groups could be achieved by raising the water temperature to 42°C for about 60 mins (Rajagopala *et al.* 2005).

7.1.4 Native Habitat and Native Oyster (*Ostrea edulis*) Restoration

Most habitats have been altered and disturbed to varying degrees and estuarine and coastal habitats are no exception. Fish and to an extent bird predation may now be at a lower level than previously, which could have resisted invasions more effectively than at present (Reise, 2010). There is considerable potential for habitat restoration and improving the resilience of the receiving ecosystem that may reduce the rate of wild Pacific oyster settlement. It has been hypothesised that the low levels of Pacific oyster settlement observed in the Fleet lagoon (Dorset) could be due to high levels of predation within this diverse system, in spite of *C. gigas* production. Strengthening the diversity of potential predators and competitors within lower levels in the food web would also help; one obvious candidate is the native oyster *Ostrea edulis* which although may not significantly compete spatially with *C. gigas*, has the capacity to filter larvae from the water column and so reduce potential settlement of Pacific oysters. There are various initiatives underway to help restore populations of this dwindling species e.g. Chichester Harbour Oyster Production Initiative (CHOPI) and the SAGB native oyster initiative. For example, a levy on Pacific oyster production could be ring-fenced for *O. edulis* restoration schemes. Clean shells of Pacific oysters are attractive to settling *O. edulis* (J Humphreys and R Herbert, personal observations).

7.1.5 Mechanical Eradication of Wild Settlement

7.1.5.1 Dredging

In the Oosterschelde area in Holland, where the main problem with *C. gigas* relates to reduced carrying capacity and trophic competition with commercial mussel farming (Wijsman, pers. comm.), an experimental dredging of 50 ha of intertidal wild oysters and sub-littoral cultivated beds was carried out using mussel dredges (Wijsman *et al.* 2008). Although the operation involved 940 boat hours (20 boat hours per ha) the oysters could be effectively removed from the beds. There was some minor erosion at one of the removal sites, although it did not persist.

50 The Green Blue: http://www.thegreenblue.org.uk.

At one of the dredging sites there was little impact on subsequent oyster settlement and, at a second site, some hard shell debris remained on the mud surface. The oysters were dumped at designated locations, presumably at the high intertidal (unspecified), however after 1 year, 10% were still alive! Oysters subsequently settled on the cleared areas, though there was no monitoring plan. It was concluded that beds should be cleared every 5-7 years to reduce potential competition between oysters and with other harvestable shellfish species, although this has not occurred (Wijsman *et al.* 2008). The general consensus of experts in the Wadden Sea is that large scale dredging would cause considerable habitat damage (Reise *et al.* 2005; K. Reise, pers. comm.).

In 2004, a large-scale restructuring of 600 ha of abandoned shellfish leasing grounds in the Bay of Marennes-Oléron, southern Brittany, involved clearance of wild *C. gigas* beds, gear and racks that had been colonised by *C. gigas*, removal of tingles (predators), *Crepidula,* and quantities of mud, sand and stones at a cost of €610,000 (Miossec and Goulletquer, 2007).

7.1.5.2 Hammering

An experiment to investigate the effectiveness of removal of wild *C. gigas* has been carried out in Strangford Lough, Northern Ireland (Guy and Roberts, 2010). Following survey work of the Lough, sites showing settlement (mean oyster density < 1 per m^2) were re-visited in the spring and shells of individuals encountered on transects were broken with a hammer. A survey the following year showed that although densities at un-culled sites continued to rise, the oyster density at most culled sites had dropped by nearly 100%. It is assumed that oysters that were hammered were killed and that there had been no further settlement at these sites. Oyster larvae are known to settle gregariously and be attracted to conspecifics, which may have caused densities to reduce. It was concluded that the measure could be beneficial at reducing population expansion in the early stages of invasion.

A pilot trial initiated by Natural England to hold the advancing line of Pacific oysters on the Thanet coast (Kent) commenced in March 2011. The objective was to reduce the wild stock that had colonised natural and hard substrata and therefore reduce potential larval supply and settlement on nearby Sandwich and Pegwell Bay National Nature Reserve, an area of chalk reefs and intertidal mudflats (McKnight, 2012). Important objectives were to assess feasibility and identify best practice. Using a variety of tools including edging spades, rods, hammer, pliers and safety equipment, over 40,000 oysters (approximately 25% of oysters were <60mm) were removed during 43 site visits (96 man hours) along three sections of the coast where they had colonised chalk reefs and mussel beds. However it remains to be seen if the rate of wild settlement in this region is reduced. It is anticipated that further work will be undertaken by a volunteer group in the locality.

7.1.5.3 Removal by grab

In shallow (<2m) areas of Lake Grevelingen (a saltwater lake in Holland) where the sharp shells of wild Pacific oysters have injured swimmers, the oysters are removed by grabs, and the remaining shells are covered by sand (Wijsman, pers. comm.).

7.1.6 Hand-collecting and Fishing for Wild Oysters

Between 1976 and 1981 handpicking was used to reduce the wild stock of Pacific oysters in the Oosterschelde estuary, Netherlands. These attempts failed and, from that time on, the new inhabitant was accepted as belonging to the Dutch fauna (Drinkwaard, 1999). After extensive establishment of Pacific oysters in the Wadden Sea, there was unanimous agreement that any eradication or control methods would also harm other components of the native ecosystem, especially of the Wadden Sea ecosystem (Reise *et al.* 2005).

However, depending on a favourable market, it is possible that some effective control on wild Pacific oyster settlement could be through regulated fishing and hand-collecting. As illustrated in the Blackwater Estuary case study (Appendix A), both hand-collecting and dredging over soft sediment habitats creates patches of open mud within oyster reefs for bird feeding. Although fishing activity creates different impacts and hand-collecting may disturb bird feeding at low tide, these activities are also managed.

Recreational and possibly commercial hand-collecting has also been observed in the Teign estuary, Southampton Water and parts of the Kent coast, however the impact has not been assessed, although there were some concerns that limpets were also being removed along with the oysters (Thanet Coast project - pers. comm.).

7.1.7 Triploidy

Allen and Guo (1996) stated that one of the only feasible modes of containment for non-native species within the aquaculture industry is reproductive sterility. In theory, a method of achieving sterility is induced triploidy, a condition in which a cell or organism has three sets of chromosomes (denoted by the abbreviation 3n) as opposed to the normal two sets of chromosomes (denoted by 2n). There are two ways in which triploidy can be induced in Pacific oysters: i) through the application of a shock treatment (chemical, heat or pressure) during egg fertilisation and ii) through the crossing of tetraploid (4n) males and diploid (2n) females (producing 'mated' triploids).

7.1.7.1 Efficacy of triploid Pacific oysters for biological containment

In theory the triploid condition confers sterility through rendering the oysters unable to produce viable gametes and hence preventing spawning and wild settlement. However, there are issues relating to the use of triploid oysters for biological containment during cultivation, namely that triploid oysters are not completely sterile and that the triploid condition is not 'stable'. A brief review of the implications of these issues in relation to the use of triploidy as a potential management measure is provided below. A more detailed review of triploidy is provided by Syvret *et al.* (2008).

With regard to sterility, although triploids generally show retarded reproductive development (Guo and Allen, 1994b), both male and female triploid Pacific oysters can produce viable gametes (Allen and Downing, 1990) and, when fertilised, some of these can develop into viable offspring (Allen, 1987). As such, triploids cannot be considered to be 'non-reproductive' (Normand *et al.* 2009).

Despite this, the likelihood of triploid oysters producing viable offspring has been reported to be extremely low and, by all practical measures, zero (Allen and Guo, 1996). For example a study of the reproductive potential of chemically induced female triploids calculated that, due to both the low fecundity (number of eggs produced) and the low survival rate of triploid x triploid progeny relative to diploids, the likelihood of triploids producing viable progeny was 1 in 125,000 (Guo and Allen, 1994b). Most surviving progeny would also be triploids but the likelihood of producing viable diploid progeny was calculated as 1 in 2 million. Once the reduced fecundity of the male triploids was also factored in, the likelihood of triploids producing viable diploid offspring was calculated as 1 in 100,000,000 (reported in Syvret *et al.* 2008).

With regard to any differences in the reproductive potential between chemical and mated triploids, Normand *et al.* (2009) showed that there was no difference in the reproductive effort (the proportion of energy allocated to reproduction) between five month old chemically induced and mated triploids, although as expected the reproductive effort of both types of triploid was lower than in diploids. However, another study of gamete production and reproductive effort in mated triploids showed that in about 25% of the mated triploids (described as α oysters), the process of gamete production, including the number of mature gametes, and the reproductive effort closely resembled that of diploid oysters. The remaining 75% of mated triploids (β oysters), appeared nearly sterile with only a few mature gametes and reproductive effort below detectable limits. The authors highlighted the importance of establishing the spawning capacity of the mature α triploids under various environmental conditions to understand their possible participation in natural spawning events.

The relative reproductive potential of triploids is increased when they are crossed with diploids (e.g. Gong *et al.* 2004, who assessed the reproductive potential of mated triploids crossed with diploids). With respect to biological containment, if triploids are deployed with diploids, the diploids will overwhelm the triploids making them irrelevant (Ximing Guo, pers. comm. to Martin Syvret, May 2008). This highlights another consideration for the use of triploidy as a measure for biological containment, the need to ensure 100% triploidy. The determination of the ploidy (n) level requires a method such as DNA analysis by flow cytometry (FCM), a technique which allows the analysis of several hundred individuals every day (Piferrer *et al.* 2009 and references therein). Allen and Guo (1996) described how prior to the trial introduction of *C. gigas* into Delaware and Chesapeake Bays (USA) for disease challenges, the oysters had be ‘certified’ as triploid before placement in either estuary, requiring the pre-screening of over 1300 oysters through biopsies and DNA analysis by FCM. The authors highlighted that this laborious requirement to ensure 100% triploidy illustrated another impediment to the use of triploids for population control.

A further issue is that the triploid condition is not stable. In the USA, a trial in which ‘certified triploid’ oysters were placed in the York River was halted when it was discovered that about 20% of the oysters had a ‘dual cell state’, containing both diploid and triploid cells (referred to as ‘mosaics’) (reported in Blankenship, 1994; Gottlieb and Schweighofer, 1996; Allen and Guo, 1996; Allen *et al.* 1999). It is thought that triploid oysters initially contain three sets of chromosomes (3n) in all tissues and gradually loose chromosomes in most tissues (Ximing Guo, pers. comm., who noted however that he had never observed reversion in the cells responsible for gamete production in male triploids). Investigating the chromosomal stability of triploid populations in the USA, Allen *et al.* (1999) reported that over a period of two years, reversion was progressive, with more diploid cells accumulating over time. The frequency of reversion in chemically induced triploids had been two to three times higher than in mated triploids. The frequency of reversion also varied between grow out sites with harsher environments potentially exacerbating the problem of reversion (Allen *et al.* 1999). Syvret *et al.* (2008) reported that scientists from IFREMER had confirmed that reversion from triploidy to diploidy occurred in both chemically induced and mated triploids and that reversion generally occurred when the oysters were over three years old. Feedback from the industry questionnaire circulated as part of this review and from UK hatchery owners, provided anecdotal evidence that the reversion of cultivated triploids in the UK does occur, based in observations of the oyster flesh going 'milky' suggesting that they are spawning.

7.1.7.2 Use of triploid Pacific oysters in the UK

Production, cost and availability of triploid Pacific oyster seed

Triploid Pacific oyster seed can be obtained from several hatcheries in the UK and Guernsey, where the chemical shock induction method of producing triploids is used. The method of producing 'mated' triploid oysters by crossing tetraploid males and diploid females is not currently used by UK hatcheries due to the method of tetraploid production being patented in the USA with licences for use in Europe but not specifically the UK (Syvret *et al.* 2008).

The hatchery production of triploid Pacific oysters is a more costly and difficult process (in terms of survival) compared to the production of diploids. For example, consultation with hatcheries that produce triploid Pacific oysters revealed that up to 80% of Pacific oyster eggs are lost during the chemical shock process to induce triploidy and triploid larval survival rates are lower than for diploids. In addition, triploids require a considerably greater food supply. Despite the more costly production process, some hatcheries still sell triploid seed for the same cost as diploid seed (and hence make a loss, having to use diploid production to subsidise triploid production), although one hatchery consulted stated that triploid seed are sold at a 15% higher cost than diploid seed.

With regard to the availability of triploid seed, the hatcheries consulted reported that triploid production constituted about 10-15% and about a third of seed production respectively. This relatively low proportion of triploid production, compared to diploid production, is due to the higher cost involved in triploid production. As such, if there was a requirement to produce greater quantities of triploids (e.g. if the industry was required to only farm triploids), this would likely have negative economic consequences for UK hatcheries (an industry consultee stated they would go out of business very quickly), especially as French hatcheries currently produce large quantities of triploids.

There are currently disease-related restrictions on the movement of Pacific oysters within the aquaculture industry. In 2010, under emergency measures put in place under Commission Regulation (EU) 175/2010, the UK started a surveillance programme, which covered every shellfish production area that held Pacific oysters, to monitor for a new variant of the oyster herpes virus. In 2011, new legislation (Commission Decision 2011/187/EU) enabled the UK and the Republic of Ireland to maintain controls under Article 43 of 2006/88/EC which permits the Member States to restrict trade from areas with no surveillance programmes for the virus. In practise these restrictions mean that shellfish farms within the disease free compartment of England and Wales can only receive certified Pacific oysters from other disease free surveillance areas and currently can receive Pacific oysters from all areas of England, Wales and Scotland except for one containment area in the UK. Shellfish farms in England and Wales (apart from the containment area) cannot import Pacific oysters from other Member states (including France) that have not established surveillance programmes.

Viability of using triploids in aquaculture

In addition to the theoretical sterility, other traits of triploid oysters may be advantageous for aquaculture. Energy usually diverted to gamete production is available for non-reproductive tissue growth and faster growth rates have been reported for both chemical and mated triploids (e.g. Nell and Perkins, 2005; Garnier-Gere *et al.* 2002, cited in Normand *et al.* 2008). However there is no significant difference in growth when the growing conditions of the area are poor (Nell, 2002). Responses obtained from the industry questionnaire and consultations undertaken for this review provided anecdotal evidence that triploids could be difficult to cultivate in the UK and did not grow well (not 'fattening up' to produce an acceptable table oyster) if the supply of food was insufficient. Conversely, anecdotal evidence indicated that in areas where conditions presumably were suitable, the fast growth rate of the triploid oysters requires high levels of husbandry that may not be viable.

In addition, in diploid oysters the reproductive tissue ramifies throughout the body tissue often rendering ripe animals unmarketable; after spawning the flesh is often severely depleted and watery in appearance. Theoretically sterile triploid oysters can therefore be produced and sold year round and have been reported to provide a firmer, more palatable product compared with diploids (Allen and Downing, 1991; Nell, 2002, cited in Piferrer *et al.* 2009). However, there have been some reports of discolouration of triploid meat which is thought to be partial reproductive tissue development (Nell, 2002). A couple of industry questionnaire responses indicated that triploids were a good/better product to sell in the summer than diploids.

7.1.7.3 Alternative methodologies for biological containment and prevention of wild settlement

Evidence was found of a potential alternative method for biological containment of cultivated non-native aquaculture species, referred to as "sterile wild" technology (Grewe *et al.* 2007; Thresher *et al.* 2009). This technology utilises a recombinant genetic method to integrate a 'genetic construct' into the farmed species which should render the organisms functionally sterile outside of hatchery conditions. Within the hatchery, however, the provision of a 'repressor compound' at a particular life history stage allows the animals to be bred and reared as usual. Hence, this "sterile wild" technology aims to provide reversible control over reproduction, does not involve production of a toxin or a gene product that is permanently present in the organism, and is potentially applicable to a wide variety of species (Thresher *et al.* 1999; Grewe *et al.* 2007).

Thresher *et al.* (2009) reported on the development of this technology and testing of it in Pacific oysters. A sterile wild 'construct', which repressed a gene specific to oyster larval development, was integrated into *C. gigas* sperm, which was then used to fertilise eggs which were allowed to develop for 72 hours. The results showed that 67% of the larvae infected with the sterile wild construct failed to develop. The results also showed that addition of the 'repressor compound' reduced larval mortality close to control levels and most larvae then developed properly. The authors noted that a robust analysis of the efficacy of the sterile wild system required the genetic construct to be stably integrated into 100% of the offspring (in the trial only 61% of the larvae carried the genetic construct). Furthermore the use of the repressor molecule in the study (doxycycline) could potentially be problematic in relation to environmental issues, as it required the discarding of tetracycline-doped water (Thresher *et al.* 2009). The authors concluded that repressible sterility would appear to be an effective means of reducing the environmental risks associated with farming exotic organisms and that a high priority for future research may be to explore alternative repressible systems.

7.1.7.4 Summary of efficacy of triploidy for biological containment

Although triploidy has been proposed as a potential method for biological containment, triploid Pacific oysters cannot be considered to be completely sterile and hence cannot provide complete containment, although evidence suggests that the reproductive potential of triploid Pacific oysters is extremely low and practically zero. However, the reproductive potential increases if triploid oysters are deployed with diploid oysters and it has been suggested in these circumstances that triploids will become irrelevant. Further issues include the requirement to ensure 100% triploidy prior to deployment and evidence that triploidy is an unstable condition with an increasing proportion of triploid populations reverting to a diploid/mosaic state over time. In addition, evidence suggests that whilst triploids may provide the advantage of fast growth rates and year round production, there is evidence that the growth rates of triploids varies between grow out sites in relation to environmental conditions and hence may not be suitable for some sites. Triploid Pacific oyster seed can currently be sourced from UK hatcheries in disease free surveillance zones, and does not appear to be substantially more expensive than diploid seed despite the more costly and difficult production process. An alternative method for biological containment of non-native aquaculture species is currently being researched.

7.2 Adaptive Management Approaches

Aquaculture development proposals are frequently within sites protected under the EU Habitats Directive (SACs, SPAs) and also National Nature Reserves. In these areas, an Appropriate Assessment will be required to address potential impacts, and mitigation. With much uncertainty concerning the impacts on biodiversity features resulting from new *C. gigas* aquaculture developments, an 'adaptive management' approach has been proposed (Woolmer, 2009).

> *"Adaptive Management applies a scientifically rigorous approach to address 'uncertainty' by developing knowledge from the results of trials of alternative management measures, essentially 'learning by doing'. When applied to shellfisheries or cultivation developments this approach may enable a shellfishery or farm operation to begin while developing best practice operational and management measures affording the protection to the environment"* (Woolmer, 2009).

Examples of mitigation and associated monitoring proposed to address potential ecological impacts arising from proposed *C. gigas* cultivation developments, utilising the adaptive management approach, are shown in Table 7.1.

Table 7.1 Identified ecological impacts and proposed mitigation and monitoring as part of an adaptive management strategy for two environmental assessments relating to proposed *C. gigas* aquaculture developments

Project	Proposal	Potential Impacts Identified	Mitigation Proposed	Monitoring	Outcome
1.Teifi, Wales	Trial using oyster trestles on an intertidal sandbank. The oysters were to be held in plastic mesh bags suspended from four inch larch posts 1.5 ft above the sediment surface.	Introduction and establishment of adult oyster escapees from the farm site. Settlement of juveniles outside the farm site that spawned from the farm stock.	Spills of oyster or escapes through damaged bags to be immediately cleared. Adherence to Pacific oyster Protocol using temperature thresholds Possibility of the use of triploid stock to negate spawning risk	Developers proposed a photographic log of the site to ensure compliance with key mitigation measures such as site clearing.	**Regulators objection. Proposal Failed**
2.Cumbria, England	Trial farming of Pacific oysters (*Crassostrea gigas*) using Boddington BST longline* over 10 years.	Community change from escaped non-native species (Pacific oyster)	Prompt removal of, any escaped Pacific oysters. Possible use of triploid seed which pose a reduced spawning risk	Monitoring for escapee/ settlement of pacific oysters (independently monitored by University)	**Proposal Successful.** '*The assessment considers that adherence to the suggested mitigation measures will avoid negative' impacts on SSSI and EMS features'*. Natural England

* Boddington BST longline is system of oyster mesh bags clipped to post supports via high tensile nylon clip lines, which can be raised and lowered to enable management measures to be undertaken.

(Source: Woolmer, 2009)

It is unclear why Proposal No. 2 illustrated in Table 7.1 above (Solway Firth) was successful, and those in Wales were not. However it is possible that the lower risk of spawning Pacific oysters in northern England was an important factor.

A proposed management plan for an oyster farm in Wales is shown in Table 7.2 (provided by operator). This proposal is still on-going, however regulators have indicated that stock should be removed if spawning is found to be occurring. Yet this is currently considered impractical by the operator due to quantities of oysters involved.

Table 7.2 Proposed management plan for an oyster farm in Wales

Measure	Description of Measure
1	Chemically-induced triploid oysters will be sourced to reduce effective population size and therefore invasion pressure. In the unlikely event that triploids are not available smallest number of diploid oysters to maintain flow of market-sized stock will be purchased, thus keeping the effective population size of oysters to a minimum, with triploid spat immediately placed on advance order.
2	As a precaution, oysters will not be sourced from established populations elsewhere, in case adaptation to local temperatures has occurred in those populations.
3	Weekly temperature readings will be obtained and degree-days calculated. Salinity readings will also be obtained. If there have been sufficient degree days above 10.55 ^{o}C (=600) for spawning to occur, sea temperature is ≥18 ^{o}C and salinity is <32, checks will be made for evidence of spawning. If there are subsequently sufficient degree days for spatfall to take place (=220) a search will take place for oyster spat on a monthly basis for 6 months over the area of the order.
4	Monitoring lays 6, 7, and 11 (those where *C. gigas* are farmed) will take place four times each year, any dropped oysters will be picked up. At the same time it will be checked that no spatfall has occurred, even if abiotic conditions have not been suitable. Spatfall will be deemed to have occurred if oysters are found that are clearly attached to the substrate. These will be destroyed. Oysters that have grown too large for sale in the shell (>150g) will be removed and either culled or sold for shucking this will be done every three months, as necessary. Misshapen oysters will be removed before or once they are >150g
5	Oysters that are still not market size after 5 years will be removed and either culled or sold for shucking.
6	Oysters will be contained in bags or trays on trestles and only on the ground where currents and wave action are not sufficient for them to be carried away at any time.
7	Mussel seed for on-growing on the Order will not be collected from areas where there are established wild oysters.
8	Oysters and associated growing structures will not be abandoned on site by any company that ceases to farm or at the end of the life of the order, if it is not renewed.
9	Triggers for reworking the above Appropriate Assessment and Management Plan will be: 1. If abiotic conditions become suitable for spatfall to occur on a regular basis (point 3); 2. If there is evidence of adaptation to local abiotic conditions (point 4, if point 3 has not acted as a trigger); and 3. If there is a spatfall.
10	In addition, any spread of already established populations from other parts of the UK and their proximity to north Wales will be monitored as far as information is available.

8. Discussion and Recommendations

Global climate change presents new challenges and risks with respect to the management and conservation of the marine environment. The biosecurity of UK marine resources, including all cultivated species, must be given a high priority in view of predicted rises in air and sea temperatures and the increased risk of economic and environmental damage caused by invasions of non-native species.

The non-native Pacific oyster was introduced under licence by UK government to support the oyster industry that was suffering from the decline of the native oyster as a result of a succession of extreme winters, disease, pollution and over-fishing. Although small in comparison to France and other EU Member States, there is no doubt that there has previously been an underestimation of the economic importance of the Pacific oyster in the UK and the cultural benefit that continued cultivation provides to the regional and national economy. Yet few could have predicted the higher fecundity of cultivated Pacific oysters, both on the continent and in the UK, and the actual and potential consequential environmental impacts and growth of wild settlement as result of higher temperatures in Europe.

Total eradication of Pacific oysters is not feasible. This, along with cultural pre-dispositions has led some European countries to adopt the Pacific oyster as a naturalised species. In the UK however, for the foreseeable future the species legal status in the wild is likely to remain as an invasive non-native species. Although it has been argued that wild Pacific oysters might provide ecosystem services in addition to food production, these are mostly speculative and largely associated with 'reef' formation that would only develop if settlement was particularly high. Further research may however yield genuine benefits of Pacific oyster 'reefs', for example as a coastal defence.

The issue of the Pacific oyster therefore locates at the intersection between two policy areas: one concerning the conservation of protected habitats, the other relating to livelihoods and the socio-economics of coastal fishing communities. In this context we have sought to present an objective review of the relevant information in a dispassionate way. In this section we develop recommendations for the management of wild settlement of Pacific oysters which are above all consistent with the scientific evidence, but also we believe compatible with the various obligations of the UK Government.

Three of our general findings are key to these recommendations:

- Firstly, there is currently wide variation in the geographical extent of wild settlement of Pacific oysters in the UK and the risk posed to native biodiversity varies greatly with location and habitat.

- Secondly, continental experience suggests that there is some inevitability that, should predictions of continued warming under the UKCP (2009) scenarios be realised, the frequency and magnitude of settlement will increase, causing existing populations to rise and new populations to become established. Most populations in the UK currently consist of only one or two age classes suggesting that settlement is still intermittent and infrequent. Yet, the evidence suggests that, frequent and dense settlement over extensive areas of certain habitats, if unmanaged, could put at risk the ecological integrity of some UK protected sites, including European Marine Sites.

- Thirdly, it is unlikely that UK cultivation of Pacific oysters is the only pathway causing wild settlement in all areas. There are several regions where wild settlement is occurring that are distant from Pacific oyster production. Introductions into marinas, harbours and ports from boat traffic as fouling or entrained larvae are as yet unproven but highly suspected. In many regions of Pacific oyster cultivation, boat traffic is commonplace, so in these areas it is difficult to quantitatively differentiate the relative impact of these different pathways. Similarly, there are areas where there are no observations of wild settlement in-spite of local, and in some cases, intensive aquaculture. The resilience of an ecosystem to restrict the growth of wild settlement is clearly complex and involves both physical and biological parameters. Further research needs to be done in this regard[51].

These findings therefore lead us to conclude that a regional approach to the management of wild Pacific oyster settlement in the UK is likely to be the most effective, as opposed to broad-scale measures that in some areas may currently be irrelevant. Image 8.1 summarises the decision making process that supports this assertion and provides examples of management options that could be selected from in a specific regional context. The current environmental impact of wild settlement in the UK varies with locality and is currently low in most regions. However, with co-management between growers/fishers, harbour authorities, regulators and Non-Governmental Organisations (NGOs) it should be possible to contain and mitigate negative impacts on a regional basis. With their regional representation of industry, regulatory and enforcement bodies, IFCAs are ostensibly well placed to monitor the extent of wild settlement and lead such decision making processes.

It is clear that adverse effects on nature conservation interests vary according to habitats; for example there is currently little evidence of impact in subtidal areas. Within intertidal areas, consisting of soft sediments, extensive and dense aggregations of oysters might develop. Here it should be possible to maintain habitats in a favourable condition and protect features of conservation interest through the development of strong partnerships between agencies and fisheries. The Blackwater Estuary provides an example of such co-operation (see Appendix A). The success and continuity of these partnerships requires a vibrant industry, therefore incentives and assistance with marketing might be required to achieve both commercial and conservation objectives. There is also evidence that recreational harvesting has the potential to contain populations and prevent risk of extensive settlement that could detrimentally impact native habitats and species.

Rocky habitats present the greatest challenge in terms of management and containment due to difficulties associated with the physical removal of oysters. Dense aggregations and reefs of Pacific oysters can transform the habitat and displace features for which it was originally designated. Volunteer schemes, such as that currently being tried in Kent (see Appendix A), may be able to contain wild settlement to prevent damage to sensitive species and habitats. The success of these schemes will depend on their size and continuity to ensure that

51 Work currently underway at Bangor University (SEAFARE project) and University College Cork may spread new light on the origins of wild settlement in the British Isles.

developing populations are controlled. It is important that an ecological and economic evaluation of control and management methods is incorporated into each regional management scheme.

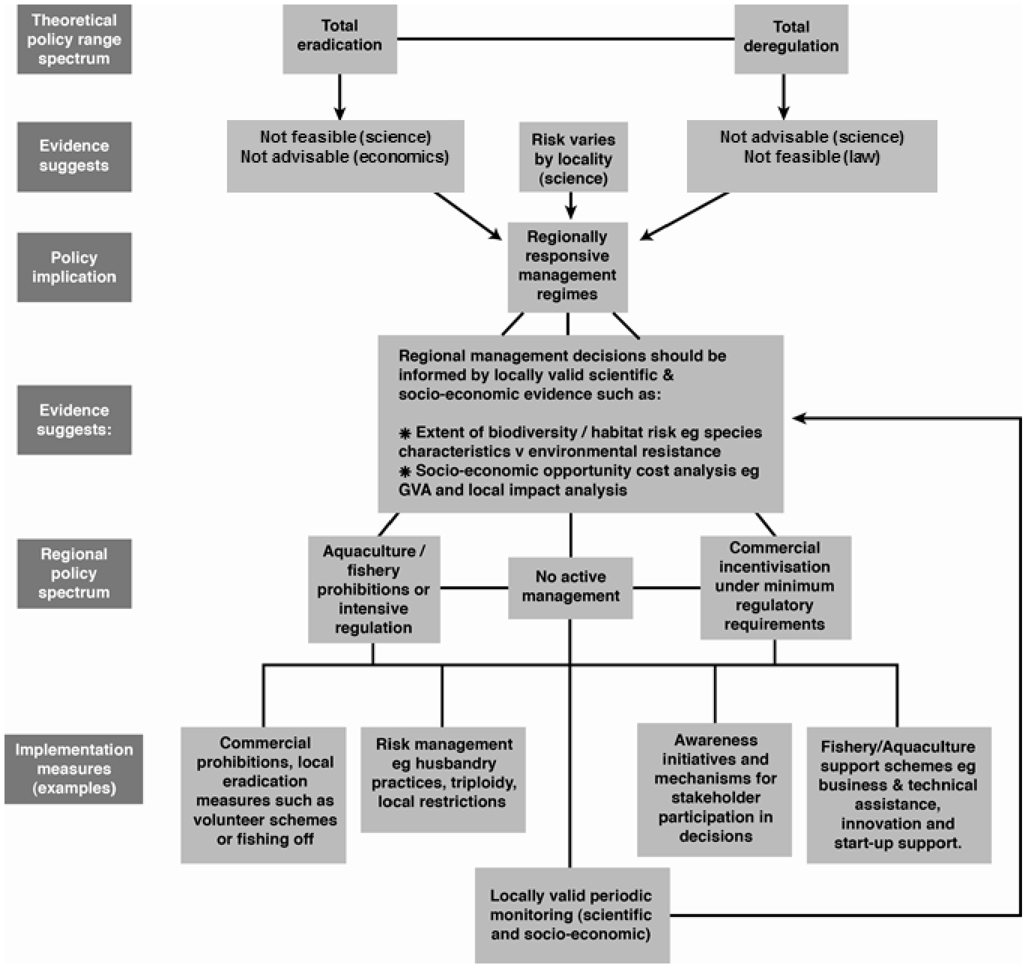

Image 8.1 Potential Regional Approach to Management of Wild Pacific Oyster Settlement in the UK

In terms of specific measures, consideration should be given to establishing regional management plans governing the size of operation and number of regional licences. This would need to take account of the physical and hydrographic characteristics of particular water bodies present in the region. Restrictions of this type could potentially limit the larval supply from reproductively active stock and minimise the risk of wild settlement. In certain circumstances, for example, it might be appropriate that a strategy for risk mitigation, such as contributions to the removal of any wild settlement that occurs, could be negotiated as part of the licensing process. The spatial extent of removal would need to be agreed with other agencies but a focus on particularly sensitive habitats, such as *Sabellaria* reefs, might be prioritized. In addition, efforts to improve habitat diversity and increase populations of vulnerable or scarce species, such as the restoration of native oyster beds, could also be encouraged.

The adoption of triploid oysters, which for a period at least are assumed to be sterile (or at least have an extremely low likelihood of producing viable offspring in the absence of diploids), could also be considered on a regional basis. It has become clear from the industry consultation that experience of triploids varies between localities and individual growers, with good growth in some areas but not in others. Clearly, in the south-east of England, where wild settlement is already highly advanced, the introduction of triploids is unlikely to have any impact as the diploid population is already so large. Unless there is a sudden heavy mortality of wild settlement in this area it is unlikely that mandatory use of triploids will be effective in this region. In parts of south-west England, Wales and northern UK where wild settlement is currently insignificant, the use of triploids may be viable, at least as part of an adaptive management strategy. However triploid production is currently difficult and costly and as such, there may be negative economic consequences for UK hatcheries if cultivation of triploids is mandatory.

Our economic analysis suggests that there is likely to be an increasing long term demand for aquaculture and oyster products in the UK, notwithstanding marketing and biosecurity challenges. In summary, stakeholders, including growers, port and harbour authorities and statutory agencies must engage in regional decision making to help minimise any negative environmental impacts of wild settlement on features of conservation interest, while at the same time, and within those constraints, maximising opportunities for sustainable industry development.

In both areas where there is extensive wild settlement or currently minimal risk, it may be possible to provide financial incentives to support and develop a sustainable industry. For example in ports, harbours and marinas, such as in the Solent, where wild settlement is likely to be occurring as a result of vessel traffic, harvesting wild oysters may be a viable way of managing the stock. Business start-up schemes and fisheries and aquaculture support schemes could be appropriate avenues for support. However it is in northern areas, where there is currently minimal risk of wild settlement leading to established populations, due to lower sea temperatures, that new growth and development of the industry might be more widely supported. In these regions, monitoring must be rigorously applied and measures to remove or reduce developing populations enacted at the earliest possible stage, yet the life of the licence although conditional should not be too precautionary to inhibit long-term investment.

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10. Abbreviations

APB	Aquaculture Production Business
ASMFC	Atlantic States Marine Fisheries Commission
ASSG	Association of Scottish Shellfish Growers
ASSI	Areas of Special Scientific Interest
C	Carbon
CBD	Convention on Biological Diversity
CCW	Countryside Council for Wales
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CHOPI	Chichester Harbour Oyster Production Initiative ()
CO2	Carbon dioxide
DARD NI	Department of Agriculture and Rural Development
DoE NI	Department of Environment (Northern Ireland)
ECJ	European Court of Justice
ELWS	Extreme Low Water Springs
EMS	European Marine Sites
ES	Ecosystem service
EU	European Union
EU	European Union
FAO	Food and Agriculture Organisation
FCM	Flow Cytometry
FOCI	Features of Conservation Importance
NNSS	Non-Native Species Secretariat
GDP	Gross Domestic Product
GIS	Geographical Information System
GMO	Genetically Modified Organism
GVA	Gross Value Added
IBM	Individual Behaviour Models;
IFCA	Inshore Fisheries and Conservation Authority
IFREMER	Français de recherche pour l'exploitation de la mer (French Research Institute for Exploration of the Sea)
JNCC	Joint Nature Conservation Committee
MAFF	Ministry of Agriculture, Fisheries and Food
MBA	Marine Biological Association
MCZ	Marine Conservation Zone
MHW	Mean High Water
MLW	Mean Low Water
MMO	Marine Management Organisation
MS	Member States
MSFD	Marine Strategy Framework Directive
MTL	Mean Tide Level
NEKEMS	North-east Kent European Marine Site
NGO	Non Governmental Organisation
NOSAP	Native Oyster Species Action Plan
Pa	Per annum
PLD	Pelagic Larval Duration

SAC	Special Area of Conservation
SAGB	Shellfish Association of Great Britain
SAGB	Shellfish Association of Great Britain
SMILE	Sustainable Mariculture in Northern Irish Lough Ecosystems
SNH	Scottish Natural Heritage
SPA	Special Protection Area
Spp.	
SSSI	Sites of Special Scientific Interest
TBT	Tributyltin
TEV	Total Economic Valuation
UK BAP	UK Biodiversity Action Plan
UKTAG	UK echnical Advisory Group
VFS	Value at First Sale
WFD	Water Framework Directive

Units

ha	hectares
km	kilometres
m	metres
nm	nautical miles
p	Pence
t	tonnes
yr	years

Appendices

Appendix A

Regional Case Studies

Appendix A. Regional Case Studies

Case Study 1: North-East Kent Coast (Thanet Coast)

Site Description

The North-east Kent coast, known as Thanet, has the UKs longest continuous stretch of coastal chalk in the UK, forming 20% and 12% of UK and European coastal chalk respectively. Much of the coast is protected by sea walls and promenades and there are important seaside resorts at Margate and Ramsgate. The Thanet coast has 250 ha of intertidal chalk reef, which is the largest in the UK, and extensive sea caves. The only significant harbour along the coast is at Ramsgate where there are ferry services to the continent and significant leisure boat movements. Between Thanet and the Thames are the Swale and Medway estuaries.

The North-east Kent European Marine Sites (NEKEMS) extends from near Birchington on the north coast to Deal, south of Ramsgate. It includes the Thanet Coast Special Area of Conservation (SAC), notable for its extensive chalk rocky reefs, Sandwich Bay SAC and Sandwich Bay Special Protection Area (SPA); the SPA has been designated for overwintering Golden Plover and Turnstone and breeding Little Tern in the summer. The Thanet coast and Sandwich Bay is also a SSSI.

Tidal currents flow west along the Thanet coast on the flood tide and east on the ebb tide. Other non-native species present in the area include the Japanese seaweeds *Sargassum muticum and Undaria pinnatifida* , barnacle *Elminius modestus* and most recently the sea squirt *Didemnum vexillum.*

Oyster Industry

Native oysters have been fished commercially off Whitstable, Kent in SE England since Roman times.

Today, the Seasalter Shellfish (Whitstable) company Ltd. operates from Reculver, eight miles east of Whitstable where the hatchery and several nursery systems produce seed all year round for a variety of molluscan shellfish including Pacific oysters[52]). A beach operation based at Seasalter concentrates on the half grown seed market. The company also owns two square miles of seabed off Whitstable known as the Pollard Ground. Seed is sold to home nations, Europe and Africa. In recent years, approximately 90% of Pacific oysters have been lost to the oyster Herpes virus (John Bayes, pers. comm.).

In addition to commercial cultivation, recreational / informal harvesting of Pacific oysters is also carried out in some areas and increasingly at Ramsgate.

Ecological Impact of Wild Settlement

Over the past decade there has been an increasing wild settlement of Pacific oysters along the north Thanet coast, and more recent settlement on the shores at Ramsgate. The settlement has so far occurred on artificial structures such as sea walls and breakwaters, rocky chalk reefs, mussel beds, *Sabellaria spinulosa* (honeycomb worm reef) and *Lanice conchilega* (sandmason worm reef) beds. No settlement has so far been reported on the sand flats of Sandwich Bay.

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52 http://www.oysterhatchery.com

Densities of Pacific oyster settlement varies around the coast (Figure A1) but small areas of oyster 'reef' (> 5m^2) are now forming on some areas of the chalk shore where abundance is approximately 200 per m^2 (Figure A2). In other areas, where oyster densities exceed 10 per m^2, the species has become a prominent component of the rocky shore community and has modified the visible appearance of the biotope, if not it's functionality.

Figure A2 shows the intertidal habitats on which the areas of 'dense' settlement (approx. 200 per m^2) has occurred at Epple Bay near Birchington. It should be noted that Figure A2 only shows broad-scale habitats and not habitats of conservation importance (such as Blue mussel beds or *Sabellaria* reefs). McKnight (2012) has reported that in Epple Bay, an area of approximately 100 m^2 of *S. spinulosa* reef formation is being displaced by *C. gigas* at ELWS. *C. gigas* is also 'occasional' on an adjacent intertidal area of *S. spinulosa* reef that *possibly represents the best example of the habitat within the North-east Kent European Marine Site* (McKnight, 2012). There are no specific conservation objectives for these biogenic reef structures for the NEKEMS, however it is possible they were not present at the time of the original survey, as with *C. gigas.*;

Review of Impact (Appropriate Assessment)

As far as the impact of invasive *C. gigas* is concerned the main conservation features at risk from wild settlement (Annex 1 listed habitats) of the NEKEMS are shown in Table A1, alongside agreed conservation objectives.

Table A1. Conservation objectives for the Annex I listed habitats in the Thanet coast area

Area	Annex 1 Habitats	Conservation Objective
North-east Kent EMS SAC	Rocky chalk reefs: including, algal and lichen communities; red algal turf communities; kelp dominated communities on animal bored rock.	Subject to natural change, maintain the rocky chalk reefs in favourable condition.
	Subtidal chalk reefs: including animal bored chalk communities.	Subject to natural change, maintain the subtidal chalk reefs in favourable condition.
	Submerged or partially submerged sea caves.	Subject to natural change, maintain the submerged or partially submerged sea caves in favourable condition.
Sandwich Bay SPA	Shallow coastal waters; Intertidal mud; Intertidal sandflats.	Subject to natural change, maintain the habitats for the internationally important populations of the regularly occurring Annex 1 bird species in favourable condition, in particular Turnstone and Golden Plover

Management Measures

There is no doubt that Pacific oysters have already significantly changed, if not yet transformed, the communities of marine organisms present on the chalk shores of the Thanet coast. Densities approaching those of the Brittany coast have not yet been realised and annual recruitment is still very intermittent in some areas. The ecological changes that could potentially occur on these shores are significant internationally, given the rarity of chalk intertidal habitat.

Although wild settlement on shores is thought to have initially originated from oyster farms near Reculver and the Swale, it is now unlikely that measures taken to limit regional production of oysters or revert totally to triploid production will have a significant impact on settlement as existing wild stock will continue to spawn in warming seas and will overwhelm triploids (Ximing Guo, pers. comm.) The Whitstable area has a long tradition of oyster production and heritage and there would be socio-economic implications should production fall. Moreover, the new settlement occurring near Ramsgate Harbour appears to be separate from that along the north Thanet coast (Willie McKnight, pers. comm.) and may originate from boat traffic and shipping.

As an attempt to prevent colonisation of sand and muddy sediment habitats at Sandwich Bay (SPA), trials to remove wild settlement from chalk shores at Ramsgate were carried out during 2011, supported by Natural England (McKnight, 2012). This has involved the removal of 40,000 oysters. Recruitment will be monitored over following years. As a result of the pilot study, Natural England is supporting a one-year project (2012-2013) for a small team of volunteers to physically remove oysters by hand at selected sites.

Conclusion

The threat to biodiversity within the Sandwich Bay SAC and SPA is being addressed by trying to 'hold the line' through active intervention and manual removal of oysters off the shore. This approach is also being trialled in Northern Ireland to manage wild settlement in Loughs. It is uncertain how long this approach can be sustained, given climatic warming and potential increased settlement. This approach, experimentally, has also been tried in Northern Ireland (Guy & Roberts, 2010) and might delay any adverse effects of wild settlement in the short and medium term. The proposed volunteer groups will require training and appropriate safety equipment.

Case Study 2: Blackwater Estuary, Essex

Site Description

The Blackwater Estuary is the largest tidal river in Essex and part of the Outer Thames estuary. The estuary is about 21 km in length and has an intertidal area of 3315 ha. The estuary is well mixed but with some stratification in the upper reaches. There are slight lateral gradients in temperature and salinity, particularly on northern shores. The saltmarshes on the Blackwater are extensive and the fifth largest in the UK. There are significant sea defences, particularly in the upper estuary. There are >6000 leisure craft, three marinas and a number of boatyards (Chesman *et al.* 2006). Tourism and leisure boating are significant industries in the area. Although still a prominent feature of the landscape, Bradwell Nuclear Power Station is being decommissioned. The Blackwater is part of the Essex Estuaries European Marine Site (EMS) that includes an SAC, SPA for water birds, SSSI and Ramsar Site. The area is also being considered as a Marine Conservation Zone (MCZ) (Marine & Coastal Access Act). In addition to Pacific oysters, the estuary accommodates several other non-native marine species including the slipper limpet (*Crepidula fornicata*) the American tingle (*Urosalpinx cinerea)* and Japanese seaweed (*Sargassum muticum*).

Oyster Industry

Native oysters (*Ostrea edulis*) have been cultivated in the West Mersea region of the Blackwater since 11th Century, yet declined in the 1960s and 1970s as a result of the cold 1962-63 winter and tributyltin (TBT) contamination. The Blackwater was the site of the original British introduction of the Pacific oyster in 1926 and the oysters were imported to this region until 1962 (Utting and Spencer, 1992). Although by 1965 the species was thought to have died out, it was known to be capable of "limited breeding" in the creeks of Essex and Kent (Cole, 1956) and it has been suggested that wild Pacific oysters persisted in the Blackwater at least until 1970 (Eno *et al.* 1997). In 1970s, further decline of the native oyster generated renewed interest in the re-introduction of the Pacific oyster by Ministry of Agriculture, Fisheries and Food (MAFF) and following trials the species was regularly imported. Following recovery from TBT, the Pacific oyster has thrived in the Blackwater and has spawned. Much of the Blackwater is now designated as shellfish waters for native and Pacific oysters and mussels. Local spatfall of Pacific oysters was recorded in the warm summers of 1989 and 1990 and has increased in frequency over the past decade with rising sea temperatures. Although cultivation and fishing for the scarce yet more valuable native oysters continues, the oyster industry is now sustained by the cultivation and fishing of Pacific oysters. In the upper estuary, towards Maldon, Pacific oysters are grown in bags supported on trestles, on adjustable long-line systems and on the river bed. The Maldon oyster company is one of the largest producers of Pacific oysters in the UK. In the creeks around Mersea, oysters are primarily grown on the river bed and here the industry is now sustained by wild settlement. There are at least 50 people directly employed in oyster production in the Blackwater and others indirectly employed in associated marine industries. Pacific oyster production available for consumption was approximately 500 tonnes in 2011, and considerably less for native oysters. There are many restaurants and bars selling local seafood including Pacific oysters.

Ecological Impact of Wild Settlement

The estuarine environment of the Blackwater provides suitable habitat for the growth and reproduction of the Pacific oyster. These include habitats listed in Annex 1 of the EU Habitats Directive and include intertidal sediment (intertidal mud, intertidal muddy sand, intertidal mixed sediments) and subtidal sediments. In addition, there are many man-made substrata, including sea defences, that provide settlement sites for *C. gigas*. The estuary also includes species features of conservation interest (FOCI) that are likely to be protected within the English MCZ Project. These include native oyster (*Ostrea edulis*) beds, the Lagoon sea slug (*Tenellia adspersa*) and European Eel (*Anguilla anguilla*).

Wild settlement of *C.gigas* is now extensive in the Blackwater and in other Essex estuaries (Images A1 and A2). Figure A3 shows the relative 'estimated' density of wild Pacific oyster settlement around the Essex coastline. It is important to note that this information is based on expert knowledge of wild Pacific oyster settlement gained through 'walk overs' of the area (i.e. a qualitative assessment, provided by Essex Wildlife Trust) and is not based on quantitative data.

(Photo: M Gray)

Image A1. Wild *C. gigas* Reef on Intertidal Mud at Brightlingsea, Essex in 2008

(Photo: M Gray)

Image A2. Close-up of Wild *C.gigas* on Intertidal Mud at Brightlingsea, Essex in 2008

Most settlement occurs on intertidal sediment habitat between Mean Tide Level (MTL) and Mean Low water (MLW) (RH personal observation). Reefs of *C. gigas* have formed in several areas and in other parts of the estuary there are dense aggregations of the oyster on intertidal sediments. Although no detailed up to date map of wild settlement has yet been produced, it is evident from field visits that large areas of intertidal mud have little or no settlement. Even within small estuarine creeks, settlement occurs on one side but not the other. Whether this is related to salinity preference is uncertain. Moreover, where dense aggregations of *C. gigas* do occur, there are large patches where the oyster has not colonised within these areas. The impact of *C.gigas* on bird populations is currently unknown however counts for the Wetland Birds Survey (WebS) from the British Trust for Ornithology do not specifically mention *C. gigas* reefs as contributing to the decline of waterbirds in the Blackwater.

As for the FOCI, to our knowledge *C.gigas* has not colonised the brackish lagoon habitat of the sea slug *Tenellia adspersa* and there is no evidence to suggest that there is direct impact of *C.gigas*, or its fishery, on eel *Anguilla anguilla* populations. Implications of the fishery and cultivation of *C.gigas* on populations of the native oyster *O. edulis* are discussed in the section below, however *O. edulis* is primarily subtidal and populations of the two species don't appear to overlap significantly in this region.

Review of Impact on Protected Areas

The main 'at risk features' (Annex 1 listed habitats) within protected areas are listed in Table A2, along with their conservation objectives.

Table A2. Conservation objectives for the Annex I listed habitats in the Blackwater Estuary

Area	Annex 1 Habitats	Conservation Objective
The Essex Estuaries European Marine Site that includes an SAC, SPA (designated for water birds), SSSI and Ramsar Site	Estuaries; Mudflats and sandflats not covered by seawater at low tide.	Subject to natural change, maintain the mudflats and sandflats not covered by seawater at low tide in favourable condition (Favourable condition' is defined as no decrease in the extent, topography and sediment character of the intertidal mudflats and sandflats or of the range and distribution of mud communities/biotopes, in particular cockle and eelgrass beds).
	Subtidal sediments.	Subject to natural change, maintain the subtidal sediments in favourable condition
Blackwater Estuary SPA	Shallow coastal waters; Intertidal mud; Intertidal sandflats.	Subject to natural change, maintain the habitats for the internationally important populations of regularly occurring migratory bird species in favourable condition ('Favourable condition' is defined as no decrease in the extent of intertidal mudflat and sandflats, abundance of invertebrate prey species and abundance of marine algae).

There is no doubt that wild settlement of the Pacific oyster has transformed parts of the intertidal mudflat habitat in the Blackwater Estuary section of the SAC. Reefs and dense aggregations of Pacific oysters now occupy large areas of mudflat in the estuary. Although no studies have yet been carried out on the impact of *C. gigas* on biodiversity in the mud of this region, other studies in France (Lejart & Hily, 2011) have shown that species diversity is likely to be greater within these reefs. It is unlikely that any species has been significantly reduced in population size or habitat area as large areas not colonised by *C.gigas* still exist in the Blackwater. It is not known whether the cockle banks and eelgrass beds have been affected.

Changes in migratory water bird populations in the Blackwater mostly follow broad-scale trends and there is little evidence for site-specific pressures (British Trust for Ornithology, 2012). Declines in numbers of Curlew since the early-1990s generally mirror broad-scale changes in the UK, although numbers in the Blackwater appeared to fall when those in most areas were still rising. This species feeds on invertebrates within mudflats and could be at risk from extensive Pacific oyster reef formation.

Management Measures

The cultivation of the Pacific oyster by fishermen is creating open patches within many of the Pacific oyster reefs. In recent years, large areas of *C. gigas* 'reef' (or rafts as they are sometimes known in this region) have been hand-picked 'clean' of wild Pacific oysters to create areas for re-laying Pacific oyster seed. This seed does not grow to maturity to form reef but is either hand-collected or dredged and re-laid in creeks for on-growing. While to our knowledge the impact of dredging and re-laying on intertidal biodiversity has not been investigated, it was evident from field observation that water birds (including oystercatcher and curlew) were feeding in areas where Pacific oysters had been removed and amongst newly laid and 1 and 2-year old seed.

Triploid oysters have been laid in parts of the Blackwater and still survive in some regions. However, from a local producer's perspective they have been generally unpopular. Currently, seed is obtained from the wild spawning 'diploid' population that reduces production costs and supports the industry. Given the abundance of spawning diploid Pacific oysters in the estuary, it is highly unlikely that the introduction of sterile triploids will have any impact on wild settlement.

Clearly, the introduction of *C.gigas* in to the Blackwater has been to support the oyster industry. The continuation of production is sustained by wild seed from the established wild population. Further introduction of *C. gigas* from outside the Blackwater may not now be permitted under the Herpes virus legislation. However, it is possible that larval drift from neighbouring Essex and Kent shores and from fouling and larval entrainment from the large regional and continental movement of leisure craft in the Blackwater, is supporting wild settlement.

Blackwater fishermen are seen as custodians of the native oyster (*O. edulis*) in the estuary and the restoration of scarce stocks of native oysters can realistically only be achieved by co- management and income arising from the more numerous Pacific oysters. Should fishing for Pacific oysters stop and boats sold off, then efforts to restore stocks of subtidal native oysters are likely to fail. Currently, there is a working partnership between the Essex Wildlife Trust, Natural England and oyster fishermen that enables attempts to restore *O. edulis* beds to continue.

Conclusion

While it may now be too late to remove the *C.gigas* population occupying mudflats in the Blackwater, it is evident that efforts to minimise 'reef formation' are carried out as part of the species local cultivation. This however is dependent on a vibrant local industry, markets and high demand for the product. The species makes a significant contribution to the local economy and has maintained the long-established maritime and culinary heritage of oyster production in the region. Arguably, the demise of the industry through closure of oyster farms may result in a long-term loss of mudflat habitat caused by un-managed wild settlement originating from the spawning of the existing *C. gigas* population. Although there is no direct evidence at this location, the high filtration capacity of Pacific oysters may be contributing to water quality objectives of the estuary. In some parts of the estuary, reef formation may be arresting the rate of coastal recession and erosion of mudflats and thus protecting the habitat. Further studies on the impact of Pacific oysters on bird populations would be helpful to assist with the management of sensitive areas.

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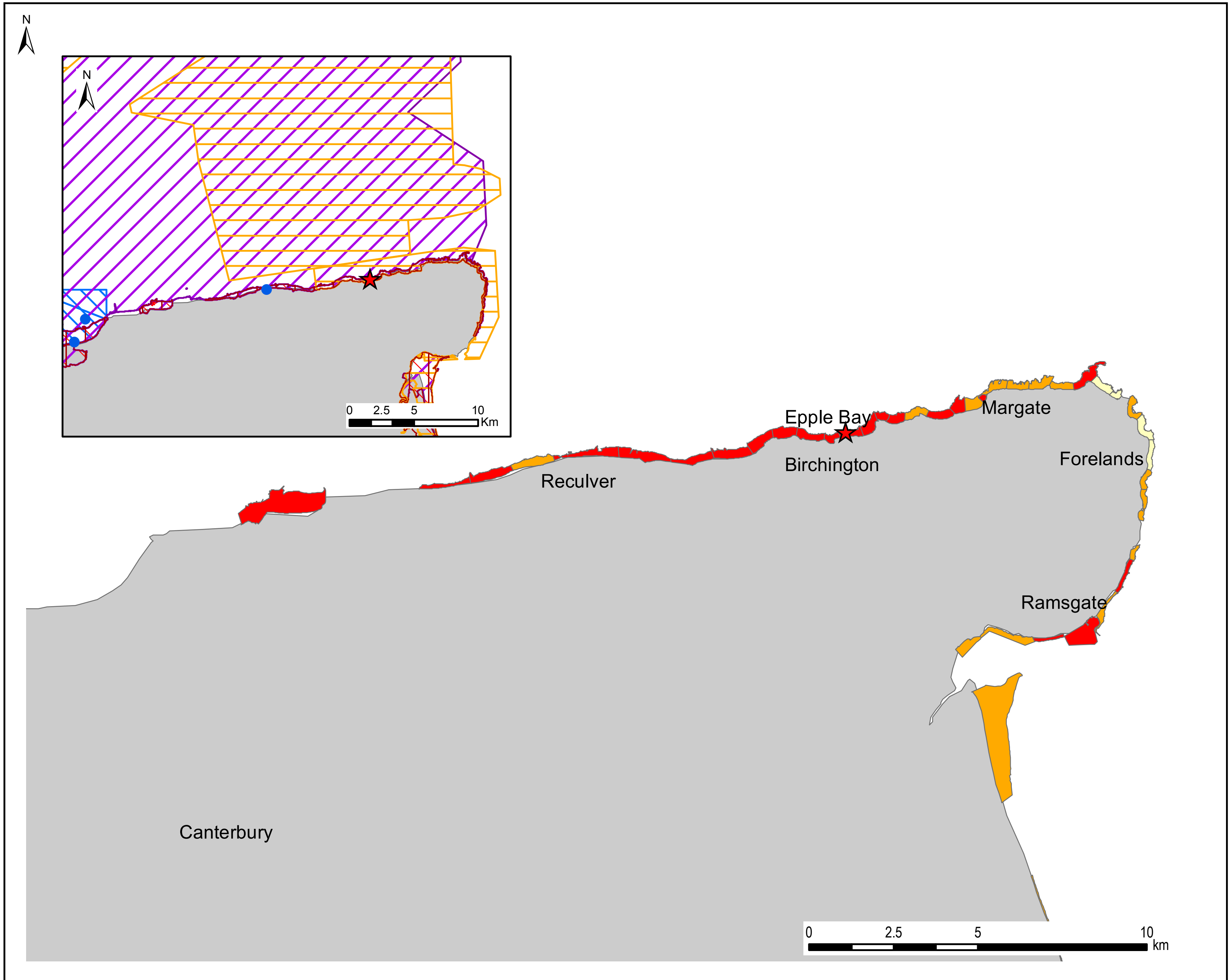
Appendix A. Figures



Main Legend

Known Dense Aggregations/ Reefs of Pacific Oysters

Pacific Oyster Peak Density
Oyster per m²

- 1
- 2 - 10
- >10

Inset Legend

- Known Dense Aggregations/ Reefs of Pacific Oysters
- Pacific Oyster APB
- Special Area of Conservation
- Ramsar
- SSSI
- Special Protection Areas
- Designated Shellfish Water

Note: Terrestrial SAC, SSSI and Ramsar sites are not shown

Aquaculture Production Business (APB)

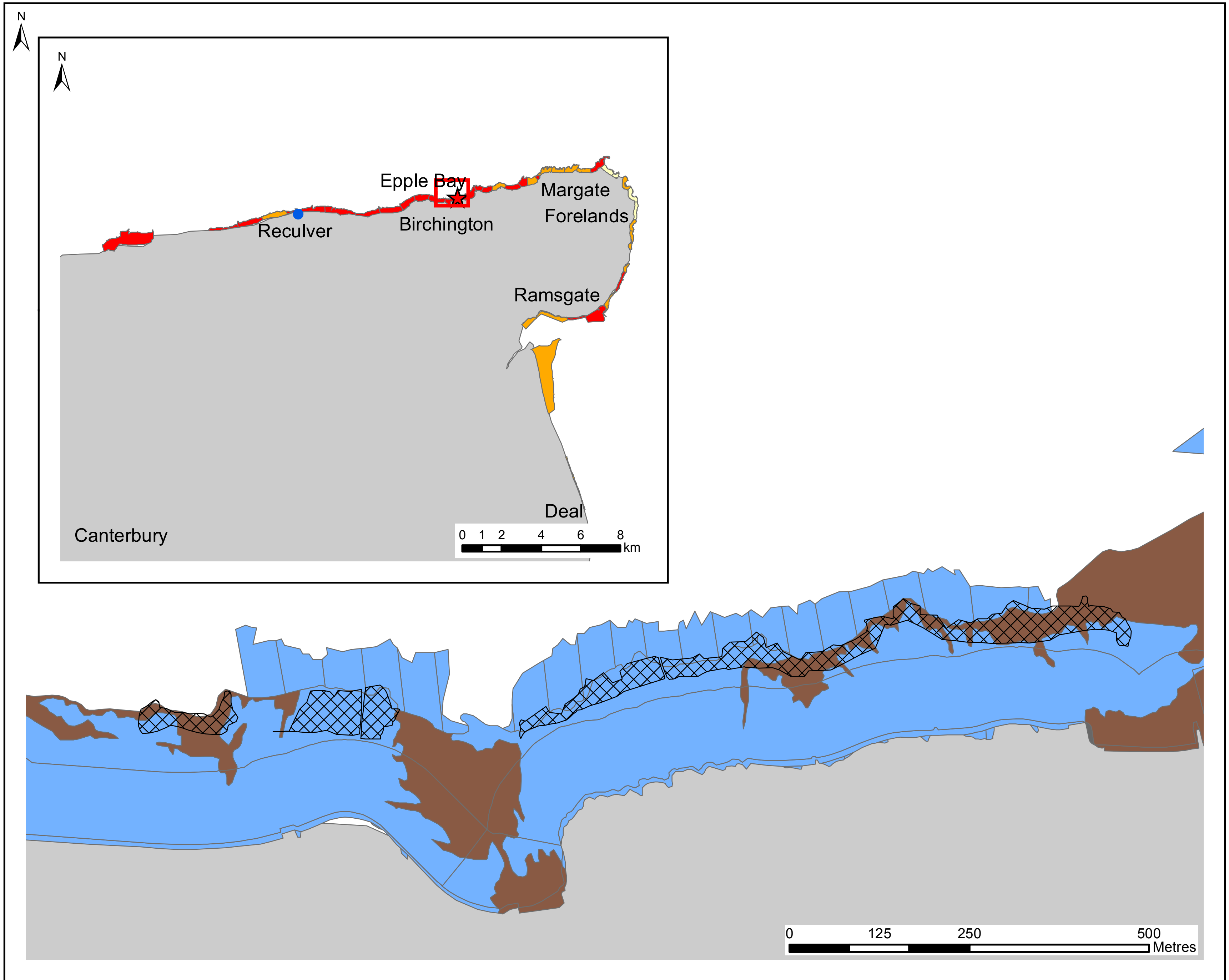
Date	By	Size	Version
May 12	MCE	A4	1
Projection		OSGB 1936	
Scale		1:160,000	
QA		JDB	
4047-Fig1_Thanet_Coast.mxd			
Produced by ABPmer Ltd			

Data Sources: Cefas, Natural England
NOT TO BE USED FOR NAVIGATION

ABP mer marine environmental research

Conservation Designations and Wild Pacific Oyster Populations and Authorised APBs Around the Thanet Coast

Figure A1



Main Legend

Known Dense Aggregations/ Reefs of Pacific Oysters (up to c.200 per m²)

Intertidal Habitat

- Littoral Chalk
- Mudflats
- Rock other than Chalk

Inset Legend

- Known Dense Aggregations/ Reefs of Pacific Oysters
- Pacific Oyster APB

Pacific Oyster Peak Density
Oyster per m²

- 1
- 2 - 10
- >10

Aquaculture Production Business (APB)

Date	By	Size	Version
May 12	MCE	A4	1
Projection		OSGB 1936	
Scale		1:7,500	
QA		JDB	
4047-Fig2_Thanet_Coast.mxd			
Produced by ABPmer Ltd			

Data Sources: Natural England, Defra,Cefas
NOT TO BE USED FOR NAVIGATION

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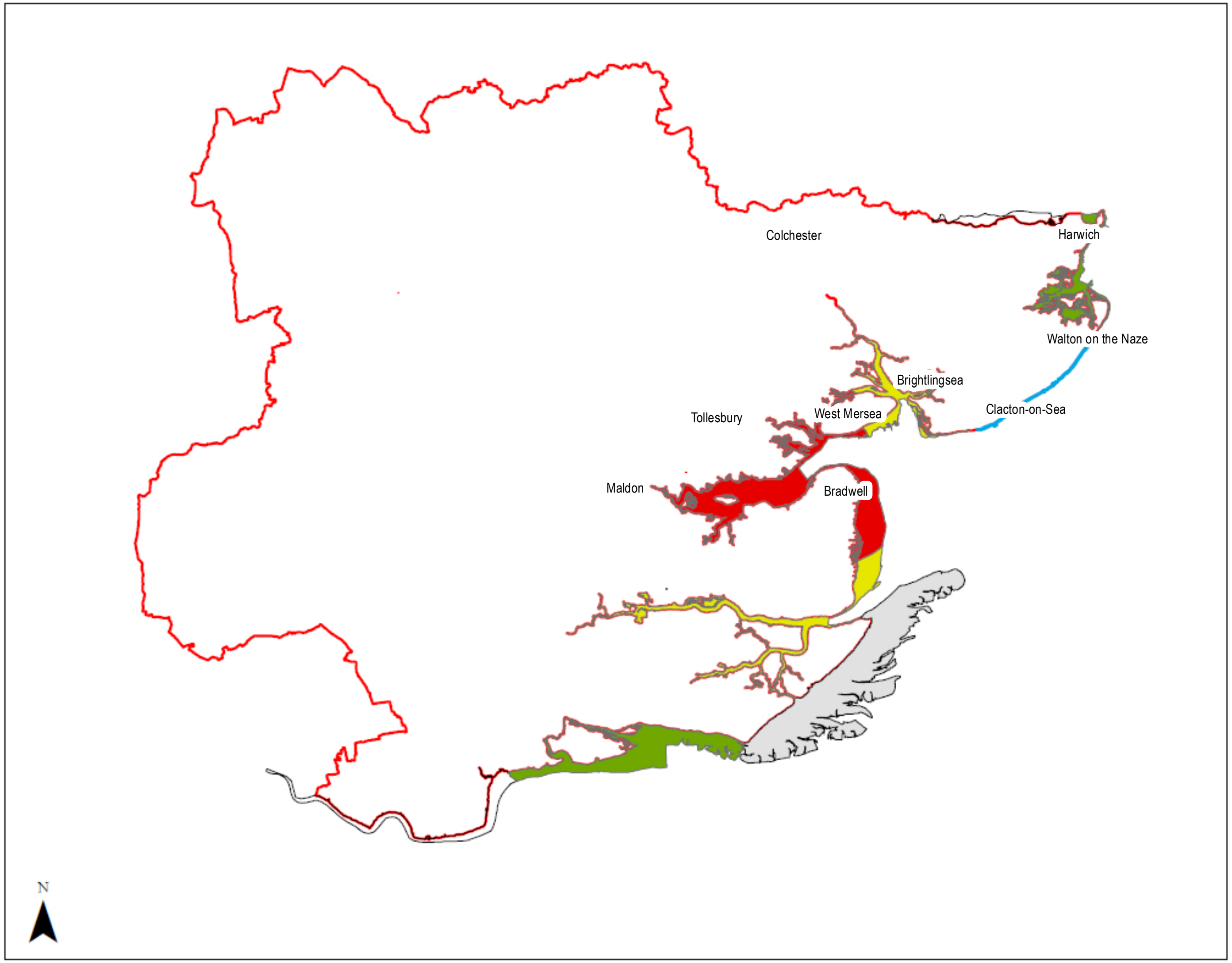
Wild Pacific Oyster Distribution within Intertidal Broadscale Habitats

Figure A2



THE wildlife TRUSTS

ESSEX Wildlife Trust

Intertial pacific oyster density

Oyster Density

- High Red
- Medium Yellow
- Low Green
- No Oysters
- No Data
- NA
- Essex_county_boundary

0 2.5 5 10 km

Date	By	Size	Version
June 12	MCE	A4	1
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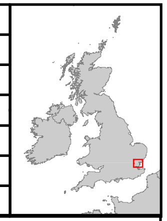
Scale		1:290,000	
QA		JDB	
4047-Fig3_Essex_PO.mxd			
Produced by ABPmer Ltd			



Data Sources: Essex Wildlife Trust (2012)
NOT TO BE USED FOR NAVIGATION

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marine environmental research

Distribution of Wild Pacific Oyster Around the Essex Coast

Figure A3

Appendix B

Industry Questionnaire

Appendix B. Industry Questionnaire

SAGB Pacific Oyster Project

The Shellfish Association of Great Britain (SAGB) has commissioned a project to obtain a balanced assessment of issues concerned with the cultivation of Pacific Oysters (PO) *Crassostrea gigas* in the UK. In particular we are interested in all information associated with the Pacific Oyster including the value of cultivation/harvesting and point of view from those for whom the Pacific Oyster represents part or all of their family income.

The report is being prepared by Bournemouth University and they would value your assistance in responding to this questionnaire. The project has a steering group of industry members and regulators. Please return questionnaire to address below. Many thanks for your assistance.

1. Which port do you operate from ?

2. Do you cultivate PO's or fish wild PO's or both or neither?

3. What and where are your markets?

4. If you cultivate a range of species or have other enterprises, about what proportion of your income would you estimate is attributable to PO cultivation?

5. Are there any benefits from PO cultivation apart from food production?

6. Have you observed any wild settlement of PO's in your locality? If so, are there any procedures in place to manage PO settlement?

7. Do you have any observations of 'recreational harvesting (hand-collecting)' of wild Pacific Oyster in your locality?

8. Do you consider that there are any benefits arising from wild settlement and reefs of PO?

9. Do you have any local observations of interactions between PO adult or spat and other marine species? e.g. predation by crabs and birds. What other species are found with PO's?10. Have you observed any large-scale mortality of cultivated PO's?

11. What are your views on use of Triploid oysters?

12. Is there anything else you would like to tell us from your knowledge of or opinions on the PO industry? For example, what challenges have you experienced with regards to the legal status of the species?

It would be useful to have your contact details written below. Otherwise an anonymous response is also useful to us

Contact Details (Optional)

Appendix C

Keywords Used as Search Terms

Appendix C. Keywords Used as Search Terms

Pacific Oyster
Crassostrea gigas
Dispersal
Biodiversity
Conservation
Marine Protected Areas
Non-native species
Non – indigenous species
Alien species
Feral
Management
Measures
Settlement
Larval transport
Larval supply
Triploid
Polyploid
Recruitment
Reefs
Ecosystem Processes
Ecosystem Services

Ecosystem Service Keyword Searches

Water quality
Water filtration
Water purification
Regulation of pollution
Wild harvesting
Aquaculture
Coastal defence
Coastal protection
Natural hazard protection
Environmental resilience
Ornamental materials
Medicines
Aquaria
Research
Education
Fertiliser
Feed
Salt
Biofuels
Tourism
Recreation
Sport
Spiritual wellbeing
Aesthetic benefits
Nature watching

Appendix D

Assumptions and Sensitivities Underlying the Estimation of the Economic Impact of UK Pacific Oyster Production

Appendix D. Assumptions and Sensitivities Underlying the Estimation of the Economic Impact of UK Pacific Oyster Production

GVA and Economic Contribution

Direct economic contribution is often expressed as an estimate of Gross Domestic Product (GDP) or Gross Value Added (GVA). The relationship between these two measures is as follows:

GVA + taxes on products - subsidies on products = GDP (ONS, 2012).

GVA would commonly be used to measure the contribution to the economy of an individual producer, industry or locality. To avoid double counting when aggregating the GVA statistics of particular industries (to estimate regional or national economies as a whole), GVA is calculated in terms of a net output by subtracting the value of goods and services purchased in the production process (intermediate consumption) from the total sales value of the product (gross output). In practice the intermediate costs are often subtracted using a “value added factor” which represents the relationship between output and intermediate costs for the type of activity in question (ONS, 2012).

GVA is a measure of direct economic contribution and does not represent the full economic impact of an activity. Conventionally full economic impact is determined by adding the benefit of an activity to its suppliers (the indirect effect of Pacific oyster production) and the proportion of personal household income from employment (generated both directly and with suppliers) which is re-spent on final goods and services (the induced effect of Pacific oyster production). In practice the indirect and induced effects of an activity can be calculated using published industry specific multiplier factors.

Limitations of the Method

Although the use of published multipliers for estimating GVA and impact is an approach commonly used by industrial and (local) governmental organisations, limitations in the approach relating to the applicability of multiplier factors in particular cases should always be recognised. As far as we are aware there are no published factors derived from, and relating specifically to bivalve fisheries and aquaculture. However there are multipliers for aquaculture, fisheries, wholesaling retailing and hospitality. This issue, to a greater or lesser extent, affects all multiplier-based studies which therefore need to be recognised as useful approximations rather than precise estimates. Should specific shellfish industry multipliers become available, the re-calibration of our model would be a straight-forward process. Despite these limitations multiplier based estimations are widely regarded as providing cost effective and valid information as a basis for decisions.

Assumptions

Although all the assumptions used in our estimations are based on evidence from the literature, or corroborated information from the industry, nevertheless our final approximations of GVA and economic impact are sensitive to variations in their validity. Therefore these assumptions have been made explicit below.

1. The annual production figure is a reliable approximation;
2. The estimate of shells per tonne is a reasonable approximation to the national mean;
3. The market structure model and supply chain prices are generally representative;
4. Our estimated percentage of UK production which is exported is valid;
5. Estimated wastage at each stage of the value chain is representative; and
6. The multiplier factors used are representative of bivalve value and impact chains.

Positive and negative differences between our assumptions and reality will interact in the calculations. In general we have taken conservative positions and on balance we believe that our figures are more likely to under-estimate, rather than over-estimate, the economic significance of UK Pacific oyster production. It should also be noted that, since our calculations exclude hatchery production and imported oysters, our figures do not represent the total contribution of the Pacific oyster to the UK economy, but rather that (major) part of it with the most relevance to the features of UK benthic habitats and related issues of fishery regulation and management, which are the focus of this report.

Further Work

Our suggested priorities for further work in this area are as follows:

- Developing bivalve specific industry derived multipliers. These would be a useful asset to apply in future decision processes;
- Honing our market model particularly in terms of the retail and consumption side;
- Examining bivalve hatchery production and markets in such a way as to also establish GVA, economic impact, export value and potential;
- Investigating the parameters of imported bivalves in the value chain; and
- Applying similar approaches to other bivalve shellfish species and/or the industry as a whole.

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