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Making Sense of the Marine Environment ™

Swansea Bay: Potential for Native Oyster Restoration

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Swansea Bay: Potential for Native Oyster Restoration

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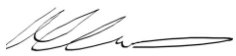
02/07/2021	Marja Aberson	1.2	Technical Review	
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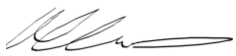
28/10/2021	Marja Aberson	2.1	Technical Review	
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1. Introduction

The European native oyster *Ostrea edulis* (native oyster) was once the basis of an important shellfish industry in South Wales; records date commercial fisheries at Mumbles and Oystermouth stretching back to Roman times. By the late 19th Century the local oyster fishery employed many hundreds of people, supported 200 vessels, together landing over 9 million oysters, many of which were transported to the London markets and beyond to the continent. This fishing pressure on the beds, combined with poor water quality from heavy industry, domestic wastewater pollution and disease, resulted in the demise of the oyster population by the 1920s.

Elsewhere in Europe, oyster populations have been further decimated by the *Bonamia* disease introduced in the 1960s. Native oysters are now designated by OSPAR as a threatened species and are a Species of Principal Importance and a Feature of Conservation Importance in Wales under Section 7 of the Environment (Wales) Act 2016. Swansea Bay is in a unique position as being the only *Bonamia* disease free oyster population in the UK, making the Bay the best candidate site nationally for *Bonamia*-free restoration.

Members of Swansea Bay Local Fisheries Local Action Group (SBFLAG) members have led efforts to restore the local native oyster population and cultural links to the fishery. Mumbles Oyster Company Ltd. attempted restoration of native oyster beds by relaying 40,000 adult oysters at Mumbles. Although there is no evidence of restored or sustained oyster densities, anecdotally they may have contributed to larval supply of the surrounding waters. Mumbles Development Trust successfully run oyster festivals in the village which annually demonstrate the community's enthusiasm for this heritage fishery and the demand for high quality local seafood.

Cyngor Abertawe/Swansea Council (hereafter called Swansea Council) is the administering authority of the SBFLAG. It is made up of volunteers wishing to represent the fishing and aquaculture sector community. Swansea Council have commissioned MarineSpace to produce a literature review of native oysters, with a focus on Swansea Bay. The literature review provides a review of the different environmental factors that may influence restoration projects within Swansea Bay, and the current restoration projects around the UK, so that an action plan can be produced which provides details of how to execute native oyster restoration in Swansea Bay.

2. Policy and Legislation

2.1. The Well-being of Future Generations (Wales) Act 2015

The policy intent of the Well-being of Future Generations (Wales) Act 2015 is to improve the social, economic, environmental and cultural well-being of Wales. The Act places a statutory duty on public bodies in relation to sustainable development, based on 7 well-being goals, shown in Figure 2.1.

The Act provides a mechanism for public bodies to set targets and report progress against indicators. Through its well-being objectives, the Act sets a clear agenda for sustainable development which can be achieved through the following 5 Ways of Working that public bodies should undertake:

- Long-term: The importance of balancing short-term needs with the needs to safeguard the ability to also meet long-term needs;
- Integration: Considering how the public body's well-being objectives may impact upon each of the well-being goals, on their objectives, or on the objectives of other public bodies;
- Involvement: The importance of involving people with an interest in achieving the well-being goals, and ensuring that those people reflect the diversity of the area which the body serves;
- Collaboration: Acting in collaboration with any other person (or different parts of the body itself) that could help the body to meet its well-being objectives;
- Prevention: How acting to prevent problems occurring or getting worse may help public bodies meet their objectives.

Oyster restoration could address specifically the second goal, a resilient Wales, through the biodiversity enhancing properties of oyster reefs, but it could also contribute to achieving the other well-being goals.

Figure 2.1: The 7 well-being goals from the Well-being of Future Generations (Wales) Act 2015

2.2. The Environment (Wales) Act 2016

The Environment (Wales) Act 2016 introduces legislation to manage Wales' natural resources in a more sustainable way, positioning Wales as a low carbon, green economy. The key parts of the Act look at the sustainable management of natural resources and climate change.

The Act also sets out the requirement, under Section 7, to establish a biodiversity list and to take steps to maintain and enhance biodiversity. This replaces the duty under section 42 of the NERC Act 2006. Native oyster is a Section 7 Priority species.

2.2.1. State of the Natural Resources Report (SoNaRR)

A duty under the Environment (Wales) Act 2016 is for Natural Resources Wales (NRW) to undertake an assessment of the state of the natural resources in Wales, identifying the extent to which they are sustainably managed and future trends that may impact them. This is documented in the State of the Natural Resources Report (SoNaRR).

The first SoNaRR was published in 2016 when the Environment (Wales) Act 2016 was first introduced. The second SoNaRR (SoNaRR2020) was published in 2020 and builds upon the 2016 version.

SoNaRR2020 assesses marine natural resources, including the economic opportunities they can provide, for example from aquaculture.

2.2.2. Natural Resources Policy

Using the 2016 SoNaRR, Welsh Ministers published the Natural Resources Policy (NRP) in 2017 as required by the Environment (Wales) Act 2016. The NRP sets out the risks, opportunities and 3 main priorities in relation to the management of Wales' natural resources. The priorities are:

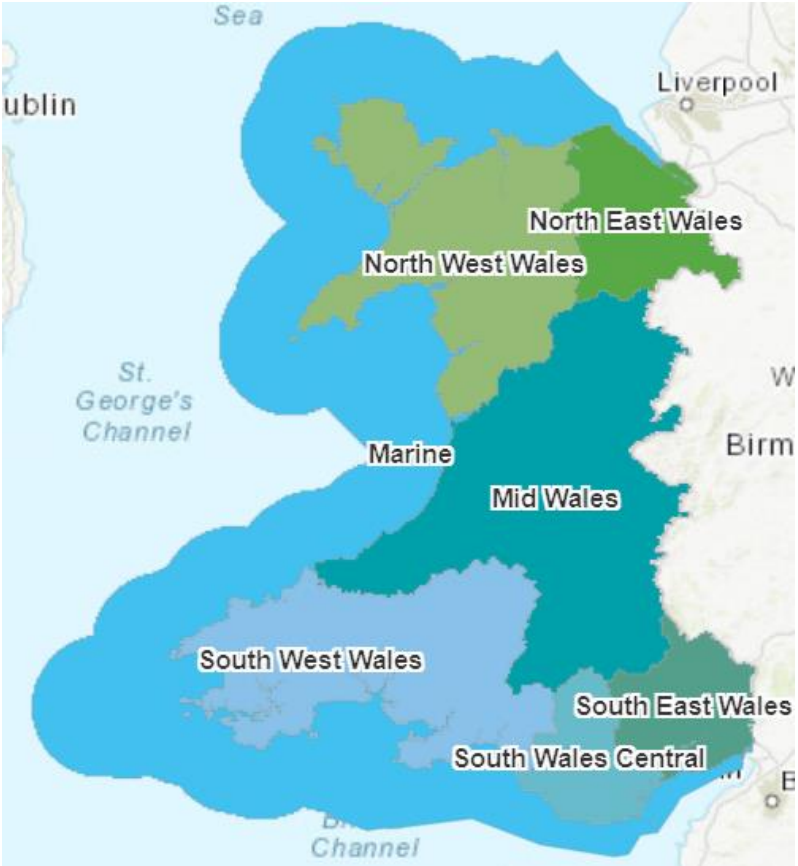
- Delivering nature-based solutions;
- Increasing renewable energy and resource efficiency;
- Taking a place-based approach.

2.2.3. Area Statements

Following on from the Natural Resources Policy, there is a requirement for NRW to lead the development of Area Statements, to implement the national priorities as well as identifying area specific themes and ways to achieve these.

The Area Statements cover 7 separate and diverse regions of Wales, as shown in Figure 2.2.

Figure 2.2: The 7 Area Statements in Wales



2.2.3.1. Marine Area Statement

The Marine Area Statement extends out to 12 nautical miles and accounts for 43% of the total Welsh territory (NRW, 2021a).

The key themes for the Marine Area Statement are:

- Building resilience of marine ecosystems;
- Nature-based solutions and adaptation at the coast;
- Making the most of marine planning.

NRW recognises that oysters can help to ensure resilient marine ecosystems. The Swansea Bay Native Oyster Restoration Project aligns well with all 3 of the Marine Area Statement themes and particularly *Building resilience of marine ecosystems.*

2.2.3.2. South West Wales Area Statement

The South West Wales Area Statement encompasses the local authorities of Swansea, Neath Port Talbot, Pembrokeshire and Carmarthenshire (NRW, 2021b).

The key themes for the South West Wales Areas Statement are:

- Reducing health inequalities;
- Ensuring sustainable land management;
- Reversing the decline of, and enhancing, biodiversity;
- Cross-cutting theme: Mitigating and adapting to a changing climate.

The Swansea Bay Native Oyster Restoration Project is aligned with the *Reversing the decline of, and enhancing, biodiversity* theme.

2.3. Wales Act 2017

The Wales Act 2017 introduces a new reserved powers model of devolution for Wales. Part A1 of The Wales Act 2017 makes the National Assembly a permanent part of the UK's political framework. As a result, the National Assembly will be able to legislate on anything not reserved to the UK Parliament.

The Wales Act 2017 devolves powers to the National Assembly and Welsh Government in areas including consenting for new energy projects and designation of marine conservation zones.

2.4. National Policy Statements and Plans

2.4.1. Maritime Spatial Planning Directive

The Maritime Spatial Planning Directive (EU Directive 2014/89) (MSPD) has been in effect since September 2014. The MSPD defines Maritime Spatial Planning as a process by which the relevant Member State's authorities analyse and organise human activities in marine areas to achieve ecological, economic and social objectives". To achieve this, the MSPD requires EU member states to draw up maritime spatial plans no later than 31 March 2021. These plans will enable public authorities to organise human activities in marine areas ensuring efficiency and sustainability of ecological, economic and social objectives.

2.4.2. Marine Policy Statement

The Marine and Coastal Access Act 2009 enshrines the UK's commitments under the MSPD into domestic legislation. From this, the Marine Policy Statement was developed which provides the policy framework for the preparation of marine plans and establishes how decisions affecting the marine area should be made in order to enable sustainable development in the UK. All UK administrations adopted the Marine Policy Statement in March 2011.

The Marine Policy Statement sets out a vision of having '*clean, healthy, safe, productive and biologically diverse oceans and seas*' by supporting the development of Marine Plans. The Marine Policy Statement identifies aquaculture as a '*key focus for future development of a sustainable food source and as a possible source of employment'.*

2.4.3. Welsh National Marine Plan

By adopting the Marine Policy Statement, the Welsh Government committed to the requirement to introduce a Marine Plan for Wales. The first Welsh National Marine Plan (WNMP) covering Welsh inshore and offshore waters was published in November 2019 by Welsh Government. The WNMP has been developed in accordance with the MSPD, the Marine Policy Statement and the Marine and Coastal Access Act 2009.

As the WNMP was adopted in November 2019, all public authorities are required to consider it (and the wider UK MPS) when making decisions regarding the marine area. This ensures that marine resources are used in a sustainable way in line with the high-level marine objectives.

The WNMP sets out a series of policies for the management and sustainable development of the Welsh marine environment. These include general and sector specific policies that aim to meet the 7 Well-Being Goals set out under the Well-Being of Future Generation (Wales) Act 2015.

2.4.4. Welsh National Marine Plan and Native Oyster Restoration

Sector polices for Aquaculture are included in the WNMP, which apply to both the Welsh inshore and offshore regions. The WNMP makes specific reference to oysters as an example of a potential new species for cultivation and research commissioned by Welsh Government which, suggests potential for shellfish aquaculture.

The Sector Objective for Aquaculture is defined as: *To facilitate the development of sustainable aquaculture in Welsh waters, including promoting innovative finfish, shellfish and marine algal businesses and associated supply chains.*

Aquaculture specific considerations within the WNMP include:

- Opportunities for coexistence or co-location, such as with renewable energy developments;
- Fitting well with or enhancing the local character of an area including heritage, landscape and seascapes;
- Support the development of local seafood industries to bring jobs and boost tourism to support local economies and the well-being of coastal communities.

A selection of policies relevant to the Swansea Bay Native Oyster Restoration Project are outlined in Table 2.1.

Table 2.1: Policies that are relevant to the Swansea Bay native oyster restoration project

Policy No.	Policy
AQU_01a **Aquaculture (supporting)**	*Proposals for new aquaculture developments will be supported where they contribute to the objectives of this plan. Proposals should comply with the relevant general policies and sector safeguarding policies of this plan and any other relevant considerations.*
AQU_01b **Aquaculture**	*Relevant public authorities and the sector are encouraged, in liaison with other interested parties, to collaborate to understand opportunities for the sustainable use*

Policy No.	Policy
(supporting)	*of aquaculture resources including the identification of: natural resources that provide aquaculture potential opportunities to define and, once in place, further develop and refine Strategic Resource Areas for aquaculture in order to support the sustainable development of the aquaculture sector through marine planning.*
ECON_01 Sustainable economic growth	*Proposals for economically sustainable activities are encouraged, particularly where they contribute to: • the sustainable management of natural resources thereby supporting ecosystem resilience; • a more resilient economy; • employment opportunities particularly for coastal communities; • protecting and creating employment at all skill levels; • maintaining communities with a high-density of Welsh speakers; and/or • tackling poverty by supporting deprived coastal communities.*
SOC_02 **Well-being of coastal communities**	*Proposals that contribute to the well-being of coastal communities are encouraged.*
SOC_04 **Welsh language and culture**	*Proposals that contribute to the promotion and facilitation of the use of the Welsh language and culture are encouraged.*
ENV_01 Resilient marine ecosystems	*Proposals should demonstrate how potential impacts on marine ecosystems have been taken into consideration and should, in order of preference: a) avoid adverse impacts; and/or b) minimise impacts where they cannot be avoided; and/or c) mitigate impacts where they cannot be minimised. If significant adverse impacts cannot be avoided, minimised or mitigated, proposals must present a clear and convincing case for proceeding. Proposals that contribute to the protection, restoration and/or enhancement of marine ecosystems are encouraged.*

2.4.5. Planning Policy Wales

Welsh Government's land use policies are set out in Planning Policy Wales (PPW). Edition 11 of PPW was published in February 2021. PPW is supported by a series of documents, including Technical Advice Notes and policy clarification letters, which collectively form the national planning policy framework for Wales. The key objective of PPW is to ensure a planning system that contributes towards sustainable development and improving the social, economic, environmental and cultural well-being of Wales. PPW also takes into consideration meeting the aims of the "*Sustaining a Living Wales*" green paper to ensure that the development does not take precedent over other factors in the environment.

Coastal Areas are a key feature throughout PPW, under the *Distinctive and Natural Linkages* theme. One of the PPW outcome for *Distinctive and Natural Linkages* is: *the role which landscapes, the historic environment, habitats and biodiversity, the characteristics of coastal, rural or urban environments play in contributing to Distinctive and Natural places are identified, understood, valued, protected and enhanced.*

The Swansea Bay Native Oyster Restoration Project aligns with PPW and can help achieve the desired outcomes of linking the coast through both enhancing habitats and biodiversity as well as linking with the historic environment.

2.4.6. Swansea Local Development Plan

The Swansea Local Development Plan (LDP) 2010 – 2025 was adopted by Swansea Council in February 2019. It is used as the primary material consideration to inform decisions on planning applications and development proposals.

The LDP vision is set out as:

- Capitalising on the distinctive relationship between its vibrant urban areas and outstanding rural and coastal environments;
- Supporting a competitive and prosperous economy that acts as a focal point for the wider Swansea Bay City Region;
- Has sustainable, distinct communities, in both urban and rural locations, that benefit from quality homes supporting infrastructure, community facilities and a wide range of opportunities for recreation;
- Providing a thriving City Centre destination that offers excellent shopping facilities and supporting leisure and business opportunities, capitalising on its proximity to the waterfront;
- Celebrates and conserves its unique natural heritage and cultural and historic environments.

3. History

The native oyster once covered vast areas of UK's coastline and constituted a central ecological and economic resource (Linnaeus, 1758). It represented up to 32% of the food intake of coastal communities and has been a source of food for humans since the Stone and Iron Ages (Kristensen, 1997). Areas called "shell middens", measuring up to 300 m long and contain up to 83,000 shell per cubic metre have been found, highlighting the historical importance of native oysters as a food source (Surge and Milner, 2003). Romans started cultivating native oyster as early as 100 BC (Iversen 1968; Gercken and Schmidt, 2014).

In the 13th century one of the first commercially operated fisheries was for native oyster and in the 14th century it was accepted as monetary equivalent to pay rent and taxes (Lotze, 2007; Young, 1886). In the mid-1800, in London alone at the peak of its production period, 700 million native oyster were consumed annually (Philpots, 1890). Dredging oysters in Britain in the mid-1800s, engaged around 120,000 men, underlining both the productivity of the beds and the scale of the harvest (Beck *et al*., 2011, Edwards, 1997). The immense demand for native oyster, together with increasingly more efficient fishing techniques led to the decline of this species throughout its geographic range. Today, Europe´s native flat oyster beds are considered endangered (Airoldi and Beck 2007; Beck *et al.,* 2009).

For millennia, Europe's vast natural oyster beds were primarily harvested for subsistence purposes. Native oysters were gathered by hand or using bucket and tongs (Yonge, 1960). Their exploitation was limited by accessibility to the lower intertidal zone and the ability of individuals to reach oysters (Gercken and Schmidt, 2014). However, improved fishing techniques and a developing market has driven the commercial exploitation of native oyster beds. Overfishing coupled with environmental factors has led to the decline of the native oyster (UMBSM, 2007).

Changes in the methods of fishing and technology eased the harvesting of oysters making it more efficient. Steamboats and railways were used in the 19th century helping to expand fishing grounds and provide efficient transport of oysters on land (Yonge, 1960; Seaman and Ruth, 1997; UMBSM, 2007). The improving technology and the change from hand gathering to oyster dredging led to a decrease in native oysters in Europe.

In 1695, extreme winters in Germany exacerbated the impacts of overfishing, bringing about the ruin of oyster beds (Gercken and Schmidt, 2014). In 1778, records of oyster stock decline were also found in Spain (Laing, 2005). In the early 19th century 100 million oysters were landed in France, but by the middle of the century local populations had been extirpated to the point that commercial harvesting was no longer profitable (Yonge, 1960). Similarly in 1864, annual oyster production in the UK fell from 700 million to 40 million oysters in 1920, and by the 1970s this had further dropped to 3 million (Figure 3.1; Philpots, 1890; Davidson, 1976; Edwards, 1997).

Figure 3.1 Total catch and value of native oysters in England and Waled from 1920-1972 (Source: Davidson, 1976)

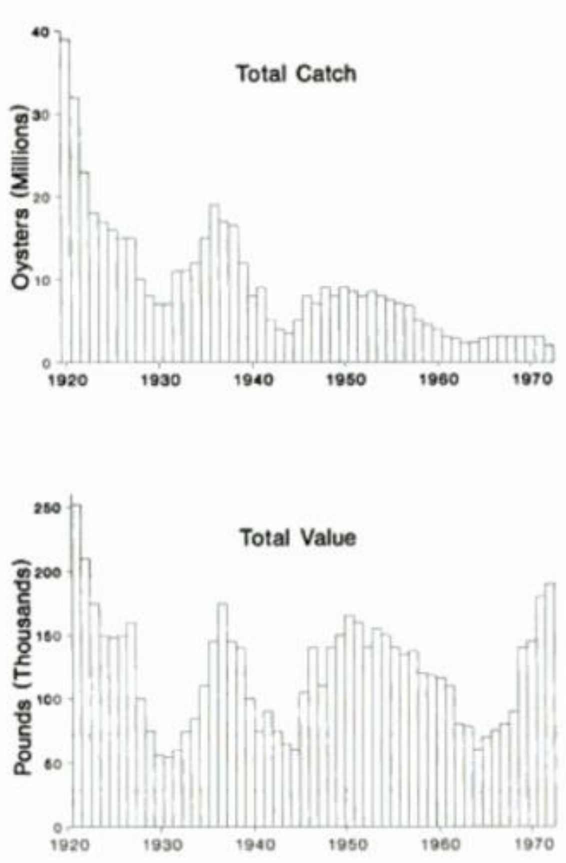


Figure 2
Landings and value of native flat oysters in England and Wales (1920–72). Source: Davidson, 1976.

Oyster stocks also continued to decrease in Spain and Germany. In 1960, oyster exploitation was no longer profitable in Spain (Laing, 2005), and in 1927, the German beds were decimated (Gercken and Schmidt, 2014). Several countries tried to prevent the decline of native oyster through systematic management. In 1703-1706 and 1882-1891 harvesting bans were implemented in Germany. In Britain, from 1709, it was forbidden to sell undersized oysters and to fish during the reproductive season (Seaman and Ruth 1997). Minimum landing sizes were introduced as well as other restrictions, and public fishing rights were granted to regulated fisheries to ensure these were adhered to. The government also banned the sales of oyster during the breeding season. This ban to sell oysters from May 14 to August 4, is still enforced in UK under the Sea Fisheries (Shellfish) Act of 1967 (Edwards, 1997; GOV UK, 2016).

In addition to harvesting restrictions, restoration attempts were conducted throughout Europe using a cultivation technique developed by the French and most likely inspired by the Roman culturing methods (Gercken and Schmidt, 2014). The method consisted in forming “oyster parks” by laying tonnes of imported breeding oysters and shell cultch as settlement substrate for larvae. Other methods to collect spat included the use of roof tiles and bundles of sticks. The young spat were removed from the tiles and placed into wire covered trays which offered protection from predators until they were large enough to be placed back into the parks (Yonge, 1960).

In Norway, the technique was modified to create hanging cultures at a depth of 1-2 m, where higher temperatures accelerated oyster growth and oysters were protected from predators (Strand and Vølstad, 1997). In the 1960s, Spain imported oysters from France which resulted in the introduction of the diseases *Bonamia* and *Marteilia*, which quickly spread and reduced the oyster population by 80% (Laing, 2005). Tests in 1982 revealed that *Bonamia* had also been introduced in England, further depleting their stocks and contributing to the depletion of donor stocks alongside overfishing (Edwards, 1997; Yonge, 1960).

In addition to fishing, coastal expansion and changes due to human population growth and development may have contributed to the demise of the native oyster. Impacts include water pollution, coastal degradation and the introduction of exotic species (Airoldi and Beck, 2007; Thurstan *et al.,* 2013). For example, unharvested stocks in Bulgaria declined drastically with no fishing. In the UK, a mixture of circumstances such as increased sedimentation due to coastal development, hypoxia events, competitive species and pathogens may have caused the virtual extinction of the native oyster populations (Todorova *et al*., 2009). Despite these challenges the main reason for the loss of most of the native oyster population is still attributed to the overfishing to the point where exploitation was no longer economically viable. The harvesting of adult oysters coincided with a reduction in larvae and a loss of shell-matrix, which is the larvae´s preferred settlement substrate and offers protection from sedimentation and predators. As a result, temporary closures were not able to revive the fisheries and the native oysters became more vulnerable to other stressors, such as diseases, non-native species and harsh winters (Gercken and Schmidt, 2014).

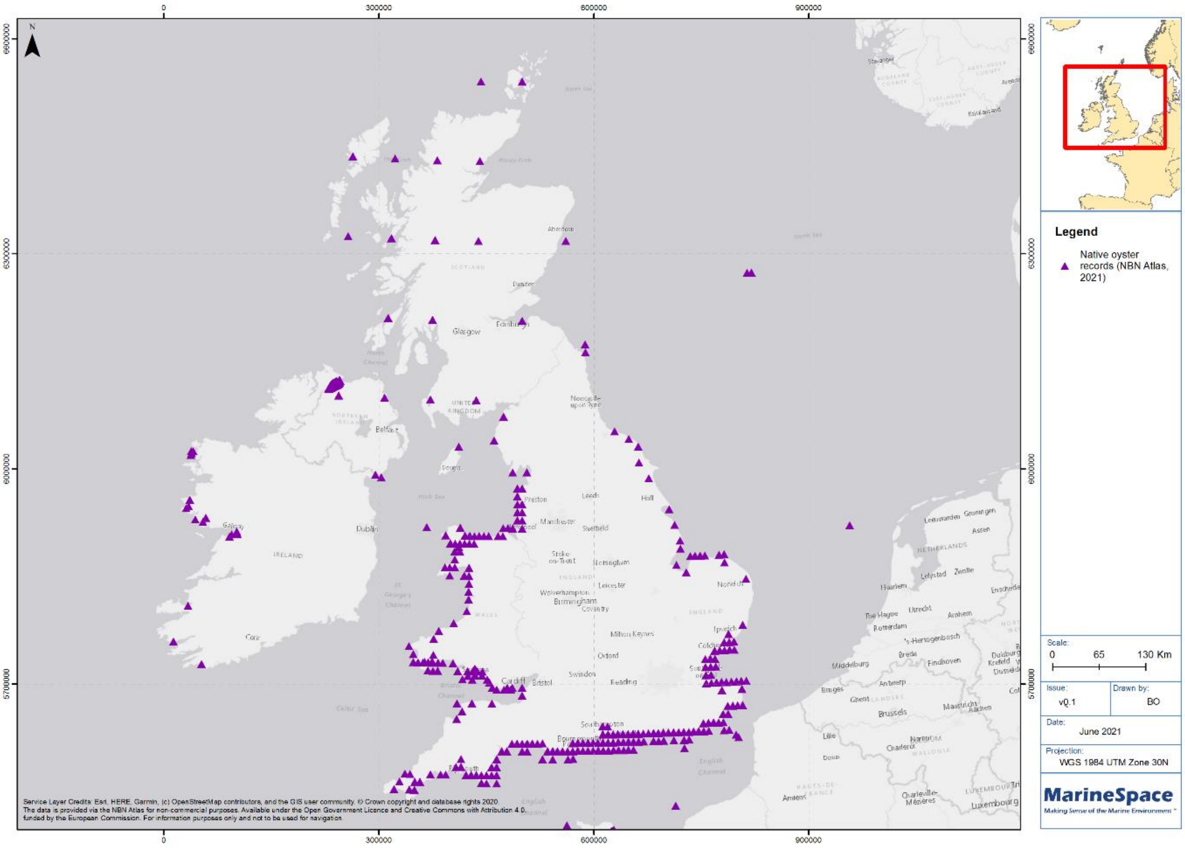
4. Description and Distribution

Native oysters were once abundant along the coasts of the UK, however due to disease, overfishing, extreme weather events, contaminants and the introduction of non-native species, oyster populations have declined. Oyster reefs are estimated to have dwindled by 85% globally according to Beck *et al*. (2011). Historical maps show the extent of native oyster reefs within the UK (Figure 4.1). They were eradicated from most of their natural range and are classified as threatened and/or declining by the OSPAR Commission (2008).

From the historical maps and more recent records, it can be determined that the distribution of native oyster reefs has been severely reduced. There are still some populations of native oysters around the UK (Figure 4.2), and some active restoration projects are aiming to restore reefs. Locations of historical native oyster reefs are important to determine as the environment was once suitable for native oysters to survive. These should be considered the optimal potential sites for restoration projects.

Figure 4.1: Historical map of the known distribution sites of *O. edulis* in 1883 around the UK (Olsen, 1883)

Figure 4.2: Current native oyster records around the UK (From: NBN Atlas, 2021)



Records of native oysters around Wales have been found close to the coast (NBN Atlas, 2021, Figure 4.3). The reproductive potential of these populations needs to be investigated to determine if populations can recover. A survey of native oyster beds in Wales was completed in 2003 and found that there were no native oysters within the areas of Swansea Bay along the surveyed transect lines. It was concluded that although the survey did not find any oysters, the mix of substrata, current conditions and the historic occurrence of the species suggested that it was likely that they were present within Swansea Bay (Emu Ltd, 2003).

Previous restoration attempts have been made within Swansea Bay by the Mumbles Oyster Company Ltd in 2013/2014. The project involved the relaying of 40,000 adult oysters on historic beds at Mumbles. Surveys were conducted in 2019 to assess the native oyster populations, however no spat or new recruits were observed. A total of 74 oysters were recorded from 40 tow stations, all of which were classified as mature organisms. There were 27 classified as recent recruits due to the shell depth <30 mm (Woolmer, 2019). Further investigation of the population dynamics of the Swansea Bay native oysters will need to be carried out.

APBmer conducted a spatial assessment of the potential for aquaculture of native oysters in Welsh waters (2015). The report concluded that Swansea Bay offered potential restoration sites for both trestle and bottom culture restoration methods (Figure 4.4). Both of these have been used in previous native restoration projects.

Figure 4.3: Current native oyster records around Wales (From: NBN Atlas, 2021)

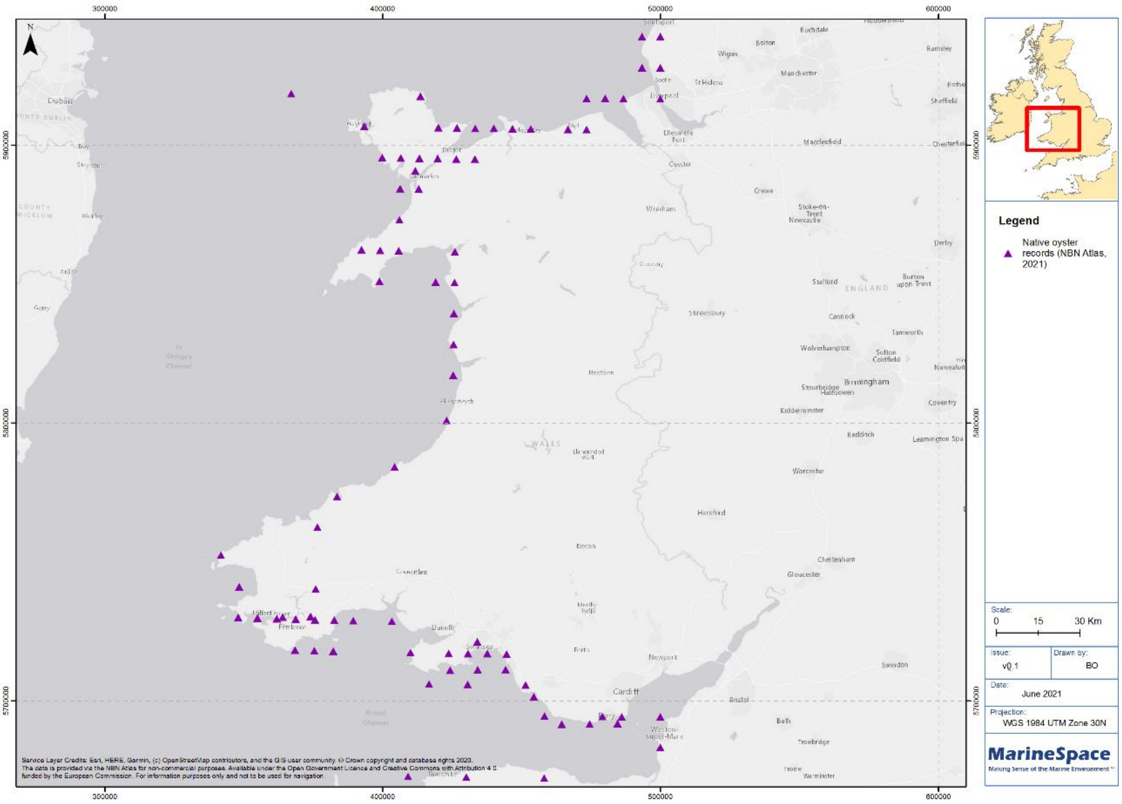
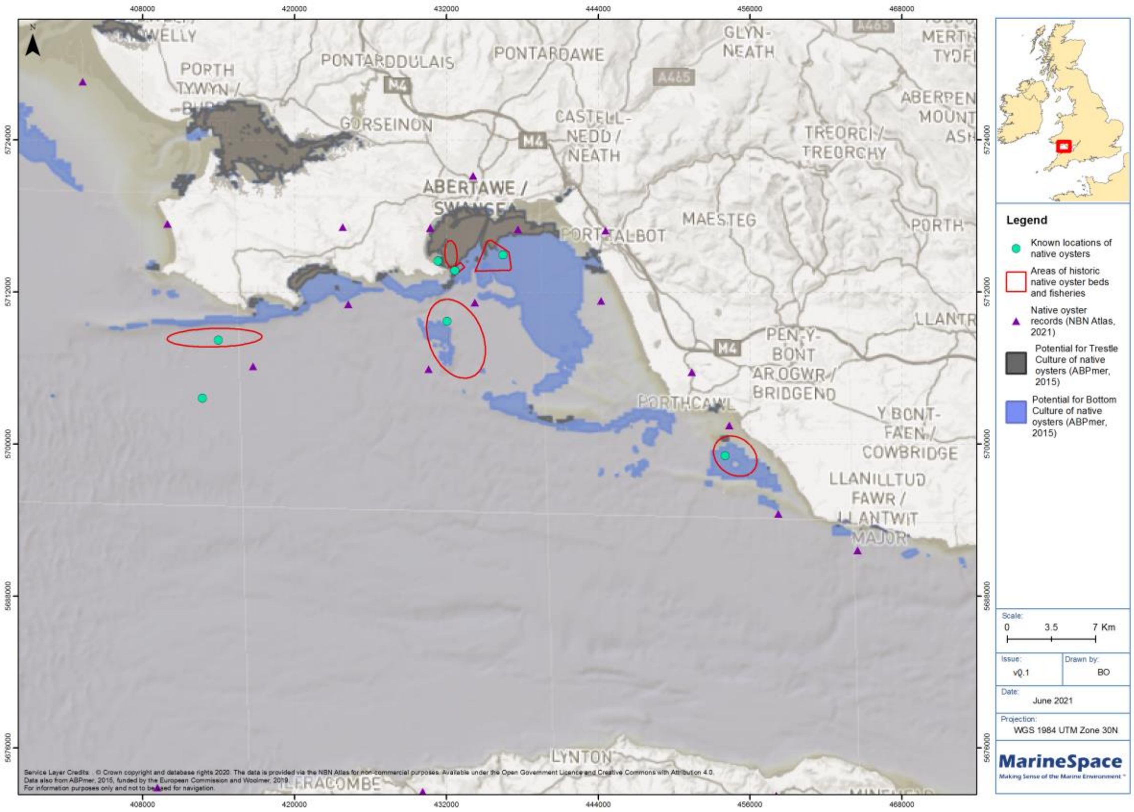


Figure 4.4: Current and historical native oyster records and potential culture areas in Swansea Bay (From: NBN Atlas, 2021; ABPmer, 2015)

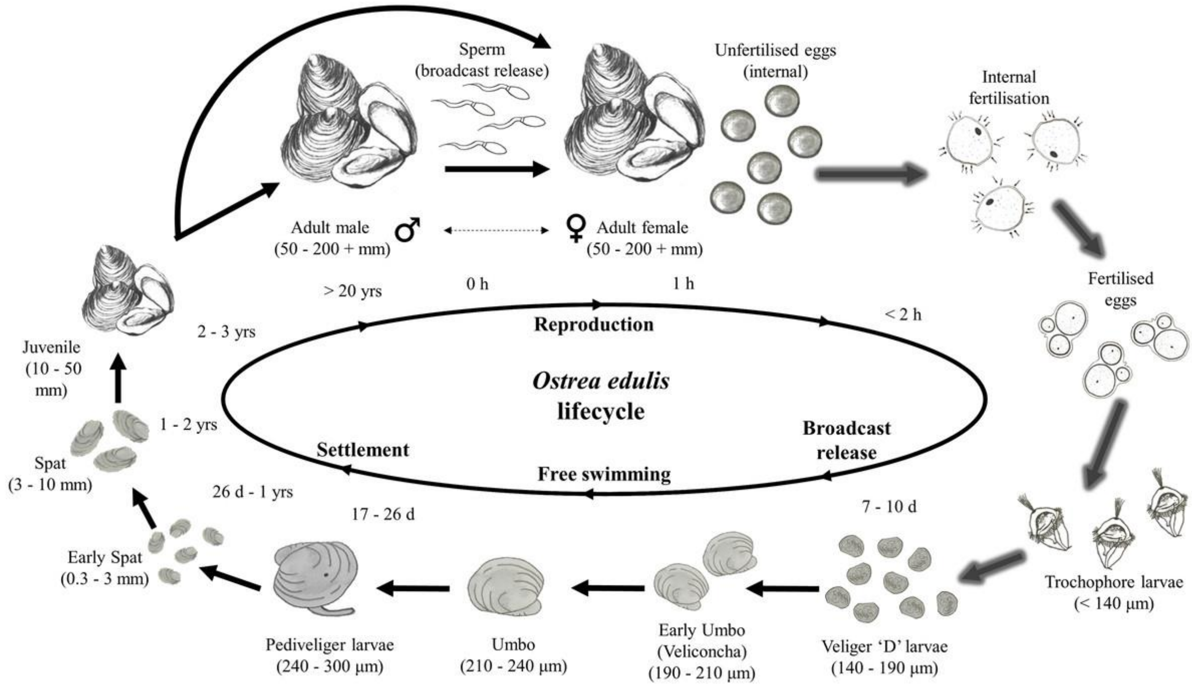


4.1. Biology

The European native oyster *Ostrea edulis* is a sessile bivalve mollusc, which belongs to the Ostreidae family. Similar to other bivalves, they inhale water and filter it through a gill chamber, thereby removing suspended food particles. Growth of oysters depends on food availability, and microalgae or organic matter are important nutritional sources (Grant *et al.*, 1990).

Native oysters mature first as males and after a few years they alternate between male and female sexual phases (Millar, 1964). The time it takes individuals to start reproducing as a female, and the subsequent rate of sex change, is strongly influenced by sea water temperature and the latitude at which the oysters occur (Spärck, 1922; Korringa, 1940). In the Bay of Biscay and the Mediterranean, gender changes may occur several times per year, whereas in Limfjord, Denmark, the first sex change occurs when the oyster is 3/4 years old and individuals form only one gender per year (Spärck, 1922; Gercken and Schmidt, 2014). It takes oysters about 2 years to start reproducing as a female and thereafter they usually function once as each gender per season (Cole, 1942). In temperate UK waters oysters reach sexual maturity in the 3rd or 4th summer after settlement (Kamphausen *et al.*, 2011; Korringa, 1952; Cole, 1941).

Figure 4.5: Lifecycle of the native oyster (Source: Helmer *et al.*, 2019)



Oysters usually spawn between late June and mid-September and remain dormant during winter; eggs or sperm are formed in spring (Hedgecock *et al.*, 2007; Kennedy and Roberts, 1999). According to Korringa (1957) it coincides with spring tides of both new and full moon. Spawning generally requires a minimum temperature of about 15°C (Korringa, 1940), although the exact temperature varies with local adaptation of the population and area (Korringa, 1957). In the warm sea water polls in Norway (which are heated by the greenhouse effect of a freshwater layer), spawning did not occur below 20°C (Korringa, 1957) where the former populations in the Firth of Forth seldom experienced temperatures above 15°C and therefore temperatures below 15°C presumably triggered spawning. It is not known if these differences between populations are genetically triggered, but translocated individuals transplanted from France to Loch Ryan in Scotland were able to adapt to local environmental conditions, and within years they spawned almost in synchrony with local individuals (Korringa, 1957; Millar, 1968).

Once the oysters have started to spawn, breeding continues as long as the temperature remains above the threshold value. The duration of the reproductive season can vary greatly and depends on the local environmental conditions (Korringa 1940). In the Dutch Oosterschelde, the breeding season ranged from June until August, peaking end of June or the beginning of July (Korringa, 1952). Similarly, the North Frisian Wadden Sea breeding season in the former German stocks began in June and ended in August or September (Gercken and Schmidt, 2014). In Scotland the spawning season extends from approximately May until August (UMBSM, 2007). In Ireland, they generally spawn between late June and mid-September (Kennedy and Roberts, 1999).

Mature males produce sperm in sperm packets, which break apart when they contact seawater. This is probably a mechanism to avoid self-fertilization, since ripe sperm packets may remain after sex change in the females (Orton, 1927; Korringa, 1952). Egg production in females increases with size and age. In one-year old oysters, egg production is around 90,000 and this increases in adult females to up to 1.5 million eggs (Cole, 1941; Walne, 1974). Adults which mature as females at the start of the breeding season produce twice as many eggs as oysters that start as males and change to females during the season (Cole, 1941).

Females transport sperm via the inhalant siphon into the mantle cavity, where eggs are fertilised (Orton, 1927). The larvae are retained in the mantle cavity for about 7 to 10 days from the date of spawning, although brooding time may exceed these values at temperatures below 15°C. Females brood fertilised eggs and larvae in their mantle cavity for 6 - 15 days, until the larvae have a fully formed shell of about 0.17 mm and are released into the water column (Hedgecock *et al.*, 2007; Newkirk and Haley, 1982, Andrews, 1979; Orton, 1927; Walne, 1974). Despite potentially high fecundity, good fertilisation success of native oysters relies on a minimum population density as sperm needs to reach a functional female. If the density of a population decreases below a threshold value, the chance of fertilisation also decreases and many eggs may remain unfertilised (Gercken and Schmidt, 2014).

The annual extent of larvae-production further depends on the number of adult oysters, the number of females participating in the reproduction event and the number of gametes they produce (Korringa, 1940). When released into the water column larvae drift in the plankton for approximately two weeks. They then develop a "foot", which enables them to settle on firm surfaces, followed by metamorphosis into a fully formed juvenile oyster (Laing *et al.*, 2005; Sobolewska and Beaumont, 2005).

Recruitment of larvae is subject to local environmental conditions, including predation, hydrographic regime, and the average summer sea water temperature (Jackson, 2007). The latter appears to be of particular importance, with less recruitment during colder summers and better recruitment occurring during warm summer sea temperatures. This is limiting the northern distribution range of native oyster (Korringa, 1940; Spärck, 1951; Korringa, 1952), which is likely due to exposure of planktonic larvae to lower temperatures, leading to high larval mortality (Korringa, 1940). Overall, recruitment success is highly sporadic and populations undergo natural phases of expansion and contraction. Successful recruitment appears to vary between 1-3 years (Loch Ryan, Scotland), or even every 6-8 years (Lough Foyle). The Limfjord fishery (Demark) was closed for 20 years to allow an oyster population to recover, and even longer periods may be required (Sparck 1951, Laing *et al.*, 2005).

4.2. Environmental Factors that Affect Growth and Survival

4.2.1. Temperature

Growth, reproduction, and survival of native oysters is influenced by temperature. This is particularly true for populations at higher latitudes, where lower sea water temperatures prolong maturation time and shorting the length of the spawning season. This decreases the amount of sex changes and the number of individuals acting as females in each spawning season. It is, therefore, assumed that recruitment at higher latitudes is lower and occurs more sporadically than at lower latitudes (Gercken and Schmidt, 2014). At lower latitudes growth may be continuous throughout the year, whereas at higher latitudes growth of native oyster is interrupted during the winter months (Korringa, 1952).

In the UK, adult native oysters grow between spring and November/December, when sea water temperatures are at least 8-9°C, forming an annual growth line each spring (Seafish, 2002; Surge and Milner, 2003). Growth rates peak in July/August, when temperatures reach maximum values of about 16-18°C (Seafish, 2002). In laboratory experiments, growth of adult individuals was optimal between temperatures of 15-20°C (Hutchinson and Hawkins 1992). Larval growth rate was high between 17.5-30°C, with virtually no growth at 10°C and a steady increase in growth with temperatures between 12.5-25°C (Davis and Calabrese, 1969). It has been suggested that the growth interruption of native oyster at low temperatures may be brought by a switch to a winter physiological state with minimal metabolic activity, which enables individuals to survive low temperatures and low salinities encountered in the winter months in more northerly shallow coastal waters (Hutchinson and Hawkins, 1992).

Native oysters can survive at various temperature thresholds, which varies among populations and is likely to depend on geographical location. For example, oysters from Britain, the Netherlands and Denmark were able to survive -1.5°C for several weeks, while French and Norwegian oysters appeared to be more sensitive to prolonged periods of cold (Korringa, 1952). In an *in vitro* experiment, larvae (from an unspecified population) were able to survive well between 12.5-27.5°C (>70% survival), while survival was reduced at 10°c -30°C (~50% survival) and seriously hampered at 32.5°C (Davis and Calabrese 1969).

Periods of extreme cold winter have caused historically drastic losses in native oyster stocks (UMBSM, 2007; Jackson, 2007; Gercken and Schmidt, 2014). Extreme winter conditions are repeatedly cited, together with overfishing, as a major factor contributing to the decline of the native oyster stocks in Europe (Gercken and Schmidt, 2014). In shallow waters, where the oysters are more exposed to wind and cold air extreme winters are more likely to be detrimental (Gercken and Schmidt, 2014). In Scotland, winter mortality was only recorded in stocks that had been re-laid in shallow waters (UMBSM, 2007).

Temperature is thus critical for the survival and growth of both larvae and adults of native oyster, and sites that are selected for restoration should not exhibit extremely cold temperature conditions (Gercken and Schmidt, 2014). Some native oyster populations seemed to thrive despite low summer temperatures (e.g. in the Firth of Forth or the deep sea stock in the North Sea), yet it is not known whether this was genetic adaption, which could now potentially be lost, or an acclimatisation, to which current populations could possibly adapt again.

4.2.2. Salinity

Ostrea edulis is an euryhaline species and it is, therefore, able to colonise estuaries and coastal waters exposed to freshwater influence (Jackson, 2007). However, optimal growth occurs in rather marine areas, with salinities between 28-34 ppt (Hutchinson and Hawkins, 1992). Normal development of native oyster was also found at a salinity range of 25 -28 ppt (Korringa, 1952). Salinities lower than 22 ppt seriously impair growth of native oyster, although this species appears to be able to tolerate salinities as low as 16 ppt if temperatures do not exceed 20°C (Hutchinson and

Hawkins, 1992). High temperatures combined with low salinities are lethal within a short period of time, due to inability of native oyster to sustain thermally accelerated metabolic processes with the need to minimise exposure to low salinities (Hutchinson and Hawkins, 1992). However, despite the ability of native oyster to sustain low salinities when combined with low temperatures, a proportion of the associated epifauna and infauna may not tolerate a reduction in salinity and may be lost (Jackson, 2007).

4.2.3. Biotope

Availability of suitable settlement substrate is considered to be one of the principal factors for recruitment success of oyster populations (Airoldi and Beck, 2007, Korringa, 1946; UMBSM,2007). For example, in the German Wadden Sea, the lack of suitable settlement sites appeared to be the main reason hampering the expansion of natural oyster beds. Although temperature, salinity and food availability seemed adequate, the sediment in most parts of the Wadden Sea contained too much silt. For areas to be suitable for oyster to settle and survive, they have to be free of silt, without too mud that is too soft and no moving sand (Gercken and Schmidt, 2014; Korringa, 1940). This is because fine sediment can impede successful attachment of the larvae, and once the larvae are attached it can bury and kill the newly settled spat in the field, especially if there is no shell matrix or elevated structure which offers protection from sedimentation (Korringa, 1940; Korringa, 1946). Settlement sites should, therefore, preferably consist of hard sandy mud, muddy shell-gravel or rock (Korringa, 1940; Todorova *et al*., 2009). In the German Helgoland, the layer below the oyster bed consisted of muddy sand, and native oyster reefs in Bulgaria had been formed on rock and mixed bottoms (Caspers, 1950; Todorova *et al*., 2009). Beds of native oyster on shallow sublittoral muddy mixed sediment have been found on cobbles, gravel or shingle, large to very large boulders, pebbles, sandy gravel, sandy mud, small boulders or mixed substratum (Tyler-Walters, 2016).

4.2.4. Exposure, Depth and Currents

Native oyster habitats are formed in the lower intertidal and deeper sublittoral regions, although the intertidal zone is generally less populated, presumably because of the stress caused by fluctuating environmental factors (Laing, 2005; Gercken and Schmidt, 2014). In the sublittoral regions this habitat can occur down to a depth of approximately 80 m as seen in the German Bight, where "deep-sea oysters" have been found, but the main registered fishing grounds were at depths of 40-50 m (Gercken and Schmidt, 2014). However, they are more commonly found at depths of up to 30 m, and reefs in Bulgaria were formed between 7-23 m depth (Laing, 2005; Todorova *et al.,* 2009).

Native oyster can be found in exposed to very sheltered sites (Jackson, 2007). In Bulgaria, native oyster reefs occurred along exposed to moderately exposed coasts (Todorova *et al.*, 2009). Overall, native oysters have to find a balance between the need for stronger currents for higher food supply, and weaker currents to avoid excessive larval loss. For example, the former “current beds” in the Wadden Sea had a continuous food supply through its strong tidal currents (Gercken and Schmidt, 2014). Some stocks presumably suffered a high amount of larval loss and had to be supported by larval supply from the “deep-sea oysters” in the open North Sea (Berghahn and Ruth, 2005). On the contrary, in the Oosterschelde only about 4% of larvae were lost each tidal cycle due to a high degree of water retention (Korringa, 1952). However, these stocks had possibly a slower growth rate than the ones in the Wadden Sea, due to a lower level of food supply from tidal currents (Korringa, 1952) and a rather turbid environment (Korringa, 1940). The optimal current intensity and exposure level also depends on the substrate composition at each site, since native oyster are sensitive to prolonged high turbidity levels. Thus, higher current velocities may only be suitable in combination with a substrate which is not easily eroded. For example, native oyster beds on shallow sublittoral muddy mixed sediment are characterised by very weak to weak tidal streams (< 50 cm/s) and are in extremely sheltered to very sheltered sites (Tyler-Walters, 2016); while the former “current beds” were exposed to strong tidal currents and located on hard substrate (Gercken and Schmidt, 2014).

Native oyster can form beds in up to a medium turbidity level, yet optimal growth requires clear water (Korringa, 1952; Jackson, 2007). While short periods of relatively high suspended sediment quantities can be tolerated, in the long term it hampers growth by reducing the oyster’s filtration rate, increasing pseudofeaces production (Korringa 1952; Laing, 2005), and restricting spatfall (Moore 1977), and therefore recruitment. Growth of native oyster can also be improved by mimicking a natural reef and placing individuals higher up in the sea bed, where current velocities are somewhat stronger. At about 80 cm above the seabed filtration rate was higher and suspended sediments were lower than at the sea bed (Sawusdee *et al.*, 2015). Korringa (1952) also observed that the way oysters were placed in the tidal currents greatly influenced their growth rate. According to Seafish (2002) tidal currents of about 50-100 cm/s are optimal for the growth of native oyster.

5. Pressures

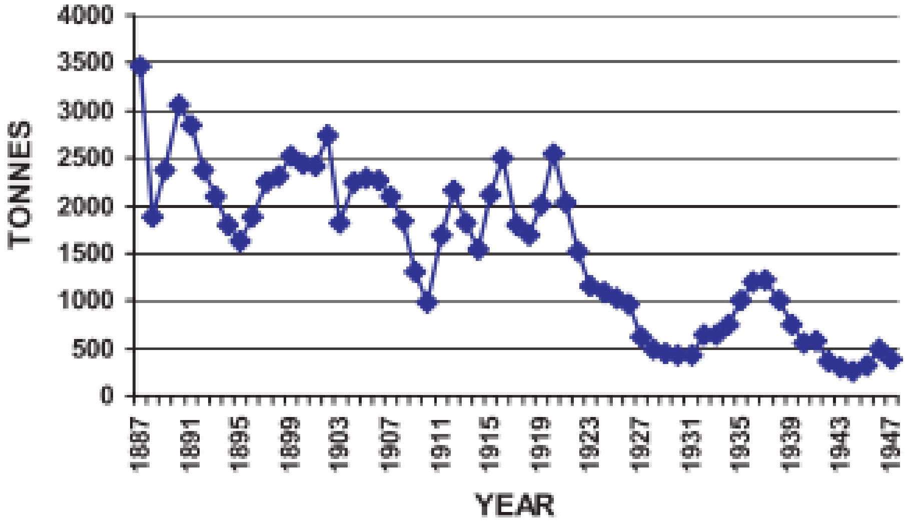
The decline of native oyster and its failure to recover is attributed to a number of factors including fishing, habitat destruction, pollution, disease, and predation and competition from non-native species. The main UK stocks are now located in the rivers and flats bordering the Thames Estuary, the Solent, the River Fal, the west coast of Scotland and Lough Foyle, while some native oyster also remain in Swansea Bay. Woolmer *et al.* (2011) reported that this relic Welsh population, of generally older animals, is subject to some fishing pressure and to impacts from America slipper limpet *Crepidula fornicata*. The slipper limpet is an invasive non-native species that is a competitor of native oyster and can cause smothering at high densities.

5.1. Fisheries

A number of external factors will affect the potential for a native oyster restoration project to succeed in the long-term. Critical factors are considered to be the use of appropriate fisheries management measures to regulate fishing activity on any newly established beds, and the prevention and management of diseases, predators and competitors of native oyster.

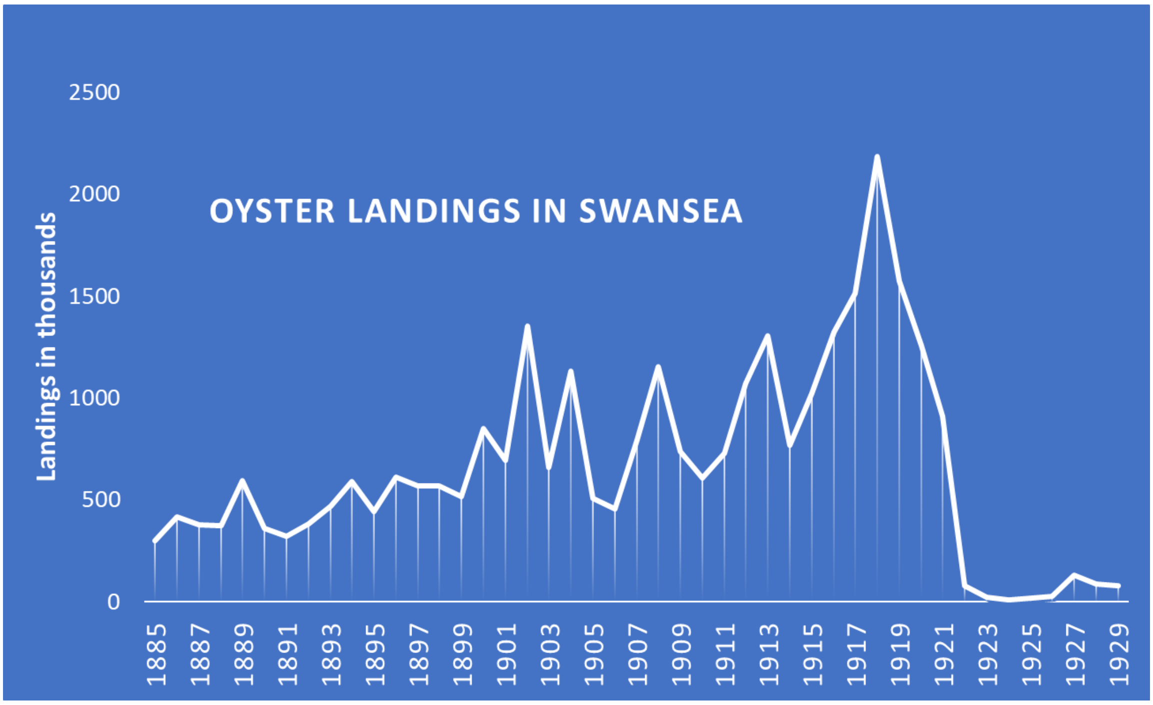
Fisheries management is, therefore, a key consideration in a native oyster restoration project. Fishing for native oysters is undertaken within a regulatory framework comprising national, regional and local management measures. Any individual may fish for native oysters in a public fishery so long as they do not contravene basic national measures and any additional local regulations. As such, and in the absence of specific measures to protect a recovering population, native oysters could be targeted and removed by fishermen operating legally and within the law. This issue was not addressed in the work undertaken to restore the native oyster population in Strangford Lough in the late 1990s.; While that population initially benefited from the restoration efforts, unregulated harvesting reduced the stock again, probably to a level below the level where the fishery collapsed in the 19th Century (Roberts *et al*., 2005).

Figure 5.1: Native oyster landings (tonnes) in England and Wales from 1887-1947 (Source: Laing *et al.*, 2006)



Native oyster fisheries around the UK started to collapse around the early 1920s. There was a slight increase in landings between1935-1939, however this then also decreased (Figure 5.1). The decline of native oysters is not only attributed to overfishing but also due to unusually cold winters in the 1930s and 1940s in some of the North Sea populations (Laing *et al.*, 2006). Oyster landing in Swansea followed the national trend, with increasing landings in the later 19th century and a collapse in the oyster fishing in the early 20th century (Figure 5.2). Fisheries management measures achieved minor improvements, but by the end 1930 the oyster stocks had collapsed.

Figure 5.2 Oysters landed in Mumbles (1885-1929). Total per year in 1000; Fisheries Investigations, Ministry of Agriculture and Fisheries, Series II. Vol. XII No. 4 1932, Report of Investigations into the past and present condition of the Natural Oyster Beds of South Wales. By F.S. Wright, Fisheries Laboratory Lowestoft



Successful restoration projects take time and in the case of Swansea Bay, where the current numbers of native oyster present are unlikely to support a viable fishery, it may require years. Time and management are highly important when planning restoration projects as illegal harvesting of native oysters has been known to occur around the UK (R. Callaway pers. comms., 2021). To support a viable fishery, a brood stock of oysters will be required and it will require a reasonable amount of time to get a big enough population of oyster to support a sustainable fishery. To improve genetic diversity the origin of the brood stock will need to be considered as well as the risk of disease.

5.2. Disease

Disease and non-native species are important factors in the continuing poor status of UK native oyster populations (Laing *et al.*, 2014). Bonamia was first identified in Northern France in 1979, and can have devastating consequences for native populations. For example, Laing *et al.* (2014) calculated that French production of native oysters dropped by 93% between the 1970s and 1982, while Oysterecover (2013) reported that there was 98% native Oyster mortality in the Cork Harbour rearing ponds when Bonamia first occurred there in 1987. Some resistance to Bonamia may be conferred on populations previously exposed to the disease as a result of spawning occurring from survivors (Beaumont *et al.*, 2005). However, populations may still suffer high morality and the initial avoidance of infection is a high priority, while infections may be managed through maintaining a relatively low density of animals on the beds (<10 m^{-2}), by minimising stress caused to the animals, and by harvesting at around age 3, after which the disease causes increasing levels of mortality. Harvesting may not be desirable, though, even if mortality may increase with age if the aim of a restoration project is to enhance biodiversity rather than to support a fishery.

The pathogens *Bonamia ostrea* and *Marteilia refringens* are currently the most serious threats to native oysters (Gercken and Schmidt, 2014). Bonamia can cause over 90% mortalities, when introduced into an uninfected population (Culloty and Mulcahy, 2007). The movement of stocks is thought to have resulted in the rapid spread of the disease and infected stocks are now present in England, France, Spain, the Netherlands, Ireland, Denmark, Scotland, Wales and Morocco (Laing, 2005; Culloty and Mulcahy, 2007) *Bonamia ostrea* is an intracellular protistan parasite, which destroys the blood cells of native oysters, and can be fatal (Oysterecover, 2016). Mortality is mainly seen in oysters, which are at least 2 years old, but the disease can be detected in juveniles (Arzul *et al.,* 2011). Lesions on the digestive gland, gills and mantle and infected oysters may appear yellow in colour but otherwise they appear normal (Laing, 2005).

Transmission of the disease can occur directly between oysters and is thought to occur through the gills (Culloty *et al.,*1999; Laing, 2005). Larvae can also be infected with *Bonamia* and may, therefore, contribute to the spread of the disease (Arzul *et al*., 2011). Some individuals of infected populations may develop resistance to *Bonamia* over time (Elston *et al.,* 1987; Culloty *et al.,* 2004). Conversely, oysters that suffer from stress caused from handling or high stocking densities are particularly susceptible to *Bonamia* infection. In experimental trials the immune system of oysters was able to combat the parasite at low population densities but failed to do so when stocking densities increased (Laing, 2005).

Another protistan of the *Bonamia* genus, *Bonamia exitosa*, was recorded in 2008 in European waters. This pathogen causes similar symptoms in oysters infected by *B. ostrea* and has been recorded in Cornwall in England, Galicia in Spain, Adriatic Sea and the Mediterranean Sea in France (Abollo *et al*., 2008; Nardsi *et al.,* 2010; OIE, 2012a). *B. ostrea* and *B. exitosa* can infect native oyster simultaneously (Abollo *et al*., 2008).

Marteiliosis, caused by the protist *Marteilia refringens*, is a disease affecting native oyster stocks in Europe (Laing, 2005). The pathogen has been reported in, Portugal, UK, Greece, France, Spain, Italy, Albania and Croatia (OIE, 2012b). *M. refringens* infects the digestive system of oysters and causes tissue necrosis, growth cessation and eventually death. Death usually occurs during the second year after initial infection, but some oysters may be infected without dying (Laing, 2005; OIE, 2012b). Mortality is usually associated with sporulation of the parasite during summer and autumn, with a mortality rate of 50-90% of the population. As with B. *ostrea,* the prevalence and consequences of the disease are greater in individuals which are at least two years old (OIE, 2012b).

Other diseases of native oyster, include Mikrocytosis (Denman Island Disease), caused by the protist *Mikrocytos mackini*. There is no evidence for a direct transfer of Mikrocytosis between oysters, and the disease is thought to be transferred through intermediate hosts. While it is not clear which species act as intermediate hosts, research points to the copepods *Paracartia grani*, *Acartia* spp., *Oithona* sp. and harpacticoida species. When outside the host, *M. refringens* can survive from several days up to 2-3 weeks. The protist needs a sea water temperature of at least 17°C to sporulate and transfer between hosts. In addition, high salinities and water renewal are detrimental to the life cycle of *M. refringens*, although temperature is the most critical factor. Infections with this pathogen are thus seldom observed in the open water, and the disease should not be prevalent in areas where the threshold temperature is not reached during summer. They are potentially very serious but do not currently occur within the UK.

Other diseases which are present in Europe and affect *O. edulis* but with less severe consequences include “the Dutch shell disease”, a fungal infection which impedes oysters to close the shell properly and the copepods *Mytilicola orientalis* and *Mytilicola intestinalis*, which partially block the guts of the oysters leading to a loss of condition (Laing 2005).

Based on current knowledge, the Swansea Bay population is clear of *Bonamia*. *Bonamia* is found widely in native oyster populations along the south coast of England but is now also present in the Milford Haven population and at various other locations in Wales, Northern Ireland and Scotland (Laing *et al.*, 2014).

5.3. Competitors and non-native Species

American Tingle *Urosalpinx cinerea* is a non-native species of whelk that is a predator of native Oysters and has the potential to devastate beds where it occurs (NNSS, 2014a). This species is currently absent from Wales. In contrast, the slipper limpet *Crepidula fornicata* is a non-native competitor of native oyster, and this species is now well-established around much of the south of the UK, including off the South Wales coastline. This species competes for food and space with other seabed species. Slipper limpets can reach very high densities, at which point it can effectively smother and change seabed habitats (NNSS, 2014b). Slipper limpets are prevalent throughout Swansea Bay, particularly in intertidal areas where they attach to pebbles and glacial till, and in subtidal areas at locations of historical oyster beds (Powell-Jennings and Callaway 2018).

Irrespective of whether some diseases or non-native species are already present in a site, careful consideration must be given to the source of any stock moved into an area, and the movement controls and practices in place to prevent disease and non-native species transmission.

5.4. Ecosystem Services

Restoration practices can provide important ecosystem services such as increasing biodiversity, supporting fish populations, improving water quality, reducing nitrogen and increasing food and economic resources. Native oysters can alter the environment and are known as ecosystem engineers. Oysters are known to improve water quality through water filtration, this can make the environment better for other species creating a ‘reef effect’. This is where there is an increase of other species within the area such as fish and invertebrates due to the newly created habitat.

In undisturbed conditions these oyster-reefs can be substantial, creating species-rich systems (Tyler-Walters 2001). Over 250 species of epibiota were found on shells in the Netherlands. In fact, the ecological term biocoenosis that describes an association of different organisms forming a closely integrated community was coined by Karl August Möbius in 1877 describing oyster beds and their biodiverse associated fauna.

As well as an increase in biodiversity and an improvement in water quality, native oysters are also known to alter wave energy in coastal areas. The exact effect of loss of native oysters around the UKs coast is unknown. However, it has been shown in other coastal areas with large oyster populations, oysters help to stabilise soft sediments, which can dissipate wave energy. Some studies have found that this effect is seen beyond the boundary of the reefs, which may encourage other species which prefer lower wave energies to settle. Dissipating wave energy is also important for coastal erosion as biogenic reefs are known to reduce coastal erosion by slowing down wave energy and even acting as storm buffers (Walles *et al.*, 2015; Alliji *et al.*, unpublished).

Restoration of native oyster can also be important to the UK from a cultural perspective; historical literature shows an intricate relationship between fishers and the marine environment. Restoration projects can help restore native oyster populations providing many benefits, but they can also help to revive the historical connection with the sea in the area. There are many paintings and literature which highlight the connections between fishers and oysters, and historical fisheries landings indicate the reliance of coastal communities on native oysters as both a food and economic resource. By restoring habitats around Wales it is likely to help revive the community's connection with the ocean as well as provide them with an alternative source of income and the other ecosystem services that accompany restoration projects.

Figure 5.5 provide examples of oysters influencing Swansea's culture and the relationship of communities with oysters. Paintings and 19th century photography can be seen in Swansea Museum and the Glynn Vivian Art Gallery.

Figure 5.3: Edward Duncan, Oyster Dredgers, Swansea Bay, 1874; © Glynn Vivian Art Gallery Swansea

Figure 5.4: On the sandbank at the Southend 1870. © History of Mumbles published by John & Carol Powell

Figure 5.5: George Wolfe 1834-1890, Landing Oysters at Mumbles. © Swansea Museum

6. Native Oyster Restoration Case Studies

6.1. Essex Native Oyster Restoration Initiative

6.1.1. Introduction

Essex Native Oyster Restoration Initiative (ENORI) is a collaboration between oyster fishers, government, conservationists, and academia. They are working together to try and create a self-sustaining population of native oysters within the Essex estuaries. The aim of the restoration project is to increase biodiversity, support sustainable fisheries, improve water quality, reduce nitrogen levels and recognise the cultural importance of native oysters. The first extensive study of native oysters was completed in 2012 and the data was used to underpin the application for The Blackwater, Crouch, Roach and Colne Estuaries Marine Conservation Zone (MCZ). This MCZ is designated for the native oyster and their associated beds in 2013. Further protection was granted through a Kent and Essex Native Oyster Permit Byelaw, confirming the legal protection of the fisheries management plan and Restoration Box in 2018. Physical restoration within the restoration box started in 2019.

6.1.2. Methods

ENORI use several different methods to help ensure that their restoration project is successful. They use a multi-disciplined approach using both traditional methods and local knowledge to find new and innovative methods.

Table 6.1: Methods used in Essex Native Oyster Restoration Initiative

Method	Description
Adaptive Management	The native oyster recovery management plan was formalised in the 2018 Native Oyster Fishery Flexible Permit Byelaw. This provides a mechanism to protect the oyster beds but will also allow a sustainable oyster fishery when the oysters have recovered sufficiently
Mother Oyster Sanctuary	As part of the restoration practices ENORI have a restoration box, where they translocate mature oysters to improve reproductive success.
Improving the Seabed	To encourage settlement of larvae ENORI place shells and gravel on the seabed as cultch. This will provide a substrate for larvae to settle on.
Shell Recycling	ENORI collect shells from restaurants to use as cultch and to improve the seabed.
Sustainable Fishery	Oyster populations are monitored within the MCZ. If oyster populations have recovered sufficiently enough low-level harvesting will be allowed.
Research	ENORI work with the University of Essex who are leading research on native oyster ecology and ecosystem services. They are also working with other partners looking at how native oysters can build resistance to disease.

Method	Description
Sustainable Finance	ENORI explore novel and innovative funding routes to ensure that they have alternative sources of funding for restoration.
Native Oyster Network	ENORI have been instrumental in the establishment of the UK Native Oyster Network. This allows people to share best practices and lessons learnt in native oyster restoration project.
International	ENORI also work internationally supporting other projects, which can help improve restoration practices within the UK.

6.1.2.1. Conclusions

ENORI have managed to create a MCZ to help protect native oysters and their beds. They have a restoration box, which specifically protects their brood stock. They have been granted a marine licence for restoration activities, which is the first of its kind. They have built a network of people interested in oyster restoration and are able to feed into research. They are also thinking of innovative ways to improve restoration practices such as re-using shells as cultch.

6.2. Solent Restoration Project

6.2.1. Introduction

The Solent Oyster Restoration Project, run by Blue Marine Foundation, aims to restore native oysters to Solent waters and create a self-sustaining population that will allow for the development of a viable oyster fishery whilst also providing a range of additional ecosystem services. The Solent, the strait running between the Isle of Wight and mainland England, was at one time Europe's largest self-sustaining native oyster fishery. In 1978, an estimated 15,000,000 oysters were harvested in a single year, supporting a fleet of 450 vessels. The fishery suffered a total collapse in 2013 following overfishing, disease, and the impact of non-natives.

The project aims to act as a model for the restoration of oyster bed habitats, with a goal of restoring 5,000,000 oysters to the Solent by 2020. UK hatcheries were to provide 10,000,000 juvenile native oysters to help achieve this. So far 69,000 oysters have been introduced across 12 sites and a volunteer network of 200 individuals have contributed to the project. The long-term goal of the project will be to establish a self-sustaining stock of native oysters which will then further allow the spread of native oysters in the region.

Project costs for the period 2016-2020 were estimated to be £1,436,500.

Partners: University of Portsmouth (Luke Helmer); University of Southampton (Zoe Holbrook, Christina Thiele); Southern IFCA; 1851 Trust; Hampshire and Isle of Wight Trust; MDL Marina Group (designed structure to contain brood stock); Land Rover Ben Ainslie Racing (owned pontoon that brood stock trials were conducted on); Seasalter Shellfish Ltd (hatchery suggested to produce seed oysters).

Funding: Marks and Spencer; MDL Marina Group; The Roddick Foundation; Selfridges; The Alice Ellen Cooper Dean Charitable Foundation; Wightlink.

6.2.2. Methods

The Blue Marine Foundation use several different methods to help ensure that their restoration project is successful. They initially researched and conducted feasibility studies to adapt their methods. Their main techniques include the use of broodstock cages and re-seeding methods.

Table 6.2: Methods used in Solent restoration project

Method	Description
Research and feasibility study	The first step of the project was to conduct a research and feasibility study, which was published in early 2014 (Gravestock *et al*. 2014).
Broodstock Cages	High densities of native oysters are placed into cages which are then hung from existing pontoons below the surface of the water. Broodstock cages are currently being used at 10 sites across the Solent, hosting approximately 23,000 oysters. This technique is popular with commercial fisheries as the high density of the oysters increases the potential for successful spawning. In addition, it allows for easy access to the oysters, meaning that their physiological and reproductive state can be checked regularly. Regular inspection may also allow for a reduced risk of disease spreading throughout the population, with infected individuals being isolated from the wider population following inspection. An estimated 100 species have been found using the reef structures created by the oysters including European eels, juvenile spiny seahorses and sea bass.
Re-seeding	The second technique being used to restore oyster stocks in the Solent are based around the re-establishment of natural oyster beds. Large numbers of oysters are being produced at the University of Portsmouth. These larvae are reared under lab conditions before being settled on old oyster shell. These seeded shells are then distributed across study area. To date 45,000 oysters have been distributed over 2 acres of seabed. It is hoped that these areas will become 'sanctuary sites' supporting a population of oysters that will be allowed to spawn, supporting a wider population within the Solent.
Stakeholder Engagement	Stakeholder consultation included a number of bodies including regulatory bodies and organisations: fishermen, fish merchants, the Southern and Sussex Inshore Fisheries Conservation Authorities (IFCAs), the Marine Management Organisation (MMO), Natural England, Hampshire and Isle of Wight Wildlife Trust, the Environment Agency, Public Health Authorities, Portsmouth and Southampton Universities and the Solent Forum. A smaller technical working group was developed from the wider stakeholder group that was involved in the planning and creation of

Method	Description
	the management plan.

6.2.3. Conclusions and Lessons Learnt

- Locations for the broodstock were carefully selected to ensure the greatest chance of survival. Selected sites were located in areas that: were inaccessible to towed gear; under pontoons; on private property to reduce poaching risk.
- Spawning was observed to be triggered by temperature change once oysters reached maturity at 3 years of age. Spawning events usually occurred in May and June, however local weather conditions can impact this date. It takes approximately 14 days for spawning to occur.
- An algal bloom resulted in the deaths of a number of broodstock, which cut short what could have been a life of over 10 years.
- Native oysters seem to be more tolerant to deeper waters than the non-native Pacific oyster *Magallana gigas*.

6.3. Conwy Bay

In the Conwy Bay in Wales, 1,300 native oysters have been returned as part of a restoration project. The Wild Oysters Project, a partnership between ZSL (Zoological Society of London), Blue Marine Foundation (BLUE) and British Marine, aims to help restore healthy, resilient coastal waters around the UK. Conwy Bay is part of the Y Fenai a Bae Conwy/ Menai Strait and Conwy Bay Special Area of Conservation (SAC), and is protected for Annex I habitats.

During the 18th and 19th centuries there were also productive native oyster beds close to Conwy Bay, in the Menai Strait near Caernarfon and Bangor, off Puffin Island and around Anglesey in Rhoscolyn and Llanddwyn Island. In the mid- 1800s, Welsh oyster boats reported landing 8,000 oysters daily, but up to 15,000-20,000 oysters in some areas. However, fishing for native oysters in Wales had begun much earlier, with native oyster shells discovered dating 12,000 years back to the Neolithic and the Bronze Age (Wild Oysters, 2021).

Partners: The Wild Oysters Project, ZSL (Zoological Society of London), Blue Marine Foundation (BLUE) and British Marine.

Funding: The Wild Oysters project, a three-year ambition, was awarded £1.18m by the Postcode Dream Trust. The Dream Fund, gives organizations the opportunity to bring ambitious, innovative and collaborative projects to life.

6.3.1. Methods

Table 6.3: Methods used in Conwy Bay restoration project

Method	Description
Broodstock Cages	Broodstock cages are used as oyster nurseries. They are placed into marinas or port sites and they release larvae into the water column, allowing the natural settlement and formation of native oyster reefs. This technique is popular with commercial fisheries as the high density of the oysters increases the potential for successful spawning. In addition, it allows for easy access to the oysters, meaning that their physiological and reproductive state can be checked regularly. Regular inspection may also allow for a reduced risk of disease spreading throughout the population, with infected individuals being isolated from the wider population following inspection. There is currently no information of on the success of this method for the Conwy Bay project.
Habitat Restoration	Alongside the broodstock cages the project aims to create cultch for larvae settlement. Cultch is a substrate that contains shells of bivalves. Cultch is seen as the preferred substrate for native oysters. Some scientists concluded that the diminished native oyster populations were due to the lack of suitable substrate available to larvae. By adding cultch to the seabed it is likely to encourage larval settlement and increase the success of the restoration project. There is currently no information of on the success of this method for the Conwy Bay project.
Stakeholder Engagement	As part of the project an important component is stakeholder engagement. The project keeps the public engaged through educational programmes, citizen science and cameras at some of their nurseries. This helps to engage the public in their efforts and help educate people about the marine environment, as well as allow them to see and enjoy Wales' biodiversity.

6.4. Swansea Bay Oyster Restoration

40,000 adult oysters from Loch Ryan were placed in an un-fished area of Swansea Bay in 2013 at densities of 10 individuals m^{-2} in a total area of two hectares (Gravestock *et al.*, 2014; Woolmer *et al.*, 2011). The site was selected on the basis of historic oyster bed locations, the presence of existing oysters and substrates for larval settlement; 4-5 tonnes of cockle shells were laid on the sea bed as cultch materials. Beds were monitored for oyster growth, mortality and predators, but to date there is no published evidence that the attempt was successful. There appears to be anecdotal evidence that the translocated oysters may have contributed to the larval settlement in the wider area. The restoration attempt did not lead to a sustained increased in oyster density at the site.

6.5. Other Oyster Restoration Projects

In France, early restoration efforts created 'oyster parks', which were based on the settlement preferences of oyster larvae. Shell cultch including adult oysters was placed on the seabed. This approach was moderately successful, although sedimentation may have compromised spat settlement and survival of new recruits (Yonge, 1966). It also remained unclear how many broodstock oysters were required to sustain population recruitment. Further, spat collectors were deployed. These were tiles coated with sand-lime cement placed in sheltered cages. Once settled oysters reached adult stage they were relocated to suitable areas.

In Norway, sheltered 'polls' or 'pools' are used for breeding, spat collecting and growing oysters using natural seawater channelled through narrow inlets (Matthiessen, 2001). In April, cages with breeding oysters or cultch for spat collection are suspended at a depth of 2-3 metres to avoid very turbid conditions on the seabed. Despite Norway's geographic position, coastal waters are sufficiently warm in summer to allow oysters to reproduce. Between June and July, oyster larvae are collected on bundles of twigs suspended at the same depth and spat is then relocated.

In Ireland, bed rotation has been trialled, i.e. the collection of spat on cultch for seeding, which is then transferred to other suitable areas, for example in Tralee Bay, Clew Bay, Cork Harbour, Lough Swilly and Lough Foyle. In 1991, 250 bags with 1000 spat each on native oyster cultch from Tralee Bay were transplanted to Lough Swilly and grown on trestles for over a year. They were subsequently seeded onto the seabed. These projects increased the catch rates the following years, but limited spat supply and the challenge of relocating oysters whilst minimising the spread of diseases remain significant challenges (OSPAR, 2009).

In 2010, the Chichester Harbour Oyster Partnership Initiative (CHOPI) was established through the cooperation between Sussex and Southern IFCA (Association of Inshore Fisheries and Conservation Authorities), Chichester Harbour Conservancy, Natural England and the local fishing community (Vause, 2010). The purpose of this collaboration was to survey and manage the *O. edulis* stock in Chichester Harbour with academic support from the Centre for Environment Fisheries and Aquaculture Sciences (Cefas) in Weymouth, the National Oceanography Centre (NOCS), and the University of Southampton (Eagling, 2012). This group identified specific areas that were closed to fishing under a voluntary fishers' agreement. It also relayed 2,298 kg of broodstock oysters on the seabed at a density of 40/m². Oysters reproduced successfully up until the spawning of larvae, but the sex ratio (male: female) of the broodstock was 3:1, differing significantly to what was naturally expected (1:1). Two years after relaying, an increased mortality of the relayed oysters was reported, especially after the spawning season, and one third of the population had died post spawning. It appears that the environmental conditions at the seabed might negatively affect oyster physiology, reducing growth and leading to increased mortality.

Current restoration efforts based on re-laying of adult oysters and shell cultch directly on the seabed seem insufficient to solve the precarious status of *O. edulis*. Therefore, to enhance and restore the flat oyster populations, new management approaches need to be identified and tested. Sustainability and resilience of the restored *O. edulis* beds appears to be the main challenge.

7. Swansea Bay

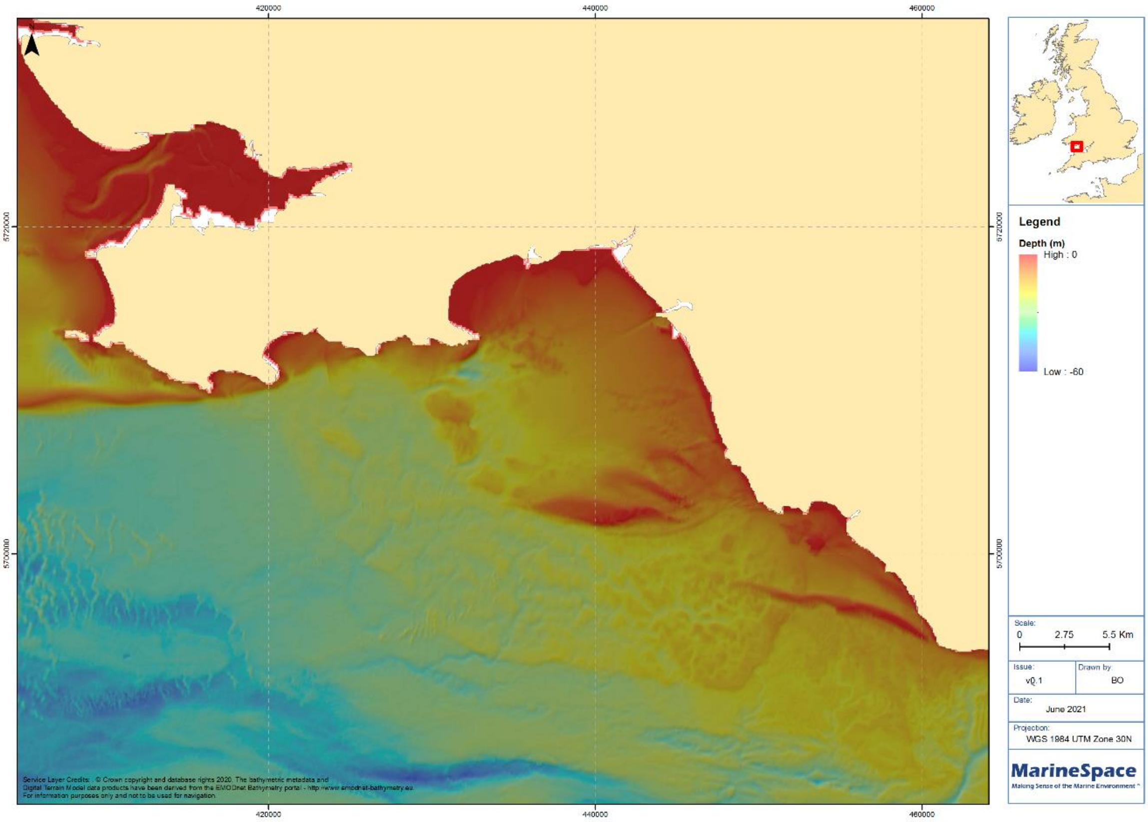
7.1. Environmental Conditions

Swansea Bay is an important area for both cultural heritage and commercial reasons. The bay is important for fisheries, shipping and aggregate dredging industries. Historically, Swansea Bay was an important area for native oysters and the area now known as Mumbles was called Oystermouth in historical literature. Historical evidence such as paintings, books and anecdotal evidence that highlights the importance of native oysters in this area. When considering native oyster restoration projects, it is important to consider environmental factors, which are known to influence the success of restoration projects (see Section 4.2). Environmental factors such as depth, temperature, current speed and substrate are all important for the survival and success of native oysters.

7.1.1. Bathymetry

Native oysters have been found at depths of up to -80 m (below chart datum (BCD)), however they most commonly are found at depths of 0-30 m. The Swansea Bay area is relatively shallow and depths range from around 0-20 m in the bay area. Further from the shore the water depths start to decrease to -60 m (BCD) (Figure 7.1). Swansea Bay would have suitable habitat for native oysters, as the depth is within its preferred range.

Figure 7.1: Bathymetry map of the Swansea Bay area in Swansea Bay

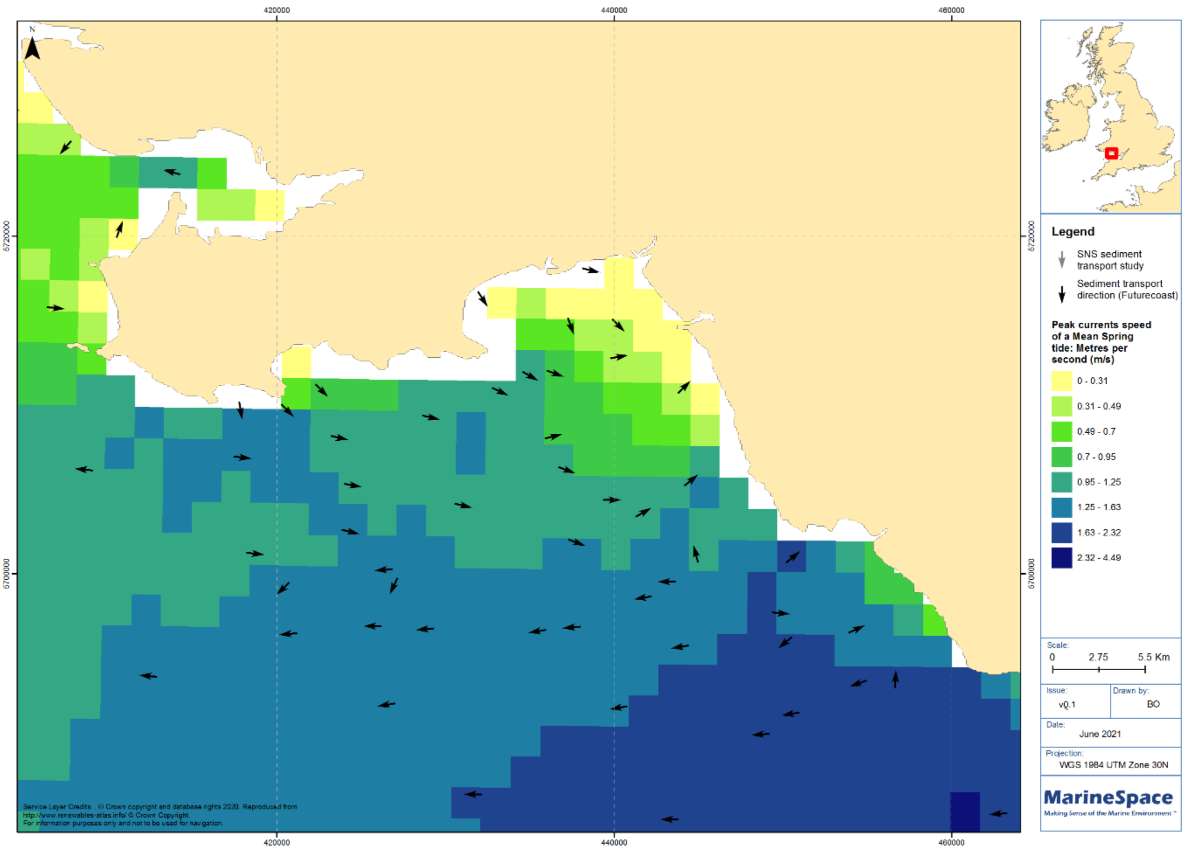


7.1.2. Current Speeds

Native oysters need to have a good balance between strong currents that supply them with food and take away waste, and weaker currents that help larval settlement. Weaker currents are associated with lower larvae loss but slower growth rates, whereas stronger currents have higher levels of larvae loss but higher provision of plankton, and therefore higher growth rates.

Seafish recommend tidal currents between 50-100 cm/s to ensure larval survival and a high growth rate. In Swansea Bay, tidal currents range from 31-95 cm/s during peak Mean Spring tide, suggesting that the range of currents are broadly suited to oyster development (Figure 7.2). Beyond direct impacts of current speed, factors such as effects on substrate need to be considered. High current speeds can be associated with high siltation rates depending on the sediment composition. High siltation rates are known to bury oysters, which can be fatal.

Figure 7.2: Peak current speed and direction during a Mean Spring tide in Swansea Bay



7.1.3. Biotopes

Swansea Bay consists of mixed sediments, mainly comprising:

- infralittoral mud;
- infralittoral coarse sediment;
- circalittoral coarse sediment;

- circalittoral sand;
- infralittoral sand;
- circalittoral mud (Figure 7.3 and Figure 7.4).

Native oysters are known to prefer hard sandy mud, but this would be dependent on the current speeds and suspended sediment concentration. Larvae require a relatively silt free environment for settlement and, therefore, areas of high silt content would not be suitable. Native oysters have been found in a range of environments including muddy sand, rock and mixed bottoms. Larvae require a relatively silt free environment for settlement and, therefore, areas of high silt content would not be suitable. Native oysters present within the Swansea Bay area are mainly found in areas that have been classified as coarse sediment or sand and mud in the circalittoral zone. Other areas that have native oysters in Wales have similar biotopes as those seen in Swansea Bay.

Figure 7.3: Broad EUNIS biotopes around Wales

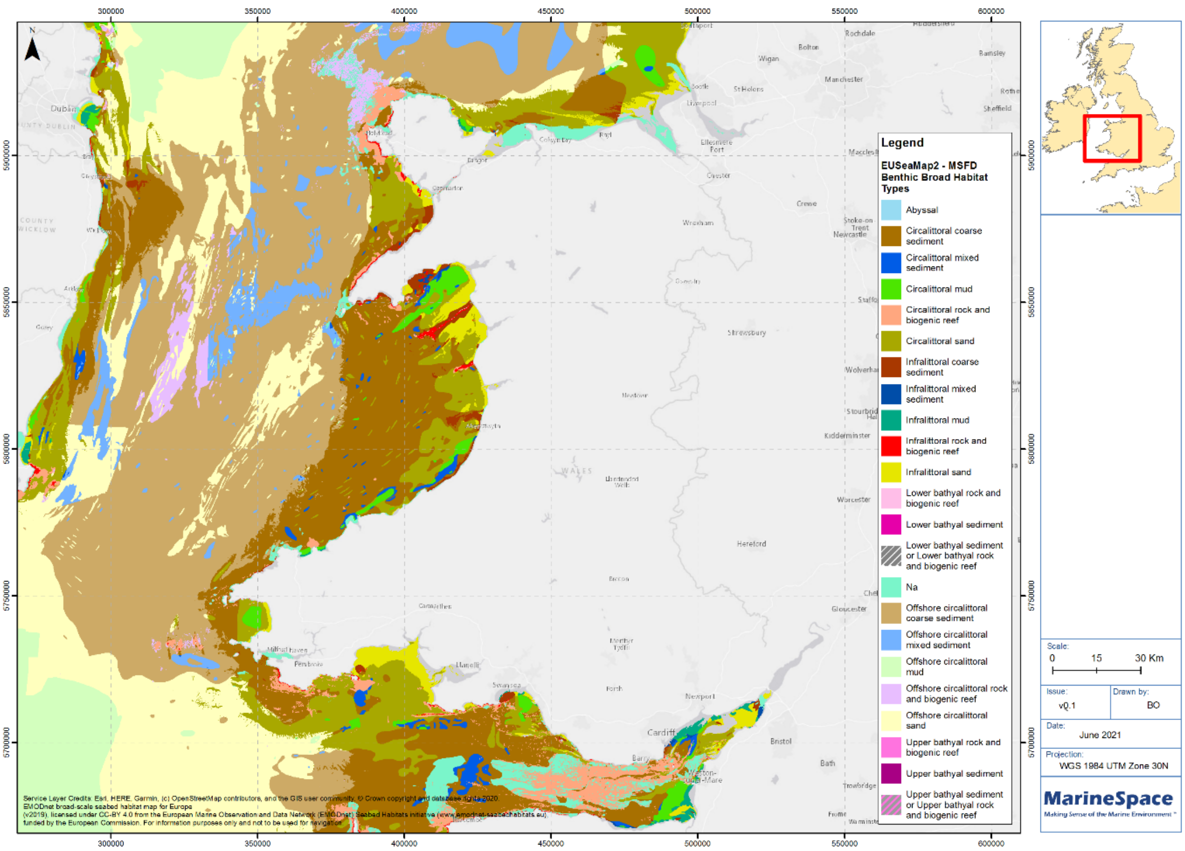
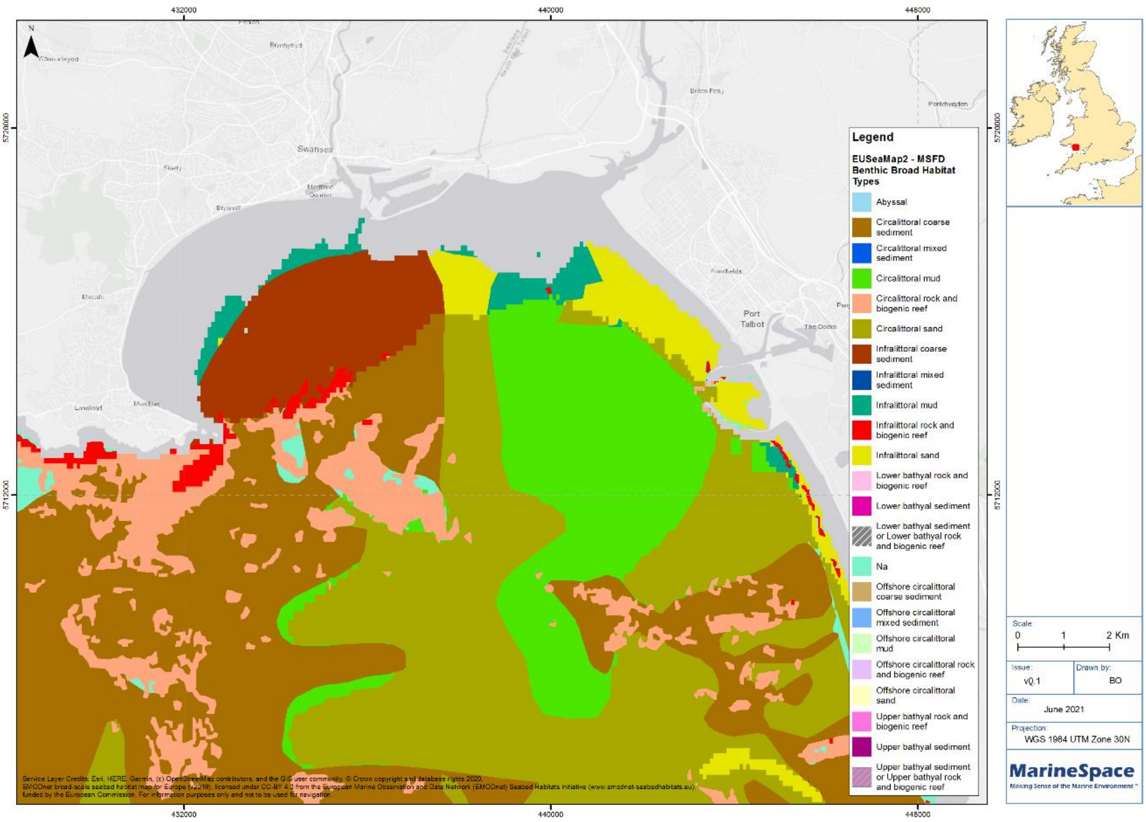


Figure 7.4: Broad EUNIS biotopes of Swansea Bay



7.1.4. Environmental Conditions

Water quality will be an important factor for native oyster restoration within Swansea Bay. Swansea Bay was classified as having good bathing water quality. In 2018, the bathing water quality was classed as sufficient (NRW, 2021). The water quality is thought to be impacted by heavy rainfall, which washes faecal material into the sea form livestock, sewage and urban drainage via rivers and streams. Bathing water quality, measures the levels of *Escherichia coli* and intestinal enterococci within the water, which would need to be low for a commercially viable oyster population.

There is a marine water temperature sensor at Swansea Bay and temperature is recorded by Cefas. The water temperature between 1976-2000 is available and the average temperature fluctuates between 9-15˚C. The coldest month is February, where the mean temperature is 5.9˚C and the warmest month is August with a mean temperature of 18.3 ˚C (Cefas, 2021).

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