Exploring the role of offshore wind in restoring priority marine habitats Case Study: Opportunities for native oyster (Ostrea edulis) restoration at the Gunfleet Sands Offshore Win...

Technical Report · January 2021

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BLUE MARINE FOUNDATION

JANUARY 2021

Exploring the role of offshore wind in restoring priority marine habitats

Case Study: Opportunities for native oyster (*Ostrea edulis*) restoration at the Gunfleet Sands Offshore Wind Farm

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Glossary

Abiotic: factors associated with physical rather than biological or living organisms.

Baseline: the condition of an area or native oyster population prior to an activity taking place.

Biotic: factors associated with, and interactions between, living organisms.

Broodstock: the group of sexually mature native oysters used in aquaculture or in restoration projects for the purpose of reproduction and larval supply.

Cultch: any substrate, such as rock or shell, that a juvenile native oyster is attached or may attach to.

Ecosystem service: the benefits provided by native oysters to humans.

Metocean: description of the physical environment, particularly the combined wind, wave and climate condition as found on a certain location.

Oyster reef: the biogenic concretions arising from the seabed formed by live and dead native oysters, providing a habitat with high surface complexity.

Recruitment: the settlement and survival of native oysters such that they contribute to the overall population.

Recruitment-limited environment: a body of water or restoration area that lacks sufficient broodstock to produce larval supply needed to populate existing or planned reefs.

Scour: in this document scour refers to the abrasive action of the tide or flow on the seabed or an object.

Scour protection: objects, usually a layer of rocks, placed in the marine environment to protect sensitive or important structures from wear, damage or erosion.

Seed: a term commonly used in the shellfish industry to describe oysters added to a restoration site to begin or augment a population.

Self-sustaining: able to continue in a healthy state without outside assistance

Settlement: the process whereby native oysters in the larval stages settle out from the water column onto suitable substrates and undergo metamorphosis, permanently cementing themselves to the surface.

Shear stress: the pulling force of water passing over the seabed or another object, as a result of a loss in velocity in the water the force is imparted onto the seabed or object.

Spat: the term used to describe juvenile oysters that have attached to a hard substrate following the free-swimming larval phase.

Spat-on-shell: juvenile oysters that have settled, naturally or intentionally in aquaculture settings, onto the empty shells of the same or another shellfish species.

Spawning: the release of eggs or eggs and sperm.

Substrate: the hard material, often shells, small stones or large rocks, that juvenile native oysters are able to settle upon. This can be naturally occurring or intentionally deployed to encourage recruitment settlement.

Executive Summary

The UK has the largest installed capacity of offshore wind in the world. With a government commitment to further expand, opportunities for co-location with conservation and restoration initiatives are being increasingly explored. Globally, over 85% of oyster beds have been lost, making them among the most imperilled marine habitats in the world. In the UK, the native oyster, or European flat oyster, has declined by 95% since the mid-1800s. Oyster restoration is a high priority at the national and European level with several pilot projects underway in Europe to investigate the potential for offshore wind farms to aid population recovery. The use of broodstock sites to increase larval supply is considered an effective strategy to restore self-sustaining populations. Restoration projects including the Solent Oyster Restoration Project led by Blue Marine Foundation (BLUE) have successfully used marinas as broodstock sites, pumping billions of larvae into the Solent. Results from a pilot in The Netherlands identified larvae in oysters housed within a North Sea wind farm and the surrounding water, showing oysters can grow and reproduce in these offshore environments.

This report provides a summary of work undertaken by BLUE and renewable energy company Ørsted, in collaboration with the Essex Native Oyster Restoration Initiative (ENORI) and includes results from a feasibility study by Resilient Coasts. The project explored the potential for the Gunfleet Sands wind farm in Essex to act as a broodstock site for the Blackwater, Crouch, Roach and Colne Estuaries Marine Conservation Zone (MCZ). The MCZ is the only designation for native oyster beds in the UK and ENORI is leading efforts to restore populations to a self-sustaining level. The feasibility study assessed the physical processes at the wind farm and how these would impact oyster survivability. Key considerations included: environmental tolerances for native oyster survival; combined hydrodynamics (waves and tides); operational requirements and the design of oyster housing. The results indicated that a spawning event, combined with a flood tide, may allow larvae to reach the MCZ under specific weather conditions. However, the perfect window of opportunity for larval transport is relatively small and unlikely to coincide with larval release. The study also concluded that, for this location, oysters should not be placed on the seabed either in untethered cages or loose because of the high energy within the site. Depth, bed sediment and infrastructure constraints further reduced the area available for broodstock installations within Gunfleet Sands. This raised concern over the potential to scale up broodstock numbers and the overall impact of the project, as well as financial investment. It was therefore decided that a pilot phase would not be developed.

The findings from this study have formed the foundation of a wider scoping analysis of over fifty UK wind farms, using broad-scale seabed habitat and energy level data. Initial results from the scoping study has presented several sites that may be suitable for restoration and habitat enhancement for native oysters. BLUE is now extending the scoping to other species and habitat enhancement opportunities, with the aim of initiating a new feasibility study in 2021.

Introduction

The European flat oyster (*Ostrea edulis*) or native oyster once formed extensive beds in European seas, particularly in the North Sea (Figure 1). Oysters are 'ecosystem engineers' and reefs contribute substantially to inshore shallow biodiversity and provide protection and nursery grounds for juvenile fish and other species (Coen et al, 2007). They are also filter feeders, cleaning waterways by removing impurities such as nitrogen (zu Ermgassen et al, 2013). In the mid-20th century populations across Europe suffered a collapse from pressures of overfishing, pollution, disease and invasive species (Helmer et al, 2019). The loss of this habitat has not only affected the health of marine ecosystems but coastal communities (Laing et al, 2006). Oysters have been a staple food since pre-Roman times and were once the subsistence food of London's poor. Over 700 million oysters were consumed in London alone in 1864, but 100 years later total landings for England fell to just 3 million (Beck et al, 2011). Wild native oyster stocks have declined by over 95% in the UK and are now one of the most threatened marine habitats in Europe (Airoldi & Beck, 2007; Beck et al, 2011).

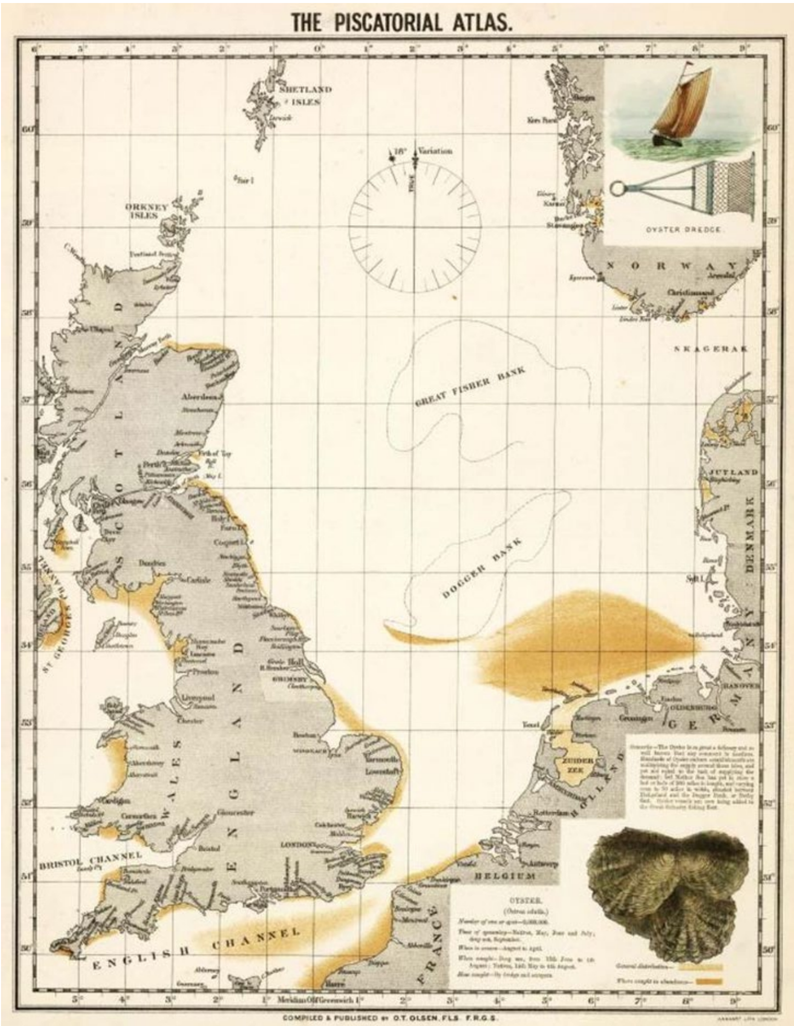

Figure 1. Distribution of the European flat oyster (*Ostrea edulis*). Source: Olsen (1883).

Recognition of their importance ecologically and culturally has made oyster restoration a high priority at the national, European and global level (Haelters and Kerckhof, 2009; Beck et al, 2011). The decline of the UK's native oyster population by 50% over 25 years was also instrumental in its classification as a priority species in the UK's Biodiversity Action Plan (UKBAP, 2009; Lallias et al, 2010). This biodiversity action plan is part of the UK's contribution to meeting global targets set by the UN Convention on Biological Diversity. Globally, an estimated 85% of oyster beds and reef habitats have been lost (Beck et al, 2011).

In response to this loss, oyster restoration initiatives have been growing worldwide (Harding, 2017). In the United States, large scale oyster restoration is mandated by top-down federal policy Government funded restoration projects, led by The Nature Conservancy (TNC) and the National Oceanic and Atmospheric Administration (NOAA), have now been running for over 15 years with significant success (NOAA Fisheries, n.d.). In areas such as Chesapeake Bay and the Gulf Coast, restoration has been undertaken for over half a century (Bersoza Hernández et al, 2018). However, restoration initiatives in the UK and Europe are still very much in their infancy. In 2017, the Native Oyster Restoration Alliance (NORA) was set up as a European information sharing network with representatives from the UK, Germany, Holland, Denmark, Ireland, France, Spain, Belgium, Sweden, Norway, Italy and Croatia (Pogoda et al, 2019). The UK has also recently formed a national native oyster restoration network which aims to provide support to regional initiatives and collectively campaign (Figure 2).

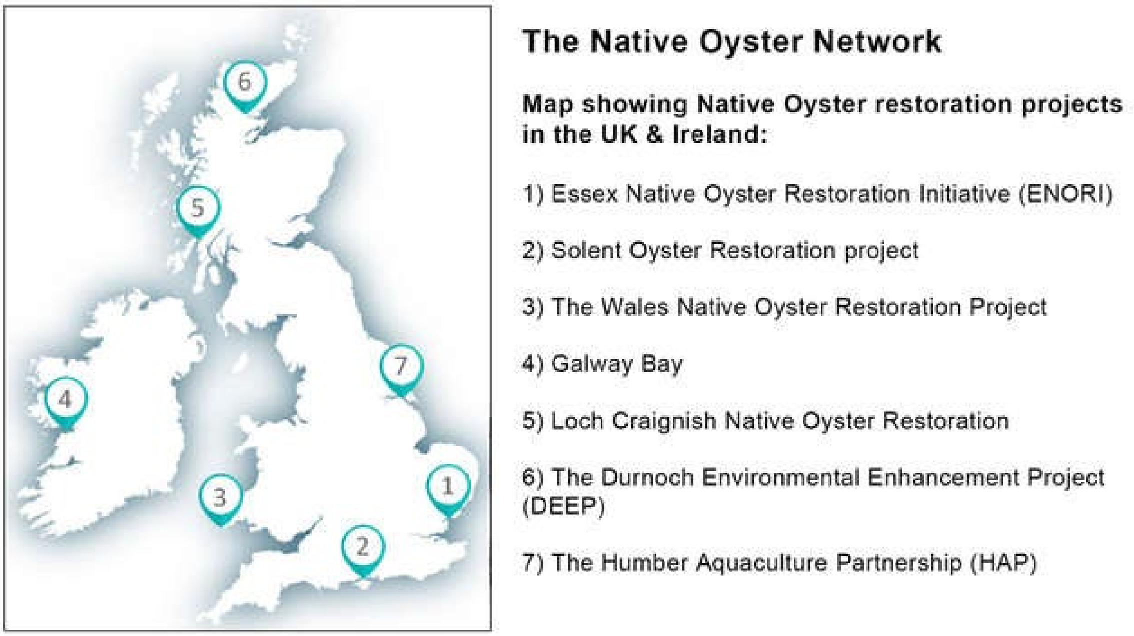

Figure 2. Active native oyster restoration projects in the UK and Ireland (Native Oyster Network, n.d.). Source: Native Oyster Network https://nativeoysternetwork.org/.

Project location and the Essex Native Oyster Restoration Initiative (ENORI)

This report focuses on the Blackwater Estuary in Essex and the Essex Native Oyster Restoration Initiative[1] (ENORI) (Figure 3). The estuary is home to the Colchester oyster, as the native oyster is locally known, which has been cultivated there since pre-Roman times. Essex has a rich heritage associated with native oyster fisheries, but as with other historically important beds in the UK, the wild native oyster population in the Blackwater has collapsed. Distribution and densities of native oysters across the Blackwater, Crouch, Roach and Colne Estuaries is concerningly low, to the detriment of the ecosystem (Lown, 2019. Lown et al, 2020).

Set up in 2013, ENORI aims to restore the native oyster population and beds in several Essex estuaries so they are self-sustaining and provide ecosystem services, increased biodiversity and sustainable fisheries while recognising their cultural importance. ENORI is a collaboration between oystermen, Government, conservationists and academia. The project focuses on a 200 ha ($2km^2$) voluntary 'Blackwater Conservation Box' within the Blackwater, Crouch, Roach and Colne Estuaries Marine Conservation Zone (MCZ) (Figure 3). This is the only MCZ in the UK that is designated to protect native oyster beds (Defra, 2013; Lown, 2019).

Inside the designated area, cultch has been laid to improve the seabed substrate and increase the opportunity for successful settlement of larvae released by protected broodstock oysters that have also been deployed. Any spatfall will extend far beyond the $2km^2$ confines of the box providing a boost to the oyster stock within the rest of the MCZ ($284\ km^2$). ENORI hopes this will ultimately lead to the public fishery within the MCZ reopening once the populations are deemed sufficiently recovered and show a stable and resilient population structure (Marine and Coastal Access Act, 2009). The criteria currently specified by Kent & Essex IFCA for recovery includes a total oyster biomass of 800t and increasing or stable stock levels for the previous three years (KEIFCA, 2019). In addition to other clauses and requirements, there must be sufficient evidence of successful reproduction occurring with the presence of juvenile oysters (KEIFCA, 2019). Lown et al*,* (2020) predicts that, under current conditions, the Essex population of *O. edulis* may take between 16 and 61 years to grow from ~300 to ~800 t without any active intervention (mean 30 years).

[1] ENORI website: https://essexnativeoyster.com/

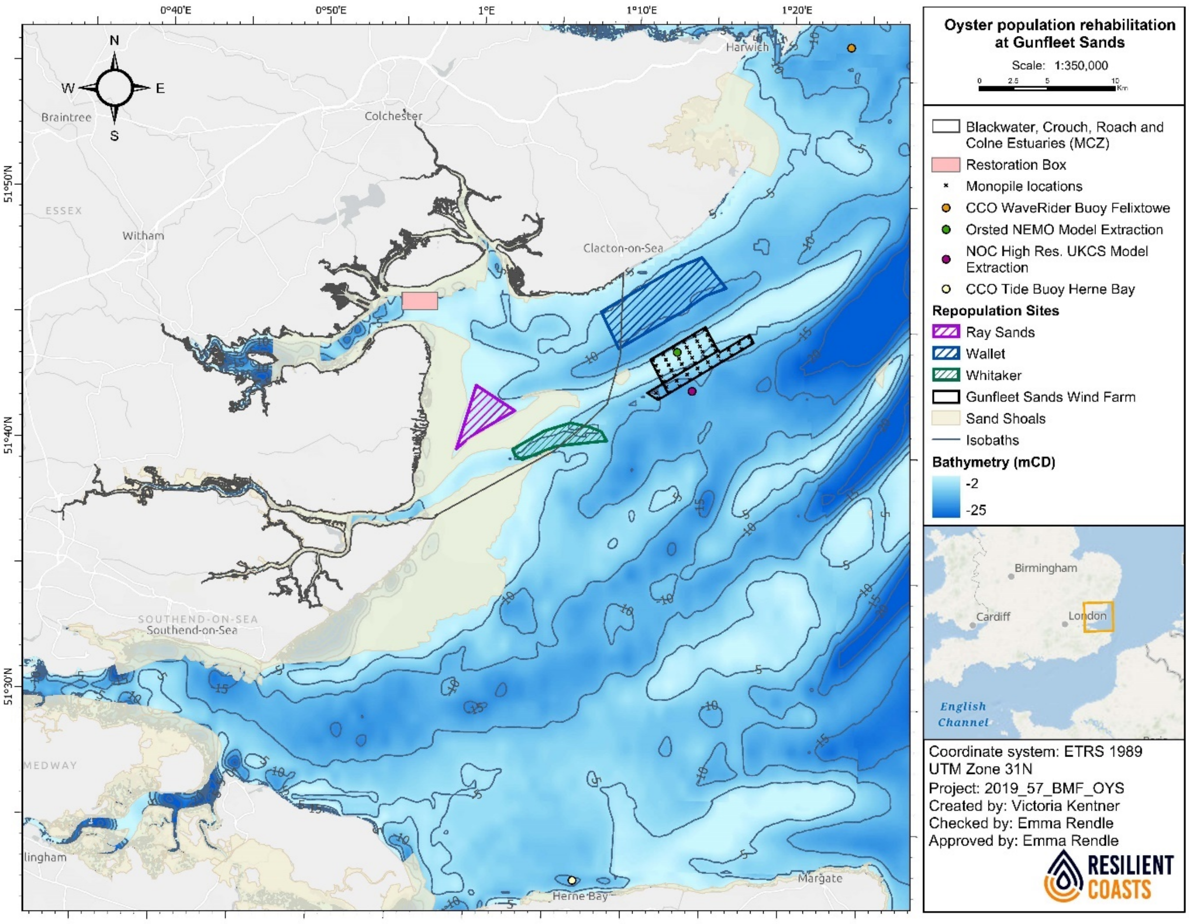

Figure 3. Blackwater, Crouch Roach and Colne Estuaries Roach Marine Conservation Zone boundary, potential receiving sites of larvae from broodstock (repopulation sites) and the ENORI Restoration Box. Source: Rendle (2020).

Suitability of wind farm sites for flat oysters

The UK has the largest installed capacity of offshore wind in the world[2], accounting for approximately 35% of global offshore wind capacity[3]. The UK's ambitious target for installed offshore wind energy has recently been raised to 40 GW by 2030 compared to the 14 GW currently installed or under construction. With this target, over a third of British electricity will be produced by offshore wind power. The expansion of the wind sector creates numerous opportunities for partnership with conservation and fisheries management initiatives.

[2] https://www.gov.uk/government/news/new-plans-to-make-uk-world-leader-in-green-energy

[3] https://www.renewableenergyworld.com/2019/12/24/seven-of-the-10-largest-offshore-wind-farms-are-in-the-uk/

Marine renewable energy installations can enhance both biodiversity and fisheries if appropriately managed and designed (Inger et al, 2009). Their hard structures act as artificial reefs and fish aggregation devices, with numerous global studies highlighting these benefits. In some cases, offshore wind farms can also create areas closed to mobile fishing methods such as bottom trawling, which could provide shelter for oyster reefs or other marine habitats (Kamermans et al, 2018). While the UK does not prohibit the use of mobile fishing gear within offshore wind farms, the risk of gear entrapment or the requirement to navigate around obstacles such as cables may reduce the chance of seabed disturbance (Gray et al, 2016). When sited within areas requiring conservation, they may also assist in the protection of wider areas of the marine environment (Halpern, 2003; Wilhelmsson et al, 2006).

This report focuses on the Gunfleet Sands Offshore wind farm, which is located close to the MCZ and ENORI project site (Figure 3). The wind farm has a capacity of 172 MW and is owned and managed by Ørsted, a leading multinational renewable energy company who are interested in ecological enhancement within their developments.

Learning from others

Relative suitability of a wind farm for oyster survival is primarily determined by small-scale seabed dynamics expressed in seabed stress, sediment composition, the concentration of suspended particles and the chance of recruitment (Smaal et al, 2015; 2017). A number of abiotic and biotic factors are also important to consider including water depth, salinity, water temperature, water oxygen content, current velocity (also in connection with larval retention and spat settlement), concentration of suspended particles in the water column and substrate type (which should also be suitable for spat settlement) (Smaal et al, 2015; 2017). Biotic factors include sufficient levels of phytoplankton, low predation, low mortality due to disease and sufficiently large populations for spat settlement levels that are able to sustain and / or expand the bed. Historical data on the range of oyster beds, as a qualitative benchmark for the suitability of sites, should also be considered.

In the North Sea, the expansion of the offshore wind farm sector has raised the question of whether this offers opportunities for concentrated native oyster restoration efforts. Competition for inshore space has already driven restoration initiatives in Holland, for example, to conduct offshore feasibility studies (Smaal et al, 2015; 2017). Recent research by Smaal et al, (2015; 2017) examined the requirements of native oysters and the habitat characteristics of existing and planned wind farm sites in the Dutch section of the North Sea. The reports concluded that the wind farm sites are suitable for the survival, growth and reproduction of native oysters, which have also been recorded within the wind farms (Smaal et al, 2015).

Case study – Eneco Luchterduinen Offshore Wind Farm

In November 2018, an artificial reef structure was installed within the Luchterduinen offshore wind farm, 23 kilometres west of the Dutch port city of Ijmuiden (Wind Energie Magazine 2018, 2019a, 2019b). The project is part of the 'Rich North Sea' initiative and is supported by €8.5m in funding from the Dutch National Postcode Lottery. The initiative plans to place artificial reefs at five locations in Dutch offshore wind farms. The first reef, installed by Van Oord (in cooperation with the North Sea Foundation, the Natuur & Milieu organisation and Eneco) in 2018, is in a three-ha area at water depths of around 20 metres and comprised of reef balls and cages containing adult oysters (Figure 4). Waardenburg Consultants, SAS Consultancy, and Wageningen Marine Research are monitoring whether the oysters will produce larvae, leading to the development of a full-scale reef.

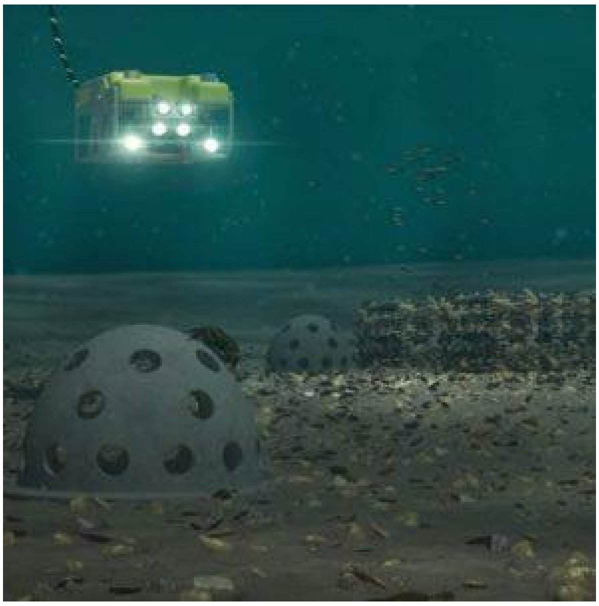

Figure 4. Oyster reef balls and cages containing adult oysters. Source: Wind Energie Magazine (2019b)

Initial monitoring results have indicated that the current reef structure and oyster cage design is not optimal for the underwater conditions at the wind farm. Surveys found that cages had sunk into the bed and become partly buried in sand. However, the remaining cages did show an encouraging survival rate (80%) and signs of growth were found in both surviving and dead oysters. Larvae was also identified in the oysters and surrounding water, which shows oysters can grow and reproduce in offshore wind farms (Van Oord, n.d.).

Project Overview: Oyster restoration in the Gunfleet Sands Wind Farm

Developing a broodstock site

It is widely accepted that Europe no longer has healthy productive native oyster beds (Airoldi & Beck, 2007; Beck et al, 2011; Preston et al, 2020). In the Blackwater, populations are alarmingly low (Lown, 2019). The ENORI project has conducted dredge, grab and benthic baseline surveys of the Blackwater, which have confirmed extremely low native oyster densities. This loss of standing stock is a limiting factor for restoration initiatives (Laing et al, 2006). It is also accepted that in order to restore self-sustaining populations of oysters to areas with severe depletion (such as the Blackwater) large quantities of larvae are needed.

One solution that has proved very successful in established restoration projects in the US is the introduction of adult oysters to increase the number of larvae released into the system. When native oysters reproduce, larvae are released into the water column and are planktonic for an active-swimming period of approximately ten days (depending on the water temperature) (Helmer et al, 2019; Preston et al, 2020). They are dispersed by currents and then settle on suitable substrate and metamorphose into spat.

Re-stocking is considered an effective strategy for native oyster restoration and broodstock programmes are integral to many restoration projects in Europe and the UK. In the Solent, BLUE has introduced 23,000 broodstock oysters into cages suspended below pontoons at marinas through the Solent Oyster Restoration Project[4] (Figure 5) (Helmer, 2019). The purpose of a broodstock site within a restoration initiative is to re-seed other 'downstream' protected or restoration areas. As a result, sites do not have to be designed to create or promote oyster habitat on the seabed. Using hydrodynamic modelling, broodstock have been placed in areas where larvae will be able to reach other prepared and protected sites. In the Blackwater, ENORI has also released 25,000 broodstock oysters into the Conservation Box within the MCZ. A single mature oyster is capable of releasing 1 to 2 million larvae a year (Eyton, 1858; Cole 1941; Walne, 1974; Utting, 1991; Helmer, 2019).

[4] BLUE's Solent Oyster Restoration Project: https://www.bluemarinefoundation.com/projects/solent/

Figure 5. Broodstock oyster cages used by BLUE for the Solent Oyster Restoration Project. Cages are regularly removed from beneath the pontoons for monitoring and cleaning before being re-submerged.

Feasibility study – Gunfleet Sands as a potential broodstock site

In 2019 BLUE and Ørsted, with the support of ENORI, initiated a project to determine if the Gunfleet Sands wind farm could make a significant contribution to native oyster restoration efforts in the UK as a broodstock site for the ENORI project. In particular, its proximity to the ENORI restoration areas provides an ideal opportunity to explore the role wind farms can play in oyster restoration in the North Sea.

The first step was to conduct a feasibility study with the aim of progressing to a pilot phase if results were encouraging. If the site was deemed suitable for oysters following the study BLUE would then develop detailed methodologies for housing oysters within the site and for testing whether oyster larvae from Gunfleet Sands would settle in inshore areas, thereby contributing to oyster restoration as part of the ENORI project. A pilot phase was proposed to deploy 2,500 adult oysters within the wind farm on the basis of a positive result from the feasibility study.

The Gunfleet Sands Wind Farm

The Gunfleet Sands Offshore Wind Farm is a 172 MW wind farm about seven kilometres off the Clacton-on-Sea coast in the Northern Thames Estuary. The wind farm is located on one of the many sand banks found in the Thames estuary. The wind farm is operated by Ørsted and was developed in three stages (GS1, GS2 and GS3). GS3 is a small addition to the existing array with two turbines. Located in very shallow water depths range from 2 m to 15 m LAT with the north-east and south-west parts exposed at low water. across the site with the north-east and south-west parts exposed at low water. Preliminary data and consultation carried out by BLUE with ENORI, local oystermen and Ørsted indicated the wind farm array area could be well positioned to act as a broodstock site providing oyster larvae to restoration sites within a local Marine Conservation Zone (MCZ) and other inshore areas (Figure 3).

Commissioned feasibility study

Following an initial consultation with local stakeholders, BLUE commissioned a feasibility study to assess in detail the suitability of the wind farm for native oyster restoration. The study was undertaken by marine consultancy Resilient Coasts and completed in February 2020 (Rendle, 2020). The study included a review of available literature and data, hydrodynamic data, sediment composition and physical processes as well as operations and management of the site. Parameters for oyster biology, ecology and survivability were drawn from literature sources and discussions with key stakeholders.

The habitat requirements and considerations for oyster restoration at wind farms were selected from Smaal et al (2017) *Oysters and Wind Farms*, which outlines suitable locations for native oysters on existing and planned wind farms in the Dutch North Sea. To date the report provides the most comprehensive suitability matrix for oyster survivability within offshore wind farms in the UK. The study also needed to consider operational requirements within the wind farm to ensure positioning and design options did not impact Ørsted operations.

The commissioned feasibility report by Resilient Coasts focused on addressing three questions:

1. *What is the most suitable location within the wind farm?*
2. *What is the most appropriate design for the cages?*
3. *Would the local currents take spats towards the shore?*

Through consultation with ENORI, including local oystermen and fishermen, BLUE identified areas within and outside of the MCZ that could, due to the tidal streams of the area, be replenished by export of larvae from inside the wind farm. Figure 3 shows the locations of the Gunfleet Sands wind farm, the Blackwater, Crouch, Roach and Colne Estuaries MCZ and historic oyster grounds that could receive larvae from within the wind farm;

- The Wallet (blue box) is a historic oyster site with large quantities of old oyster shell – a substrate highly favoured by settling oyster larvae – which could be re-seeded by broodstock located in the wind farm.
- The Ray Sand Channel (purple box) sits inside the MCZ. This was an important oyster ground up until a few years ago and presents an opportunity to re-seed a fishing ground;
- The Whitaker Channel (green box) was another important oyster ground and would be well situated to receive larvae from the wind farm;
- The 2km^2 'restoration box' managed by ENORI has been re-laid with oysters and could benefit from larval input.

1. Most suitable location within the wind farm

Position within the wind farm

Throughout the study, depth was a key consideration for positioning oysters within the wind farm to ensure protection of oysters from exposure and drying, low temperature and high wave energy. To increase oyster survivability, any areas of seabed at less than 10m water depth (measured against CD) were not considered. Operation risks around scour protection stones and cables on the seabed were also assessed alongside navigational risks to ensure hull clearance and collision avoidance. Positioning further considered current direction and dispersion in relation to the MCZ and protection of larvae from wind-wave driven surface processes. It was assumed closer proximity to the MCZ would increase the likelihood of larvae dispersal into the estuary system with the flood tides. This analysis resulted in a focus on southwest of Gunfleet Sands, which is the deepest area near to the MCZ (Figure 3).

Options for how to place or house oysters within the site were guided by results from pilots underway in the Dutch North Sea. The seabed of Gunfleet Sands is a sandy environment with a high bedload transport and turbidity. Oysters are highly sensitive to sedimentation and the study indicated placing oysters loose onto the seabed would result in significant mortality or loss. Studies have shown physiological performance is improved when raised off the seabed (Sawusdee et al, 2015). The decision was therefore made to house oysters in a solid structure. However, the risk of erosion and scour around any structures or cages used to house oysters on the seabed was also deemed to be high with structures likely to move or be flipped unless secured down to a solid base. The sandy or muddy sand seabed present within the wind farm also suggested a high chance of any housing sinking into the bed and becoming buried by sand (as observed in Holland at the Eneco Luchterduinen wind farm test site), unless weight was appropriately distributed, or a scour mattress used.

It was therefore recommended that the scour protection at the foot of the wind turbine monopiles be used to provide a solid and secure surface for housing. Placing housing on scour protection would also position oysters above the seafloor reducing the impacts of sedimentation. Preference was given to scour stones with a large footprint to allow weight from the housings to be spread over a wider area (Figure 6). The oysters would be exposed to extreme flows around the monopiles, however advanced modelling was required to calculate the subsequent combined shear stress. This modelling was beyond the scope for this feasibility study but is a recommendation for future consideration.

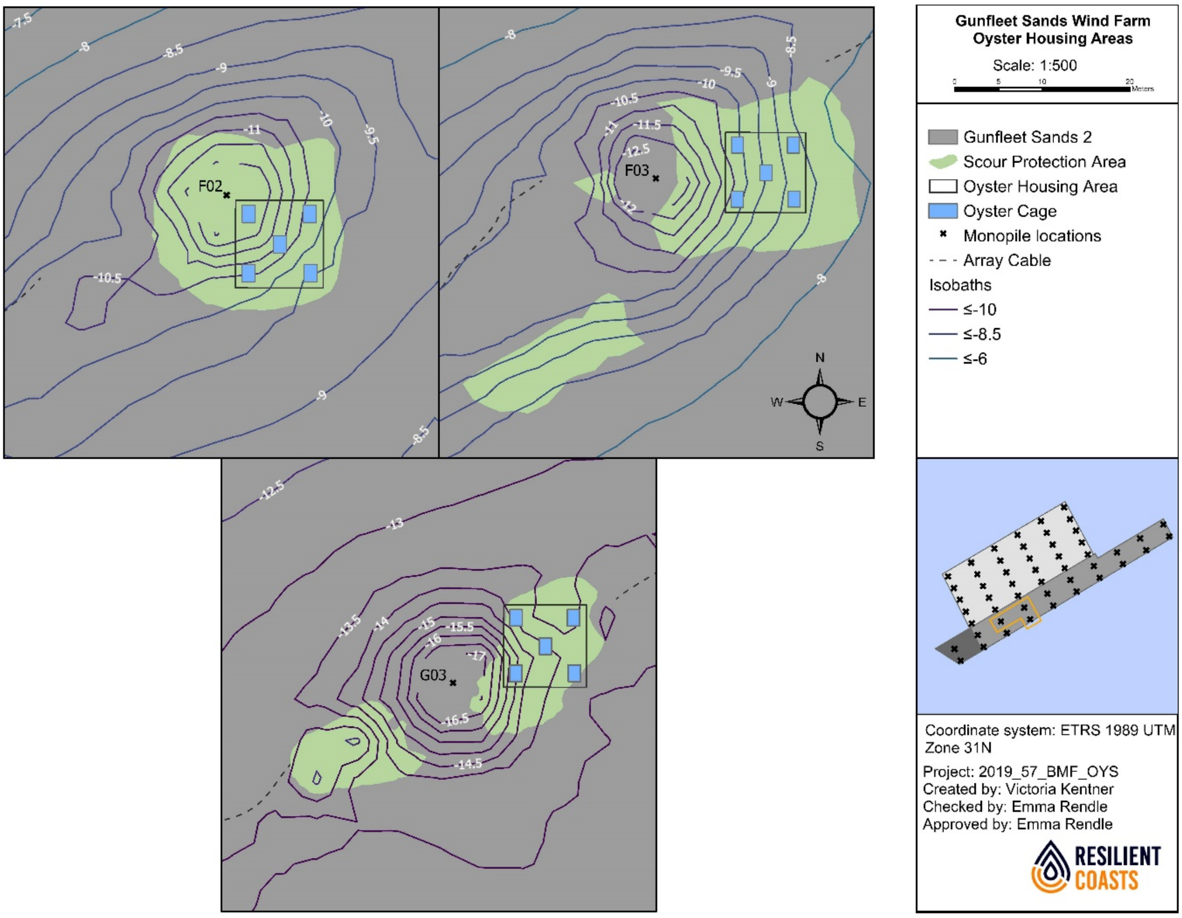

Figure 6. Example of cage positioning on scour protection areas adjacent to monopile locations. Source: Rendle (2020).

Several monopiles in the southwest region of the wind farm were identified and ordered by preferences based on Ørsted's wind farm operation considerations, the environmental tolerances of native oysters and distance from the MCZ. Some monopiles were disregarded due to operational constraints and other monopiles were discounted for either being too shallow or too far from the restoration areas of interest. Focusing on one site within the wind farm was recommended to reduce costs of multiple installation sites, plus additional costs associated with mooring sinkers and marker buoys. The analysis indicated the southwest extent of the array is located in water deep enough to provide protection to the broodstock oysters and allow for appropriate hull clearance (monopile rows G and F only). The most suitable locations within this area were monopiles and cable scour protection in the following order: G00 and F00 (in GFS3), followed closely by G03, and F02 and F03 (in GFS2) (Figure 7). It was recommended that if survivability proved successful, GFS3 be reconsidered for use at a roll-out phase since it had a greater area of scour stone protection available for multiple oyster housing.

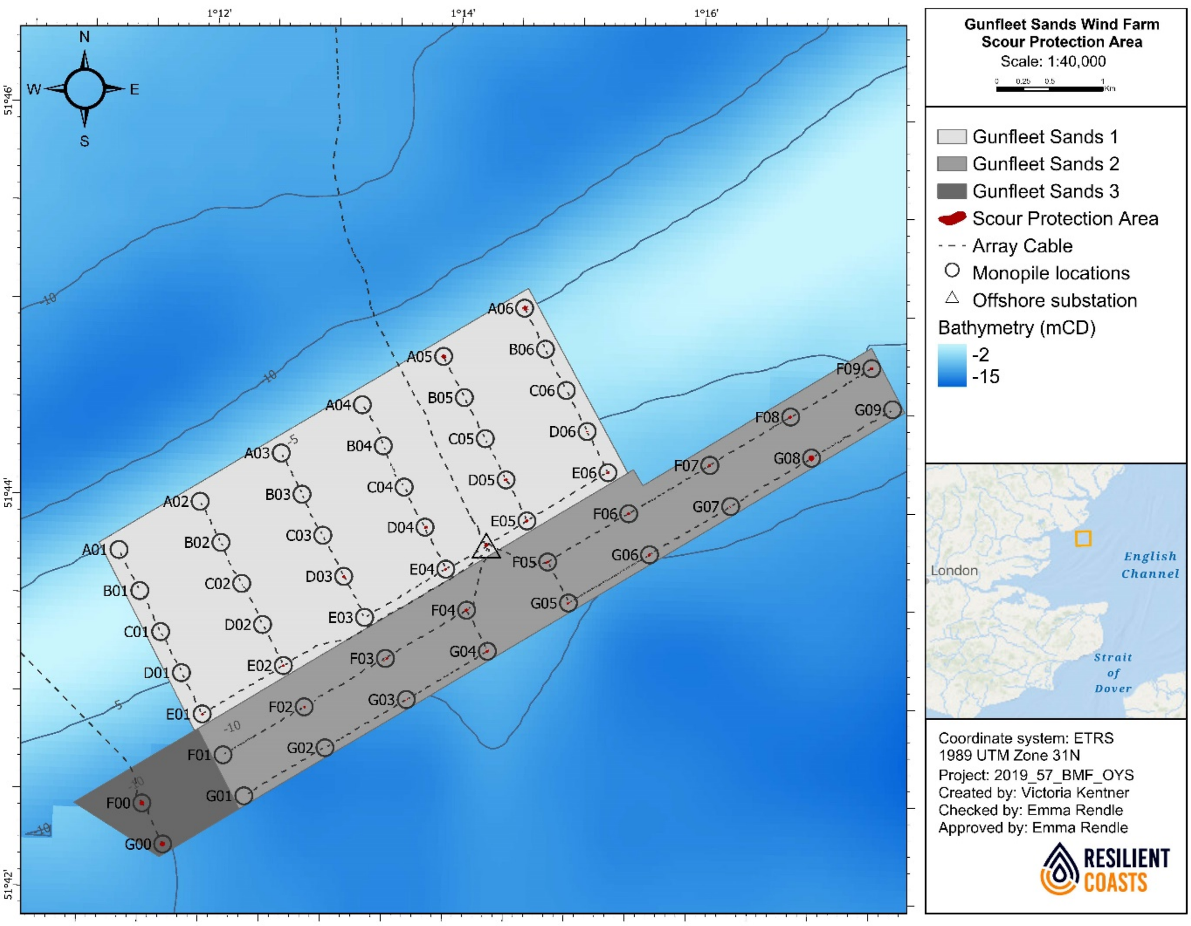

Figure 7: The scour protection for the monopiles is highlighted in red; some monopiles have significantly more solid bed, while some have no scour protection. GFS3 is located to the southwest of the site. Source: Rendle (2020).

Navigational safety

As summarised in the Gunfleet Sands Environmental Statement (Dong Energy, 2010), the area is predominately used by anglers and smaller vessels. There are no shipping routes that pass through the wind farm site, though other traffic includes Gunfleet Sands crew transfer vessels and recreational craft. Marker buoy location may be required to improve navigational safety.

2. Sourcing oysters and most appropriate design for cages

Sourcing broodstock oysters

Sourcing native oysters to be used for a pilot was dependent on several factors; availability, disease and invasive non-native species, related biosecurity restrictions and license to translocate, plus a consideration for benefits of wild vs. farmed (see Helmer et al, 2020 and zu Ermgassen et al, 2020). Removing wild oysters by dredge has negative environmental consequences, however wild oysters are likely to be more resilient and robust than those reared in farms even if they are genetically similar. It was agreed that local stock should be used where possible and to use a combination of two sources to allow for comparison. The pilot planned to use 2,500 oysters with 50% from wild fisheries (oysters are caught as by-catch) where the shells are known to be thicker due to their lifetime exposure to the North Sea conditions, and 50% from Essex oyster growers from private grounds managed under a Several Order.

Oyster housing design and installation

For oyster housing and installation, the feasibility study recommended oysters be housed within secured cages on scour stones (Figure 8). With the wind farm being located on a high energy sandbank, the study also recommended that oysters be housed in mesh bags made of high-density polyethylene (HDPE). HDPE mesh bags are easy to handle, non-corrosive and nontoxic. In order to maximise survivability, a large mesh should be used to reduce the risk of sedimentation and debris, and poor circulation. The decision was also made to limit oysters per bag to 25 or less. Results from other studies have shown greater mortality of oysters in small mesh bags (Alison Debney, pers comm 2020). Greater mortality in oysters housed in narrow micro reefs was also observed in a Dutch study by Didderen et al. (2018).

To hold the mesh bags of oysters the study recommended a simple rectangular outer housing be designed with a focus on spreading weight and increasing flow through the housing. Galvanised mild steel angle (75mm) was suggested as the outer housing due to its versatility and cost. To further prevent sedimentation effects the outer housing was designed to have large spaces to allow debris to pass. The design further considered risks from the housing becoming silted up, moving or flipping and any damage that the cages might cause to the array cables or infrastructure. It was decided that the HDPE mesh bags each containing 25 oysters should be placed at the top of the housing, approximately one metre above the base. This design would reduce sedimentation and allow mobile bed sediment to pass under the oysters and through the lower housing providing less opportunity for drag and movement. It was agreed that if the project progressed to a pilot phase housing design would need to be tested and developed further.

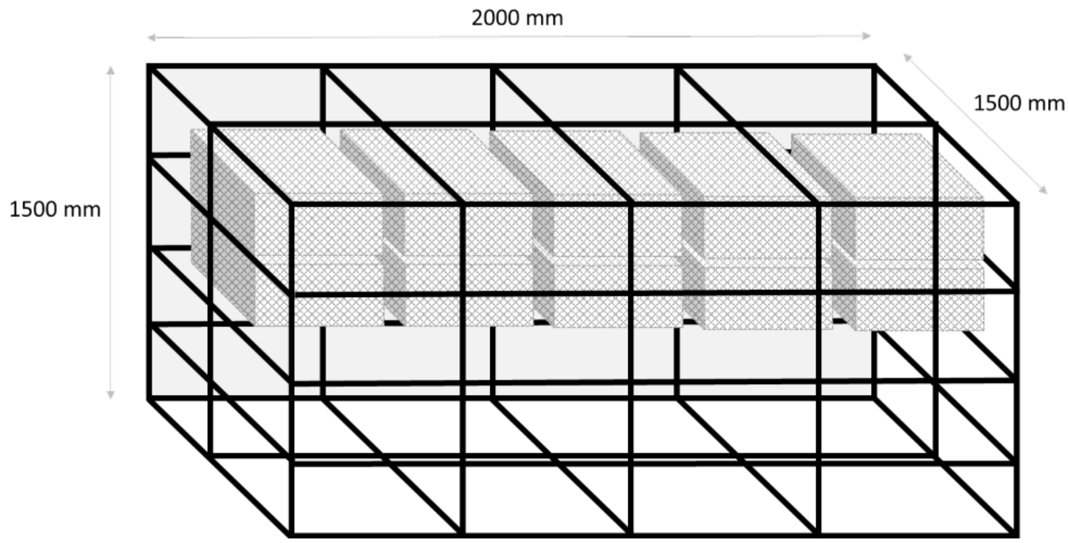

Figure 8. Example of housing design for oysters using a galvanised iron outer frame with steel rebar to provide support and strength, with 20 mesh bag arrangement[5]. Source: Rendle (2020).

To allow for monitoring of oyster health including mortality and reproduction the study considered the use of acoustic release devices set with ropes and large buoys attached to several of the HDPE mesh bags. Using acoustic release devices would allow the return of some oysters to the surface without needing to remove the entire housing for sampling. This would allow for monitoring to be conducted without the need for divers reducing costs and safety risks.

[5] Example of mesh bags: https://www.oyster-mesh.com/oystermesh/hdpe-oyster-mesh.html

3. Spawning and enhancement of local oyster population after reef/bag installation

Larval dispersal

Establishing a broodstock oyster site within Gunfleet Sands aimed to take advantage of tidal currents to transport larvae to the nearby MCZ and other identified sites of interest. The feasibility study found that the dominant form of transport for larvae released within the site is tide induced currents. Larvae will be carried with the prevailing current, either the ebb or flood tide depending on timing of the spawning event. Under low wind and wave conditions when it is relatively calm, the tidal flow will carry larvae back and forth along the rear of the sand bank and the spawning plume will become more diluted and dispersed overtime. The array area represents a highly dispersive site so it's likely that the larvae will be well-mixed and disperse quickly with the combined tide, wind and wave energy.

To understand whether the larvae will reach areas of interest, the study used a simple linear estimation. This was based on passive transport, i.e. no active larval influence and the larvae are carried with the prevailing flow, using a given particle size to represent the larvae transport in an average current flow. This was outlined as a highly limited approach and should be considered indicative of whether, given a successful spawning event of the broodstock, it is possible for the larvae to reach the identified sites from the wind farm site. Assumptions on this linear calculation included the following (Rendle, 2020):

- Input parameters are based on standard averages.
- Native oyster larvae are particle size 0.140 µm = 0.00014 mm (Helmer, 2019).
- Distance is from a point of input in this case.
- Average current speed is 0.6 m/s (average over a 6-hr tidal cycle).
- The tide oscillates through flow speed; tides reverse and counter max flow strength.
- Particles will not fall out of suspension, travel one direction in single 6 hr tide.
- No active transport or wave driven transport.

The feasibility study found that if spawning occurs during high energy events, larvae may reach the MCZ. There is also a chance that larvae would reach the outer edges of Ray Sands in the MCZ on a single flood tide, given the proximity to the wind farm. If they are pushed up and over the saddle of the sand bank (west of GFS3) then they could also reach The Wallet on the ebb tide. The likelihood of larvae being pushed further into the MCZ and reaching the Conservation Box however, given freshwater flows offshore and diminishing onshore currents, was low. As the outer edges of the MCZ are exposed to wave energy, larvae settling and population restoration is most likely to occur where there is some shelter, such as the regions nearest the southwest corner of Gunfleet Sands, e.g. Ray Sands and

Whitaker (Figure 3). The lack of suitable substrate through the MCZ was also considered to be a barrier preventing oysters from settling on the seabed.

Based on the understanding of larvae behaviour, the site's physical processes/hydrodynamics and linear calculations, the window of opportunity for conditions to carry larvae onshore within the MCZ is small, but not impossible. However, a pilot study of 2,500 broodstock oysters is unlikely to make a noticeable difference and would require an adequate timeframe for monitoring. The study also recommended consideration be given to the benefits of larvae released from within the wind farm for the wider North Sea region.

The results showed that while the perfect conditions for larval transport may occur at the site, the window of opportunity is small and unlikely to align with larval release. These findings underpinned the decision to not develop a pilot project. To obtain further confidence for scaling up activities, the study recommended that a hydrodynamic numerical model should be developed. Since then, Rendle et al. (in preparation) have completed this study and the results demonstrate that it is highly likely that larvae will travel offshore and will not reach the required regions for restoration, implying the Gunfleet Sands is unsuitable for successful restoration of native oysters. This reaffirms the decision to not develop a pilot project at the site.

Conclusion

This report summarises a collaboration between BLUE, Ørsted and ENORI aimed at determining the suitability of the Gunfleet Sands Offshore Wind Farm to act as a broodstock site to aid native oyster restoration within a nearby MCZ. The project was supported by a feasibility study (Rendle, 2020) which provided an assessment of environmental tolerances for native oyster survival; combined hydrodynamics (waves and tides); operational requirements and preliminary design of oyster housing to support a pilot phase. The results indicated a spawning event, combined with a flood tide, may allow larvae to reach the MCZ under specific weather conditions. However, the perfect window of opportunity for larval transport is relatively small and unlikely to coincide with larval release. In addition, to make a meaningful contribution to populations within the MCZ a significant number of broodstock oysters would need to be housed within the wind farm. Depth, bed sediment and infrastructure constraints reduced the area available for broodstock installations to are small number of monopiles and surrounding scour stones. This raised concern over the potential to scale up broodstock numbers and the overall impact of the project, as well as financial investment. It was therefore decided that a pilot phase to determine survivability and reproduction of oysters would not be developed. The lessons within this study however have implications for future work and BLUE remains committed to exploring opportunities within Gunfleet Sands.

Next steps

While BLUE is not pursuing the pilot phase of the Gunfleet Sands Offshore Wind Farm project, the significant interest and potential of oyster restoration and other integral marine species, habitats and even monoculture opportunities within offshore wind farms is recognised. BLUE has now concluded a preliminary analysis of over fifty UK wind farms and extensions at various development phases using GIS and broad-scale seabed habitat data. A site selection matrix has also been developed and used to assess site variables including dominant substrate, energy levels, maximum depths, proximity to shore and proximity to potential oyster restoration areas. Initial results from the scoping study present several potentially suitable offshore wind farm sites and BLUE will continue to investigate these areas in more detail. BLUE will work closely with relevant stakeholders during this process to ensure all opportunities and challenges associated with species restoration and habitat enhancement are addressed, paving the way for a new feasibility study.

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