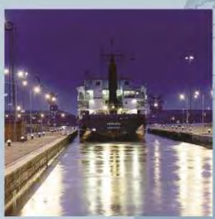
The Welsh Government

A Spatial Assessment of the Potential for Aquaculture in Welsh Waters

Report R.2384

May 2015

Creating sustainable solutions for the marine environment





Page intentionally left blank

The Welsh Government

A Spatial Assessment of the Potential for Aquaculture in Welsh Waters

Date: May 2015

Project Ref: R/4297/01

Report No: R.2384

Version	Details of Change	Date
1	Issue for Client Comment	13.03.2015
2	Final Report	31.03.2015
3	Extended Final Report	14.05.2015

Document Authorisation		Signature	Date
Project Manager:	C A Roberts	C. Roberts.	14.05.2015
Quality Manager:	S F Walmsley		14.05.2015
Project Director:	S C Hull	Steve Hull	14.05.2015

ABP Marine Environmental Research Ltd
Quayside Suite, Medina Chambers, Town Quay, Southampton, Hampshire SO14 2AQ

Tel: +44 (0) 23 8071 1840 Fax: +44 (0) 23 8071 1841
Web: www.abpmer.co.uk Email: enquiries@abpmer.co.uk

ABPmer is certified by:

Disclaimer:

- *Any 'Draft' issue of this report, and any information contained therein, may be subject to updates and clarifications on the basis of any review comments before 'Final' issue. All content should therefore be considered provisional, and should not be disclosed to third parties without seeking prior clarification from ABP Marine Environmental Research Ltd ("ABPmer") of the suitability of the information for the intended disclosure and should not be relied upon by the addressee or any other person.*

- *Unless previously agreed between the addressee and ABPmer, in writing, the 'Final' issue of this report can be relied on by the addressee only. ABPmer accepts no liability for the use by or reliance on this report or any of the results or methods presented in this report by any party that is not the addressee of the report. In the event the addressee discloses the report to any third party, the addressee shall make such third party aware that ABPmer shall not be liable to such third party in relation to the contents of the report and shall indemnify ABPmer in the event that ABPmer suffers any loss or damage as a result of the addressee failing to make such third party so aware.*

- *Sections of this report rely on data supplied by or drawn from third party sources. Unless previously agreed between the addressee and ABPmer, in writing, ABPmer accepts no liability for loss or damage suffered by the addressee or any third party as a result of any reliance on third party data contained in the report or on any conclusions drawn by ABPmer which are based on such third party data.*

Summary

Aquaculture is considered to be a key area for development in the UK due to its potential to contribute to the sustainability and security of the UK food supply and economic development. The Welsh Government commissioned the current study to develop a spatial model to identify coastal and marine areas potentially suitable for future marine aquaculture developments to support the sustainable development of aquaculture, inform the development of the National Marine Plan and feed into the Aquaculture Multi-Annual National Plan for the European Maritime and Fisheries Fund (EMFF).

The aim of the study was to assess the potential for aquaculture within the Welsh Marine Plan Areas, highlighting locations of opportunity for potential future marine aquaculture developments over the next 20 years (i.e. up to 2035) through development of a spatial model. For the purposes of this study, the term offshore aquaculture has been used to describe potential areas for aquaculture development beyond the coastal/shallow marine areas that aquaculture currently occupies, however, it has been assumed that these sites will likely occur within the Welsh Inshore Marine Plan Area which extends to 12nm.

The spatial model considered three ‘core components’ relating to:

- Natural resource constraints (e.g. water depth, substratum, temperature etc.);
- Marine Spatial Planning (MSP) constraints (e.g. nature conservation designated sites, areas of other marine industry activity, infrastructure and exclusion zones, recreational activity etc.); and
- Investment-dependent constraints (e.g. proximity to landing ports, depuration facilities, and invasive non-native species (INNS)).

Each core component comprised multiple data layers overlaid to identify areas with the fewest (or no) constraints to aquaculture development. The species and cultivation methods considered within the model, which may have the potential to support increased production and/or new viable aquaculture businesses in Welsh Waters, were identified through consultation with the aquaculture industry. The study also considered the influence of non-spatial drivers and constraints (for example, relating to policy and regulation) on the potential for expansion and development of aquaculture in Welsh Waters. Identification and influence of non-spatial drivers and constraints were achieved through a review of available literature and stakeholder consultation undertaken with regulatory authorities, statutory nature conservation bodies, industry body representatives, aquaculture production businesses and research institutions undertaking aquaculture-related research. The influence of these factors on the viability of future aquaculture developments were addressed qualitatively within the study.

It should be noted that the spatial model has limitations relating to spatial data availability and resolution and the report makes recommendations for future development of the model to address these issues. Furthermore, areas of opportunity for aquaculture development are likely to be influenced by available technology, biosecurity, site-specific natural resource and/or planning factors and expert knowledge regarding how these factors are likely to affect the viability of any aquaculture development. As such, it is important to note that the model outputs should only be considered to indicate broad areas where there may be opportunity for future aquaculture development, and that, for the reasons referred to above, some areas presented may overestimate the areas of potential and areas which were not highlighted as suitable should not be considered ‘out of bounds’ for aquaculture development.

It is recommended that further assessment of aquaculture potential at a more local or site-specific level, particularly in the inshore area where in the short term future industry expansion is likely to occur, should be undertaken using the model developed, utilising higher resolution data sets for areas of interest.

Shellfish Aquaculture

The model outputs suggest that there is potential space for the development of the shellfish aquaculture industry, although as would be expected potential inshore areas are far more limited (due to existing activities) compared to offshore areas. Inshore areas may be further constrained in relation to water quality issues which could not be included in the spatial model within the timescale of this study.

Larger areas of potential are indicated to exist offshore for bivalve mollusc species both via bottom culture and rope culture. However, potential issues for aquaculture production in offshore areas include whether current technology for rope cultivation of bivalve molluscs offshore is adequate for the conditions off the Welsh coast. Currently rope grown mussels are only commercially produced in a sheltered location in Wales, although trials for rope grown mussels in more exposed locations have are currently underway. The economic viability of offshore aquaculture remains uncertain.

Security of shellfish stocks (against theft) in offshore waters, disease (including the ability to source disease free seed/spat), were also considered to be serious issues facing the industry and hence possibly pose further spatial constraints on areas of potential. It was issues relating to licensing (specifically the relatively short duration of leases, agreement of Several Order Fishery terms and the time for Several Order Fisheries to be renewed) that were considered to result in a major lack of security for current producers and to potentially discourage new entrants to the industry.

Macroalgal Aquaculture

The model outputs indicate that there are relatively large areas of potential for offshore cultivation of macroalgal species which can tolerate moderate energy environments. Pilot-scale trials of offshore macroalgae cultivation are being undertaken in the Irish Sea and Scotland, however, for this potential to be realised, the technology will need to be proven. Furthermore, whilst research into high value extracts from macroalgal products for the pharmaceutical, cosmetic and nutraceutical industries is currently being undertaken in Wales, the market demand for, and economic viability of, large scale production of macroalgal species would need to be established. The water quality in which the seaweed is cultivated can influence the potential uses for the end product, although it is assumed that water quality would not be an issue in offshore waters.

Crustacean Aquaculture

Stakeholder consultation for the current study indicated that European lobster (*Hommarus gammarus*) and European spiny lobster (*Palinurus elephas*), also referred to as crawfish, are high value species of potential interest to the aquaculture sector and hence the model incorporated the potential for on-growing (or ranching) of hatchery-reared crustacean species. However, it is important to note that the on-growing of *Hommarus gammarus* has not yet been carried out on a commercial scale in the UK and hence little is known about the optimal rearing conditions. Furthermore *Palinurus elephas* is notoriously difficult to rear in the laboratory. Hence whilst the model outputs indicated there were areas of suitable natural resources with minimal constraints for placement of hatchery reared lobsters for on-growing to a marketable size, it is acknowledged that the viability of hatchery production of spiny lobster and the ability to 'contain' the on-growing lobsters (of either species) within a given marine area and thus ensure the security of the stock are major issues facing the establishment of this practice.

Finfish Aquaculture

The model outputs indicated that there are relatively large areas of potential for offshore sea cage culture of finfish species (particularly Atlantic salmon and sea trout). However, potential issues for aquaculture production in offshore areas include the lack of economic viability in competing with the Scottish salmon industry and whether such methods would be feasible in the more exposed environment off the Welsh coast. Whilst stakeholder feedback has indicated that sea trout may be a more viable species to cultivate (from a market supply and demand perspective), the areas of potential that were highlighted are likely to be further constrained once more detailed sea temperature data can be incorporated into the model.

Additional Potential Opportunities for Expanding Aquaculture

Stakeholder feedback highlighted additional potential opportunities for expanding aquaculture within Wales, which could not be incorporated into the spatial model, including:

- Co-location of aquaculture with Offshore Wind Farms (OWFs) - proposed as a potential opportunity to share resources and increase spatial efficiency in the offshore marine environment;
- Co-location of aquaculture activity within tidal lagoons - where 'sheltered' conditions within the lagoons which may lend themselves to aquaculture developments that may previously have not been feasible in that location (such as for the release of juvenile lobsters on the seawalls and for growth of macroalgae on longlines);
- Integrated multitrophic aquaculture (IMTA) - the culture of aquaculture organisms of different trophic levels in proximity to each other (e.g. seaweed / bivalves, seaweed / fish, and seaweed / fish / bivalves cultivated as monocultures in close proximity in the marine environment). The principle of IMTA systems is the use of shared nutrient flows to culture multiple organisms at different trophic levels, thus maximising productivity per nutrient and economic investment through provision of additional commercial product(s);
- Development of a shellfish hatchery in a disease (*Bonamia*) free area could help with the supply of biosecure seed for both native and Pacific oysters. The recent lapse in the patent of the method for production of 'mated' triploid oysters could provide a further opportunity for the establishment of a hatchery in Wales to rear triploid strains of Pacific oyster (supported by appropriate research and development of this management technique); and
- Land-based Recirculation Aquaculture Systems (RAS), which stakeholder feedback indicated has the potential to contribute to the Welsh Government's target for doubling finfish production by 2020. Currently in Wales this type of system is used for the commercial production of seabass.

Recommendations for Development of the Model

Based on the gaps and limitations in the spatial data incorporated into the model, the following recommendations to further improve the model were made.

- Water quality – incorporation of graduated constraints around point sources of sewage-related consented discharges, based on the population equivalent of the discharge. This would help to further refine the model outputs with respect to providing additional constraints relating to water quality outside of designated shellfish waters).
- Sensitive benthic habitats – the model does incorporate 'habitat' data from the FishMap Mon project which could be utilised to indicate the habitats in areas of potential for more site specific investigations;
- Carrying capacity – adequate growth rates and yields of shellfish will require developments to be established in areas with suitable biological carrying capacity based on food availability and ecosystem productivity. It was not considered within the scope of the current study to be able to incorporate this factor into the spatial model. However, where appropriate models are available they could be incorporated for more site-specific assessments of aquaculture potential.

Acknowledgements

Report prepared for the Welsh Government by ABP Marine Environmental Research Ltd (ABPmer), Eno Consulting, Marine Ecological Surveys Ltd and Marine Planning Consultants.

To preserve anonymity, the names of the individual aquaculture producers and businesses consulted have not been shown below, however, the information and feedback they provided for this study is gratefully acknowledged.

We would also like to thank the organisations listed below who provided data, technical information and/or feedback for this study:

David Smith	Cefas
Owen Wilson	Cefas
Stacey Clarke	Marine Management Organisation
Aisling Lannin	Marine Management Organisation
Mark Charlesworth	Natural Resources Wales
Holly Whiteley	Seafish
Craig Burton	Seafish
José Constantino	Welsh Government
Phil Coates	Welsh Government
Robert Floyd	Welsh Government
Bruce Jackson	Welsh Government
James Dowling	Welsh Government

Abbreviations

AA	Appropriate Assessment
ABPmer	ABP Marine Environmental Research Ltd
AIS	Automatic Identification System
APB	Aquaculture Production Business
CD	Chart Datum
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CFP	Common Fisheries Policy
cSAC	Candidate Special Area of Conservation
CSAR	Centre for Sustainable Aquatic Research
Defra	Department of Environment, Food and Rural Affairs
DEM	Digital Elevation Model
EA	Environment Agency
EC	European Commission
EMFF	European Maritime and Fisheries Fund
EMS	European Marine Site
EU	European Union
FAO	United Nations Food and Agricultural Organisation
GB	Great Britain
GB NNSS	GB Non-Native Species Secretariat
GES	Good Environmental Status
GIS	Geographic Information System
IMO	International Maritime Organisation
IMTA	Integrated Multitrophic Aquaculture
INNS	Invasive Non-Native Species
IUCN	International Union for Conservation of Nature
JNCC	Joint Nature Conservation Committee
MANP	Multi-Annual National Plan
MCA	Maritime and Coastguard Agency
MCAA	Marine and Coastal Access Act
MCZ	Marine Conservation Zone
MFSAP	Marine and Fisheries Strategic Action Plan
MMO	Marine Management Organisation
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
NIS	Non-indigenous species
NISE	Novel Ingredients from Seaweed Extracts
NRW	Natural Resources Wales
OWF	Offshore Wind Farm
Pcrit	Critical Oxygen Threshold
PEXA	Military Practice and Exercise Area
pSAC	Possible Special Area of Conservation
pSPA	Potential Special Protected Area

RAS	Recirculation Aquaculture System
RYA	Royal Yachting Association
SAC	Special Area of Conservation
SAMS	Scottish Association of Marine Science
SCI	Site of Community Importance
SHA	Statutory Harbour Authority
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
SWD	Shellfish Waters Directive
SWOT	Strengths, Weaknesses, Opportunities and Threats
TCE	The Crown Estate
UK	United Kingdom
UN	United Nations
WFD	Water Framework Directive
WG	Welsh Government

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

A Spatial Assessment of the Potential for Aquaculture in Welsh Waters

Contents

Appendices

Tables

Figures

1. Introduction

1.1 Project Background

Aquaculture is considered to be a key area for development in the UK due to its potential to contribute to the sustainability and security of the UK food supply and economic development. The Welsh Government's Marine and Fisheries Strategic Action Plan states that it is committed to the sustainable development of aquaculture (marine and freshwater) and aims to double annual shellfish and finfish aquaculture output by 2020 (Welsh Government, 2013).

The Welsh Government commissioned the current study to develop a spatial model to identify coastal and marine areas potentially suitable for future marine aquaculture developments, to support this sustainable development of aquaculture, inform the development of the National Marine Plan and feed into the Aquaculture Multi-Annual National Plan for the European Maritime and Fisheries Fund (EMFF), which requires Member States to identify priorities and opportunities for the development of sustainable fisheries and aquaculture.

Specifically, the project required the development of spatial data layers that indicate the location of current marine aquaculture activity and that highlight areas where there is potential for further aquaculture development, based on suitable natural resources, other marine uses of the Welsh Marine Area and proximity to essential infrastructure.

1.2 Project Aims and Scope

The aim of the current study has been to assess the potential for aquaculture in Welsh Waters, highlighting locations of opportunity for potential future marine aquaculture developments over the next 20 years (i.e. up to 2035).

The study has considered the potential for aquaculture within the Welsh Marine Plan Area (see Figure 1.1) which comprises the Welsh inshore region (extending from the high water mark to the 12nm limit) and the Welsh offshore region (extending from 12nm up to the equidistant line between the Welsh coast and the coasts of other countries, up to a maximum of 200nm). It should be noted that for the purposes of this study, the term 'offshore aquaculture' has been used to describe potential areas for aquaculture development beyond the coastal/shallow marine areas that aquaculture currently occupies, however, it has been assumed that these sites will likely occur within the Welsh Inshore Marine Plan Area which extends to 12nm. This is based on previous consultation with aquaculture industry stakeholders regarding likely technological advances, and the implications for the location of future developments, in the time period up to 2033 (Marine Management Organisation (MMO), 2013a).

For the purposes of the study, aquaculture has been defined using the United Nations (UN) Food and Agricultural Organisation's definition (FAO, 1988):

> "*Aquaculture is the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc.*

Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their rearing period contribute to aquaculture, while aquatic organisms which are exploitable by the public as a common property resources, with or without appropriate licences, are the harvest of fisheries".

Marine aquaculture has been taken to include sea-based cultivation of marine finfish, shellfish, crustaceans and macroalgae and the study has focussed on the production of 'food' species given that one of the main drivers for aquaculture expansion is food security. It is acknowledged that there are likely to be other species of finfish, invertebrate, macroalgae and microalgae that will be of commercial interest and value to the aquaculture sector in Wales, for example, in relation to the ornamental aquatic trade, pharmaceutical, nutraceutical and cosmetic industries and for use as biofuels (e.g. macro- and microalgae). However, it was considered beyond the scope of the current study to be able to model potential areas of opportunity for such species, particularly for those which would be predominantly produced in land-based systems.

Although the project specification referred to freshwater aquaculture, it was agreed with the Welsh Government that while the study would seek to highlight the current location of freshwater aquaculture production businesses (subject to available relevant data layers and commercial confidentiality issues), the spatial model would not be suitable for highlighting potential areas for expansion/development of freshwater or land-based marine aquaculture (e.g. through Recirculation Aquaculture Systems (RAS)). The study has considered the future potential of land-based marine finfish aquaculture, with regard to limitations and constraints, where information is available.

1.3 Project Oversight

The execution of the project has been overseen by the Welsh Government. The study team has also engaged with aquaculture businesses and research institutions in Wales to understand current and future constraints and opportunities.

1.4 Report Structure

This report contains the following sections:

Section 1: Introduction (this section);
Section 2: Methodology;
Section 3: Current aquaculture activity in Wales;
Section 4: Potential future aquaculture species and methods in Wales;
Section 5: Natural resource requirements;
Section 6: Marine Spatial Planning related opportunities and constraints;
Section 7: Proximity to essential infrastructure and investment-related constraints;
Section 8: Modelled potential for aquaculture in Welsh Waters; and
Section 9: Conclusions and recommendations.

2. Methodology

2.1 Identification of Current Aquaculture Species and Methods in Wales

Information on current aquaculture activity (species, methods, production volumes and values) was collated using publically available information (e.g. Defra, 2014; Welsh Government, 2013), project team knowledge of Welsh aquaculture and consultation with the Welsh Government.

Spatial data sources relating to current aquaculture activity in Welsh Waters are shown in Table A1 in Appendix A.

Non-spatial data sources relating to aquaculture activity in Welsh Waters, included:

- Public register of Aquaculture Production Businesses in England and Wales (data for registered active mollusc and finfish farms in 2013 provided by Cefas, February 2015);
- Wales Marine and Fisheries Strategic Action Plan (MFSAP) and update (Welsh Government, 2013, 2014a); and
- Welsh Government website: Several Orders in Wales (Welsh Government, 2014b).

Production statistics (at UK level) for finfish and shellfish in 2012 (the latest available statistics) were obtained from Cefas (2015).

2.2 Identification of Potential Future Aquaculture Species and Methods

In order to inform the spatial model, the study needed to identify the species and cultivation methods which have the potential to support either increased production and/or new viable aquaculture businesses in Welsh Waters over the next 20 years (i.e. up to 2035). These species were identified from the literature (e.g. Syvret *et al*. 2013) and consultation with the Welsh Government and aquaculture industry.

2.3 Approach to the Development of the Spatial Model

The current study built upon a spatial model developed by Marine Planning Consultants for the MMO to assess spatial trends in aquaculture potential in the East and South Marine Plan Areas (MMO, 2013b).

The spatial model was developed using ArcGIS v10.2 software utilising Arc 'ModelBuilder' and python scripting to create a repeatable and iterative model. The final Geographic Information System (GIS) outputs comprised an Arc v10.2 geodatabase housing all the model outputs as feature classes and accompanying layer files to define the symbology.

The model considered three 'core components', each comprising of multiple data layers relating to:

- Natural resource requirements (e.g. water depth, substratum, wave and tidal exposure etc.);
- Marine Spatial Planning (MSP) related constraints (e.g. areas of other marine industry activity, infrastructure and exclusion zones, nature conservation designated sites, recreational activity etc.); and
- Proximity to essential infrastructure and investment-dependent constraints (e.g. proximity to landing ports, depuration facilities, and invasive non-native species (INNS)).

The available data layers relevant to each core component are listed in Tables A2 to A4 in Appendix A.

The natural resource component spatially represents areas which are potentially suitable for the cultivation of certain species/species groups (e.g. macroalgae), based on the ecological requirements of the species and the natural resource requirements of the cultivation method (e.g. water of a certain depth for rope cultivation or firm sediment for intertidal trestles etc.).

The MSP component spatially represents the relative magnitude of constraints relating to other marine sector activities, infrastructure or nature conservation designated areas within the Welsh Marine Plan area. Some specific types of marine sector activities or associated infrastructure may effectively exclude aquaculture activity from an area, whereas other marine sector activity or nature conservation designations with particularly sensitive features may only lead to a degree of competition for space, or requirement for additional consideration, and hence may pose a certain level of constraint but not exclude the activity. The proposed exclusion areas, buffer areas and/or constraint levels associated with other marine sector activities, associated infrastructure and designated areas (referred to as Marine Spatial Planning related constraints; see Section 6.4) are shown in Tables B2 to B4 and described in detail in Appendix B. Data limitations are also presented in Appendix B and discussed further in Section 8.

It should be noted that areas where aquaculture is currently undertaken are by definition suitable, and whilst stakeholder feedback indicated a strong interest in increasing productivity at those sites, within the model these areas were considered to be already fulfilling the aquaculture potential and hence not highlighted as areas of potential for further future development. Modelling the potential to increase productivity within these areas was beyond the scope of the current study but is an area that could be further assessed in future studies (see Section 9).

For the purposes of the current study, investment-related constraints, which would affect the viability of an aquaculture business, were considered to include:

- Distance of cultivation site from landing port;
- Distance to depuration facility;
- Location of INNS[1]; and
- Confirmed designation areas of disease (e.g. *Bonamia ostreae*).

These essential infrastructure and investment-related factors are discussed further in Section 7 and Appendix B. Consideration of the proximity between farm sites/installations and seafood supply chain businesses and markets in the spatial model was considered to be outwith the scope of the current study.

The MSP-related constraint component and the essential infrastructure/investment-related constraint component were combined additively and overlaid with the natural resource component layer to illustrate the relative magnitude of combined constraints within the areas identified as potentially suitable for cultivation of a given species/method in the natural resource component layer (note, not all constraints were equally weighted; see Appendix B for further description of constraint types and weighting).

2.4 Approach to Identification of Non-Spatial Constraints

The study also considered the influence of non-spatial drivers and constraints on the potential for expansion and development of aquaculture in Welsh Waters, although the influence of these factors can only be addressed qualitatively within this study. Identification and influence of non-spatial drivers and constraints were achieved through a review of available literature and stakeholder consultation undertaken with regulatory authorities, statutory nature conservation bodies, industry body representatives, aquaculture production businesses and research institutions undertaking aquaculture-related research. The stakeholders consulted have not been identified to preserve anonymity.

[1] In the current study it has been assumed that *Didemnum vexillum* has the highest potential to constrain aquaculture development in Welsh Waters and hence the spatial model will consider this species. The slipper limpet *Crepidula fornicata* was also incorporated into the model but not considered to pose the same magnitude of constraint.

3. Current Aquaculture Activity in Wales

The types of existing aquaculture in Wales are:

- Finfish aquaculture – freshwater production of Atlantic salmon, rainbow trout and brown trout and land-based production of seabass (in seawater recirculation systems);
- Shellfish aquaculture – marine production of blue mussel and Pacific oyster; and
- Crustacean aquaculture – freshwater production of crayfish for conservation.

There are numerous other types of aquaculture being researched and trialled in Wales and there is strong collaboration between the aquaculture industry and research institutions such as the Universities of Bangor and Swansea. For example, offshore cultivation of macroalgae is being piloted in the Eastern Irish Sea by an Industry/Bangor University partnership and research into macroalgae hatchery technology is undertaken at the Centre for Sustainable Aquatic Research (CSAR) at Swansea University. Microalgae (in land-based seawater recirculation systems) are cultivated for both research and commercial purposes. In addition to commercial production of seabass in land-based recirculation aquaculture systems (RAS), trials are underway to assess the viability of culturing other finfish species using this method (described further in Section 9). The innovative nature of the aquaculture industry is highlighted by the projects which have received European Fisheries Funding (EFF) in Wales in recent years, shown in Appendix C.

This current commercial aquaculture activity is described in further detail below, however, it must be noted that the information presented relates to aquaculture activity undertaken in 2013 and 2012 the most recent years for which information was available.

3.1 Finfish Aquaculture

Commercial finfish aquaculture in Wales has traditionally focused on the freshwater production of salmonids, including Atlantic salmon (*Salmo salar*; for stocking), rainbow trout (*Oncorhynchus mykiss)* and brown trout (*Salmo trutta)* for consumption and recreational fishing) (Cefas *et al*. 2014), produced in onshore facilities. However, finfish aquaculture also includes the production of seabass (*Dicentrarchus labrax*) using land-based closed recirculation systems. In 2012, total finfish production from aquaculture in Wales was 452.7 tonnes, with an estimated value of £1.4 million.

In 2013, there were 31 aquaculture production businesses (APBs) registered as finfish farms in Wales (Cefas supplied data, 3 February 2015). The finfish species produced by these APBs in 2013 were sea bass, koi carp (*Cyprinus carpio*), Atlantic salmon, rainbow trout, sea/brown trout (*Salmo trutta*) (all produced at multiple sites), turbot (*Scophthalmus maximus*; note this species is not currently being produced in Wales), goldfish (*Carassius auratus auratus*) and Nile tilapia (*Oreochromis niloticus*) (produced at single sites). The locations of these freshwater finfish cannot be made publically available for data protection reasons and hence they are not presented spatially within this report. It can be noted that there is currently no sea-based aquaculture (mariculture) of marine finfish species in Welsh Waters.

As noted in Section 1.3, the core components of the spatial model are not applicable to the freshwater environment and hence the potential for cultivation of freshwater species has not been considered further in this study. Although the spatial model is not suitable for highlighting potential areas for expansion/development of land-based marine finfish cultivation (e.g. through RAS), the study has considered the future potential of land-based marine aquaculture, with regard to limitations and constraints, where information was available (discussed further in Section 9).

3.2 Shellfish Aquaculture

Marine aquaculture in Wales has traditionally focused on the managed cultivation of shellfish in the sea. The commercial shellfish aquaculture sector in Wales produces the highest annual tonnage of shellfish of all the UK devolved administrations (Cefas, 2015; see production statistics for 2012 in Table 3.1).

The mussel (*Mytilus edulis*) cultivation sector in North Wales is the principle component of Wales' aquaculture sector, producing approximately 7,000–8,000 tonnes of mussels per annum and contributing the largest proportion of total mussel production in the UK (see Table 3.1). The majority of farmed mussel production comes from on-bottom cultivation (Defra, 2014), although rope grown mussels are also produced (see Section 5 for further description of these shellfish farming methods). The majority of the mussels are exported as live fresh produce to Europe (mainly to the Netherlands). All mussel farming in Wales relies on mussel seed (juvenile bivalve for on-growing) sourced from the wild for on-bottom cultivation. Mussel seed is typically obtained from low intertidal or sublittoral ephemeral seed mussel beds that are often located in similar locations from one year to the next (see Figures 3.1 and 3.2). In 2012, the UK shellfish industry used 7,734 tonnes of wild mussel seed, of which 50–55% was used in Wales (industry stakeholder, pers. comm.).

The Pacific oyster (*Crassostrea gigas*) is also farmed in Wales, with hatchery-produced spat being on-grown for harvesting on trays and trestles.

The total tonnage of mussel and Pacific oyster harvested in each devolved administration in 2012 is shown in Table 3.1. The estimated value (calculated using estimated farm gate prices) of mussels and Pacific oysters harvested in Wales in 2012 was £8.9million and £12,000 respectively.

Table 3.1 Shellfish production volume (tonnes) of mussel and Pacific oyster in the UK in 2012 (adapted from Cefas, 2015)

Species	England	Wales	Scotland	Northern Ireland
Mussel	5966	8996	6277	4783
Pacific oyster	850	3	216	138

(Source: Cefas, 2015)

In 2013 there were nine APBs registered as mollusc farms in Wales (Cefas supplied data, 3 February 2015). The mollusc species produced by these APBs were mussels (at eight sites), Pacific oysters (at two sites), native oysters (*Ostrea edulis*) (at two sites) and cockles

(*Cerastoderma edule*) (at one site; relating to a trial for moving and replanting cockles) (information provided by Cefas, February 2015). Figures 3.1 and 3.2 show that the active mollusc farms in 2013 were generally located in the Menai Strait (in North Wales) and Swansea Bay (in South Wales).

The majority of mussel farming in Welsh Waters occurs in Several Order fisheries which grant exclusive fishing or management rights within a designated area. Several Orders allow legal ownership of certain named shellfish species in a private shellfishery for a defined period of time.

The current Several Orders in Wales are listed below (based on Welsh Government, 2014b) and are shown in Figures 3.1 and 3.2. Proposed Several Orders (for which information is not publically available) are not listed or shown in the figures to protect commercial confidentiality:

- The Lydstep Haven Mussel Fishery Order 2013;
- The Mumbles Oyster Fishery Order 2013[2];
- The Swansea Bay (Thomas Shellfish Limited) Mussel Fishery Order 2012; and
- The Menai Strait Oyster and Mussel Fishery Order 1962.

It should be noted that leases which have recently lapsed due to delays in renewals being reissued are not shown in the figures. Such lapses are a current cause of much concern amongst shellfish farmers.

There is also a proposed Several Order for a mussel fishery, for 3 years duration, in Angle Bay, Milford Haven.

The returns (i.e. the tonnage) of shellfish harvested from these Several Orders are reported to Defra.

Regulating Orders allow management rights to designated natural shellfisheries. There are currently two Regulating Orders in Welsh Waters from which cockles are harvested. However, for the purposes of the current study, harvesting of natural cockle populations within Regulating Orders is considered to comprise fisheries activity rather than aquaculture.

3.3 Crustacean Aquaculture

In 2012, crustacean aquaculture within Wales was limited to production of white-clawed crayfish (*Austropotamobius pallipes*; a freshwater species) for release in restocking/ conservation schemes (Cefas, 2015).

2 The Mumbles Oyster Company aim to be producing native oysters to market in the 2014/2015 season

4. Potential Future Aquaculture Species and Methods in Wales

Based on the consultation undertaken with the Welsh Government and aquaculture industry, and information from the literature (e.g. Syvret *et al*. 2013), Table 4.1 shows the species and cultivation methods which may potentially support increased production and/or form the basis of new aquaculture production businesses in Welsh Waters over the next 20 years. Information relating to the natural resource requirements of these species and cultivation methods are summarised in Section 5 and described in detail in Appendix C.

Table 4.1 Potential future marine aquaculture species and cultivation methods

Taxa	Species	Method	Location
Marine macroalgae	Badderlocks or winged kelp (*Alaria esculenta)*	Cultivation (seeding) Rope growing	On land Inshore
	Kelp or tangle (*Saccharina latissima)*	Cultivation (seeding) Rope growing	On land Inshore
	Dulse (*Palmaria palmata)*	Cultivation (seeding) Raft growing	On land Inshore
	Foliose red algae (Laver) (*Porphyra spp.)*	Cultivation (seeding) Raft growing	On land Inshore
	Irish moss/carrageen moss (*Chondrus crispus)*	Cultivation (seeding) Raft growing	On land Inshore
Marine shellfish	Blue Mussel (*Mytilus edulis)*	Bottom culture (expansion) Rope – seed collection and growing Bouchot poles Trestle/bag culture	Inshore Inshore/Offshore Intertidal Intertidal
	Pacific oyster (*Crassostrea gigas)*	Hatchery reared Trestle/bag culture	On land Intertidal / Inshore
	Native flat Oyster (*Ostrea edulis)*	Hatchery reared Bottom culture Trestle/bag culture	On land Inshore Inshore
	King scallop (*Pecten maximus*)	Bottom culture Rope growing	Inshore/Offshore
	Clam (*Tapes*)	Bottom culture	Intertidal
Marine crustaceans	European lobster (*Homarus gammarus*)	Hatchery reared Ranching	On land Inshore
	Crawfish (*Palinurus elephas*)	Hatchery reared Ranching	On land Inshore
Marine Finfish	Atlantic Salmon (*Salmo salar)*	Suspended net-cages	Inshore – sheltered bay
	Other finfish species e.g. Cod (*Gadus morhua)*	Suspended net-cages RAS	Inshore – sheltered bay
	Sea trout (*Salmo trutta*)	Suspended net-cages	Inshore – sheltered bay
	High value species (for which RAS technology proven)	Recirculation aquaculture system (RAS)	On land

As noted in Section 1.2, the study has focussed on shellfish, crustacean and finfish species for ‘food’ production. Other invertebrate species of interest for cultivation referred to by stakeholders included the giant keyhole limpet, *Megathura crenulata*, for extraction of keyhole limpet hemocyanin which is used in the production of antibodies for research, biotechnology and therapeutic applications and jellyfish, for extraction of collagen. However, it was beyond the scope of the current study to be able to model potential areas of opportunity for marine based or land-based developments for such novel species.

Interest in commercial-scale macroalgal production relates to the potential supply of specific compounds which can be extracted from seaweed and have a range of high value uses both as food ingredients and in cosmetic applications (Bangor University, 2015). In other areas of the UK, there is growing interest in developing commercial cultivation of seaweed in relation to their use in biofuels. As noted in Section 1.2, it was considered beyond the scope of the current study to be able to model potential areas of opportunity for land-based developments of microalgal species. Opportunities for marine-based development of macroalgae have been considered within the model.

5. Natural Resource Requirements

Site selection based on the natural resource requirements of the species to be farmed, and the equipment required, is a key factor in the success and sustainability of any aquaculture operation. This section summarises the natural resource requirements for the species and cultivation methods identified in Section 4 which have been incorporated within the spatial model. The brief literature reviews on which these data are based are provided in Appendix D. The resulting spatial maps are presented in Section 8.

It should be noted that while the natural resource requirements incorporated into the spatial model provide an assessment of the environmental conditions under which aquaculture developments are most likely to be successful, it was beyond the scope of the current study to address issues such as biological carrying capacity or wild seed/spat supply within the model, although the influence of these factors on the viability of future aquaculture developments are considered qualitatively in Section 9.

5.1 Bottom Culture of Bivalves

Bottom culture aquaculture is the practice of rearing seed or young shellfish directly on the seabed. Bottom culture involves re-laying the shellfish seed in the chosen nursery area and then letting them grow to a harvestable size. This form of aquaculture is often practised in shallow (subtidal and intertidal) coastal or estuarine areas but can also be undertaken in deeper waters where boats use dredges to collect, relay and harvest shellfish (Nehls *et al*., 2009; Cefas, 2009; Hagos, 2007; Laing, 2002; Wieland and Paul, 1983).

In general, the management of relayed mussels may include occasional monitoring and removal of predators if practicable. However, stakeholder feedback indicated that substantially more husbandry is undertaken for the mussel lays in the Menai Strait, for example, relating to the locations and densities at which mussels are initially re-laid and the timing for moving different cohorts of mussels to different parts of the leased areas. These practices have been informed through the outputs of various industry/research partnerships.

Harvesting techniques for bottom cultured shellfish can vary from dredging to simple hand-collection or hand-raking on lower yield operations (Spencer, 2002).

Species that are currently being cultivated in this way in Wales include the blue mussel, *Mytilus edulis*. Other native species that are typically cultivated in this way in the UK and have the potential for future development in Wales include the native oyster, *Ostrea edulis*, and the king scallop, *Pecten maximus,* the European clam (*Ruditapes decussatus*; commonly present in the south and west coast of the British Isles) and the non-native species Pacific oyster *Crassostrea gigas*.

The natural resource requirements of these species cultivated using this method, are summarised in Table 5.1, where information was available (for further detail see Appendix D).

Table 5.1 Summary of the key environmental requirements of shellfish species typically cultivated through bottom culture

Species	Temperature (°C)*	Salinity**	Sediment Type	Wave/Tidal Exposure	Water Quality***	Depth
Blue Mussel, *Mytilus edulis*	2.5-19	>20	Coarse/firm sediment	Low to Moderate Exposure	n/a	Intertidal to 20m below CD
King Scallop, *Pecten maximus*	n/a	>30	Sands, fine gravel and sandy gravel	Low to Moderate Exposure	n/a	5 to 30m below CD
Pacific Oyster, *Crassostrea gigas*	19 for optimal growth	25 for optimal growth	Coarse/firm sediment	Low to Moderate Exposure	n/a	Intertidal to 15m below CD
Native Flat Oyster, *Ostrea edulis*	n/a	>20	Coarse/firm sediment	Low to Moderate Exposure	n/a	Intertidal to 15m below CD
European Clam, *Ruditapes decussatus*	3-30	<40	Sand and silty mud	Favour sites away from high hydrodynamics	n/a	Intertidal Zone
Bottom cultured bivalves (in general)	>20 and <3 can cause physiological stress to shellfish and even mortalities	Limiting at the species level only	All sediments except rock	Low-moderate exposure, tidal currents < 1160 N /m² or wave exposure <1200 N /m²	≥80% dissolved oxygen recommended by Council Directive 79/923/EEC	Intertidal to 30m below CD (currently limited by the cultivation and harvest mechanics and cost)

* Temperature has not been used within the model due to the resolution of the available spatial data and no incorporation of seasonal variation within the model.
** Salinity has not been used within the model due to the resolution of the available spatial data. However, salinity was considered to limit areas potentially suitable for fully marine species (i.e. King scallop) and hence an indicative boundary in the Bristol Channel, east of which salinity was considered to be on average below 30, was derived from Severn Tidal Limits data and added as a constraint to the model. It should also be noted that any areas indicated as suitable for this species in the upper reaches of Milford Haven should be disregarded.
*** Water quality in Shellfish waters has been incorporated into the MSP model component.
CD Chart Datum

(Source: Rosenberg *et al*., 1991; Laing, 2002; Spencer, 2002; Laing and Spencer, 2006; Cassis *et al*., 2011; Kapetsky *et al*., 2013; FAO, 2015a)

5.2 Trestle/Bag Culture of Bivalve Shellfish

Trestle/bag aquaculture is the practice of rearing juvenile shellfish, commonly Pacific and native oysters, in bags or plastic cylinders that are held above the seabed by timber or metal frames. These frames are approximately 50 cm in height and 1km^2 of trestles with rows 10m apart could produce over 500 tonnes of harvest-size oysters (Jon King, Bangor University, pers. comm.). Oysters cultivated in plastic net bags supported above the ground are afforded greater protection from predators and have greater access to free-flowing nutrients; thus, they grow faster than bottom culture oysters (Laing and Spencer, 2006; Brown, 2010). Little maintenance is required, apart from occasional grading and possibly predator removal, until the oysters are of a suitable size to harvest. There is also potential to rear juvenile mussels in this way although this method is not commonly associated with the species.

The natural resource requirements of these species cultivated using this method, are summarised in Table 5.2, where information was available (for further detail see Appendix D).

Table 5.2 Summary of the key environmental requirements of shellfish species typically through trestle and/or bag culture

Species	Temperature (ºC)*	Salinity**	Sediment Type	Wave/Tidal Exposure	Water Quality***	Depth
Pacific oyster, *Crassostrea gigas*	19	25 for optimal growth	Firm sediment	Low to Moderate Exposure	n/a	Intertidal to 3m below CD
Native oyster, *Ostrea edulis*	n/a	>20	Firm sediment	Low to Moderate Exposure	n/a	Intertidal to 3m below CD (limited by culture technique)
Blue mussel, *Mytilus edulis*	2.5-19	>20	Firm sediment	Low to Moderate Exposure	n/a	Intertidal to 3m below CD (limited by culture technique)
Trestle/bag cultured bivalves in general	>20 and <3 can cause physiological stress to shellfish and even mortalities	All- limiting at the species level only	All substrates except rock	Low-moderate exposure, tidal currents < 1160 N/m² or wave exposure < 1200 N/m²	≥ 80% dissolved oxygen recommended by Council Directive 79/923/EEC	Intertidal to 3m below CD

* Temperature has not been used within the model due to the resolution of the available spatial data and no incorporation of seasonal variation within the model.
** Salinity has not been used within the model due to the resolution of the available spatial data.
*** Water quality in Shellfish waters has been incorporated into the MSP model component.
CD Chart Datum

(Source Laing and Spencer, 2006; Laing, 2002; Spencer, 2002; Cassis *et al*., 2011)

5.3 Rope/Line Grown Bivalve Shellfish

Rope/line-grown shellfish aquaculture in the UK is limited to mussels (*Mytilus edulis*) and king scallops (*Pecten maximus*). Mussels are commonly cultivated by longlines connected to large floats and anchored at both ends, which support a large number of “droppers” (ropes). The coiling “droppers”, on which the mussels are grown, are suspended in the top 2–3 m of the water column in time for the wild spat fall. Once seed mussels have settled the droppers are uncoiled to their full length (generally 6–10m). Little further management is required in this form of aquaculture until the bivalves have reached the desired size for harvesting.

Cultivation methods using pearl and lantern nets suspended from long-lines are typically used to raise scallop seed, although lantern nets can also be suspended between larch poles embedded in the intertidal area. Pearl nets are generally used for small (10–30mm shell height) scallops and lantern nets for larger animals (Laing, 2002). As with mussel suspended culture, the main lines are held afloat by buoys and anchored by mooring blocks. Farmers use spacing and orientation of the culture ropes to control growth and condition of the crop (Spencer, 2002).

The natural resource requirements of these species cultivated using this method, are summarised in Table 5.3, where information was available (for further detail see Appendix D).

Table 5.3 Summary of the key environmental requirements of shellfish species typically cultivated on ropes or lines

Species	Temperature (ºC)*	Salinity**	Sediment Type	Wave/Tidal Exposure	Water Quality***	Depth
Blue mussel, *Mytilus edulis*	2.5-19	>20	n/a	Low to Moderate Exposure	n/a	>13m below CD
King Scallop, *Pecten maximus*	n/a	>30	n/a	Low to Moderate Exposure	n/a	>13m below CD
Rope/line cultured bivalves in general	>20 and >3 can cause physiological stress to shellfish and even mortalities	Fully marine	Any areas of Seagrass beds and Saltmarsh have been avoided although these habitats are unlikely to occur at the depths required for the culture method.	Low-moderate exposure, tidal currents < 1160 N /m² or wave exposure < 1200 N /m²	≥ 80% dissolved oxygen recommended by Council Directive 79/923/EEC	>13m below CD (currently limited to nearshore environments *circa* 50m depth by the cost of mooring structures)

* Temperature has not been used within the model due to the resolution of the available spatial data and no incorporation of seasonal variation within the model.

** Salinity has not been used within the model due to the resolution of the available spatial data. However, salinity was considered to limit areas potentially suitable for fully marine species (i.e. King scallop) and hence an indicative boundary in the Bristol Channel, east of which salinity was considered to be on average below 30, was derived from Severn Tidal Limits data and added as a constraint to the model. It should also be noted that any areas indicated as suitable for this species in the upper reaches of Milford Haven should be disregarded.

*** Water quality in Shellfish waters has been incorporated into the MSP model component.

CD Chart Datum

(Source: Laing and Spencer, 2006; Laing, 2002; Spencer, 2002; Kapetsky, *et al*., 2013)

5.4 Macroalgae Production

There has not been a great incentive for macroalgae culture in the UK to date, partly because UK shores are very productive. This means that ample macroalgae can be harvested to meet the current demand, without the need for artificial enhancement (Werner, *et al*., 2004). For example there is a long history of knotted wrack, *Ascophyllum nodosum*, harvest in the Western Isles of Scotland which was reported to supply the alginate industry with around 12,000 tonnes (wet weight) per year in the early nineties (ERT Ltd, 1995). The export market has growing potential as the use of macroalgae as a biofuel and in pharmaceuticals increases (Walsh and Watson, 2011). At present the market price for macroalgae remains low and its culture is unlikely to be profitable in Europe, where labour costs are comparatively high, until the market price increases (Werner *et al*., 2004; Werner and Dring, 2011).

Although there is currently no commercial cultivation of macroalgae in the UK, trials are underway. The Scottish Association of Marine Science (SAMS) has been cultivating macroalgae for a number of years and this effort has recently increased with the inception of the BioMara project (BioMara, 2013) which aimed to demonstrate the feasibility and viability of producing third generation biofuels from marine biomass. Through the course of the study numerous seaweed species were screened for their potential in biofuels and many were found to grow well in the waters off Scotland, including the three kelp species *Alaria esculenta*, *Saccorhiza polyschides* and *Saccharina latissima* (BioMara, 2013). As noted in Section 4, the NISE project at Bangor University has been established to research the potential for extraction of compounds from seaweed species for high value uses both as food ingredients and in cosmetic applications while CSAR at Swansea University has research projects relating to the use of seaweeds for biofuel and for development and commercialisation of advanced bio-products, processes and services from algae.

Seaweed cultivation and harvest is now an established process. Macroalgal spores are collected from ripe plants and are then seeded onto polyamide strings. Here the spores germinate to form tiny plants 2mm long, which are transferred to sea after two months. Macroalgae is grown using a similar set-up to that used in rope/line bivalve culture whereby drop ropes are suspended from a main rope, held afloat by buoys and anchored to the seabed by mooring blocks. The plants are generally harvested six to eight months later, when they will have attained a length of over two metres. In Ireland, a Business Plan for the establishment of a seaweed hatchery & grow-out farm has been produced by Bord Iascaigh Mhara (Irish Sea Fisheries Board) (Watson and Dring, undated).

The natural resource requirements for these species cultivated using this method, are summarised in Table 5.4, where information was available (for further detail see Appendix D).

Table 5.4 Summary of the key environmental requirements for the culture of macroalgae

Species	Light	Temperature (ºC)*	Salinity**	Sediment Type	Wave/Tidal Exposure	Water Quality***	Depth
Badderlocks or winged kelp, *Alaria esculenta*	Medium	10-12	Fully marine	Any	High exposure (currents > 1160 N /m² and waves > 1200 N /m²)	n/a	n/a
Kelp or tangle, *Saccharina latissima*	High	10-15	Fully marine	Any	Medium exposure (currents >130 and <1160 N/m² and waves > 210 and < 1200 N/m²)	n/a	n/a
Dulse, *Palmaria palmata*	Low-Medium	10-15	Fully marine	Any	High exposure (currents > 1160 N /m² and waves > 1200 N /m²)	Low pollution	n/a
Foliose red algae (Laver), *Porhyra* spp.	High	Species dependent 5-20	Low to fully marine	Any	Medium exposure (currents >130 and <1160 N/m² and waves > 210 and < 1200 N/m²)	n/a	n/a
Irish moss or carrageen moss, *Chondrus crispus*	High	12-15	Low to fully marine	Any	Medium exposure (currents >130 and <1160 N/m² and waves > 210 and < 1200 N/m²)	Low pollution	n/a
Sea lettuce, *Ulva* spp.	High	Species dependent 10-20	Low	Any	Medium exposure (currents >130 and <1160 N/m² and waves > 210 and < 1200 N/m²)	n/a	n/a
Macroalgae in general	Species dependent but seaweed can be cultured in most light conditions	Optimal temperatures 10-15°C but will survive 0-25°C	Species dependent but seaweed can be cultured in most salinities	Any, areas of Seagrass beds and Saltmarsh have been avoided although these habitats are unlikely to occur at the depths required for the culture method.	Species specific tolerances	Low turbidity required for optimal photosynthesis levels. Low/no pollution where macroalgae is intended for consumption	10-25m below CD (but likely to extend into deeper waters as technology advances and the industry is less dependent on divers)

* Temperature has not been used within the model due to the resolution of the available spatial data and no incorporation of seasonal variation within the model.
** Salinity has not been used within the model due to the resolution of the available spatial data.
*** Water quality in Shellfish waters has been incorporated into the MSP model component.
CD Chart Datum

(Source Werner *et al*., 2004; Bruton *et al*., 2009)

5.5 Hatchery Reared Crustaceans

5.5.1 Lobster, *Homarus gammarus*

Intensive lobster, *Homarus gammarus* farming in pens is unlikely to be economically viable in the foreseeable future (Burton, 2003), although the National Lobster Hatchery in Padstow is currently investigating several locations on the south coast of Cornwall. A longer-term assessment, as well as a feasibility study of the potential for growing lobster through to market size will be undertaken shortly (MMO, 2013b). However, utilising hatchery-reared juvenile animals for release into natural habitats for stock enhancement purposes has been successful in a few locations around the UK coast (Orkney Lobster Hatchery, 2012), including Wales (via the programme at 'The Lobster Hatchery of Wales' based at Anglesey Sea Zoo). This process is mainly concerned with taking wild brood-stock (ideally from the intended release area) and rearing larvae to 3 months of age, at which point the juvenile lobsters are re-introduced into the natural environment to restock the wild population (Burton, 2003). However, it should be noted that for the purposes of the present study this would not be considered to comprise 'aquaculture'.

Until recently any hatchery-reared lobsters placed in to the sea became common property and could be fished by anyone. Consequently, there was no way of safeguarding the investment which groups undertaking stocking programmes might make. In early 1997 the Sea Fisheries (Shellfish) (Amendment) Act 1997 passed into UK law. It extended the coverage of Several and Regulated Fishery Orders to encompass lobsters and other crustaceans. The Act allows additional management, over and above national or local regulations, for lobster fisheries where stocking is taking place through the use of a regulating order and sole harvest rights can be assigned using a Several Fishery Order. As the on-growing or ranching of lobsters has not yet been carried out on a commercial scale in the UK little is known about the optimal rearing conditions. What is known at this time is summarised in Table 5.5, below.

5.5.2 Crawfish, *Palinurus elephas*

Palinurus elephas is the most commercially important spiny lobster species in the Mediterranean and North East Atlantic (Goñi *et al*., 2003) and is classed as vulnerable in the International Union for Conservation of Nature (IUCN) Red List of threatened species.

The relatively short larval life of *Palinurus elephas* makes them attractive for culture (Ceccaldi & Latrouite, 1994). However, *Palinurus elephas* is notoriously difficult to rear in the laboratory despite hatching at an advanced stage (see e.g. Kittaka & Ikegami, 1988) and attempts at culture have been unsuccessful. Until hatchery production becomes commercially-viable, the only practical way of increasing the volume of marketed spiny lobster is to capture juveniles from the wild and on-grow them to market size; thereby circumventing the high natural mortality that otherwise occurs (Phillips *et al*., 2003).

While crawfish are not frequently encountered, there is potential for brood-stock to be obtained (e.g. from fishermen if an attractive price is offered and they are willing to hold them for this purpose) to supply future commercial hatcheries. Mature spiny lobsters can be successfully maintained on diets of bivalve mollusc (mussels) and crustacean flesh (Wickens and Lee, 2002).

Laboratory-scale rearing of the larvae from egg to puerulus has been achieved for many species of spiny lobsters including *Panulirus japonicus*, *Panulirus longipes*, *Jasus lalandii*, *Jasus edwardsii* and *Sagmariasus verreauxi* (Kittaka, 2000; Matsuda and Yamakawa, 2000). However, commercially-viable hatchery production of spiny lobsters is still some way off although the recent large-scale larval rearing of the tropical ornate *Panulirus ornatus* spiny lobster in a commercial shrimp hatchery (MMO, 2013b) augurs well for the future. There is a pilot project currently underway on Anglesey looking at the feasibility of rearing juvenile spiny lobsters for marketing and release into the wild in Wales.

The natural resource requirements for this species, are summarised in Table 5.5, where information was available (for further detail see Appendix D).

Table 5.5 Summary of the key environmental requirements of hatchery reared European lobster and Crawfish

Species	Temperature (ºC)*	Salinity**	Sediment Type	Wave/Tidal Exposure	Water Quality***	Depth
European lobster, *Homarus gammarus*	2-18°C	Fully marine	Rock	Sheltered to moderate (tidal currents < 1160 N /m² or wave exposure < 1200 N /m²)	Unknown	10-30m below CD
Crawfish, *Palinurus elephas*	10-19°C	Fully marine	Rock	Exposed coasts (tidal currents > 130 N/m² and waves > 210 N/m²)	Chemical oxygen demand of culture water increased from 0.2 to 1.6 ppm over a 20 day period with a daily increase of about 0.05 ppm	Circalittoral (5 to 50m below CD)

* Temperature has not been used within the model due to the resolution of the available spatial data and no incorporation of seasonal variation within the model.
** Salinity has not been used within the model due to the resolution of the available spatial data. However, salinity was considered to limit areas potentially suitable for these fully marine species and hence an indicative boundary in the Bristol Channel, east of which salinity was considered to be on average below 30, was derived from Severn Tidal Limits data and added as a constraint to the model. It should also be noted that any areas indicated as suitable for these species in the upper reaches of Milford Haven should be disregarded.
*** Water quality in Shellfish waters has been incorporated into the MSP model component.
CD Chart Datum

(Sources: Burton, 2003; Jackson *et al*., 2009; Kittaka & Ikegami, 1988; Kittaka, 1994)

5.6 Marine Finfish Cage Culture

The culture of marine finfish in the UK is almost exclusively focused in Scottish waters, off the west coast and around the Orkney and Shetland Islands. The only marine finfish cultivated in England and Wales uses land-based recirculation systems to culture European sea bass and Turbot (Defra, 2012); although turbot is not currently being produced in Wales, it was previously cultivated on Anglesey. Scottish finfish culture is focused primarily on sea cage production of Atlantic salmon, with production exceeding 158,000 tonnes in 2011 (Marine Scotland Science, 2012). In this same year 83 tonnes of Halibut, *Hippoglossus hippoglossus* were also estimated to have been produced commercially in Scotland. Cod was farmed commercially in Scotland up until 2011 but there has not been any reported production since this time.

The downturn in cod culture is thought to be strongly linked to the recovery of wild fish populations in recent years, driving down the market price of cultured fish. However, considerable effort and funding has been allocated to improving the culture of cod (Bailey *et al*., 2005; Bolton-Warberg and Ftizgerald, 2012; Chabot and Dutil, 1999; Cromey *et al*., 2007; Joerstad *et al*., 2006; Ottera *et al*., 2006; Seafish, 2002; Watson *et al*., 2006; Jones, 1984) and it is possible that this will again become an important cultivated species as cultivation becomes more cost-effective. On the face of it, cod is an attractive option for culture since their requirements are very similar to those of Atlantic salmon and existing cage infrastructure may be used where it exists (Bailey *et al*., 2005). However, attempts to farm this species in the UK have not been successful to date and Norwegian cod farming activities have also reduced significantly from roughly 35 farms operational in 2008 to just 3 or 4 farms in 2011 (Fish Farming International, 2011). As in Scotland, the collapse of the cod culture market in Norway is thought to be driven primarily by the recovery of wild stocks driving down the price of farmed cod. Other low cost white fish alternatives such as Alaskan pollack (*Theragra chalcogramma*) are also thought to have brought down the price of farmed cod such that the high costs associated with start-up of this sector could not be recovered. Unless significant funding is made available for research and development in this sector it is unlikely that the UK will see a rapid revival in cod culture.

Sea trout rearing is often seen as an alternative to the culture of Atlantic salmon when salinity and summer temperatures are too high. The transfer process at sea is always a delicate operation and unlike the Atlantic salmon, sea trout does not really smoltify in culture (no changes in colour, swimming behaviour; FAO, 2015b). Sea trout is of great importance to Wales, with almost every river and stream that enters the sea containing a natural and self-sustaining run of migratory trout. A large number of these rivers support productive rod fisheries and in some instances, commercial net fisheries (Harris and Milner, 2008). Rearing sea trout (on land) has previously been trialled in wales using raceways, however any future land-based rearing of this species would likely require optimisation to control temperature more strictly for this species (e.g. via the use of deep tanks).

Finfish aquaculture is typically carried out in suspended net-cages sited in sheltered bays or sea lochs, held by moorings to the seabed. Cages are designed to contain fish and allow the free exchange of water to provide clean, oxygenated conditions and allow the export of waste products.

The siting of finfish cages is critical since the environmental conditions under which the fish are grown can influence their welfare as well as the production efficiency of the farm. The physiological and behavioural responses of farmed fish to changes in environmental conditions are in many cases well documented (Bailey *et al*., 2005; Chabot and Dutil, 1999; Cote *et al*., 2012; Hendry and Cragg-Hine, 2003; Johansson *et al*., 2007; Johansson *et al*., 2006; Stevenson, 2007). However, there remain large gaps in our understanding of the interactions between multiple, related, environmental factors and their cumulative impact on marine fish, as well as the impact of environmental changes on fish that are not yet farmed extensively. The interactions between finfish and their environment tend to be species-specific, with different species having different tolerances and different behavioural responses to environmental change. Information regarding the environmental requirements of finfish of interest to this study, where available, is summarised in Table 5.6 (for further detail see Appendix D).

Table 5.6 Summary of the key environmental requirements the finfish cage culture

Species	Temperature (ºC)*	Salinity**	Sediment Type	Wave/Tidal Exposure	Water Quality***	Depth
Atlantic salmon, *Salmo salar*	10-18	pH 6-9	n/a	Low-moderate exposure	n/a	15 to 50m below CD
Cod, *Gadus morhua*	2-14	>30	n/a	Low-moderate exposure	n/a	15 to 20m below CD
Sea Trout, *Salmo trutta*	12-16	>30	n/a	Low-moderate exposure	n/a	15 to 50m below CD
Marine finfish in general	Species dependent	>30		The highest wave and tidal currents may damage cages and increase escapes (Low-moderate exposure, tidal currents < 1160 N/m^2 or wave exposure < 1200 N/m^2)	Not well understood	Cages should be constructed in water depths and current regimes that minimise waste feedback.

* Temperature has not been used within the model due to the resolution of the available spatial data and no incorporation of seasonal variation within the model.
** Salinity has not been used within the model due to the resolution of the available spatial data. However, salinity was considered to limit areas potentially suitable for some finfish species (cod, sea trout) and hence an indicative boundary in the Bristol Channel, east of which salinity was considered to be on average below 30, was derived from Severn Tidal Limits data and added as a constraint to the model. It should also be noted that any areas indicated as suitable for these species in the upper reaches of Milford Haven should be disregarded.
*** Water quality in Shellfish waters has been incorporated into the MSP model component.

(Sources: Jones, 1984; Chabot and Dutil, 1999; Bailey *et al*., 2005; Perez *et al*., 2003; Hendry and Cragg-Hine, 2003; Johansson *et al*., 2006, 2007)

6. Marine Spatial Planning Related Opportunities and Constraints

As noted in Section 2, areas of sea which are currently utilised by other marine activities, or have nature conservation related designations, may effectively exclude or constrain to some degree, the potential for future increases in aquaculture activity or development of new activity.

This section provides an overview of the influence of MSP-related issues (including other marine sector activity and related infrastructure) on the potential for sustainable aquaculture development in the Welsh Marine Plan areas.

6.1 Drivers of Aquaculture Expansion

Aquaculture continues to be the world's fastest-growing animal-food-producing sector. World food fish aquaculture production more than doubled from 32.4 million tonnes in 2000 to 66.6 million tonnes in 2012 (FAO, 2014), although it can be noted that most of this growth has occurred in Asia whilst European aquaculture production has been relatively stagnant (European Commission (EC), 2012).

The long-term trend for the aquaculture industry is expected to be one of continued growth, despite recent declines in the level of activity in some areas due to the economic downturn. Aquaculture is considered to be a key area for development by UK administrations due to its potential to contribute to the sustainability and security of the UK food supply and economic development.

European, UK and national policies which aim to drive the expansion of both finfish and shellfish aquaculture are reviewed briefly below. Environmental legislation, which will be a major influencing factor on the potential of areas for future aquaculture development, are reviewed in Section 6.2.

6.1.1 European Commission Blue Growth Strategy

Blue Growth (EC, 2012) is a European Strategy to support sustainable growth in the marine and maritime sectors. The Strategy recognises that the sea and coast are drivers of the economy and identifies five sectors, including aquaculture, for which there is an opportunity for 'blue growth' i.e. harnessing the potential of Europe's oceans, seas and coasts for jobs and growth.

With regard to aquaculture, the Strategy states that this sector has the potential to grow through the provision of quality products to consumers, to help coastal communities diversify their activities and to alleviate fishing pressure and thus help to preserve fish stocks. The Strategy notes that the lack of available maritime space for aquaculture activities, competition in the global market, administrative constraints (in particular concerning licensing procedures which need to be improved) and lack of capital for investment since the economic crisis, have provided challenges to growth.

Aquaculture will be promoted through the reformed Common Fisheries Policy (CFP) (see below) and measures to increase sustainable production will be supported by the EMFF from 2014 to 2020. The Strategy states that the future Horizon 2020 programme for research and innovation should also play an important role in unlocking the growth potential of European aquaculture, for example, through the farming of new species or moving further offshore (EC, 2012).

6.1.2 Reformed Common Fisheries Policy

As noted above, the EC intends to boost aquaculture through the CFP reform and the EMFF (the financial instrument to support CFP implementation), and has published 'Strategic Guidelines for the Sustainable Development of EU Aquaculture' (EC, 2013) which presents common priorities and general objectives at EU level. Four priority areas have been identified in consultation with all relevant stakeholders:

1. Reducing administrative burdens;
2. Improving access to space and water (i.e. through co-ordinated spatial planning);
3. Increasing competitiveness of EU aquaculture and exploiting competitive advantages due to high quality; and
4. Health and environmental standards.

With respect to improving access to space and water, the Strategic Guidelines set a target for Member States:

> *"to put in place coordinated spatial planning, including maritime spatial planning at sea basin level, to ensure that aquaculture's potential and needs are taken into account and to secure an adequate allocation of space in waters and land for sustainable aquaculture development".*

The Strategic Guidelines state that the Commission will monitor the implementation of coordinated maritime planning and disseminate studies and experiences to help Member States in their planning.

In addition, Member States were asked to set up multiannual plans to promote aquaculture based on the Strategic Guidelines, and the Commission will assist with the coordination and exchange of best practices.

6.1.3 UK Multiannual National Plan for the Development of Sustainable Aquaculture

The 'UK Multiannual National Plan for the Development of Sustainable Aquaculture' (Defra, 2014) was produced in response to the above Strategic Guidelines, and outlines how the UK intends to foster growth in the aquaculture industry. The UK's Multiannual National Plan for aquaculture takes account of four major areas:

1. The structure, management and national support of the industry as it exists in 2013, and the inherent or latent trends in its development and in the developments of the markets it supplies;
2. The European Union's clearly articulated objectives for growth in sustainable aquaculture, as a component of Blue Growth, thereby enhancing long term seafood security;
3. The outcomes of the Strengths, Weaknesses, Opportunities and Threats (SWOT) Analysis and Needs Assessment undertaken in preparation for the new EMFF, which will operate for the period 2014–2020; and
4. Consideration of specific Articles in the (draft) EMFF Regulation, and how these might serve to support elements of the three strands noted above.

6.1.4 Welsh Marine and Fisheries Strategic Action Plan

The MFSAP for Wales (Welsh Government, 2013) aims to provide a framework for clean, healthy, safe, productive and biologically diverse seas. Specifically, the Marine and Fisheries Strategic Action Plan aims to safeguard environmental resources, use them as a driver for economic growth and help Wales fully develop a sustainable marine and fisheries industry.

The Plan lays out the Welsh Government's commitment to supporting the sustainable growth of aquaculture with targets to double Wales' annual finfish aquaculture output, from 1,000 tonnes to 2,000 tonnes by 2020, and shellfish aquaculture production from 8,000 tonnes to 16,000 tonnes. To ensure such growth, the Plan states that the current administrative and licensing procedures must be simplified, supporting innovation and collaboration between industry and academic research centres and developing the co-location of aquaculture with other marine industries. Furthermore, the Welsh Government will ensure that the new EMFF is aligned to develop programmes that will support the delivery of the MFSAP (Welsh Government, 2013).

Consultation with aquaculture industry stakeholders in Wales, undertaken for the current study indicated that the some stakeholders felt these production targets were quite ambitious whilst others felt they were not ambitious enough. While some stakeholders suggested that the finfish production target could be met through production of fish via land-based recirculation systems (i.e. RAS), in general it was thought that the shellfish target would be more challenging to meet for a number of reasons including: restrictions imposed by the current consenting framework (see Section 6.3); lack of incentives for co-location of offshore renewables with aquaculture (see Sections 6.16 and 6.4.2); and lack of targeted funding.

6.1.5 Welsh Government Aquaculture Advisory Group

An Aquaculture Advisory Group has recently been established by the Welsh Government to prioritise areas where there is potential for aquaculture development. Initial outputs are expected in 2015.

6.1.6 Policy Driving Expansion of the Offshore Renewable Energy Sector

Expansion of offshore renewables, such as offshore wind farms (OWFs), could provide increased opportunities for shellfish cultivation through the co-location of renewable energy devices (structures) and shellfish aquaculture installations, provided the offshore renewables industry is willing to engage. Indeed, there are policy drivers which specifically support or encourage the co-location of aquaculture with offshore renewable developments including the Marine Policy Statement and the Marine and Coastal Access Act (and associated Marine Plans) (Syvret *et al*. 2013). The potential for co-location of aquaculture and offshore renewables, and potential barriers to co-location are discussed further in Section 6.4.2.

6.2 Influence of Environmental Policy and Legislation

Marine policy in the UK aims to promote sustainable development in the marine area, to achieve a balance of environmental, social and economic aspects. This results in overarching policies, policies specific to environmental protection and policies that reflect the ambitions for marine development in the various sectors.

This section considers policies which will act as key influences on commercial aquaculture activity, focussing on the implications for this sector within Welsh Waters where information allows.

6.2.1 Marine Strategy Framework Directive

The Marine Strategy Framework Directive (MSFD) (2008/56/EC) came into force in 2008 and was transposed into UK law in 2010. It was developed to provide a framework for Member States to protect the European marine environment more effectively by maintaining biodiversity and providing diverse and dynamic oceans which are clean and healthy whilst allowing the sustainable use of marine resources. Member States are required to develop a Marine Strategy that must be reviewed every six years and to achieve Good Environmental Status (GES) by 2020. To help achieve GES, eleven descriptors of the state of the environment were defined (biodiversity, non-indigenous species (NIS), commercial fish, food webs, eutrophication, sea floor integrity, hydrographical conditions, contaminants, food safety, litter and underwater noise) and a detailed set of criteria and indicators developed by groups of experts to help interpretation (Cefas, 2012).

Cefas (2012) states that while aquaculture may have local impacts that could affect some MSFD descriptors, the MSFD is set up to manage ecosystems at a sub-regional scale and, given that many of the impacts of aquaculture are at small scales, it is unlikely that aquaculture will affect the descriptors of GES unless a significant proportion of the sub-region is used for aquaculture, the region is enclosed, or the introduction is the important factor (i.e. alien species). However, it is possible that some regions are more sensitive to pressures from aquaculture due to their physical environment or hydrodynamics. Multi-Annual National Plans (MANPs) will be developed that will assess the proportion of regions to be developed for aquaculture (Cefas, 2012).

Conversely, the MSFD may provide potential benefits to aquaculture, for example through the reduction of contaminants in fish and seafood (GES Descriptor 9) and a reduction in marine litter (GES Descriptor 10) that can affect marine cages. Aquaculture may benefit MSFD by delivering GES through more sustainable exploitation of commercial fish stocks (GES Descriptor 3) (Cefas, 2012).

The MSFD Programme of Measures consultation document (Defra, 2015) describes existing, planned and new programme measures to achieve GES for NIS (Descriptor 2). Existing measures in the UK which specifically address the aquaculture pathway of potential introduction of NIS are listed as (Defra, 2015):

- Alien and Locally Absent Species in Aquaculture (England and Wales) Regulations 2011, Alien and Locally Absent Species in Aquaculture Regulations (Northern Ireland) 2012;
- Molluscan Shellfish (Control of Deposit) Order (Northern Ireland) 1972, Lobsters (Control of Deposit) Order 1981, Lobsters (prohibition of Introduction) Order (Northern Ireland) 1982; and
- Guidance on fish movements.

Planned 'cross-cutting' measures (agreed but not yet implemented) include (Defra, 2015):

- Infrastructure Bill (England and Wales) – provides for species control orders where a voluntary approach cannot be agreed and there is a clear and significant threat from inaction. They could be applied to marinas, ports, offshore platforms and vessels moored there;
- Regulation (EU) No 1143/2014 of the European Parliament and of the Council on the prevention and management of the introduction and spread of invasive alien species (effective from January 2015) – applies to all invasive alien species other than where they alter their natural range without human intervention and where controls on them exist under other European regulatory regimes (including the use of alien and locally absent species in aquaculture);
- Invasive species action plans – an action plan for *Didemnum vexillum* is under development; and
- River basin management plans (under the Water Framework Directive (WFD)) – measures for the control of NIS will be implemented in the second cycle of management plans.

The consultation document also highlights a number of ongoing projects/initiatives which include measures related to biosecurity including:

- Marine Pathways Project (due for completion March 2015) - concerned with the management of pathways by which marine invasive NIS may be introduced into the UK and Ireland, which covers:
  - Specific NIS guidance and voluntary best practice for marina operators and boat owners, particularly focussing on developing consistent advice on in-water cleaning and a common Great Britain-wide approach;
  - Specific NIS guidance and voluntary best practice for aquaculture, which also explores how it can be combined with the existing Biosecurity Measure Plan guidance as a voluntary addition;
  - Voluntary best practice for offshore industries; and
  - Identification of locations at high risk of introduction where biosecurity efforts should be focused.

- LIFE Natura 2000 programme (LIFE N2K) - an EU-funded Natura 2000 programme for Wales to produce a strategic prioritised and costed plan for the conservation, management and restoration of existing Welsh Natura 2000 sites, comprising Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). Thematic action plans for crosscutting issues or risks occurring in Welsh Natura 2000 sites will be developed, based on actions proposed in Natura 2000 sites, consideration of any wider management outside sites and will make recommendations where appropriate. Actions taken to manage known issues or risks associated with marine invasive NIS are likely to contribute towards MSFD targets.

A Code of Good Practice, relating to sourcing mussel seed and importing it onto the Menai Strait for seabed lay mussel fisheries, was drawn up by an inter-agency group[3] in 2008 (Bangor Mussel Producers Association, 2008). The Code of Good Practice is applicable to both ship-borne and road movements of mussel seed into the Menai Strait to prevent the accidental introduction of INNS not currently occurring in North Wales. The Code includes monitoring of mussel lays post seed movement and eradication measures in the event that an INNS is discovered in mussel lays.

This Code of Practice has since been made a condition of issuing shellfish movement licences[4] (which are only available to vessels harvesting seed mussel for deposit on registered shellfish farms) and a licence will only be issued subject to scientific advice that the dredging operation would not be incompatible with wider environmental considerations. Consultation with industry stakeholders in Wales indicated that the increasing constraints posed by measures to restrict

---

[3] Inter-agency group comprised the Menai Strait mussel fishing sector, Seafish, the Countryside Council for Wales (now NRW), the Welsh Assembly Government, the Marine and Fisheries Agency (now the Marine Management Organisation), Cefas and the GB Non-Native Species Secretariat (GB NNSS).

[4] It can be noted that the mussel producers in the Menai Strait insisted that adherence to the Code of Good Practice was inserted as a condition in the leases they hold to operate inside the boundaries of the 1962 Menai Strait East Fishery Order (stakeholder feedback).

the spread of INNS (e.g. the requirement for trials prior to moving seed) is putting extra pressure on those in the industry seeking seed.

6.2.2 The EU Habitats and Wild Birds Directives

The Habitats Directive (92/43/EEC) requires Member States to introduce protection measures for habitats and species listed in its Annexes. This is implemented through a series of protected areas known as SACs which, together with SPAs implemented under the EU Wild Birds Directive (codified 2009/147/EC), form a network of statutory protected Natura 2000 sites. The intertidal and subtidal areas of both SACs and SPAs are referred to as 'European Marine Sites' (EMS).

To ensure effective conservation of protected habitats and species in SACs, Article 6 of the Directive requires that all operations and activities in or adjacent to SACs which are likely to have a significant effect thereon, individually or in combination with other operations or activities, are subject to an Appropriate Assessment (AA). Article 7 of the EU Habitats Directive also applies similar requirements to SPAs designated under the Wild Birds Directive for the protection of wild birds and their habitats throughout the EU. Hence, working within, or close to, areas that are designated as EMS requires that activities, including aquaculture-related activity, do not cause adverse effect to designated features of the site. This does not mean that aquaculture cannot be undertaken in or near an EMS (indeed the majority of Welsh aquaculture production occurs within EMS; see below), however, it does require that where a likely significant effect on the site (with regard to its conservation objectives) cannot be excluded, an appropriate assessment (AA) is required to assess whether the activity will affect the integrity of the site. It should be noted that, according to Welsh Government policy, Ramsar sites (designated under the 1971 Ramsar Convention for their internationally important wetlands) should receive the same level of protection as European sites.

There are numerous EU and UK guidance documents relating to the implementation of the EU Habitats and Wild Bird Directives, including specifically in relation to aquaculture activity and Natura 2000 sites (EC, 2012). The available guidance sets out a clear procedure to be followed, underpinned by case law defining how the process needs to be interpreted and applied.

However, it is reported in MMO (2014) that interpretation and application of nature conservation related legislation is considered by some English stakeholders in the shellfish aquaculture industry to be the primary factor constraining the future growth and investment in the industry. Yet this was not highlighted as a major constraint by stakeholders in Wales (raised by only one stakeholder), other than where management was considered unreasonable or inconsistent. Numerous reports have highlighted the potential for the development of the aquaculture industry to be constrained by nature conservation designations and complex regulatory systems requiring aquaculture developments to minimise or eliminate impacts to protected species, communities or habitats (e.g. MMO, 2013a; MMO, 2013c). Aquaculture industry stakeholders consulted for MMO (2013a) confirmed that management measures associated with EMS (on the south coast of England) had resulted in a lack of availability of wild seed due to policy-related management measures in designated sites preventing collection (e.g. through the use of dredge gears for seabed culture systems). Access to seed from an EMS in England did appear to have caused issues for mussel operators but this was related more to management decisions than agreed management measures. Woolmer (2009 and references therein) described how uncertainties over the effects of the development on EMS features can cause significant delays or prevent the consenting process of new shellfishery or farm developments in these sites. Such delays in the consenting process and/or increased pre or post consent survey/monitoring requirements or mitigation measures will increase costs to the sector as well as increasing uncertainty over sourcing seed and may deter investment. A study conducted in 2006 showed that while the impact on protected bird species was listed as the most common reason for an AA to be triggered by shellfisheries within EMS in the UK, the potential impacts of dredge gears on habitats was also a common concern for the statutory nature conservation organisations (Lake 2006, cited in MMO, 2013a). It is hoped that this is now an outdated view as dredges used in the mussel industry are designed to cut through the mussel mud (pseudo faeces) and are unlikely to cause damage to the underlying substrate, particularly as prospecting on new and unfamiliar terrain is likely to be preceded by non-invasive sampling.

It should also be highlighted that the mussel cultivation sector in North Wales, which is the principle supplier of Welsh aquaculture production lies within the boundaries of an EMS and that the seed mussel to supply this area is sourced from EMSs. Furthermore plans for expanding the sector within this region, both through the application for Fishery Orders and for marine licences, are also within the boundaries of EMSs.

6.2.3 Water Framework Directive

The Water Framework Directive (WFD) (2000/60/EC) applies to groundwater, surface water bodies and coastal waters within 1nm of the coast and requires Member States to achieve good ecological and chemical status in all water bodies by 2015.

Given that many aspects of the aquaculture industry rely on good water quality (e.g. for finfish or shellfish hatcheries, shellfish cultivation), implementation of the WFD should result in improved water quality in coastal areas, as Member States implement programmes of measures to improve the ecological and chemical status of water bodies. This should increase opportunities for aquaculture. However, the Directive will also have important implications for aquaculture with respect to the regulation of potential detrimental impacts, for example, on hydro-morphological quality through abstraction and/or the presence of infrastructure; on chemical quality through the discharge of particulate waste, dissolved nutrients and chemotherapeutants (e.g. sea lice treatments, antibiotics; finfish farming only); and on biological quality through escapees (finfish farming), disease and/or parasites (Cefas, 2012).

It can be noted that the WFD has repealed the Shellfish Waters Directive (SWD), although at the time of writing this had not been transposed into UK legislation through regulations. When this occurs, Shellfish Waters designated under the repealed SWD will become protected areas under the WFD and will need to be afforded at least the same level of protection that they had under the SWD (Welsh Government, pers. comm.).

It should be noted that, in contrast to the previous SWD, the WFD includes consideration of 'disproportionate costs' in achieving its objectives. Hence under the WFD, when considering designation of a new shellfish water protected area, a disproportionate cost assessment may be required which would assess the costs and benefits of any proposed programme of measures to improve water quality, the distribution of costs of these measures between stakeholders, and appraise the overall affordability of implementing the measures. It is not currently known what the implications of this may be for the potential to expand aquaculture in Welsh Waters, however, it is possible that if costs to improve water quality to standards required for viable aquaculture production (i.e. the equivalent of 'Class B' designated shellfish harvesting areas) are considered disproportionate, this could potentially constrain aquaculture developments outside of designated shellfish waters. However it can be noted that the UK WFD-implementing legislation only extends to 1nm, hence any future offshore aquaculture development may occur outside the jurisdiction of the WFD[5]. Furthermore it can also be noted that a classified bivalve mollusc production area (under the Food Safety and Hygiene (England) Regulations 2013) can be established outside of designated shellfish waters and hence the absence of a shellfish water protected area under the WFD is not anticipated to constrain shellfish production (Welsh Government, pers. com.).

6.2.4 Marine and Coastal Access Act

The Marine and Coastal Access Act (MCAA) 2009 establishes an integrated planning system for managing the seas, coasts and estuaries, a legal framework for decision-making, streamlined regulation and enforcement (including a marine licensing system) and access to the coast. Furthermore, the MCAA 2009 also established a framework for the creation of a network of Marine Conservation Zones (MCZs) for conserving the diversity of UK nationally rare or threatened habitats and/or species and those places containing habitats and/or species that are representative of the biodiversity in the seas around England and Wales.

Under section 44 of the MCAA, the Marine Policy Statement (MPS) was developed which sets out short and long-term objectives for the sustainable use of the marine environment by both UK government and the devolved administrations. The MPS is the framework for preparing Marine Plans and taking decisions affecting the marine environment and also sets out the UK high level marine objectives (listed below) to achieve the UK vision for 'clean, healthy, safe, productive and biologically diverse oceans and seas' and reflect the principles for sustainable development:

- Achieving a sustainable marine economy;
- Ensuring a strong, healthy and just society;
- Living within environmental limits;
- Promoting good governance; and
- Using sound science responsibly.

---

5 Beyond 1nm, the MSFD will apply, which requires EU Member States to meet or maintain Good Environmental Status of their marine waters by 2020 as described in Section 6.2.1.

Further to the commencement of provisions of Part 5 of the MCAA in Wales in December 2014, which repealed the Marine Nature Reserve powers under the Wildlife and Countryside Act 1981, Skomer Island has become Wales' first MCZ.

The Welsh Government, Natural Resources Wales (NRW) and the Joint Nature Conservation Committee (JNCC) are undertaking an assessment of the 128 existing marine protected areas (MPAs) in Welsh Waters to assess whether there are any gaps in the UK network of MPAs that can be addressed in Wales and if so, to consider the most appropriate means of fulfilling Wales' contribution which may require the identification and designation of MCZs (Welsh Government, 2014c).

6.3 Licensing and Consent of Aquaculture in Wales

The administrative process for the establishment of an aquaculture farm in Wales depends on the nature of the farm (i.e. the species to be farmed and method of cultivation). As such, the specific consents and licences required before an aquaculture farm can operate, are location and development dependent. A summary of consents and licences required for shellfish and finfish farms is provided below (based on Defra, 2014; Syvret *et al*. 2013 and Welsh Government/stakeholder engagement).

A lease from The Crown Estate (TCE) (or other landowner) - for deployment of aquaculture equipment on the seabed out to 12nm (fixed gear aquaculture; note does not cover 'ranching');

- A Marine Licence:
  - For deposition of equipment on the sea bed (where not exempt) (fixed gear aquaculture) from NRW;
  - Regarding Navigational Risk (in relation to the presence of infrastructure)
    - From the Statutory Harbour Authority (SHA) within a SHA area
    - From NRW (in consultation with the Maritime and Coastguard Agency (MCA)) outwith a SHA area;
- Several Order (granted under the Sea Fisheries (Shellfish) Act 1967 by Welsh Ministers) – for on-bottom cultivation of shellfish out to 6nm;
- Planning permission from the Local Authority for finfish farms or any onshore facility;
- Authorisation by the Fish Health Inspectorate (Cefas) under Aquatic Animal Health (England and Wales) Regulations 2009 – all aquaculture regardless of method to prevent the introduction and spread of diseases;
- Consent from NRW for discharges from a fish farm, or a Marine Licence for discharge from a boat – finfish farming only;
- Abstraction licence from NRW – for finfish/plant aquaculture; and
- Mussel seed licence from the Welsh Government – for shellfish aquaculture (mussel).

It can be noted that under the Marine Licensing (Exempted Activities) (Wales) Order 2011, that the following shellfish propagation and cultivation activities are exempt from needing a marine licence (Article 13(1)):

a) The deposit of any shellfish, trestle, raft, cage, pole, rope or line in the course of the propagation or cultivation of shellfish; and
b) A removal activity or dredging activity carried on for the purpose of moving shellfish within the sea in the course of its propagation or cultivation.

Consultation with shellfish aquaculture industry stakeholders in Wales indicated that restrictions related to licensing issues were considered to be the most significant issue facing both the continued viability of existing production businesses and the future development/expansion of the industry. Specific issues highlighted included the relatively short duration of leases, agreement of Several Order Fishery terms and the time for Several Order Fisheries to be granted or renewed, which had already led to the suspension and closure of some production businesses. Furthermore, as highlighted above, Several Fishery Orders granted under the Sea Fisheries (Shellfish) Act 1967, where rights of ownership or tenure accrue to the aquaculture producer, do not extend beyond 6nm, hence further offshore there is no legal protection to the right of shellfish cultivated on the seabed. Syvret *et al*. (2013) highlight that Welsh Ministers may have the power to issue Fishery Orders out to 12nm under seabed cultivation of shellfish beyond 6nm (although this may be grantable out to 12nm under Section 189 of the Marine and Coastal Access Act 2009 if the Act covers this type of Fishery Order), but that this needed to be confirmed and the extent or limitations of any such powers identified.

It should also be noted that the Welsh Government Environment Bill White Paper (Welsh Government, 2013) proposed measures to revise the application process and ongoing operation of Several and Regulating Orders at Part 1 of the Sea Fisheries (Shellfish) Act 1967. The White Paper was consulted on between October 2013 and January 2014. However, it was not within the remit of this study to assess what the implications of proposed legislation would be for the Welsh shellfish industry.

6.4 Interaction with Other Marine Sector Activities and Associated Infrastructure

The suitability of marine areas for future aquaculture development will be influenced by the presence of other existing, or planned, uses of the area, for example, by other marine sector activities or infrastructure. Such activities may exclude or constrain aquaculture development or conversely be able to co-exist with aquaculture development or even potentially facilitate the development of the sector. This section briefly describes the potential constraints and opportunities provided by other marine sector activities and infrastructure.

6.4.1 Constraints to Aquaculture Development

It is possible that other marine sector activity/expansion may constrain the development of aquaculture in the future through excluding the industry from areas into which current farms could expand, or where new farms could be established. Several reports have highlighted the potential for the development of the aquaculture industry to be constrained by or conflict with recreational activities (e.g. due to the incompatibility of marine recreational activities such as yachting race courses with the presence of aquaculture infrastructure; MMO, 2013b; MMO, 2013d). Competition for space with recreational activities may be reduced in more offshore waters, however, competition for space with other activities or sectors (e.g. offshore renewables) may occur in these locations.

Within the spatial model, 'exclusion areas' were assigned to areas where existing or planned marine sector activity and/or infrastructure was considered to be fundamentally incompatible with aquaculture activity using any cultivation method. These activities, areas and infrastructure were:

- Marine renewables – wave and tidal lease areas (note excluding any OWFs or areas under consideration for potential tidal lagoon schemes, see Section 6.4.2);
- Oil and Gas – platforms and pipelines;
- Subsea cables;
- Marine aggregates – application areas, licence areas;
- Shipping – International Maritime Organisation (IMO) Traffic Separation Schemes;
- Ports and harbours – anchorage points, anchorage areas, navigation channels, open dredge disposal sites;
- Historic protected sites – protected wreck exclusion zones;
- Consented discharges – combined storm overflows;
- INNS – known presence of *Didemnum vexillum* (see Section 7.3); and
- Aquaculture – current aquaculture locations (based on the assumption that this activity will continue).

Further description of how these areas were incorporated into the spatial model, and any 'buffer zones' applied to them (relating to standard industry exclusion areas around activity areas/infrastructure) is provided in Appendix B. However, it is important to note, that whilst some activities or areas relating to a specific marine sector were considered to exclude aquaculture activity, e.g. open disposal sites or navigation channels within the Ports and Harbour sector, this did not mean that all areas where any port-related activity occurs were excluded.

For example, other marine activities and/or associated infrastructure were considered likely to potentially constrain future aquaculture development, although not exclude it completely. For some areas, this level of constraint was considered to be constant across the area which the activity occurred in (referred to as defined constraint areas; note this constraint was also applied where the resolution of the data prevented assessment of different intensities of activity within an area, for example, yacht racing areas). For other activities, the degree of constraint was considered to relate to the intensity of the activity or the distance from the activity (referred to as a graduated constraint area), for example, areas with known differing densities of shipping movements or commercial fishing activity.

Activities and areas which were considered to potentially constrain future aquaculture development were:

- Defined constraint areas:
  - Nature conservation designations (collectively referred to as MPAs) – i.e. SAC, Site of Community Importance (SCI), candidate SAC (cSAC), possible SAC (pSAC), SPA, potential SPA (pSPA), Ramsar[6] site, Marine Sites of Special Scientific Interest (SSSI), MCZ (Skomer);
  - Protected features – grey seal haul out sites (data resolution insufficient to allow calculation of a graduated constraint level from a centre point)[7]
  - Other protected areas – wrecks;
  - Marine aggregates – Option areas, exploration and option areas;
  - Military – Military practice and exercise areas (PEXA);
  - Recreation – Royal Yachting Association (RYA) racing areas, angling, windsurfing, surfing, swimming, blue flag beaches;
- Graduated constraint areas:
  - Commercial shipping – constraint level related to shipping density;
  - Commercial fishing – constraint level related to fishing effort; and
  - Shellfish Waters – constraint level related to the number of times that the designated area complied with shellfish flesh *E.coli* standards between 2011 and 2013.

Additional graduated constraints which were not possible to apply within the model due to data limitations or availability related to:

- Waste water management – sewage related discharges to controlled waters for which the constraint level would relate to the distance from the point source and the population equivalent; and
- Seascape sensitivity – at the time of writing, there were no data available which provided a quantitative assessment of seascape sensitivity for the whole of the Welsh coast. Once these data becomes available (a study is currently being undertaken; Welsh Government, pers. comm.) they should be incorporated into the model.

A further description of data gaps and how the available data layers were incorporated into the spatial model is provided in Appendix B.

---

6 Ramsar sites are wetlands of international importance, designated under The Convention on Wetlands (Ramsar, Iran, 1971).

7 Seal haul outs were assumed to represent 'hotspots' of activity at the coast. The data supplied relating to mobile features (e.g. cetaceans and seabirds) showed overall distribution rather than hotspots and as such it was felt that applying defined constraints based on these data may misrepresent the constraint posed by such mobile features.

6.4.2 Opportunities for Aquaculture Development

Locating aquaculture activities within offshore windfarms (OWFs) has been proposed as a potential opportunity to share resources and increase spatial efficiency in the offshore marine environment (e.g. James and Slaski, 2006; Mee, 2006; Blyth-Skyrme, 2010; Michler-Cieluch *et al*. 2009).

There are several policy 'drivers' for the co-location of aquaculture with offshore renewable developments (see also Section 6.2). These include (Syvret *et al*. 2013):

- MCAA 2009 (and associated Marine Plans); and
- Marine Policy Statement.

The proposed advantages of developing offshore aquaculture include (Cheney *et al*. 2010 and references therein):

- A reduction of production costs owing to larger farm design and economies of scale with consequent reductions in unit production costs ultimately leading to increased profitability. Increased efficiency that will be gained with experience of working offshore and increased research efforts should help to recover the extra costs involved with lease negotiations, new equipment costs etc. associated with working offshore;
- Growth rates, meat yields and production rates of shellfish comparable to "better" inshore farms (Cheney *et al*. 2010 summarising research from the USA and New Zealand) likely related to lower stress (e.g. from the more constant environmental conditions offshore when compared to inshore sites), reduced turbidity and better water exchange;
- Enhanced market image and perception linked to the idea that these offshore cultivated shellfish are grown in pristine water conditions. This could be linked to certification standards in terms of reduced environmental impacts, reduction of non-native issues, shellfish hygiene etc.

Further benefits of the potential of co-location of industries includes (Syvret *et al*. 2013 and references therein; MMO 2013e and references therein):

- A reduction in spatial conflict elsewhere;
- Enhancement of the social acceptance of developments in local communities;
- The provision of further employment for local communities; and
- The opportunity for employment diversification for fishermen.

The culture of aquaculture species such as mussels within OWFs has been shown to be biologically and economically feasible if suitable management measures are followed (e.g. Syvret *et al*. 2013; Michler-Cieluch and Krause, 2008; Buck *et al*. 2010), although success will depend on improved safety and technological development (Faber Maunsell Limited, 2008; Defra, 2008, cited in Marine Scotland, 2013). For example, Syvret *et al*. (2013) provide a comprehensive review of the feasibility of shellfish aquaculture in OWF sites in which the trials of seabed cultivation of mussels (*Mytilus edulis*) within the North Hoyle 'nearshore' wind farm is described. The authors describe how in the short term the blue mussel is the most obvious species for economically viable commercial operations in OWFs although further work is required to fully assess aquaculture feasibility. It is suggested that once UK operators have gained experience in operating in offshore environments, there will be an opportunity to diversify into other shellfish species (e.g. oysters). Little information is available at present on the feasibility of co-locating finfish culture with OWFs (MMO, 2013e).

However, stakeholders consulted for this study suggested that in order for the opportunity for increased offshore shellfish production to be realised, policy has to do more than encourage co-location of activities to occur and that 'consideration of co-location' should be a condition of any offshore renewable development. This is currently the case in Germany, where evidence has to be presented that co-location has been considered, even if it is ultimately disregarded. Furthermore, Syvret *et al*. (2013) highlight that while OWFs can be constructed beyond 12nm, there is no clear legislation covering the right/legality of establishing fixed structure cultivation activities beyond 12nm, so policy or legislative changes may need to be explored to facilitate colocation beyond 12 nm.

In relation to other types of marine renewable developments, stakeholder consultation highlighted that development of tidal lagoons may present further opportunities for aquaculture development. Such developments would result in more sheltered conditions within the lagoons (except in close proximity to the turbine housings) which may lend themselves to aquaculture developments that may previously have not been feasible in that location. Further research on this subject is required.

7. Proximity to Essential Infrastructure and Investment-related Constraints

It is likely that expansion of aquaculture in the UK will require the industry to look to develop operations further offshore to address the issue of competition for space in shallow coastal waters (e.g. MMO, 2013a). The issues surrounding the expansion of aquaculture developments further offshore are complex and it was considered beyond the scope of the current study to account for technological advances that may be required to develop/expand offshore within the model.

However, it has been noted that investment-dependent constraints are often correlated with distance i.e. larger distances to essential supporting services have a cost implication for developments, and these issues are considered further below in Sections 7.1 and 7.2. An additional potential constraint to business viability is the presence of INNS and disease. The influence of these factors on the viability of aquaculture development are considered in Sections 7.3 and 7.4 respectively. The influence of other issues affecting the viability of aquaculture businesses, including seed/spat supply and hatchery locations, location of processing units and markets have been considered qualitatively and are discussed further in Sections 8 and 9.

7.1 Proximity to Suitable Landing Ports

Fisheries landing ports in North and South Wales (MMO data obtained from the Environment Agency Geostore; see Appendix A) are shown in Figures 3.1 and 3.2. Initially it was intended that the distance of areas suitable for aquaculture (with respect to natural resource requirements; see Figures 8.1 to 8.14) would have a graduated constraint applied that was proportional to the distance to the nearest landing port. However, stakeholder consultation undertaken for this study indicated that landing ports do not seem to pose a constraint for small fishing vessels in Wales; harbours are required to house boats and offload the catches which are transferred to lorries which just require road access. Hence it was assumed that small-scale aquaculture operations would not be constrained by distance to landing port either. Species that are cultivated intertidally (e.g. oysters) would only require road access for the transportation of the product. Where there may be opportunities for larger-scale developments, it was considered that there were ports of adequate size for vessels to offload the harvested species. The distance that operators are willing to travel to such a port will likely relate to the value of the species being cultivated. For example, scallop is a high value species and it was noted that the commercial fishing vessels that travel the farthest distance to utilise port facilities in Wales were scallop fishing vessels. Based on this information, distance to landing port has not been included as a constraint in the spatial model, although it is recognised that this aspect will influence an APB's operational cost.

7.2 Proximity to Depuration Facilities

Depuration is a process used to ensure that shellfish consumers are protected from the risks associated with sewage-contaminated shellfish. The process entails placing shellfish in tanks of clean seawater (treated by ultraviolet disinfection prior to purification to prevent possible contamination of shellfish during the process) for a minimum of 42 hours to purge any microbiological contamination they may have bio-accumulated while in the environment. Only shellfish harvested from class B harvesting areas (and where deemed necessary, class A areas) are permitted to be depurated.

The distance to adequate depuration facilities will influence an APB's operational cost and hence may affect a business' viability. Existing registered depuration facilities are shown in Figures 3.1 (North Wales) and 3.2 (South Wales). Some APBs in Wales depurate their own stock (and one offers the ability to manufacture depuration facilities for other APBs), while APBs that generate large volumes of shellfish currently export their stock to the Netherlands (which has the most developed processing industry and the most mature market for benthic cultivated mussels) where they are depurated prior to entering the supply chain. Stakeholder feedback indicated that depurating the mussels in Wales and then exporting them to the Netherlands would be more costly then exporting them direct to the Netherlands for depuration and subsequent sale.

Given that some shellfish are currently exported outside of Wales for depuration, it was not possible to sensibly incorporate 'distance to depuration facilities' into the current model. However, it can be noted that the stakeholder engagement did highlight the lack of suitable depuration facilities for the current tonnage of shellfish produced and hence indicates that this is an area that will require further consideration if the Welsh MFSAP seeks to double shellfish production by 2020. Stakeholder concern was expressed relating to the lack of capital for a large scale depuration facility in Wales.

7.3 Proximity to Invasive Non-native Species

INNS are non-native plant or animal species which have the ability to spread causing damage to the environment, the economy and/or human health (GB Non-Native Species Secretariat (GB NNSS), 2015a). Such INNS may impact shellfish farming activities through competition with the farmed species for food or other resources (e.g. the slipper limpet *Crepidula fornicata*), through predation (e.g. the American tingle *Urosalpinx cinerea*) or through causing significant fouling of aquaculture infrastructure or smothering of farmed organisms (e.g. *Sargassum muticum, Didemnum vexillum*). Hence, the proximity to non-native species may present an 'investment' risk to APBs for example, in relation to the high costs associated with cleaning aquaculture equipment.

Eight INNS have been identified with the potential to be present in mussel seed areas, either in the mussel seed, substrate or surrounding water and hence have the potential to be transported with seed (cited in Bangor Mussel Producers Association, 2008):

- Violet sea squirt *Botrylloides violaceus;*
- Carpet sea squirt *Didemnum vexillum;*
- Solitary sea squirt *Corella eumyota;*
- Slipper limpet *Crepidula fornicata;*
- American jack knife clam *Ensis americanus;*
- Chinese mitten crab *Eriocheir sinensis;*
- Veined rapa whelk *Rapana venosa* (only one occurrence in UK; Clare Eno, pers. comm.)*;*and
- Wakame *Undaria pinnatifida.*

For the purposes of this study, the most significant risk to potential future aquaculture developments was considered to arise from the carpet sea squirt *Didemnum vexillum.* This species occurs in colonies, grows quickly and has been found to carpet whole marine communities in areas that it has invaded, having a significant impact on biodiversity and species richness. This species has the potential to affect the commercial viability of shellfish aquaculture businesses, as it has been shown to readily overgrow mussels and aquaculture gear. Based on current predictions this species could cost mussel farming (in the UK) between £1.3 and £6.8 million over the next ten years (GB NNSS, 2015b).

As such, in this study it has been assumed that the presence of this species in Holyhead marina would pose a significant risk to any type of future aquaculture development and a 5km exclusion zone around this area was imposed. There are nonetheless leases / dormant Several Orders shortly to be renewed within the vicinity, for which close monitoring will be required to ensure against incursion by this didemnid. Meanwhile efforts are continuing by NRW and others to eradicate any potential invasion from Holyhead harbour.

The slipper limpet, *Crepidula fornicata,* is considered (by at least one stakeholder) to be a major threat to many marine fisheries and aquaculture activities in Wales due to its propensity to spread and potentially dominate benthic communities. It is one of several species that need to be screened for to avoid accidental spread to new areas by other aquaculture activities such as collection of seed. The Bangor Mussel Producers jointly produced a Code of Good Practice with the Countryside Council for Wales (now NRW) to minimise the risk of any such movements and this has been working demonstrably well for several years (see Section 6.2.1).

The use of brine dipping / rinsing for killing slipper limpets has been promoted since the 1950s and was recently revisited experimentally and found to be highly effective (Fitzgerald, 2008), although the economic and practical viability of undertaking such practices has still to be determined. This research is nonetheless encouraging and could be put into practice should any new introductions of this species occur in mussel growing areas such as the Menai Strait.

Any potential risk to current or future aquaculture activities posed through the accidental transfer of this species into new areas, for example via movement of mussel seed, could not be represented spatially within the model. However, given that the presence of the species may potentially impact on shellfish aquaculture activities (e.g. through competition for resources or economic impacts related to increased processing time (e.g. sorting stock) or damage to stock (e.g. during removal of slipper limpets from shells), areas where this species is well established were assigned a defined constraint (albeit at a relatively low level, see Appendix B). This constraint level was applied to the maps of natural resource potential for the bottom culture of bivalve molluscs. Areas in which the species was considered to be established included Milford Haven and Swansea Bay, based on records provided by NRW in which the species was recorded annually over a period of many years (see Appendix B for further detail). This defined constraint level was applied within a 'buffer area' of 2.5km radius from these established locations.

Stakeholder feedback also highlighted the potential for the Chinese mitten crab *Eriocheir sinensis* to impact on the Welsh aquaculture industry, in relation to its potential to be present in mussel seed and hence be transferred during movement of mussel seed. However, as noted above, it was not possible to incorporate this potential risk into the spatial model.

7.4 Disease

Both Pacific and native oysters are affected by disease and stakeholder consultation undertaken for this study indicated that for the oyster producing industry there are increasing issues associated with obtaining disease-free seed.

Pacific oysters are affected by the Oyster Herpes Virus (OsHV-1). Disease-related restrictions on the movement of Pacific oysters mean that shellfish farms within 'disease-free' compartments of England and Wales can only receive Pacific oysters (including seed) from other disease free areas under 'surveillance' (Herbert *et al*. 2012).

Native oysters are affected by *Bonamia ostreae* which has caused high levels of mortality in wild and cultivated populations across Europe. Shellfish movements from infected areas are thought to be the main vector of *B. ostreae* and there is no short-term solution for infected populations. *B. ostreae* was found in Milford Haven by Cefas in 2006 (Cefas, 2009; Woolmer *et al*. 2011). Restrictions which apply to molluscan shellfish in this *Bonamia ostreae* designated area are (Cefas, 2009):

1. Native oysters (*Ostrea edulis*) may be taken from the area for relaying into other confirmed designation areas for *Bonamia ostreae*;
2. Farmed/cultivated Pacific oysters (*Crassostrea gigas*) may be moved from the area for relaying elsewhere provided that they are thoroughly cleaned and that there are no other species present;
3. Subject to hygiene regulations molluscan shellfish of any species may be taken from the area for direct human consumption;
4. Molluscan shellfish of any species may be put into a depuration plant within this or another confirmed designation area; and
5. Pacific oysters (*Crassostrea gigas*) only, may be put into any depuration plant outside the areas with a confirmed designation for *Bonamia ostreae* provided that they are thoroughly cleaned and that there are no other species present.

Stakeholder consultation indicated that sourcing *Bonamia*-free seed was becoming more difficult. Furthermore, research suggests that other invertebrate species, including the Pacific oyster and brittlestars may be incidental carriers of *Bonamia* (e.g. Lynch *et al*. 2010).

The implication for the current study is that in relation to the potential spread of diseases which impact on oysters, it will be important to consider minimum distances between farms to prevent the spread of disease through oyster larvae distribution. Native oyster larvae only remain in the plankton for approximately 8 days in contrast to Pacific oyster larvae which remain in the plankton for 3 to 4 weeks prior to settling, and hence have the potential to disperse (and therefore carry any disease) over a wider area. The required distance between oyster cultivation sites to prevent such disease transmission would depend on the prevailing hydrographic conditions which would need to be modelled (Jon King, Bangor University, pers. comm.). In order to highlight this potential influence on oyster cultivation, 'confirmed designated' areas of *Bonamia ostreae* were included in the spatial model and a relatively low level of defined constraint was applied only to areas identified as potentially suitable for oyster cultivation (intertidal or subtidal areas) (see Appendix B for further detail).

8. Modelled Potential for Aquaculture in Welsh Waters

The following section summarises the results obtained from the spatial model which highlights the relative magnitude of constraints to future aquaculture developments based on the natural resource requirements of the species and cultivation method assessed, any MSP-related constraints (including other marine sector activity and associated infrastructure) and investment-related constraints (INNS and disease).

It must be noted that the model has various limitations which are highlighted in Section 8.1 (and described further in Appendix B) and the outputs of the model must be considered in within the context of these limitations. Recommendations for future development of the spatial model are made in Section 9.

8.1 Model Limitations

The model developed in this study was based on available data and as such it must be noted that the model has various limitations, for example, where data were unavailable at a relevant resolution or where data gaps exist. Key data limitations and gaps are summarised in Appendix B. Recommendations for future development of the model to address these issues are presented in Section 9.

Areas of opportunity for aquaculture development are likely to be influenced by available technology, site-specific natural resource and/or MSP factors and expert knowledge regarding how these factors are likely to affect the viability of any aquaculture development. As such, it is important to note that the model outputs indicate broad areas at a Plan level where there may be opportunity for future aquaculture development, and that due to limitations or gaps in data, appropriate technology, biosecurity etc. the areas presented should not be considered to be the 'definitive' areas of potential.

Given the relatively simplistic nature of the model, it is possible that some areas of potential have been overestimated. Conversely, stakeholder feedback indicated that it was important not to consider areas which were not highlighted as 'suitable' to be considered 'out of bounds' for aquaculture development. It is recommended that further assessment of aquaculture potential at a more local or site-specific level could be undertaken using the model developed, utilising higher resolution data sets for the area of interest (see also Section 9).

The species and cultivation methods incorporated into the model were based on project team knowledge and stakeholder and Welsh Government consultation. However, as noted in Section 1.2, this does not exclude the potential for the commercially viable production of other species, for example through land-based cultivation of finfish, invertebrate or algal species (e.g. microalgae). Stakeholder opinions on the potential for such land-based production are described further in Section 9.

8.2 Natural Resource Suitability

Maps showing the distribution of areas where natural resources are potentially suitable for the cultivation of the species and methods assessed (i.e. the derived natural resource core component data layers) are shown in Figures 8.1 to 8.14. These figures represent areas of potential for aquaculture development based solely on the natural resource requirements of the species/cultivation method, prior to any constraints associated with other marine sector activities or infrastructure being taken into consideration. The literature and data underlying these natural resource maps is described in Section 5 and in further detail in Appendix B and C.

The areas shown in these natural resource maps represent:

- Intertidal and/or subtidal areas potentially suitable for bottom culture of bivalves (European clam, oyster (Pacific and native), mussel, scallop) (Figures 8.1 to 8.4);
- Intertidal and/or shallow subtidal areas potentially suitable for trestle/bag culture of bivalve molluscs (mussel and oyster (Pacific and native),) (Figure 8.5 to 8.6);
- Offshore areas potentially suitable for rope culture of bivalve molluscs (mussel, king scallop) (Figure 8.7 to 8.8);
- Offshore areas potentially suitable for rope culture of macroalgae: medium exposure tolerant species (Figure 8.9) and high exposure tolerant species (Figure 8.10);
- Subtidal areas potentially suitable for bottom culture (ranching) of crustaceans (European lobster and spiny lobster) (Figures 8.11 to 8.12); and
- Offshore areas potentially suitable for sea cage culture of finfish (Atlantic salmon, sea trout and cod) (Figures 8.13 to 8.14).

8.3 Marine Spatial Planning Related Constraints

Maps showing all of the MSP-related constraints in Welsh Waters which are likely to influence the potential for future aquaculture development are shown in Figure 8.15. The constraint levels shown in this figure represents the ‘combined’ (additive) constraints based on all marine sector activities, associated infrastructure, nature conservation designations, protected features (for which data were readily available) and location of combined storm overflows. It should be noted that not all ‘defined’ constraints were equally weighted, for example, designated sites were given a higher constraint level compared to recreational activity due to the statutory nature of such designations. In addition, graduated constraints were normalised on a scale of 0-1, where 1 represented the highest intensity or value of the constraint (see Appendix B for further description of constraint types and weighting). Hence, it is important to note that the resulting MSP-related constraint levels shown in Figure 8.15 represents the ‘relative’ level of combined constraints and not the absolute number of constraints. These indicative constraint levels were considered to apply equally to all types of sea-based aquaculture considered in the present study.

8.4 Investment Related Constraints

Maps showing the investment related constraints, in relation to specific INNS (*Didemnum vexillum* and *Crepidula fornicata*) and *Bonamia ostreae* (affecting oyster culture only) are shown in Figures 8.16 to 8.19. The constraint levels shown in these figures represent the 'combined' (additive) constraints based on:

- The potential constraint to bottom culture of oysters (native and Pacific oysters as these two species were modelled together) from the presence of *Didemnum vexillum* (Holyhead marina), *Crepidula fornicata* (Milford Haven and Swansea Bay) and *Bonamia ostreae* (Menai Strait and Wooltack Point to St Govan's Head including Milford Haven) (Figure 8.16);
- The potential constraint to bottom culture of bivalve molluscs except oysters (i.e. mussel, king scallop and European clam oysters) from the presence of *Didemnum vexillum* (Holyhead marina) and *Crepidula fornicata* (Milford Haven and Swansea Bay) (Figure 8.17);
- The potential constraint to intertidal trestle culture of oysters (native and Pacific oysters as these two species were modelled together) from the presence of *Didemnum vexillum* (Holyhead marina), and *Bonamia ostreae* (Menai Strait and Wooltack Point to St Govan's Head including Milford Haven) (Figure 8.18); and
- The potential constraint to culture of all other species/methods (excluding bivalve molluscs) from the presence of *Didemnum vexillum* (Holyhead marina) only (Figure 8.19).

As described in Section 7.3, the presence of *Didemnum vexillum* in Holyhead marina was considered to exclude any aquaculture potential in that area. Defined constraints (at a relatively low level of 0.5 on a scale of 0 to 2) were assigned to areas where *C. fornicata* and *B. ostreae* were present, for the relevant species as listed above (see Appendix B for further description of constraint types and weighting). The resulting investment-related constraint levels shown in Figures 8.16 to 8.19 represent the 'relative' level of these combined constraints and not the absolute number of constraints.

8.5 Outputs from the Model

Figures 8.20 to 8.33 show the relative level of opportunity for aquaculture development (no/low constraint equating to the highest potential) within the areas identified as having suitable natural resources for each of the species/cultivation methods assessed.

It should be noted that the 'excluded areas' shown in these figures include areas of current aquaculture activity, mapped using existing Several Orders Fisheries for mussel and classified bivalve mollusc (mussel) harvesting areas (with the caveat that not all bivalve mollusc harvesting areas for mussel relate to 'aquaculture' activity). However, for the purposes of the current study the presence of wild capture mussel fisheries would not be considered compatible with an aquaculture development and hence would still constitute a constraint. As such, it should be noted that the constraint levels in these areas may be overestimated and the potential in these inshore areas should be assessed further (see Section 9). Areas where no colour is shown represent areas where the natural resources are not considered suitable for the species/method assessed.

Initial outputs from the model are briefly summarised below and should be interpreted in the light of the model limitations described in Section 8.1.

8.5.1 Bottom Culture of Bivalve Molluscs

Figures 8.20 to 8.23 show the relative level of constraint within areas of suitable natural resources for the on-bottom culture of European clam, oysters (native and Pacific considered together), mussel and king scallop respectively. Native and Pacific oysters were grouped together because the resource requirements of these species using this cultivation method were similar enough to model together (see Table 5.1, Section 5). It should be noted that, in contrast to the other bivalve mollusc species included in the model, based on its salinity requirements (i.e. fully marine), areas of potential for culture of scallop in the Bristol Channel were only considered where the salinity was, on average, above 30, which was assessed using Severn tidal limits data and resulted in areas east of Limpet Bay, West Aberthaw not being considered suitable for the culture of this species.

A relatively general pattern emerged in which areas of highest potential (no/least constraint) were highlighted in offshore areas around Swansea Bay, Cardigan Bay, between the Llyn peninsula and Anglesey and east of Anglesey for species which can be cultivated subtidally (mussel, scallop, native oyster and Pacific oyster). Note it was assumed that the Pacific oyster could be cultivated at the same depths as native oysters based on Syvret *et al*. (2013).

The model indicated the largest areas of potential (suitable natural resources and no/least MSP constraint) for king scallop and mussel and smaller areas for native and Pacific oysters and clams.

The model indicated that the smallest areas of potential were for the cultivation of the European clam, due to its requirement for cultivation within intertidal/shallow subtidal habitat. The figure appears to indicate that areas of greatest potential (least constraint) for cultivation of this species occur within estuaries, in the eastern Menai Strait and along the coastline east of Cardiff within the Bristol Channel. It is important to note that the potential of these areas may be further constrained by water quality, which it has not been possible to model all around the Welsh coast within the current study. Shellfish aquaculture developments are only economically viable where water quality (and shellfish flesh) meets the Class B classification for bivalve mollusc harvesting areas and it may be particularly difficult to meet this requirement within estuaries and some locations within the Bristol Channel.

The above noted limitation with respect to water quality will apply to all cultivation of shellfish, however, it is assumed that any water quality issues would be greatest in inshore waters and reduced further offshore.

Additional factors which may influence the potential to establish bottom culture of bivalves in the areas indicated which were not considered within the spatial model include:

- The technological capability required to undertake bottom-culture offshore (although stakeholder feedback has indicated this is not a major constraint);
- Possible increased predation levels (e.g. by starfish);
- Security of stock (against theft);
- The requirement for adequate spacing between oyster culture sites in relation to *B. ostreae* which affects native and Pacific oysters (a requirement highlighted by stakeholder feedback);
- Requirement for establishment of Several Orders Fisheries;
- The availability of wild mussel/oyster seed/spat for relaying; and
- Prevention of wild settlement of cultivated Pacific oysters (e.g. via the use of triploids).

8.5.2 Trestle/Bag Culture of Bivalve Molluscs (Includes Native Oysters, Pacific Oysters and Mussels)

Figures 8.24 and 8.25 show the relative level of constraint within areas of suitable natural resources for the trestle/bag cultivation of three bivalve species: mussel, native oyster and Pacific oyster (the latter two species were grouped together within the assessment because the resource requirements of these species via this cultivation method were similar enough to model together; see Table 5.2, Section 5).

The relatively small area of potential for this cultivation method is linked to the requirement of the equipment and stock to be accessible and hence located in the intertidal or very shallow subtidal area.

Within the areas highlighted as having suitable natural resources, the model output shows that a considerable proportion of these areas are excluded from potential development, due to a combination of existing marine sector activities or infrastructure which was considered to exclude new aquaculture developments (see Figure B5).

Additional factors which may influence the potential to establish intertidal trestle/bag cultivation of bivalves in the areas indicated which were not considered within the spatial model include:

- Water quality (particularly within estuaries as described above);
- Seed/spat availability; and
- Prevention of wild settlement of cultivated Pacific oysters (e.g. via the use of triploids).

8.5.3 Rope Culture of Bivalve Molluscs (Mussel, King Scallop)

Figure 8.26 and 8.27 show the relative level of constraint within areas of suitable natural resources for the rope cultivation of two bivalve species (mussel and king scallop). As noted in Section 8.4.1, as king scallop requires fully marine conditions, areas where the average salinity was below 30 in the Bristol Channel were not considered potentially suitable for culture of this species (see Table 5.3, Section 5). This was not the case for mussel which have a wider salinity tolerance.

The relatively large extent of potential areas indicated for both species (suitable natural resources and no/least MSP constraint) reflects the 'offshore' nature of this technique (modelled between depths of 13-50m below chart datum (CD)), although in certain areas relatively large exclusion zones exist presumably related to other offshore industry activity.

The largest areas of potential (with low levels of constraint) are indicated to exist offshore to the west and east of Anglesey and adjacent to Swansea Bay in south Wales. Further areas are indicated in various locations throughout Cardigan Bay (where the slightly higher areas of constraint relate to the presence of EMSs).

Additional factors which may influence the potential to establish rope culture of bivalves in the areas indicated which were not considered within the spatial model include:

- The technological capability required to undertake rope cultivation offshore – whilst successful trials of rope cultivation in Wales have been undertaken, some of the areas of potential highlighted in this assessment are extremely exposed and may not be feasible with current technology;
- Investment related constraints – with respect to suitable depuration facilities (if required) for the tonnage of shellfish that may be produced offshore;
- Supply chain/market related constraints – for example with respect to consistency of supply from offshore production sites (due to potential weather constraints to harvesting) and/or impacts on smaller inshore producers (e.g. in relation to market saturation);
- Benefit of offshore production would include wild mussel seed settlement directly onto ropes rather than having to relay wild mussel seed from other areas (although husbandry may be required to transfer seed from seed collector ropes to grow out ropes) and the assumption of good water quality offshore compared to sites inshore.

8.5.4 Rope Culture of Macroalgae (Medium Energy Environments)

Figure 8.28 shows the relative level of constraint within areas of suitable natural resources for the rope cultivation of macroalgal species which can tolerate medium energy environments (in relation to wave and tidal currents; see Table 5.4, Section 5).

The relatively limited areas of potential (suitable natural resources and no/least MSP constraint) reflects the constraint imposed by the requirement for cultivation to occur in the photic zone.

The largest area of potential with least MSP constraints extends offshore from Swansea Bay to the sea area adjacent to Barry. Much smaller areas of potential with minimal MSP-related constraints are shown in Cardigan Bay, between the Llyn peninsula and Anglesey and east of Anglesey.

Additional factors which may influence the potential to establish rope culture of macroalgal species in the areas indicated which were not considered within the spatial model include:

- The technological capability required to undertake rope cultivation offshore – as noted above some of the areas of potential highlighted in this assessment are extremely exposed and may not be feasible with current technology; and
- Market-related constraints – for example, how established is the market demand for macroalgal products, particularly on the scale that offshore cultivation may produce.

8.5.5 Rope Culture of Macroalgae (High Energy Environments)

Figure 8.29 shows the relative level of constraint within areas of suitable natural resources for the rope cultivation of macroalgal species which can tolerate high energy environments (in relation to wave and tidal currents; see Table 5.4, Section 5).

The extremely limited potential areas (suitable natural resources and no/least MSP constraint) reflect the lack of overlap between the high energy requirements preferred by this species and the photic zone in the offshore environment.

The only areas of potential are shown off the northern most tip of Anglesey, off the western most tip of the Llyn peninsula, west of Ramsey Island and south east of Porthcawl.

Additional factors which may influence the potential to establish rope culture of macroalgal species in the areas indicated, which were not considered within the spatial model, are described above.

8.5.6 Bottom Culture/Ranching – European Lobster and Spiny Lobster

Figures 8.30 and 8.31 show the relative level of constraint within areas of suitable natural resources for the bottom cultivation (ranching) of the European lobster and spiny lobster (see Table 5.5, Section 5).

The extremely limited potential areas (suitable natural resources and no/least MSP constraint) are related to the constraint imposed by the assumed the requirement for rocky subtidal habitat for these species. The areas of potential highlighted offshore relate to the depth at which natural populations of lobster occur and the larger areas of potential shown for the spiny lobster relate to the greater maximum depth (50m) modelled for that species in the assessment.

It should also be noted that the salinity requirements of these species are ‘fully marine’. As such, areas where salinity is, on average, below 30 in the Bristol Channel were not considered to be suitable for this species. However, the figures still indicate considerable areas of potential, particularly for crawfish in the Bristol Channel, and it should be made clear that such areas are not likely to be suitable and the areas of potential have been overestimated for these species despite the salinity constraints applied within the model.

Although these species and culture method (on-bottom ranching of hatchery-reared lobsters were included in the model it must be stressed that this type of cultivation is unlikely for multiple reasons including containment of stock, security of stock and the viability of this method even in shallower water.

8.5.7 Cage Culture of Finfish (Atlantic Salmon and Sea Trout)

Figure 8.32 shows the relative level of constraint within areas of suitable natural resources for the sea cage cultivation of Atlantic salmon and sea trout. These species were grouped together (as salmonids) within this assessment because the resource requirements of these species via this cultivation method were similar enough to model together (see Table 5.6, Section 5).

The relatively large extent of potential areas (suitable natural resources and no/least MSP constraint) reflects the 'offshore' nature of this technique (modelled between depths of 15-50m).

The general pattern in relation to areas of highest potential (suitable natural resources and least constraint) are similar to those described for the rope culture of bivalve molluscs due to the similar depth requirements used in the model. The largest areas of potential (with low levels of constraint) are shown to exist offshore adjacent to Swansea Bay in south Wales and offshore to the west and east of Anglesey, in addition to various locations throughout Cardigan Bay (where the slightly higher areas of constraint shown relate to the presence of EMSs).

It should also be noted that the salinity requirements of sea trout were considered to be 'fully marine' (salinity over 30). As such, areas where salinity is, on average, below 30 in the Bristol Channel were not considered to be suitable for this species. As Atlantic salmon and sea trout were modelled together, this spatial limit was also applied to Atlantic salmon.

Additional factors which may influence the potential to establish cage culture of salmonids in the areas indicated which were not considered within the spatial model include:

- The technological capability required to undertake sea cage culture offshore – although the technology for finfish farming is well established in Scotland – unlike current finfish farms locations in Scotland, some of the areas of potential highlighted in this assessment are extremely exposed and may not be feasible with current technology;
- Even if the appropriate technology to undertake this cultivation method in offshore/exposed waters is developed, Atlantic salmon production in Wales would be competing with the established Scottish salmon farming industry and this is not likely to be feasible;
- Stakeholder feedback has suggested that if sea cage finfish farming is technically feasible, there would be more interest and potential for farming sea trout;
- It should be noted that as the model excluded temperature as a constraining factor (due to the resolution of the available data layer; see Appendix B), further examination of the areas which may provide the best potential for cultivating sea trout would require the model to incorporate seasonal variations in sea temperature. It is reasonable to assume that such further analysis would likely show greater temperature-related constraint in northern Wales compared to southern Wales.

8.5.8 Cage Culture of Cod

Figure 8.33 shows the relative level of constraint within areas of suitable natural resources for the sea cage cultivation of cod.

The general pattern of potential areas (suitable natural resources and no/least MSP constraint) is similar to those for the salmonid species, except there are fewer suitable resource areas for cod, reflecting the shallower depth requirements modelled for this species (15-20m). The shallower maximum depth used in the model relates to previous research into the vertical distribution of Atlantic cod which showed that surface feeding motivation resulted in cod preferentially occupying the upper reaches of a sea cage (<13m) and for physiological reasons related to cod having a closed swim bladder which make them vulnerable to sudden pressure reductions which may occur during lifting of cages (e.g. Kristiansen *et al*. 2011; see also Appendix C).

As noted above, due to the relatively coarse resolution of the temperature data layer used in the model (mean sea temperature), further assessment of the areas of potential should incorporate seasonal variations in sea surface temperature to establish whether such cultivation is viable, and if so, further refine the areas of greatest potential.

Additional factors which may influence the potential to establish sea cage culture of cod in the areas indicated which were not considered within the spatial model include:

- Technological capability in relation to the exposed wave climate in some of the areas of potential highlighted in the output, as described above for salmonid species;
- Investment-related constraints – even if suitable technology is developed, sea cage farming of cod is not likely to be economically viable due to recently increased supplies of wild capture cod into the market (for further information see Section 9 and Appendix D).

9. Conclusions and Recommendations

Conclusions from the study are summarised below and discussed in relation to the main themes raised by stakeholders. This Section also provides recommendations regarding how the model can be developed (i.e. in relation to additional data layers that could be incorporated) to further improve assessment of potential areas for future aquaculture development.

9.1 Conclusions

In general, the model highlighted greater areas of potential for aquaculture in more offshore areas, as opposed to inshore coastal waters. Whilst this was not unexpected, development in such areas will rely on innovation or new technology and require significant investment to realise this potential and as such some stakeholders suggested that such areas were unlikely to contribute to the Welsh Government's stated target of doubling the volume of aquaculture production by 2020. Stakeholder feedback indicated that current aquaculture operators and practices would focus predominately inshore (especially given that the majority of aquaculture producers in Wales are micro-businesses; Holly Whitely, Seafish; pers. comm.), where the model indicated relatively higher levels of constraint due to competition for space. Stakeholder feedback also stated that the locations of existing (and in many cases long-standing) production sites were the best indicators of suitable areas and that in the short-term future the industry and Welsh Government should focus on increasing productivity in these areas.

9.1.1 Shellfish Aquaculture

The model outputs suggest that there is potential space for the development of the shellfish aquaculture industry, although as would be expected potential inshore areas are far more limited (due to existing activities) compared to offshore areas. Inshore areas may be further constrained in relation to water quality issues which could not be included in the spatial model within the timescale of the study (see recommendations below).

Larger areas of potential are indicated to exist 'offshore' for bivalve mollusc species both via bottom culture and rope culture. Potential issues for aquaculture production in offshore areas have been noted in Section 8 and include whether current technology for rope cultivation of bivalve molluscs offshore is adequate for the conditions off the Welsh coast. Currently rope grown mussels are only being produced in a sheltered environment (Queen's Dock) in Swansea. Trials of offshore mussel rope cultivation were undertaken in Cardigan Bay and Holyhead, two locations that were considered too exposed, however the mussels survived for 12 months. A small trial of rope grown mussels off Anglesey (located in water 13-15m deep with 7m droppers on a long-line 3m below the surface), which is relatively sheltered from wave action and in a quiet spot for shipping, is currently working well. However, currently, the economic viability of offshore aquaculture remains uncertain.

Security of shellfish stocks (against theft) in offshore waters may also be an issue which would affect business viability. For example, one stakeholder highlighted that given the likely cost of scallop seed (if this were available), it would be unlikely that anyone would take the risk of cultivating this species outside of a contained or highly controlled area. Further stakeholder feedback indicated that disease, including the ability to source disease-free seed/spat, was considered to be a serious issue facing the industry. This factor is likely to pose further spatial constraints on areas of potential.

However, stakeholders considered the two most significant issues facing the industry related to licensing and reliable seed supply. With regard to licensing, specific concerns raised were the relatively short duration of leases, agreement of Several Order Fishery terms and the time for Several Order Fisheries to be renewed. These issues were considered to result in a lack of security, to undermine the continued viability of current producers and to potentially discourage new entrants to the industry. For some current producers, the most immediate constraint related to mussel seed supply. The on-bottom culture mussel industry is dependent upon a reliable yearly supply of seed. The ability to transport seed into mussel lays from outside the growing areas relates to both the natural occurrence (availability) of seed and the permission to collect and transport it. Stakeholders felt that the latter has become an increasing constraint in recent years, for example due to divergent views on management (e.g. the extent of ephemeral mussel seed beds required by wild birds) which prevent agreements lasting for several years and hence increase instability for the industry. Another potential issue, highlighted throughout the report (although not particularly raised by stakeholders), relates to the spread of INNS, which if indicated to be present in traditional seed harvesting areas may prevent permission to deposit seed into the growing areas. Where the source of seed has become the most critical and unpredictable point in their business, mussel growers may look to other more reliable sources which could come from spat collectors close to their beds. This is not an economically viable option at present, however, it may ultimately prove to be the only way for the business to prosper. A further constraint raised by some stakeholders was the lack of capital funds to develop a suitable sized depuration facility for high volumes (tonnages) of shellfish.

9.1.2 Macroalgal Aquaculture

The model outputs indicate that there are relatively large areas of potential for offshore cultivation of macroalgal species which can tolerate moderate energy environments (see Appendix B for definition of wave and tidal exposure levels). Pilot scale trials of offshore macroalgae cultivation are being undertaken in the Irish Sea and Scotland, however, for this potential to be realised, the technology will need to be proven. Furthermore, whilst research into high value extracts from macroalgal products for the pharmaceutical, cosmetic and nutraceutical industries is currently being undertaken in Wales, the market demand for, and economic viability of, large scale production of macroalgal species would need to be established. The water quality in which the seaweed is cultivated can influence the potential uses for the end product, although it is assumed that water quality would not be an issue in offshore waters. It can be noted that there is a business in Swansea which is currently producing crispy Nori seaweed, promoted as a ‘healthy snack’, seaweed sheets for rolling sushi and condiment seaweed sprinkles (Selwyn’s Penclawdd Seafoods, 2015).

9.1.3 Crustacean Aquaculture

The model included the on-bottom culture (or ranching) of crustacean species as per previous studies (e.g. MMO, 2013b) and stakeholder consultation for the current study indicated that European lobster and spiny lobster are high value species of potential interest to the aquaculture sector. However, where hatchery cultivation of European lobster is undertaken in other parts of the UK (e.g. Cornwall, Scotland) the primary aim of this cultivation is 'restocking' to support wild populations and existing fisheries.

For the purposes of the current study, 'restocking' is not considered to constitute aquaculture activity, however, if lobster species were cultivated in hatcheries and placed in the marine environment for on-growing to a marketable size this would constitute aquaculture. However, it is appreciated that the offshore areas highlighted in the model outputs may not be practical for such purposes. The ability to contain the on-growing lobsters within a given marine area and thus ensure the security of the stock would be a major issue facing the establishment of this practice. Furthermore, stakeholder feedback indicated that culture and ranching of the European lobster in this manner, if undertaken, would undermine one of the most important wild capture crustacean fisheries in Wales (Holly Whitely, Seafish, pers. comm.).

9.1.4 Finfish Aquaculture

The species chosen for the model were purely illustrative in terms of fish that could possibly survive under the environmental conditions prevalent on the coast of Wales. The model outputs indicated that there are relatively large areas of potential for offshore sea cage culture of finfish species (particularly Atlantic salmon and sea trout). Potential issues for aquaculture production in offshore areas have been noted in Section 8, including the lack of economic viability in competing with the Scottish salmon industry (discussed further below) and whether such methods would be feasible in the more exposed environment off the Welsh coast.

Even if current sea-based technology was viable in the local offshore conditions, a further issue is that such areas would be too exposed for personnel to service farms (e.g. on a daily basis). Based on stakeholder feedback, the only potential site for sea cages would be the Milford Haven, where the pressure from other developments means the potential for fish farm developments, and the effects they bring that would be cumulative to those already present would make it highly unlikely to be licensed.

Of the species included in the model, farming sea trout is the most attractive of these options. The market for cod is too closely linked to that of wild caught fish and now that cod stocks have started to recover, the price is not attractive enough to consider farming cod (which is why it hasn't taken off in Scotland or Norway where physical conditions are favourable). The market for salmon is specifically for farmed fish (wild caught salmon, while holding a very high price, is such a niche market that it does not compete with farmed salmon). Nonetheless, Scotland and Norway have cornered the market in this respect and such investments in Wales are unlikely to be a viable commercial proposition.

Whilst sea trout may be a more viable species to cultivate from a market supply and demand perspective, the areas of potential highlighted in the model are likely to be further constrained once more detailed sea temperature data can be incorporated into the model. It should also be noted that there has been strong opposition to proposed sea cage farming of salmonid species in other parts of the UK (e.g. Cornwall) based on concerns relating to biosecurity, pollution and parasitology. A further potential constraint would relate to the level of investment required to establish the required infrastructure. The cost of the infrastructure associated with setting up cage farms is prohibitive, such that onshore facilities or dock facilities would be more cost effective.

Based on the above issues, and stakeholder feedback, it is likely that the only viable option for increasing finfish production in Wales is through land-based sites using RAS. This was not be modelled in this study, which considered the Marine Plan area only.

The main considerations for RAS are scale and running costs. There have been small developments in Wales producing up to 20 to 50 tonnes which are not economically viable to stand alone once funding has been removed. Even farms producing up to 300 tonnes a year are border-line in terms of their economic viability. The main buyers may boast and promote sustainable practices, but will generally place orders on the base of price alone, thus driving the bulk price down for more sustainable growers. Niche markets are limited, so to compete in a world market, farmers must be able to provide reliable, competitively-priced fish and have the flexibility to cover fluctuations in the markets (and hence grow a variety of species for which there is a farmed fish market).

The investment required to start a fish farm is considerable, and while grant aid is particularly helpful for pilot studies, the farms ultimately have to be able to survive without subsidies. The example of Greece is a poignant one where huge investment from European grants led to the expansion of the sea bream (and later seabass) farm production during the 1990s from about 10,000 to 120,000 tonnes in a mere ten years. The whole industry developed on a false economy and flooded the market, selling fish at a low price which did not reflect the true cost of running a business. This was an example of boom and bust where the rapid expansion was grant funded.

Where governments wish to encourage the expansion of aquaculture, as does the Welsh Government, the question then arises how it can best do this. One approach in Western Australia is interesting and could well be adopted in Wales. It relates to the use of land or the re-development of land. In Western Australia land is designated specifically for aquaculture use. The sites are very extensive and the prices are fixed, thus encouraging large commercial investments. There are sites which could be used as a base for fish farms around the coast of Wales, however they require some redevelopment. Furthermore, aquaculture developments do not pay business rates, but agricultural rates, the same as farmers. Yet, current pressure to develop other commercial businesses and housing generally takes the land out of the scope of aquaculture developers. Planning law could be addressed to identify and designate sites specifically for use by aquaculture. Although this could take time to introduce, there are many precedents for businesses putting in proposals for sites for offshore wind, oil and gas etc.

As with the need to encourage synergies between offshore renewable energy developers and offshore aquaculture, similar schemes should also be investigated and promoted on land. There is huge potential for industrial synergies with energy producers/power companies who often produce waste heat and cheap energy that could be utilised by fish farmers. There is one such proposal on Anglesey where synergies between a wood powered power station and an aquaculture development (growing a range of species) have been made. The possibility of expanding this idea to take advantage of waste carbon dioxide (the biggest killer of fish) and waste nutrients from the fish to grow plants, such as *Salicornia* and algae, which would in turn lend itself to shellfish hatcheries (in the form of feed), allows the possibility for the development of multi-trophic systems covering a broad spectrum of aquaculture species and outlets.

In essence, the role of government needs to be one of facilitator. This relates to the development of facilitative legislation, licensing, markets and sales. Seed funding is helpful provided it leads to growing synergies and opening up options for major expansion to ensure businesses can become independent.

9.2 Other Areas of Opportunity Not Considered Within the Spatial Model

Stakeholder feedback highlighted additional potential opportunities for expanding aquaculture within Wales, which could not be spatially modelled in the current study. Some of these opportunities have been mentioned in Section 6.4.2. These are expanded upon below.

- Co-location of aquaculture with OWFs - proposed as a potential opportunity to share resources and increase spatial efficiency in the offshore marine environment;
- Co-location of aquaculture activity within tidal lagoons - where ‘sheltered’ conditions within the lagoons which may lend themselves to aquaculture developments that may previously have not been feasible in that location;
- Integrated multitrophic aquaculture (IMTA) - the culture of aquaculture organisms of different trophic levels within proximity to each other (e.g. seaweed / bivalves, seaweed / fish, and seaweed / fish / bivalves cultivated as monocultures in close proximity in the marine environment). The principle of IMTA systems is the use of shared nutrient flows to culture multiple organisms at different trophic levels, thus maximising productivity per nutrient (and hopefully economic) investment. An example provided by Welsh stakeholders included the potential to use nutrient rich effluent from land-based fish farms to grow *Salicornia* (Samphire) / Sea aster, to improve the water quality of the effluent and provide an additional commercial product.
- Development of a shellfish hatchery in a disease (*Bonamia*) free area could help with the supply of biosecure seed for both native and Pacific oysters. The recent lapse in the patent of the method for production of ‘mated’ triploid oysters could provide an opportunity for the establishment of a hatchery in Wales to rear triploid strains of Pacific oyster (supported by appropriate research and development of this management technique; see Appendix C for further information regarding the production of triploid Pacific oyster seed/spat).
- Land-based RAS – stakeholder feedback indicated that RAS has the potential to contribute to the Welsh Government’s target for finfish production in 2020. These systems require the ability to abstract seawater (with appropriate water quality) for use in land-based recirculation systems and a licence for discharge of the effluent (smaller volumes than abstracted). As noted above, it has been suggested that this effluent, which is rich in nutrients, can be used for growing plant species either for bioremediation or for the production of another marketable species (e.g. aquaponics, a food production system that combines raising aquatic animals in tanks with the cultivation of plants in water). Some species are currently being grown (such as seabass) and trials with others (such as lumpsuckers) are underway in RAS in Wales. Yellow tail, grouper and other exotics could be reared if a lucrative market were available to subsume the initial costs. RAS is the only way that water temperature and

quality can be maintained, escapees eliminated, biosecurity maximised, and a body of exportable knowledge developed in Wales. Research collaborations with industry and to train aquaculture developers in the UK and abroad are also available at universities in Wales, such as Swansea University.

9.3 Recommendations for Development of the Model

The following factors were not incorporated into the spatial model due to a lack of suitable data layers, inadequate resolution or incomplete coverage of data layers available:

- Water quality – this is a key data gap to be addressed. Incorporation of graduated constraints around point sources of sewage-related consented discharges, based on the population equivalent of the discharge, would refine the model outputs with respect to providing additional constraints relating to water quality outside of designated shellfish waters. This is a high priority given the importance of water quality on aquaculture development potential;
- Sensitive benthic habitats – the model does incorporate 'habitat' data from the FishMap Mon project, which for the purposes of the 'natural resource requirement' core component were grouped into higher classification units (e.g. rock, biogenic reef, mud, sand, mixed sediment, coarse sediment, seagrass and saltmarsh). However, the higher resolution of the underlying data could be utilised to indicate the habitats in areas of potential for more site-specific investigations and be used in conjunction with other available information (e.g. Tillin *et al*., 2010) to provide an indication of the sensitivity of the underlying habitats to pressures arising from aquaculture. In such a site-specific assessment, a graduated constraint could be applied in relation to the presence of particularly sensitive features, rather than a defined constraint level being applied across the whole site as per the current model;
- Carrying capacity – adequate growth rates and yields of shellfish will require developments to be established in areas with suitable biological carrying capacity based on food availability and ecosystem productivity. It was not considered within the scope of the current study to be able to incorporate this factor into the spatial model. However, some research has been conducted into this topic previously (e.g. Berx *et al*. 2007) and where appropriate models are available they could be incorporated for more site-specific assessments of aquaculture potential; and
- Further assessment of the aquaculture potential of inshore areas – the current study has assessed the potential for aquaculture within the Welsh Marine Plan area i.e. at a Plan level. Stakeholders have expressed an interest in further assessment of the potential of inshore waters (which will be the focus of expansion in the short-term future). The above recommendations could assist with such an assessment, and the knowledge of industry stakeholders could be used to highlight additional inshore (or offshore) areas of interest to focus such further consideration.

10. References

Bailey, J., Pickova, J., Alanärä, A., (2005). The prerequisites for, and potential of, cod farming in Sweden, [pdf] Uppsala: Swedish University of Agricultural Sciences. Available at: https://www.havochvatten.se/download/18.64f5b3211343cffddb2800018437/1348912831823/finfo2005_12.pdf S [Accessed 23 February 2013]

Bangor Mussel Producers Association, (2008). Code of good practice for mussel seed movements. Version 1: July 2008.

Bangor University (2015). Bangor University website: Novel Ingredients from Seaweed Extracts (NISE). Available online: http://gwymon-seaweed.bangor.ac.uk/ [accessed March 2015].

Berx, B., Simpson, J., Mould, K. (2007). Tides bring feeding bonanza to Menai Strait Mussels. In Shellfish News, No. 23, Spring/Summer 2007.

BioMara, (2013). The BioMara project: A joint research programme between the UK and Ireland led by the Scottish Association for Marine Science (SAMS). [Online] Available at: http://www.biomara.org/ [Accessed 8 January 2015]

Blyth-Skyrme, R.E. (2010). Options and opportunities for marine fisheries mitigation associated with windfarms. Final report for Collaborative Offshore Wind Research Into the Environment contract FISHMITIG09. COWRIE Ltd., London. 125p.

Bolton-Warberg, M. and Ftizgerald, R. D., (2012). Benchmarking growth of farmed Atlantic cod, Gadus morhua: a case study in Ireland. Aquaculture Research, [e-journal] Volume 43, pp. 670-678. Available through: Wiley Online Library http://dx.doi.org/10.1111/j.1365-2109.2011.02872.x [Accessed 25 February 2013]

Brown, J. H., (2010). SIPF093 Innovative Shellfish System for High Energy Conditions (B080) Seafish Report No. SR649, [pdf] Edinburgh: Seafish. Available at: http://www.seafish.org/media/Publications/SR649__SIPF093_Innovative_shellfish_system_for_high_energy_conditions.pdf [Accessed 22 January]

Bruton, T., Lyons, H., Lerat, Y., Stanley, M., Bo Rasmusse, M. (2009) A review of the potential of marine algae as a source of biofuel in Ireland. Report prepared for Sustainable Energy Ireland. Available through: http://www.seai.ie/Publications/Renewables_Publications_/Bioenergy/Algaereport.pdf [Accessed 20 January 2015]

Buck B.H., Ebeling M.W., Michler-Cieluch T. (2010). Mussel cultivation as a co-use in offshore wind farms: potential and economic feasibility. Aquaculture Economics & Management 14: 255-281.

Burton, C., (2003). Lobster hatcheries and stocking programmes: An Introductory Manual , Seafish Report SR552 [pdf] Edinburgh: Seafish. Available at: http://www.seafish.org/media/Publications/Lobstehatcheriesandstockingprogrammes_IntoManual.pdf [Accessed 21 January 2015]

Cassis, D., Pearce, C. M. and Maldonado, M. T., (2011). Effects of the environment and culture depth on growth and mortality in juvenile Pacific oysters in the Strait of Georgia, British Columbia. Aquaculture Environmental Interactions, [e-journal] Volume 1, pp.259-274. Available through: Inter-Research Marine Ecology Progress Series http://www.int-res.com/abstracts/aei/v1/n3/p259-274 [Accessed 20 January 2015]

Ceccaldi, H.J. & Latrouite, D., (1994). The French fisheries for the European spiny lobster *Palinurus elephas*. Oxford: Fishing News Books.

Cefas, (2009). Classification of bivalve mollusc production areas in England and Wales.Sanitary Survey Poole Harbour, [pdf] Weymouth: Cefas. Available at: http://www.cefas.defra.gov.uk/media/566208/final%20poole%20harbour%20sanitary%20survey%20report%202009%20%282012%29.pdf [Accessed 22 January 2015]

Cefas, (2009). Confirmed designations for *Bonamia Ostrea*. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/278755/Bonamia_ostreae.pdf

Cefas, (2012). Guidance on aquaculture and environmental protection: Background information for sustainable aquaculture development addressing in particular environmental protection. Draft. Service request (under Framework contract ENV.D.2/FRA/2012/0025). Available online: http://www.medpan.org/documents/10180/0/Background+Information+for+Sustainable+Aquaculture+Development/131ad4cb-7cff-46a6-9637-77e834a2feb5?version=1.0

Cefas, (2015). Aquaculture statistics for the UK, with a focus on England and Wales: 2012. Published by Cefas, January 2015. Available online at: https://www.gov.uk/government/publications/aquaculture-statistics-for-the-united-kingdom-2012

Cefas, ABPmer and Eunomia, (2014). Marine Planning in Wales – Initial Strategic Scoping Exercise. Cefas contract report C6275.

Chabot, D. and Dutil, J.-D., (1999). Reduced growth of Atlantic cod in non-lethal hypoxic conditions. Journal of Fish Biology, [e-journal] Volume 55, pp. 472-491. Available through: Wiley Online Library http://dx.doi.org/10.1111/j.1095-8649.1999.tb00693.x [Accessed 27 February 2015]

Cheney, D., Langan, R., Heasman, K., Friedman, B. and Davis, J. (2010). Shellfish Culture in the Open Ocean: Lessons Learned for Offshore Expansion (Ed. John S. Corbin). Marine Technology Society Journal, Vol. 44, Number 3, May/June 2010, pp. 55-67. http://www.ljhs.sandi.net/faculty/DJames/NOSB/Study%20Guides/Aquaculture%20MTS%2044.3.pdf

Cote, J., Roussel, J.M., Le Cam, S., Bal, G., Evanno, G., (2012). Population differences in response to hypoxic stress in Atlantic salmon. Journal of Evolutionary Biology, [e-journal] Volume 25, pp. 2596-2606. Available through: Wiley Online Library://dx.doi.org/10.1111/jeb.12007 [Accessed 27 February 2015]

Cromey, C., Nickell, T. and Treasurer, J., (2007). Cod farming in the marine environment. CERC02/03. Final Report 2004-2007, [pdf] London: The Crown Estate. Available at:http://www.ecasatoolbox.org.uk/the-toolbox/eiaspecies/models/goodness-of-fit/depomod-cod-report [Accessed 28 February 2015]

Defra (2008). The United Kingdom operational program for the European Fisheries Fund (2007-2013).

Defra, (2012). Planning for sustainable growth in the English aquaculture industry. Report by the England Aquaculture Plan Consultation Group, [pdf] London: Department for Food, Environment and Rural Affairs (Defra). Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/82402/120112-aquaculture-consult-doc.pdf [Accessed 21 January 2015]

Defra, (2014). United Kingdom multiannual national plan for the development of sustainable aquaculture. April 2014. Available online at: https://consult.defra.gov.uk/fisheries/european-maritime-and-fisheries-fund-in-the-uk/supporting_documents/Multiannual%20National%20Plan%20for%20the%20Development%20of%20Sustainable%20Aquaculture.pdf [accessed March 2015].

Defra, (2015). Marine Strategy Framework Directive consultation: Programme of Measures. January 2015. Available online at: https://consult.defra.gov.uk/marine/msfd-programme-of-measures

EC, (2012). Blue Growth: Opportunities for marine and maritime sustainable growth. Available online at: http://ec.europa.eu/maritimeaffairs/documentation/publications/documents/blue-growth_en.pdf..

EC, (2013). Strategic guidelines for the sustainable development of EU aquaculture. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. Brussels, 29.4.2013 COM(2013) 229 Final. Available online at: http://ec.europa.eu/fisheries/cfp/aquaculture/official_documents/com_2013_229_en.pdf

ERT Ltd, (1995). The Minch Project. Littoral Seaweed Resource Management, Perth: Scottish Natural Heritage and Western Isles Island Council.

Faber Maunsell Limited, (2008). Scottish Marine Bill Strategic Environmental Assessment (SEA): Environmental Report (ER). Scottish Government.

FAO, (1988). Definition of aquaculture, Seventh Session of the IPFC Working Party of Experts on Aquaculture, IPFC/WPA/WPZ, p.1-3, RAPA/FAO, Bangkok.

FAO, (2014). The state of world fisheries and aquaculture: Opportunities and challenges. Food and agricultural organisation of the United Nations. Rome, 2014.

FAO (2015a). Cultured Aquatic Species Information Programme *Ruditapes decussatus* (Linnaeus, 1758). Available through: FAO Fisheries and Aquaculture Department http://www.fao.org/fishery/culturedspecies/Ruditapes_decussatus/en [Accessed 1 February 2015]

FAO (2015b). Cultured Aquatic Species Information Programme *Salmo trutta* (Berg, 1908). Available online at: FAO Fisheries and Aquaculture Department http://www.fao.org/fishery/culturedspecies/Salmo_trutta/en#tcNA0160 [Accessed 1 February 2015].

Fish Farming International, (2011). Norwegian cod farmers merge. Fish Farming International, August 2011, p. 9.

GB Non-native Species Secretariat (GB NNSS), (2015a). GB NNSS Website: Definition of terms. Available at: http://www.nonnativespecies.org/index.cfm?pageid=64

GB NNSS, (2015b). GB NNSS Website: Carpet Sea Squirt. Available at: http://www.nonnativespecies.org/index.cfm?pageid=155

Goñi, R., Quetglas, A. & Reñones, O., (2003). Size at maturity, fecundity and reproductive potential of a protected population of the spiny lobster Palinurus elephas (Fabricius, 1787) from the western Mediterranean. Marine Biology, 143, 583-592.

Hagos, K. W., (2007). On-bottom mussel culture in Maine and the Netherlands: A comparative analysis, [pdf] Kingston, Rhode Island: Ecological Aquaculture Studies and Reviews, University of Rhode Island. Available at :http://www.ecologicalaquaculture.org/Hagos%282007%29.pdf [Accessed 20 January 2015]

Harris G., Milner, N. (2008). Sea Trout: Biology Conservation and Management. John Wiley & Sons, 15 Apr 2008 - Technology & Engineering

Hendry, K. and Cragg-Hine, D., (2003). Ecology of the Atlantic Salmon. Conserving Natura 2000 Rivers. Ecology Series No. 7, [pdf] Peterborough: Life in UK Rivers (EN, CCW, EA, SEPA, SNH and SNIFFER). Available at: http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFileandrep=fileandfil=SMURF_salmon.pdf [Accessed 4 February 2015]

Herbert, R.J.H., Roberts, C., Humphreys, J. and Fletcher, S., (2012). The Pacific Oyster (*Crassostrea gigas*) in the UK: Economic, Legal and Environmental Issues Associated with its Cultivation, Wild Establishment and Exploitation. Report for the Shellfish Association of Great Britain.

Jackson, A., Marshall, C., Wilding., (2009). *Palinurus elephas*. European spiny lobster. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: http://www.marlin.ac.uk/speciesfullreview.php?speciesID=4022 [Accessed 21 January 2015]

James, M.A. and Slaski, R. (2006). Appraisal of the opportunity for offshore aquaculture in UK waters. Report of Project FC0934, commissioned by Defra and Seafish from FRM Ltd., 199 pp.

Joerstad, K. E., Fjalestad, K. T., Agustsson, T. and Marteinsdottir, G., (2006). Atlantic cod – *Gadus morhua*. In: D. Crosetti, S. Lapegue, I. Olesen and T. Svaasand, eds. Genetic effects of domestication, culture and breeding of fish and shellfish, and their impacts on wild populations. [pdf] Viterbo, Italy: GENIMPACT project: Evaluation of genetic impact of aquaculture activities on native populations, pp. 1-6. Available at : http://www.imr.no/genimpact/filarkiv/2006/01/atlantic_cod_leaflet.pdf/en [Accessed 27 February 2015]

Johansson, D., Juell, J.K., Oppedal, F., Stiansen, J.E., Ruohonen, K., (2007). The influence of the pycnocline and cage resistance on current flow, oxygen flux and swimming behaviour of Atlantic salmon (*Salmo salar* L.) in production cages. Aquaculture, [e-journal] Volume 265, pp. 271-287. Available through: ScienceDirect website http://dx.doi.org/10.1016/j.aquaculture.2006.12.047 [Accessed 27 January 2015]

Johansson, D., Ruohonen, K., Kiessling, A., Oppedal, F., Stainsen, J.K., Kelly, M., Juell, J.K., (2006). Effect of environmental factors on swimming depth preferences of Atlantic Salmon (Salmo salar L.) and temporal and spatial variations in oxygen levels in sea cages at a fjord site. Aquaculture, [e-journal] Volume 254, pp. 294-605. Available through: ScienceDirect website: http://dx.doi.org/10.1016/j.aquaculture.2005.10.029 [Accessed 27 January 2015]

Jones, A., (1984). Does cod farming have a commercial future? A technical and economic assessment. In: E. Dahl, D. S. Danielssen, E. Moksness and P. Solemdal, eds. The Propagation of Cod Gadus morhua L.. [pdf] Norway: Institute Marine Research. Flodevigen Biological Station, pp. 773-785. Available at: http://brage.bibsys.no/imr/bitstream/URN:NBN:no-bibsys_brage_6379/1/773-786.pdf [Accessed 27 January 2015]

Kapetsky, J. M., Aguilar-Manjarrez, J. and Jeness, J., (2013). A global assessment of potential for offshore mariculture development from a spatial perspective. FAO Fisheries and Technical Paper, [pdf] Volume 549, p. 181. Available at :http://www.fao.org/docrep/017/i3100e/i3100e.pdf [Accessed 28 January 2015]

Kittaka, J., (1994). Culture of phyllosomas of spiny lobster and its application to studies of larval recruitment and aquaculture. Crustaceana, vol. 66, no. 3, 257-270

Kittaka, J., (2000). Culture of larval spiny lobsters. In: Spiny Lobsters: fisheries and culture, 2 edn (eds B.F. Phillips& J. Kittaka) pp. 508-532. Fishing News Books, Oxford, UK.

Kittaka, J. & Ikegami, E., (1988). Culture of the Palinurid *Palinurus elephas* from egg stage to puerulus. Nippon Suisan Gakkaishi, 54, 1149-1154

Kristiansen, T.S., Stien, L.H., Fosseidengen, J.E., Strand, E., Juell, J.E. (2011). Voluntary responses and limits of tolerance to pressure reduction and swimbladder expansion in farmed Atlantic cod. Aquaculture International, 19:625-636.

Laing, I., (2002). Scollop cultivation in the UK: a guide to site selection, [pdf] Lowestoft: Centre for Fisheries, Environment and Aquaculture Science (Cefas) . Available at:http://www.cefas.defra.gov.uk/publications/files/scallop_cultivation.pdf [Accessed 20 January 2015]

Laing, I., Lees, D. N., Page, D. J. and Henshilwood, K., (2004). Research on shellfish cultivation: A synopsis of research funded by the Department for Environment Food and Rural Affairs (Defra) between 1990 and 2003. Science Series Technical Report No.122,[pdf] Lowestoft: Cefas. Available at:http://www.cefas.defra.gov.uk/publications/techrep/tech122.pdf [Accessed 20 January 2015]

Laing, I. and Spencer, B. E., (2006). Bivalve cultivation: criteria for selecting a site. Science Series Technical Report no.136. [pdf] Weymouth: Centre for Fisheries, Environment and Aquaculture Science (Cefas). Available at: http://www.cefas.co.uk/publications/techrep/techrep136.pdf [Accessed 20 January 2015]

Lake, N. (2006). European marine sites and current impact of environmental appropriate assessments on the management and operation of commercial fishing and aquaculture activities. Report for the Sea Fish Industry Authority, March 2006, Seafish, Grimsby, 41 pp.

Lynch, S.A, Abollo, E., Ramilo, A., Cao, A., Culloty, S.C., Villalba, A. (2010). Observations raise the question if the Pacific oyster, *Crassostrea gigas*, can act as either a carrier or a reservoir for *Bonamia ostreae* or *Bonamia exitiosa*. Parasitology, 137, 1515-1526.

Marine Scotland Science, (2012). Locational Guidelines for the Authorisation of Marine Fish Farms in Scottish Waters, [pdf] Edinburgh: The Scottish Government. Available at: http://www.scotland.gov.uk/Resource/0041/00411563.pdf {accessed 25January]

Marine Scotland (2013). Developing the socio-economic evidence base for offshore renewable sectoral marine plans in Scottish Waters. Final Report. A report by ABP Marine Environmental Research Ltd, and RPA, Report R.2045, June 2013.

Matsuda, H., Yamakawa, T.Y., (2000). The complete development and morphological changes of larval Panulirus longipes (Decapoda, Palinuridae) under laboratory conditions. Fish. Sci.,66:278-293

Mee L. (2006). Complementary Benefits of Alternative Energy: Suitability of OWFs as Aquaculture Sites. Inshore Fisheries and Aquaculture Technology Innovation and Development, Seafish Project Ref: 10517, University of Plymouth Marine Institute.

Michler-Cieluch T., Krause G. (2008). Perceived concerns and possible management strategies for governing 'wind farm-mariculture integration'. Marine Policy 32: 1013-1022.

Michler-Cieluch, T., Krause, G. and Buck, B.H. (2009). Marine aquaculture within offshore wind farms: Social aspects of multiple use planning. GAIA - Ecological Perspectives for Science and Society, Vol. 18(2), pp. 158-162.

MMO, (2013a). Future trends in Fishing and Aquaculture in the South Inshore and Offshore Marine Plan Areas. A report produced for the Marine Management Organisation, pp 257. MMO Project No: 1051. ISBN: 978-1-909452-20-6.

MMO, (2013b). Spatial trends in aquaculture potential in the South and East Inshore and Offshore Marine Plan Areas. A report produced for the Marine Management Organisation, pp 202. MMO Project No: 1040. ISBN: 978-1-909452-18-3.

MMO, (2013c). Economic baseline assessment of the South Coast. A report produced for the Marine Management Organisation by Eunomia Research & Consulting Ltd, pp 125. MMO Project No: 1050. ISBN: 978-1-909452-13-8.

MMO, (2013d). Social impacts of fisheries, aquaculture, recreation, tourism and marine protected areas (MPAs) in marine plan areas in England. A report produced for the Marine Management Organisation, pp 192. MMO Project No: 1035. ISBN: 978-1-909452-19-0.

MMO, (2013e). Potential for co-location of activities in marine plan areas. A report produced for the Marine Management Organisation, pp 98. MMO Project No: 1010. ISBN: 978-1-909452-08-4.

MMO, (2014). Social Impacts and Interactions Between Marine Sectors. A report produced for the Marine Management Organisation, pp 273. MMO Project No: 1060. ISBN: 978-1-909452-30-5.

Nehls, G., Witte, S., Dankers, N., Vlas, J., Quirijns, F., Kristensen, P.S., (2009). Fishery. Thematic Report No.3.3. In: H. Marencic and J. de Vlas, (Eds). Quality Status Report 2009.Waddeb Sea Ecosystemn No. 25.. [pdf] Wilhelmshaven, Germany: Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, p. 14. Available at:http://www.waddensea-secretariat.org/sites/default/files/downloads/03.3-fishery-10-03-14-rev.pdf [Accessed 21 January 2015]

Orkney Lobster Hatchery, (2012). Orkney Lobster Hatchery. [Online] Available at: http://www.orkneylobsterhatchery.co.uk/restocking.html

Ottera, H., Agnalt, A.-L. and Jorstad, K. E., (2006). Differences in spawning time of captive Atlantic cod from four regions of Norway, kept under identical conditions. ICES Journal of Marine Science, [pdf] Volume 63, pp. 216-223. Available at:
http://icesjms.oxfordjournals.org/content/63/2/216.full.pdf+html [Accessed 26 January 2015]

Phillips B.F., Melville-Smith R., Rossbach M., Cheng Y.W., Caputi N., Thomson A.W., Mills D. and Crear B., (2003), Towards establishing techniques for large scale harvesting of pueruli and obtaining a better understanding of mortality rates. Pp. 1–138 in 'Fisheries Research and Development Corporation (FRDC) Project 1998/302—Rock Lobster Enhancement and Aquaculture Subprogram'. FRDC: Canberra

Rosenberg, R., Hellman, B. and Johansson, B., (1991). Hypoxic tolerance of marine benthic fauna. Marine Ecology Progress Series, [pdf] Volume 79, pp. 127-131. Available at: http://www.int-res.com/articles/meps/79/m079p127.pdf [Accessed 26 January 2015]

Scott, D., McLeod, D., Young, J., Brown, J.,Immink, A., Bostock, J., (2010). A study of the prospects and opportunities for shellfish farming in Scotland. Study funded by Marine Scotland., [pdf] Stirling: Stirling Aquaculture. Available at: http://www.scotland.gov.uk/Resource/Doc/295194/0118352.pdf [Accessed 26 January 2015]

Seafish, (2002). The Cod Hyperbook, [pdf] Edinburgh: Seafish. Available at: http://www.seafish.org/media/publications/cod_hyperbook_show_print_comp.pdf [Accessed 20 January 2015]

Selwyn's Penclawdd Seafoods, (2015). Selwyn's Penclawdd Seafoods website: Crispy Seaweed. Available online at: http://www.selwynsseafoods.co.uk/Crispy%20Seaweed.html

Spencer, B., (2002). 11. Criteria for selecting a site for bivalve cultivation. In: Molluscan Shellfish Farming. [e-journal] Oxford: Fishing News Books, a division of Blackwell Publishing, pp. 228-244. Available through: Wiley Online Library http://onlinelibrary.wiley.com/doi/10.1002/9780470995709.ch11/summary [Accessed 26 January 2015]

Stevenson, P., (2007). Closed Waters: The welfare of farmed Atlantic salmon, rainbow trout, Atlantic cod and Atlantic halibut, [pdf] Surrey: Compassion in World Farming and World Society for the Protection of Animals. Available at: http://www.ciwf.org.uk/includes/documents/cm_docs/2008/c/closed_waters_welfare_of_farmed_atlantic_salmon.pdf [Accessed 20 January 2015]

Syvret, M., FitzGerald, A., Gray, M., Wilson, J., Ashley, M. and Ellis Jones, C., (2013). Aquaculture in Welsh Offshore Wind Farms: A feasibility study into potential cultivation in offshore wind farm sites. Report for the Shellfish Association of Great Britain, 250p.

Vanstaen, K. (2010). Development of an integrated fishing activity data layer for English and Welsh Waters, and development of a GIS toolbox for future inshire fishing activity data analysis. MB0106: Further development of marine pressure data layers and ensuring the socio-economic data and datalayers are developed for use in the planning of marine protected area networks. Cefas contract report C3405. Report 5 for Defra. Final.

Walsh, M. and Watson, L., (2011). Market analysis towards the further development of seaweed aquaculture in Ireland,[pdf] Dublin: Irish Fisheries Board, Bord Iascaigh Mhara.

Watson and Dring, (undated). Business Plan for the establishment of a seaweed hatchery and grow out farm. Part 2. Bord Iascaigh Mhara (Irish Sea Fisheries Board). Available online at: http://www.bim.ie/media/bim/content/publications/Business%20Plan%20fot%20the%20Establishment%20of%20a%20Seaweed%20Hatchery%20and%20Grow-out%20Farm.pdf

Watson, J. T., Sales, S., Cumming G., Fitzsimmons, S.D., Walden, J., Arthur, G., Saravanan, S., McEvory L.A., (2006). Comparison of performance of two size groups of farmed cod (*Gadus morhua* L.) juveniles following transfer to sea cages. ICES Journal of Marine Science, [pdf] Volume 63, pp. 340-345. Available at: http://icesjms.oxfordjournals.org/content/63/2/340.full.pdf [Accessed 21 February 2015]

Welsh Government, (2013). Wales Marine and Fisheries: Strategic Action Plan. November 2013. Available online at: http://gov.wales/docs/drah/publications/131127marine-and-fisheries-strategic-action-plan-en.pdf

Welsh Government, (2014a). Marine and Fisheries Strategic Action Plan: Update. Available online at: http://gov.wales/docs/drah/publications/140702marineandfisheriesstrategicactionplanupdateen.pdf

Welsh Government, (2014b). Welsh Government website: Several Orders in Wales. Last updated 04 July 2014. Available online at: http://gov.wales/docs/drah/publications/131127marine-and-fisheries-strategic-action-plan-en.pdf [accessed March 2015].

Welsh Government, (2014c). Welsh Government website: Skomer Marine Conservation Zone: http://gov.wales/topics/environmentcountryside/fisheries/marine/conservation/protected/skomermarineconservationzone/?lang=en [accessed March 2015].

Werner, A., Clarke, D. and Kraan, S., (2004). Strategic review of the feasibility of seaweed aquaculture in Ireland, [Online] Galway: Marine Institute. Available at: http://hdl.handle.net/10793/327 [Accessed 25 January 2015]

Werner, A. and Dring, M., (2011). Aquaculture explained no.27. Cultivating Palmaria palmata, [pdf] Dublin: Irish Fisheries Board, Bord Iascaigh Mhara (BIM). Available at: http://www.bim.ie/media/bim/content/publications/Aquaculture%20Explained%20Issue%2027%20-%20Cultivating%20Palmaria%20palmata.pdf [Accessed 25 January 2015]

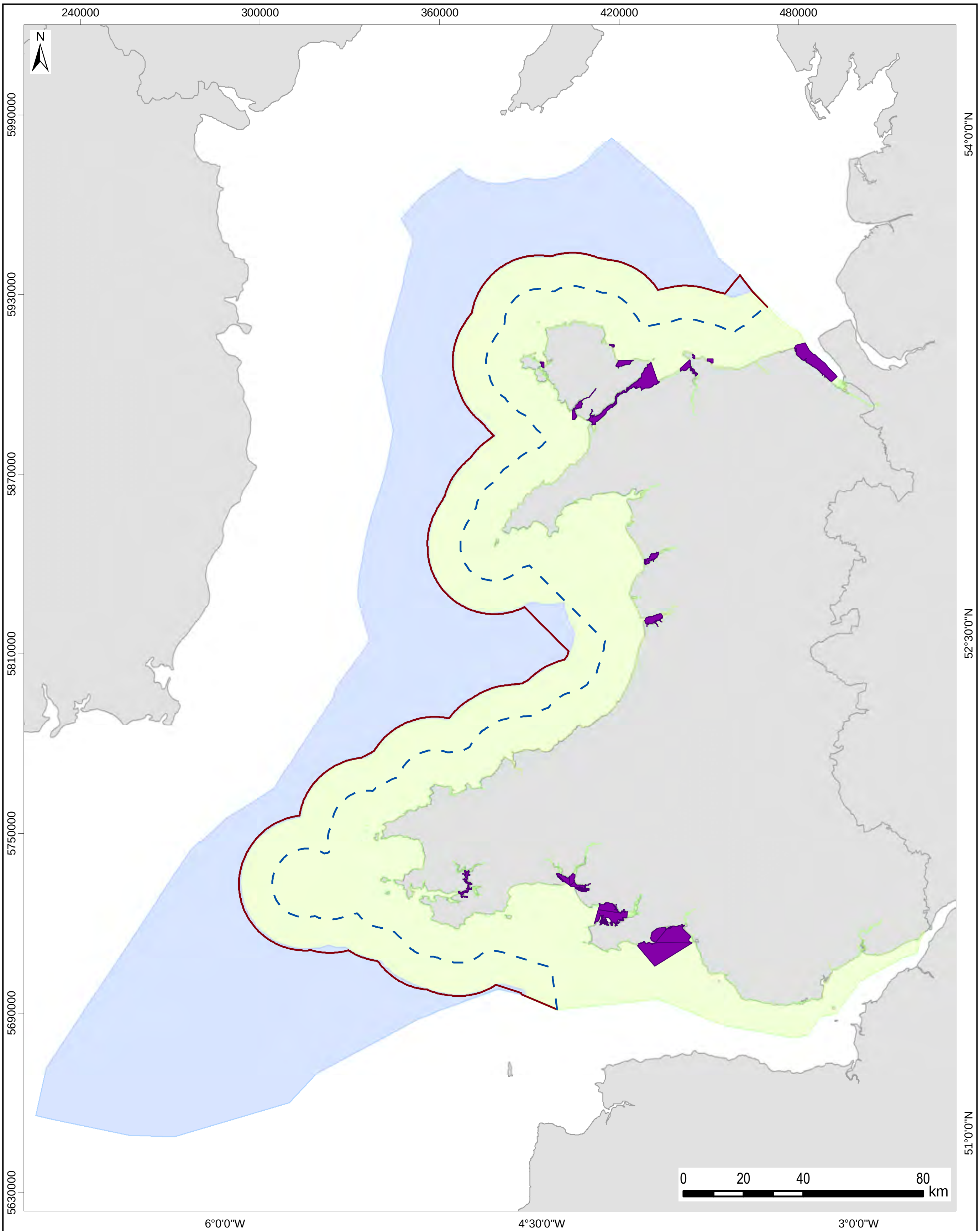
Wieland, T. and Paul, J., (1983). Potential for Scallop Cultivation in the UK. A joint report by the Industrial Development Unit and the Marine Fish Farm at Ardtoe. Technical Report No.224, [pdf] Edinburgh: Sea Fish Industry Authority Industrial Development Unit. Available at: http://www.seafish.org/media/Publications/SR224.pdf [Accessed 20 January 2015]

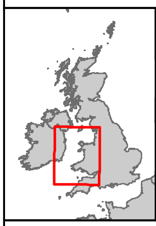
Wickens J.F., Lee, D. O'C., (2002). Crustacean Farming, Ranching and Culture. [e-book] Blackwell Science. Available through: Sainsburys e-books http://samples.sainsburysebooks.co.uk/9780470995075_sample_388324.pdf [Accessed 20 January 2015]

Woolmer, A. (2009). Appropriate Assessments & Shellfisheries: Adaptive Management Protocol. Report to Shellfish Industry Development Strategy

Woolmer, A.P., Syvret, M., Fitzgerald, A. (2011). Restoration of native oyster, *Ostrea edulis*, in South Wales: options and approaches. CCW Contract Science Report No. 960.

Figures





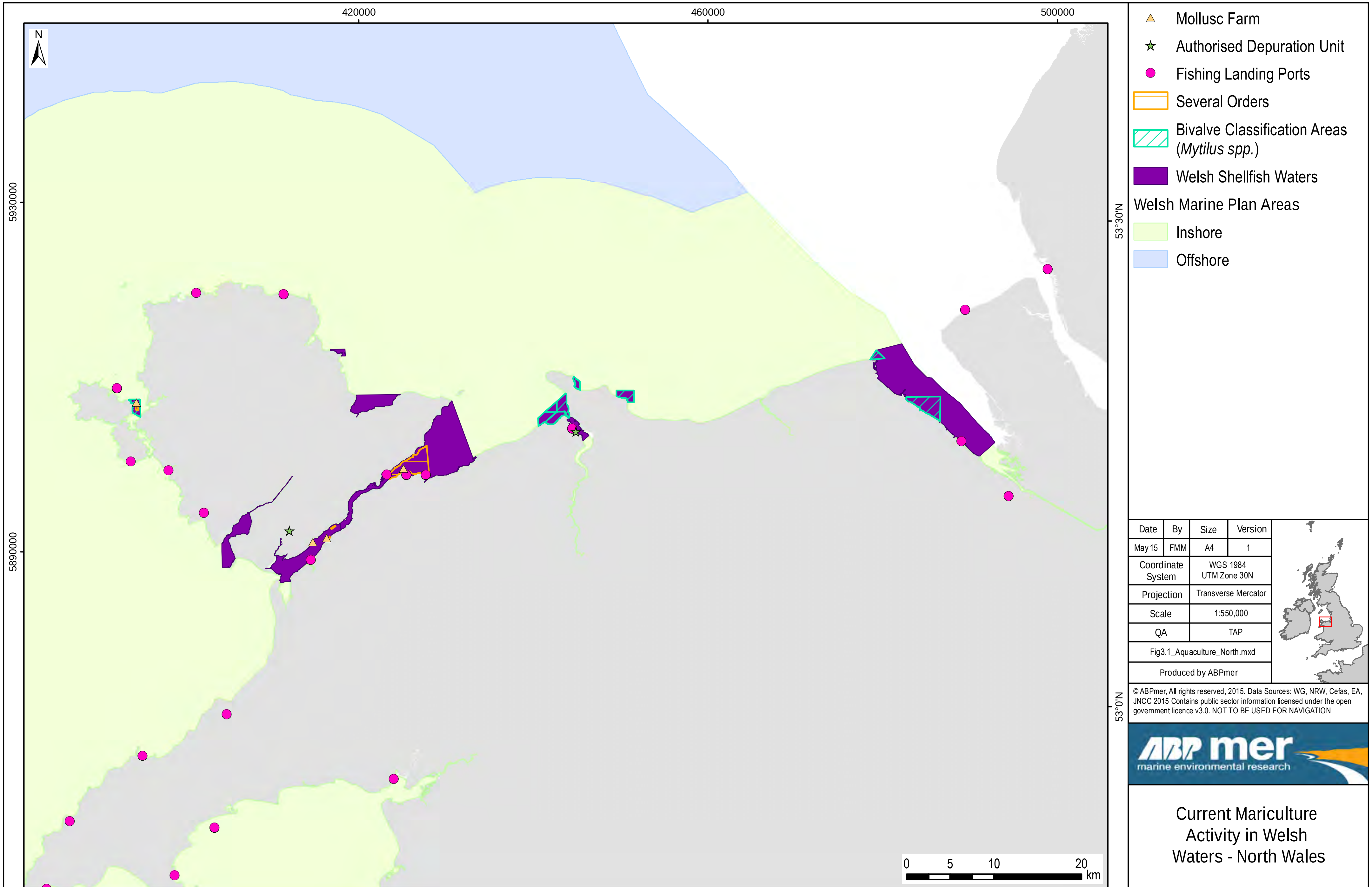
Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig1.1_Study_Area.mxd			
Produced by ABPmer			

Welsh Shellfish Waters
6 NM Limit
12 NM Limit
Welsh Marine Plan Areas
Inshore
Offshore

ABP mer marine environmental research

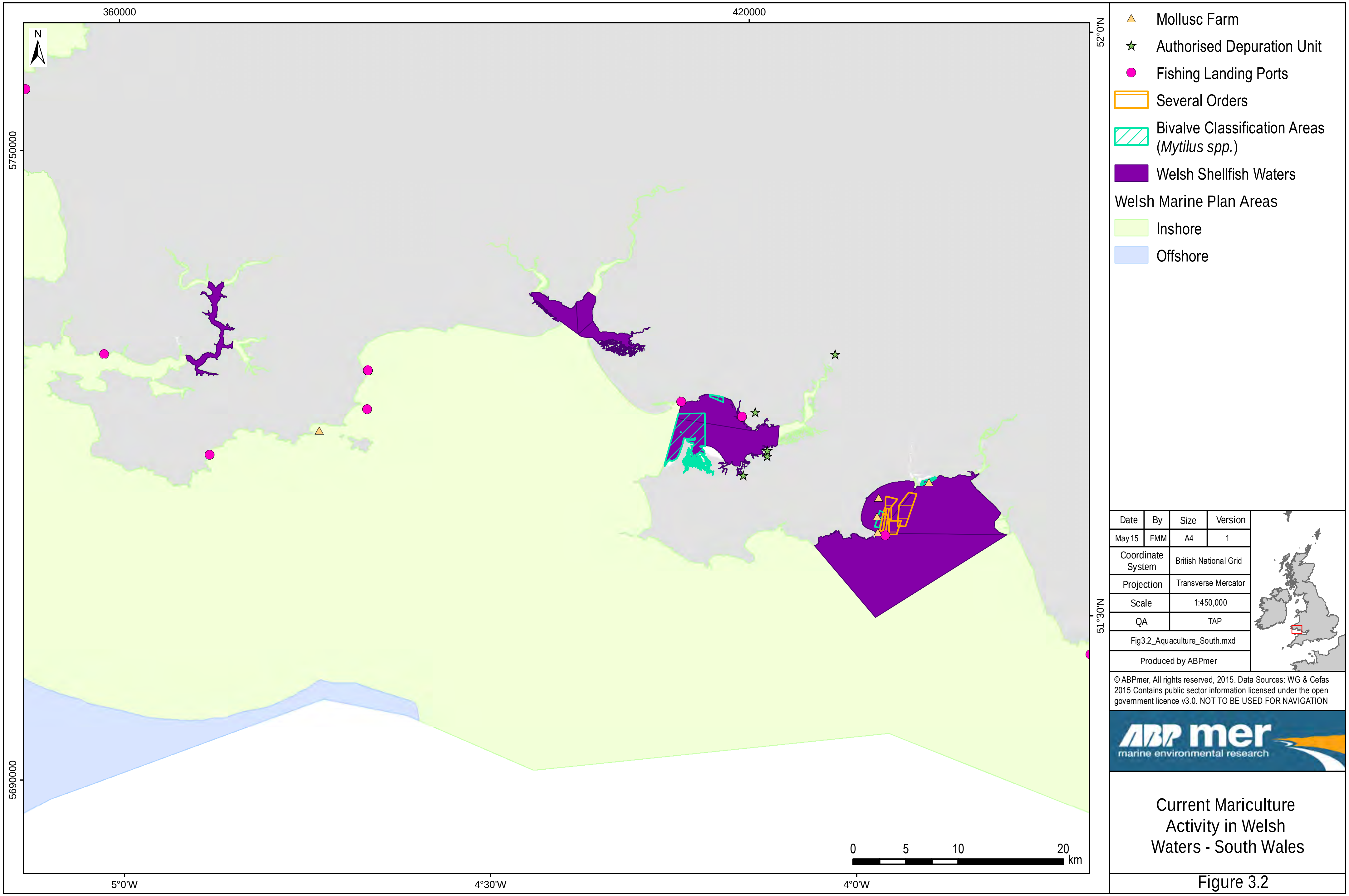
Study Area (Welsh Marine Plan Area)

Figure 1.1



N
420000
460000
500000
5930000
5890000
53°30'N
53°0'N
4°30'W
4°0'W
3°30'W
3°0'W
0
5
10
20
km
Mollusc Farm
Authorised Depuration Unit
Fishing Landing Ports
Several Orders
Bivalve Classification Areas (*Mytilus spp.*)
Welsh Shellfish Waters
Welsh Marine Plan Areas
Inshore
Offshore
Date | By | Size | Version
May 15 | FMM | A4 | 1
Coordinate System: WGS 1984 UTM Zone 30N
Projection: Transverse Mercator
Scale: 1:550,000
QA: TAP
Fig3.1_Aquaculture_North.mxd
Produced by ABPmer
© ABPmer, All rights reserved, 2015. Data Sources: WG, NRW, Cefas, EA, JNCC 2015 Contains public sector information licensed under the open government licence v3.0. NOT TO BE USED FOR NAVIGATION
marine environmental research
Current Mariculture Activity in Welsh Waters - North Wales

Figure 3.1

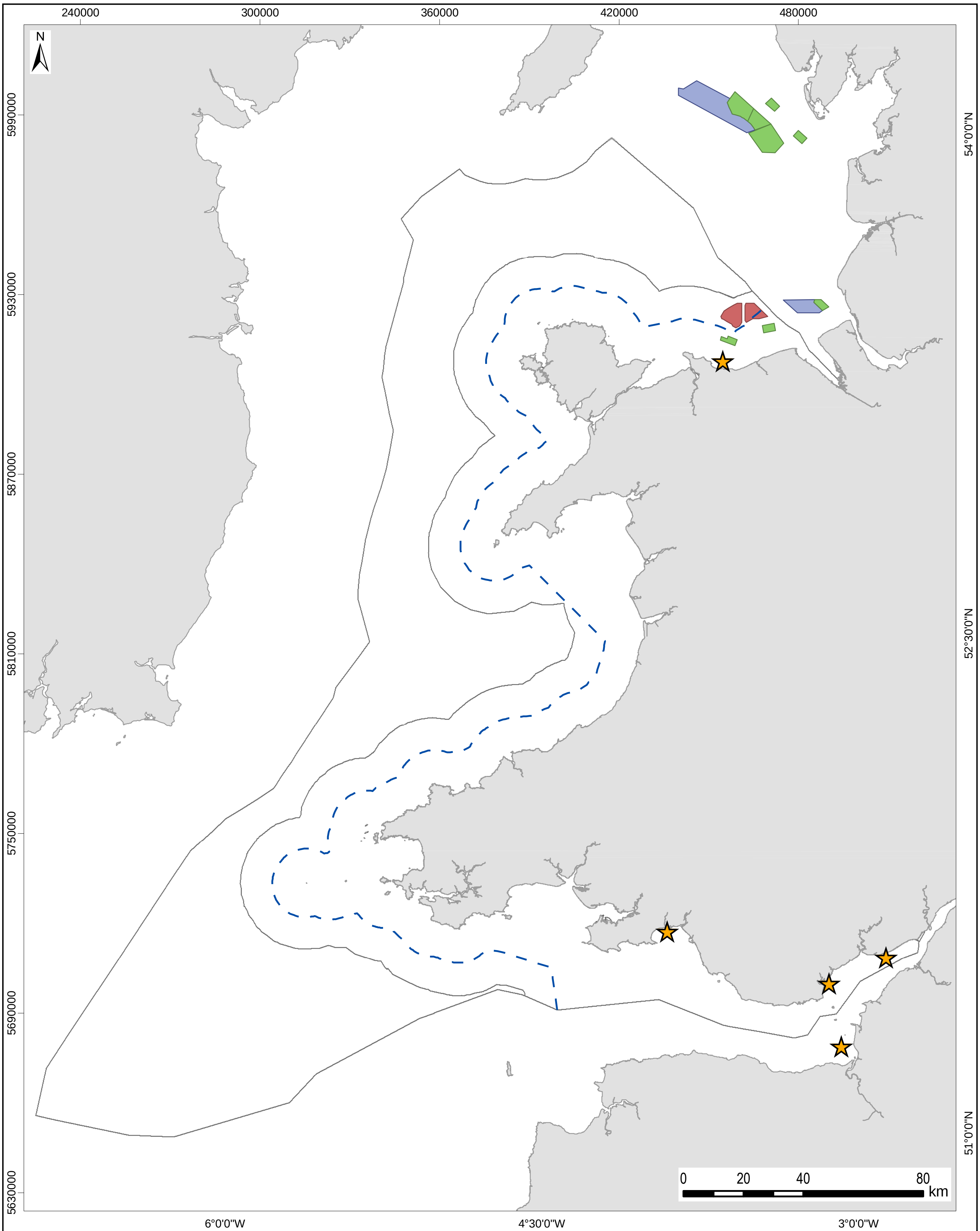


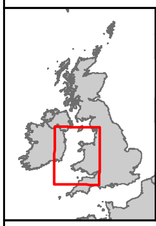
Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System	British National Grid		
Projection	Transverse Mercator		
Scale	1:450,000		
QA	TAP		
Fig3.2_Aquaculture_South.mxd			
Produced by ABPmer			

ABP mer marine environmental research

Current Mariculture Activity in Welsh Waters - South Wales

Figure 3.2





Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System	WGS 1984 UTM Zone 30N		
Projection	Transverse Mercator		
Scale	1:1,800,000		
QA	TAP		
Fig6.1_Energy.mxd			
Produced by ABPmer			

6 NM Limit

Welsh Marine Plan Areas

Potential Tidal Lagoon Location

Offshore Wind Farm Status

Consented

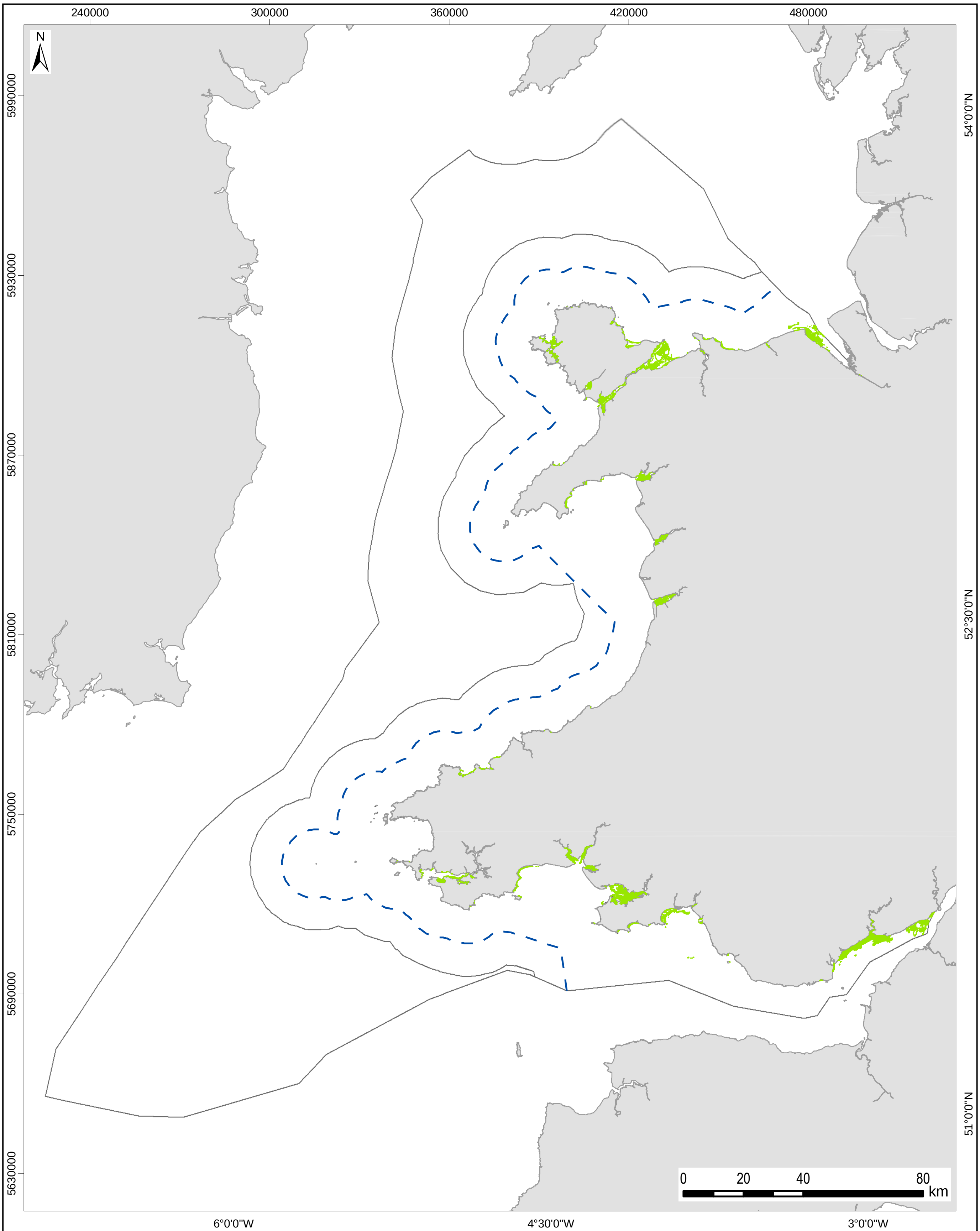
In Operation

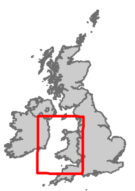
Under Construction

ABP mer marine environmental research

Location of Offshore Wind Farm Developments and Potential Tidal Lagoons

Figure 6.1





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.1_Bottom_EC_NR.mxd			
Produced by ABPmer			

Potential for Bottom Culture of European Clam

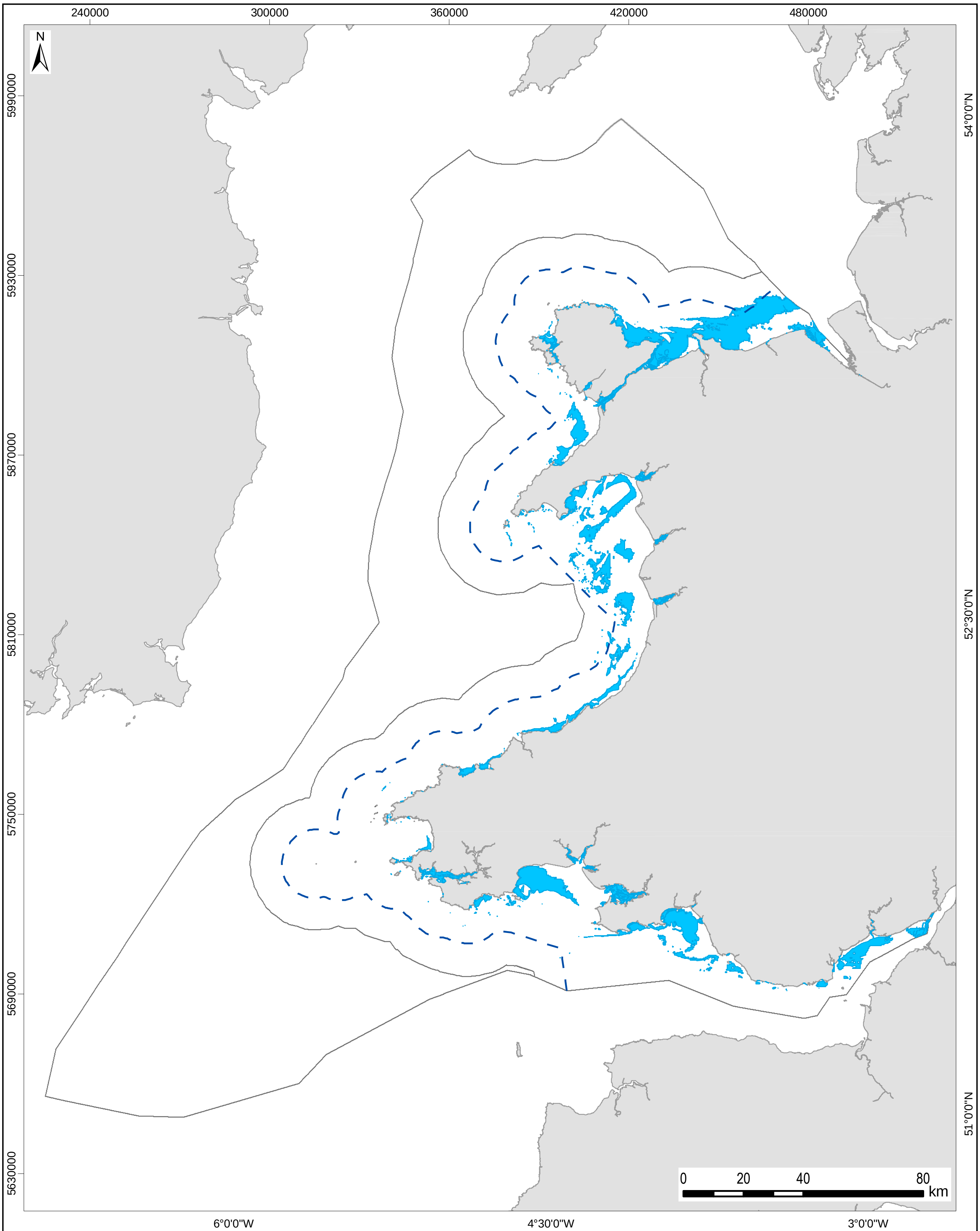
6 NM Limit

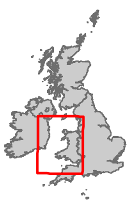
Welsh Marine Plan Areas

ABP mer marine environmental research

Areas where Natural Resources are Potentially Suitable for Bottom Culture of European Clam

Figure 8.1





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.2_Bottom_OY_NR.mxd			
Produced by ABPmer			

Potential for Bottom Culture of Oyster Species

6 NM Limit

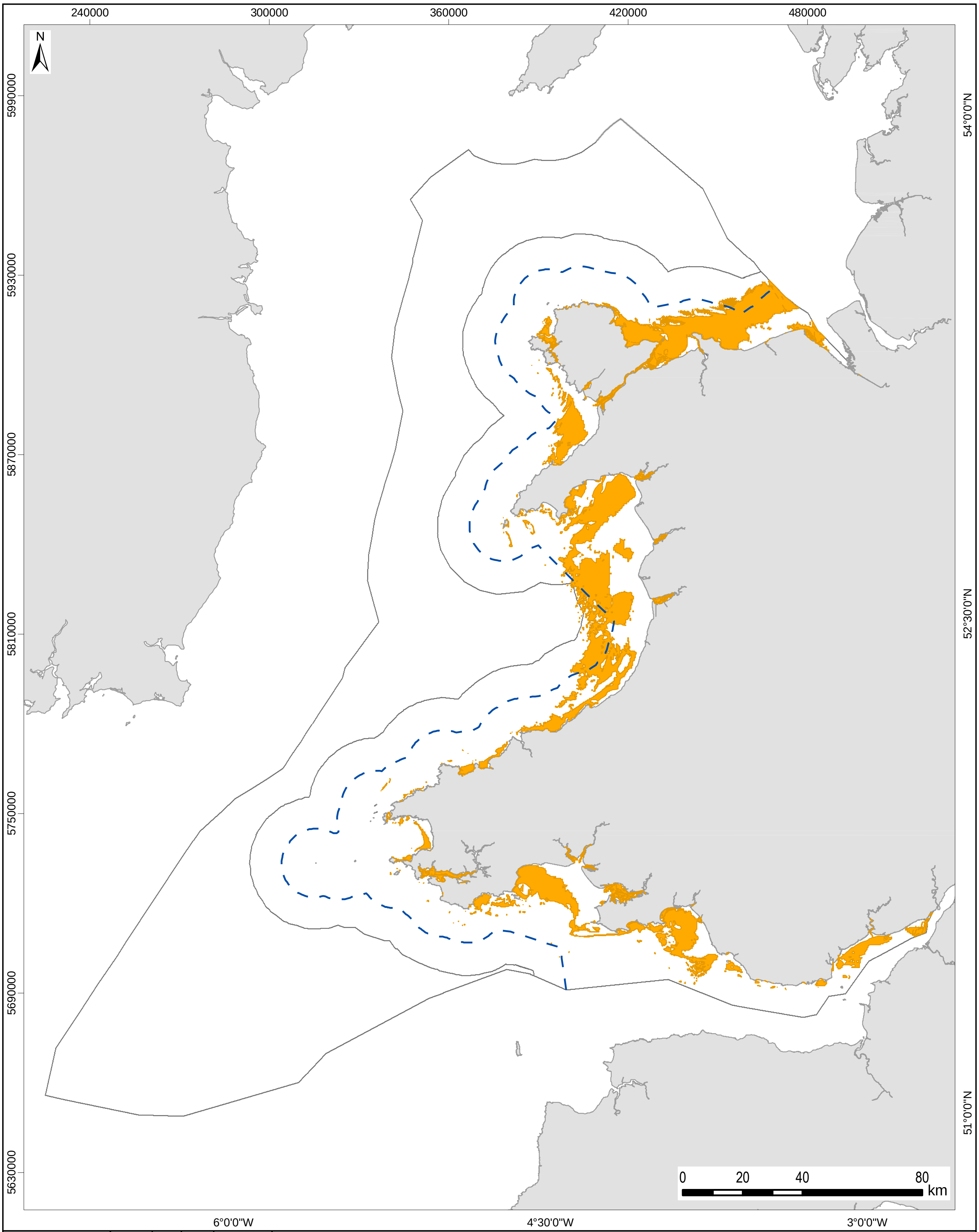
Welsh Marine Plan Areas

N.B. Oyster Species refers to Native Oyster and Pacific Oyster

ABP mer marine environmental research

Areas where Natural Resources are Potentially Suitable for Bottom Culture of Oyster Species

Figure 8.2



Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.3_Bottom_BM_NR.mxd			
Produced by ABPmer			

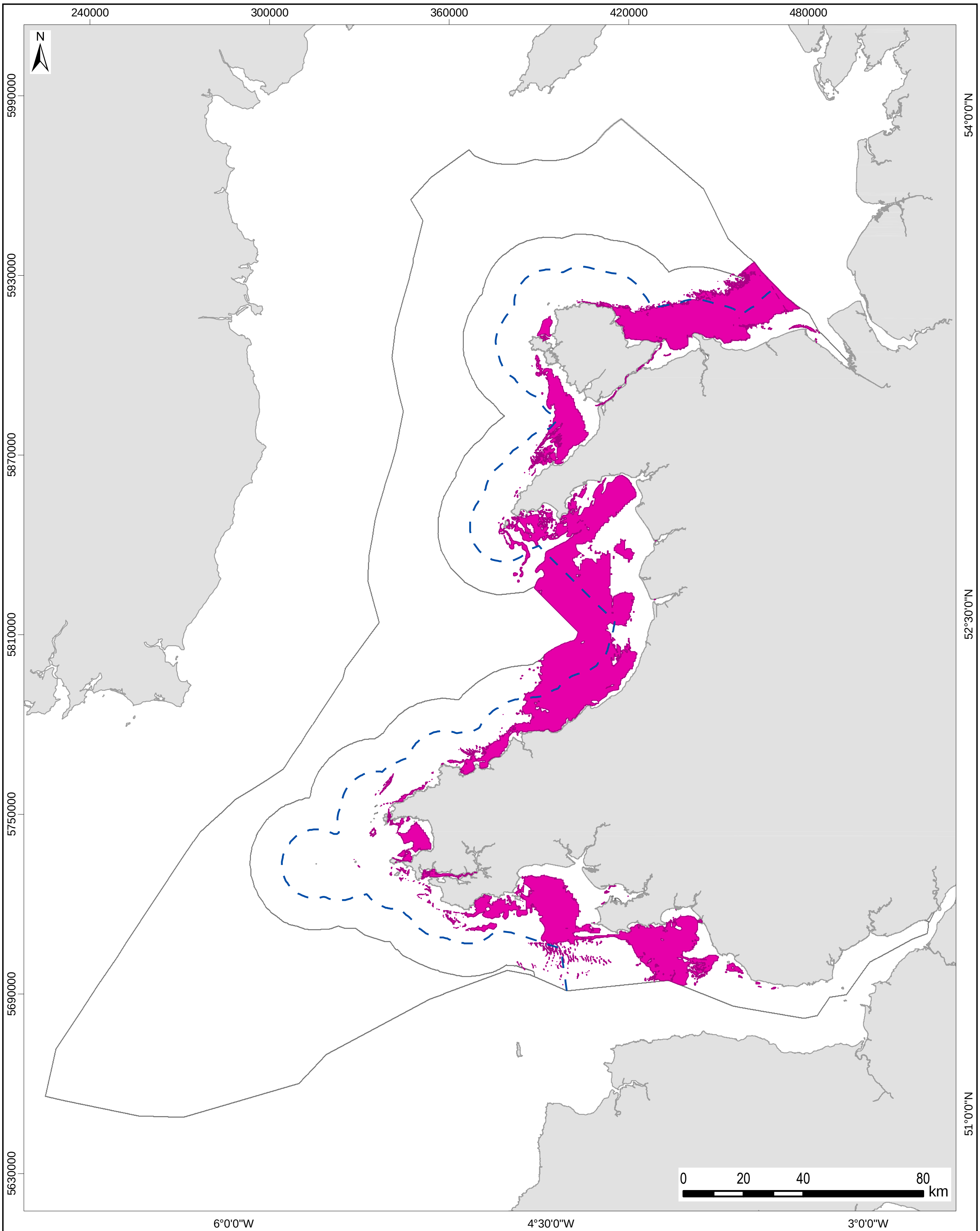
Potential for Bottom Culture of Blue Mussel

6 NM Limit

Welsh Marine Plan Areas

Areas where Natural Resources are Potentially Suitable for Bottom Culture of Blue Mussel

Figure 8.3



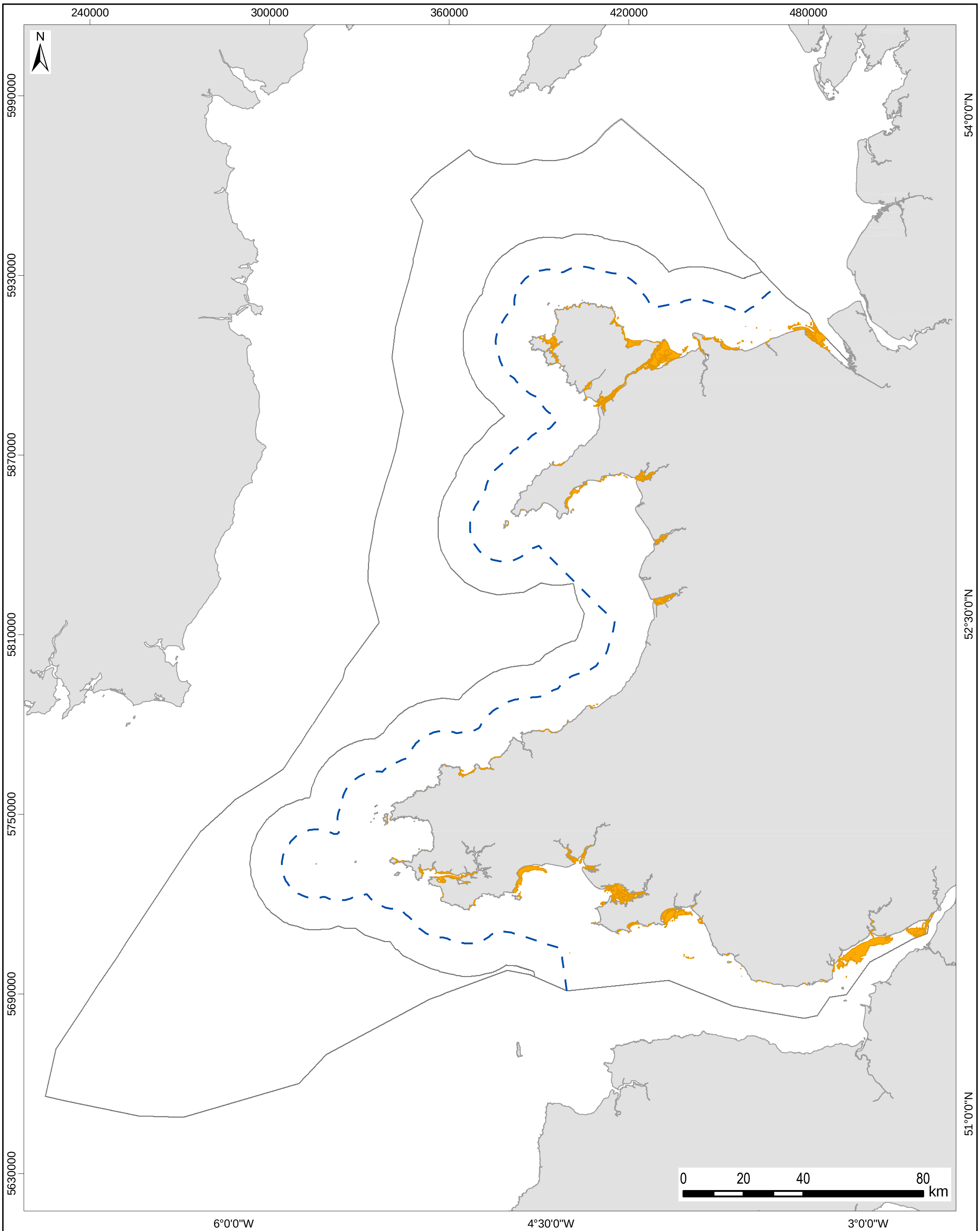
Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.4_Bottom_KS_NR.mxd			
Produced by ABPmer			

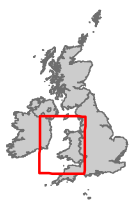
Potential for Bottom Culture of King Scallop
6 NM Limit
Welsh Marine Plan Areas

ABPmer marine environmental research

Areas where Natural Resources are Potentially Suitable for Bottom Culture of King Scallop

Figure 8.4





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.5_Trestle_SF_NR.mxd			
Produced by ABPmer			

Potential for Trestle Culture of Blue Mussel

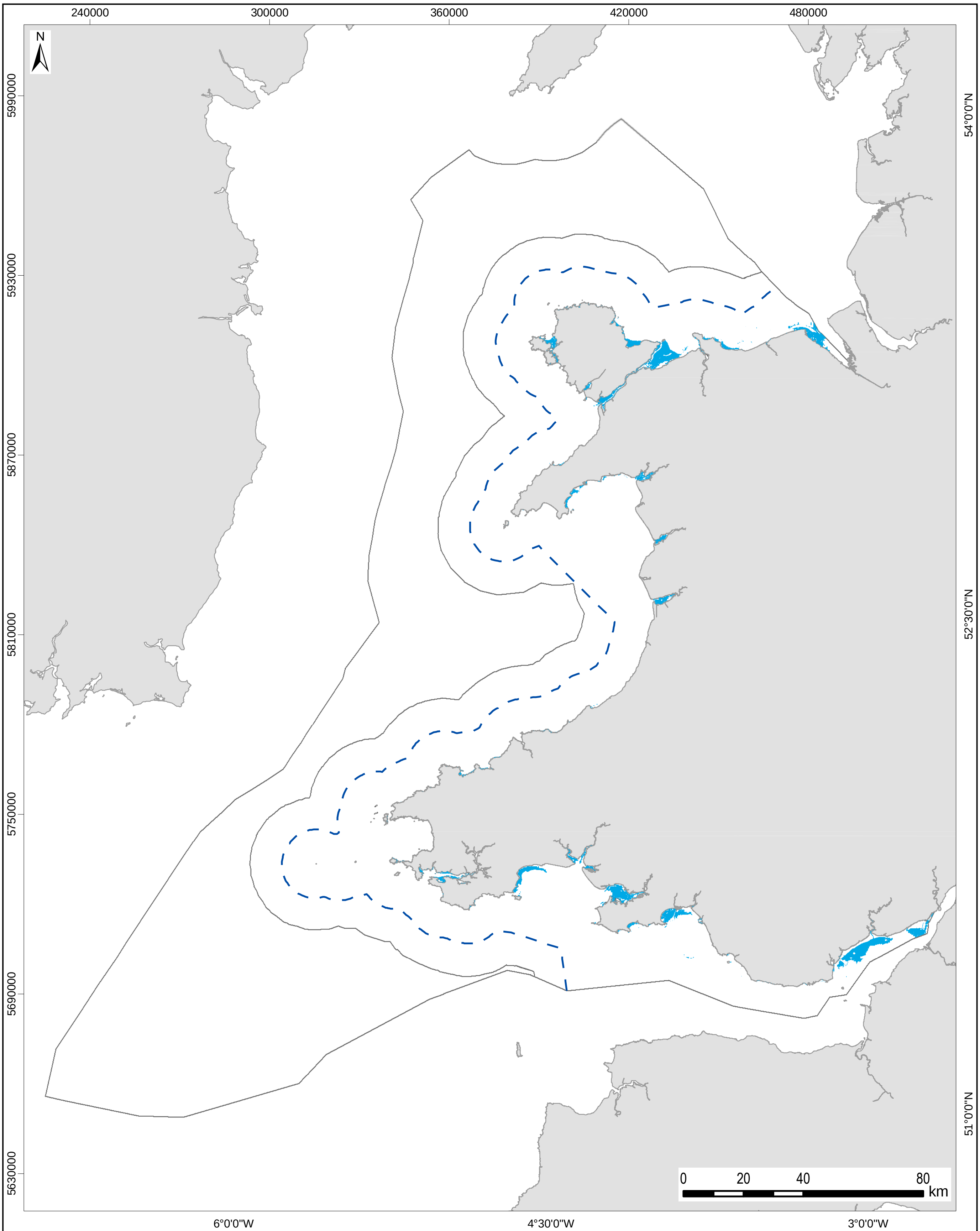
6 NM Limit

Welsh Marine Plan Areas

ABP mer
marine environmental research

Areas where Natural Resources are Potentially Suitable for Trestle/ Bag Culture of Blue Mussel

Figure 8.5



Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.6_Trestle_SF_oys_NR.mxd			
Produced by ABPmer			

Potential for Trestle Culture of Oysters

6 NM Limit

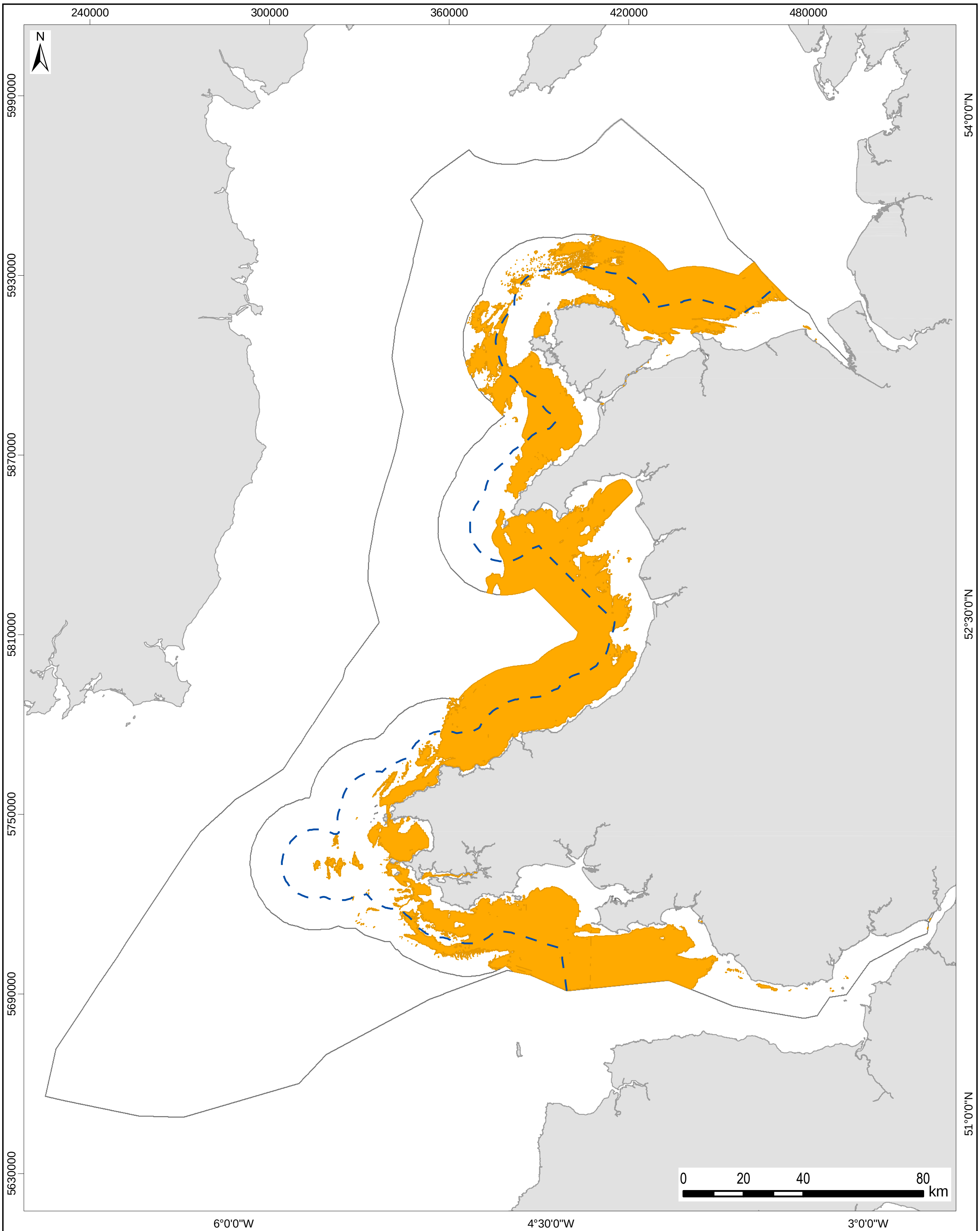
Welsh Marine Plan Areas

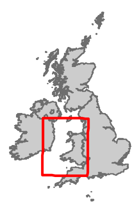
N.B. Oyster Species refers to Native Oyster and Pacific Oyster

ABP mer marine environmental research

Areas where Natural Resources are Potentially Suitable for Trestle/ Bag Culture of Oyster Species

Figure 8.6





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System	WGS 1984 UTM Zone 30N		
Projection	Transverse Mercator		
Scale	1:1,800,000		
QA	TAP		
Fig8.7_Rope_BM_NR.mxd			
Produced by ABPmer			

Potential for Rope Culture of Blue Mussel

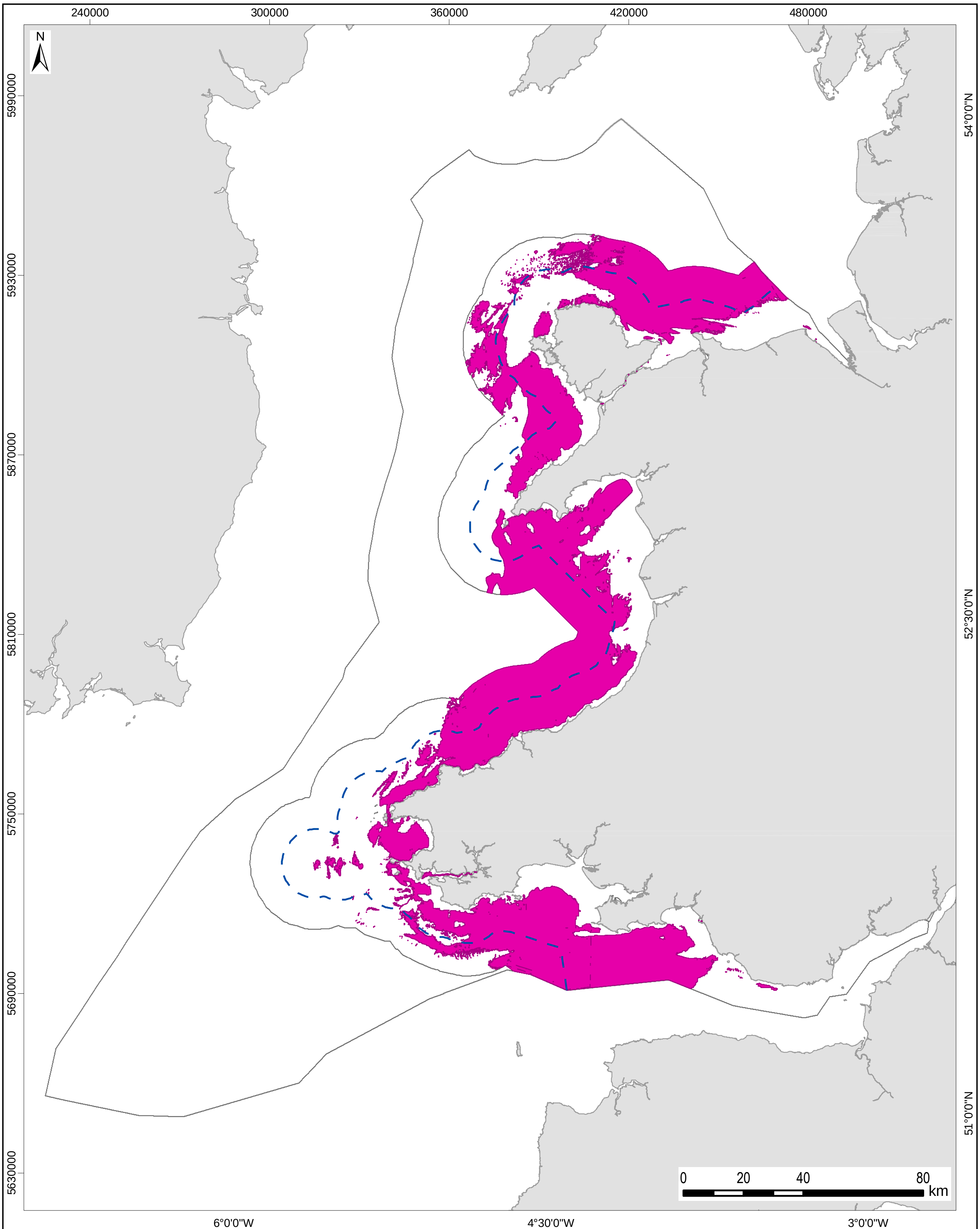
6 NM Limit

Welsh Marine Plan Areas

ABPmer marine environmental research

Areas where Natural Resources are Potentially Suitable for Rope Culture of Blue Mussel

Figure 8.7



Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.8_Rope_KS_NR.mxd			
Produced by ABPmer			

Potential for Rope Culture of King Scallop

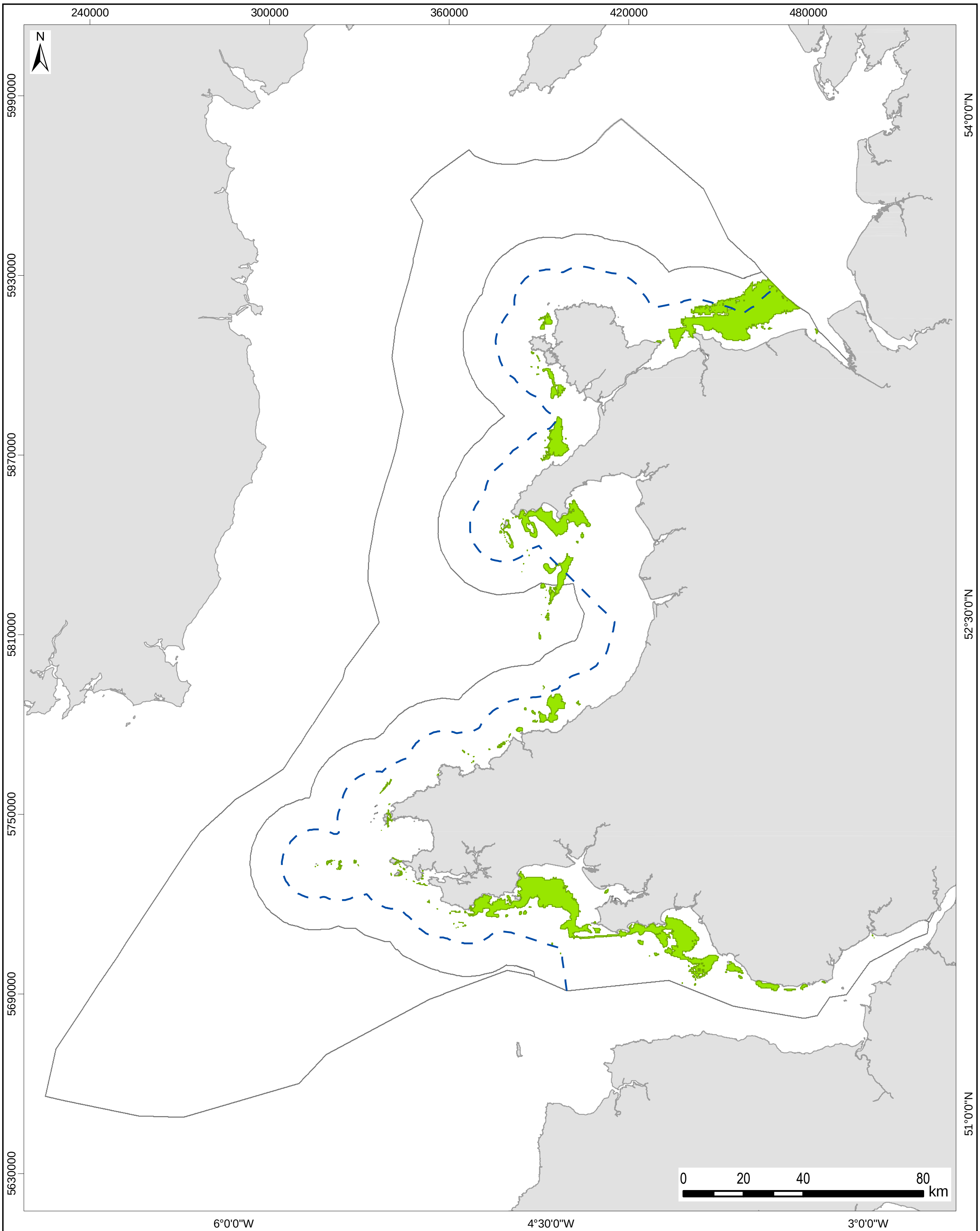
6 NM Limit

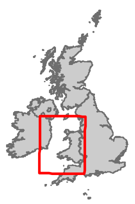
Welsh Marine Plan Areas

ABPmer marine environmental research

Areas where Natural Resources are Potentially Suitable for Rope Culture of King Scallop

Figure 8.8





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.9_Rope_MacMed_NR.mxd			
Produced by ABPmer			

Potential for Rope Culture of Moderate Exposure Tolerant Macroalgae

6 NM Limit

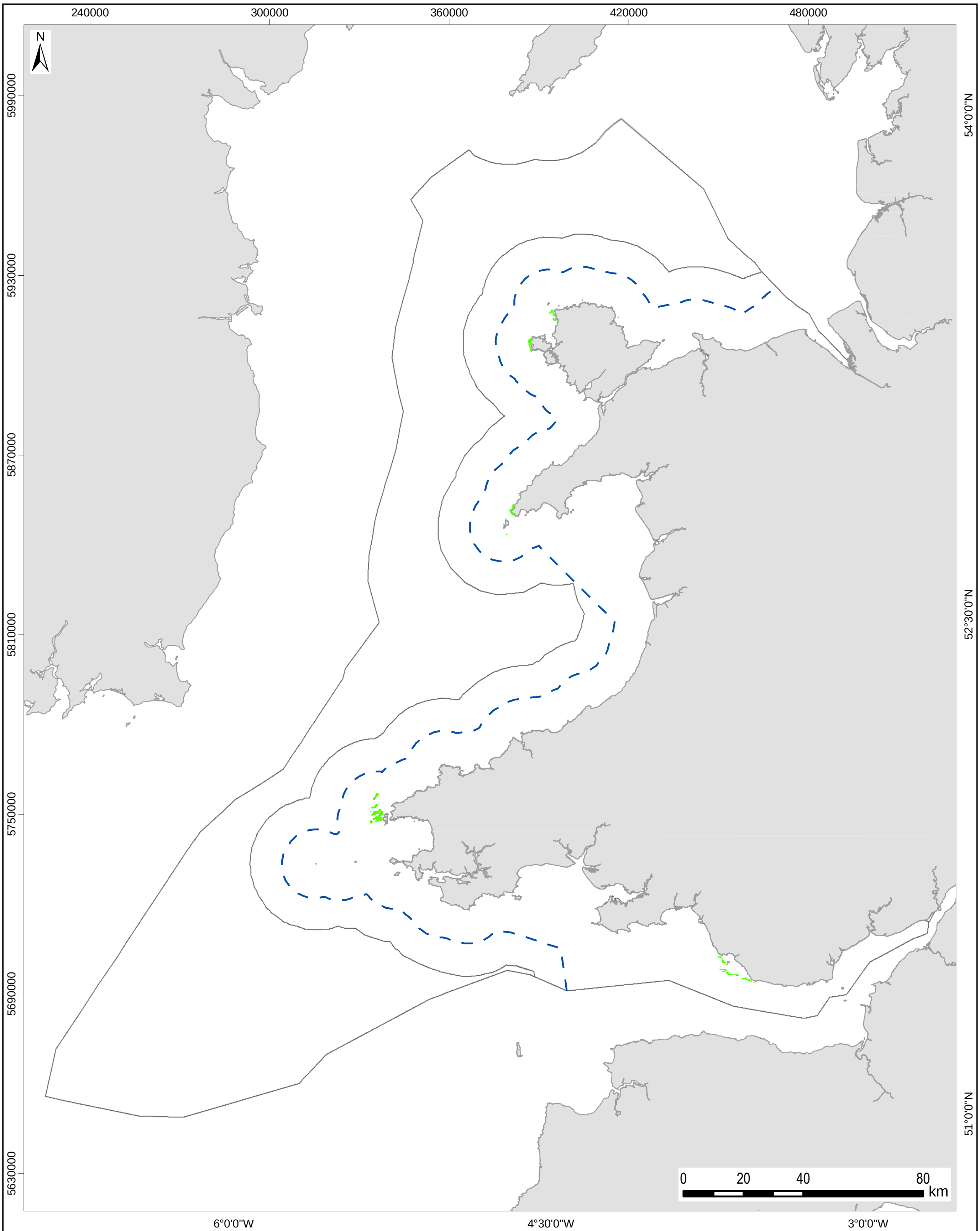
Welsh Marine Plan Areas

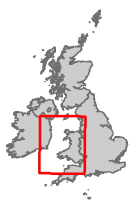
N.B. Moderate Exposure Tolerant Species refers to Kelp, Foliose Red Algae and Irish Moss

ABP mer
marine environmental research

Areas where Natural Resources are Potentially Suitable for Rope Culture of Moderate Exposure Tolerant Macroalgae Species

Figure 8.9





Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.10_Rope_MacHigh_NR.mxd			
Produced by ABPmer			

Potential for Rope Culture of High Exposure Tolerant Macroalgae

6 NM Limit

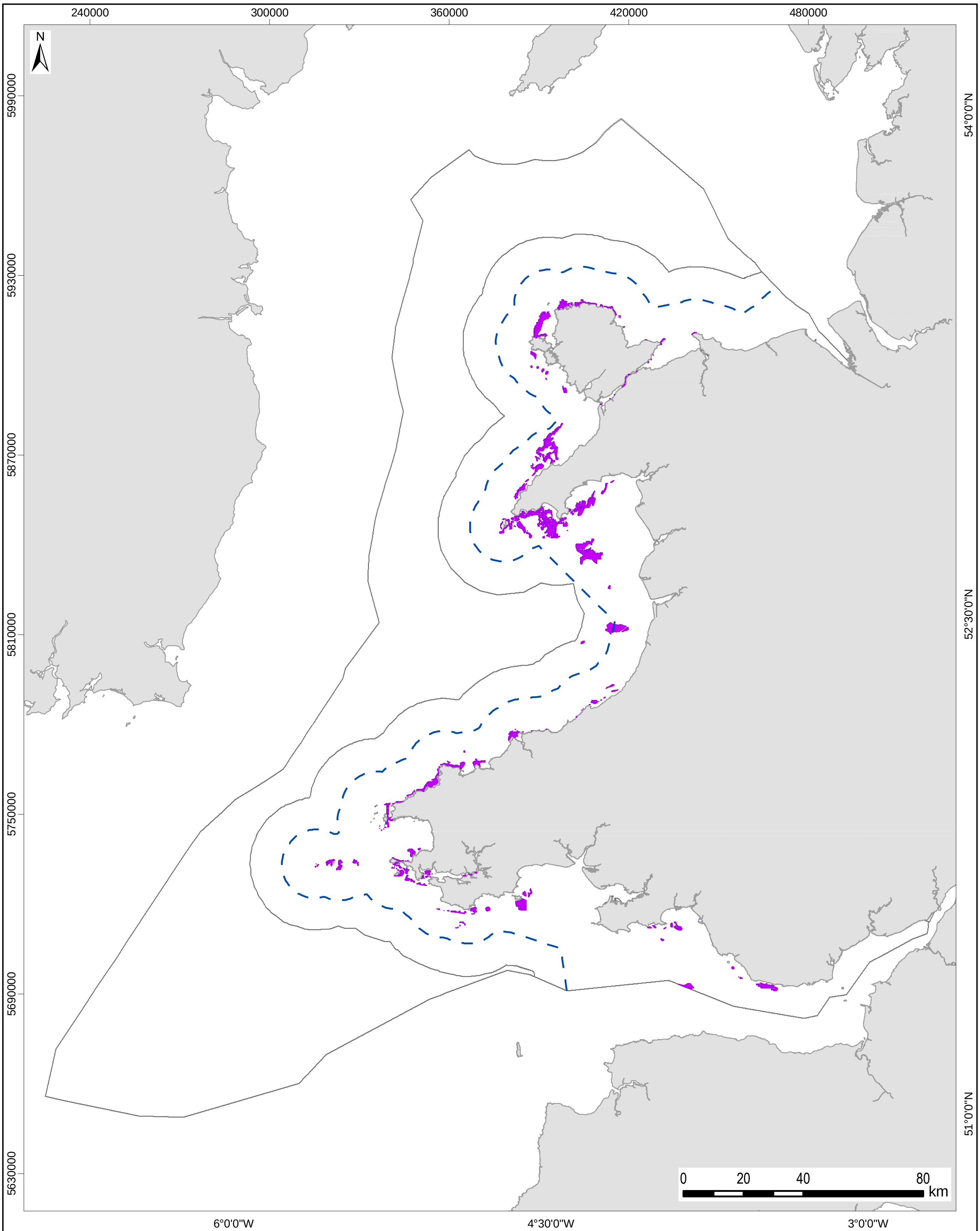
Welsh Marine Plan Areas

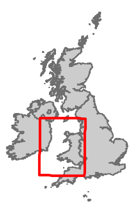
N.B. High Exposure Tolerant Species refers to Badderlock and Dulse

ABP mer marine environmental research

Areas where Natural Resources are Potentially Suitable for Rope Culture of High Exposure Tolerant Macroalgae Species

Figure 8.10





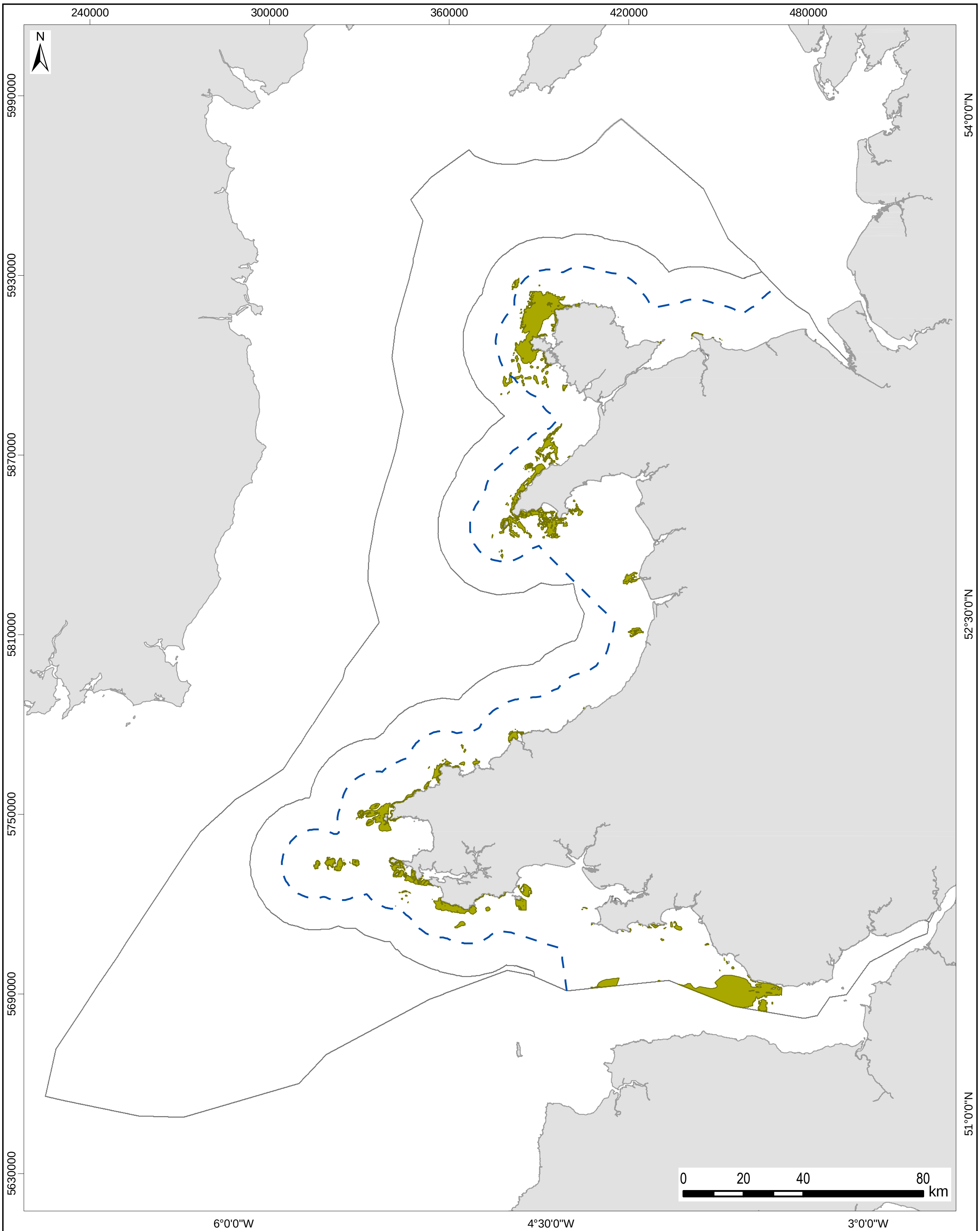
Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.11_Ranching_Lob_NR.mxd			
Produced by ABPmer			

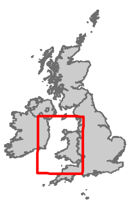
Potential for Ranching Culture of Lobster
6 NM Limit
Welsh Marine Plan Areas

ABP mer marine environmental research

Areas where Natural Resources are Potentially Suitable for Ranching of European Lobster

Figure 8.11





Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.12_Ranching_CF_NR.mxd			
Produced by ABPmer			

Potential for Ranching Culture of Crawfish

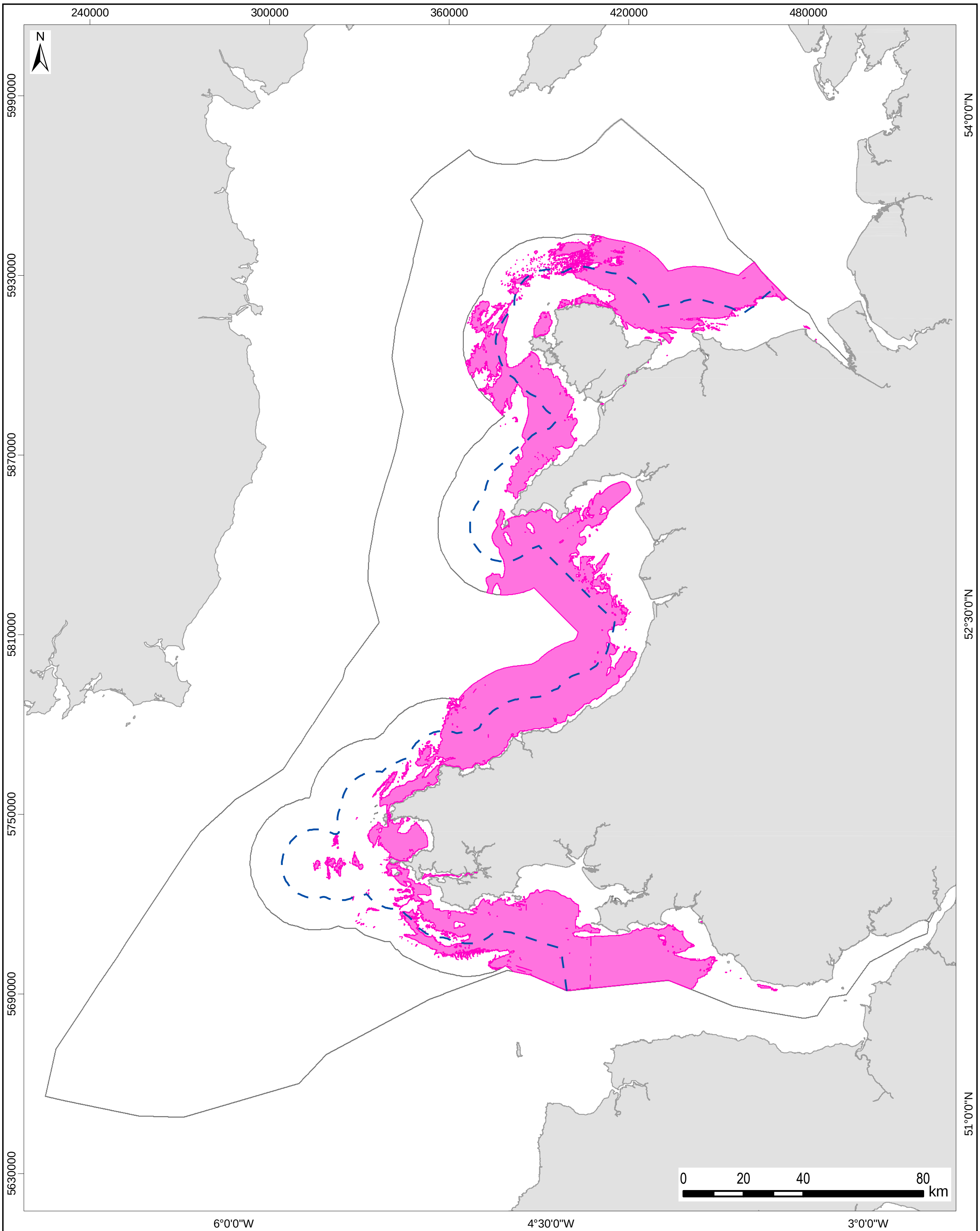
6 NM Limit

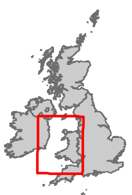
Welsh Marine Plan Areas

ABP mer marine environmental research

Areas where Natural Resources are Potentially Suitable for Ranching of Crawfish

Figure 8.12





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.13_Cage_FF_NR.mxd			
Produced by ABPmer			

Potential for Cage Culture of Salmon and Sea Trout

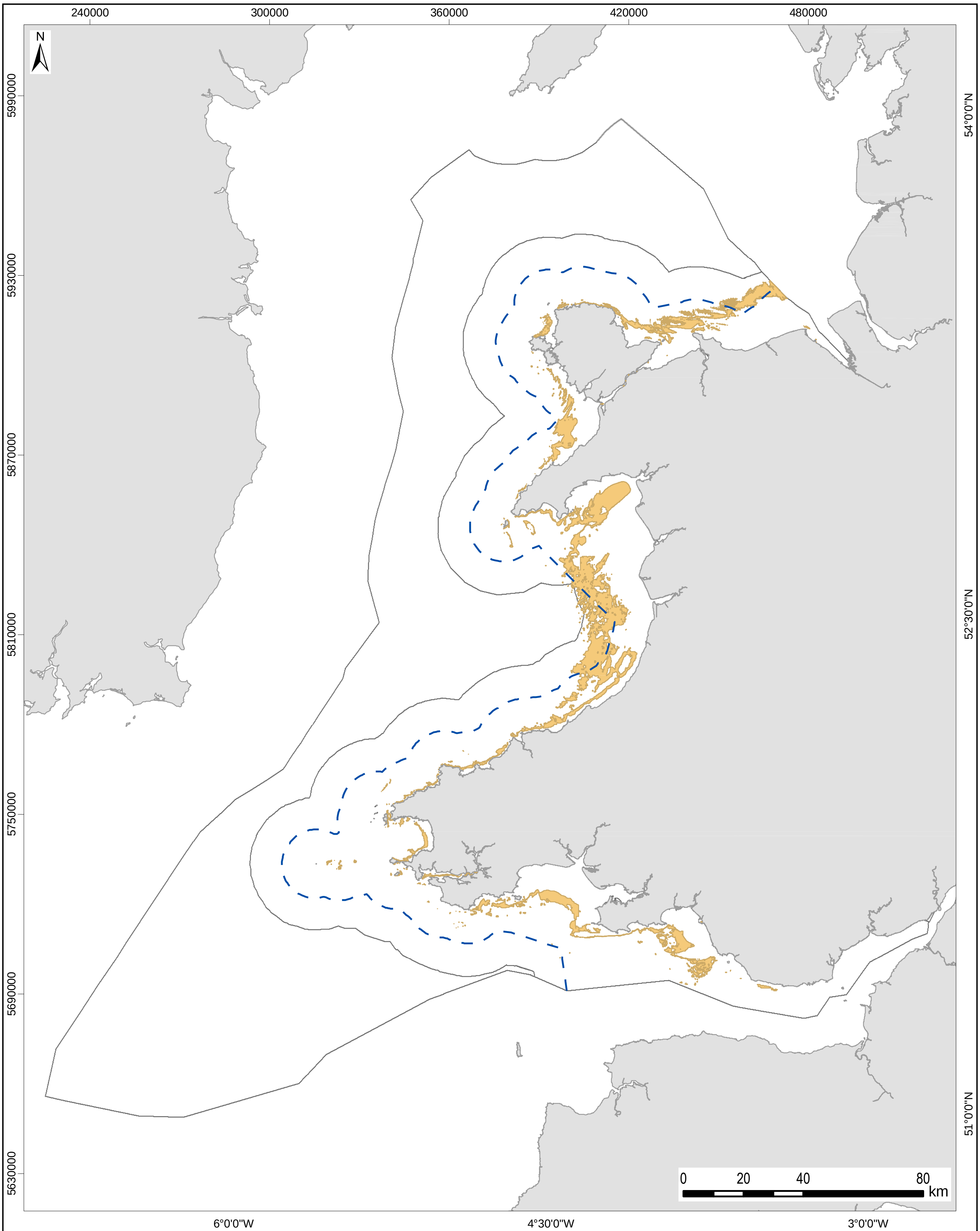
6 NM Limit

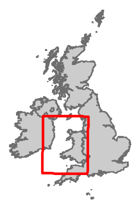
Welsh Marine Plan Areas

ABP mer marine environmental research

Areas where Natural Resources are Potentially Suitable for Cage Culture of Atlantic Salmon and Sea Trout

Figure 8.13





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System	WGS 1984 UTM Zone 30N		
Projection	Transverse Mercator		
Scale	1:1,800,000		
QA	TAP		
Fig8.14_Cage_Cod_NR.mxd			
Produced by ABPmer			

Potential for Cage Culture of Cod

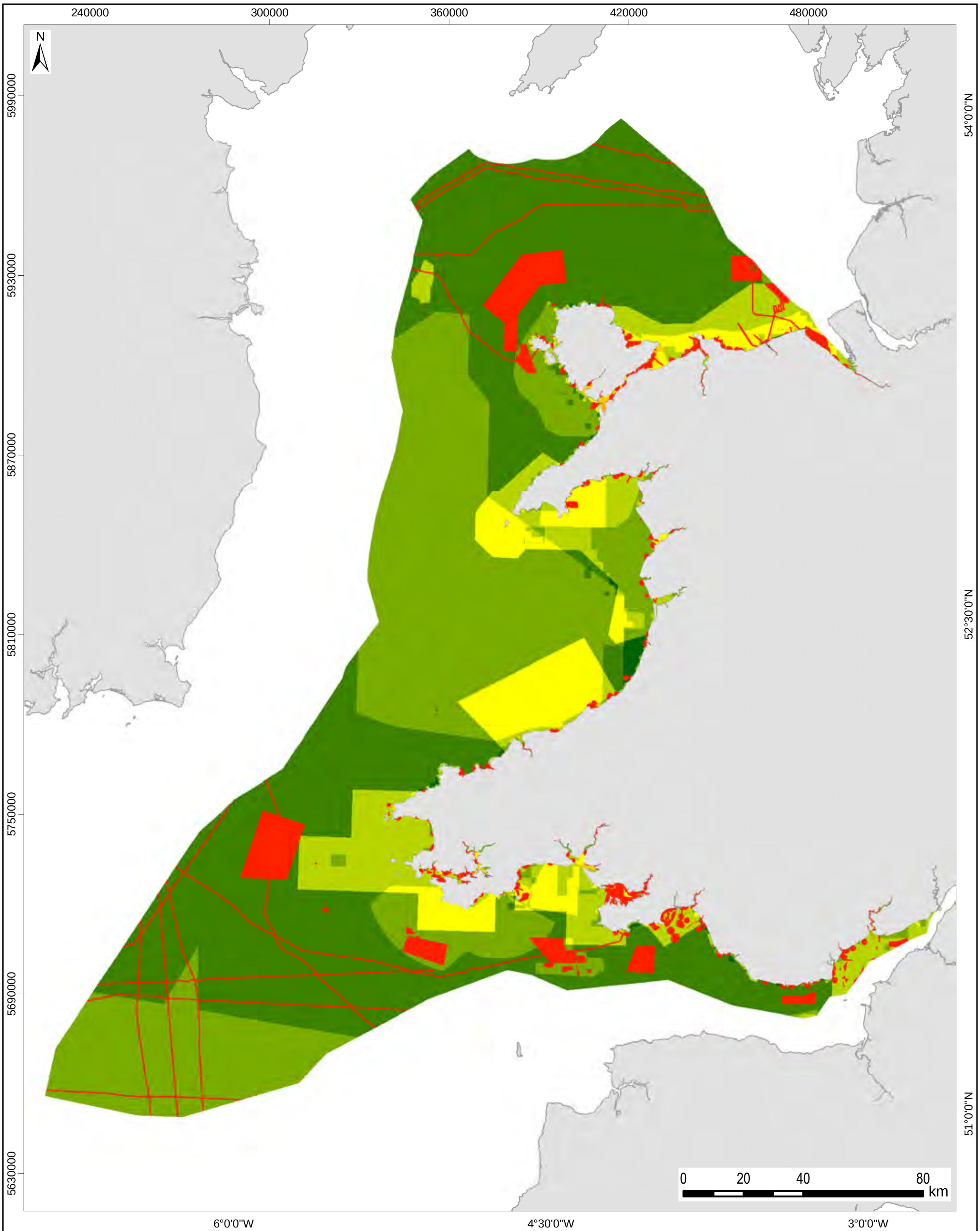
6 NM Limit

Welsh Marine Plan Areas

ABP mer marine environmental research

Areas where Natural Resources are Potentially Suitable for Cage Culture of Cod

Figure 8.14

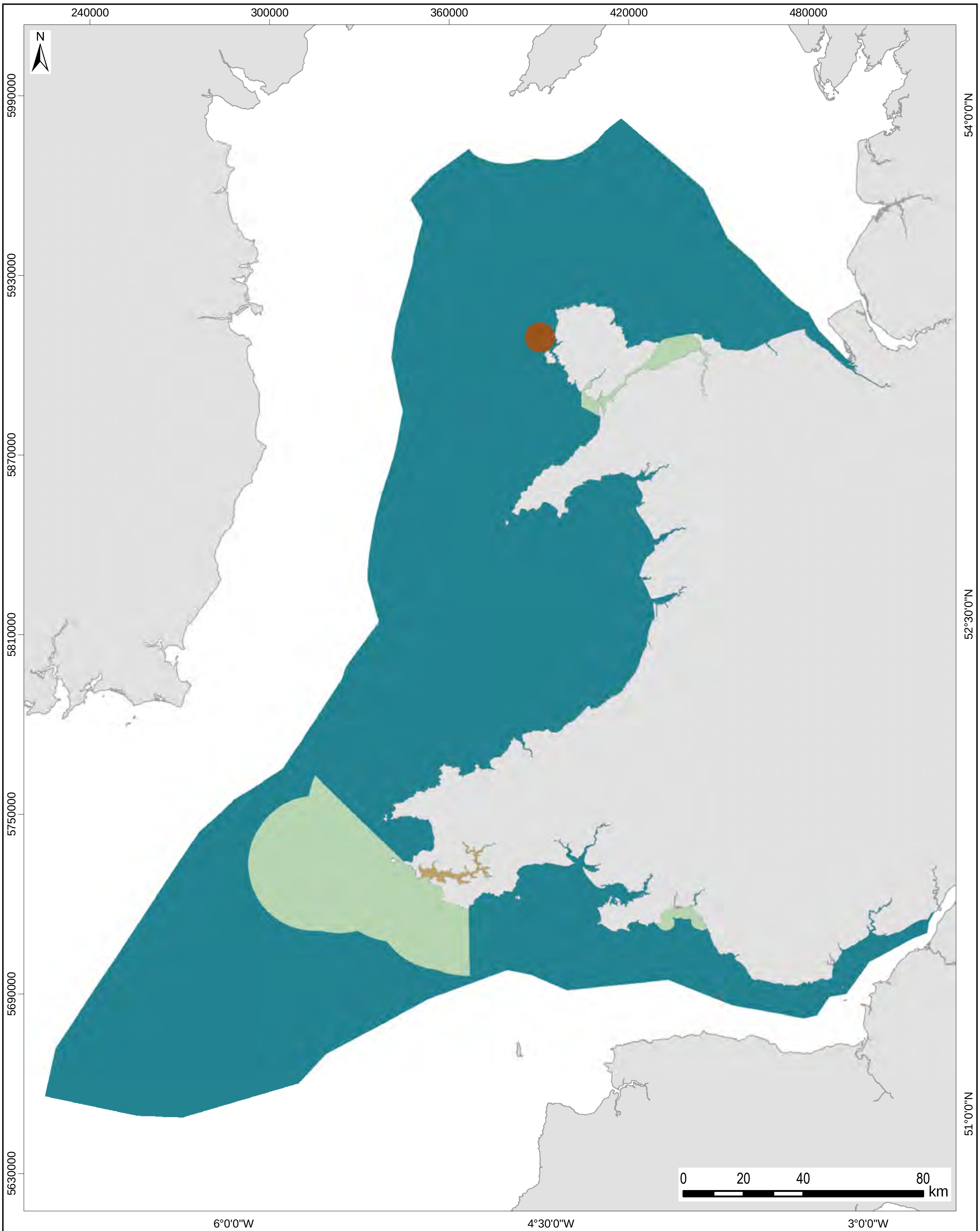


Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.15_Planning_Constraints.mxd			
Produced by ABPmer			

ABP mer marine environmental research

Magnitude of Marine Spatial Planning Related Constraint Levels in Welsh Waters

Figure 8.15



Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.16_Invest_Const_Bottom_Oys.mxd			
Produced by ABPmer			

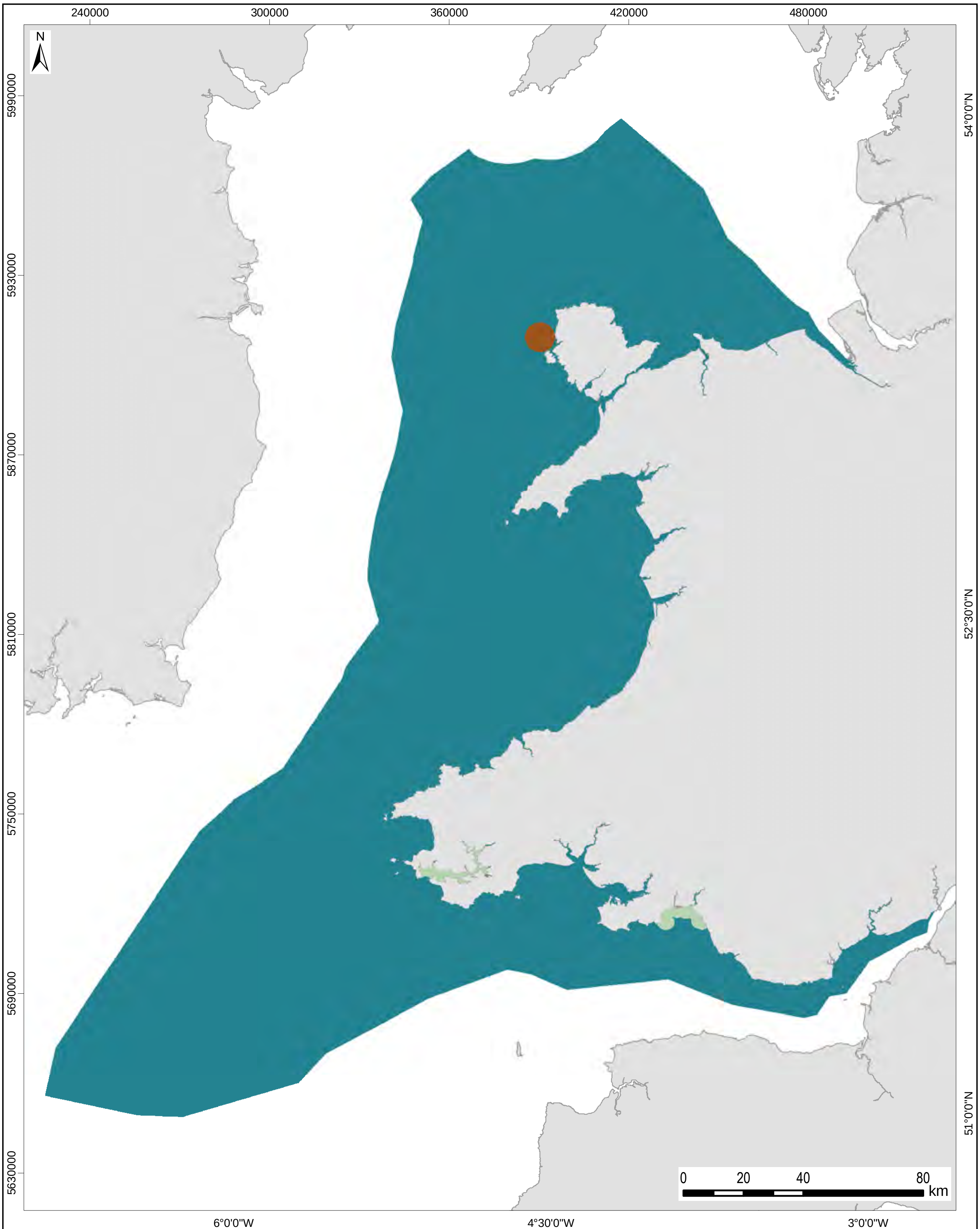
Investment Constraint Levels
- 0
- 0.1 - 0.5
- 0.6 - 1
- Excluded

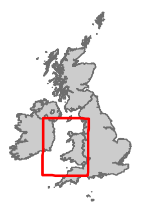
N.B. Oyster Species refers to Native Oyster and Pacific Oyster

ABP mer marine environmental research

Magnitude of Investment Related Constraint Levels for Bottom Culture of Oysters

Figure 8.16





Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System	WGS 1984 UTM Zone 30N		
Projection	Transverse Mercator		
Scale	1:1,800,000		
QA	TAP		
Fig8.17_Invest_Constraints_Bottom_Biv			
Produced by ABPmer			

Investment Constraint Levels

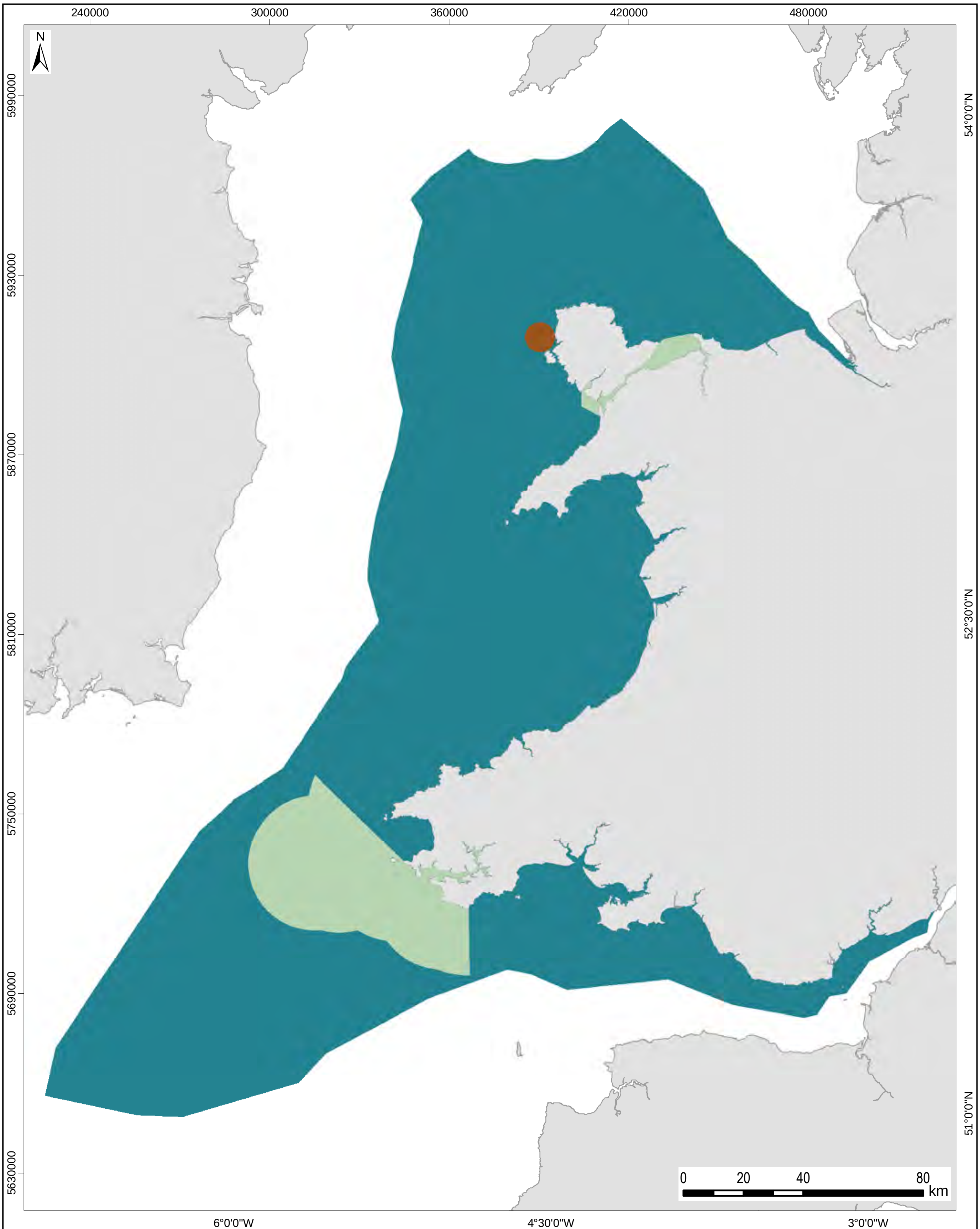
- 0
- 0.1 - 0.5
- 0.6 - 1
- Excluded

N.B. Bivalve Mollusc Species refers to Blue Mussel, European Clam and King Scallop

ABP mer marine environmental research

Magnitude of Investment Related Constraint Levels for Bottom Culture of Other Bivalve Mollusc Species

Figure 8.17



Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System	WGS 1984 UTM Zone 30N		
Projection	Transverse Mercator		
Scale	1:1,800,000		
QA	TAP		
Fig8.18_Invest_Const_Trestle_Oys.mxd			
Produced by ABPmer			

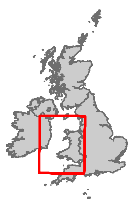
Investment Constraint Levels
- 0
- 0.1 - 0.5
- 0.6 - 1
- Excluded

N.B. Oyster Species refers to Native Oyster and Pacific Oyster

ABP mer
marine environmental research

Magnitude of Investment Related Constraint Levels for Trestle/ Bag Culture of Oysters

Figure 8.18



Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.19_Invest_Constraints_Others.mxd			
Produced by ABPmer			

Investment Constraint Levels

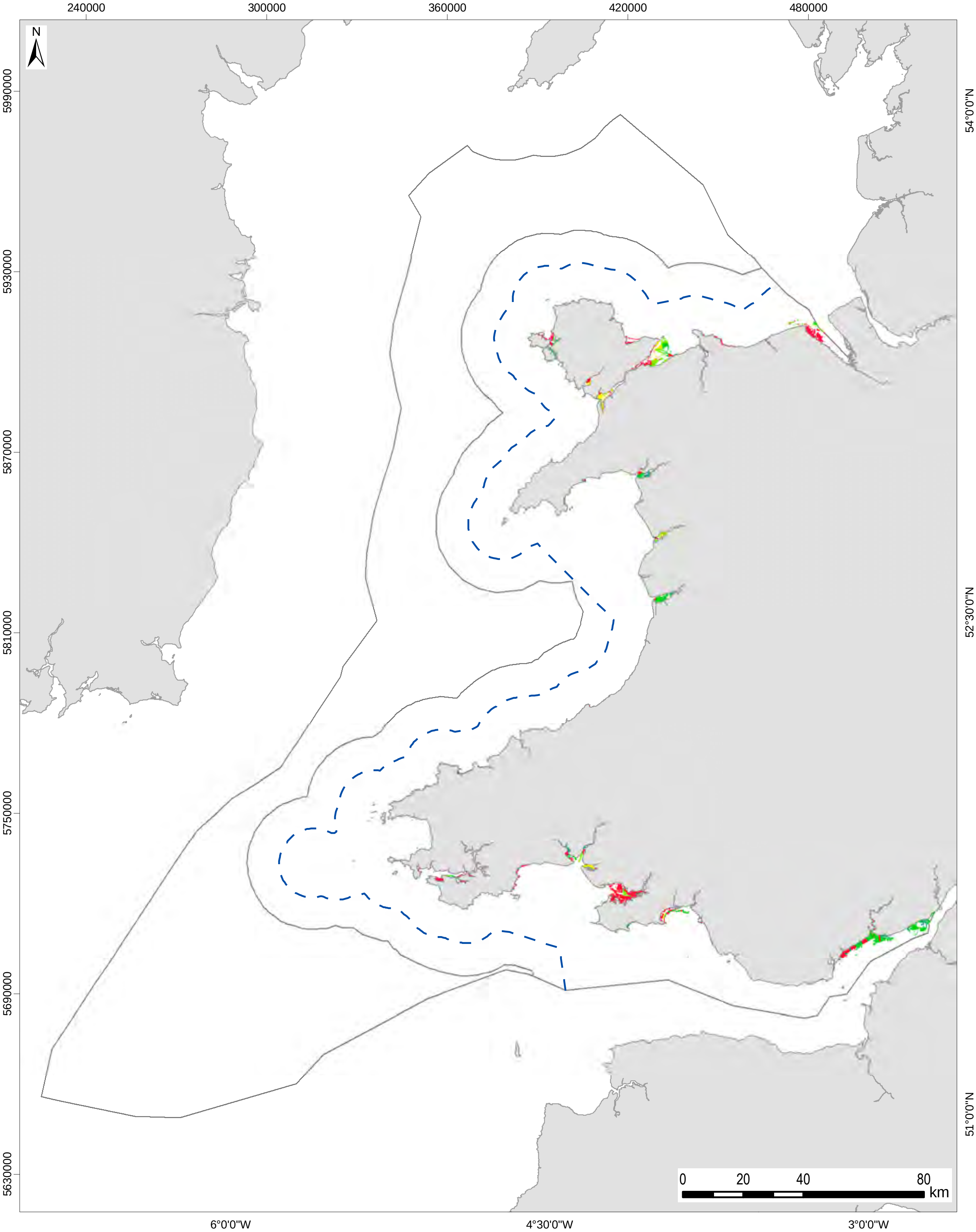
- 0
- 0.1 - 0.5
- 0.6 - 1
- Excluded

N.B. Other Methods refers to Trestle Culture of Blue Mussel, Rope Culture of Bivalve Molluscs and Macroalgae, Ranching of Lobster and Crawfish, and Cage Culture of Salmon, Sea Trout and Cod.

ABP mer
marine environmental research

Magnitude of Investment Related Constraint Levels for all Other Methods and Species

Figure 8.19



Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.20_Bottom_EC.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas
6 NM Limit

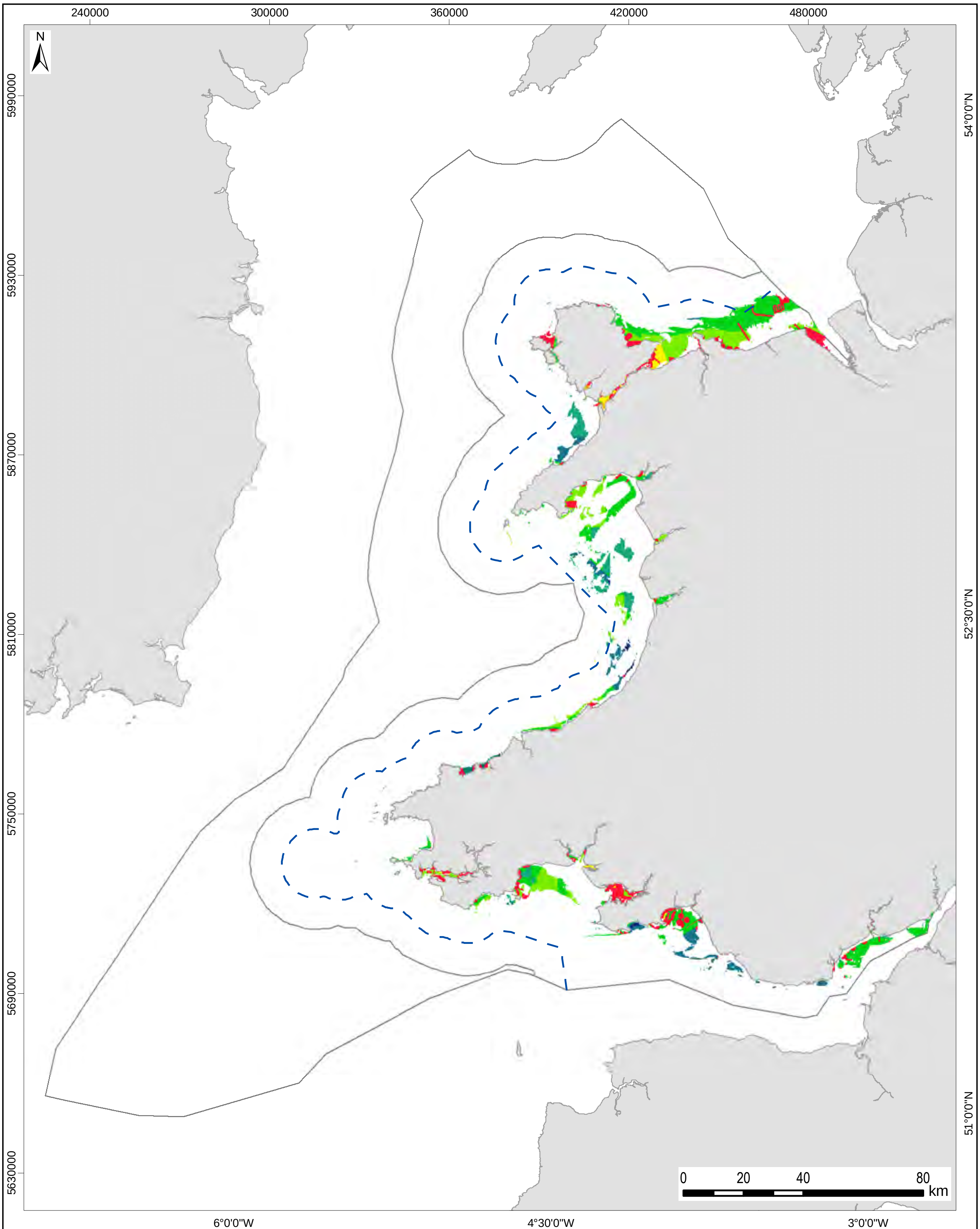
Constraint Levels

- 0
- 0.01 - 1
- 1.01 - 2
- 2.01 - 3
- 3.01 - 4
- 4.01 - 5
- 5.01 - 6
- 6.01 - 7
- Excluded

ABP mer marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Bottom Culture of European Clam

Figure 8.20



Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.21_Bottom_OY.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas
6 NM Limit

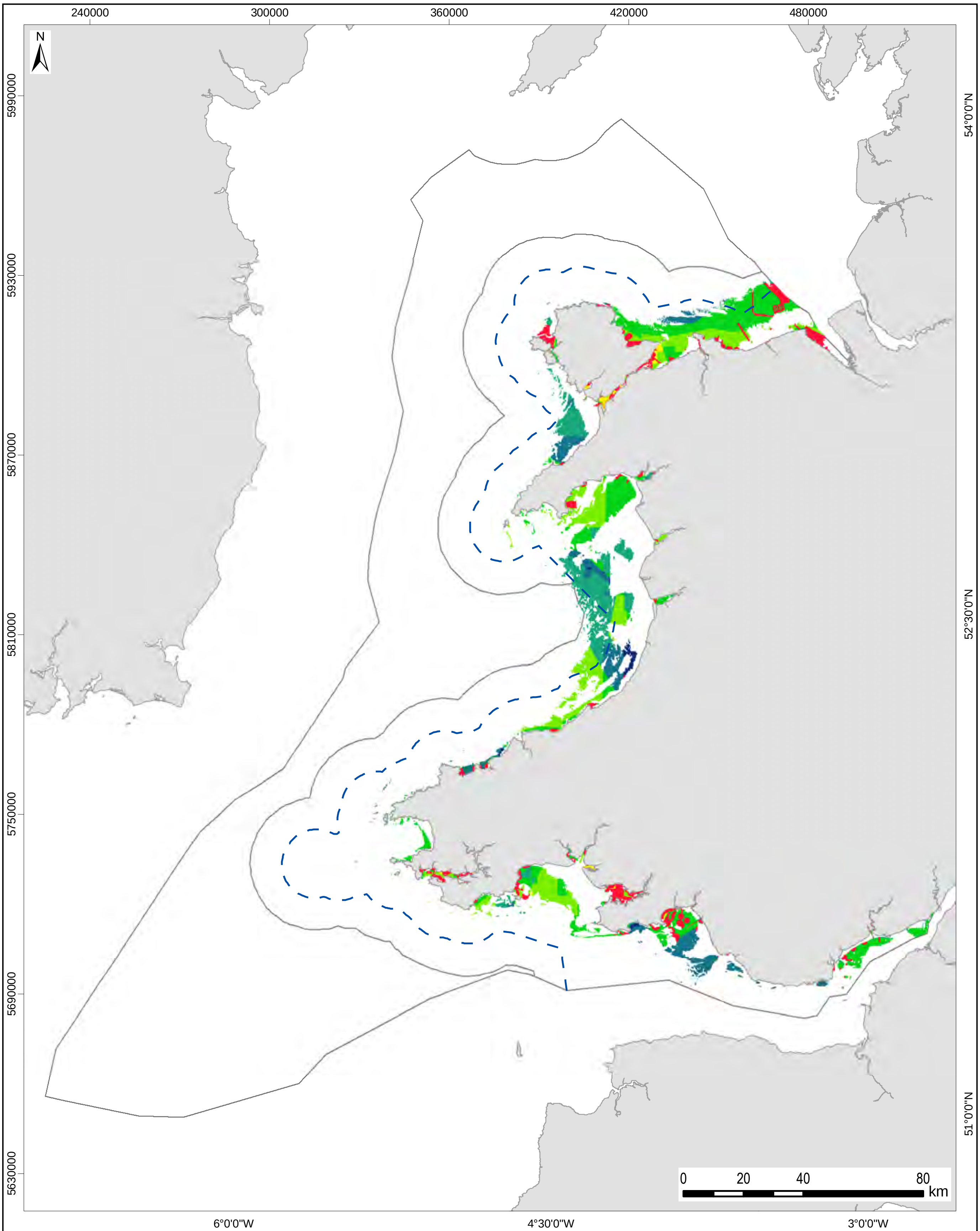
Constraint Levels
- 0
- 0.01 - 1
- 1.01 - 2
- 2.01 - 3
- 3.01 - 4
- 4.01 - 5
- 5.01 - 6
- 6.01 - 7
- Excluded

N.B. Oyster Species refers to Native Oyster and Pacific Oyster

ABP mer marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Bottom Culture of Oyster Species

Figure 8.21



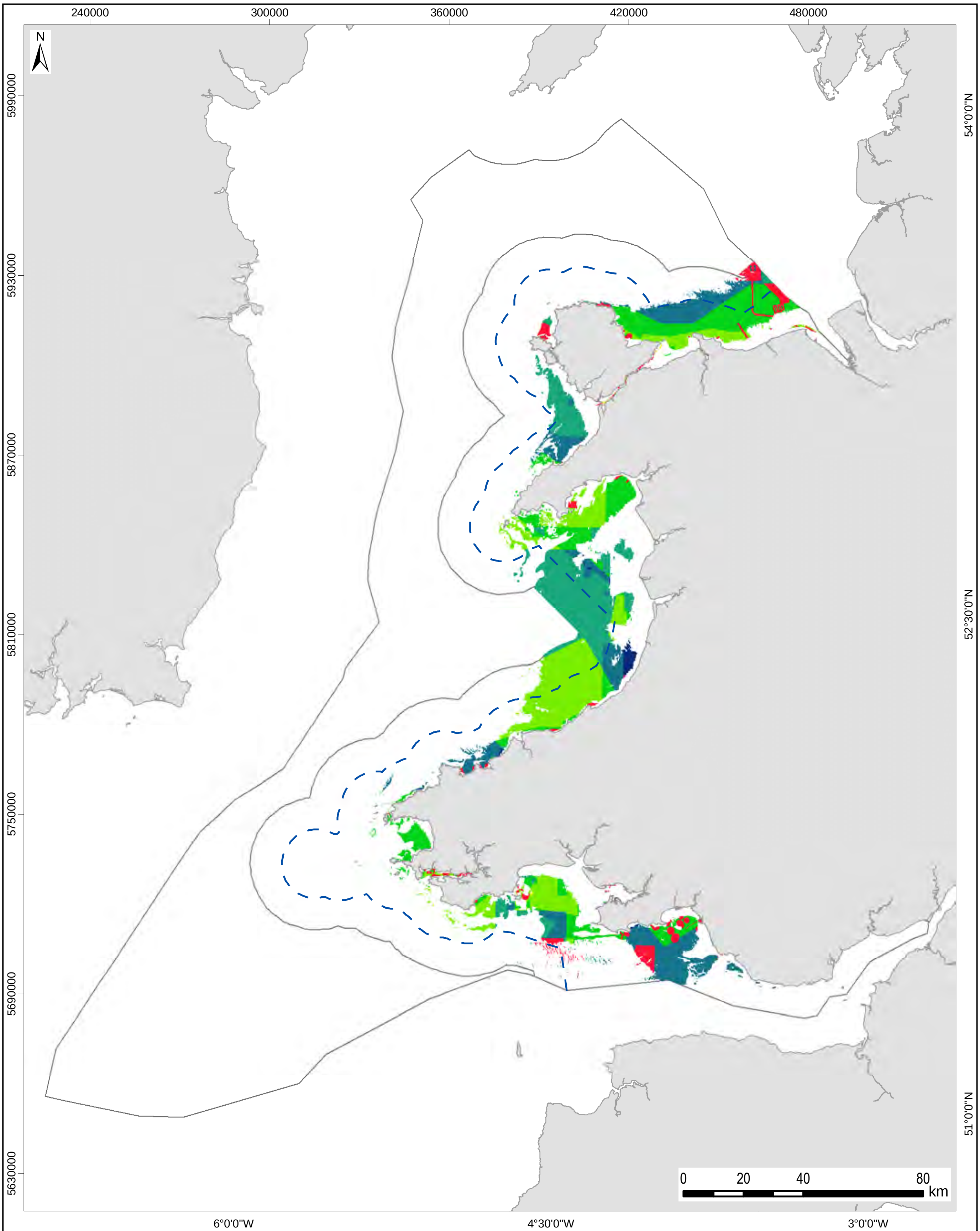
Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.22_Bottom_BM.mxd			
Produced by ABPmer			

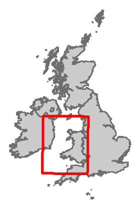
Welsh Marine Plan Areas
6 NM Limit
Constraint Levels
0
0.01 - 1
1.01 - 2
2.01 - 3
3.01 - 4
4.01 - 5
5.01 - 6
6.01 - 7
Excluded

ABP mer
marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Bottom Culture of Blue Mussel

Figure 8.22





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.23_Bottom_KS.mxd			
Produced by ABPmer			

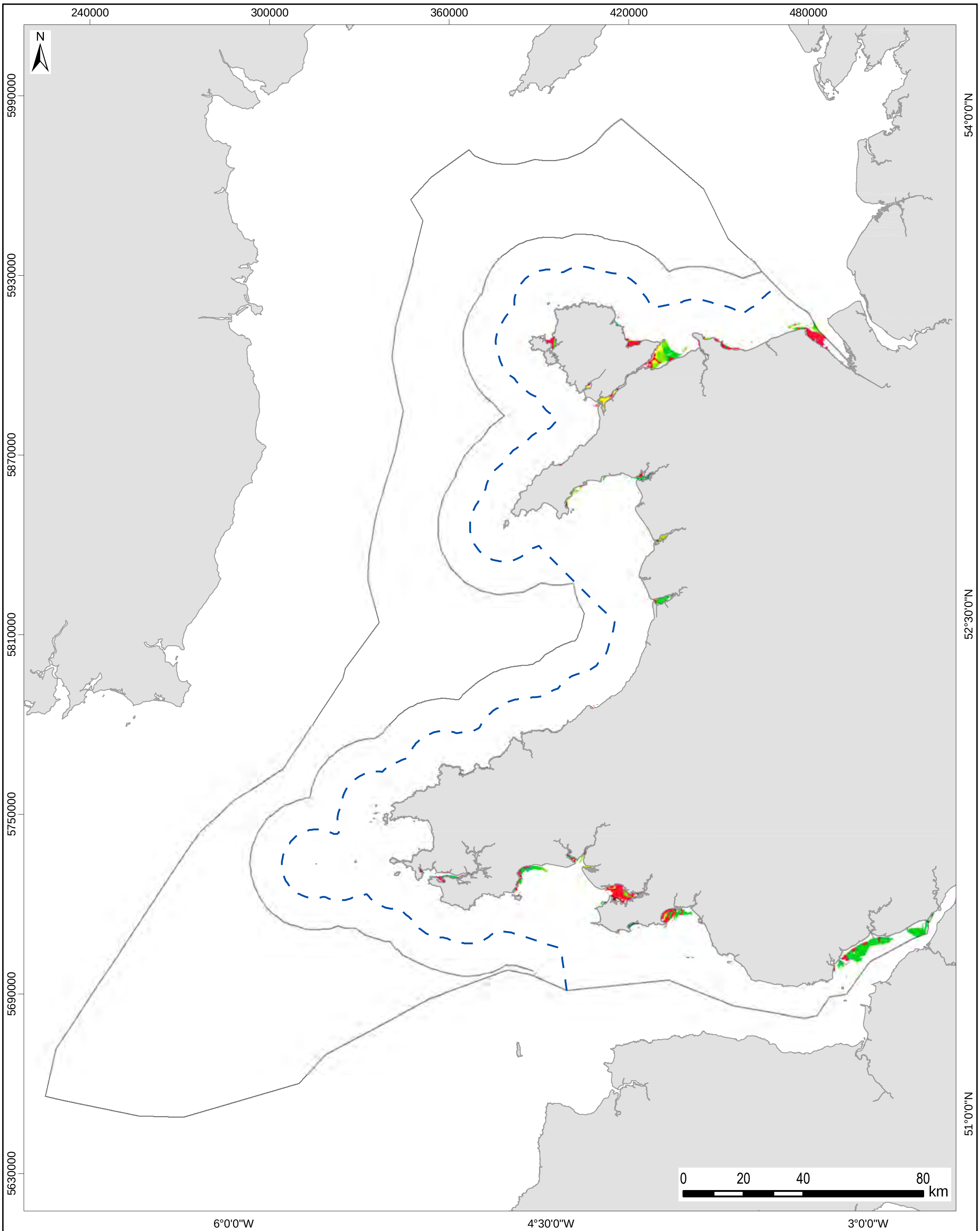
Welsh Marine Plan Areas
6 NM Limit

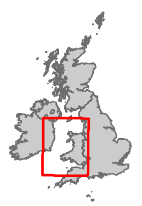
Constraint Levels
- 0
- 0.01 - 1
- 1.01 - 2
- 2.01 - 3
- 3.01 - 4
- 4.01 - 5
- 5.01 - 6
- 6.01 - 7
- Excluded

ABP mer marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Bottom Culture of King Scallop

Figure 8.23





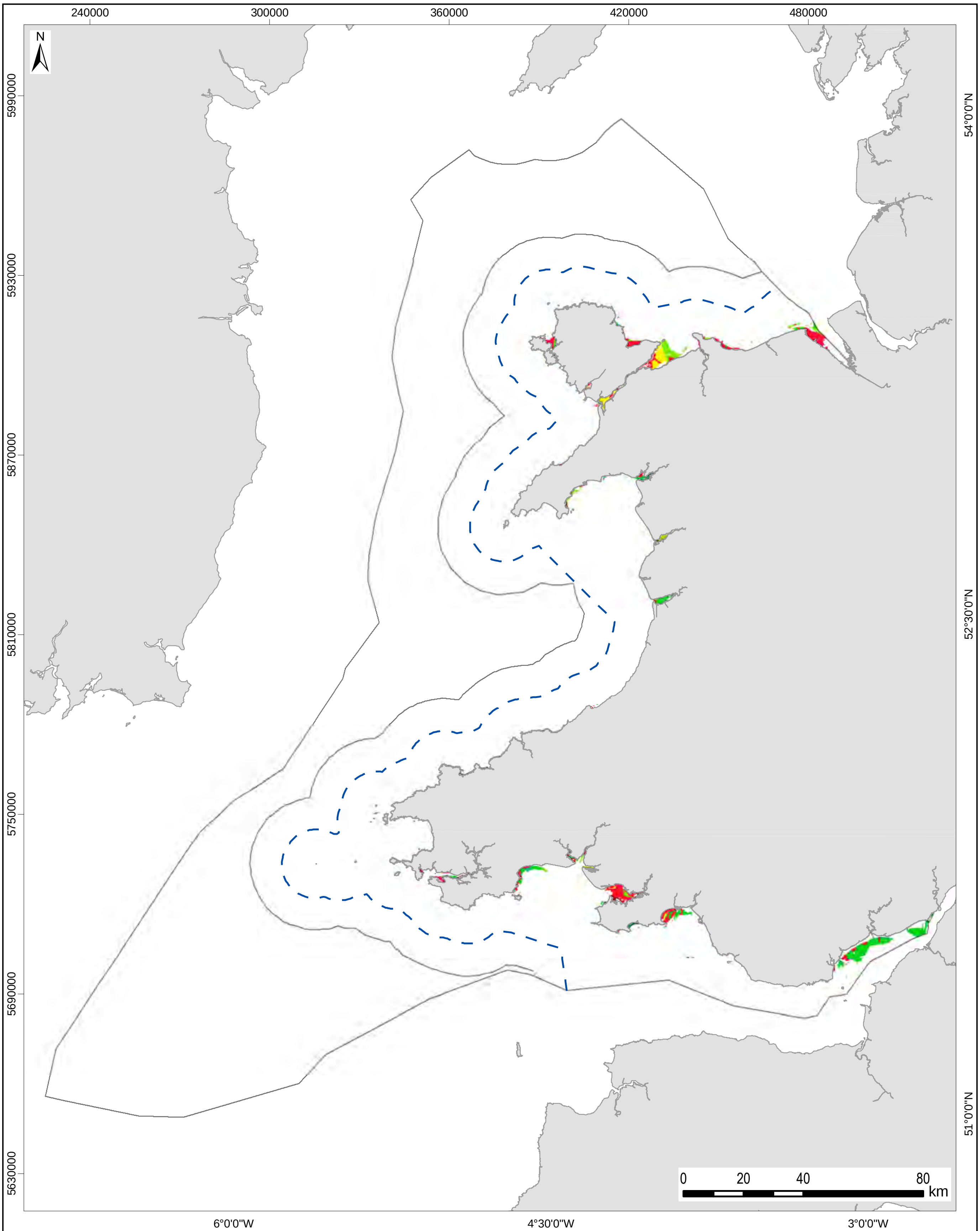
Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System	WGS 1984 UTM Zone 30N		
Projection	Transverse Mercator		
Scale	1:1,800,000		
QA	TAP		
Fig8.24_Trestle_SF.mxd			
Produced by ABPmer			

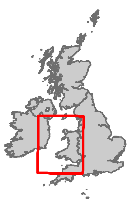
Welsh Marine Plan Areas
6 NM Limit
Constraint Levels
0
0.01 - 1
1.01 - 2
2.01 - 3
3.01 - 4
4.01 - 5
5.01 - 6
6.01 - 7
Excluded

ABP mer
marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Trestle/ Bag Culture of Blue Mussel

Figure 8.24





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.24_Trestle_Oys.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas
6 NM Limit

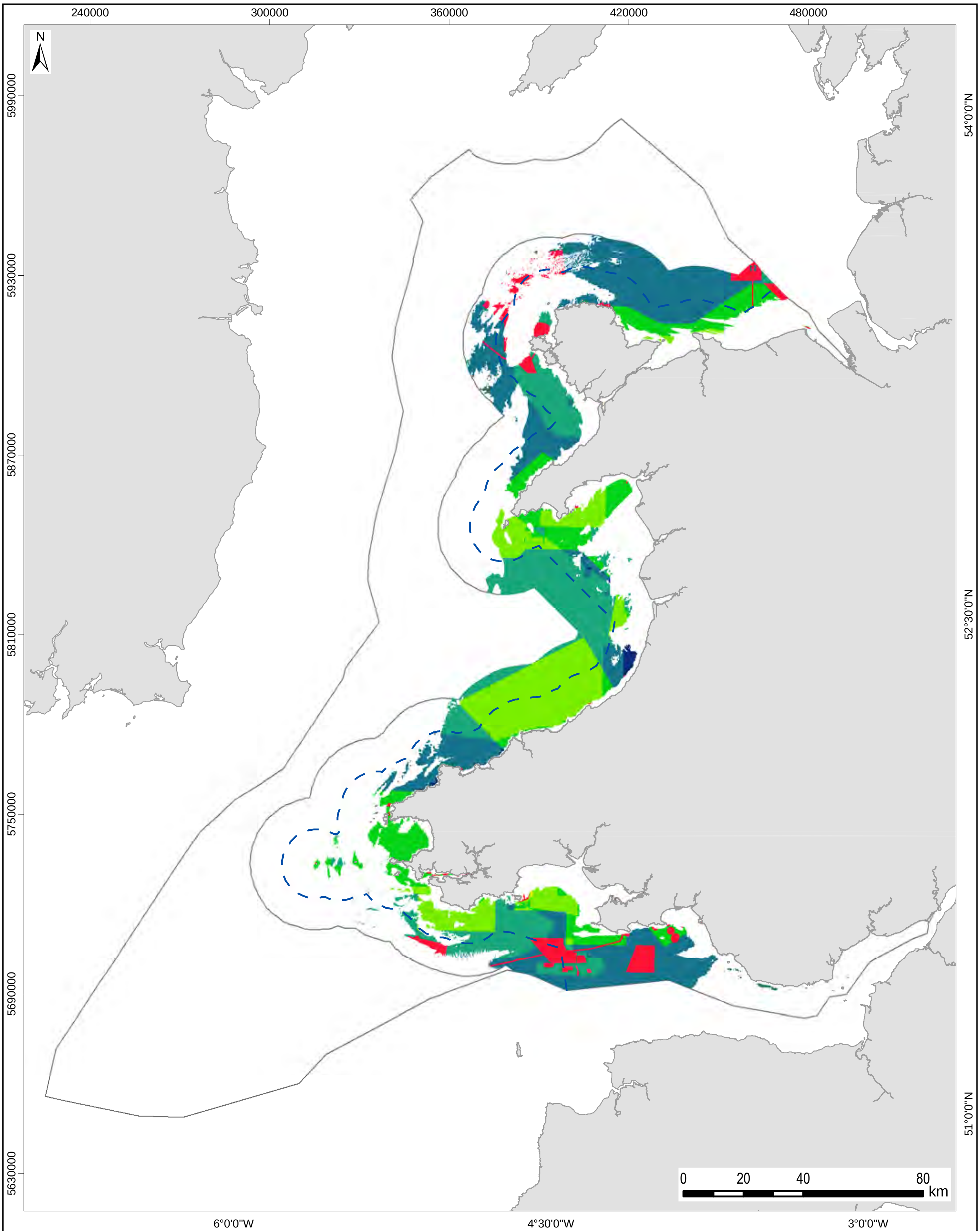
Constraint Levels
- 0
- 0.01 - 1
- 1.01 - 2
- 2.01 - 3
- 3.01 - 4
- 4.01 - 5
- 5.01 - 6
- 6.01 - 7
- Excluded

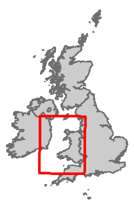
N.B. Oyster Species refers to Pacific Oyster and Native Oyster

ABP mer
marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Trestle/ Bag Culture of Oysters

Figure 8.25





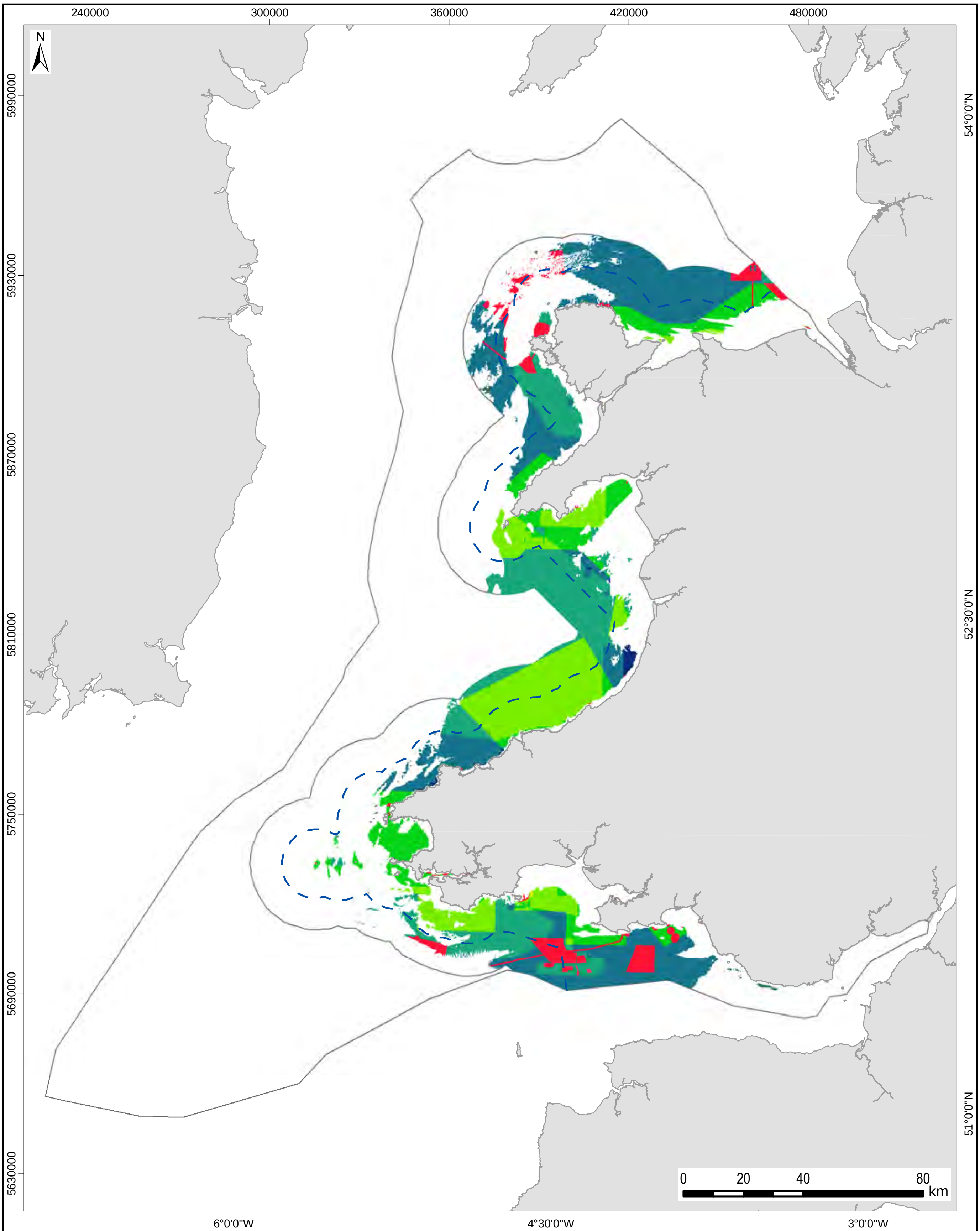
Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.26_Rope_SF.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas
6 NM Limit
Constraint Levels
0
0.01 - 1
1.01 - 2
2.01 - 3
3.01 - 4
4.01 - 5
5.01 - 6
6.01 - 7
Excluded

ABP mer
marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Rope Culture of Blue Mussel

Figure 8.26



Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.27_Rope_KS.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas

6 NM Limit

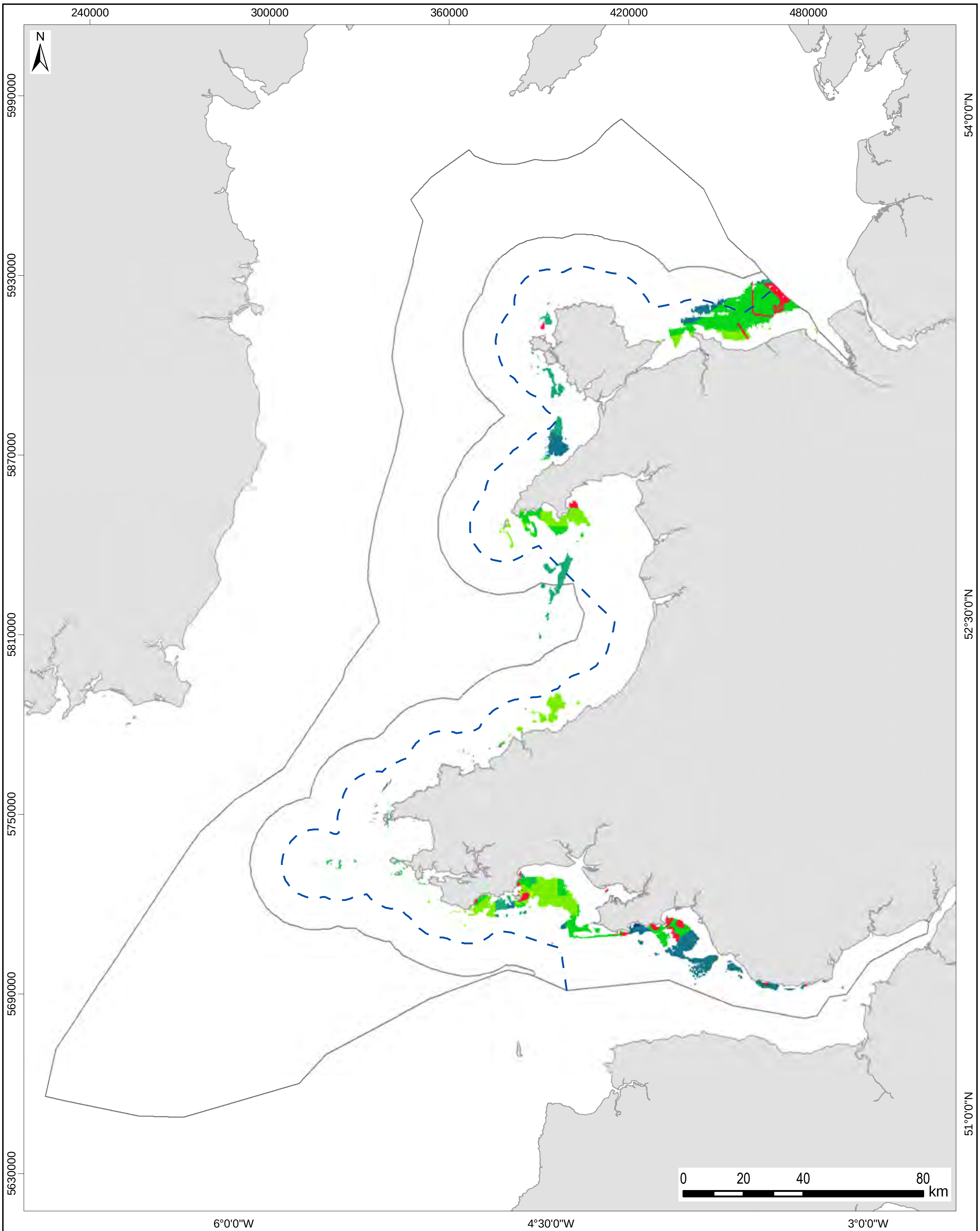
Constraint Levels

- 0
- 0.01 - 1
- 1.01 - 2
- 2.01 - 3
- 3.01 - 4
- 4.01 - 5
- 5.01 - 6
- 6.01 - 7
- Excluded

ABPmer marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Rope Culture of King Scallop

Figure 8.27



Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.28_Rope_MacMed.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas
6 NM Limit

Constraint Levels

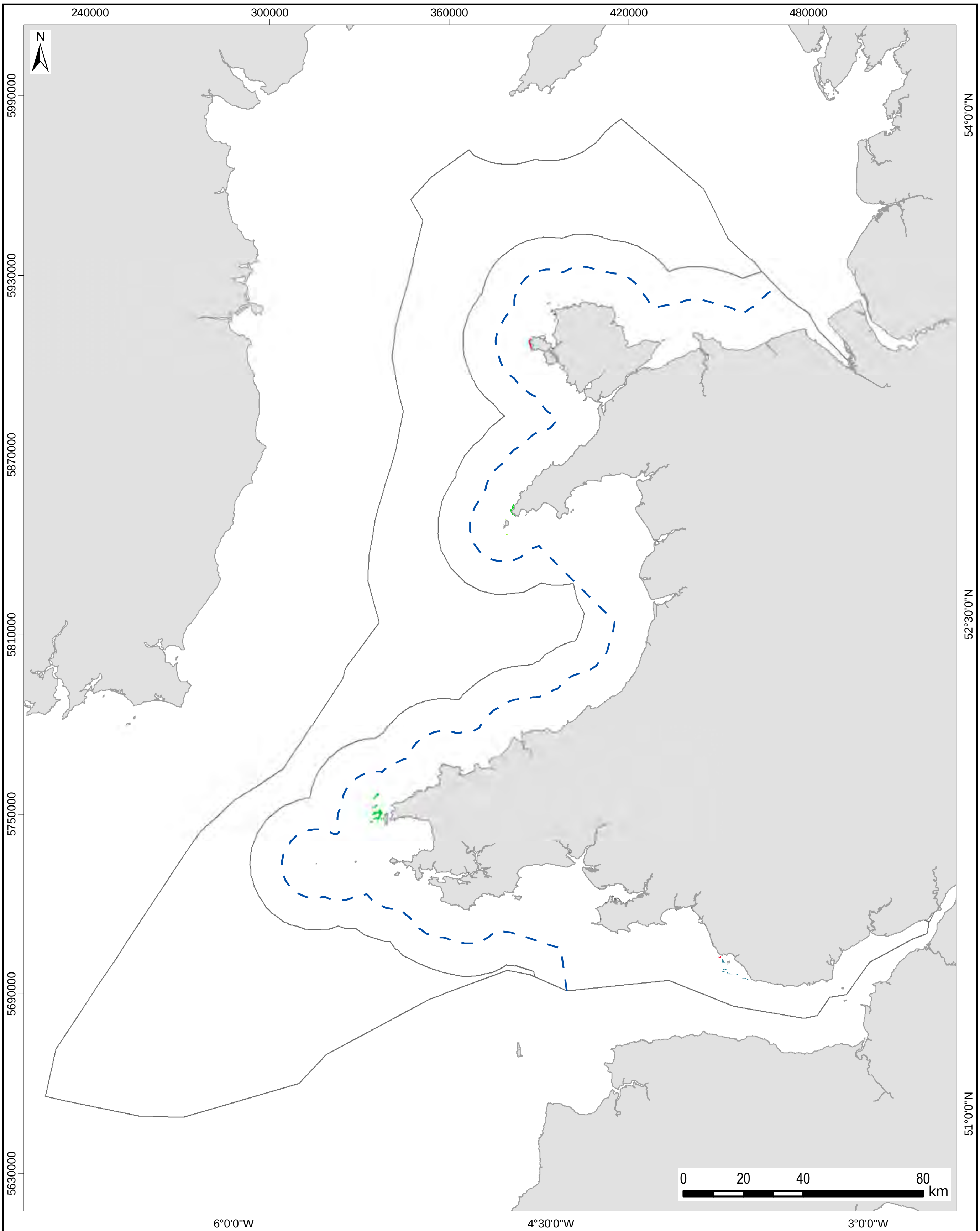
- 0
- 0.01 - 1
- 1.01 - 2
- 2.01 - 3
- 3.01 - 4
- 4.01 - 5
- 5.01 - 6
- 6.01 - 7
- Excluded

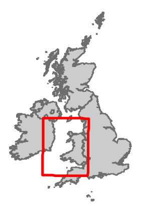
N.B. Moderate Exposure Tolerant Macroalgae Species refers to Kelp, Foliose Red Algae and Irish Moss

ABP mer marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Rope Culture of Moderate Exposure Tolerant Macroalgae Species

Figure 8.28





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.29_Rope_MacHigh.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas

6 NM Limit

Constraint Levels

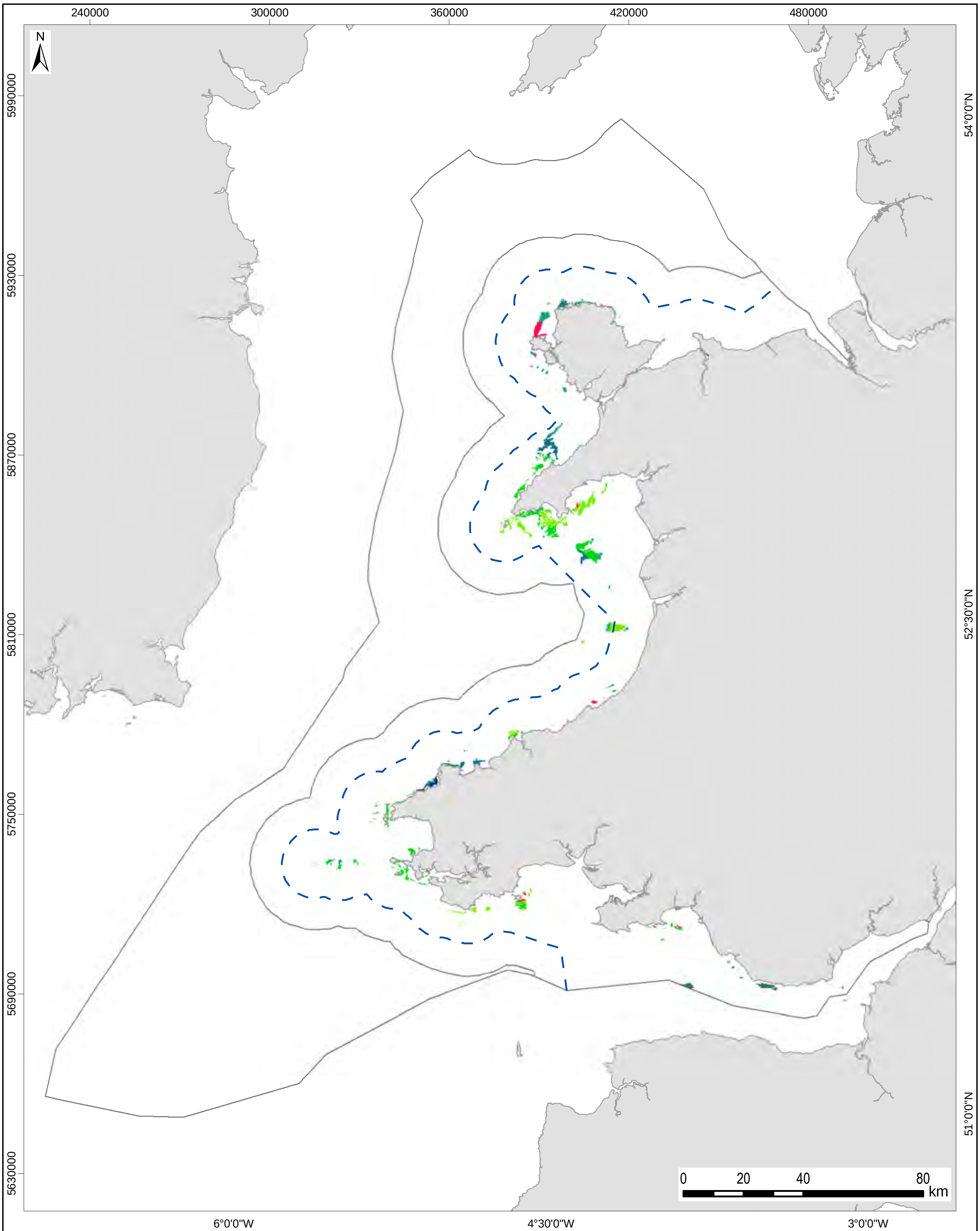
- 0
- 0.01 - 1
- 1.01 - 2
- 2.01 - 3
- 3.01 - 4
- 4.01 - 5
- 5.01 - 6
- 6.01 - 7
- Excluded

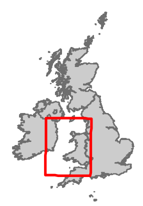
N.B. High Exposure Tolerant Macroalgae Species refers to Badderlock and Dulse

ABP mer marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Rope Culture of High Exposure Tolerant Macroalgae Species

Figure 8.29





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.30_Ranching_Lob.mxd			
Produced by ABPmer			

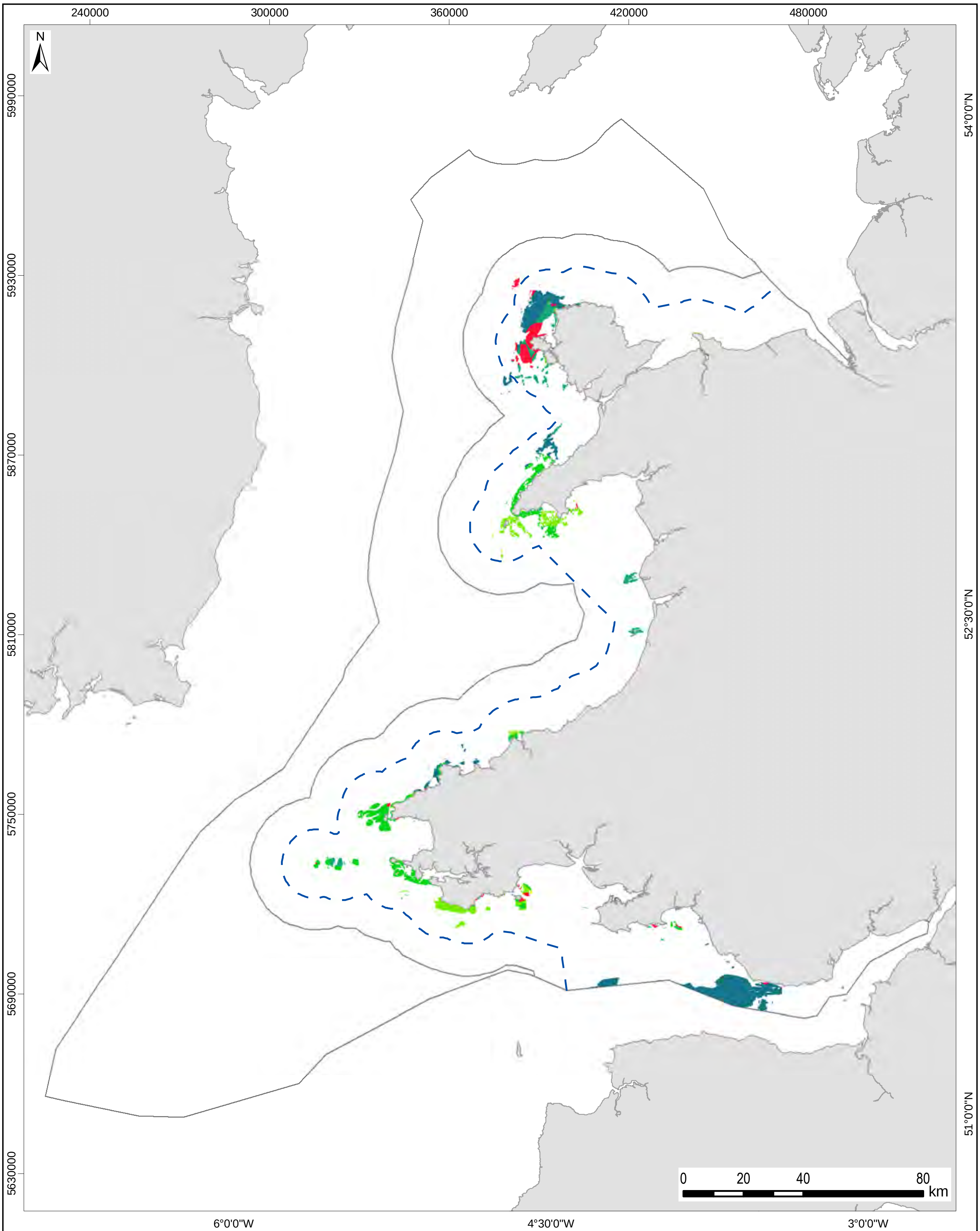
Welsh Marine Plan Areas
6 NM Limit

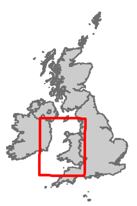
Constraint Levels
- 0
- 0.01 - 1
- 1.01 - 2
- 2.01 - 3
- 3.01 - 4
- 4.01 - 5
- 5.01 - 6
- 6.01 - 7
- Excluded

ABP mer marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Ranching of European Lobster

Figure 8.30





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.31_Ranching_CF.mxd			
Produced by ABPmer			

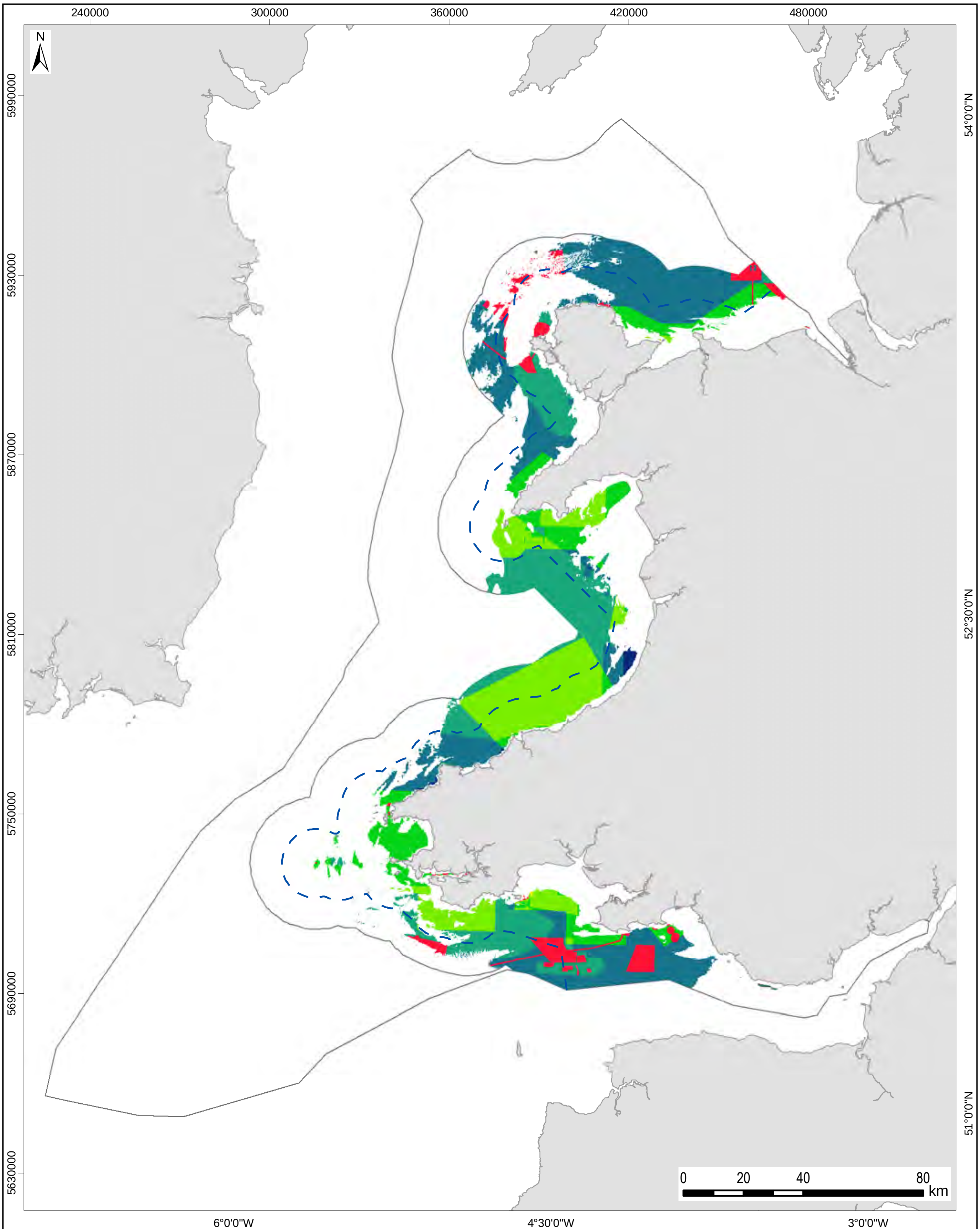
Welsh Marine Plan Areas
6 NM Limit

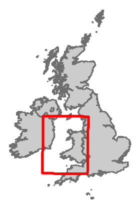
Constraint Levels
- 0
- 0.01 - 1
- 1.01 - 2
- 2.01 - 3
- 3.01 - 4
- 4.01 - 5
- 5.01 - 6
- 6.01 - 7
- Excluded

ABP mer
marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Ranching of Crawfish

Figure 8.31





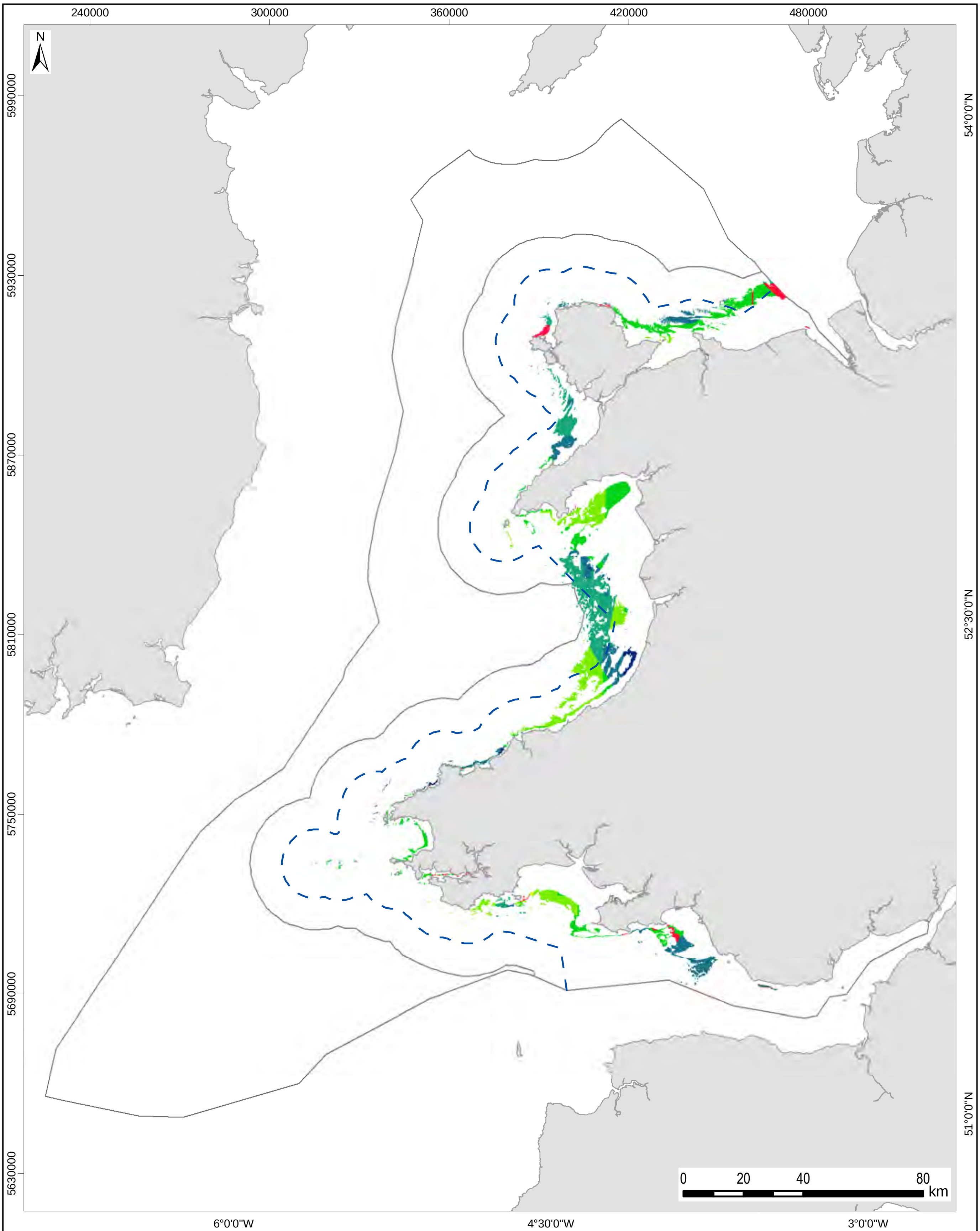
Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.32_Cage_FF.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas
6 NM Limit
Constraint Levels
0
0.01 - 1
1.01 - 2
2.01 - 3
3.01 - 4
4.01 - 5
5.01 - 6
6.01 - 7
Excluded

ABP mer
marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Cage Culture of Atlantic Salmon and Sea Trout

Figure 8.32



Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
Fig8.33_Cage_Cod.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas
6 NM Limit
Constraint Levels
0
0.01 - 1
1.01 - 2
2.01 - 3
3.01 - 4
4.01 - 5
5.01 - 6
6.01 - 7
Excluded

ABP mer marine environmental research

Relative Level of Constraint within Areas of Suitable Natural Resource for Cage Culture of Cod

Figure 8.33

Appendices

Appendix A

Data Layers

A. Data Layers

A.1 Introduction

This appendix shows the data layers which were collated in order to spatially represent current aquaculture activity in the Welsh Marine Plan Area (Table A1) and to develop the 'natural resource constraint' and 'policy related constraint' core components of the spatial model (Tables A2 and A3 respectively). Some of the data layers were not incorporated into the spatial model due to limitations in resolution or coverage of the data set and these reasons are presented in Appendix B.

Table A1. Current aquaculture activity

Data Layer	Data Description	Supplier/SOURCE
Bivalve Harvesting Classification Areas	Bivalve classification areas in Welsh waters.	Cefas provided direct (February 2015).
Several & Regulating Orders	Several & Regulating Orders in Welsh waters.	NRW provided direct by the Welsh Government (WG) (December 2014). Adjustments were made to the layer through discussions with WG in February 2015.
Mussel Seed Harvesting Areas	Mussel Seed Harvesting Areas in Welsh Waters.	WG provided direct (December 2014).
Aquaculture Production Businesses	*Point locations of aquaculture production businesses in Wales.*	*Cefas provided direct (February 2015).*
Fishing Landing Ports	*Point locations of landing ports for fishing in Welsh waters.*	*MMO data available via Environment Agency (EA) Geostore "Download Environmental OpenData" web portal accessed December 2015.*
N.B. *Grey text* identifies data layers which were not used within the model (see Appendix B for reason for exclusion)		

Table A2. Natural resource constraints

Natural Resource	Data Layer	Data Description	Supplier/Source
Depth	Digital Elevation Model (DEM)	Digital Elevation Model for Welsh waters.	OceanWise DEM (December 2014) - provided direct by WG through contractor licence.
Sediment Type	Combined Seabed Habitat Region	Seabed habitat data for Welsh waters.	NRW data provided direct by WG (December 2014). Data from FishMapMon project.
Light	Photic Zone	Extent of photic zone in UK waters.	Data from MB0102 Defra contract (2012) - permission granted for use within study.
Temperature	*Mean Sea Surface Temperature*	*Annual mean sea surface temperature for 1961 to 1990.*	*Defra UK Climate Projections User Interface (Accessed January 2015).*
Salinity	Severn Tidal Limits	Indicative limit within the Severn Estuary where the salinity is, on average, below 30 psi.	Severn Tidal Power 2010

Natural Resource	Data Layer	Data Description	Supplier/Source
Wave Exposure	Celtic and North Seas Wave Energy	Wave energy (N /m²) data layer used as an input to the EUSeaMap model.	EMODnet Seabed Habitats – Data was created as part of the EUSeaMap project 2012 (Accessed February 2015).
Tide Exposure	Celtic and North Seas Current Energy	Current energy (N /m²) data layer used as an input to the EUSeaMap model.	EMODnet Seabed Habitats – Data was created as part of the EUSeaMap project 2012 (Accessed February 2015).
N.B. *Grey text* identifies data layers which were not used within the model (see Appendix B for reason for exclusion)			

Table A3. Marine Spatial Planning-related constraints

Sector	Data Layer	Data Description	Supplier/SOURCE
Aggregates	Aggregate Licence Areas	Locations and attributes of licenced dredging areas in England and Wales.	TCE "Maps and GIS data" portal (Accessed January 2015).
Aggregates	Aggregate Application Areas	Locations and attributes of application dredging areas in England and Wales.	TCE "Maps and GIS data" portal (Accessed January 2015).
Aggregates	Aggregate Option Areas	Locations and attributes of option dredging areas in England and Wales.	TCE "Maps and GIS data" portal (Accessed January 2015).
Aggregates	Aggregate Exploration & Option Areas	Locations and attributes of exploration and option areas in England and Wales.	TCE "Maps and GIS data" portal (Accessed January 2015).
Cables	MTF Industrial Lines - Cables	Locations of telecommunication and power cables in Welsh waters.	OceanWise Marine Themes (December 2014) - provided direct by WG through contractor licence.
Energy	Wave Lease Areas	Extent of live wave leases in UK waters.	TCE "Maps and GIS data" portal (Accessed January 2015).
Energy	Tidal Lease Areas	Extent of live tide leases in UK waters.	TCE "Maps and GIS data" portal (Accessed January 2015).
Energy	MTF Industrial Points - Oil & Gas Platforms	Locations of Oil & Gas platforms in Welsh waters.	OceanWise Marine Themes (December 2014) - provided direct by WG through contractor licence.
Energy	MTF Industrial Lines - Oil & Gas Pipelines	Locations of Oil & Gas pipelines in Welsh waters.	OceanWise Marine Themes (December 2014) - provided direct by WG through contractor licence.
Fishing	Integrated Fishing Effort	MB0106 Integrated fishing effort data layer for 2007 to 2011 (data represents the relative intensity of fishing activity (mobile and static gears) in the inshore and offshore areas for all UK vessels and non-UK vessels.	Defra MB0106 contract–permission granted for use within study.

Sector	Data Layer	Data Description	Supplier/SOURCE
		For further details see Vanstaen, (2010).	
Military	MTF Administrative Areas - Military Practice Areas	Locations of military practice areas in Welsh waters.	OceanWise Marine Themes (December 2014) - provided direct by WG through contractor licence.
Protected Areas	Marine & Offshore SACs including pSACs	Extents of Marine SACs including pSACs in Welsh waters.	NRW data provided direct by WG (December 2014).
Protected Areas	Marine & Offshore SACs including pSACs	Extents of Marine Offshore SACs including pSACs in Welsh waters.	JNCC "Protected Sites" web portal accessed January 2015.
Protected Areas	Marine SPAs including pSPAs	Extents of Marine SPAs including pSPAs in Welsh waters.	NRW data provided direct by WG (December 2014).
Protected Areas	Ramsar Sites	Extents of Ramsar sites in Welsh waters.	NRW data provided direct by WG (December 2014).
Protected Areas	Marine SSSIs	Extents of Marine SSSIs in Welsh waters.	NRW data provided direct by WG (December 2014).
Protected Areas	Marine Nature Reserves	Extents of Marine Nature Reserves in Welsh waters.	NRW data provided direct by WG (December 2014).
Protected Areas	Protected Wrecks Exclusion Zones	Extents of Protected Wrecks with defined exclusion zones.	MCA "Receiver of wreck: protected wrecks" web page accessed October 2014.
Protected Areas	Protected Wrecks points outside of Exclusion Zones	Locations of Protected Wrecks with no defined exclusion zones.	MCA "Receiver of wreck: protected wrecks" web page accessed October 2014.
Protected Areas	MTF Obstructions Points - Wrecks	Locations of all wrecks in Welsh waters.	OceanWise Marine Themes (December 2014) - provided direct by WG through contractor licence.
Protected Features	Grey Seal Haul Out Sites	Grey Seal haul out sites in Welsh waters buffered to 250m.	NRW data provided direct by WG (December 2014).
Ports & Harbours	MTF Obstructions Points & Areas - Anchorage Points & Anchorage areas	Locations of individual anchorages and anchorage areas.	OceanWise Marine Themes (December 2014) - provided direct by WG through contractor licence.
Ports & Harbours	MTF Administrative Points - Pilot Boarding Areas	Locations of pilot boarding areas.	OceanWise Marine Themes (December 2014) - provided direct by WG through contractor licence.
Ports & Harbours	MTL Elevation Areas - Maintenance Dredging	Maintenance dredging areas including navigational channels.	OceanWise Marine Themes (December 2014) - provided direct by WG through contractor licence.
Ports & Harbours	Dredge Disposal Sites	Extents of open dredge disposal sites in 2013.	Cefas provided direct in March 2014.
Ports & Harbours	Holyhead Marina Exclusion Zone	Extent of exclusion zone applied around Holyhead Marina due to presence of *Didemnum*.	Sambrook *et al*. 2014

Sector	Data Layer	Data Description	Supplier/SOURCE
Recreation	RYA Racing Areas	Extents of RYA racing areas (2008).	RYA provided direct in 2014 used under ABPmer annual licence.
Recreation	Angling Points	Popular locations where angling occurs in Welsh waters.	NRW data provided direct by WG (December 2014). Marine and Coastal Recreation Audit, 2009.
Recreation	Windsurfing Points	Popular locations where windsurfing occurs in Welsh waters.	NRW data provided direct by WG (December 2014). Marine and Coastal Recreation Audit, 2009.
Recreation	Surfing Points	Popular locations where surfing occurs in Welsh waters.	NRW data provided direct by WG (December 2014). Marine and Coastal Recreation Audit, 2009.
Recreation	Swimming Locations	Popular locations where swimming occurs in Welsh waters.	NRW data provided direct by WG (December 2014). Marine and Coastal Recreation Audit, 2009.
Recreation	Blueflag Beaches	Locations of Blueflag beaches	BlueFlag "Awarded Sites - Wales" web portal accessed January 2015.
SeaScape	*Seascape Visibility*	*The sensitivity of the coastal landscapes and Seascapes of Wales to tidal stream developments, March 2011.*	*NRW data provided direct by WG (December 2014).*
Shipping	MTF Transportation Points - IMO Traffic Separation schemes	Areas of shipping traffic separation.	OceanWise Marine Themes (December 2014) - provided direct by WG through contractor licence.
Shipping	AIS Shipping Density 2012	Density grid of shipping in UK waters for 2012 – annual average.	MMO data available via EA Geostore "Download Environmental OpenData" web portal accessed December 2015.
Water Quality	Consented Discharges	Location of controlled discharges in Welsh waters.	NRW data provided direct by WG (December 2014).
Water Quality	Shellfish Waters	Location of Shellfish Waters in Welsh waters and data on directive assessments of the waters for 2011.	Cefas data provided direct by WG (December 2014).
Water Quality	*Bathing Waters*	*Location of bathing waters in Welsh waters and sample results 1992 to 2013.*	*NRW data provided direct by WG (December 2014). Updated sample results provided by NRW March 2015.*

N.B. *Grey text* identifies data layers which were not used within the model (see Appendix B for reason for exclusion)

Table A4. Investment related constraints

Constraint	Data Layer	Data Description	Supplier/SOURCE
Disease	*Bonamia ostreae.*	Welsh confirmed designations for *Bonamia ostreae* areas.	Cefas data provided direct April 2015.
Invasive Non Native Species	Holyhead Marina Exclusion Zone	Extent of exclusion zone applied around Holyhead Marina due to presence of *Didemnum*.	Sambrook *et al*. 2014
Invasive Non Native Species	*Crepidula fornicata*	Polygon extents were created where a time series of points were clustered to represent areas where *Crepidula fornicata* has been regularly sampled.	Point data provided by NRW direct April 2015,

A.2 Websites/Sources Referred

The Crown Estate "Maps and GIS data". Available at: http://www.thecrownestate.co.uk/energy-and-infrastructure/downloads/maps-and-gis-data/ [Accessed 20 January 2015].

Defra "UK Climate Projections User Interface". Available at: http://ukclimateprojections-ui.metoffice.gov.uk/ui/admin/login.php [Accessed 12 February 2015].

EMODnet, "Seabed Habitats Interactive Map". Available at: http://www.emodnet-seabedhabitats.eu/default.aspx?page=1974 [Accessed 6 March 2015].

Joint Nature Conservation Committee, "Protected Sites – Download GIS data". Available at: http://jncc.defra.gov.uk/protectedsites/SACselection/gis_data/terms_conditions.asp [Accessed 28 January 2015].

BlueFlag "Awarded Sites – Wales". Available at http://www.blueflag.org/menu/awarded-sites/2014/northern-hemisphere/wales [Accessed 28 January 2015].

Environment Agency "EA Geostore – download Environmental OpenData". Available at: http://www.geostore.com/environment-agency/WebStore?xml=environment-agency/xml/ogcDataDownload.xml [Accessed 20 December 2015].

Maritime and Coastguard Agency "MCA "Receiver of wreck: protected wrecks" web page accessed October 2014". Available at https://www.gov.uk/government/publications/receiver-of-wreck-protected-wrecks [Accessed October 2014].

Sambrook, K., Holt, R.H.F., Sharp, R., Griffiths, K., Roche, R.C., Newstead, R.G., Wyn, G., Jenkins, S.R. Capacity, capability and cross-border challenges associated with marine eradication programmes in Europe: The attempted eradication of an invasive non-native ascidian, *Didemnum vexillum* in Wales, United Kingdom. Marine Policy, 48, 51-58.

Appendix B

Spatial Model Parameters and Rules

B. Spatial Model Parameters and Rules

The following tables show data layers which were used to develop the core components of the spatial model and the rules which were applied within the model to reflect the level of constraint that each parameter may pose to the future expansion of existing, or development of new, marine aquaculture activities.

B.1 Model Component 1 – Natural Resource Constraints

The following parameters have been identified as a limiting natural resource for one or more species and/or methods of aquaculture considered within this study. For each potential future aquaculture species, the rules applied within the spatial model will be determined by the ecological and natural resource requirements of each species and method of cultivation (described in Appendix C). Table B1 and Figures B1 to B4 show the natural resource parameters which were included in the spatial model.

Table B1. Natural resources and potential constraints on aquaculture

Natural Resource	Species, Taxa or Method Constrained	Data Layer	Rules or Reason for Exclusion
Light	Rope culture of Marine Macroalgae.	Photic Zone	Restricted to the spatial extent of the photic zone layer as macroalgae growth is restricted by available light.
Salinity	Culture of Pacific and Native Oyster. Ranching of Lobster and Crawfish.	Severn Tidal Limits	Restricted to higher salinity areas i.e. greater than 30 due to species requirements. It should be noted that the derived 'boundary' in the Bristol Channel where salinity, on average, was considered to be below 30, is indicative only. Due to the resolution of available data for the rest of the Welsh coastline, salinity was not included as a constraint for any species beyond the Bristol Channel.
Temperature	All Methods and Species	-	Due to the resolution of the available data layer, the range of temperature tolerances of all species, and the temperature range in Welsh waters, temperature was not a constraint for any species therefore has not been included in the model.
Sediment Type	Bottom Culture of Blue Mussels, King Scallop, Pacific and Native Oysters.	Combined Seabed Habitat Region	Restricted to coarse sediment, mixed sediment & sand areas. Firm sediments are required for the culture method to take place.
	Bottom Culture of European Clam.	Combined Seabed Habitat Region	Restricted to mud and sand areas due to the species which requires sandy or silty mud.
	Trestle /Bag Culture of all Bivalve species.	Combined Seabed Habitat Region	Restricted to coarse sediment, mixed sediment & sand areas. Firm sediments are required for the culture method infrastructure.

Natural Resource	Species, Taxa or Method Constrained	Data Layer	Rules or Reason for Exclusion
	Hatchery Reared Ranching of Crustaceans.	Combined Seabed Habitat Region	Restricted to rock areas due to the requirements of the crustacean species.
	Cage Culture of all Finfish species.	Combined Seabed Habitat Region	Restricted to sediments (except saltmarsh and seagrass beds, although saltmarsh and seagrass beds are not likely to occur in the depths which are required for cage culture).
	Rope Culture of all Bivalve and Macroalgae species.	Combined Seabed Habitat Region	Restricted to sediments (except saltmarsh and seagrass beds, although saltmarsh and seagrass beds are not likely to occur in the depths which are required for rope culture).
Wave Exposure	Bottom Culture of all Bivalve species.	Celtic and North Seas Wave Energy	Restricted to areas of low to moderate wave exposure < 1200 N/m^2 due to the exposure tolerance of bivalve species.
	Trestle /Bag Culture of all Bivalve species.	Celtic and North Seas Wave Energy	Restricted to areas of low to moderate wave exposure < 1200 N/m^2 due to the infrastructure requirements of the culture method.
	Hatchery Reared Ranching of Crustaceans.	Celtic and North Seas Wave Energy	Restricted to areas of low to moderate wave exposure < 1200 N/m^2 due to the exposure tolerance of crustacean species.
	Cage Culture of all Finfish species.	Celtic and North Seas Wave Energy	Restricted to areas of low to moderate wave exposure < 1200 N/m^2 due to the infrastructure requirements of the culture method.
	Rope Culture of all Bivalve species.	Celtic and North Seas Wave Energy	Restricted to areas of low to moderate wave exposure < 1200 N/m^2 due to the exposure tolerance of bivalve species.
	Rope Culture of Macroalgae species with medium exposure tolerance levels.	Celtic and North Seas Wave Energy	Restricted to areas of moderate wave exposure >210 and < 1200 N/m^2 due to the exposure tolerance of macroalgae species.
	Rope Culture of Macroalgae species with high exposure tolerance levels.	Celtic and North Seas Wave Energy	Restricted to areas of high wave exposure >1200 N/m^2 due to the exposure tolerance of macroalgae species.
Tide Exposure	Bottom Culture of all Bivalve species.	Celtic and North Seas Current Energy	Restricted to areas of low to moderate current exposure < 1160 N/m^2 due to the exposure tolerance of bivalve species.
	Trestle /Bag Culture of all Bivalve species.	Celtic and North Seas Current Energy	Restricted to areas of low to moderate current exposure < 1160 N/m^2 due to the infrastructure requirements of the culture method.
	Hatchery Reared Ranching of Crustaceans.	Celtic and North Seas Current Energy	Restricted to areas of low to moderate current exposure < 1160 N/m^2 due to the exposure tolerance of crustacean species.
	Cage Culture of all Finfish species.	Celtic and North Seas Current Energy	Restricted to areas of low to moderate current exposure < 1160 N/m^2 due to the infrastructure requirements of the culture method.

Natural Resource	Species, Taxa or Method Constrained	Data Layer	Rules or Reason for Exclusion
	Rope Culture of all Bivalve species.	Celtic and North Seas Current Energy	Restricted to areas of low to moderate current exposure < 1160 N/m² due to the exposure tolerance of bivalve species.
	Rope Culture of Macroalgae species with medium exposure tolerance levels.	Celtic and North Seas Current Energy	Restricted to areas of moderate current exposure >130 and < 1160 N/m² due to the exposure tolerance of macroalgae species.
	Rope Culture of Macroalgae species with high exposure tolerance levels.	Celtic and North Seas Current Energy	Restricted to areas of high wave exposure >1160 N/m² due to the exposure tolerance of macroalgae species.
Depth	Bottom Culture of Blue Mussels.	DEM	Restricted to the intertidal zone down to 20m below CD, due to species depth tolerances.
	Bottom Culture of King Scallop.	DEM	Restricted to depths of 5 to 30m below CD due to species depth tolerances.
	Bottom Culture of Pacific Oysters and Native Flat Oysters.	DEM	Restricted to the intertidal zone down to 15m below CD, due to species depth tolerances.
	Bottom Culture of European Clam.	DEM	Restricted to the intertidal zone due to species depth tolerances.
	Trestle /Bag Culture of all Bivalve species	DEM	Restricted to the intertidal zone down to 3m below CD due to the culture method infrastructure requirements.
	Hatchery Reared Ranching of Crawfish.	DEM	Restricted to depths of 5 to 50m below CD due to species depth tolerances.
	Hatchery Reared Ranching of Lobster.	DEM	Restricted to depths of 10 to 30m below CD due to species depth tolerances.
	Cage Culture of Salmon and Sea Trout.	DEM	Restricted to depths of 15 to 50m below CD due to species depth tolerances and culture method infrastructure requirements.
	Cage Culture of Cod.	DEM	Restricted to depths of 15 to 20m below CD due to species depth tolerances and culture method infrastructure requirements.
	Rope Culture of all Bivalve species.	DEM	Restricted to depths of 20 to 50m below CD due to culture method infrastructure requirements.
	Rope Culture of all Macroalgae species. *Does not include Sea Lettuce species which has not been modelled.	DEM	Restricted to depths of 10 to 25m below CD due to culture method infrastructure requirements.
Water Quality	*All methods and species*	*Controlled Discharges*	*Discharges from combined storm overflows was used as a constraint in the marine spatial planning component of the model, see Table B2.*

N.B. *Grey text* identifies data layers which are not used within the model.
CD = Chart Datum.

B.2 Model Component 2 – Marine Spatial Planning Related Constraints

The following section describes the type of constraint posed to future aquaculture developments by MSP-related constraints (which includes other marine activities, associated infrastructure and nature conservation designations).

B.2.1 Constraint Type – Exclusion Areas

Exclusion areas were assigned where there is a fundamental incompatibility between an aquaculture method and an existing activity. Table B2 and Figure B5 show the activities and associated infrastructure/areas which are considered to be incompatible with future aquaculture expansion or development. All of these exclusion areas within the Welsh Marine Plan Areas will be merged together within the spatial model and this 'composite' exclusion layer will represent areas where there is considered not to be any potential for future aquaculture development. The 'buffer' applied represents standard industry exclusion zones around lease/licence areas or infrastructure, except for anchorage points, where the average size of a yacht was used.

Table B2. Sectors and data layers which will form the exclusion layer

Sector	Area (Data Layer)	Buffer Applied	Comment
Aquaculture	Bivalve Harvesting Classification Areas	None	
Aquaculture	Several & Regulating Orders	None	
Aquaculture	Mussel Seed Harvesting Areas	None	
Aggregates	Aggregate Licence Areas	None	
Aggregates	Aggregate Application Areas	None	
Cables	Cables	250m	Industry standard distance used for buffer.
Energy	Wave Lease Areas	None	
Energy	Tidal Lease Areas	None	
Energy	Oil & Gas Platforms	500m	Industry standard distance used for buffer.
Energy	Oil & Gas Pipelines	250m	Industry standard distance used for buffer.
Ports & Harbours	Anchorage Points	10m	Size of average small mooring yacht to determine to possible area where the yacht could swing round the anchor.
Ports & Harbours	Anchorage Areas	None	
Ports & Harbours	*Pilot Boarding Areas*	*None*	*None exist within Welsh waters therefore the layer is not included in the model.*
Ports & Harbours	Maintenance Dredging (Navigation Channels)	None	
Ports & Harbours	Open Dredge Disposal Sites	None	
Protected Sites	Protected Wrecks Exclusion Zones	None	
Protected Sites	Protected Wrecks points outside of Exclusion Zones	50m	Small exclusion zone (50m) applied where none has been defined for the wreck i.e. it is not included in the Protected Wrecks Exclusion Zones layer.

Sector	Area (Data Layer)	Buffer Applied	Comment
Shipping	IMO Traffic Separation schemes	None	
Water Quality	Consented Discharges – Storm Overflows	1km	Storm Overflow discharges were extracted from the data layer and those locations buffered to 1km.
N.B. Grey text identifies data layers which are not used within the model.			

B.2.2 Constraint Type – Defined Areas

Defined constraint areas refer to areas that have a 'set constraint' level within their borders, for example, areas used for yacht racing have a set constraint level within their border and no constraint outside of the border. Table B3 and Figures B6 to B7 show the marine activities and nature conservation designated sites which are considered to have the potential to conflict with future aquaculture expansion or development, and for which the potential conflict has been considered to be 'set' (or constant) over the entire area. Within the spatial model, these areas were assigned a defined value of 1, with the exception of protected areas which were given a double weighting and thus a defined value of 2. The defined values do not exclude the areas from possible future aquaculture expansion/development, but highlight areas where conflicts could arise.

Table B3. Sectors and data layers which will be given a defined constraint value

Sector	Area (Data Layer)	Buffer Applied	Comment
Aggregates	Option Areas	None	These sites were merged to remove duplication. Constraint value assigned 1.
Aggregates	Exploration & Option Areas	None	
Protected Areas	Marine & Offshore SACs including pSACs	None	All these protected areas were merged together then treated as one layer to avoid double counting where multiple designations overlap. The protected areas merged value were given a defined value double weighting, i.e. a value of 2.
Protected Areas	Marine SPAs including pSPAs	None	
Protected Areas	Ramsars	None	
Protected Areas	Marine SSSIs	None	
Protected Areas	Marine Nature Reserves	None	
Protected Areas	Wrecks	50m	
Protected Features	Grey Seal Haul Out Sites	None	
Military	Military Practice Areas	None	
Recreation	RYA Racing Areas	None	These sites were merged to avoid over-weighting areas where multiple activities occur. Constraint value assigned 1.
Recreation	Angling points	50 m	
Recreation	Windsurfing points	1 km	
Recreation	Surfing points	50 m	
Recreation	Swimming points	50 m	
Recreation	Blue Flag Beaches points	50 m	

B.2.3 Constraint Type – Graduated Areas

Graduated constraint areas refer to areas where an activity may vary in frequency or intensity across a given area, hence generating a range of constraint levels from high to low within the area. This type of constraint is usually linear/distance based i.e. the closer the activity or feature the higher the constraint level. Table B4 shows the activities and features for which this type of constraint is considered to apply and the data used to apply the graduated constraint level. These areas will be given a value from 0.1 to 1 depending on their overall contribution to the activity, e.g. the areas with the highest levels of fishing activity were given a value of 1 whereas areas with the lowest levels of fishing activity were given a value of 0.1.

Table B4. Sectors and data layers assigned a graduated constraint value

Sector	Area (Data Layer)	Buffer Applied	Comment
Shipping	AIS Shipping Density	none	The data were normalised by giving the highest density a value of 1.
Fishing	Integrated Fishing Effort	none	The data were normalised by giving the highest density a value of 1.
Seascape	*Seascape Visibility*	-	*Data layer was not used within the model due to the lack of quantitative seascape sensitivity data for the whole of the Welsh coastline*
Water Quality	Shellfish Waters	none	Constraint level related to the number of times that waters complied with shellfish flesh *E.coli* standards between 2011 and 2013. Highest constraint value of 2 given to areas which failed testing in 2013, value of 1 given to areas which failed in 2011 or 2012. Areas which did not fail were given a value of 0 i.e. no constraint.
N.B. *Grey text* identifies data layers which are not used within the model.			

B.3 Model Component 3 – Proximity to Essential Infrastructure and Investment Related Constraints

For the purposes of the current study, investment-related constraints, which would affect the viability of an aquaculture business, were considered to include:

- Distance of cultivation site from landing port;
- Distance to depuration facility; and
- Location of INNS.

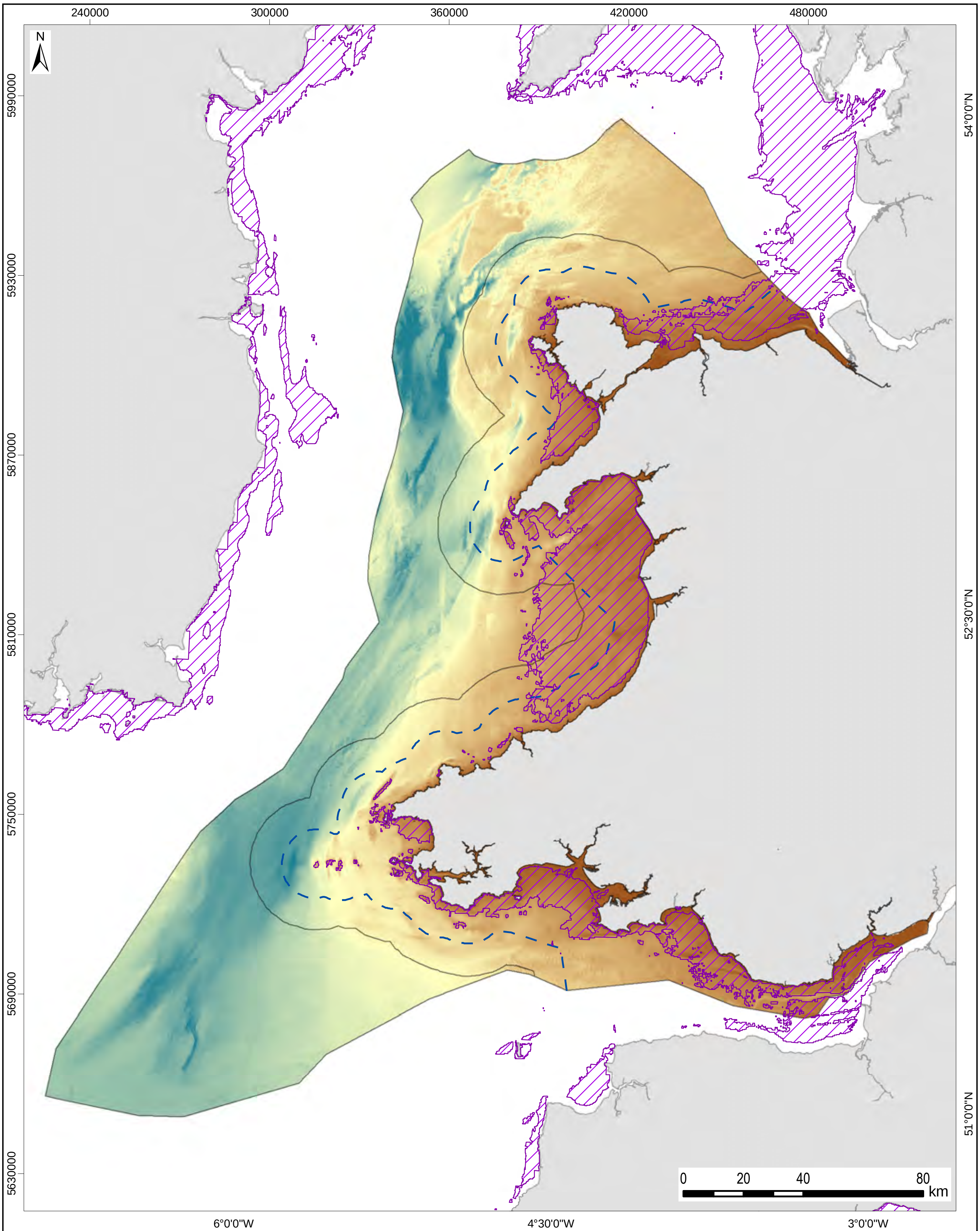
As described in Section 7, the distance between areas of potential for aquaculture development and landing ports and depuration centres were not considered to be significant constraints and/or not possible to assess accurately within the current study (see Section 7 for further detail). Hence these two potential constraint factors have not been included within the spatial model.

For the purposes of this study, the most significant risk to potential future aquaculture developments was considered to arise from the carpet sea squirt *Didemnum vexillum*, an INNS that has been shown to readily overgrow mussels and aquaculture gear. As such, in this study it has been assumed that the presence of this species in Holyhead marina would pose a significant risk to any type of future aquaculture development so an exclusion zone around this area was imposed as described in Table B5.

Table B5. Sectors and data layers used to represent an investment-related constraint

Constraint	Species, Taxa or Method Constrained	Area (Data Layer)	Buffer Applied	Comment
Disease	Bottom culture and trestle/bag culture of native and pacific oysters	*Bonamia ostreae.*	None	The polygon extents were given a defined value of 0.5.
Invasive Non Native Species	All species and methods	Holyhead Marina Exclusion Zone	Extent of exclusion zone applied around Holyhead Marina due to presence of *Didemnum*.	Data layer created by ABPmer, 5km buffer was applied to location of Holyhead Marina (March 2015). This area was given an exclusion value.
Invasive Non Native Species	Bottom culture of bivalve species	Crepidula fornicata	2.5km	Where a time series of points exists within a bay or estuary the points were buffered. These buffers were merged and dissolved to create two polygons.

Figures



Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System	WGS 1984 UTM Zone 30N		
Projection	Transverse Mercator		
Scale	1:1,800,000		
QA	TAP		
FigB1_NR_Bathymetry.mxd			
Produced by ABPmer			

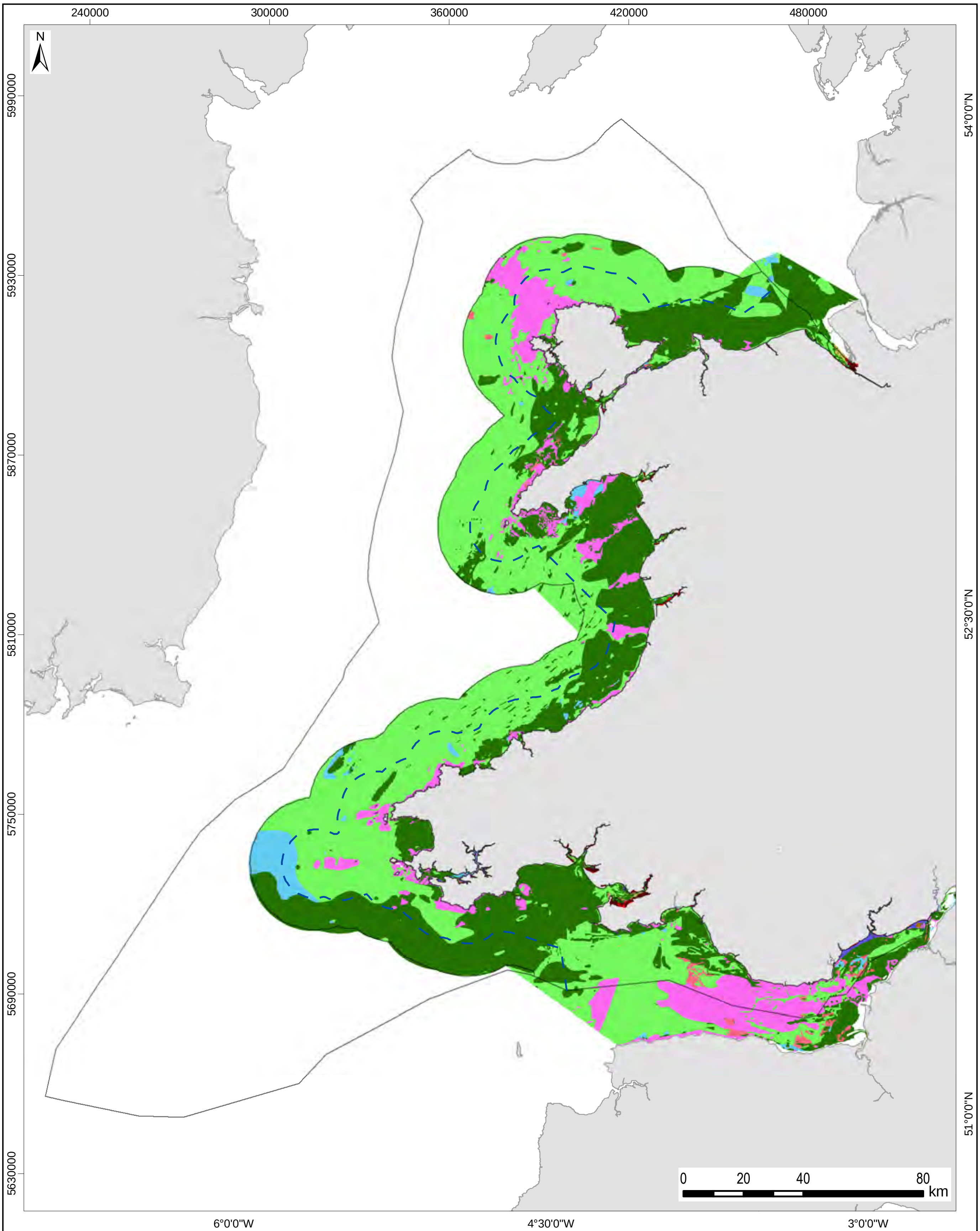
Extent of Photic Zone
6 NM Limit
Welsh Marine Plan Areas

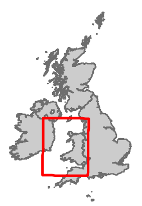
Bathymetry m CD
High : 9.941
Low : -182.035

ABP mer marine environmental research

Natural Resource Parameters - Bathymetry and Photic Zone

Figure B1





Date	By	Size	Version
Apr 15	TAP	A4	1
Coordinate System	WGS 1984 UTM Zone 30N		
Projection	Transverse Mercator		
Scale	1:1,800,000		
QA	FMM		
FigB2_NR_Seabed_sediments			
Produced by ABPmer			

Welsh Marine Plan Areas
6 NM Limit

Sediment Type

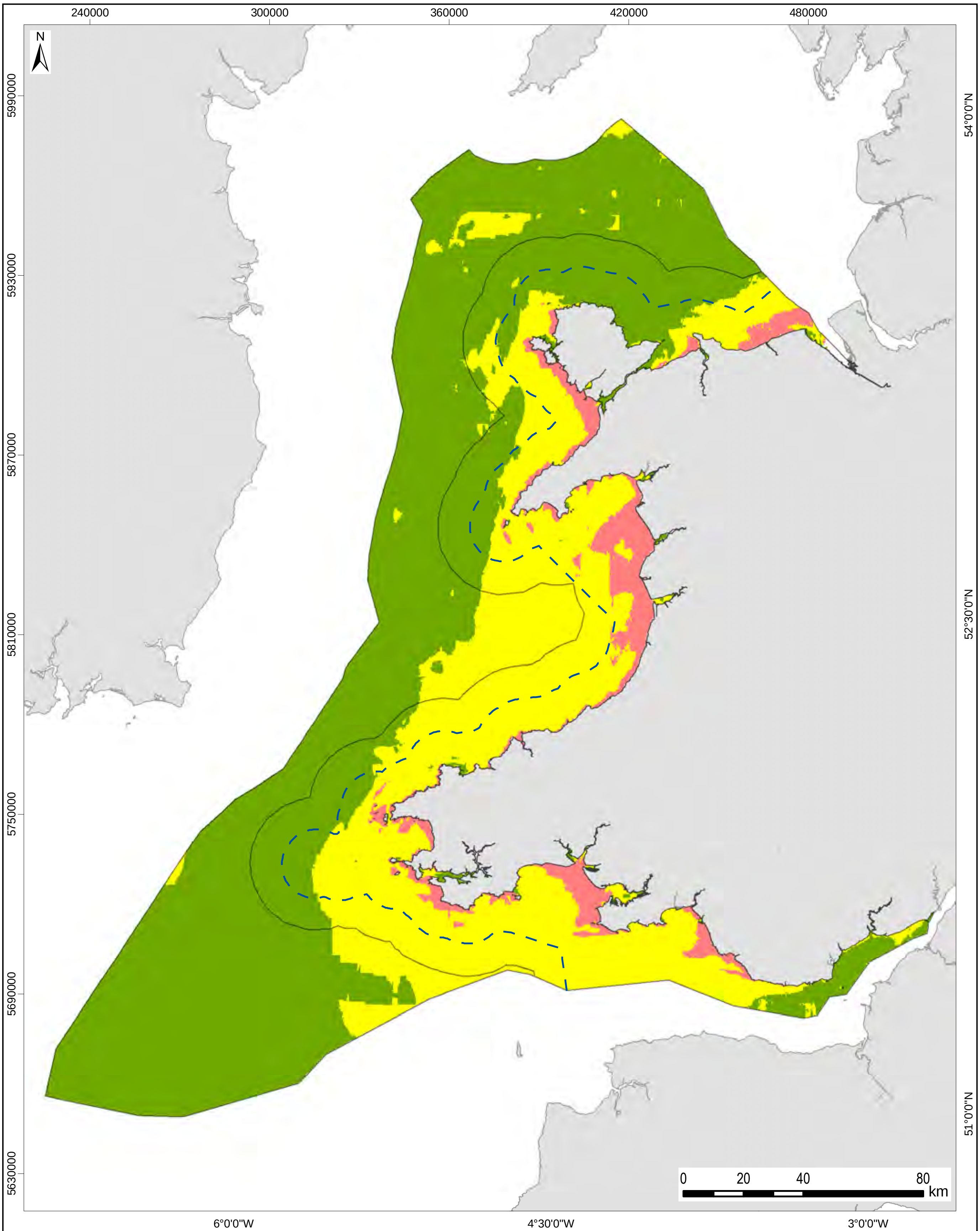
- Biogenic
- Coarse Sediment
- Mixed Sediment
- Mud
- Mud and Sand
- Rock
- Saltmarsh
- Sand
- Seagrass Beds

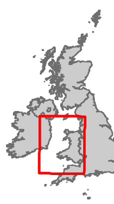
N.B. The sediment type was derived from "Combined Sediment Habitat Region" FishMapMon layer.

ABP mer marine environmental research

Natural Resource Parameters – Seabed Sediments

Figure B2





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System	WGS 1984 UTM Zone 30N		
Projection	Transverse Mercator		
Scale	1:1,800,000		
QA	TAP		
FigB3_NR_Waves.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas

6 NM Limit

Wave Exposure (Kinetic Energy N/m^2)

Low (<210)

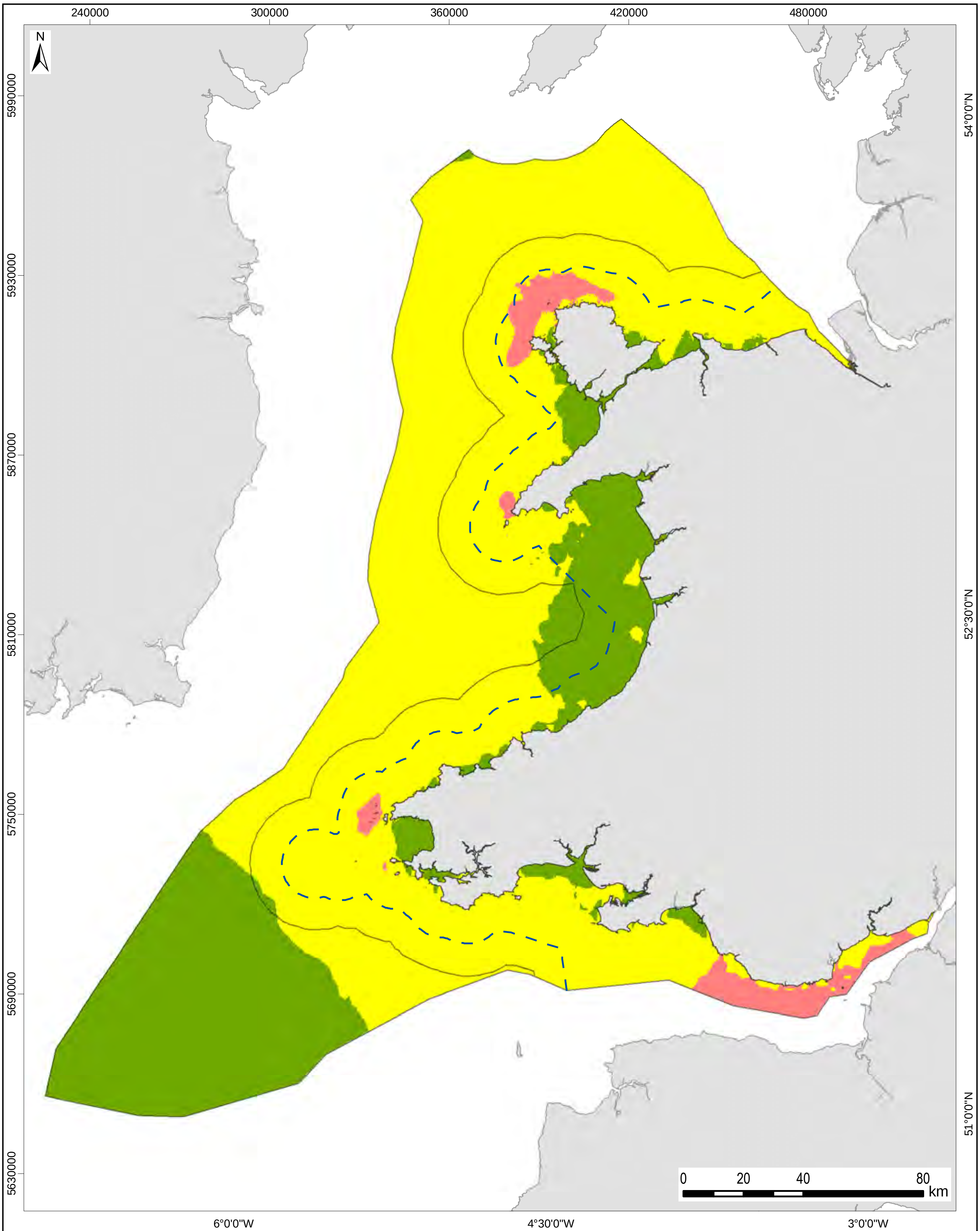
Moderate (210-1200)

High (>1200)

ABP mer
marine environmental research

Natural Resource Parameters – Wave Exposure (Kinetic Energy)

Figure B3



Date	By	Size	Version
Apr 15	TAP	A4	1
Coordinate System	WGS 1984 UTM Zone 30N		
Projection	Transverse Mercator		
Scale	1:1,800,000		
QA	FMM		
FigB4_NR_Tide.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas

6 NM Limit

Tidal Current Exposure (Kinetic Energy N/m²)

Low (<130)

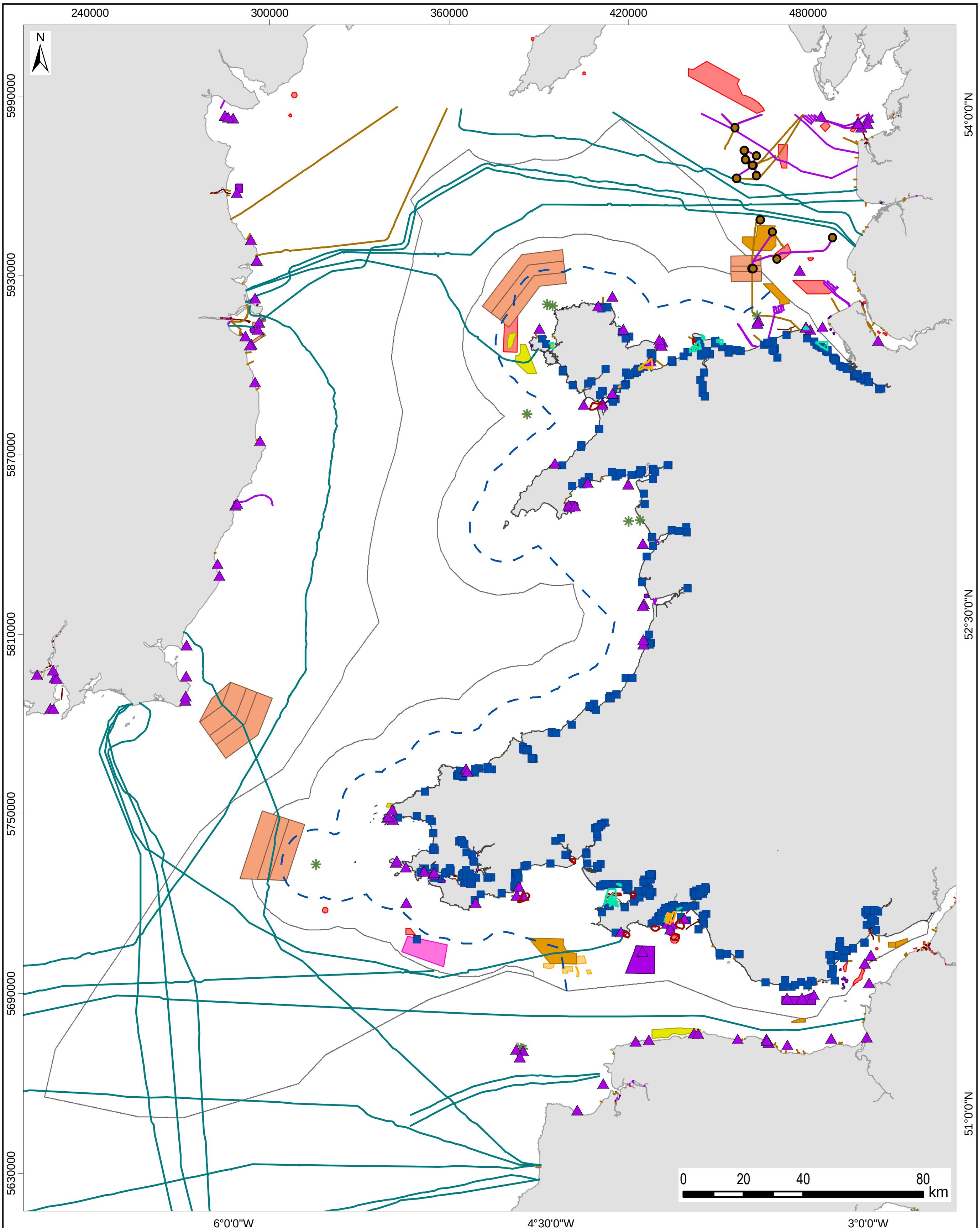
Moderate (130-1160)

High (>1160)

ABP mer marine environmental research

Natural Resource Parameters – Tidal Current Exposure (Kinetic Energy)

Figure B4



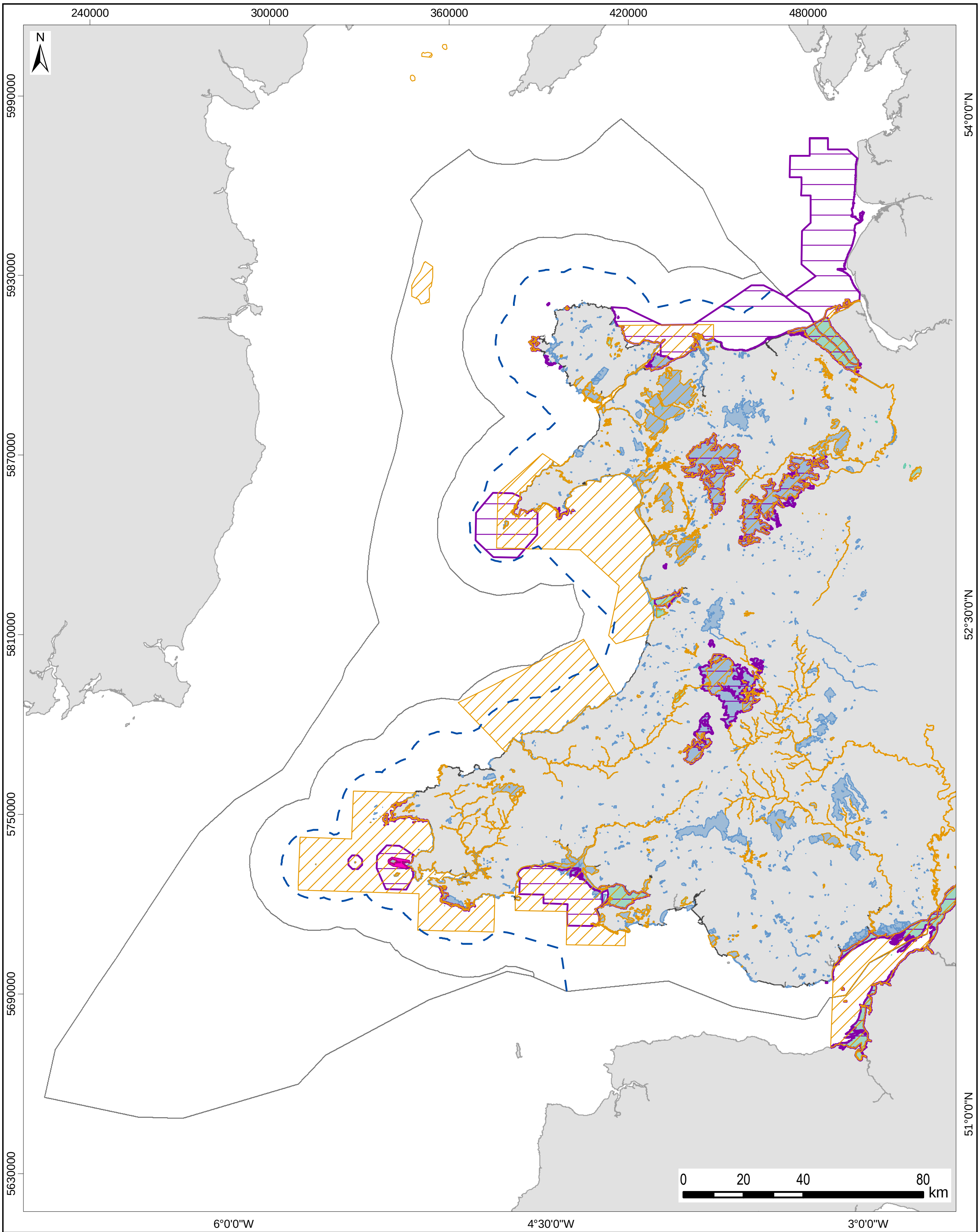
Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
FigB5_Plan_Exclusion.mxd			
Produced by ABPmer			

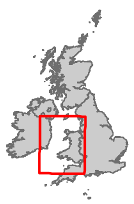
- 6 NM Limit
- Welsh Marine Plan Areas
- Oil and Gas Platforms
- Anchorages
- Storm Overflow Discharges
- Protected Wrecks
- Telecommunication Cables
- Power Cables
- Oil and Gas Pipelines
- Several Orders
- Classified Bivalve Harvesting Areas
- Mussel Seed Dredging
- Wave Lease Areas
- Tidal Lease Areas
- Aggregate Licence Areas
- Aggregate Application Areas
- Maintenance Dredge Areas
- Traffic Separation Schemes
- Anchorage Areas
- Open Disposal Sites
- Protected Wrecks Exclusion Zones

ABP mer marine environmental research

Marine Spatial Planning Parameters - Exclusion Area Constraint Activities

Figure B5





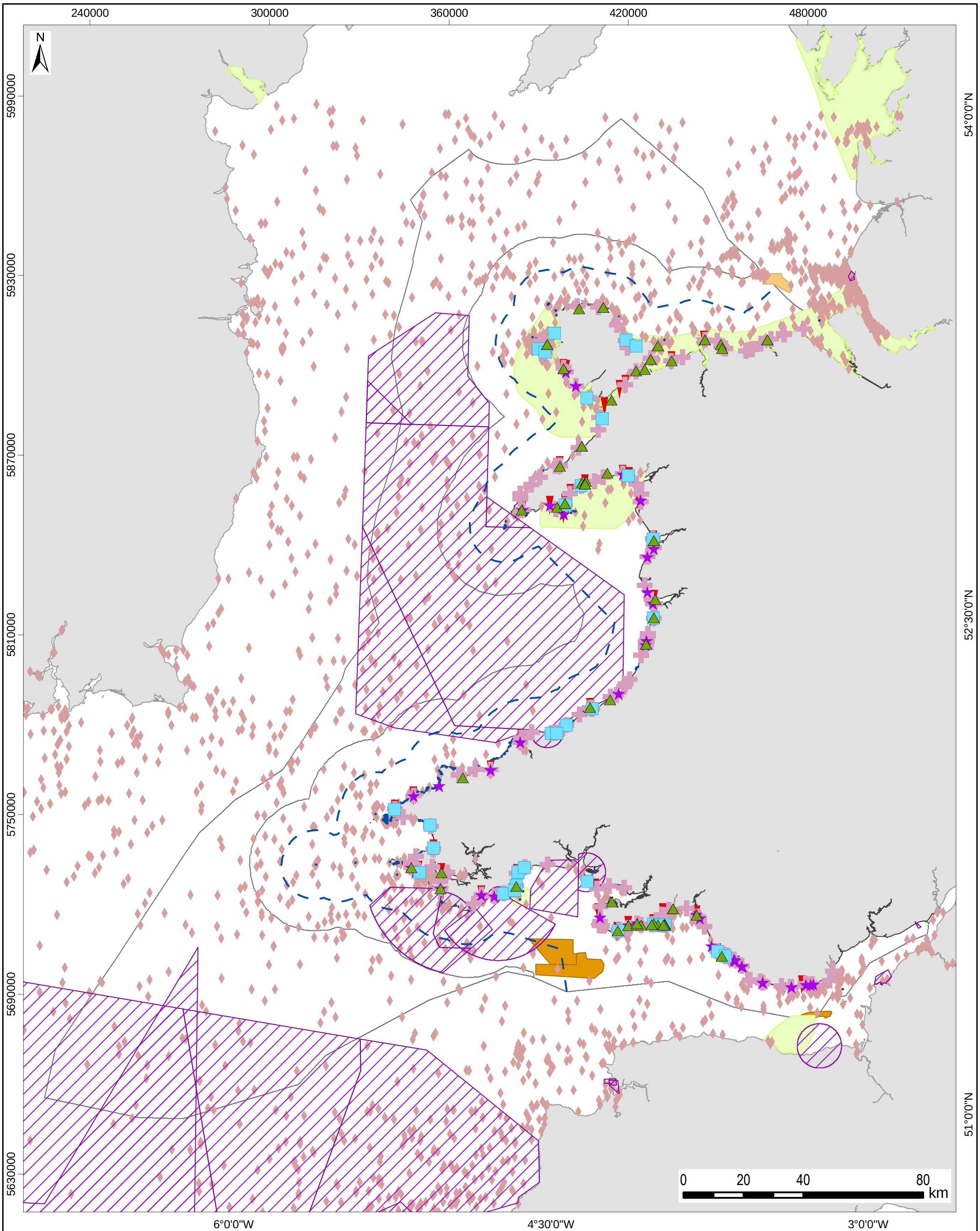
Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System	WGS 1984 UTM Zone 30N		
Projection	Transverse Mercator		
Scale	1:1,800,000		
QA	TAP		
FigB6_Plan_Defined_ProSites.mxd			
Produced by ABPmer			

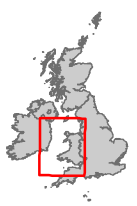
- Welsh Marine Plan Areas
- 6 NM Limit
- Marine Conservation Zone
- Ramsar Sites
- Special Areas of Conservation
- Special Protection Areas
- Sites of Special Scientific Interest

ABPmer marine environmental research

Marine Spatial Planning Parameters - Defined Area Constraint Protected Sites

Figure B6





Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System	WGS 1984 UTM Zone 30N		
Projection	Transverse Mercator		
Scale	1:1,800,000		
QA	TAP		
FigB7_Plan_Defined_Other_Activities.mxd			
Produced by ABPmer			

- Welsh Marine Plan Areas
- 6 NM Limit
- Wrecks
- Seal Haul Out Sites
- Military Practice Areas
- Aggregate Exploration and Option Areas
- Aggregate Option Areas

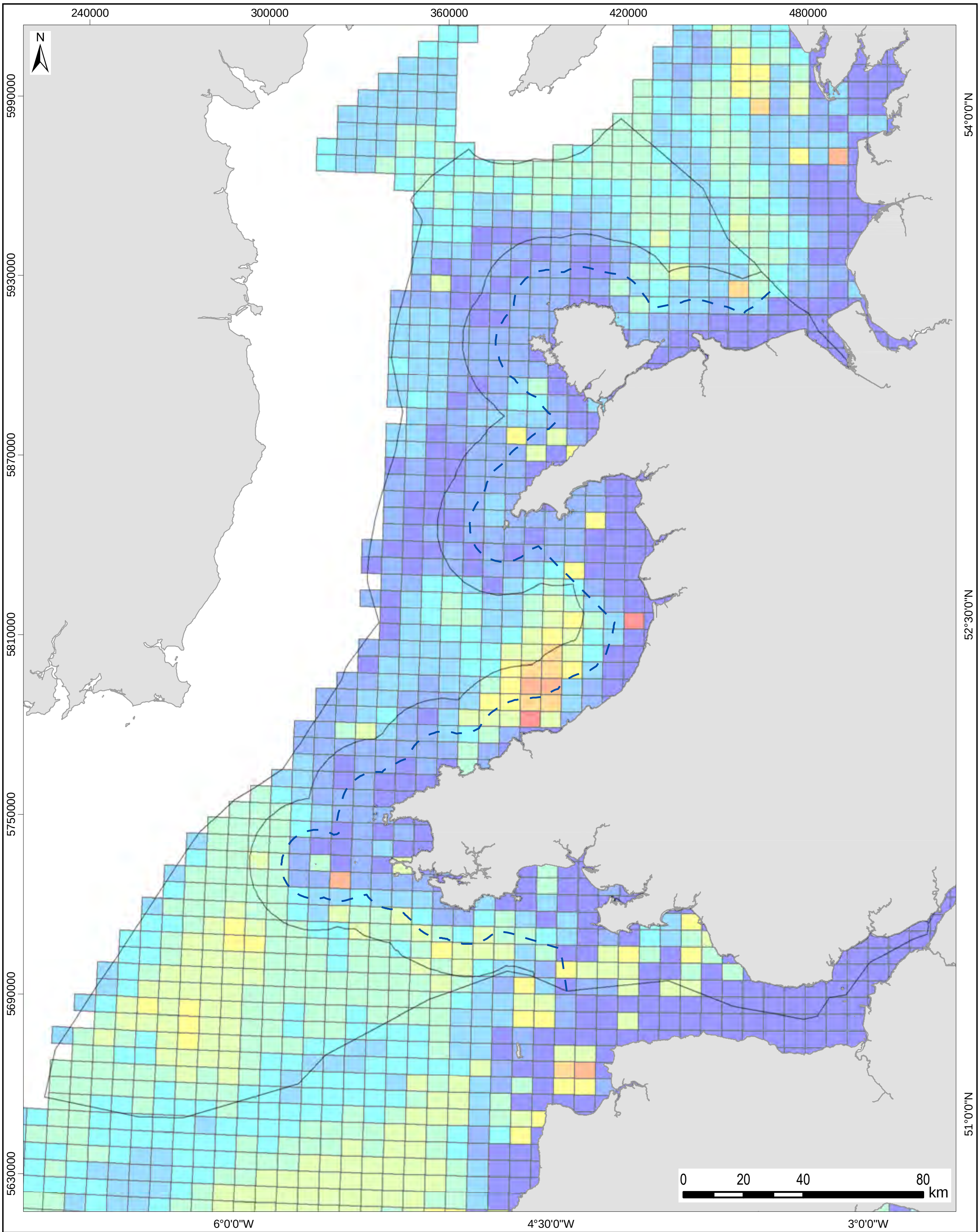
Recreation Activities

- Angling Sites
- Blue Flag Beaches
- Surfing Sites
- Swimming Sites
- Windsurfing Sites
- RYA Racing Areas

ABPmer
marine environmental research

Marine Spatial Planning Parameters - Defined Area Constraint Other Activities

Figure B7



Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
FigB8_Plan_Graduated_Fishing.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas
6 NM Limit

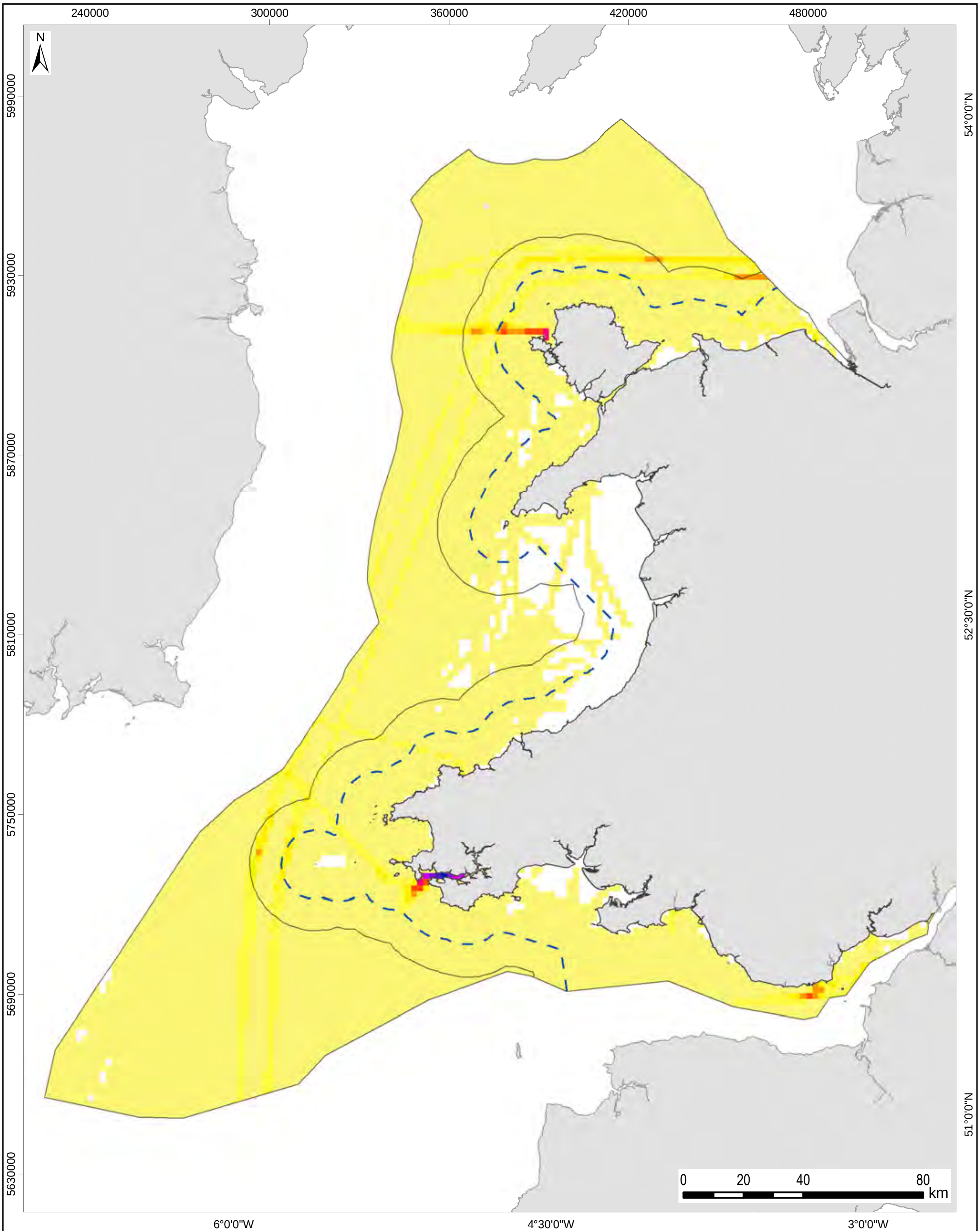
Integrated Fishing Effort (SPUE)
- 0.0000 - 0.0001
- 0.0002 - 0.0010
- 0.0011 - 0.0100
- 0.0101 - 0.0200
- 0.0201 - 0.0500
- 0.0501 - 0.1000
- 0.1001 - 0.2000
- 0.2001 - 0.2500
- 0.2501 - 0.5000
- 0.5001 - 1.0000

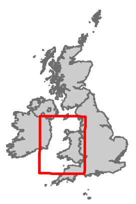
N.B. Fishing data is from Vanstaen 2010 (Defra contract MB0106). SPUE is Species Per Unit Effort.

ABP mer
marine environmental research

Marine Spatial Planning Parameters - Graduated Area Constraint Commercial Fishing

Figure B8





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
FigB9_Plan_Graduated_Shipping.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas

6 NM Limit

NOTE:
2 km Weekly Average Density Grid, created from 42 days of AIS-A and AIS-B data (MMO project 1066).

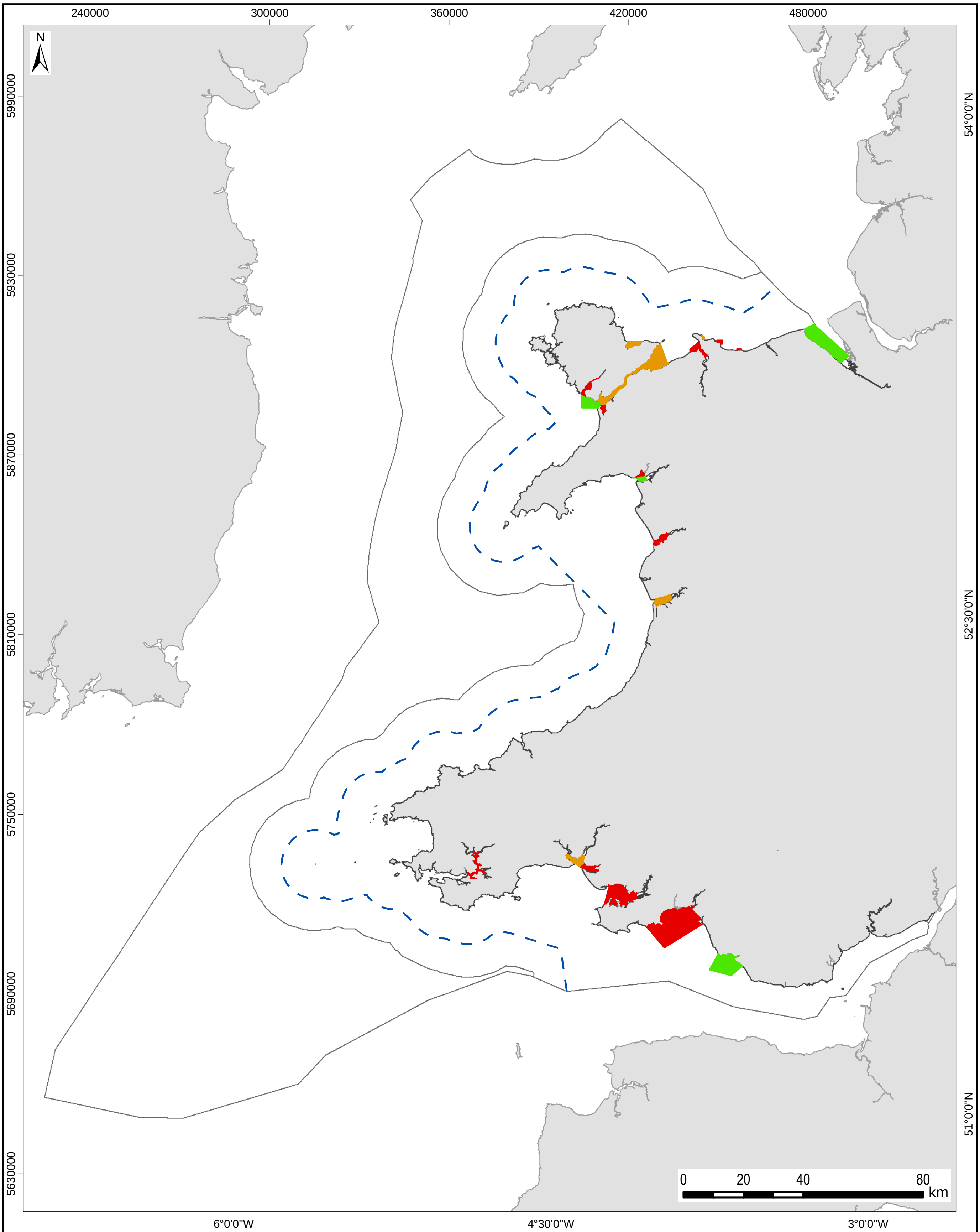
Shipping Density Weekly Average

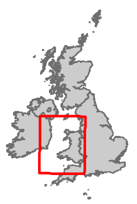
- 0.00 - 0.01
- 0.02 - 25.00
- 25.01 - 50.00
- 50.01 - 75.00
- 75.01 - 100.00
- 100.01 - 150.00
- 150.01 - 200.00
- 200.01 - 250.00
- 250.01 - 300.00
- 300.01 - 400.00
- 400.01 - 500.00
- 500.01 - 556.83

ABP mer
marine environmental research

Marine Spatial Planning Parameters - Graduated Area Constraint Shipping

Figure B9





Date	By	Size	Version
Apr 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
FigB10_Plan_Graduated_Water_Quality.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas

6 NM Limit

Shellfish Water Compliance with Flesh *E.coli* Standards

Passed in 2013 & 2011 or 2012

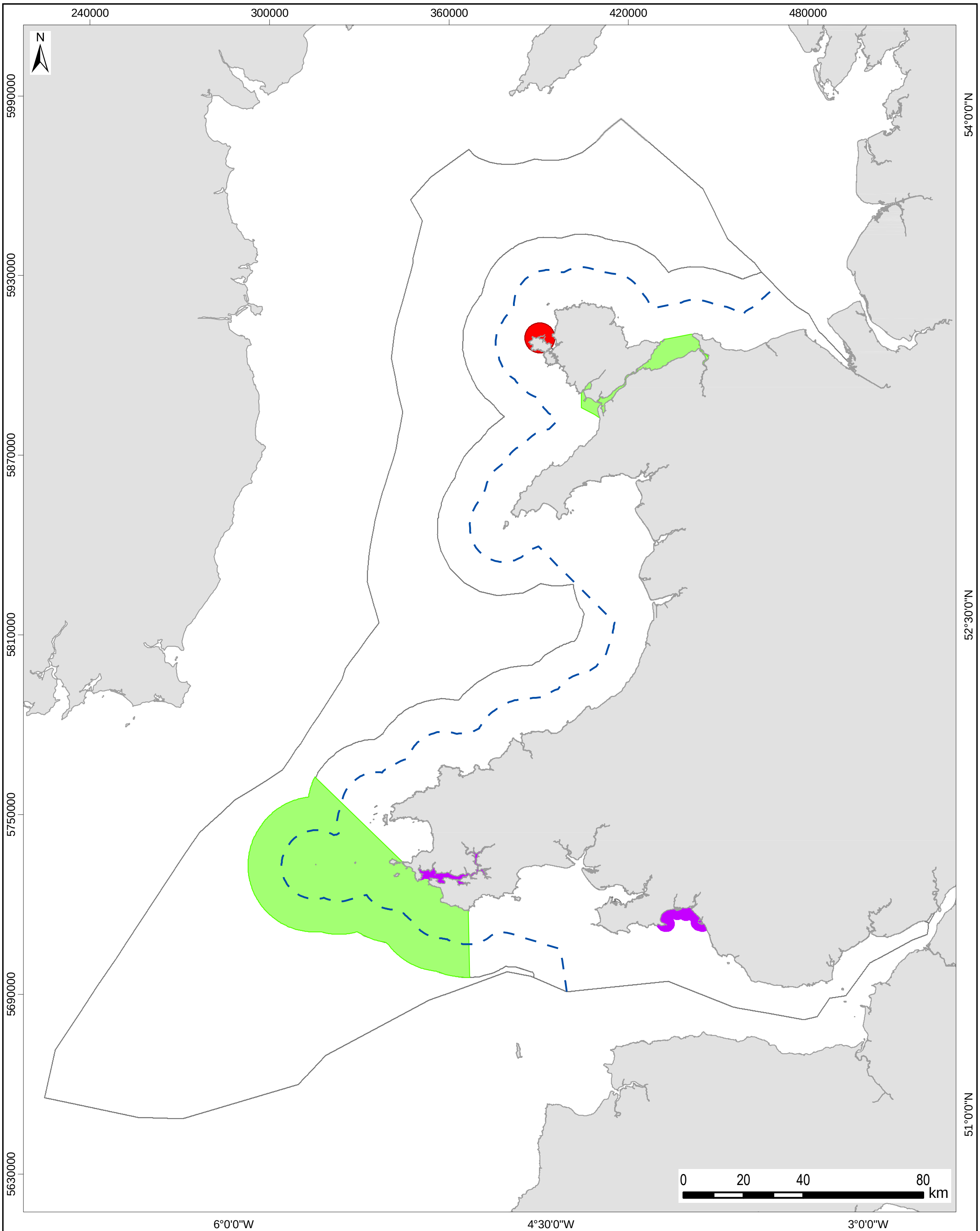
Failed in 2011 and 2012 but passed in 2013

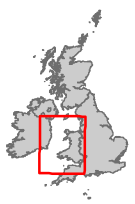
Failed in 2013

marine environmental research

Marine Spatial Planning Parameters - Graduated Area Constraint Water Quality

Figure B10





Date	By	Size	Version
May 15	FMM	A4	1
Coordinate System		WGS 1984 UTM Zone 30N	
Projection		Transverse Mercator	
Scale		1:1,800,000	
QA		TAP	
FigB11_Investment_related.mxd			
Produced by ABPmer			

Welsh Marine Plan Areas
6 NM Limit
Crepidula fornicata (INNS)
Holyhead Marina - *Didemnum vexillum* (INNS)
Confirmed Designations for*Bonamia ostreae* (Disease)

ABP mer
marine environmental research

Investment Parameters - Invasive Non-Native Species and Disease

Figure B11

Appendix C

Examples of Recent European Fisheries Fund Projects Undertaken in Wales

C. Examples of Recent European Fisheries Fund Projects Undertaken in Wales

Table C1 shows aquaculture projects in Wales that have been funded through the European Fisheries Fund, and illustrate the innovative nature of the industry in Wales.

Table C1. Recent aquaculture projects in Wales funded through the EFF (2012-2015)

Company	Project Title	Description of Project	Timescale
Mumbles Oyster Co Ltd	Re-instatement of Traditional Oyster Beds	To provide proof of concept that ranching is an effective cultivation technique for native oysters and to develop clear best practice guidance to enable the development of new native oyster cultivation businesses.	2013 / 2015
South & West Wales Fishing Community Ltd	Native Oyster Restoration/ Slipper Limpet Management (Scoping Project)	Study of native oysters that are under threat from slipper limpets and associated habitat loss. Project seeks to inform sustainable marine resource development and restoration of new aquaculture businesses.	2014 / 2015
Mumbles Oyster Company Ltd	Ranching seed native oysters trial	Project to provide 'test of concept' of oyster ranching as a method of commercial aquaculture.	2014 / 2015
Thomas Shellfish Ltd	Queen's Dock, Swansea, Mussel Fishery Marine Stewardship Council (MSC) Certification	Project will certify that Queen's Dock Mussel Fishery, Swansea, complies with standards set out by the Marine Stewardship Council (MSC) and will allow them to use this label on their products.	2013 / 2015
Thomas Shellfish Ltd	Queen's Dock, Swansea, Mussel fishery	To develop a new commercial mussel fishery within the Queen's dock in Swansea.	2011 / 2014
Selwyn's Seafoods Ltd	Seaweed Processing Plant	Development of Seaweed Snacks.	2013 / 2015
Seiont Research Ltd	Pilot Culture Programme for the European Spiny Lobster, *Palinurus elephas*	Pilot project to develop and refine culture techniques required for controlled *Palinuras elephas* (European spiny lobster) juvenile production through improved understanding of nutritional and water requirements of the larvae.	2013 / 2015
Anglesey Aquaculture Ltd	Upgrading of water treatment system and improved stock management	Investments to improve oxygenation, water treatment systems and provide improved stock management in existing recirculating aquaculture fish farm for bass.	2012 / 2014
Shellfish Association of Great Britain	Aquaculture in Welsh Offshore Wind Farms: A feasibility study into potential shellfish cultivation in offshore wind farms sites	To develop and provide a pathway that will enable and encourage the cultivation of shellfish in Welsh offshore wind farms. This project is a desk-top study which involves the development of links between the shellfish industry, off-shore renewable operators and managers.	2012 / 2015
Bangor University	Human Pathogens & Shellfish in the Conwy, Menai Strait & Burry Inlet	Sampling & mapping of human pathogen pollution which affects fish & shellfish health in Conwy estuary & Menai Straits.	2012 / 2015
Vitaplankton ltd	Marine phytoplankton for human consumption	Will test out the viability of growing marine phytoplankton for human consumption.	2013/2015

Appendix D

Review of Natural Resource Requirements

D. Review of Natural Resource Requirements

Site selection based on the natural resource requirements of the species to be farmed, and the equipment required, is a key factor in the success and sustainability of any aquaculture operation. This Appendix provides an overview of the cultivation methods which have the potential to support future aquaculture production in Welsh Waters (identified in Section 4 of the main report) and the natural resource requirements for the species which may be cultivated using these methods. Abridged versions of these reviews are presented in Section 5 of the main report, where it was also noted that while the natural resource requirements incorporated into the spatial model provide an assessment of the environmental conditions under which aquaculture developments are most likely to be successful, it was beyond the scope of the current study to address issues such as biological carrying capacity, wild seed/spat supply or disease within the model. The influence of these factors on the viability of future aquaculture developments have been considered qualitatively in Sections 8 and 9 of the main report.

D.1 Bottom Culture of Bivalves

Bottom culture aquaculture is the practice of rearing 'seed' or young shellfish directly on benthic substratum (i.e. the foreshore or seabed). Species that are currently being cultivated in this way in Wales include the blue mussel, *Mytilus edulis* at sites in the Menai Strait and oyster in Swansea Bay. Other native species that are typically cultivated in this way in the UK and have the potential for future development in Wales include the native flat oyster, *Ostrea edulis*, and the king scallop, *Pecten maximus*. Harvesting of the European clam (*Ruditapes decussatus*) mainly occurs in Spain and France, although is commonly present in the south and west coast of the British Isles. Culture technique for *Ruditapes decussatus* is simple and consists of regular maintenance of the substrate, avoiding overgrowth by algae, starfish and other predators; oxygenating the substrate; and maintaining an appropriate clam density and seeding juvenile clams (FAO, 2015). A number of introduced bivalve species are also cultured in the UK including the Pacific oyster *Crassostrea gigas* and the manila clam, *Venerupis philippinarum* (Laing and Spencer, 2006; Seafish, 2012; Spencer, 2002).

Bottom culture involves re-laying shellfish seed in the chosen nursery area and then letting them grow to a harvestable size. This form of aquaculture is often practised in shallow (subtidal and intertidal) coastal or estuarine areas but can also be undertaken in deeper waters where boats use dredges to collect, relay and harvest shellfish (Nehls *et al*., 2009; Cefas, 2009; Hagos, 2007; Laing, 2002; Wieland and Paul, 1983). There is little on-going management required in this form of aquaculture until the shellfish have reached the desired size for harvesting, apart from occasional monitoring and removal of predators if practicable, although stakeholder feedback in the current study indicated that substantially more husbandry is undertaken for the mussel lays in the Menai Strait (described in Section 5.1 of the main report)

Harvesting techniques for bottom cultured shellfish can vary from dredging to simple hand-collection or hand-raking on lower yield operations (Spencer, 2002). High densities of species result in a relatively small area being utilised, and as the plots are usually re-used soon after harvest, the ecosystem could be classified as a permanent commercial shellfish bed. This form of aquaculture is sometimes referred to as "ranching". The Sea Fisheries (Shellfish) Act 1967 (as amended) allows for sole harvest rights using 'Several and Regulated Fishery Orders' where stocking is taking place.

Image D1. Photographs of bottom cultured blue mussels (*Mytilus edulis*) being harvested

There may be the potential for increased production of the Pacific oyster in Wales, through the use of triploid seed produced by crossing tetraploid males and diploid female oysters (to produce 'mated triploids), for the biological containment (prevention of wild settlement) of this non-native species.

Triploidy impedes reproductive success and constrains reproductive effort (in theory producing sterile oysters) leaving more resources for flesh production and the potential for year round production. Triploid oyster seed can currently be obtained from several hatcheries in the UK and Guernsey.

Research has suggested that the effectiveness of triploidy for preventing wild settlement is greater in 'mated' triploid oysters (produced by crossing tetraploid males and diploid females) than through the chemical shock induction method currently used in UK hatcheries due to a patent which has prevented 'mated' triploid production (see Herbert *et al*. 2012). However, a recent lapse in this patent may provide an opportunity for production of 'mated' triploid seed in the UK.

Theoretically it is possible to obtain batches of triploid embryos at 100% success rate when 'mating' tetraploid males and diploid females and there is also evidence that triploid Pacific oysters are more resistant to summer mortality events (Syvret, 2008). However significant resources are required to undertake selective breeding (Syvret, 2008) and the method can be costly and time consuming.

D.1.1 Temperature

Seawater temperature plays an important role in the seasonal growth of shellfish and is thought to be one of the main contributing factors to differences in growth rates between sites (Laing and Spencer, 2006). Bivalves usually begin to grow when sea water temperatures rise to 8-9°C and the fastest growth occurs over the summer when water temperatures reach 16-18°C. Growth declines to a low level in the winter when temperatures fall below 8-9°C (Laing and Spencer 2006; Spencer 2002; Camacho *et al*., 1995; Mallet *et al*., 1987).

High mortalities of Pacific oyster, spat have been observed when held at 3°C in lab experiments (Child and Laing, 1998) indicating that production could be severely impacted by low temperatures. At the other end of the scale temperatures exceeding 20°C have been found to cause physiological stress and mortality in bivalves, especially when combined with high stocking densities, high salinities, low levels of water exchange, the introduction of chemical pollutants or depleted food resources (Laing and Spencer, 2006; Newell and Pye, 1970; Hutchinson and Hawkins, 1992).

D.1.2 Salinity

The open coastal areas that are the subject of this study are fully marine and salinities are likely to fluctuate between 30 and 35 over most of the area. However, fresh water inputs from rivers and outfalls will reduce the salinity in some areas and a greater range of salinities will also occur in shallow intertidal areas where rainfall can reduce salinities and water evaporation on hot days can cause the salinity to rise.

An ambient salinity of 30 or above is required for the king scallop, *P. maximus* which is a fully marine species, meaning that areas adjacent to freshwater inputs will not be suitable for the cultivation of this species (Laing, 2002). Conversely, the Pacific oyster requires salinities around 25 for optimal growth rates to be achieved (Laing and Spencer, 2006) and is well suited to culture in the inshore areas from which the king scallop is excluded. Species such as the native oyster, *O. edulis*, the blue mussel, *M. edulis* and the European clam, *R. decussatus* which naturally occur in estuaries, are well adapted to salinity changes and site selection for these species is unlikely to be limited by salinity.

It is worth noting that there is an additive relationship between salinity and temperature stress for most bivalve species. For example, scallops can survive temperatures as low as 3°C at salinities above 30, but they may die at temperatures below 5°C if salinity falls to less than 26 (Laing and Spencer, 2006). Therefore these two aspects of the environment should ideally be considered in tandem.

D.1.3 Substrate

The substrate on which bivalves are cultivated using bottom culture techniques is critical and ideally must reflect the environment in which they are normally found. Oysters and mussels require sediment sufficiently firm to prevent them from sinking or becoming smothered. Clam cultivation requires softer sediments such as mud or sands to enable them to bury themselves sufficiently to avoid predation. Scallops can evade predation by “swimming” or clapping their shells together as well as partially burying themselves in the substrate and as a result they are found on a much wider variety of substrate types typically ranging from sands and fine gravels to sandy gravels (Laing, 2002).

Other considerations associated with substrate for bivalve bottom cultivation sites include access and harvesting. It is important to consider the type of equipment likely to be used for planting, maintenance and harvesting, particularly for intertidal clam beds. Some beaches will support wheeled or tracked vehicles, while others are too soft and will require the use of a boat to transport equipment.

D.1.4 Exposure to Air

Bivalves can only breathe, feed and grow when they are submersed and therefore growth rates are strongly influenced by the length of time during which the animals are covered by the tide. Native oysters are generally kept fully submerged whilst being cultured, as their desiccation tolerance is relatively low (Laing, 2002). Scallops are fully marine and have little to no tolerance of desiccation because their two shells do not fully close (Laing, 2002). Similarly, it is recommended that very small

Pacific oysters and clams are kept as close to the spring low water limit as possible to ensure almost 100% submergence, whilst allowing for maintenance access. Submergence also offers some protection against frosts or near freezing air temperatures which most bivalve species cannot tolerate. Larger Pacific oysters and clams are able to withstand periodic exposure to air and will continue to grow when subjected to 35% and 50% exposure respectively (Laing and Spencer, 2006).

D.1.5 Wave/Tidal Exposure

Wave exposure needs to be considered carefully when selecting a site for bivalve culture. Strong waves can easily cause physical damage to the shellfish being cultured and can even result in wholesale losses in extreme conditions (Brown, 2010). The optimal tidal flow is thought to be around 1-2 knots, which ensures a good food supply but oysters can cope with weaker currents where adequate water exchange is maintained by wave action (Laing and Spencer, 2006; Spencer, 2002).

D.1.6 Water Quality

Water quality is thought to be one of the biggest limiting factors influencing growth of the shellfish culture industry in the UK (Laing and Spencer, 2006). All shellfish growing sites must have or obtain a classification, in accordance with EU regulations, according to the degree of microbiological contamination of the waters in which cultivation is taking place (see Sections 6.2.3 and 7.2 in the main report). Shellfish waters are monitored for numerous water quality parameters including suspended solids, dissolved oxygen and a variety of contaminants. Shellfish are also closely monitored for coliforms in their flesh and within their plankton food to ensure that they are safe to eat. Depuration is a vital stage in the shellfish production process, which ensures that any potential contaminants have been washed out of the animal before consumption. Water quality therefore has an economic implication for the production of shellfish since those grown in pristine waters will not need to undergo this process, thus reducing the cost.

D.1.7 Depth

Bottom culture occurs across the intertidal zone and well into the subtidal zone, where management and harvesting is undertaken using mechanical and suction dredges and/or divers. Mussel culture in the Netherlands extends down to water depths of around 20m (Nehls *et al*., 2009; Wieland and Paul, 1983) whilst scallop culture or on-growing can extend down to 30m (Laing, 2002). As this type of bivalve ranching extends into deeper waters the distinction between aquaculture and enhanced capture fisheries does start to become blurred. However, for the purpose of this study any fishery that is enhanced is considered to be aquaculture and these activities would, therefore, qualify for inclusion.

The culture of different bivalve species will be more or less successful in different water depths depending on the species desiccation, temperature and salinity tolerances and food availability, as previously discussed. Management of offshore bottom culture sites may be problematic as there may be conflicts with commercial fisheries operating in the area and poaching by divers could also represent a significant threat.

Table D1. Summary of the key environmental requirements of shellfish species typically cultivated through bottom culture

Species	Temperature (^{o}C)*	Salinity**	Sediment Type	Wave/Tidal Exposure	Water Quality***	Depth
Blue Mussel, *Mytilus edulis*	2.5-19	>20	Coarse/firm sediment	Low to Moderate Exposure	n/a	Intertidal to 20m below CD
King Scallop, *Pecten maximus*	n/a	>30	Sands, fine gravel and sandy gravel	Low to Moderate Exposure	n/a	5 to 30m below CD
Pacific Oyster, *Crassostrea gigas*	19 for optimal growth	25 for optimal growth	Coarse/firm sediment	Low to Moderate Exposure	n/a	Intertidal to 15m below CD
Native Flat Oyster, *Ostrea edulis*	n/a	>20	Coarse/firm sediment	Low to Moderate Exposure	n/a	Intertidal to 15m below CD
European Clam, *Ruditapes decussatus*	3-30	<40	Sand and silty mud	Favour sites away from high hydrodynamics	n/a	Intertidal Zone
Bottom cultured bivalves (in general)	>20 and <3 can cause physiological stress to shellfish and even mortalities	Limiting at the species level only	All sediments except rock	Low-moderate exposure, tidal currents < 1160 N /m^2 or wave exposure <1200 N /m^2	≥80% dissolved oxygen recommended by Council Directive 79/923/EEC	Intertidal to 30m below CD (currently limited by the cultivation and harvest mechanics and cost)

* Temperature has not been used within the model due to the resolution of the available spatial data and no incorporation of seasonal variation within the model.

** Salinity has not been used within the model due to the resolution of the available spatial data. However, salinity was considered to limit areas potentially suitable for fully marine species (i.e. King scallop) and hence an indicative boundary in the Bristol Channel, east of which salinity was considered to be on average below 30, was derived from Severn Tidal Limits data and added as a constraint to the model. It should also be noted that any areas indicated as suitable for this species in the upper reaches of Milford Haven should be disregarded.

*** Water quality in Shellfish waters has been incorporated into the MSP model component.

CD Chart Datum

(Source: Rosenberg *et al*., 1991; Laing, 2002; Spencer, 2002; Laing and Spencer, 2006; Cassis *et al*., 2011; Kapetsky *et al*., 2013; FAO, 2015a)

D.2 Trestle/Bag Culture of Bivalve Shellfish

Trestle/bag aquaculture is the practice of rearing juvenile shellfish, commonly Pacific and native oysters, in bags or plastic cylinders that are held above the seabed by timber or metal frames. These frames are approximately 50 cm in height and 1km^2 of trestles with rows 10m apart could produce over 500 tons of harvest-size oysters (Jon King, Bangor University, pers. comm.). Oysters cultivated in plastic net bags supported above the ground are afforded greater protection from predators and have greater access to free-flowing nutrients; thus, they grow faster than bottom culture oysters (Laing and Spencer, 2006; Brown, 2010). Little maintenance is required, apart from occasional grading and possibly predator removal, until the oysters are of a suitable size to harvest. There is also potential to rear juvenile blue mussels in this way although this method is not commonly associated with the species.

D.2.1 Temperature

As with bivalves cultured on sediments those reared in trestles and bags are generally tolerant to temperatures ranging from 3 to 20°C. Bivalves grown in this manner may be afforded less protection from freezing temperatures as they are exposed to air for periods of time. Similarly they may be more susceptible to high temperatures especially where they are densely stocked and/or exposed for longer periods of time (Laing and Spencer, 2006; Spencer, 2002).

D.2.2 Salinity

Optimal growth rates in the Pacific oyster, are generally achieved at salinities around 25 and so this species is perhaps best suited to estuarine and coastal waters with some freshwater input. The native oyster, *Ostrea edulis*, naturally occurs in areas with varying salinities and hence this is unlikely to be a major limiting factor in site selection for this species (Laing and Spencer, 2006).

D.2.3 Substrate

Substrate is less critical for trestle/bag culture as the containers themselves act as the substrate for the shellfish whilst simultaneously offering some protection from predators. Intertidal cultivation on trestles does however require firm sediment to prevent the equipment from sinking, although horizontal plates fitted to the feet of the trestles reduce this effect (Spencer, 2002). As the trestle/bag structures must be anchored into the sediments, rock substrates are not usually suitable for this type of culture.

D.2.4 Exposure to Air

Bivalves can only breathe, feed and grow when they are submersed and therefore growth rates are strongly influenced by the length of time during which the animals are covered by the tide. Pacific oysters are able to withstand periodic exposure to air and will continue to grow when exposed to air up to 35% of the time, whilst native oysters will grow better if fully submersed all of the time (Laing and Spencer, 2006). Brenner *et al*. (2012) tested the effect of air exposure on blue mussels that were collected from suspended culture ropes; the study revealed that mussels displayed a high tolerance to aerial exposure, with moderate levels of mortality after 12 to 48 hours of exposure.

D.2.5 Wave/Tidal Exposure

Wave exposure can damage trestle/bag culture systems and very exposed areas are likely to become uneconomical. The optimal tidal flow is thought to be around 1-2 knots, which ensures a good food supply, but oysters can cope with weaker currents where adequate water exchange is maintained by wave action (Laing and Spencer, 2006; Spencer, 2002; Seafish, 2012).

D.2.6 Water Quality

As detailed in Section C1.6 for bottom cultured bivalves.

D.2.7 Depth

Trestle/bag cultivation techniques are typically carried out in areas where there is a large intertidal zone although the move towards raised trestles means that there is potential for this type of aquaculture to move into shallow subtidal environments. There is also a possibility that trestle/bag culture could extend into the offshore environment to make use of shallow offshore sandbanks that are exposed or nearly exposed during low tides, although the economic returns are unlikely to justify the additional overheads associated with offshore developments of this type.

Table D2. Summary of the key environmental requirements of shellfish species typically through trestle and/or bag culture

Species	Temperature (ºC)*	Salinity**	Sediment Type	Wave/Tidal Exposure	Water Quality***	Depth
Pacific oyster, *Crassostrea gigas*	19	25 for optimal growth	Firm sediment	Low to Moderate Exposure	n/a	Intertidal to 3m below CD
Native oyster, *Ostrea edulis*	n/a	>20	Firm sediment	Low to Moderate Exposure	n/a	Intertidal to 3m below CD(limited by culture technique)
Blue mussel, *Mytilus edulis*	2.5-19	>20	Firm sediment	Low to Moderate Exposure	n/a	Intertidal to 3m below CD (limited by culture technique)
Trestle/bag cultured bivalves in general	>20 and <3 can cause physiological stress to shellfish and even mortalities	All- limiting at the species level only	All substrates except rock	Low-moderate exposure, tidal currents < 1160 N/m² or wave exposure < 1200 N/m²	≥ 80% dissolved oxygen recommended by Council Directive 79/923/EEC	Intertidal to 3m below CD

* Temperature has not been used within the model due to the resolution of the available spatial data and no incorporation of seasonal variation within the model.
** Salinity has not been used within the model due to the resolution of the available spatial data.
*** Water quality in Shellfish waters has been incorporated into the MSP model component.
CD Chart Datum

(Source Laing and Spencer, 2006; Laing, 2002; Spencer, 2002; Cassis *et al*., 2011)

D.3 Rope/Line Grown Bivalve Shellfish

Rope/line-grown shellfish aquaculture in the UK is limited to blue mussels (*Mytilus edulis*) and king scallops (*Pecten maximus*). Mussels are commonly cultivated by longlines connected to large floats and anchored at both ends, which support a large number of “droppers” (ropes). The coiling “droppers”, on which the mussels are grown, are suspended in the top 2 – 3 m of the water column in time for the wild spat fall. Once seed mussels have settled, the droppers are uncoiled to their full length (generally 6 – 10m). Little further management is required in this form of aquaculture until the bivalves have reached the desired size for harvesting.

Cultivation methods using pearl and lantern nets suspended from long-lines are typically used to raise scallop seed, although lantern nets can also be suspended between larch poles embedded in the intertidal area. Pearl nets are generally used for small (10-30mm shell height) scallops and lantern nets for larger animals (Laing, 2002). As with mussel suspended culture, the main lines are held afloat by buoys and anchored by mooring blocks. Farmers use spacing and orientation of the culture ropes to control growth and condition of the crop (Spencer, 2002).

D.3.1 Temperature

As with bivalves cultured in the intertidal zone, rope/line grown bivalves are generally tolerant to temperatures ranging from 3 to 20°C. Bivalves grown in this manner are less likely to experience the extremes in temperatures that they are sensitive to as they will be permanently submerged (Laing and Spencer, 2006).

D.3.2 Salinity

As with temperature, the salinity of the open ocean is relatively stable and this is unlikely to be a limiting factor for the growth of mussels or king scallop on ropes and lines.

D.3.3 Substrate

Rope/line aquaculture can be deployed on more or less any substrate since the only contact is made by the anchors. However, the extent of anchorage required is a function of the sediment resilience and the sites exposure; as a result the nature of the chosen substrate will have economic consequences.

D.3.4 Wave/Tidal Exposure

Although suspended culture of shellfish need some current and wave action to ensure they get sufficient food, the farms are relatively fragile and easily damaged in heavy seas and strong currents unless they are securely anchored. A moderate current (between 1-2 knots) is required (Laing and Spencer, 2006) to ensure an adequate supply of food.

D.3.5 Water Quality

As detailed in Section C1.6 for bottom cultured bivalves.

D.3.6 Depth

Sufficient depth is required to ensure that the dropper ropes do not bottom out at low tide. The maximum depth limit is currently dictated by the economic and technological limitations posed by longer moorings but it is likely that rope grown mussel culture will move further offshore in the future. The first English offshore mussel culture licences were granted in 2010 for the Lyme Bay area where three trial sites are due to be set-up between 3 and 6 nautical miles offshore.

Table D3. Summary of the key environmental requirements of shellfish species typically cultivated on ropes or lines

Species	Temperature (ºC)*	Salinity**	Sediment Type	Wave/Tidal Exposure	Water Quality***	Depth
Blue mussel, *Mytilus edulis*	2.5-19	>20	n/a	Low to Moderate Exposure	n/a	>13m below CD
King Scallop, *Pecten maximus*	n/a	>30	n/a	Low to Moderate Exposure	n/a	>13m below CD
Rope/line cultured bivalves in general	>20 and >3 can cause physiological stress to shellfish and even mortalities	Fully marine	Any, areas of Seagrass beds and Saltmarsh have been avoided although these habitats are unlikely to occur at the depths required for the culture method.	Low-moderate exposure, tidal currents < 1160 N /m² or wave exposure < 1200 N /m²	≥ 80% dissolved oxygen recommended by Council Directive 79/923/EEC	>13m below CD (currently limited to nearshore environments *circa* 50m depth by the cost of mooring structures)

* Temperature has not been used within the model due to the resolution of the available spatial data and no incorporation of seasonal variation within the model.
** Salinity has not been used within the model due to the resolution of the available spatial data. However, salinity was considered to limit areas potentially suitable for fully marine species (i.e. King scallop) and hence an indicative boundary in the Bristol Channel, east of which salinity was considered to be on average below 30, was derived from Severn Tidal Limits data and added as a constraint to the model. It should also be noted that any areas indicated as suitable for this species in the upper reaches of Milford Haven should be disregarded.
*** Water quality in Shellfish waters has been incorporated into the MSP model component.
CD Chart Datum

(Source: Laing and Spencer, 2006; Laing, 2002; Spencer, 2002; Kapetsky, *et al*., 2013)

D.4 Macroalgae Production

There has not been a great incentive for macroalgae culture in the UK to date, partly because our shores are very productive. This means that ample macroalgae can be harvested to meet the current demand, without the need for artificial enhancement (Werner, *et al*., 2004). For example there is a long history of knotted wrack, *Ascophyllum nodosum* harvest in the Western Isles of Scotland which was reported to supply the alginate industry with around 12,000t (wet weight) per year in the early nineties (ERT Ltd, 1995). The export market has growing potential as the use of macroalgae as biofuel and in pharmaceuticals increases (Walsh and Watson, 2011). At present the market price for macroalgae remains low and its culture is unlikely to be profitable in Europe, where labour costs are comparatively high, until the market price increases (Werner *et al*., 2004; Werner and Dring, 2011).

Although there is currently no commercial cultivation of macroalgae in the UK, trials are underway. The Scottish Association of Marine Science (SAMS) has been cultivating macroalgae for a number of years and this effort has recently increased with the inception of the BioMara project (BioMara, 2013). BioMara was an Interreg programme which concluded in 2012. The research undertaken by the team aimed to demonstrate the feasibility and viability of producing third generation biofuels from marine biomass. Through the course of the study numerous seaweed species were screened for their potential in biofuels and many were found to grow well in the waters off Scotland, including the three kelp species *Alaria esculenta*, *Saccorhiza polyschides* and *Saccharina latissima* (BioMara, 2013). As noted in Section 4 of the main report, the NISE project at Bangor University has been established to research the potential for extraction of compounds from seaweed species for high value uses both as food ingredients and in cosmetic applications while CSAR at Swansea University has research projects relating to the use of seaweeds for biofuel and for development and commercialisation of advanced bio-products, processes and services from algae.

Seaweed cultivation and harvest is now an established process. Macroalgal spores are collected from ripe plants and are then seeded onto polyamide strings. Here the spores germinate to form tiny plants 2mm long, which are transferred to sea after two months. Macroalgae is grown using a similar set-up to that used in rope/line bivalve culture whereby drop ropes are suspended from a main rope, held afloat by buoys and anchored to the seabed by mooring blocks. The plants are generally harvested six to eight months later, when they will have attained a length of over two metres.

D.4.1 Light

Light is the single most important factor in macroalgae culture since it is required for photosynthesis and hence growth. Different seaweed species have different light requirements much like their terrestrial light and shade loving equivalents. Sites with all but the most turbid waters are therefore likely to have suitable light conditions for at least some species of macroalgae (Luning, 1990).

D.4.2 Temperature

High water temperatures are the main limiting factor for growth of most seaweeds common to UK waters. In contrast minimum temperatures are not considered a problem unless there is the possibility of ice formation. Areas where there is a risk of large fluctuations in temperature should also be avoided, e.g. large, exposed intertidal areas that will heat up rapidly during the day at low tide: this is usually more common over sandy substrates than rocky substrates. Average optimal range for growth is 10-15°C although the survival temperature range is 0-25°C (Luning, 1990).

D.4.3 Salinity

Most seaweed species grow optimally at salinities around 30 but can tolerate some fluctuations i.e. brackish waters in estuaries (Werner *et al*., 2004).

D.4.4 Substrate

Rocky substrates are often considered the optimal locations, as this can indicate that the current flow rates are high as there is no sediment deposition. Less sediment in an area also results in a lower risk of reduced photosynthesis (and growth) caused by high turbidity (Werner and Dring, 2011). However, since macroalgae are primarily cultivated on ropes suspended at sea, there is no real limitation on the substrate type utilised.

D.4.5 Wave/Tidal Exposure

The demands of commercially important seaweeds, with respect to exposure and tidal current, vary considerably however these demands have to be balanced with the feasibility for an aquaculture operation to work efficiently at any season and weather condition to avoid damage to the farm (Bruton *et al*. 2009). Whereas the kelp species, *Alaria esculenta*, inhabits very exposed sites, Dulse, *Palmaria palmata* grows on less exposed sites with a good tidal current. Other algae such as the kelp *Saccharina latissima* and the intertidal species *Porphyra* spp. (Laver), *Chondrus crispus* and *Ulva* spp. (sea lettuce) are typically found in more sheltered areas. Exposure to very high wave or tidal currents could cause damage to the mooring systems as well as damaging the macroalgae itself.

D.4.6 Water Quality

Seaweeds have the ability to remove nutrients from surrounding waters and also internally accumulate heavy metals (e.g. mercury, arsenic, cadmium, copper, lead, zinc), radionuclides (e.g. Caesium–137 and Technetium–99) and other contaminants (Werner *et al*., 2004). Therefore potential pollution of certain areas has to be considered especially with respect to the production of macroalgae for human consumption. Low turbidity levels are also preferable as high sediment loading can reduce the level of photosynthesis.

D.4.7 Depth

Usually a minimum of 10m depth at low water is sufficient to maintain good water flow and minimise the risks of bleaching. Maximum depth is influenced by the cost of installation, equipment and ease for divers to make safe inspections or carry out maintenance, therefore maximum depth is currently 20 – 25m (Werner and Dring, 2011; Werner *et al*., 2004). It is anticipated that this industry will spread into deeper waters as technology improves and maintenance becomes more automated.

Table D4. Summary of the key environmental requirements for the culture of macroalgae

Species	Light	Temperature (ºC)*	Salinity**	Sediment Type	Wave/Tidal Exposure	Water Quality***	Depth
Badderlocks or winged kelp, *Alaria esculenta*	Medium	10-12	Fully marine	Any	High exposure (currents > 1160 N /m² and waves > 1200 N /m²)	n/a	n/a
Kelp or tangle, *Saccharina latissima*	High	10-15	Fully marine	Any	Medium exposure (currents >130 and <1160 N/m² and waves > 210 and < 1200 N/m²)	n/a	n/a
Dulse, *Palmaria palmata*	Low-Medium	10-15	Fully marine	Any	High exposure (currents > 1160 N /m² and waves > 1200 N /m²)	Low pollution	n/a
Foliose red algae (Laver), *Porhyra* spp.	High	Species dependent 5-20	Low to fully marine	Any	Medium exposure (currents >130 and <1160 N/m² and waves > 210 and < 1200 N/m²)	n/a	n/a
Irish moss or carrageen moss, *Chondrus crispus*	High	12-15	Low to fully marine	Any	Medium exposure (currents >130 and <1160 N/m² and waves > 210 and < 1200 N/m²)	Low pollution	n/a
Sea lettuce, *Ulva* spp.	High	Species dependent 10-20	Low	Any	Medium exposure (currents >130 and <1160 N/m² and waves > 210 and < 1200 N/m²)	n/a	n/a
Macroalgae in general	Species dependent but seaweed can be cultured in most light conditions	Optimal temperatures 10-15°C but will survive 0-25°C	Species dependent but seaweed can be cultured in most salinities	Any, areas of Seagrass beds and Saltmarsh have been avoided although these habitats are unlikely to occur at the depths required for the culture method.	Species specific tolerances	Low turbidity required for optimal photosynthesis levels. Low/no pollution where macroalgae is intended for consumption	10-25m below CD (but likely to extend into deeper waters as technology advances and the industry is less dependent on divers

* Temperature has not been used within the model due to the resolution of the available spatial data and no incorporation of seasonal variation within the model.
** Salinity has not been used within the model due to the resolution of the available spatial data.
*** Water quality in Shellfish waters has been incorporated into the MSP model component.
CD Chart Datum

(Source Werner *et al*., 2004; Bruton *et al*., 2009)

D.5 Hatchery Reared Crustaceans

D.5.1 Lobster, *Homarus gammarus*

Intensive lobster, *Homarus gammarus* farming, in pens, is unlikely to be economically viable in the foreseeable future (Burton, 2003), although the National Lobster Hatchery in Padstow is currently investigating several locations on the south coast of Cornwall. A longer term assessment, as well as a feasibility study of the potential for growing lobster through to market size will be undertaken shortly (MMO, 2013b). However, utilising hatchery-reared juvenile animals for release into natural habitats for 'ranching' or stock enhancement has been successful in a few locations around the UK coast (Orkney Lobster Hatchery, 2012), including Wales (via the programme at 'The Lobster Hatchery of Wales' based at Anglesey Sea Zoo). Lobster culture is mainly concerned with taking wild brood-stock (ideally from the intended release area) and rearing larvae to 3 months of age (stage XII), at which point the juvenile lobsters are re-introduced into the natural environment (Burton, 2003).

Depending upon the size of juvenile released, it can take from four to seven years before the first animals reach the minimum landing size. The animals can be recaptured using conventional fishing gear (pots or creels) set in the normal way. It has been estimated that, depending upon the size of juvenile released, up to 40% of the stock can survive to a marketable size (Seafish, 2012).

Early Benthic Phase lobsters are rarely caught and the habitat to which they recruit remains largely unknown (Linnane, *et al*., 2000). However, as hatchery reared lobsters are usually collected from an existing stock the conditions are thought to be suitable. These are usually in temperatures of between 2 - 18°C. The ideal release areas resemble an underwater scree slope, being composed of a wide variety of rock sizes, from cobble to boulder. It is the gaps between the rocks, which offer the habitat for the lobsters. Juveniles are released directly onto the seabed and not at the surface to avoid attracting predators. Lobsters are not usually found at depths exceeding 50m (Holthius, 1991).

Until recently any hatchery-reared lobsters placed into the sea became common property and could be fished by anyone. Consequently, there was no way of safeguarding the 'investment' which groups undertaking stocking programmes might make. In early 1997 the Sea Fisheries (Shellfish) (Amendment) Act 1997 passed into UK law. It extended the coverage of several and regulated fishery orders to encompass lobsters and other crustaceans. The Act allows additional management, over and above national or local regulations, for lobster fisheries where stocking is taking place through the use of a regulating order and sole harvest rights can be assigned using a several fishery order. As the on-growing or ranching of lobsters has not yet been carried out on a commercial scale in the UK, little is known about the optimal rearing conditions. What is known at this time is summarised in Table C5, below.

D.5.2 Crawfish, *Palinurus elephas*

Palinurus elephas, is the most commercially important spiny lobster species in the Mediterranean and North East Atlantic (Goñi *et al*., 2003) and is classed as vulnerable in the IUCN Red List of threatened species.

Palinurus elephas has a low resilience (it reaches sexual maturity at 4–5 years and lives up to 25 years; Quetglas *et al*. 2003; Goñi *et al*.,2003), which along with the intense exploitation to which it has been submitted for decades, has led to overfishing of most Mediterranean populations (Petrosino *et al*., 1985; Quetglas *et al*. 2003; Latrouite & Noel, 1997; Soldo *et al*., 2001). *Palinurus elephas* is mostly caught with lobster pots, occasionally on hook-and-line and by spearing, rarely with trawls, tangles, or trammel nets (Holthius, 1991). Crawfish typically live on rocky, exposed coasts in the circalittoral zone typically occurring in depths between 5-70 m but can be recorded as deep as 150 m (Lock, 2010).

The relatively short larval life of *Palinurus elephas* makes them attractive for culture (Ceccaldi & Latrouite, 1994). However, *Palinurus elephas* is notoriously difficult to rear in the laboratory despite hatching at an advanced stage (see e.g. Kittaka & Ikegami, 1988) and attempts at culture have been unsuccessful. Until hatchery production becomes commercially-viable, the only practical way of increasing the volume of marketed spiny lobster is to capture juveniles from the wild and on-grow them to market size; thereby circumventing the high natural mortality that otherwise occurs (Phillips *et al*., 2003).

While crawfish are not frequently encountered, there is potential for brood-stock to be obtained (e.g. from fishermen if an attractive price is offered and they are willing to hold them for this purpose) to supply future commercial hatcheries. Mature spiny lobsters can be successfully maintained on diets of bivalve mollusc (mussels) and crustacean flesh (Wickens and Lee, 2002). Laboratory-scale rearing of the larvae from egg to puerulus (late larval stage lobsters) has been achieved for many species of spiny lobsters including *Panulirus japonicus*, *Panulirus longipes*, *Jasus lalandii*, *Jasus edwardsii* and *Sagmariasus verreauxi* (Kittaka, 2000; Matsuda and Yamakawa, 2000). However, commercially-viable hatchery production of spiny lobsters is still some time off although the recent large-scale larval rearing of the tropical ornate *Panulirus ornatus* spiny lobster in a commercial shrimp hatchery (MMO, 2013b) augurs well for the future. Furthermore a pilot study is currently underway in North Wales to develop hatchery rearing of *Palinurus elephas* (see Appendix C).

Table D5. Summary of the key environmental requirements of hatchery reared European lobster and Crawfish

Species	Temperature (ºC)*	Salinity**	Sediment Type	Wave/Tidal Exposure	Water Quality***	Depth
European lobster, *Homarus gammarus*	2-18°C	Fully marine	Rock	Sheltered to moderate (tidal currents < 1160 N /m² or wave exposure < 1200 N /m²)	Unknown	10-30m below CD
Crawfish, *Palinurus elephas*	10-19°C	Fully marine	Rock	Exposed coasts (tidal currents > 130 N/m² and waves > 210 N/m²)	Chemical oxygen demand of culture water increased from 0.2 to 1.6 ppm over a 20 day period with a daily increase of about 0.05 ppm	Circalittoral (5 to 50m below CD)

* Temperature has not been used within the model due to the resolution of the available spatial data and no incorporation of seasonal variation within the model.

** Salinity has not been used within the model due to the resolution of the available spatial data. However, salinity was considered to limit areas potentially suitable for these fully marine species and hence an indicative boundary in the Bristol Channel, east of which salinity was considered to be on average below 30, was derived from Severn Tidal Limits data and added as a constraint to the model. It should also be noted that any areas indicated as suitable for these species in the upper reaches of Milford Haven should be disregarded.

*** Water quality in Shellfish waters has been incorporated into the MSP model component.

CD Chart Datum

(Sources: Burton, 2003; Jackson *et al*., 2009; Kittaka & Ikegami, 1988; Kittaka, 1994)

D.6 Marine Finfish Cage Culture

The culture of marine finfish in the UK is almost exclusively focused in Scottish waters, off the west coast and around the Orkney and Shetland Islands. The only marine finfish cultivated in England and Wales uses land based recirculation systems to culture European sea bass, *Dicentrarchus labrax* and Turbot, *Scophthalmus maximus* (Defra, 2012), although the latter species is not currently being produced. Scottish finfish culture is focused primarily on Atlantic salmon, *Salmo salar* with production exceeding 158,000 tonnes in 2011 (Marine Scotland Science, 2012). In this same year 83 tonnes of Halibut, *Hippoglossus hippoglossus* were also estimated to have been produced commercially in Scotland. Cod (*Gadus morhua*) was farmed commercially in Scotland up until 2011 but there has not been any reported production since this time.

The downturn in cod culture is thought to be strongly linked to the recovery of wild fish populations in recent years, driving down the price of cultured fish. However, considerable effort and funding has been allocated to improving the culture of cod (Bailey *et al*., 2005; Bolton-Warberg and Ftizgerald, 2012; Chabot and Dutil, 1999; Cromey *et al*., 2007; Joerstad *et al*., 2006; Ottera *et al*., 2006; Seafish, 2002; Watson *et al*., 2006; Jones, 1984) and it is possible that this will again become an important cultivated species as cultivation becomes more cost-effective. On the face of it, cod is an attractive option for culture since their requirements are very similar to those of Atlantic salmon and existing cage infrastructure may be used (Bailey *et al*., 2005). However, attempts to farm this species in the UK have not been successful to date and Norwegian cod farming activities have also reduced significantly from roughly 35 farms operational in 2008 to just 3 or 4 farms in 2011 (Fish Farming International, 2011). As in Scotland, the collapse of the cod culture market in Norway is thought to be driven primarily by the recovery of wild stocks driving down the price of farmed cod.

Other low cost white fish alternatives such as Alaskan pollack (*Theragra chalcogramma*) are also thought to have brought down the price of farmed cod such that the high costs associated with start-up of this sector could not be recovered. Unless significant funding is made available for research and development in this sector it is unlikely that the UK will see a rapid revival in cod culture.

Sea trout rearing is often seen as an alternative to the culture of Atlantic Salmon when salinity and summer temperatures are too high. The transfer process at sea is always a delicate operation and unlike the Atlantic salmon, sea trout does not really smoltify in culture (no changes in colour, swimming behaviour; FAO, 2015b). Sea Trout is of great importance to Wales, with almost every river and stream that enters the sea containing a natural and self-sustaining run of migratory trout. A large number of these rivers support productive rod fisheries and in some instances, commercial net fisheries (Harris and Milner, 2008).

Finfish aquaculture is typically carried out in suspended net-cages sited in sheltered bays or sea lochs, held by moorings to the seabed. Cages are designed to contain fish and allow the free exchange of water to provide clean, oxygenated conditions and allow the export of waste products.

The siting of finfish cages is critical since the environmental conditions under which the fish are grown can influence their welfare as well as the production efficiency of the farm. The physiological and behavioural responses of farmed fish to changes in environmental conditions are in many cases well documented (Bailey *et al*., 2005; Chabot and Dutil, 1999; Cote *et al*., 2012; Hendry and Cragg-Hine, 2003; Johansson *et al*., 2007; Johansson *et al*., 2006; Stevenson, 2007). However, there remain large gaps in our understanding of the interactions between multiple, related, environmental factors and their cumulative impact on marine fish, as well as the impact of environmental changes on fish that are not yet farmed extensively. The interactions between finfish and their environment tend to be species specific, with different species having different tolerances and different behavioural responses to environmental change. In the subsequent sections below we explore briefly what is known about the environmental requirements of finfish of interest to this study, which includes Sea Trout (*Salmo trutta*), Atlantic Salmon (*Salmo salar*) and Cod (*Gadus morhua*). This information is then synthesised in Table C6.

D.6.1 Water Quality

It is impractical to attempt to control water quality in cage culture systems, therefore culture must be established in areas that have adequate water quality and exchange. Since the presence of high fish densities and the cage structures can act to deteriorate water quality, a standard that exceeds the minimum quality required by the fish is likely to give the best results. Dissolved oxygen is critical to finfish production rates and hence this is considered separately below.

Aside from dissolved oxygen, the main water quality parameters thought to influence finfish production are suspended sediments and contaminant/nutrient levels. High levels of suspended sediments may choke fish or disrupt feeding behaviour (Hendry and Cragg-Hine, 2003). The level at which sediment loading become detrimental to fish health and feeding is not well documented for Atlantic salmon and is not documented at all for most other species. A suspended sediment load of less than 25mg l^{-1} is generally recommended for the culture of salmon, although they are likely to be able to deal with sporadic occurrences of much higher levels. More research in this area would be highly beneficial if aquaculture is to further expand in England and Wales.

D.6.2 Dissolved Oxygen

Fish species generally respond to decreasing oxygen concentrations in one of two ways. They are either oxygen conformers, whereby their metabolic rate decreases in parallel with the decreasing environmental oxygen concentration, or they are oxygen regulators meaning that they are able to maintain a constant metabolic rate over a wide range of environmental oxygen concentrations until they reach a critical oxygen threshold (Pcrit). Once the Pcrit has been reached, oxygen regulators switch to become oxygen conformers and their metabolic rate is then dependent on the environmental oxygen concentrations. The vast majority of farmed finfish are considered to be oxygen conformers, influenced by their high oxygen demands (Barnes *et al*., 2011).

Other physiological and behavioural changes have also been documented in farmed finfish in response to dissolved oxygen levels, which typically include reduced growth rates and an increased susceptibility to disease in low oxygen saturations: feeding activity may also be reduced under low oxygen conditions (Chabot and Dutil, 1999; Cote *et al*., 2012; Stevenson, 2007; Johansson *et al*., 2007; Johansson *et al*., 2006). Super oxygenated conditions can also be very damaging to the health of finfish causing liver damage and mortalities (Espmark and Baeverfjord, 2009; Lygren *et al*., 2000).

Although less commonly reported, super-oxygenation of marine waters can occur as a result of high levels of photosynthesis which can be expected in the presence of algal blooms. Intermittent hypoxic conditions are recorded from finfish farms relatively frequently in the literature (Burt *et al*., 2012; Johansson *et al*., 2006; Johansson *et al*., 2007; Barnes *et al*., 2011; Oppedal *et al*., 2011) indicating that Atlantic salmon at least are partially tolerant of these conditions. Hypoxia can also be controlled to some degree by altering husbandry practices such as stocking densities and feeding practices. Some farms may even consider aeration or cage submergence when hypoxia is prolonged (Espmark and Baeverfjord, 2009; Dempster *et al*., 2009; Korsoen *et al*., 2013; Korsoen *et al*., 2009).

D.6.3 Temperature

The influence of temperature on finfish is species specific and variable and is likely to be a critically important factor in determining which species can be cultured where. Atlantic Salmon and Sea Trout optimum growth rates are between 10–18 °C (Table C6). Cod, prefer much colder waters (Joerstad *et al*., 2006) and their culture may be limited to deeper waters or more southerly areas.

D.6.4 Wave/Tidal Exposure

Water flows need to be sufficient to eliminate waste and to supply well oxygenated water. However, high currents can also cause fish cages to collapse reducing the space available for the fish and increasing the likelihood of escapes. The precise current speed required by fish like salmon, is size specific such that smaller fish would quickly become exhausted if placed in a current that would be optimal for adult fish. Currents that are too fast or too slow can cause exhaustion and physiological stress in many finfish species.

D.6.5 Depth

One of the biggest sources of nutrients and suspended sediments in finfish cages is the uneaten food and faeces (Perez *et al*., 2003). It is important therefore to place cages in water depths and or areas with appropriate topography such that waste feedback is minimised. Other considerations in terms of depth include the presence or absence of a swim bladder in the species of interest. Those that have swim bladders will need access to the surface but those without could be cultured in a fully submersed system which gives greater flexibility in terms of locating the cage in optimal water temperatures.

Offshore finfish aquaculture (defined by depths over 50m) is desired by the UK industry but has not yet been achieved as the nets and mooring systems available are not yet strong enough to withstand offshore weather conditions. There has been significant investment in the development of offshore fish pen technology however, and it is likely that this industry will expand offshore in the not too distant future.

D.6.6 Substrate

Since finfish cages are suspended in the water column the substrate upon which they are placed is of little relevance other than providing good anchorage for mooring systems. One possible exception to this is very fine sediment since this may be more likely to be disturbed by the presence of the cage(s) and fine sediments in suspension can clog the gills of marine fish.

Table D6. Summary of the key environmental requirements the finfish cage culture

Species	Temperature (ºC)*	Salinity**	Sediment Type	Wave/Tidal Exposure	Water Quality***	Depth
Atlantic salmon, *Salmo salar*	10-18	pH 6-9	n/a	Low-moderate exposure	n/a	15 to 50m below CD
Cod, *Gadus morhua*	2-14	>30	n/a	Low-moderate exposure	n/a	15 to 20m below CD
Sea Trout, *Salmo trutta*	12-16	>30	n/a	Low-moderate exposure	n/a	15 to 50m below CD
Marine finfish in general	Species dependent	>30		The highest wave and tidal currents may damage cages and increase escapes (Low-moderate exposure, tidal currents < 1160 N /m² or wave exposure < 1200 N /m²)	Not well understood	Cages should be constructed in water depths and current regimes that minimise waste feedback.

* Temperature has not been used within the model due to the resolution of the available spatial data and no incorporation of seasonal variation within the model.
** Salinity has not been used within the model due to the resolution of the available spatial data. However, salinity was considered to limit areas potentially suitable for some finfish species (cod, sea trout) and hence an indicative boundary in the Bristol Channel, east of which salinity was considered to be on average below 30, was derived from Severn Tidal Limits data and added as a constraint to the model. It should also be noted that any areas indicated as suitable for these species in the upper reaches of Milford Haven should be disregarded.
*** Water quality in Shellfish waters has been incorporated into the MSP model component.
CD Chart Datum

(Sources: Jones, 1984; Chabot and Dutil, 1999; Bailey *et al*., 2005; Perez *et al*., 2003; Hendry and Cragg-Hine, 2003; Johansson *et al*., 2006, 2007)

D.7 References

Bailey, J., Pickova, J., Alanärä, A., (2005). The prerequisites for, and potential of, cod farming in Sweden, [pdf] Uppsala: Swedish University of Agricultural Sciences. Available at: https://www.havochvatten.se/download/18.64f5b3211343cffddb2800018437/1348912831823/finfo2005_12.pdf S [Accessed 23 February 2013]

Barnes, R. K., King, H. and Carter, C. G., (2011). Hypoxia tolerance and oxygen regulation in Atlantic salmon, Salmo salar from a Tasmanian population. Aquaculture,[e-journal] Volume 318, pp. 397-401. Available through: ScienceDirect website http://dx.doi.org/10.1016/j.aquaculture.2011.06.003 [Accessed 26 February 2013]

BioMara, (2013). The BioMara project: A joint research programme between the UK and Ireland led by the Scottish Association for Marine Science (SAMS). [Online] Available at: http://www.biomara.org/ [Accessed 8 January 2015]

Bolton-Warberg, M. and Ftizgerald, R. D., (2012). Benchmarking growth of farmed Atlantic cod, Gadus morhua: a case study in Ireland. Aquaculture Research, [e-journal] Volume 43, pp. 670-678. Available through: Wiley Online Library http://dx.doi.org/10.1111/j.1365-2109.2011.02872.x [Accessed 25 February 2013]

Brenner, M., Broeg K., Wilhelm, C., Buchholz, C., Koehler, A. (2012) Effect of air exposure on lysosomal tissues of Mytilus edulis from natural intertidal wild beds and submerged culture ropes. Comp Biochem Physiol A Mol Integr Physiol (3):327-36

Bruton, T., Lyons, H., Lerat, Y., Stanley, M., Bo Rasmusse, M. (2009) A review of the potential of marine algae as a source of biofuel in Ireland. Report prepared for Sustainable Energy Ireland. Available through: http://www.seai.ie/Publications/Renewables_Publications_/Bioenergy/Algaereport.pdf [Accessed 20 January 2015]

Brown, J. H., (2010). SIPF093 Innovative Shellfish System for High Energy Conditions (B080) Seafish Report No. SR649, [pdf] Edinburgh: Seafish. Available at: http://www.seafish.org/media/Publications/SR649__SIPF093_Innovative_shellfish_system_for_high_energy_conditions.pdf [Accessed 22 January]

Burt, K. *et al*., (2012). Environmental conditions and occurrence of hypoxia within production cages of Atlantic salmon on the south coast of Newfoundland. Aquaculture Research, [e-journal] Volume 43, pp. 607-620. Available through; Wiley Online Library http://dx.doi.org/10.1111/j.1365-2109.2011.02867.x

Burton, C., (2003). Lobster hatcheries and stocking programmes: An Introductory Manual , Seafish Report SR552 [pdf] Edinburgh: Seafish. Available at: http://www.seafish.org/media/Publications/Lobstehatcheriesandstockingprogrammes_IntoManual.pdf [Accessed 21 January 2015]

Cassis, D., Pearce, C. M. and Maldonado, M. T., (2011). Effects of the environment and culture depth on growth and mortality in juvenile Pacific oysters in the Strait of Georgia, British Columbia. Aquaculture Environmental Interactions, [e-journal] Volume 1, pp.259-274. Available through: Inter-Research Marine Ecology Progress Series http://www.int-res.com/abstracts/aei/v1/n3/p259-274 [Accessed 20 January 2015]

Camacho, A. P., Labarta, U. and Beiras, R. (1995). Growth of mussels *Mytilus edulis gallprovinciallis*) on cultivation rafts: influence of seed source, cultivation site and phytoplankton availability. Aquaculture, [e-journal] Volume 138, pp. 349-362. Available through: ScienceDirect website http://www.sciencedirect.com/science/article/pii/0044848695011390 [Accessed 20 January 2015]

Ceccaldi, H.J. & Latrouite, D., (1994). The French fisheries for the European spiny lobster Palinurus elephas. Oxford: Fishing News Books.

Cefas, (2009). Classification of bivalve mollusc production areas in England and Wales.Sanitary Survey Poole Harbour, [pdf] Weymouth: Cefas. Available at: http://www.cefas.defra.gov.uk/media/566208/final%20poole%20harbour%20sanitary%20survey%20report%202009%20%282012%29.pdf [Accessed 22 January 2015]

Chabot, D. and Dutil, J.-D., (1999). Reduced growth of Atlantic cod in non-lethal hypoxic conditions. Journal of Fish Biology, [e-journal] Volume 55, pp. 472-491. Available through: Wiley Online Library http://dx.doi.org/10.1111/j.1095-8649.1999.tb00693.x [Accessed 27 February 2015]

Child, A. R. and Laing, I., (1998). Comparative low temperature tolerance of small juvenile European, Ostrea edulis L., and Pacific oysters, Crassostrea gigas Thunberg. Aquaculture Research, [e-journal] 29(2), pp. 103-113. Available through: Wiley Online Library http://onlinelibrary.wiley.com/doi/10.1046/j.1365-2109.1998.00934.x/abstract [Accessed 22 January 2015]

Cote, J. *et al*., (2012). Population differences in response to hypoxic stress in Atlantic salmon. Journal of Evolutionary Biology, [e-journal] Volume 25, pp. 2596-2606. Available through: Wiley Online Library http://dx.doi.org/10.1111/jeb.12007 [Accessed 27 February 2015]

Cromey, C., Nickell, T. and Treasurer, J., (2007). Cod farming in the marine environment. CERC02/03. Final Report 2004-2007, [pdf] London: The Crown Estate. Available at: http://www.ecasatoolbox.org.uk/the-toolbox/eiaspecies/models/goodness-of-fit/depomod-cod-report [Accessed 28 February 2015]

Defra, (2012). Planning for sustainable growth in the English aquaculture industry. Report by the England Aquaculture Plan Consultation Group, [pdf] London: Department for Food, Environment and Rural Affairs (Defra). Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/82402/120112-aquaculture-consult-doc.pdf [Accessed 21 January 2015]

Dempster, T., Korsoen, O., Folkedal, O., Juell, J.E., Oppedal, F., (2009). Submergence of Atlantic salmon (Salmo salar L.) in commercial scale sea-cages: A potential short-term solution to poor surface conditions. Aquaculture, [e-journal] Volume 288, pp. 254-263. Available through: ScienceDirect website http://dx.doi.org/10.1016/j.aquaculture.2008.12.003 [Accessed 1 March 2013]

ERT Ltd, (1995). The Minch Project. Littoral Seaweed Resource Management, Perth: Scottish Natural Heritage and Western Isles Island Council.

Espmark, A. M. and Baeverfjord, G., (2009). Effects of hyperoxia on behavioural and physiological variables in farmed Atlantic salmon (Salmo salar) parr. Aquculture International, [e-journal] 17(4), pp. 341-353. Available through: Springer Link http://link.springer.com/article/10.1007/s10499-008-9206-6# [Accessed 1 March 2015]

FAO (2015a) Cultured Aquatic Species Information Programme Ruditapes decussatus (Linnaeus, 1758). Available through: FAO Fisheries and Aquaculture Department http://www.fao.org/fishery/culturedspecies/Ruditapes_decussatus/en [Accessed 1 February 2015]

FAO (2015b) Cultured Aquatic Species Information Programme Salmo trutta (Berg, 1908). Available through: FAO Fisheries and Aquaculture Department http://www.fao.org/fishery/culturedspecies/Salmo_trutta/en#tcNA0160 [Accessed 1 February 2015]

Fish Farming International, (2011). Norwegian cod farmers merge. Fish Farming International, August 2011, p. 9.

Goñi, R., Quetglas, A. & Reñones, O., (2003). Size at maturity, fecundity and reproductive potential of a protected population of the spiny lobster Palinurus elephas (Fabricius, 1787) from the western Mediterranean. Marine Biology, 143, 583-592.

Hagos, K. W., (2007). On-bottom mussel culture in Maine and the Netherlands: A comparative analysis, [pdf] Kingston, Rhode Island: Ecological Aquaculture Studies and Reviews, University of Rhode Island. Available at: http://www.ecologicalaquaculture.org/Hagos%282007%29.pdf [Accessed 20 January 2015]

Harris G., Milner, N. (2008) Sea Trout: Biology Conservation and Management. John Wiley & Sons, 15 Apr 2008 - Technology & Engineering

Hendry, K. and Cragg-Hine, D., (2003). Ecology of the Atlantic Salmon. Conserving Natura 2000 Rivers. Ecology Series No. 7, [pdf] Peterborough: Life in UK Rivers (EN, CCW, EA, SEPA, SNH and SNIFFER). Available at: http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFileandrep=fileandfil=SMURF_salmon.pdf [Accessed 4 February 2015]

Herbert, R.J.H., Roberts, C., Humphreys, J. and Fletcher, S., 2012. The Pacific Oyster (Crassostrea gigas) in the UK: Economic, Legal and Environmental Issues Associated with its Cultivation, Wild Establishment and Exploitation. Report for the Shellfish Association of Great Britain.

Holthius, L. B., (1991). FAO species catalogue. Vol. 13. Marine lobsters of the world. Annotated and illustrated catalogue of species of interest to fisheries known to date. FAO Fisheries Synopsis. No. 125, Vol. 13., [pdf] Rome: Fisheries and Agriculture Organisation (FAO). Available at: ftp://ftp.fao.org/docrep/fao/009/t0411e/t0411e00.pdf [Accessed 27 January2015]

Hutchinson, S., Hawkins, L. E. (1992). Quantification of the physiological responses of the European flat oyster Ostrea edulis to temperature and salinity. Journal of Molluscan Studies, [e-journal] 58(2), pp. 215-226. Available through: Oxford Journals website http://mollus.oxfordjournals.org/content/58/2/215.abstract [Accessed 20 January 2015]

Jackson, A., Marshall, C., Wilding., (2009) Palinurus elephas. European spiny lobster. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: http://www.marlin.ac.uk/speciesfullreview.php?speciesID=4022 [Accessed 21 January 2015]

Joerstad, K. E., Fjalestad, K. T., Agustsson, T. and Marteinsdottir, G., (2006). Atlantic cod – Gadus morhua. In: D. Crosetti, S. Lapegue, I. Olesen and T. Svaasand, eds. Genetic effects of domestication, culture and breeding of fish and shellfish, and their impacts on wild populations. [pdf] Viterbo, Italy: GENIMPACT project: Evaluation of genetic impact of aquaculture activities on native populations, pp. 1-6. Available at : http://www.imr.no/genimpact/filarkiv/2006/01/atlantic_cod_leaflet.pdf/en [Accessed 27 February 2015]

Johansson, D., Juell, J.K., Oppedal, F., Stiansen, J.E., Ruohonen, K., (2007). The influence of the pycnocline and cage resistance on current flow, oxygen flux and swimming behaviour of Atlantic salmon (Salmo salar L.) in production cages. Aquaculture, [e-journal] Volume 265, pp. 271-287. Available through: ScienceDirect website http://dx.doi.org/10.1016/j.aquaculture.2006.12.047 [Accessed 27 January 2015]

Johansson, D., Ruohonen, K., Kiessling, A., Oppedal, F., Stainsen, J.K., Kelly, M., Juell, J.K., (2006). Effect of environmental factors on swimming depth preferences of Atlantic Salmon (Salmo salar L.) and temporal and spatial variations in oxygen levels in sea cages at a fjord site. Aquaculture, [e-journal] Volume 254, pp. 294-605. Available through: ScienceDirect website: http://dx.doi.org/10.1016/j.aquaculture.2005.10.029 [Accessed 27 January 2015]

Jones, A., (1984). Does cod farming have a commercial future? A technical and economic assessment. In: E. Dahl, D. S. Danielssen, E. Moksness and P. Solemdal, eds. The Propagation of Cod Gadus morhua L.. [pdf] Norway: Institute Marine Research. Flodevigen Biological Station, pp. 773-785. Available at: http://brage.bibsys.no/imr/bitstream/URN:NBN:no-bibsys_brage_6379/1/773-786.pdf [Accessed 27 January 2015]

Kapetsky, J. M., Aguilar-Manjarrez, J. and Jeness, J., (2013). A global assessment of potential for offshore mariculture development from a spatial perspective. FAO Fisheries and Technical Paper, [pdf] Volume 549, p. 181. Available at: http://www.fao.org/docrep/017/i3100e/i3100e.pdf [Accessed 28 January 2015]

Kittaka, J., (2000) Culture of larval spiny lobsters. In: Spiny Lobsters: fisheries and culture, 2 edn (eds B.F. Phillips& J. Kittaka) pp. 508-532. Fishing News Books, Oxford, UK.

Kittaka, J. & Ikegami, E., (1988). Culture of the Palinurid Palinurus elephas from egg stage to puerulus. Nippon Suisan Gakkaishi, 54, 1149-1154

Korsøen, O. J., Dempster, T., Fosseidengen, J.E., Karlsen, Ø., Oppedal, F., Stien, L.H., Kristiansen, S., (2013). Towards cod without spawning: artificial continuous light in submerged sea-cages maintains growth and delays sexual maturation for farmed Atlantic cod Gadus morhua. Aquaculture Environment Interactions, [pdf] Volume 3, pp.245-255. Available at: http://www.int-res.com/articles/aei2013/3/q003p245.pdf [Accessed 20 January 2015]

Korsøen, O. J., Dempster, T., Fjeldal, P.G., Oppedal, F., Kristiansen, T.S., (2009). Long-term culture of Atlantic salmon (Salmo salar L.) in submerged cages during winter affects behaviour, growth and condition. Aquaculture, [e-journal] Volume 296, pp. 373-381. Available through: ScienceDirect website http://dx.doi.org/10.1016/j.aquaculture.2009.08.036 [Accessed 21 February 2015]

Laing, I., (2002). Scollop cultivation in the UK: a guide to site selection, [pdf] Lowestoft: Centre for Fisheries, Environment and Aquaculture Science (Cefas) . Available at: http://www.cefas.defra.gov.uk/publications/files/scallop_cultivation.pdf [Accessed 20 January 2015]

Laing, I., Lees, D. N., Page, D. J. and Henshilwood, K., (2004). Research on shellfish cultivation: A synopsis of research funded by the Department for Environment Food and Rural Affairs (Defra) between 1990 and 2003. Science Series Technical Report No.122,[pdf] Lowestoft: Cefas. Available at: http://www.cefas.defra.gov.uk/publications/techrep/tech122.pdf [Accessed 20 January 2015]

Laing, I. and Spencer, B. E., (2006). Bivalve cultivation: criteria for selecting a site. Science Series Technical Report no.136. [pdf] Weymouth: Centre for Fisheries, Environment and Aquaculture Science (Cefas). Available at: http://www.cefas.co.uk/publications/techrep/techrep136.pdf [Accessed 20 January 2015]

Lygren, B., Hamre, K. and Waagbo, R., (2000). Effect of induced hyperoxia on the antioxidant status of Atlantic salmon Salmo salar L. fed the different levels of dietary vitamin E. Aquaculture Research, [e-journal] Volume 31, pp. 401-407. Available through: Wiley Online Library http://dx.doi.org/10.1046/j.1365-2109.2000.00459 [Accessed 20 January 2015]

Latrouite, D., Noel, P., (1997). Pêche de la langouste rouge Palinurus elephas en France, éléments pour fixer une taille marchande. ICES CM 1997/BB:13.

Linnane, A., Ball, B., Munday, B. and Mercer, J., (2000). Short communication on the occurrence of juvenile lobster Homarus gammarus in intertidal habitat. Journal of the Marine Biological Association of the United Kingdom, [e-journals] 80(2), pp. 375-376. Available through: Cambridge Journals http://journals.cambridge.org/article_S0025315499002039 [Accessed 27 January 2015]

Lock, K., (2010) Seasearch Wales - Crawfish Palinurus elephas historical diver records. Wales Biodiversity Partnership pp10. Available through: http://www.seasearch.org.uk/downloads/crawfishWales2011%20report.pdf [Accessed on 20 January 2015]

Luning, K., (1990). Seaweeds: Their environment, biogeography and ecophysiology. New York: Wiley-Interscience Publication.

Mallet, A. L., carver, C. E., Coffen, S. S. and Freeman, K. R., (1987). Winter growth of the blue mussel Mytilus edulis L.: importance of stock and site. Journal of Experimental Marine Biology and Ecology, [e-journal] Volume 108, pp. 217-228. Available through: ScienceDirect website http://www.sciencedirect.com/science/article/pii/0022098187900864 [Accessed 20 January 2015]

Quetglas, A., Gaamour, A., Reñones, O., Missaoui,. H., Zarrouk, T., Elabed, A., Goñi, R. (2004) Spiny lobster (Palinurus elephas Fabricius 1787) fishery in the western Mediterranean: A comparison of Spanish and Tunisian fisheries. Boll. Soco Hist. Nat. Balears, 47: 64-80

MMO (2013b). Potential for co-location of activities in marine plan areas. A report produced for the Marine Management Organisation, pp 98. MMO Project No: 1010. ISBN: 978-1-909452-08-4.

Marine Scotland Science, (2012). Locational Guidelines for the Authorisation of Marine Fish Farms in Scottish Waters, [pdf] Edinburgh: The Scottish Government. Available at: http://www.scotland.gov.uk/Resource/0041/00411563.pdf {accessed 25January]

Matsuda, H., Yamakawa, T.Y., (2000) The complete development and morphological changes of larval Panulirus longipes (Decapoda, Palinuridae) under laboratory conditions. Fish. Sci.,66:278-293

Nehls, G., Witte, S., Dankers, N., Vlas, J., Quirijns, F., Kristensen, P.S., (2009). Fishery. Thematic Report No.3.3. In: H. Marencic and J. de Vlas, (Eds). Quality Status Report 2009.Waddeb Sea Ecosystemn No. 25.. [pdf] Wilhelmshaven, Germany: Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, p. 14. Available at: http://www.waddensea-secretariat.org/sites/default/files/downloads/03.3-fishery-10-03-14-rev.pdf [Accessed 21 January 2015]

Newell, R. C. and Pye, V. I., (1970). Seasonal changes in the effect of temperature on the oxygen consumption of the winkle *Littorina littorea* (L.) and the mussel Mytilus edulis. Comparative Biochemistry and Physiology, 34(2), pp. 367-383.

Oppedal, F., Dempster, T. and Stien, L., (2011). Environmental drivers of Atlantic Salmon behaviour in sea-cages: A review. Aquaculture, [e-journal] Volume 311, pp. 1-18. Available through: Science Direct website: http://dx.doi.org/10.1016/j.aquaculture.2010.11.020 [Accessed 20 February 2013]

Orkney Lobster Hatchery, (2012). Orkney Lobster Hatchery. [Online] Available at: http://www.orkneylobsterhatchery.co.uk/restocking.html

Ottera, H., Agnalt, A.-L. and Jorstad, K. E., (2006). Differences in spawning time of captive Atlantic cod from four regions of Norway, kept under identical conditions. ICES Journal of Marine Science, [pdf] Volume 63, pp. 216-223. Available at:
http://icesjms.oxfordjournals.org/content/63/2/216.full.pdf+html [Accessed 26 January 2015]

Petrosino, G., Bello, G., De Metrio, G., Lenti, M., Sciscioli, V., (1985) Andamento della pesca dell'aragosta, Palinurus elephas (Fabr.) lungo la costa ionica salentina (Golfo di Taranto) dal 1978 al 1983. Oebalia 11(2), 609–621.

Phillips B.F., Melville-Smith R., Rossbach M., Cheng Y.W., Caputi N., Thomson A.W., Mills D. and Crear B., (2003) Towards establishing techniques for large scale harvesting of pueruli and obtaining a better understanding of mortality rates. Pp. 1–138 in 'Fisheries Research and Development Corporation (FRDC) Project 1998/302—Rock Lobster Enhancement and Aquaculture Subprogram'. FRDC: Canberra

Perez, O. M., Ross, L. G., Telfer, T. C. and del Campo Barquin, L. M., (2003). Water quality requirements for marine fish cage site selection in Tenerife (Canary Islands): predictive modelling and analysis using GIS. Aquaculture, [pdf] Volume 224, pp. 51-68. Available at: http://www-aqua.stir.ac.uk/public/GISAP/pdfs/Tenerife_water_quality.pdf [Accessed 21 January 2015]

Rosenberg, R., Hellman, B. and Johansson, B., (1991). Hypoxic tolerance of marine benthic fauna. Marine Ecology Progress Series, [pdf] Volume 79, pp. 127-131. Available at: http://www.int-res.com/articles/meps/79/m079p127.pdf [Accessed 26 January 2015]

Scott, D., McLeod, D., Young, J., Brown, J.,Immink, A., Bostock, J., (2010). A study of the prospects and opportunities for shellfish farming in Scotland. Study funded by Marine Scotland., [pdf] Stirling: Stirling Aquaculture. Available at: http://www.scotland.gov.uk/Resource/Doc/295194/0118352.pdf [Accessed 26 January 2015]

Seafish, (2002). The Cod Hyperbook, [pdf] Edinburgh: Seafish. Available at: http://www.seafish.org/media/publications/cod_hyperbook_show_print_comp.pdf [Accessed 20 January 2015]

Seafish, (2012). The Seafish Guide to Aquaculture, [pdf] Edinburgh: Seafish. Available at: http://www.seafish.org/media/742179/seafishguidetoaquaculture_201211.pdf [Accessed 20 January 2015]

Soldo, A., Cetinic, P., Dulcic, J., Jardus, I., Pallaoro, A., (2001) The lobster fishery with gillnets in the Eastern Adriatic. Rapp. Comm. Int. Mer Médit. 36, 324.

Spencer, B., (2002). 11. Criteria for selecting a site for bivalve cultivation. In: Molluscan Shellfish Farming. [e-journal] Oxford: Fishing News Books, a division of Blackwell Publishing, pp. 228-244. Available through: Wiley Online Library http://onlinelibrary.wiley.com/doi/10.1002/9780470995709.ch11/summary [Accessed 26 January 2015]

Stevenson, P., (2007a). Closed Waters: The welfare of farmed Atlantic salmon, rainbow trout, Atlantic cod and Atlantic halibut, [pdf] Surrey: Compassion in World Farming and World Society for the Protection of Animals. Available at: http://www.ciwf.org.uk/includes/documents/cm_docs/2008/c/closed_waters_welfare_of_farmed_atlantic_salmon.pdf [Accessed 20 January 2015]

Stevenson, P., (2007b). Closed Waters: The welfare of farmed Atlantic salmon, rainbow trout, Atlantic cod and Atlantic halibut, [pdf] Surrey: Compassion in World Farming and World Society for the Protection of Animals. Available at: http://www.ciwf.org.uk/includes/documents/cm_docs/2008/c/closed_waters_welfare_of_farmed_atlantic_salmon.pdf [Accessed 20 January 2015]

Syvret M., Fitzgerald A., Hoare P., 2008. Development of a Pacific Oyster aquaculture protocol for the UK – Technical Report FIFG project no: 07/ENG/46/04. Report for the Sea Fish Industry Authority.

Walsh, M. and Watson, L., (2011). Market analysis towards the further development of seaweed aquaculture in Ireland,[pdf] Dublin: Irish Fisheries Board, Bord Iascaigh Mhara.

Watson, J. T., Sales, S., Cumming G., Fitzsimmons, S.D., Walden, J., Arthur, G., Saravanan, S., McEvory L.A., (2006). Comparison of performance of two size groups of farmed cod (Gadus morhua L.) juveniles following transfer to sea cages. ICES Journal of Marine Science, [pdf] Volume 63, pp. 340-345. Available at: http://icesjms.oxfordjournals.org/content/63/2/340.full.pdf [Accessed 21 February 2015]

Werner, A., Clarke, D. and Kraan, S., (2004). Strategic review of the feasibility of seaweed aquaculture in Ireland, [Online] Galway: Marine Institute. Available at: http://hdl.handle.net/10793/327 [Accessed 25 January 2015]

Werner, A. and Dring, M., (2011). Aquaculture explained no.27. Cultivating Palmaria palmata, [pdf] Dublin: Irish Fisheries Board, Bord Iascaigh Mhara (BIM). Available at: http://www.bim.ie/media/bim/content/publications/Aquaculture%20Explained%20Issue%2027%20-%20Cultivating%20Palmaria%20palmata.pdf [Accessed 25 January 2015]

Wickens J.F., Lee, D. O'C., (2002) Crustacean Farming, Ranching and Culture. [e-book] Blackwell Science. Available through: Sainsburys e-books http://samples.sainsburysebooks.co.uk/9780470995075_sample_388324.pdf [Accessed 20 January 2015]

Wieland, T. and Paul, J., (1983). Potential for Scallop Cultivation in the UK. A joint report by the Industrial Development Unit and the Marine Fish Farm at Ardtoe. Technical Report No.224, [pdf] Edinburgh: Sea Fish Industry Authority Industrial Development Unit. Available at: http://www.seafish.org/media/Publications/SR224.pdf [Accessed 20 January 2015].

Appendix E

Stakeholder Consultation
(Separate Document)

ABP Marine Environmental Research Ltd (ABPmer)
Quayside Suite, Medina Chambers, Town Quay, Southampton SO14 2AQ

T +44 (0)23 80 711840
F +44 (0)23 80 711841
E enquiries@abpmer.co.uk

www.abpmer.co.uk

Creating sustainable solutions for the marine environment