ORJIP Impacts from Piling on Fish at Offshore Wind Sites: Collating Population Information, Gap Analysis and Appraisal of Mitigation Options

Final Report - June 2018

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List of Abbreviations

Abbreviation	Definition
ACOM	ICES Advisory Committee
ADD	Acoustic deterrent devices
AFBI	Agri-Food and Biosciences Institute
AfL	Agreement for Lease
BEIS	Business, Energy & Industrial Strategy
BIAS	Baltic Sea Information on the Acoustic Soundscape
BOEM	Bureau of Ocean Energy Management
BMAPA	British Marine Aggregate Producers Association
BSH	Bundesamt für Seeschifffahrt und Hydrographie
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CFP	Common Fisheries Policy
CIEEM	Chartered Institute for Ecology and Environmental Management
CNS	Central North Sea
COWRIE	Collaborative Offshore Wind Research into the Environment
CPA	Coastal Protection Act
DCO	Development Consent Order
DECC	Department of Energy and Climate Change
dML	Deemed Marine Licence
DOI	Department of the Interior
DPSC	Discretionary Project Steering Committee
EcIA	Ecological Impact Assessment
EEZ	European Economic Zone
EIA	Environmental Impact Assessment
EMF	Electromagnetic fields
EUNIS	European Nature Information System
FAO	Food and Agriculture Organisation of the United Nations
FEPA	Food and Environment Protection Act
FRS	Fisheries Research Services (now MSS)
GoBe	GoBe Consultants Limited
HAWG	Herring Assessment Working Group
HMSO	Her Majesty's Stationery Office
IBTS	International Bottom Trawling Survey
ICES	International Council for the Exploration of the Seas
IFCA	Association of Inshore Fisheries and Conservation Authorities

Abbreviation	Definition
IHLS	International Herring Larval Surveys
JNCC	Joint Nature Conservation Committee
kJ	Kilojoule
MAREA	Marine Aggregate Regional Environmental Assessment
MCEU	Marine Consents and Environment Unit
MI	Marine Institute
MMO	Marine Management Organisation
MSFD	Marine Strategy Framework Directive
MS-LOT	Marine Scotland Licensing Operations Team
MSS	Marine Scotland Science
NIGFS	Northern Ireland Ground Fish Survey
NOAA	National Oceanic and Atmospheric Administration
NRW	Natural Resources Wales
ORJIP	Offshore Renewables Joint Industry Programme
OSPAR	The Convention for the Protection of the Marine Environment of the North-East Atlantic
OWF	Offshore wind farm
PMF	Priority Marine Feature
PTS	Permanent Threshold Shift
SFF	Scottish Fishermen's Federation
SFPA	Scottish Fisheries Protection Agency
SNH	Scottish Natural Heritage
SPFA	Scottish Pelagic Fishermen's Association
SSACN	Scottish Sea Angling Conservation Network
SSB	Spawning Stock Biomass
STW	Scottish Territorial Waters
TTS	Temporary Threshold Shift
UK	United Kingdom
USA	United States of America
WGS84	World Geodetic System 1984
WP	Work Package

Executive Summary

As part of the Offshore Renewables Joint Industry Programme (ORJIP) Offshore Wind Programme, GoBe Consultants Limited (GoBe) has undertaken environmental research and review in relation to a study to help inform the current understanding of the impact of piling during the construction of offshore wind farms (OWFs) upon herring (*Clupea harengus*) spawning.

OWF construction activities, such as pile driving, generate noise (both sound pressure and particle motion), which can disturb or injure fish. Due to potential effects, conditions incorporated into UK offshore renewables consents (such as Marine Licences issued by the Marine Management Organisation (MMO) or Marine Scotland Licensing Operations Team (MS-LOT)) may restrict construction activities during times when fish are considered to be most vulnerable to disturbance, such as during spawning and migration. Such restrictions can be temporal, spatial or technical in nature and are designed to minimise risk of disturbance or injury occurring to fish as well as to the population viability.

Inclusion of these conditions within consents ensures that development of OWFs can proceed, with controls over the way in which the development is undertaken to ensure impacts are limited in order to protect habitats, species and other key receptors. It is important to ensure that the established controls are appropriately formulated to deliver a protection benefit without unnecessarily burdening development (e.g. in terms of increased costs or time constraints). To achieve this there needs to be a sufficient level of understanding of the impact source - receptor pathway, the sensitivity of the receptor to the impact and evaluation of potential risk. There is also a need for consistency in the approach used to provide advice to the industry. Despite extensive academic literature and survey work, and their use in Environmental Impact Assessments (EIAs), uncertainty remains on both the accuracy of the fish spawning information currently available and the level / significance of impacts from piling activity on fish species.

Through the application of literature reviews, data gathering, data analysis and consultations, GoBe has completed a study looking at these aspects, with the following aims:

- Review and consolidate available data and information to define (where possible) UK populations, key spawning areas and key spawning periods for herring;
- Identify any gaps in our understanding of herring populations, spawning areas and periods;
- Define and gain acceptance with consenting authorities and experts on herring populations, spawning areas and periods, where data is available; and
- Discuss and understand how the current mitigation approaches are agreed by consenting authorities with the aim of ensuring mitigation is fit for purpose, for example in understanding what is required to ensure protection of the fish stocks, whilst also ensuring that restrictions are minimised and proportionate.

Population Information and OWFs

A review of literature and herring data sources has illustrated that there is a good understanding of the main spawning areas[1] for the different herring stocks that are present within UK waters and that a broad-based identification of the key areas is possible. It is also possible to identify more specific spawning areas for most

[1] Definition of the terms ‘spawning area’, ‘spawning ground’ and ‘spawning bed’ is presented within Section 2.2.29.

of these stocks through the combined use of historical fish sensitivity maps, more recent International Council for the Exploration of the Seas (ICES) International Herring Larvae Survey (IHLS) and International Bottom Trawl Surveys (IBTS) data and predicted seabed habitat types, along with other specific seabed habitat data. Through review of this combined information, the main spawning areas can be discerned. A notable outcome of this study is that through assessment of recent IHLS data (covering the last ten years) and analysis on a year to year basis as well as cumulatively, the comparison of these data with historical fish sensitivity maps produced by Coull *et al*. (1998) has enabled some refinement of the historical data. This may provide more confidence during EIA for both developers and regulators in assessing potential impact significance and mitigation options.

This study suggests that there is an ability to identify areas within the historical mapping (Coull *et al*., 1998) where spawning activity is focused within more defined spawning grounds. Even from larval data with drift that hasn't been back-calculated to a specific location, it is possible to demonstrate that there are specific locations (spawning grounds) where spawning activity is focused within these historical spawning areas. This is illustrated by the 'hot spots' in the heat mapping.

The specific, discrete pockets of spawning beds that herring use are, however, not so easily identified as they can change from year to year. This is due to the specific habitat and environmental conditions that herring require to enable successful spawning to take place. The literature review confirms that without undertaking intrusive grab sampling surveys during spawning periods, or by using drop down video surveying, it is difficult to locate or identify exact spawning bed locations (only identifiable through the presence of mats of eggs). As such, there are gaps in the current knowledge of where specific spawning beds are located for all of the stocks.

The use of the IHLS data to identify spawning grounds has been questioned due to larvae freely drifting away from spawning beds on the prevailing currents and so the confidence that these larval surveys are identifying actual spawning areas is reduced. However, the use of larvae to determine spawning areas has been accepted since 1957 (Parrish *et al*., 1957) and most recently the use of larvae was reviewed within the aggregate dredging industry for the BMAPA by MarineSpace (2013) where it was concluded that of all methods that can be used to determine spawning grounds, the IHLS data was the best indicator and is a direct measure of spawning where fish of length 0 – 11mm were caught. This study concluded that the methodology of using IHLS data to produce heat maps of spawning areas is widely accepted. Indeed, using this method to support further discussions on reducing herring restrictions for OWFs has recently been accepted in England by consenting authorities (as identified through this review).

Being able to take drift rates and apply back-calculation to larvae to identify spawning beds would provide an ability to be more definitive on the precise location of spawning beds. There are limitations with this method however. Attempts to undertake back-calculations of where larvae may have drifted from based upon published prevailing water current information, larvae age and growth rates have been undertaken (e.g. Beatrice Offshore Wind Farm Limited, 2016; Brown and May Marine, 2007) but these reports show how broad the resulting conclusions are, with very large areas being cited as potential spawning beds, with no exact location identification possible due to using estimates of current speeds and directions. From a review of literature, there is only one instance where the exact location of a spawning bed has been identified (Ballantray Bay in the Clyde) and this was via grab sampling, where herring eggs were incidentally located on the seabed (Parrish et al., 1959). It has been recognised since 1959 that due to changing environmental conditions and spawning beds being discrete pockets of suitable habitat (which can change from year to year) within a spawning ground or area, it is extremely difficult to identify the exact location of spawning beds unless they are recorded through grab sampling or by drop down video surveys.

There is a need to be proportionate in terms of risks posed by OWF developments that do not appear to affect the main spawning grounds within the Coull *et al*., 1998 mapping area, as refined by the heat mapping 'hot spots' versus the OWF developments that clearly do affect the 'hotspots'. Given that the noise modelling undertaken for EIA is precautionary and that the fish sensitivity maps are also precautionary, then balanced consideration needs to be given to the level of potential effects that may result from OWF developments located on the fringes of spawning areas illustrated on the fish sensitivity maps and what the benefit of restricting piling at such developments might be in terms of safeguarding a herring population.

Although the herring stocks around the UK are identified within various scientific papers and within ICES advisory documents, there remains some uncertainty regarding the status of the West of Scotland and West Irish stocks and whether they are in fact components of one stock, or are genetically separate stocks. A review of literature suggests that genetic testing is underway to determine the status of these stocks, along with the relationship between the different stock components of the West of Scotland stock. These results are expected to be available in 2018.

The perceived impacts of piling on herring focus on spawning herring as opposed to other life stages such as eggs, larvae and juveniles. Perceived impacts are related to underwater sound pressure and particle motion, with there being more understanding of sound pressure and the potential effects upon herring than particle motion. Several studies have identified specific sound exposure criteria for fish and specific thresholds do exist for herring. There are no thresholds currently identified in terms of particle motion. The main effects are perceived to be behavioural changes that arise as a result of piling activities, with there being less concern regarding physiological effects due to the localised extents to which actual injury from levels of noise extends (a very small area around the piling so the risk of population level effect is minimal). Furthermore, sound pressure is considered to be of greater concern for herring as they are considered 'hearing specialists', with their swim bladder linked to the inner ear.

There is limited understanding of how behavioural changes affect herring populations (and other fish populations in general) and at what point the behavioural changes become significant and are unacceptable. Most research into this topic has been undertaken in laboratory or confined conditions and have not necessarily reflected conditions in the open sea.

Understanding Consenting Restrictions

A total of 19 OWF projects have been identified to date as having herring restrictions or other mitigation requirements for this species associated with marine licences. The reason that piling restrictions are applied is due to the potential effect of piling upon spawning adult herring and / or their behaviour. The conditions are not related to potential effects of piling noise on herring larvae, principally because of the assumption that the limited range of noise levels is considered to pose little if any risk to eggs or larvae.

Initially in England, blanket piling restrictions were put in place due to the use of a 'design envelope' approach for EIAs supporting consent applications. This was due to limited information on the actual final design of the OWFs being available at that time, leading to uncertainty in the actual level of potential impact risk associated with the individual projects and the application of a precautionary approach to ensure protection of spawning herring. Such restrictions would have caused considerable additional expense to developers at the time. As the offshore wind industry became more established, a more evidence based approach was adopted by The Planning Inspectorate, during the Development Consent Order (DCO) process, to piling restrictions with the introduction of flexibility within consent requirements and conditions to reduce or remove these restrictions, subject to the provision of further information and agreement with the MMO and their advisors. As a result of this, further discussions to reduce or remove restrictions have taken place in more recent years, with new evidence being submitted to support these discussions. This evidence has included further seabed sediment and habitat analysis, further specific herring larvae surveys and more refined engineering design information on what will actually be constructed at the OWF. However, the most recent licences to be granted for OWF (for example Hornsea Projects One and Two) have reverted back to the exclusion of this flexibility to further discuss removal of restrictions and have gone on to request further sediment grab sampling to identify whether a suitable spawning habitat is present or not in order to determine the need for further restrictions or mitigation for herring. For these two developments at Hornsea, the concern has changed from one of potential impacts from piling activity to potential impacts from dredging and disposal activities. The area of uncertainty, however, still remains the determination of the extent of suitable herring spawning ground habitat.

Within Scotland, the herring is listed as a Priority Marine Feature (PMF) and is given special consideration in line with the National Marine Plan. Three OWFs in Scottish waters have had herring conditions included within their marine licence. These conditions are for further herring larvae surveys to be undertaken in order to determine the need for further mitigation. This approach is different to that generally applied in English waters and for Beatrice Offshore Wind Farm, herring larvae surveys were undertaken post-consent along with the application of back calculations to determine that spawning grounds were not located within the modelled noise impact zone (which extends beyond the development area). Subsequently MS-LOT determined that no further mitigation would be required for herring.

It is important to recognise that regulators are required to make decisions according to the development site and design that the applicant applies for and the information that is available at that time. If the design envelope is broad, the assessment of impacts may therefore be greater than that which would arise in reality. The onus is on the applicant/developer to make their design envelope as realistic as possible which, in turn, allows any necessary restrictions to be applied at a proportionate level at the time of consent determination.

Regulations and Guidance

Through international and European consultation and literature review, it would appear that spawning herring have not been a concern for OWF development in non UK countries to date, with the main concern being related to the effects of underwater noise on marine mammals, particularly harbour porpoise in a European context. This limited concern seems to be related to the absence of herring spawning areas close to OWFs and this would appear to be by chance, rather than through strategic assessment of proposed OWF lease areas in relation to fish spawning grounds. As such, there is no specific guidance or regulations in place specifically to address herring in non-UK waters.

In the UK and the Republic of Ireland, there are some general regulations and guidance that relate to spawning fish populations as well as to sound exposure criteria and thresholds. In addition, the UK has a

Marine Policy Statement in place, which sets out the process for UK countries to form and adopt National and Regional Marine Plans. It is through these Marine Plans that specific policies are / will be set for adoption during determination of OWF applications. For example, in Scotland, herring is listed as a PMF (with specific mention to spawning adults and juveniles in territorial waters) and therefore its conservation needs to be considered during the decision-making process.

Recommendations

The method of undertaking heat mapping of IHLS data (and IBTS data) to identify herring larvae hotspots and therefore determine the main herring spawning grounds is promoted in order to enable a more up to date appraisal of spawning grounds than that presented within the historical Coull *et. al* (1998) fish sensitivity maps. By using the heat mapping technique alongside the historical data, while overlaying seabed sediment and habitat information, the previous approach of relying upon the Coull *et al*. mapping can be further refined and modernised to provide more up to date information. This approach can be kept up to date each year by using the most recent 10 years of IHLS data, or five years worth of IBTS data. The benefit of using the 10 year data set (rather than just the most recent single year) is to ensure consideration of a robust data set accounting for inter-annual variation, whilst enabling a contemporary evaluation of current use of the spawning ground. This novel approach fits well when compared with the historical fish sensitivity maps and is an all-encompassing approach using all available evidence base as opposed to a series of older spawning maps. The technique can also be used for any fish species of conservation interest where larvae surveys are undertaken and available over a suitable time series.

One area of uncertainty is identification of the exact location where herring spawn (spawning beds). Attempts to undertake back-calculations of where larvae may have drifted from based upon published prevailing current information, larvae age and growth rates have been undertaken (e.g. Beatrice Offshore Wind Farm Limited, 2016; Brown and May Marine, 2007) but these reports show how broad the resulting conclusions are, with very large areas being cited as potential spawning beds and no exact identification available due to using estimates of current speeds and directions. Marine Space (2013) also looked at this within the aggregate dredging industry for the BMAPA (Section 2.2) and concluded that of all methods that can be used to determine spawning beds, the IHLS data was the best indicator and is a direct measure of spawning where fish of length 0 – 11mm were caught. From a review of literature, there is only one instance where the exact location of a spawning bed has been identified (Ballantray Bay in the Clyde) and this was via grab sampling, where herring eggs were incidentally located on the seabed (Parrish *et al*., 1959)).

It is recommended that the undertaking of back-calculations is examined in more detail as part of a future study. The approach to undertaking this exercise should be assessed in detail and build upon the earlier work undertaken for the Beatrice and Thanet Offshore Wind Farms. It is recommended that further review of the previous method used is undertaken and that this approach is developed further to provide a more robust methodology of back-calculation. This should include specific prevailing current modelling for the stock / stock component being analysed (e.g. Scottish Shelf Model) rather than utilising generic prevailing current information, which leads to a wide possible area of distribution being identified for drifting larvae. A thorough review of larval growth rates and also the movement of larvae within the water column should be undertaken, along with consideration of possible temporal (diurnal) components such as determining the time of day that the larvae tend to move.

By undertaking this more detailed back-calculation and then applying the IHLS heat mapping technique in combination with provision of seabed habitat data, it may be possible to further refine the historical fish sensitivity maps that are currently used to assist with licence determination and the identification of licence restrictions and other consent conditions.

1. Introduction

1.1. Project Background

1.1.1. As part of the Offshore Renewables Joint Industry Programme (ORJIP) Offshore Wind Programme, GoBe Consultants Limited (GoBe) is providing environmental technical support to Carbon Trust Advisory Limited (Carbon Trust) in relation to a study to help inform the current understanding of the impact of piling during the construction of offshore wind farms (OWFs) upon herring (*Clupea harengus*) spawning. The study is specifically looking at the impacts on spawning herring and where spawning takes place; the study does not consider impacts on non-spawning adult herring, eggs or larvae.

1.1.2. ORJIP was set up in 2012 by the UK Department for Business, Energy & Industrial Strategy (BEIS) (previously Department of Energy and Climate Change (DECC)), The Crown Estate, The Crown Estate Scotland, Marine Scotland and 16 offshore wind developers (referred to as the Developers) and each project undertaken is also supported by an advisory expert panel (referred to as the Experts), which includes leading experts from Statutory Nature Conservation Bodies, academics and other organisations.

1.1.3. During development and consent of OWFs, environmental data is gathered from a number of sources, including desk-based literature reviews and site-specific surveys, to assess possible environmental impacts that an OWF may have on species that live, use or frequent the marine environment. Environmental surveys are a good indicator (depending on their design and timing) for identifying which species are present within the proposed OWF site, with fish and fish spawning grounds being a particular area of focus during the licensing process.

1.1.4. OWF construction activities, such as pile driving, generate different physical manifestations of noise within the environment (e.g. sound pressure or particle motion), which can disturb or injure fish. Due to potential effects, conditions incorporated into UK offshore renewables consents (such as Marine Licences issued by the Marine Management Organisation (MMO) or Marine Scotland Licensing Operations Team (MS-LOT)) may restrict construction activities during times when fish are considered to be most vulnerable to disturbance, such as during spawning and migration. Such restrictions can be temporal, spatial or technical in nature and are designed to minimise risk of disturbance or injury occurring to fish as well as population dynamics / viability.

1.1.5. Inclusion of these conditions within consents ensures that development of OWFs can proceed, whilst maintaining controls over the way in which the development is undertaken to ensure impacts arising are limited in order to protect habitats, species and other key receptors. The fundamental aspect is to ensure that these controls that are established are appropriately formulated to deliver a protection benefit without unnecessarily burdening development (e.g. in terms of increased costs or time constraints). It is also acknowledged that the current approach to OWFs receiving consent is through the application of a design envelope[2] where minimum and maximum design parameters are identified in order to capture future technological advances in turbines and their associated infrastructure. For each environmental technical area, the realistic worst case scenario of the design envelope is then assessed within the Environmental Impact Assessment (EIA). Following further engineering and design development post-consent, these design envelopes become refined and reduced and the impacts of the 'to be built' OWF are often significantly less than the assessed worst case scenarios. It is at this point that licence conditions may be reduced or removed. There is also a need for country-wide consistency in the advice that is provided to the industry as well as an understanding of how different policy detail in different countries affects that advice. For example, within the UK future regional marine plans and policies will be put in place under the national marine planning system, which will be used for future

[2] Otherwise commonly referred to as a 'Rochdale Envelope'.

OWF decision-making. Despite extensive academic literature and survey work, and their use in EIAs, uncertainty remains on the accuracy of the fish spawning information that is available to date and the level / significance of impacts from piling activity on fish species.

1.2. Project Aims and Objectives

1.2.1. The aims of this study are as follows:

- Review and consolidate available data and information to define (where possible) UK populations, key spawning areas and key spawning periods for herring;
- Identify any gaps in our understanding of herring populations, spawning areas and periods;
- Define and gain acceptance with consenting authorities and experts on herring populations, spawning areas and periods, where data is available; and
- Discuss and understand how the current mitigation approaches are agreed by consenting authorities with the aim of ensuring mitigation is fit for purpose e.g. to understand what is required to ensure protection of the fish stocks but also ensure that restrictions are minimised and proportionate.

1.3. Scope of the Study

1.3.1. The study comprises of five key work packages (WPs), each with its own deliverables. The WPs are summarised as follows:

- WP1 – Population information and OWF impacts;
  - Contract award / Kick-off meeting;
  - Review and collation of existing fish spawning data;
  - Literature review of perceived impacts upon herring; and
  - Gap analysis.
- WP2 – Understanding consenting restrictions;
  - Review of OWF construction restrictions;
  - Implications of uncertainty; and
  - Consents management.
- WP3 – Regulations and guidance;
  - Identification of relevant regulations and guidance.
- WP4 – Interim and Final report;
  - Interim report;
  - Final report; and
  - Peer reviewed paper.
- WP5 – Project management and stakeholder engagement.

1.3.2. The findings of the technical WPs identified above (WPs 1 -3) are set out and discussed in detail within this report.

1.4. Purpose of the Report

1.4.1. This report presents the findings of the research associated with the technical WPs identified above (WPs 1 – 3). The report presents a summary of the literature reviews, data gathering, mapping exercises and consultations that have been completed and provides detailed examination and appraisal of the information gathered, providing a technical review of the literature, data and spreadsheets that have been gathered / produced.

1.4.2. The purpose of the report is to cover the following points:

- Describe the herring population data sourced, where the information came from, its availability, potential for error and including maps showing the population and spawning grounds of herring (including densities);
- Describe the sources of potential impact associated with piling at OWFs on herring, including literature references, the resulting potential for effect, the potential for uncertainty in an assessment of impact and how the significance of that impact is determined (locally and nationally);
- Describe how the potential for impact has been mitigated in various projects, including the available mitigation methods, the benefits and draw backs of these, the uncertainty behind the methods and how successful or appropriate each measure is (or is expected to be). Include a summary of how and why the requirement for mitigation has been modified on a case by case basis (up to 5 cases) in terms of consenting restrictions;
- Present the gap analysis – identifying where gaps exist in the baseline data, the understanding of the potential for impact (and the significance and certainty of that impact), the type and effectiveness of available mitigation, and the level of certainty behind each of these (including the implications of that uncertainty);
- Describe the current understanding of any regulations, guidance and advice that is applicable to herring and OWF development, as identified through the literature searches undertaken, but also from the stakeholder consultation exercise; and
- Present a made-up 'test case' within a defined location (location to be confirmed at the kick off meeting, but suggested in the southern North Sea), to highlight how the information could be used at project level. This will include the population distribution and dynamics of herring, the limitations and gaps in that dataset, the types of mitigation that might be required in that area and the effectiveness of such mitigation.

2. Population Information and OWF Impacts

2.1. Introduction

2.1.1. This section of the report reviews the literature that is publicly available for herring and examines in detail the ecology of the Atlantic herring (*Clupea harengus*) and the population distribution and spawning activity in the UK. Available data sources are then examined in order to further define the spawning activity of Atlantic herring and identify any gap in the current knowledge regarding spawning ground locations and spawning periods.

2.1.2. Following on from this initial baseline identification, existing literature and research that identifies the perceived impacts upon Atlantic herring that may result from development of offshore wind farms is reviewed in order to understand what these impacts might be. The findings of these literature reviews are then summarised at the end of this section of the report.

2.2. Review and Collation of Existing Fish Spawning Data

Approach to Literature Review

2.2.1. Through web-based research and consultation with the ORJIP Discretionary Projects Steering Committee (DPSC) / Experts, a list of available and relevant literature covering herring spawning and spawning activity was collated as far as possible (Appendix A). The contents of this list were then reviewed, summarised and used to present an overall description of the currently understood status of the herring spawning activity around the UK. This literature review was also used as 'ground truthing' to confirm and support (or demonstrate uncertainty in) the examination and mapping of available herring spawning data. Public sources of information that were reviewed included:

- The Crown Estate's Marine Data Exchange (http://marinedataexchange.co.uk/);
- MS-LOT website (http://marine.gov.scot/), interactive mapping (http://marine.gov.scot/maps/nmpi) and publications library (http://www.gov.scot/Topics/marine/Publications);
- MMO website (https://www.gov.uk/government/organisations/marine-management-organisation);
- Cefas website (https://www.cefas.co.uk/);
- ICES website (http://www.ices.dk/Pages/default.aspx);
- The Marine Aggregate Regional Environmental Assessment website (www.marine-aggregate-rea.info/documents), as set up by The British Marine Aggregate Producers Association (BMAPA), The Crown Estate and MMO;
- ICES Planning Group for Herring Surveys website (www.clupea.net/contact/index.html) ; and
- General 'Google' web searches using the terms 'herring spawning stocks', 'herring spawning activity', potential impacts upon herring', 'herring and offshore wind' and similar key words / phrases.

Sources of Data and Data Analysis Methodology

<u>Sources of Data</u>

2.2.2. Several sources of relevant data that could be analysed and used for a mapping exercise were identified and a list of these data sources was collated. The data were then reviewed, obtained and used, as appropriate, to inform the identification of areas of known herring spawning activity. These sources of data included:

- ICES IHLS (http://www.ices.dk/marine-data/data-portals/pages/eggs-and-larvae.aspx);
- Coull, K.A., Johnstone, R., and Rogers, S.I. (1998). Fisheries Sensitivity Maps in British Waters (https://www.cefas.co.uk/media/52612/sensi_maps.pdf);
- Northern Ireland Ground Fish Surveys (NIGFS) (https://datras.ices.dk/Data_products/Download/Download_Data_public.aspx);
- Scottish Ground Fish Survey (Quarter 3 data only available) (https://datras.ices.dk/Data_products/Download/Download_Data_public.aspx);
- IBTS (Scottish and North Sea data) (https://datras.ices.dk/Data_products/Download/Download_Data_public.aspx); and
- Predictive European Nature Information System (EUNIS) seabed habitats. European Marine Observation and Data Network (EMODnet) (2017) (http://www.emodnet.eu/).

ICES Herring Larvae Data

2.2.3. The ICES IHLS has been carried out since 1972 and covers most of the potential and historic spawning grounds of herring. The surveys are designed to provide a quantitative estimate of herring larval abundance to be used as a relative index of the changes in herring spawning stock biomass.

Adult Herring Abundance Data

2.2.4. Herring catch data, provided by the ICES database of fish trawl surveys (Irish Ground Fish Surveys (IGFS) and Scottish West Coast Bottom Trawl Surveys (SWC-IBTS)) has also been used to investigate usage of the spawning areas at key times of the year.

Fisheries Sensitivity Maps

2.2.5. This series of fish sensitivity maps (Coull *et al*., 1998) were initially produced to assist the oil and gas industry with understanding the potential interactions of their activities with fisheries. The intention being that the maps would assist with the planning process and ensure meaningful dialogue between parties and discussion of concerns or issues at an early stage in the process. The fish sensitivity maps provide valuable information on the spawning and nursery areas of key commercial fisheries species, including herring. The maps were produced based upon survey data collected by the Fisheries Research Services (FRS; now Marine Scotland Science (MSS)) and Cefas. These sensitivity maps now form an important part of the EIA process that is undertaken for OWFs as well as in the decision-making process of consenting these developments.

Ground Fish Surveys / International Bottom Trawl Surveys

2.2.6. Ground fish survey (GFS) and international bottom trawl survey (IBTS) data is available through ICES DATRAS (the Database of Trawl Surveys) and includes relevant data covering the North Sea, Northern Ireland and Scotland. These data are based on trawl surveys that are focused on multiple species of fish and is designed to assist with long term monitoring of demersal fish.

EMODnet Predicted Habitats

2.2.7. The European Marine Observation and Data Network (EMODnet) Seabed Habitats project (EMODnet, 2017) is a broad-scale physical habitat mapping database which started in 2009 and comprises of three different phases of work covering the periods 2009 – 2013, 2013 – 2016 and 2017-2019. The mapping consists of a publicly available GIS database containing information on the predicted sea bed habitats present across Europe, mapped in accordance with the European Nature Information System (EUNIS) habitat classification system. These predicted sea bed maps provide valuable habitat information that is currently used to inform the EIA and planning processes. The predicted habitat maps, when used in conjunction with the fish sensitivity maps, can provide an indication of the likelihood of suitable spawning or nursery habitat to be present within a proposed development area.

Data Analysis

2.2.8. The approach adopted for data analysis was presented to the DPSC for approval (Appendix B).

Data Review and Heat Mapping

2.2.9. The data mining and presentation exercise has been undertaken in an attempt to provide a novel and up to date mapping method to try to provide a more refined indication of the spawning locations of herring around the UK, focusing primarily on the North Sea. This method has utilised the existing data on spawning locations and known habitat preferences to refine these areas and provide a more nuanced view of the spawning trends of herring over the previous decade.

2.2.10. IHLS data for the years 2007/08 – 2016/17 were downloaded from the ICES Eggs and Larvae data pages (http://www.ices.dk/marine-data/data-portals/Pages/Eggs-and-larvae.aspx). The purpose of this study was to provide an updated analysis of the distribution of areas of high importance for herring larvae; therefore, the most recent 10 years of data was selected. This period of data was chosen to provide the most up-to-date data (rather than relying on historical trends) but is considered to provide sufficient data to prevent any skewing of the data (position of the high importance areas or abundances) by a single year of data. All surveys undertaken as part of the IHLS programme follow a fixed methodology, ensuring the full dataset can be treated as one without the need for consideration of variations in survey methodology or data processing/presentation. The data download from the ICES website includes (amongst other data) the trawl start coordinates, totals caught for each larval or egg stage, total caught per metre squared (m^2) and the date the survey was completed.

2.2.11. Once the IHLS data had been downloaded, the data were opened in MS Excel, sorted by date and then categorised by the spawning season during which the data were collected (i.e. each spawning season for North Sea herring lasts from August of one year to January of the next, as such the seasons (or years) are referred to as 2007/08 or 2008/09). The data were then imported into MS Access where queries were created to extract the data for each season and for the full 10-year dataset. It was necessary to produce a query for the full 10-year dataset as the IHLS data has multiple repeats for each trawl which were required to be removed. The raw ICES data contains repeat data for each survey trawl as records are provided for each "length" along the trawl. Each length data point contains the number of larvae recorded at that length, however, each record for each trawl shows the "total per m^2" for the whole trawl. As the data component used for the analysis was the total per m^2, only one data record for each trawl was required for the analysis. For ease of management of the dataset, any component not used as part of the analysis or required for data management was stripped from the dataset prior to import into Access, including the length component and the number of larvae recorded at each length point. Therefore, the dataset then contained multiple records of the total larvae per m^2 for each trawl (up to 40 records per trawl). While averaging could have been used to reduce the dataset down, this would not change the values used within the analysis (as the same value for total larvae per m^2 was given for each record for each specific trawl). Additionally, Access has the functionality to allow the extraction of "unique records" from a dataset, thus permitting an accurate and efficient method for extracting one record per trawl. If the repeats were not removed, this would result in a false weighting of the data in favour of certain locations that would not be represented by the number of larvae per m^2. The query outputs were separate datasets for each year (i.e. 2007/08, 2008/09, etc.) and a dataset for the full 10-year period (2007/08 – 2016/17) containing single records for each trawl showing the total larvae per m^2 caught in that trawl.

2.2.12. The datasets were exported from Access as .xls files. These files were then used to create point data shapefiles in ArcGIS (v10.5), which retained the larval counts for each data point. These shapefiles were then opened in QGIS (v2.18.11) and heat maps were created, with the algorithm weighted by the values of the total larval per m^2 to ensure the heat maps reflected this parameter, rather than just the number of points in an area. The heatmaps were created using the WGS84 UTM31N map projection, with a radius of 50km. This distance has been selected to allow a sufficient overlap between points so that the extrapolation of the heat maps covers the full survey area, without being too large to result in a blurring of the 'hot spots' within the heat map.

2.2.13. The resulting rasters[3] produced by the heat map tool were then imported into ArcGIS where the data were categorised using the following methodology:

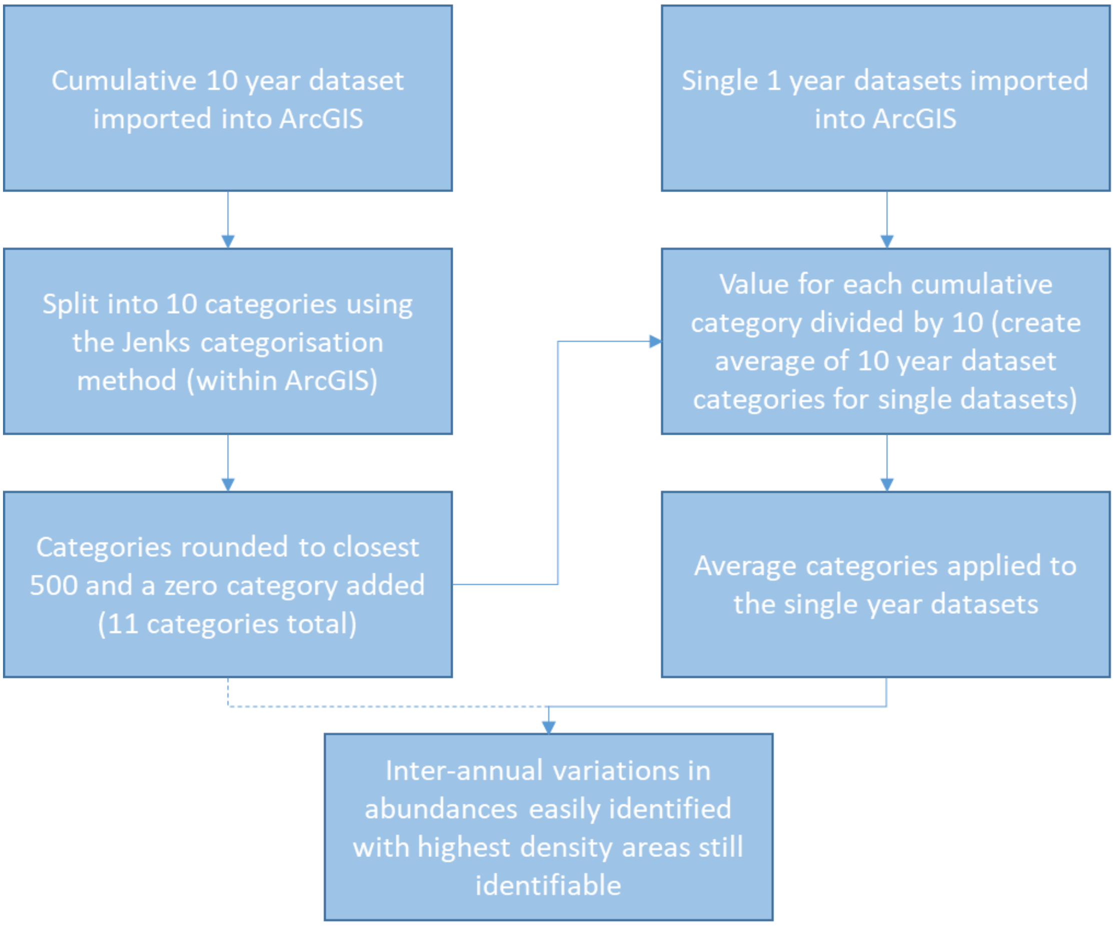

Figure 2-1: Data categorisation methodology

2.2.14. This categorisation method allows easy visualisation of the location of the 'hot spots' within each dataset but also allows comparison of the relative abundance between years. For the 10-year dataset for the whole of the North Sea, the categorisation method for each single year also allows determination of any variation in the relative importance of each spawning area in any one year.

2.2.15. For the Atlantic Ocean, Irish Sea and Celtic Sea, the main data source comprised the International Bottom Trawling Survey (IBTS) and Northern Ireland Ground Fish Survey (NIGFS) data. For the WP1 analysis, the data analysis has been limited to the most recent five years of data for the IBTS data due to the size of the datasets. The IBTS data covers adult herring (thus giving an indication of the presence / distribution of mature females) and these data have been used to give more weight to the IHLS dataset (which is more robust), with the IBTS data either filling in the gaps or comprising additional evidence.

[3] A pattern of closely spaced rows of dots (or pixels) that form a line or an image.

The NIGFS data is much more restricted in its use for this particular study as there are very few data available for the Irish Sea herring stock.

2.2.16. The heat maps presented for the study therefore take the best available real-time data and present the herring larvae and mature female data to show 'hot spots' for particular stocks of herring around the UK and Republic of Ireland that can be used to assist in identifying spawning grounds.

2.2.17. Draft heat mapping was produced and submitted to Carbon Trust in mid-August 2017. Generic IHLS heat maps covering each of the years from 2007 to 2017 were produced, along with a cumulative heat map showing all 10 years worth of data presented together. Generic IBTS heat maps were produced for Irish, North Sea and Scottish regions for the last five years of data. At the same time GoBe produced an example heat map of the NIGFS data for cod (*Gadus morhua*) to illustrate how such a mapping exercise could be undertaken for other key species of fish for which survey data exists. At the same time as the draft mapping was submitted, GoBe proposed to carry out further mapping for the Buchan and Banks stock components, looking at localised temporal and spatial variations of the IHLS data and making comparison to the Coull fish sensitivity maps (Coull *et al*, 1998) and the EUNIS predicted habitats mapping (European Marine Observation and Data Network (EMODnet), 2017).

2.2.18. Following the draft mapping, the heat maps were then reviewed and comments received from Carbon Trust, which were then incorporated into the final heat maps produced in early September 2017. Further mapping and analysis of the Banks and Buchan, in addition to the Downs stock, was agreed with Carbon Trust and the Developers in September 2017 and this was undertaken with more detailed graphics showing the IHLS data for each stock component presented for each of the 10 years, along with the cumulative mapping for the 10 years plotted with the Coull mapping overlaid. Due to the complexity of the predicted habitat mapping and the IHLS heat maps when overlaid, it was not possible to present these together, so a two-frame graphic was created (example shown in Appendix C, Figure C-12).

2.2.19. For information purposes, the IHLS ten year data heat mapping has also been plotted on a graphic which shows the location of current OWF developments in relation to the key herring spawning areas (Figure 2-2).

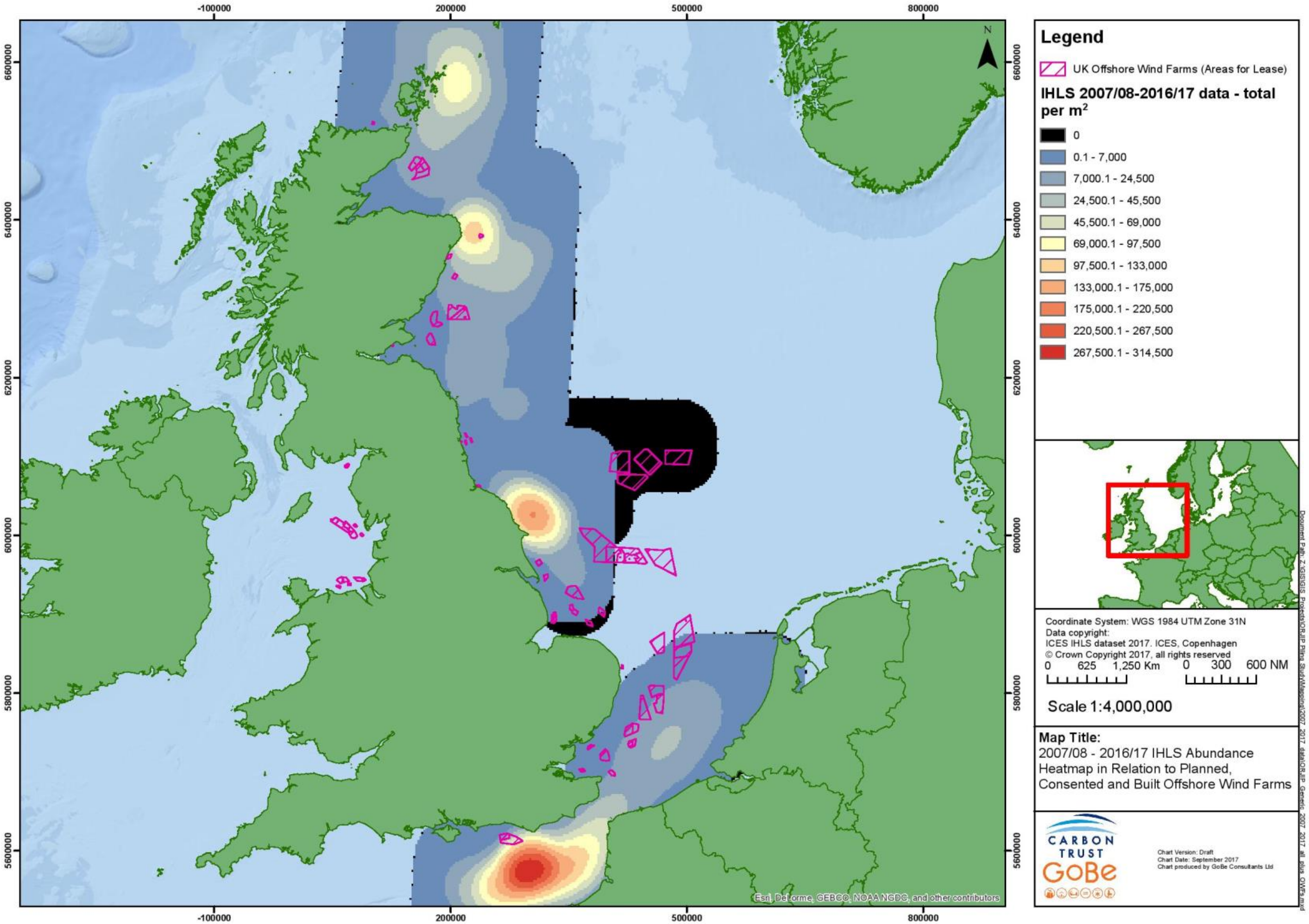

Figure 2-2 IHLS 10 year data in relation to planned, consented and built OWFs

Ecology and Behaviour of Herring

2.2.20. The herring is a silver coloured, pelagic[4] fish which belongs to the family Clupeidae[5] and occurs in large shoals (ICES, 2006; and http://britishseafishing.co.uk/herring/). The most abundant and commercially important species belong to the genus Clupea and they are found mostly in continental shelf seas to depths of 200 m, particularly in shallow, temperate waters of the North Pacific and the North Atlantic Oceans, including the Baltic Sea, as well as off the west coast of South America (http://www.gma.org/herring/biology/distribution/default.asp). Three species of *Clupea* are recognised; Atlantic herring, Pacific herring (*Clupea pallasii*) and Araucanian herring (*Clupea bentincki*) and these species account for about 90% of all herrings captured in fisheries.

2.2.21. The Atlantic herring is found on both sides of the Atlantic Ocean, with a relatively broad distribution from Greenland to the northern Bay of Biscay in the eastern Atlantic and from Labrador to South Carolina in the western Atlantic (ICES, 2006; Figure 2-3). Adult herring primarily feed on zooplankton, in particular *Calanus* spp. but target all zooplankton groups (consuming copepods, arrow worms (chaetognatha), pelagic amphipods hyperiidae, mysids and krill from the pelagic zone), with larger herring also feeding on small fish (Food and Agriculture Organisation of the United Nations (FAO), 2010; ICES, 2006; Last, 1989). Baltic herring is a distinct subspecies (*Clupea harengus membras*) that is found only within the inner waters of the Baltic Sea (Figure 2-4). The distribution of Atlantic herring is illustrated in Figure 2-3. Further information on the state of the herring stocks around the world is due to become available through a communication platform currently under development for herring researchers (www.clupea.net/stocks/index.html). At the time of production of this report, only information on the European stocks is available.

Figure 2-3 Distribution and range of *Clupea harengus*
(taken from International Union for Conservation of Nature (IUCN) red list website[6])

[4] Living or occurring in the upper waters of open sea (http://www.thefreedictionary.com/pelagic).

[5] Clupeidae is a family of ray-finned fishes comprising the herrings, shads, sardines, hilsa and menhadens. It includes many of the most important food fishes in the world (http://www.definitions.net/definition/clupeidae).

[6] http://maps.iucnredlist.org/map.html?id=155123

2.2.22. Herring are known to form very large schools of fish in the open ocean, aggregating in groups that consist of thousands to hundreds of thousands or even millions of individuals. The schools traverse the open oceans migrating between spawning grounds, feeding grounds and nursery / overwintering grounds. These schools of fish primarily make up different stocks (Further information on the term 'stock' is provided in Section 2.2.29).

2.2.23. Herring can attain a maximum length of 40 cm, although most adult fish in the North Sea are in the range of 20 to 30 cm (ICES, 2006). Atlantic herring reach sexual maturity when they are between two and four years old and their life expectancy once mature can be up to 10 years. Most North Sea herring are less than seven years old. Once mature, herring move in towards their respective spawning grounds as their milt and roe begin to develop, congregating in coastal waters in the months prior to spawning (Maravelias *et al*., 2000). Herring are unusual in being the only marine clupeid that lays demersal[7] eggs, with other species spawning their eggs near the surface of the water which then take on a planktonic[8] lifestyle until they develop a swim bladder and transform into their adult form. As such, they have specific requirements in terms of spawning grounds, with seabed sediment being the primary determinant (Maravelias *et al*., 2000). The preferred sediment for spawning is gravel, with some tolerance of more sandy sediments, although these are primarily on the edge of any spawning grounds (Stratoudakis *et al*., 1998). Atlantic herring spawning beds are typically small localised features. Actual spawning habitat, or habitat that could be used for spawning activity in the future, likely comprises relatively small seabed features, with discrete spatial extents, although these may be spread across wide areas of suitable seabed sediment habitat at a regional-scale e.g. spawning grounds (MarineSpace *et al*., 2013). During spawning, shoals of mature herring congregate near the seabed, where females perform specialised movements to deposit their eggs on the substrate, and males 'spray' the surrounding area with milt (Haegele & Schweigert 1985). Female herring produce a single batch of eggs per year. Eggs are laid on the sea bed, usually in water 10-80 m deep, in areas of gravel, or similar coarse habitats (e.g. coarse sand, shell, maerl), with well oxygenated waters (Ellis *et al*., 2012; Bowers, 1980; de Groot, 1980; Rankine, 1986; Aneer, 1989; Stratoudakis *et al*., 1998). Herring eggs have a slightly negative buoyancy and quickly stick to the sediment and to each other, gradually building a fairly uniform multi-layer mat (5 to 10 layers thick) along the spawning ground (Napier, 1993). The eggs then incubate for 10-30 days depending on sea temperature (FAO, 2010).

2.2.24. Herring larvae upon hatching are typically 5.5 – 9 mm long (Miller *et al*., 1997), solitary and pelagic, and drift with the currents. When the larvae have reached a length of 50 mm, they metamorphose, beginning to develop scales and moving to inshore nursery grounds, usually estuaries (Ellis *et al*., 2012). After spending their first two years in coastal nurseries, the two-year-old herring move offshore into deeper waters eventually joining the adult population in the feeding and spawning migrations (Mackenzie, 1985). In areas to the west of Scotland, at two years old 60% of herring will be sexually mature. This increases to 95% at three years of age, and at four years almost all herring will be sexually mature.

2.2.25. Herring have a high spawning philopatry[9], and it is considered that once a herring has exhibited a spawning preference (i.e. season and location) that this preference will continue for the life of that

[7] Sinking to or deposited near the bottom of a body of water.

[8] the aggregate of passively floating, drifting, or somewhat motile organisms occurring in a body of water (http://www.dictionary.com/browse/planktonic)

[9] The tendency of an organism to return or remain near a particular site or area (https://en.oxforddictionaries.com/definition/philopatric)

individual (Geffen et al., 2011), although the intensity of spawning varies and over time some areas may be deserted and new ones occupied.

Hearing Capability of Herring

2.2.26. Herring are physostomous, i.e. they have an open swim bladder where a duct connects the swim bladder to the oesophagus. In addition, the Clupeidae are a family of fish species that have an anatomical arrangement that provides them with a sensitive hearing system. This comprises a swim bladder that is connected to the inner ear of the fish as the diverticula of the swim bladder extends into the skull. For these fish, there is the presence of a thin duct that leads from the swim bladder and expands into two air-filled vesicles (bullae) close to the internal ear (labyrinth). The most anteriorly located of the two vesicles (prootic bulla) is located directly at the sensory epithelium of the utricle (a sac present in the membranous canals of the inner ear). A membrane in the prootic bulla separates the air from the endolymph (the fluid contained in the membranous canals of the inner ear, and pressure changes produced by sound result in the membrane vibrating (Enger, 1967). With the exception of other families of fish with hearing sensitivities, this anatomy is unusual to most fish species where more typically the swim bladder is not connected to the inner ear. Due to this anatomy, clupeids are considered to have a well-developed sense of hearing and are referred to as 'hearing specialists' (ICES, 2006; Thomsen *et al*., 2006). Popper *et al.* (2014) refer to herring as being 'Fishes in which hearing involves a swim bladder or other gas volume' and that they are susceptible to barotrauma and detect sound pressure as well as particle motion. Potential internal injuries can be sustained by repeated rapid motion of the swim bladder against surrounding tissue in fish species with a similar swim bladder type when subjected to sound pressure waves (Halvorsen *et al.,* 2012). However, studies by Casper *et al.* (2012) and Casper *et al.* (2013) show that fish with swim bladders can recover within 10 minutes of exposure to high intensity sounds.

2.2.27. Atlantic herring hear in an extended range of frequencies between 30 Hz and 4 kHz, with a hearing threshold of 75 dB re 1 µPa at 100 Hz (Thomsen *et al*., 2006).

2.2.28. Along with an inner ear, herring also possess a 'lateral line' along the sides of the fish's body. This lateral line forms another principal mechanosensory organ. The lateral line system is stimulated by low frequency (generally below 150 Hz) water flow relative to the fish body and is considered to be able to detect acoustic fields very close to a sound source but that the limited detection range makes the lateral line probably unimportant in the context of the reaction of fish to signals from wind turbines (Thomsen *et al.,* 2006).

General Population Status of Herring Around the UK and Europe

2.2.29. For the purposes of this section the following definitions are used:

- Spawning area: a number of spawning grounds in a larger geographical region;
- Spawning ground: one or more spawning beds located in a larger spatial unit, enclosing all contiguous potential spawning habitat or substrate type;
- Spawning bed: a discrete spatial unit of sea bed over which herring eggs are deposited, or over which actively spawning herring have been identified;
- Stock: a self-sustaining population of a species that occurs within a defined region of the ocean. As a rule, the different stocks of a fish species are spatially separated to such an extent that the individuals from one stock cannot breed with those of another, even though they belong to the same species. These may be genetically unrelated fish populations; and

- Stock component: a group of fish from one specific stock that might use different areas of the sea to spawn, feed or nursery within, but that interact with the rest of the fish at other times of their lifecycle. These may be genetically related fish groups.

2.2.30. There are various stocks of Atlantic herring present around the UK and within European waters. Information provided by World Ocean Review (http://worldoceanreview.com/en/wor-2/ecosystems-and-species/fish-habitats/one-species-multiple-stocks/) on the distribution of herring stocks describes how the individual stocks of herring are distinctly separate from one another. According to World Ocean Review the term 'stock' is defined as '*a self-sustaining population of a species that occurs within a defined region of the ocean*. *As a rule, the different stocks of a fish species are spatially separated to such an extent that the individuals from one stock cannot breed with those of another, even though they belong to the same species'*. One example of this is that the individuals in Norwegian waters spawn in the spring, whereas herring in the North Sea spawn in autumn. As such, there is a very clear separation between the two stocks. For fishery management and discussions of overexploitation of fish species, it is crucial to consider the stocks individually. Rarely is a species completely overfished, rather it is usually only a particular stock of the species. The herring stock of autumn spawners in the North Sea recovered after just five years, while the stock of spring spawners off Norway took almost 20 years to recover. Figure 2-4 is indicative of the various stocks of herring and their perceived spawning seasons. It should be noted that the boundaries for each stock shown in Figure 2-4 may not be accurate, for example the Norwegian Spring spawners and North Sea Autumn spawners are not separated by an area of sea containing no herring stock. These stocks both need to be considered within this particular area.

2.2.31. There are different spawning behaviours between spatial populations of herring; the 'oceanic' group breeds in spring within the Celtic Sea to Iceland, Norway and White Sea; and the 'shelf' group breed in the autumn within the Irish Sea to North Sea and Baltic Sea. As well as 'shelf' herring, there are also related inshore spring spawning populations along the North Sea coast of Britain (Miller *et al*., 1997).

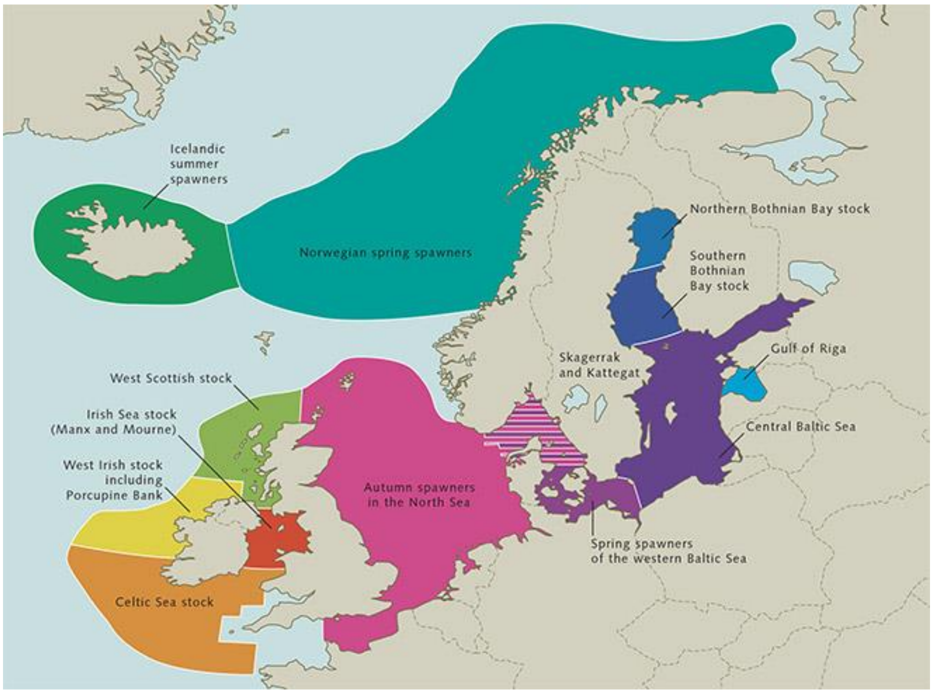

Figure 2-4 Illustration of UK and European herring stock locations (taken from http://worldoceanreview.com).
(Note that boundaries between different stocks may not be accurate and are indicative only).

2.2.32. Within and around the British Isles, the migrations and breeding seasonality of the herring is, however, very complex. Fisheries sensitivity maps are available for the British waters (Coull *et al*., 1998) and these maps include detailed information on the spawning activity for herring. These maps were developed to assist with the environmental impact assessment (EIA) process and this data (Figure 2-5) shows the various key spawning areas for herring and the specific times that spawning takes place. The maps are based on data collected and collated by the FRS and Cefas. Prior to production of these sensitivity maps, information was provided within the 1951 Herring Atlas (ICES, 1951). This Atlas shows, through a series of 12 monthly maps, the average distribution of herring concentrations in the north east Atlantic area along with their condition (e.g. spent herring, full of roe etc.). In 2012, with the aim of updating the 1998 sensitivity maps due to availability of further survey data, additional mapping was produced (Ellis *et al*., 2012). The maps are informed by numerous surveys (including IHLS, GFS and BTS surveys) undertaken by Cefas and other UK fisheries laboratories. The maps present similar findings to that of Coull *et al.* (1998), indicating the spawning grounds associated with the main four spawning components which make up with the North Sea stock (Shetland and Orkney, Buchan, Banks [Central North Sea] and Downs [Southern North Sea]). It also confirms the presence of the more discrete spawning stocks such as the Greater Thames Estuary. This report recognises that while the presence of eggs and larvae can be indicative of spawning grounds, it should be noted that later larval stages may have been advected away from the spawning site. Surveys for herring larvae do, however, indicate which of the nominal spawning grounds are in active use. For example, the Ellis 2012 data suggests limited use of the Dogger Bank area for spawning. It is also recognised that while some historic spawning grounds (e.g. Dogger Bank) currently have no, or very little, spawning activity, it should be recognised that spawning grounds can be 'recolonised' over time (e.g. Corten, 1999) and so ensuring that the physical nature of these grounds does not restrict re-colonisation (e.g. habitat and seabed conditions are not altered but are maintained) is an appropriate management measure (Ellis *et al*., 2012).

2.2.33. The North Sea and west of Scotland herring stocks have both experienced overexploitation in the past leading to collapse (Simmonds, 2001). The North Sea stock declined in the late 60s and early 70s leading to a collapse and closure in the mid 1970's. Following a diversion of the fishing fleet after the closure in the North Sea the west Coast stock collapsed in the late 1970's. Whilst both stocks are reported to have since recovered, recovery rates are slow. The west of Scotland stock peaked in 1980 and has declined steadily thereafter (HAWG, 2017). The spawning stock biomass fell below its Limit reference point in 2013 and despite very limited fishing, the stock has continued to decline with no signs of recovering. ICES currently advises that '*under precautionary considerations, activities that have an impact on the spawning habitat of herring should not occur, unless the effects of these activities have been assessed and shown not to be detrimental*' (ICES, 2017b).

2.2.34. Further information on each of these individual stocks and their spawning activity is presented in Figure 2-5.

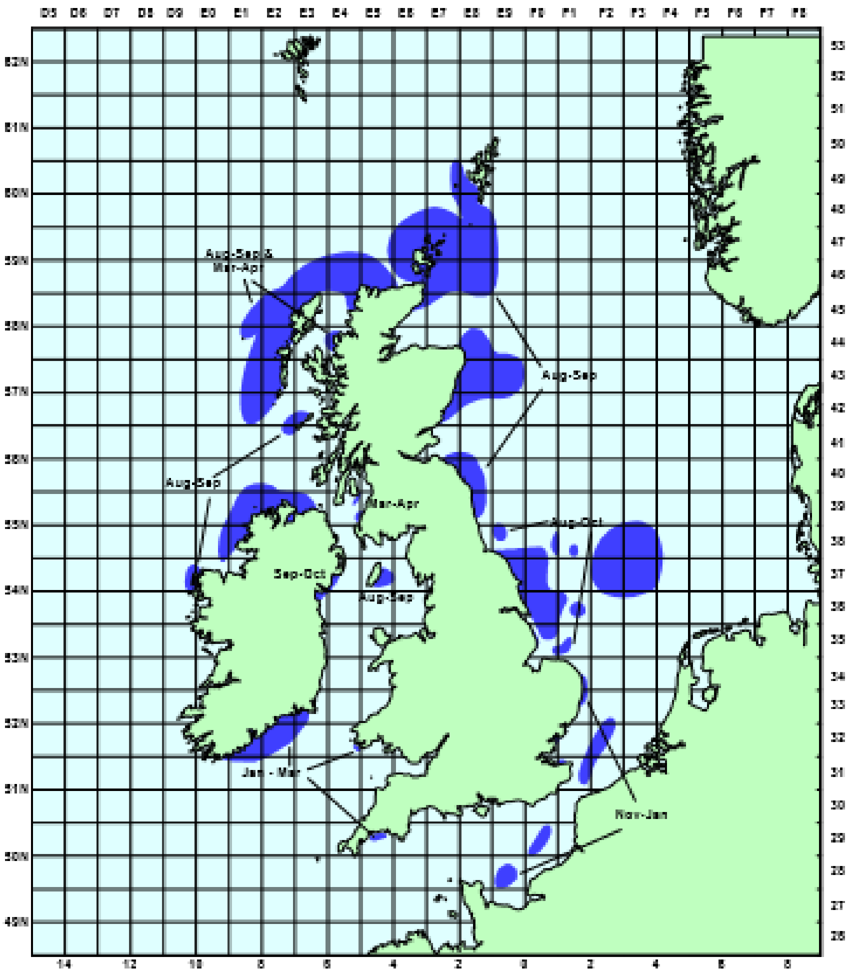

Figure 2-5 Herring spawning areas as identified in Coull *et al.*, 1998.

<u>North Sea and English Channel Stock</u>

2.2.35. Within the North Sea, the commercial fishery for herring is managed as a single stock, however it is acknowledged that there are variations in the timing of spawning throughout the North Sea, with the herring stock split into four spawning components (Orkney / Shetland, Buchan, Banks and Downs). These four spawning components are classed as autumn spawners (Figure 2-5), however the northerly components commence spawning in August/September and the most southerly component (Downs component) commences spawning in December/January (Figure 2-5).

2.2.36. While the four spawning components in the North Sea are highly mixed outside the spawning season within the feeding grounds, they have discrete spawning locations, with differing migration routes and productivity. The recruitment trends of the three northerly components are similar, while the Downs component differs from these and is considered to be subject to different environmental drivers (ICES, 2017), including larval retention and food availability (Sinclair & Tremblay, 1984). The Downs component also shows genetic differences from the other three stocks, which, while minor, show that the spawning segregation between the stocks is distinct (Mariani *et al*., 2005).

2.2.37. Recent studies by Bekkevold *et. al.* (2015) looked at assigning individual herring from the Northeast Atlantic (Skagerrak and Western Baltic) to their regional origin through genetic evidence). This study found that herring from the Baltic Sea contribute to catches from the North Sea. It also found that Western Baltic feeding aggregations are from the western Baltic, but there are also contributions from the eastern Baltic. Another study by Limborg *et. al*. (2012) analysed the genetics of 607 herring from 18 spawning locations in the northeast Atlantic, including two temperature clines (5–12 °C) and two salinity clines (5–35‰). From this study four genetically distinct groups of herring were identified: Baltic Sea, Baltic–North Sea transition area, North Sea/British Isles and North Atlantic.

2.2.38. Genetic studies undertaken within the North Sea stock (Mariani *et al*., 2005) looked at the population structure across the major herring spawning aggregations in the North Sea and adjacent waters over a two year period (2002 and 2003) and concluded the presence of a genetically homogeneous unit off Northern Scotland with a temporally stable pattern of isolation by distance, determined predominantly by the divergence of the English Channel samples and, in 2003, by the Norwegian spring spawners. The current view of North Sea herring as a unit-stock is therefore acceptable, but the study also confirms that there is a considerable degree of demographic independence of the herring populations in the English Channel.

2.2.39. In the HAWG 2017 report (ICES, 2017a), ICES consider that the North Sea stock is in a low productivity phase although the current North Sea spawning stock biomass is considered by ICES to be around 2.6 million tonnes (ICES, 2017a) and sustainably above the precautionary level of 1.3 million tonnes. The current management strategy is to maintain the stock within the precautionary limit for spawning stock biomass.

2.2.40. Part of the MAREA study completed in 2013 by the BMAPA, The Crown Estate and MMO involved looking at the potential impacts of the aggregates industry upon herring spawning at a regional strategic level (MarineSpace *et al*., 2013) as well as the cumulative impacts of all developments. This was undertaken to assist with the EIA process within the marine aggregates industry and was focused on habitat / sediment impacts (e.g. removal of spawning habitat and eggs and / or physical alteration on sediment structure) rather than the impacts associated with underwater noise. Within this work, similar conclusions and graphics were presented showing the locations of spawning components within the North Sea and English Channel to those presented here, having used ICES IHLS data (2002 – 2011), regional BMAPA habitat data, fish sensitivity maps to inform their mapping. BMAPA are currently in the process of updating the MAREA herring assessments, by incorporating more recent seabed sampling data acquired through the sector's regional seabed monitoring programme[10].

2.2.41. A discrete stock of spawning herring exists within the Greater Thames Estuary (often referred to as the Blackwater stock), which spawns off the North Kent Coast and is recognised as a spring spawning stock. The stock is considered separate to the North Sea stock as it has physiological differences present (one less vertebra). A lucrative drift net fishery existed within the Thames for these herring (where bylaws enforced a closure during the spawning season of February for the drift net fishery and March for the wider Thames fishery), however the stock has seen a collapse due to vacating its spawning grounds in recent years. Specific survey work completed to gather data on this stock in relation to the Thanet and Gunfleet Sands offshore wind farm developments has been completed and has identified that spawning appeared to be confined to a small shallow inshore area to the north of Herne Bay, in proximity to Studhill.

Celtic Sea

2.2.42. The Celtic Sea stock includes herring in the southern Irish Sea, Celtic Sea and to the southwest of Ireland and comprises both autumn and winter spawning components (on occasion referred to as the Dunmore autumn / winter spawners). For the purpose of stock assessment and management, these areas have been combined since 1982. Some juveniles of this stock are present in the Irish Sea for the first year or

[10] As advised by Paul Kirk, Marine Licensing Case Manager, MMO on 13/10/2017 (via his personal communications with the Executive Director of Planning, Mineral Resources & BMAPA).

two of their life. Juveniles, which are believed to have originated in the Celtic Sea move to nursery areas in the Irish Sea before returning to spawn in the Celtic Sea (Seafish, 2017).

2.2.43. The spawning grounds for herring in the Celtic Sea (which contain one or more spawning beds) are well known and are located inshore close to the coast (O'Sullivan *et al*. 2013). They cover three main areas that correspond to ICES divisions VIIj, VIIg and VIIaS. The spawning components are not separated out individually for management purposes, nor are they referred to by specific names, however Figure 2-6 illustrates the known spawning locations.

2.2.44. Other herring stocks are found in the Celtic Sea and Irish Sea (both autumn/winter spawners), with small sub-stocks of inshore spring spawning herring. The stocks outside the North Sea are not subject to the same survey effort as the North Sea stock, with no larval time-series data being available for these stocks (ICES, 2017). The Celtic Sea autumn and winter spawning stock is estimated to be at a low level and of high risk, declining from a recent high biomass that peaked in 2011 (ICES, 2017a; Seafish, 2017).

Figure 2-6. Spawning grounds (in red text) and spawning areas (in blue text) of herring around the Republic of Ireland (O'Sullivan *et al*., 2013; ICES, 2014).

Irish Sea Stock

2.2.45. The Irish Sea autumn spawning stock is considered a part of the Malin Shelf stock complex and comprises of the Manx and Mourne spawning components. Herring spawning grounds are found in coastal waters to the west, north and east of the Isle of Man (Manx component) and on the eastern Irish Coast (Mourne component) (Dickey-Collas *et al*., 2001; Isle of Man Government, 2013). The Manx component are identified as spawning on the Douglas Bank and to the north at Point of Ayre, while the Mourne component spawn close to Annalong. Herring spawning takes place from September to November in both areas, occurring slightly later on average off the Irish Coast than off the Isle of Man. The fishery for herring occurs during August and September, with an annual area closure (21 September to 15 November) for herring, to the east of the island, aimed at protecting vulnerable stages of the life cycle (this annually closed area is referred to as the 'herring box'). The herring box is protected under the Sea-Fisheries (Technical Measures) Bye-laws 2000, Part III Special Provisions Relating to Fishing for Certain Sea-Fish and covers a substantial area of the Manx Territorial Sea. In 2001, fishing activity for herring was very low in the Irish Sea and the Mourne component was reported to only comprise of 3% of the overall Irish Sea stock (Dickey-Collas *et al*., 2001). More recently in 2017, the Irish Sea autumn spawning herring was benchmarked and the assessment shows a stable spawning stock biomass in 2016 compared to previous years at around 26,000 tonnes, estimated substantially higher than pre-benchmark. The stock increased owing to large incoming year classes in the most recent years since 2006 (ICES, 2017a).

2.2.46. Acoustic surveys of the herring grounds around the Isle of Man are now undertaken annually by the Northern Irish Agri-Food and Biosciences Institute (AFBI) as part of their wider Irish Sea survey. The survey work is usually carried out in the autumn from the Research Vessel Corystes, using an echosounder to detect fish. The findings from these surveys are provided to and used by ICES within their assessments of the Irish Sea fish stocks. There is sometimes a mis-match in the survey times with herring migration patterns and in addition, the acoustic survey contains an unknown amount of fish from other stocks. Due to the presence of herring from other stocks, the assessment may therefore overestimate the Irish Sea stock (ICES, 2017c).

West Irish Stock

2.2.47. The herring stocks present around the Republic of Ireland are well described within O'Sullivan (2013), with further detail on the West Irish stock presented in the most recent, relevant ICES advisory note (ICES, 2017e). There is one West Irish stock, referred to as the Donegal herring stock. The stock has several known spawning areas present along the north-west coast of Ireland, which are referred to as the Malin Head and Rossaveal components (Figure 2-6).

2.2.48. The Donegal stock comprises of five key spawning areas (Donegal North, Donegal West, Donegal Bay, Mayo and Galway). For each spawning area, through consultation with commercial fishermen, it has been possible to identify spawning grounds and even some detail on spawning beds present within each ground (Figure 2-6). A total of five spawning areas, 21 spawning grounds and 36 spawning beds are associated with the West Irish stock (O'Sullivan, 2013).

2.2.49. The West Irish stock is managed by ICES together with the West of Scotland stock as one unit. This is because it is not possible to segregate the two stocks in commercial catches or surveys, however it is considered that these are two separate stocks in terms of ecology and population dynamics. The SSB has been declining since 2004 and ICES has advised that a stock recovery plan should be developed for both stocks. This should include rebuilding targets and time lines for catches, as well as protections for each stock. This would also include a research component to resolve the lack of information on stock mixing and recruitment.

2.2.50. ICES note that there has been an increase in marine anthropogenic activity, particularly construction and development of marine renewable energy and make reference to the disturbance of the seabed from wind farms as being an issue. ICES do not mention associated underwater noise being an issue.

West Scottish Stock

2.2.51. According to the Scottish Sea Angling Conservation Network (SSACN), the West Scottish herring stock is much smaller than the North Sea herring stock and is fished mainly by vessels from the UK, Netherlands, Germany and France. The fishing fleets and their technology have not changed significantly over the years (ICES, 2017a). In the late 1970s the fishery witnessed a dramatic collapse which led to it being closed completely for two years and more recently, it was established by the Scottish Fisheries Protection Agency (SFPA) that the stocks had been over-exploited by the pelagic vessels and there had been substantial misreporting of landings up until 2006, which led to the Scottish component of pelagic quotas being reduced for several years (http://www.ssacn.org/west-coast-herring-plan/).

2.2.52. As mentioned in section 2.2.48, the West of Scotland stock is assessed with the West Irish stock as one unit by ICES in terms of fisheries management and advice, and this has been the case since 2016. However, ICES recognise that these are separate discrete stocks (although this is a point of recent discussion) and up until 2015 ICES managed the two stocks separately (ICES, 2017a). The stock is currently considered to be in a poor condition (with lowest stock biomass and recruitment recorded in 2016 (ICES, 2017a)) with little commercial fisheries importance (ICES, 2017e). ICES advise that a stock recovery plan should be developed for this stock and unit. Genetic and morphometric sampling is currently being undertaken on the West Scottish and West Irish stocks in order to confirm stock separation and this data should be available in early 2018 (ICES, 2017e).

2.2.53. The West Scottish stock comprise three main stock components. These comprise the Clyde, Skye and Minches components. They are an autumn / winter spawning stock, with the exception of the Clyde component which spawns in the spring (Table 2-1). There seems to be limited information available regarding the West Scottish stocks and where the main spawning beds are present (Rankine, 1986).

2.2.54. The Minches component (often also referred to as the Cape Wrath component) is considered a ‘shelf’ population and believed to be interconnected to the Irish, Celtic and Clyde components (Geffen *et al*., 2011). The Minches component is known to spawn at numerous spawning grounds occurring over a wide area off the north coast of Scotland, off Lewis and the Uists, and at St Kilda and Tiree (Rankine, 1986). Some surveying of these herring populations was undertaken in 2017 by various key organisations (Mackinson *et al*., 2017) in order to improve the knowledge base on spawning of these herring components. Part of this study has included samples being collected for genetic analysis (to date these results are not publicly available).

2.2.55. Similar to the Cape Wrath, the Clyde stock is believed to be a recipient of herring larvae from eight Irish spawning areas (O’Sullivan, 2013). Additional studies undertaken on the otoliths of west coast herring stocks (Geffen *et al*., 2011) has suggested that the Clyde component is interconnected and overlaps with the Irish, Celtic and Cape Wrath components. ICES however manage the Clyde component as a separate stock (ICES, 2015). The Clyde component spawns in the spring between late February and March (Parrish *et al*., 1959) at two main spawning grounds, located at Ballantray Bank, off the coast of Ayrshire (this is the more important area) and a smaller one of the south west corner of the Isle of Arran. Larvae hatch in March and April and spend three or four years in the upper reaches of the Firth in their nursery grounds. The majority of the herring spawned here are reported to not return to the Clyde as adults (Parrish *et al*., 1959).

2.2.56. The Skye component is thought to be more distinct than the Cape Wrath and Clyde components with no connectivity to either of these identified through otolith analysis (Geffen *et al*., 2011). There is limited information available on whether this component is truly discrete or interconnected with other west coast components. The Skye component would appear to spawn to the east between Skye and the coast of Wester Ross (Coull *et al.,* 1998; Ellis *et al.*, 2012).

2.2.57. Coull *et al*., (1998) and Ellis *et al*., (2012) also record a spawning area for herring along the western coast of Tiree (Figure 2-5). This component appears to spawn in August and September.

2.2.58. Recent research indicates that despite the numerous and widely dispersed spawning areas, the herring to the west of the British Isles (e.g. West Scottish stock and West Irish stock) are interconnected and may actually represent a single population, with various levels of mixing between spawning and nursery area groups (Geffen *et al*., 2011). The level of mixing among the groups takes place at several stages of the life history and can be quite complex between the various stocks and components (ICES, 2015).

Spawning Activity Summary and Key Periods

2.2.59. A review of the data within Coull *et al*. (1998) provides an initial indication of the key spawning periods associated with each of the UK spawning stocks / components. In addition to this data, any other information regarding more specific periods or locations of spawning activity that have been identified during the literature review exercise have been recorded. These are presented in Table 2-1.

Table 2-1. Key Spawning Periods for Herring Stocks around the UK.

Herring Stock / Spawning Component	Key Spawning Period (Coull *et al*., 1998)	Other Documentation
North Sea		
Shetland / Orkney	August - September	No further information available
Buchan	August - September	1 – 15 September; 16 – 30 September (Schmidt *et al.*, 2009◆). 1 – 15 September peak period (Beatrice Offshore Windfarm Ltd, 2014 & 2016)
Banks	August - October	1 – 15 September; 16 – 30 September, 1 – 15 October (Schmidt *et al*., 2009◆)
Downs	November - January	16 – 31 December; 1 – 15 January; 16 – 30 January (Schmidt *et al*., 2009◆)
Discrete Stocks		
Blackwater Thames Estuary	Not specified	2 March – 9 May 2007 & 26 March – 3 April 2008 peak period covering 2 – 3 weeks but spawning commenced in February (Brown and May Marine Ltd, 2007 & 2008) 15 March – 22 April 2009 (Vattenfall, 2009).
Celtic Sea	January - March	No further information available
Irish Sea		
Manx	August to September	September to November (Isle of Man, 2013) Late September onwards for three – four weeks (Douglas Bank & Point of Ayre) (Dickie-Collas *et al.*, 2013).
Mourne	September to October	No further information available

Herring Stock / Spawning Component	Key Spawning Period (Coull *et al*., 1998)	Other Documentation
West Irish		
Donegal	August – September	No further information available
West of Scotland		
Minches	August – September	No further information available
Clyde	March - April	Late February – March (Parrish *et al*., 1959)
Skye	August – September	No further information available

◆ As presented in MarineSpace *et al*. (2013).

2.2.60. Table 2-1 clearly shows that for some of the herring stocks and components, some refinement of the original Coull / Ellis spawning periods has been undertaken and most literature now accepts that there are clearly key spawning periods of a shorter peak spanning weeks (mostly 2 – 4 weeks), rather than months. The literature review also clearly identifies that these peak periods vary year on year depending on a range of other key physical and environmental parameters.

2.2.61. There are very few survey data available regarding the exact location of spawning beds for herring, with the only published data being available for herring egg sampling that took place at Ballantray Bay in the Clyde, via grab sampling, where herring eggs were located on the seabed (Parrish *et al*., 1959). Similarly, few surveys have been completed to identify herring spawning grounds, with those that have been completed primarily being undertaken by offshore wind farm developers as part of the EIA process or as part of the discharge process for marine licence conditions. The main sources of information that have been used to determine key spawning areas are associated with surveys for herring larvae (e.g. IHLS surveys) to give an indication of the presence of larvae, consultation with fishermen and fishing organisations (to determine where fishing takes place for herring roe) and also through analysis of the stomach contents of larger fish that prey upon herring. These data, along with analysis, mapping and consideration of seabed habitats are generally used to identify potential spawning grounds and beds. Some studies where herring larval surveys have been completed (e.g. Beatrice and Thanet offshore wind farms) have taken these data and assigned back-calculations to the larval data to identify actual spawning distances from where larvae were sampled.

2.2.62. Suitable habitat sediment is not the only parameter (datum) that indicates potential spawning habitat. There are other environmental (physical, chemical and biotic) parameters such as: oxygenation, siltation, overlap with range of spawning populations, micro-scale seabed morphological features e.g. ripples and ridges; which all contribute to the suitability of seabed habitat to be used as spawning beds by Atlantic Herring. Sea temperature is also a key driver, with research suggesting temperatures of 5°c needing to be present to initiate spawning (Vattenfall, 2009).

2.2.63. With regard to the key spawning periods, it is thought that herring spawning takes place in a select period that enables larvae to grow and metamorphose to coincide with spring and autumn plankton blooms (Sinclair & Tremblay, 1984). Dispersion rates of larvae and food availability at the spawning site is thought to determine if spawning occurs in the winter or spring (Sinclair & Tremblay, 1984) potentially explaining the differences in spawning times of the North Sea population. When assessing these spawning periods, it is worth mentioning their potential to change overtime. This may primarily occur due to increased sea surface temperature (SST), associated with climate change, which may cause seasonal, spatial and productivity shifts in plankton blooms which could change the behaviour of higher trophic species (Barton *et al.*, 2016; Edwards *et al.*, 2013). Research has also highlighted the potential impact of SST on Pacific herring fecundity showing increased fecundity of herring which overwinter in warmer water (Tanasichuk & Ware, 1987). However, Payne et al., (2009) suggest that the failure in North Sea herring recruitment between 2002-2007 was primarily due to changes in the environment, such as SST and food availability.

Analysis of Current Data and Mapping

2.2.64. The assessment of the impacts of offshore wind installations on herring have until now been based on the nominal spawning grounds delineated by Coull *et al*. (1998). While the spawning grounds for many species were updated by Ellis *et al*. (2010), the spawning grounds for herring were not updated. However, Ellis *et al*. did note that Coull *et al.* were correct when stating "spawning distributions are under continual revision, it *follows that these maps should not be seen as rigid, unchanging descriptions of presence or absence*".

2.2.65. While it is important to protect known suitable spawning habitats for herring and ensure the integrity of historical spawning grounds that may yet be recolonised, it is useful to provide an update to the existing spawning grounds. This study aims to provide this update to ensure that mitigation for offshore wind farms to protect spawning herring is targeted at the appropriate projects, which will further support the continuing decrease in offshore wind farm development costs. This will aid in preventing excessive installation costs having to be absorbed by the developers to adhere to seasonal restriction where there is no evidence of ecological benefit.

Overview

2.2.66. The full 10-year IHLS dataset shows a clear delineation of the four North Sea stock components (Orkneys/Shetland, Buchan, Banks and Downs), with the location of each component identified by a hotspot in the larval densities. The hotspots generated by the heatmapping analysis for the Orkneys/Shetland, Buchan and Banks stock components all fall within the Coull *et al*. (1998) spawning ground areas, suggesting that the analysis used here is an accurate estimation of the spawning location (albeit that it does not directly sample the spawning grounds). While the hotspot for the Downs stock component does not match as closely with the Coull *et al*. (1998) spawning areas, the hotspot does overlap with the spawning areas and, as discussed in paragraph 2.2.61, the spawning grounds are subject to change over time.

2.2.67. While herring demonstrate a clear preference to spawn on gravel (or gravelly sands), predictive sediment habitat mapping has a high chance of being significantly conservative when used to predict spawning areas. This can be seen clearly on the heatmapping (Appendix C), with the potential habitat for herring spawning extending across the majority of the North Sea basin. Furthermore, the sediment types within the Coull *et al*. (1998) spawning grounds vary within the individual spawning areas means this approach is limiting.

2.2.68. The 10-year time-series for the full dataset clearly shows that there is a high degree of variation in the abundances recorded between years in the IHLS surveys. The relative importance of each of the spawning components changes from year to year: in some years, the data shows a much higher abundance of larvae in the Down component and in other years the component of highest abundance may be the Banks or the Buchan components. While the sampling dates for all the IHLS surveys are highly consistent between years (start dates +/- approximately 3 days) and sampling is undertaken across a week for each spawning component, these variations could have multiple causes including: delays in hatching until after the surveys have taken place; reduced spawning due to environmental or anthropogenic factors; or biological pressures such as competition with other plankton such as jellyfish (Lynam *et al*., 2005).

<u>Areas of Focus</u>

2.2.69. Following the initial production of the heatmap figures, it was requested by the Steering Group that figures that focused in on the Buchan, Banks and Downs stock components be produced to provide a more detailed view of these areas.

Buchan

2.2.70. The larval hotspot for the Buchan IHLS data for the 10-year dataset shows a high correlation with the Coull *et al*. (1998) spawning ground data, with the area of highest larval density off Peterhead almost full contained within the Coull *et al*. (1998) spawning ground. In addition, the highest larval density matches well with the sediment map, with the highest larval density occurring over an area of coarse sediment.

2.2.71. The individual year figures further show the high degree of inter-annual variation of the larval density recorded in the IHLS surveys, with, for example, the years 2007/08 and 2008/09 having apparently low abundances of herring larvae and years 2012/13 and 2013/14 having apparently high abundances of herring larvae.

2.2.72. Additionally, in some years it appears that there are two areas of importance for herring spawning, with a second area of higher larvae abundance occurring to the east of the Firth of Forth. The hotspot to the east of the Firth of Forth does not appear in the data for all years and often occurs above an area of sandy sediments rather than coarse (gravel) sediments. Herring are known to have a strong affinity with spawning grounds and therefore, this suggests that the hotspot seen in these years may be the result of larval drift from the main spawning ground as opposed to a distinct spawning location. The 2014/15 and 2016/17 provide some support to this argument, with the distribution of the larvae seemingly more spread out from the Peterhead area southwards.

Banks

2.2.73. Traditionally, the Banks component included herring spawning on the Dogger Bank, however, this spawning area has not been productive for many years (ICES, 2017a). While some survey effort is directed towards the Dogger Bank in some years (2007/08, 2013/14, 2015/16 and 2016/17), none of the surveys recorded any herring larvae in this region. This suggests that this historical spawning ground is not currently utilised.

2.2.74. The 10-year dataset for the Banks component shows a strong correlation with the Coull *et al*. (1998) spawning ground around Flamborough Head. However, it is clear from the heatmap that the larvae are found primarily within the northern section of this spawning ground, and the centre of the hotspot is to the north of Flamborough Head.

2.2.75. Similar to the Buchan stock component, the Banks stock component IHLS data show high inter-annual variation in the total abundance of larvae recorded, but a high consistency with regards to the location of the hotspot in each year, with only occasional variations. Only the 2010/11 data show a definite small shift in the hotspot location of the larvae abundance to just south of Flamborough head.

2.2.76. The Banks dataset shows the primary importance of the Flamborough Head spawning ground to the Banks herring, however, as evidenced by the 2009/10 and 2016/17 data, there is a secondary hotspot of larvae occasionally recorded to the north of the primary ground, off the Northumberland coast. This data provides support for the principle of protecting historical spawning grounds, however it is also important to consider the potential effects of any impacts in these areas in relation to the contribution of the spawning ground to the overall stock component. For example, the spawning ground around Flamborough Head may be considered to have a higher sensitivity to the impacts from offshore wind farm development as it is a more consistent area of high larval abundance. Whereas, the

Northumberland coast spawning ground makes a much lower contribution to the overall Banks stock component and may be considered to be of lower sensitivity to offshore wind farm impacts as larvae are only found in that region intermittently.

2.2.77. As herring are known to be highly philopatric, and once they have spawned at one location they will continue to spawn there for the rest of their life, it is important to continue to produce updated maps to identify any new larval hotspots or those that are becoming more used over time. It is for this reason that the IHLS surveys periodically extend further east towards the Dogger Bank spawning ground.

Downs

2.2.78. The Downs stock component spawns latest in the year, with spawning occurring in December and January and the IHLS categorisation criteria for the Downs herring differs slightly from the other components with “small” larvae being defined as <11mm for the Downs herring but <10mm for the other stock components (ICES 2017a). These differences support the potential management of the Downs herring as a separate stock, rather than them being grouped with the wider North Sea stock.

2.2.79. As shown in the combined 10-year dataset, the correlation between the larval hotspot and the Coull *et al*. (1998) spawning grounds for the Downs herring is not as strong as for the Banks and Buchan herring. However, this may partly be due to the reduced area extents of the Coull *et al*. spawning grounds in the English Channel region compared to the North Sea region, which may be partially due to the lower contribution to the overall North Sea herring stock from the Downs component historically (being the last stock to recover following the stock collapse (ICES 2017a)).

2.2.80. All of the single year data show a strong association with the central Coull *et al*. (1998) spawning ground for the Downs stock component, although the relative position of area of highest abundance and the relative abundance varies from year to year. The spawning ground in the southern-most section of the North Sea, to the east of the Thames Estuary, does not appear to be a major spawning zone, based on the recorded larval abundances. However, in occasional years, a hotspot is identified around that spawning ground or the hotspot originating in the English Channel extends through into the North Sea.

Spawning grounds update

2.2.81. While it is not possible to exactly determine herring spawning grounds based on the IHLS data due to the potential for ocean currents to have dispersed the larvae from the spawning grounds, the heatmaps do provide a robust assessment of the position of the areas of highest herring larval abundance. The position of herring larvae has the potential to be used as a proxy for spawning grounds of herring, particularly when compared to the historical defined herring spawning grounds (Coull *et al*. 1998). Where there is a high level of agreement between the distribution of the herring larvae from the IHLS data and the herring spawning grounds, the IHLS data may provide a valuable dataset with which to refine the extent of the spawning grounds based on recent data rather than the historical data used to define the spawning ground extents.

2.2.82. The approximate location of the spawning grounds for the IHLS data could be roughly calculated using residual current data (where available), however, it would not be possible to provide an exact location due to the larvae being classified into size groups, rather than the individual length for each larva being provided. The circulation in the North Sea flows predominantly in a clockwise motion (Nihoul, 1980; Otto *et al*., 1990), with a southward flow along the east coast of the UK. The English Channel has a residual eastward flow, with the water entering the North Sea and joining the clockwise circulation. Based on the predominant residual currents around the North Sea, the close association of the Buchan and Banks stock component with the Coull *et al*. (1998) spawning grounds, and in particular the hotspots being generally at the northern end of the spawning grounds, suggests that the IHLS data could be used as a proxy for potentially refining the main areas of currently used spawning grounds. If the hotspots were generally found at the more southerly extents of the Coull *et al*. (1998) spawning grounds, it is more likely that the larvae would have been dispersed on the currents to this location; however, this potential dispersal is less likely with the hotspots identified at the northerly extents of the spawning grounds.

2.2.83. There is a need to be proportionate in terms of risks posed by OWF developments that do not appear to affect the main spawning grounds within the Coull *et al*., 1998 mapping area, as refined by the heat mapping ‘hot spots’ versus the OWF developments that clearly do affect the ‘hotspots’. Given that the noise modelling undertaken for EIA is precautionary and that the fish sensitivity maps are also precautionary, then balanced consideration needs to be given to the level of potential effects that may result from OWF developments located on the fringes of spawning areas illustrated on the fish sensitivity maps and what the benefit of restricting piling at such developments might be in terms of safeguarding a herring population.

Current Gaps in Knowledge of Herring in UK Waters

2.2.84. The stock dynamics for the West of Scotland herring stock are less well understood than for some of the other stocks within the UK waters. In terms of the interconnection between the three stock components of Skye, Minches and Clyde, there is some confusion as to whether some of these stock components are separate stocks rather than components of the same stock. This position may become clearer in the near future as genetic and morphometric sampling takes place.

2.2.85. In a similar situation is the interaction between the West Irish, West Scottish and Clyde populations. There would appear to be some complex mixing of these stocks / stock components, which makes it difficult to determine whether the Clyde herring are a component of the West Irish or West Scotland stocks, or whether the West Scotland stock is indeed a separate stock to the West Irish stock or should be categorised as all part of the same Western stock, as is reflected by the ICES management of these herring populations. Genetic and morphometric sampling is currently being undertaken on the West Scottish and West Irish stocks in order to confirm stock separation and these data should be available in early 2018.

2.2.86. There is a question about the level of confidence that can be placed upon the use of larval survey data to determine spawning grounds. Acceptance that IHLS data can confidently indicate spawning areas for herring is fundamental to this study and does identify that there is limited information available on the location of exact spawning beds as opposed to the presence / absence of herring larvae. This brings up the issue that there is difficulty associated with mapping exact spawning grounds and beds as this can only be undertaken by the use of intrusive survey techniques such as grab sampling during spawning periods. This is discussed further in Section 3.5 in relation to the implications that uncertainties can have on licence restrictions.

2.2.87. The IHLS data also show that there are areas where IHLS sampling is not carried out and that sampling does not cover the whole of the North Sea, but takes place in areas known to support spawning herring. The survey design is, however, consistent from year to year in order to obtain an index of what has spawned, rather than to obtain a fine scale distribution of larvae. There is no clear information available on how the survey area is chosen each year other than that surveys are repetitive and comparable between years and so there is no clear understanding of what happens within the ‘white space’ where sampling is not focused. Through review of the heat mapping, it is evident that the sampling does take place in the areas where herring larvae are present and that the white space is within areas where herring larvae have not been caught, or are in very low densities. The heat maps would suggest that the surveys are focused on the correct areas and so the presence of the ‘white space’ is not seen to present any discrepancies when mapping of the key spawning areas takes place. It is presumed that if the IHLS data showed one year that larvae were being caught in increased numbers towards one of the 'white spaces' then the sampling effort in that area would be revisited for the following year.

2.2.88. Exploitation by fishing fleets is also an area where there is little understanding of how fishing effort targeted specifically at adult herring at spawning areas impacts at a population level. According to ICES (2006), the North Sea stock and the Western Baltic stock comprise the majority of the herring landings. In recent years a profitable fishery for herring roe has developed during the spawning season and this was also mentioned during consultations with the Scottish Pelagic Fishermen's Association (SPFA). It is therefore unclear what proportion of fishing mortality takes place before spawning, and what effects this will have upon recruitment of the North Sea stock if fishing activity is specifically focused upon mature but unspent female herring.

2.3. Literature Review of Perceived Impacts Upon Herring

Approach to Literature Review

2.3.1. The potential causes of impacts from offshore wind farms (both during construction and operation) on fish species are well known (e.g. installation of the foundations or the electromagnetic fields generated by the operational cables); however, the degree of any impact on the fitness of the individual or on different life stages is not fully understood for any species. Herring, being an important species commercially and ecologically (and considered to be sensitive to underwater noise, being categorised as a 'hearing specialist' (Fay and Popper, 1999)), has been studied more than many species, although knowledge gaps still exist.

2.3.2. A review of perceived impacts has been undertaken through literature review of available published reports and also through consultation with international and European organisations (more information on consultations is presented under Section 2.5).

2.3.3. An online search was undertaken to identify any academic literature or EIA reporting attached to OWFs which contained details of the perceived types of impacts that can potentially occur to herring (and other fish species as relevant). In addition to online research, any documents or reports that the DPSC or other experts were aware of and considered relevant were requested and obtained. Information was collated from the same sources as identified in Section 2.2, as well as the following:

- Tethys database (https://tethys.pnnl.gov/); and
- MaRVEN Project (https://tethys.pnnl.gov/publications/marven-environmental-impacts-noise-vibrations-and-electromagnetic-emissions-marine).

2.3.4. Detailed information on the sources of the literature and documentation that was reviewed is set out within Appendix A.

2.3.5. As underwater noise is a complex issue, with the potential for impact stemming from more than one aspect of noise, the available literature was reviewed with the aim of presenting an understanding of both the impact of sound pressure and of free particle movement (referred to as particle motion) on herring, followed by summarising the reaction types and potential consequences of / to herring. This was reviewed taking into consideration the fish behaviour or motivation at that time which potentially affects the actual response of a fish to noise disturbance (e.g. during feeding, passage or spawning) as well as their ability to avoid predation, interrupted / failed spawning, physical injury, temporary threshold shift (TTS) and masking[11]). Information such as the levels at which these were / are considered

[11] Masking occurs when noise interferes with a marine animal's ability to hear a sound of interest. It is the reduction in the detectability of a given sound (signal) as a result of the simultaneous occurrence of another sound (noise).

to occur and the ecological / stock consequence is described where information is available, followed by a summary of those types of impacts that are considered definite, probable, possible, unlikely or those where there is no evidence to support that they would occur or are likely to be impossible. The effectiveness of mitigation methods is then examined.

Perceived Impacts

Pile Driving

2.3.6. There has been concern (both in the UK and internationally) regarding potential adverse effects from underwater noise generated by pile driving during the construction of OWFs (Bolle *et al*., 2014). Piles are large support structures generally constructed from steel or reinforced concrete that are installed into the seabed, more usually in shallower marine environments. Once installed, the piles extend from above the water surface to most commonly a few metres to 30 metres, but sometimes piles can be as much as 150 metres below the seabed (Geobuuk (http://geobuuk.com/deepest-pile/)). Installation of the pile can be completed via drilling or driving. Pile driving is commonly used for the construction of foundations for a large number of structures including bridges, buildings, retaining walls, harbour facilities, offshore wind turbines and offshore oil and gas platforms and structures. The piling is undertaken using a hammer to repeatedly strike the top of the pile, pushing it into the seafloor. There are two types of hammers, an impact type (diesel or hydraulic) and vibratory type. Vibratory type hammers generate lower source levels, but the signal is continuous, whereas impact hammers are louder and impulsive. The blows are delivered approximately once per second (http://dosits.org/animals/effects-of-sound/anthropogenic-sound-sources/pile-driving/) and can be operated at different energy levels (measured in kilojoules (kJ)). Depending on the size of the hammer, pile diameter, seabed / ground properties and the required penetration depth, it may take several hours and as many as 5,000 strikes to drive one pile into the seabed. Pile driving can be a source of underwater sound if the pile being driven is in water or on land near water. The substrate can contribute either via direct propagation or via interface (Sholte) waves (Hazelwood, 2012; Hazelwood and Macey, 2015). The latter originate at the water-sediment interface and have large particle velocity components that decay rapidly with distance from the interface (Brekhovskikh and Lysanov, 1982). Shear waves and interface waves travel slower than sound waves within the substrate and their peak energy is at lower frequencies (Dowding, 2008). The loud, impulsive sounds that arise from these activities could result in fatal injuries in fish species. For many years there have also been concerns about underwater noise from many other sources such as acoustic surveys, oil and gas exploration, detonation of unexploded ordnance (UXO) and shipping traffic. While some of these noise sources are considered to be likely to have an impact on fish, the impacts from pile driving are generally considered to be greater, due to differences in the type of noise generated (constant noise from shipping compared to impulsive), the area of effect from the noise (acoustic surveys and oil and gas exploration is highly targeted and often impacts on a reduced area) and the duration of the noise (UXO detonations are often discrete events with a single noise as opposed to hours long noise from pile driving).

Background to Underwater Noise

2.3.7. The Marine Strategy Framework Directive (MSFD; European Commission, 2008) includes underwater noise as a qualitative descriptor for determining good environmental status. It is within this European Directive that underwater noise is listed in Annex III as a physical disturbance pressure and impact. The MSFD states that countries will need to be able to define potentially harmful levels of underwater noise and assess these levels against different marine species.

2.3.8. Sound is transmitted as a pressure wave and sound is commonly measured in decibels (dB). There are two categories of underwater noise (Science Communication Unit, 2012):

- Impulsive noise - loud, intermittent or infrequent noises, such as those generated by piling, and seismic surveys; and
- Continuous noise - lower-level constant noises, such as those generated by shipping and operational wind turbines.

2.3.9. Underwater sound is measured by its frequency level (Hertz (Hz)), with some sources of sound producing higher frequencies (e.g. small recreational vessels producing below 1.5 kilohertz (kHz)) and others lower frequencies (e.g. seismic airguns producing between 4 Hz and 200 Hz (Prideaux G., 2016)). Different species are sensitive to different frequencies of sound, with herring known to react to sounds between 100 Hz and 4 kHz (Kastelein *et al*., 2008).

Types of Underwater Noise

2.3.10. Noise (or sound) travels significantly faster through denser mediums such as water, compared to gases, such as air, with sound travelling through the marine environment four times faster than on land. Noise is transmitted as either a pressure wave or as particle motion within water, radiating out in all directions from its source. There are two sources of underwater noise within the marine environment, these being ambient (background) and anthropogenic (man-made).

2.3.11. Two metrics for assessing the potential impacts of pile driving sounds are used. These are: 1) peak sound pressure levels (SPL_{peak}); and 2) sound exposure level (SEL). SEL can be calculated from a single strike (SEL_{ss}) or cumulatively (SEL_{cum}). The duration of the sound used to define the SEL_{cum} must always be clearly stated. Another "peak" metric that is sometimes used is the peak-to-peak sound pressure level, which gives the level of the difference between the highest and the lowest value sound pressure signal in a specified time interval (Dahl *et al*., 2015).

2.3.12. Peak sound pressure levels measured from impact pile driving are on the order of 220 dB re 1 µPa[12] at a range of ~10 m from 0.75 m diameter piles and on the order of 200 dB re 1 µPa at a range of 300 m from piles that are 5 m in diameter (Dahl *et al*., 2015). Acoustic modelling reports that are produced for individual OWF projects provide site-specific data on source levels (at 1 m), which can then be compared to the values stated above for different pile diameters.

2.3.13. Particle motion is the displacement or movement of fluid particles within a sound field. Most fish respond to particle motion as it is detected by the lateral line of fishes, which contain hundreds of flow sensors and neuromasts (hair cell sensors), and also by the otolithic organs which contain sensory epithelium and sensory hair cells which cause otoliths to vibrate, which the fish then detect.

Types of Impact

2.3.14. It is apparent through this literature review and from the international and European consultations undertaken as part of this study that research into the impacts of anthropogenic noise has primarily focused on marine mammals, particularly European populations of harbour porpoise (Dahl *et al*. 2015; Mueller-Blenkle *et al*., 2010; Thomsen *et al*., 2006). Less work has been undertaken on fish and other species and so the extent of impacts upon fish remains uncertain (Science Communication Unit, 2012). Such uncertainty exists in determining the severity of impacts and the level at which they become unacceptable as well as whether it is the noise frequency, repetition or other aspects that cause significant effects. Uncertainty also exists on the levels of population consequences that result from behavioural changes. These aspects are hard to address given the difficulties of monitoring and surveying these effects in the wild. In recent years however, there have been numerous laboratory studies completed in order to attempt to improve knowledge and fill some of these information gaps.

[12] Sound pressure level in decibels is 20 x the logarithm of the ratio of the sound pressure to the reference sound pressure of 1 micro Pascal (http://www.acoustic-glossary.co.uk/sound-pressure.htm)

2.3.15. A review of the literature (e.g. Radford *et al.*, 2013; Dahl *et al*., 2015; Merchant *et al*., 2017) has indicated that there are three main types of effect documented for fish:

- Physiological;
- Behavioural; and
- Environmental.

2.3.16. The physiological impacts associated with pile driving is considered to result in effects upon fish falling into the following categories: mortality (or death), permanent injury or temporary injury.

2.3.17. Mortality of, or permanent injury to, an individual fish results from irreversible physiological change to the body or tissues of a fish. This type of effect would be associated with a fish possessing a swim bladder (studies have shown that fish without swim bladders do not suffer injury (e.g. Halvorsen *et al*., 2012)). The swim bladder contains gases and is very sensitive to changes in pressure, with any changes either affecting internal gas pressure or making the swim bladder walls vibrate. A fish relies on its swim bladder for buoyancy within the marine environment and cannot survive once permanent damage has occurred to this organ. When there is an increase in pressure waves, this can affect the gases, causing them to alter (including expand) and result in the rupture of the swim bladder, which causes death. Other types of internal and external injury that are reported in literature include hematomas (bleeding), damage to the internal organs that are most closely linked to the swim bladder, such as the kidneys, gonads and spleen, as well as permanent hearing loss (otherwise referred to as Permanent Threshold Shift (PTS)).

2.3.18. Temporary injury is where a physiological change to the body or tissues of a fish takes place but this recovers and returns to normal over a period of time. An example of this is temporary hearing loss (or Temporary Threshold Shift (TTS)). For both these permanent and temporary types of injury, it is considered that a fish would need to be in the immediate vicinity of, or very close to, pile driving and stay there long enough to be exposed to a sufficient SEL_{cum}. Laboratory conditions are very different to those within the wild and so scientific studies do not reflect differences that might occur in terms of how a fish would react to piling within the open sea, however it is considered that physiological impacts will be of less significance than behavioural impacts, given that fish will be able to hear piling over large distances from the activity and should be able to avoid or move away from sources of significant underwater noise. Within Halvorsen *et al*. (2012), it was found that the onset of physiological effects never occurred until the SEL_{cum} was above 203 dB re 1 $\mu Pa^2 \cdot s$ and in most species above 207 dB re 1 $\mu Pa^2 \cdot s$. The noise emissions (SEL_{cum}) produced during pile driving will depend on various factors including the hammer energy being used, the diameter of the pile and the type of material / seabed that the pile is being driven in to. All of these factors are modelled specifically for a certain scenario to determine when acceptable sound exposure levels will be exceeded.

2.3.19. In addition to the physiological impacts to individual fish, it is thought that piling can also cause similar types of impacts to eggs and larvae as these life stages contain air sacs. Other impacts such as poor body condition post hatching could occur. For herring, a laboratory study (Bolle *et al*., 2014) that exposed herring larvae to piling noise of up to 186 dB re 1 µPa2·s SEL_{ss} and of up to 216 dB re 1 µPa2·s SEL_{cum} reported that there were no significant differences in mortality between the exposure group when compared to the control group. This work was restricted to looking at lethal injury only. However, data on specific species under specific scenarios is lacking (Radford *et al.*, 2013; Popper, 2003; Slabbekoorn *et al.* 2010).

2.3.20. The behavioural changes associated with pile driving include: habitat displacement (both temporary and permanent), predation and communication disturbance as well as 'startle' response. The behavioural changes that could result in fish moving from a breeding or feeding site or masking the ability of a fish to hear biologically important sounds or communications are considered to be the most significant as they generally result in population consequences (Dahl *et al*., 2015).

2.3.21. Habitat displacement is interpreted as fish not reaching key habitats that are required as part of their lifecycle (such as their spawning (breeding) or feeding (overwintering) grounds) due to high sound pressure levels affecting their normal behaviour. For example, if piling activity is to take place close to a known spawning bed or ground for herring during the key spawning period then the behaviour of the spawning herring could potentially be disturbed, resulting in the fish using avoidance or 'flee' reactions. This in turn may lead to spawning taking place in less suitable locations, or not at all. Population level effects on recruitment / mortality could then ensue. Similarly startle and alarm responses, or changes in shoaling behaviour may occur and alter feeding or migration patterns. According to a study by Thomsen *et al*., (2006) 'startle' responses in herring shoals can be caused by frequencies between 70 Hz und 200 Hz.

2.3.22. Predation and communication disturbance means that fish may not be able to hear certain important acoustic signals due to the masking arising from the piling activity and therefore they may not be able to acoustically locate mates, detect approaching predators or detect food sources. This type of disturbance could result in long term effects on reproduction and population parameters (Mueller-Blenkle *et al.,* 2010).

2.3.23. Masking might be a slightly less important issue considering pile driving noise and the intermittent nature of the sound. However, pile-driving might affect communication indirectly due to the stress induced by the noise. Herring produce sounds falling in three categories: incidental noises associated with jaw movements while feeding; tonal sounds ('whistles'); and a variety of pulsed vocalisations (Thomsen *et al*., 2006).

2.3.24. Auditory scene analysis is described by Popper *et. al*. (2014) as 'the perceptual scene (but not necessarily a scene with spatial dimensions) made up of all the animate and inanimate sources producing or scattering sounds that are detectable by an animal. Auditory scene analysis involves the animal perceiving its acoustical surroundings, or soundscape, as a collection of different sources'. When a fish undertakes this type of analysis it is able to identify critical information that helps with its orientation, navigation and general assessment of the environment. Anthropogenic sounds may result in difficulty for a fish to undertake this analysis.

2.3.25. Other environmental changes can result too, such as avoidance strategies used by fish resulting in displacement away from potential fishing grounds which then leads to reduced catches of commercially important species (Mueller-Blenkle *et al*., 2010).

<u>Responses to Impacts</u>

2.3.26. While juvenile and adult fish may actively swim away from a sound source, planktonic larvae are passively transported by currents and are therefore not capable of avoiding sound exposure (Bolle *et al*., 2014). Recent research by Bolle *et al.* (2014) has indicated that fish larvae mortality may not differ when exposed to pile driving noise in laboratory conditions to that of larvae that are not exposed to pile driving. This research looked at the larvae of sole, bass and herring during three different swim bladder development stages and exposed them to pile driving noise reproduced at zero-to-peak sound pressure levels up to 210 dB re 1 µPa, and single pulse sound exposure levels up to 186 dB re 1 µPa^{2}s. The highest cumulative sound exposure level (SEL_{cum}) applied was 216 dB re 1 µPa^{2}s. Herring larvae were monitored over a period of ten days and for all fish species, the larvae showed no significant difference in mortality levels that those of the control group.

2.3.27. A study was completed in 2005 off the coast of Norway which looked at the behaviour of spawning herring in relation to sound pressure emitted from a survey vessel with a 710 gross registered tonnage travelling at a speed of 10-11 knots (Skaret *et al.,* 2005). The study was undertaken during the night when the survey vessel made several passes over a pre-recorded demersal shoal of spawning herring. The study concluded that there was no evidence of the herring being disturbed by the passing vessel and that reproductive activities taking place were of a higher priority than the avoidance of a passing survey vessel. This supports the theory that herring respond differently during spawning activity than they might do during wintering or spawning migration periods, as herring are known to exhibit strong avoidance reactions to survey vessels during these behaviours.

2.3.28. Studies undertaken in the early 1980's (Blaxter and Hoss, 1981) demonstrated that herring show a marked 'startle' response to sound emitted from a vibrating source. These laboratory studies suggested that sound pressure was important in triggering the 'startle' response and most likely with measuring the strength of the stimulus, while the detection of particle velocity provided the directional information that allowed the fish to move away from the source. However, Blaxter *et al*. (1981), believed that the sound pressure was more important in triggering responses to sound. In this study a shoal of herring was exposed to various sound stimuli and is was concluded that herring are able to move away from the sound irrespective of whether this was a single cycle of sound or many cycles. This is referred to by Popper *et al*. (2014) as 'directional hearing' and is key to assisting a fish to move towards food or a mate.

2.3.29. One of the first studies to attempt to record the behavioural reactions of marine fish to offshore wind farm piling was undertaken in 2010 (Mueller-Blenkle *et al*., 2010). This COWRIE project looked at sole and cod that were placed within net enclosures and exposed to play back of piling noise. The study concluded that the behaviour witnessed would likely be applicable to all marine fish. The results indicate that a range of received sound pressure and particle motion levels will trigger behavioural responses in sole and cod and that there is a relatively large zone of behavioural response to pile-driving sounds in marine fish. Behavioural responses include increased swimming speeds in reaction to the playing of sound, as well as directional movements away from the sound. There was also evidence of some habituation to the sound when exposed multiple times to the sound. Hawkins *et al*. (2014) completed similar playback studies with sonar / echo sounders upon sprat (*Sprattus sprattus*) and mackerel (*Scomber scombrus*) and found that behavioural responses took place, with these increasing when there was a sound level increase.

2.3.30. In one study (Thomsen *et al*., 2006) it was identified that herring will be able to perceive piling noise at large distances, perhaps up to 80 km from the sound source and so this could mask potential communicative signals over considerable distances.

Efficiency of Mitigation Measures

2.3.31. According to Thomsen *et al*. (2006) mitigation measures can be applied to the source of the noise (piling activity) as well as to the receptors (herring). There are various types of mitigation that are mentioned within literature and within licence conditions and these are set out in Table 2-2.

Table 2-2. Different types of mitigation applied during pile driving.

	Type of Mitigation
Source of noise (piling activity)	Mantling of the ramming pile with acoustically-isolated material
	Bubble curtain
	Screening
	Coffer Dams
	Acoustic deterrent devices (ADDs)
	Ramp up / soft start procedures
	Technological restrictions (reduced hammer energy levels etc.)

	Type of Mitigation
Receptor (herring)	Seasonal restrictions (to avoid the most sensitive periods such as spawning or migration). These may be temporal (no piling during a certain period of time), spatial (no piling in specific areas) and / or technical (limited piling hammer energy in certain areas and / or at specific times).

2.3.32. The results of a COWRIE study undertaken in 2010 (Mueller-Blenkle *et al.*, 2010) have important implications for regulatory advice and the implementation of mitigation measures in the construction of offshore wind farms in the UK and elsewhere. First, the concerns raised about the potential effects of pile-driving noise on fish were well founded. This suggests to both regulators and developers that the costs imposed by some mitigation measures that have so far been applied following the precautionary principle go some of the way to addressing a real problem. The report also identifies a suggestion that the behavioural thresholds noted are considered in assessments of impacts of offshore wind farms in the UK and elsewhere. Mitigation measures should be further discussed developed and, if meaningful, applied especially if these could lead to a reduction of acoustic energy that is emitted into the water column.

2.3.33. Thomsen *et al*. (2006) report that the use of air bubble curtains at piling activity can potentially decrease sound by 10-20 dB, depending on frequency, and may potentially be very efficient, albeit expensive for a developer to install and perhaps only working best within the shallower waters. Mantling the ramming pile with materials such as plastic, could result in a decrease of 5 –25 dB SEL, with higher frequencies reported as being better than lower ones. However, there is little application of this technique and so little information on the benefits and costs are understood to date. The 'soft start' process is far more widely applied to offshore wind farms and features as a standard application in most, if not all, Construction Environmental Management Plans for OWFs. The term 'soft start is used to describe the process where lower hammer energy levels are used to start the pile driving activity, and then the force of pile driving is gradually increased or 'ramped up' over time to higher, and eventually the maximum, hammer energy being used. It is theoretically believed to be efficient although as for most mitigation, the true effectiveness is not easily measured or understood.

2.3.34. Acoustic Deterrent Devices (ADDs) have been demonstrated to be effective at deterring both high frequency cetaceans such as harbour porpoise and low frequency cetaceans such as minke whale from the ensonified area (McGarry *et al.*, 2017). While no specific studies have examined the potential effectiveness of ADDs on fish species, the potential exists that these devices may also be effective on hearing specialist fish species, including herring, due to these devices now having been demonstrated to be effective over a wide range of sound frequencies (McGarry *et. al.,* 2017; Coram *et. al.,* 2014). ADDs are not, however, considered appropriate mitigation for spawning areas as they could potentially result in displacement of spawning fish from spawning grounds.

Summary

2.3.35. In terms of the type of impacts that are perceived to affect herring and other fish, agreement seems to be in place within the offshore wind industry that these are sound pressure impacts upon spawning herring as opposed to eggs, larvae and juveniles. It would seem from most recent research that herring larvae are not significantly impacted by pile driving and this seems to reflect the approach adopted in marine licence conditions, where the main perceived impact is related to the behaviour and viability of adult herring during spawning activity. Significant impacts upon herring eggs and larvae are therefore considered to be unlikely, although some literature suggests that there is insufficient information available regarding eggs and larvae so impacts could still be possible.

2.3.36. Reaction thresholds and the spatial extension of the zone of responsiveness varies greatly and therefore the impacts of pile-driving on the behaviour of adult fish cannot easily be calculated. Behavioural effects are identified as being possible (Thomsen *et al*., 2006). The zone of potential masking might in some cases coincides with the zone of audibility. Also physical effects, like internal or external injuries or deafness (TTS/PTS) up to cases of mortality, are probable only in the close vicinity of pile driving.

2.3.37. Yet, the exact nature and extent of the behavioural response needs to be investigated further. Further studies should investigate the response at critical times (e.g. mating and spawning) and the effects of pile-driving on communication behaviour. It will also be necessary to further investigate habituation to the sound to effectively manage effects of pile-driving sound on marine fish.

2.3.38. Noise impacts have been widely studied and the models now used for various impacts are increasingly accurate, however they currently only focus on the effects of sound pressure on marine organisms, with a gap in understanding of the propagation and effects of particle motion generated by noise sources (primarily in relation to pile driving and explosions). The effects of sound pressure are greatest on fish species that have a swim bladder, and in particular where the swim bladder is used in hearing (Hawkins *et al*., 2014; Bolle *et al.,* 2014) as is the case for herring. It has been reported that the lack of study of particle motion could result in the potential underestimation of the effects of noisy activities on non-hearing specialist species that are less sensitive to sound pressure (Popper & Hawkins, 2017).

2.3.39. Herring do demonstrate a clear change in reaction towards sound pressure noise if they are engaged in specific behaviours; when engaged in spawning or feeding, the reaction to noise is dramatically reduced or not apparent compared to when not engaged in these activities (Nøttestad *et al*., 1996; Axelsen *et al*.,2000; Misund, 1994). Skaret *et al.* (2005) suggest that this lack of an avoidance reaction during spawning is due to the short time available for spawning (3-7 days) and that the risk-reward in terms of moving away from a potential predator and continuing to engage in the particular activity changes when a years-worth of energy put into reproduction is at stake. The avoidance reactions seen at other times are considered to be due to the adoption of a low-risk behaviour to potential predators to maximise the chances of successful reproduction later on in the year (Skaret *et al*., 2005). The research therefore implies that spawning fish may be less likely to move away from piling noise if they are already undertaking spawning activity (or feeding), but there is no actual evidence available to suggest that this actually occurs during offshore wind pile driving. The use of soft-start as a mitigation measure to avoid potential effects upon spawning adults may therefore be queried as to whether it would also be effective at encouraging fish to move away from pile driving, however this would require further studies to measure the efficacy of this mitigation on fish.

Current Gaps in Knowledge of Perceived Impacts

2.3.40. The overall effect of underwater sound pressure on fish in general is not fully understood, particularly in terms of the fitness of individuals once exposed, or how the various life stages are affected. For example, there is conflicting information on whether larvae and eggs are impacted upon, with some evidence suggesting that, for herring, these life stages are not affected. So, there is some doubt over the extent that eggs and larvae might be affected.

2.3.41. Sound pressure impacts are more understood than those that are related to particle motion. While it is recognised that particle motion can affect a far wider range of fish and invertebrate species than sound pressure, there is currently little information available on the levels of threshold for which particle motion can have significant effects and how this differs for different fish species or hearing / sensing capabilities. Levels of acceptability for particle motion are not established or understood. There is, however, a lot of interest in this field currently and it is likely that further understanding will be forthcoming in the near future as research into particle motion takes place.

2.3.42. Much of the research is undertaken in a controlled environment, within either laboratory conditions or confined research spaces in the wild such as net cages or confined spaces. The way in which species of fish react within the wild is likely to be different to that within a confined space and so the behavioural reactions observed during research may not be a true reflection of what would happen in the open sea. As a result, the severity of an impact is difficult to determine and little information is known regarding the point at which an impact becomes so severe that is becomes unacceptable. The consequences upon a stock at a population level is also not fully understood.

2.3.43. In terms of the various mitigation measures that are applied in order to reduce impacts to levels that will not be significant, the true effectiveness of these measures is not yet fully understood. Some research identified above suggests that mitigation can be effective but the costs and benefits of these measures are not yet identifiable. The costs of applying a seasonal restriction for herring to an OWF will be considerable given the costly nature of working within the marine environment, but the benefits are not yet easily measured (and in some cases perhaps not even measurable).

3. Understanding Consenting Restrictions

3.1. Introduction

3.1.1. Although there is a UK Marine Policy Statement in place to help guide marine spatial planning in the UK (Section 4.4), there are separate national marine plans and policies in place. Separate consenting processes and country-specific consenting authorities are therefore involved in the licensing process for OWFs. This leads to the potential for different interpretation of UK marine policies and subsequent approaches in the determination of levels of significant effects on ecological sensitivities. This in turn can lead to different ways or methods for minimising these effects being employed through the use of licensing conditions and / or the application of mitigation. A review of the various marine licence consenting restrictions and other conditions that are applied to herring enables any differences, or similarities, to be examined and understood. In order to understand how effective these approaches are, the value and success of these types of restrictions is important, as well as how they are addressed once a project is consented / constructed.

3.1.2. In addition, the 'Rochdale Envelope' process is often applied to OWF EIA and this approach is a key factor in how consenting restrictions are applied. The 'Rochdale Envelope' is a term used to describe a range of design parameters (a 'design envelope') that may be used during the construction of an OWF, but where there is uncertainty (due to technological advances over time) which actual parameters will be used if the OWF is consented and built. For example, the number of turbines that may be constructed might reduce if a larger capacity wind turbine generator is to be used, or the size of the turbine blades may become larger as the generators that might be used become more powerful. For this design envelope approach, as the envelope for an OWF development can contain a large range of parameters, the realistic worst case scenario is used for EIA purposes and this can be based upon numerous uncertainties or lack evidence and so can be overly cautious. Consenting restrictions applied at this stage are therefore wide-scale and precautionary to cover all the uncertainties. However, once consent is achieved and a OWF development progresses through to final design and construction, the uncertainties decrease and the evidence base improves. In many cases the evidence base improves sufficiently to justify reducing or even removing the restrictions. It is important to note that the consenting restrictions are always based on the evidence available at the time of the application.

3.1.3. The aim of this WP is to review past and present consenting restrictions (and other conditions) in order to:

- Gain an understanding of the basis and aims of these consenting restrictions;
- Establish the key concerns that have resulted in piling restrictions, how they have been approached / applied and how consistent the advice has been across projects and between consenting authorities / scientific advisors;
- Explore how uncertainty has impacted upon the approach taken with the application of restrictions;
- Analyse cases where further discussions have taken place to vary construction restrictions and the evidence base required to successfully amend or remove restrictions; and

3.1.4. Compare and understand the current evidence base supporting restriction decisions in the UK and internationally.

3.2. Approach

3.2.1. For this work package, a detailed review of previous and current consenting conditions has been undertaken where restrictions have been applied to construction activities due to the presence or perceived presence of herring spawning grounds and herring larvae.

3.2.2. In order to identify projects that have / are currently subject to piling restrictions, or other mitigation for herring, and to gather relevant documentation to inform the review (including Environmental Statements, baseline survey reports, original licences, licence variation requests, supporting information submissions and approved licence variations), the following sources of on-line information have been reviewed:

- MMO's public register of marine licence applications and decisions (https://www.gov.uk/check-marine-licence-register;
- MS-LOT's current marine renewable energy projects (http://www.gov.scot/Topics/marine/Licensing/marine/scoping);
- National Infrastructure Planning register of applications (https://infrastructure.planninginspectorate.gov.uk/projects/register-of-applications/);
- 4 C Offshore Website information (http://www.4coffshore.com/about-us.aspx);
- Various OWF developer companies and project websites (referenced as required); and
- Other various websites that are returned during specific licence / project specific web searches for topics such as 'marine licence herring restriction' (referenced as required).

3.2.3. In addition to the above websites, a report published in April 2014 detailing the findings of a MMO review of licence conditions entitled 'Review of Post-Consent OWF Monitoring Data Associated with Licence Conditions' (MMO, 2014) was considered to elicit information on OWFs with licence conditions related to herring. Relevant information was used to validate the WP2 findings, as well as serving as a check for any OWFs not previously identified for inclusion.

3.2.4. An email was issued to Developers from Carbon Trust, on behalf of GoBe, on 8th August 2017 requesting assistance with the identification of documentation or herring spawning data that may not be publicly available. This included a request for any documents that provide detail on the restrictions in place or on further discussions that have resulted in restrictions being reduced or removed. At this time copies of herring larvae surveys were received from SSE Renewables, which were undertaken for the Beatrice Offshore Wind Farm. An additional information request and review of the details was made as part of the Interim Report submission for this study and input to the appendix was also provided at that time.

3.3. Stakeholder Engagement

3.3.1. The first stage of stakeholder engagement involved the identification of relevant consultees within the appropriate regulatory organisations in each of the following countries: Netherlands, Sweden, Belgium, Germany, Denmark and the United States of America (USA). The initial list was reviewed by Carbon Trust, who also provided contact details on any other consultees they held and considered relevant (including Norway and France). The final list of consultees was then used to initiate contact and seek consultee input to the study. Alongside this exercise, a Consultation Proforma was drafted in July 2017 for future circulation around the consultees. The Consultation Proforma captured the key areas where information / feedback was being sought and asked a series of key questions with response prompts included. This draft Consultation Proforma was approved by Carbon Trust in August 2017, finalised and circulated around the Developers after the kick-off meeting was held.

3.3.2. Initial contact was made to each consultee via an introductory email from Carbon Trust in early August. A follow-up email was then issued by GoBe with a copy of the Consultation Proforma. Subsequent follow-up emails or telephone calls[13] were subsequently made to consultees where responses were

[13] Follow-up effort varied between one to three communications and a combination of email and telephone call was also used for some consultees. The approach was dependent upon individual responses received.

outstanding. A full list of international consultees is presented in Table 3-1, along with their response status.

3.3.3. In addition to the international consultees identified, key regulatory organisations were also identified for the UK and the Republic of Ireland. A full list of these consultees is presented in Table 3-2, along with their response status.

International Consultation

3.3.4. A total of 13 international organisations from eight countries were consulted. Responses were received from 10 organisations, with no response received from three. Of the 10 organisations that responded:

- Two completed Consultation Proforma;
- Four emailed through detailed information;
- Two emailed through limited information; and
- Two did not supply any information.

3.3.5. Further information on relevant regulations and guidance that are applied within these countries is provided in Section 4.5.

Table 3-1: List of International Consultees.

Country	Consultee	Response
Belgium	MUMM Scientific Service	Response received Limited information provided
Denmark	Centre for Energy Resources Danish Energy Agency (Danish Ministry of Energy, Utilities and Climate)	No response received
	Nature Agency Danish Ministry of Environment	Response received Information provided
France	French Marine Protected Areas Agency	Response received Limited information provided
Germany	Bundesamt für Seeschifffahrt und Hydrographie (BSH)	Response received Consultation Proforma received
	Bundesamt für Naturschutz (Federal Agency for Nature Conservation)	No response received
Netherlands	Netherlands Enterprise Agency	Response received No detailed information included
	Rijkswaterstaat North Sea	Response received from OSPAR[14] was routed through this organisation – see entry below for OSPAR)
Norway	Institute of Marine Research	No response received
	Directorate of Fisheries	Response received No detailed information included

[14] The Convention for the Protection of the Marine Environment of the North-East Atlantic.

Country	Consultee	Response
Sweden	Swedish Agency for Marine and Water Management	Response received Information provided
United States of America (USA)	The Department of the Interior (DOI) Bureau of Ocean Energy Management (BOEM) Offshore Renewable Energy Programme	Responses received Information provided
OSPAR	OSPAR commission's Environmental Impacts of Human Activities Committee	Response received from Rijkswaterstaat on behalf of OSPAR Consultation Proforma received

<u>USA</u>

3.3.6. Although the USA are in the early stages of their offshore wind industry (Atlantic Ocean), herring are not a species that are known to spawn within the areas currently under investigation for offshore wind or for those already being constructed. Atlantic herring tend to spawn mostly in the Gulf of Maine / northern edge of Georges Bank, with some on Nantucket Shores, north of the current project areas. Therefore the USA do not have any active projects where they have needed mitigation measures to protect spawning aggregations during piling. Their main concern has been associated with underwater noise impacts upon marine mammals. The regulators (Bureau of Ocean Energy Management; BOEM) in the USA showed knowledge of the importance of spawning herring within the UK however.

3.3.7. From a review of the potential leasing areas for offshore wind in the USA, it is likely that spawning herring may become a concern and need to be addressed in the future, in relation to future Maine leases. These may be determined to potentially impact upon the herring spawning grounds. An internet search confirms that Important commercial fisheries for juvenile herring exist along the coasts of Maine and New Brunswick (Canada). Development of large-scale fisheries for adult herring is comparatively recent, primarily occurring in the western Gulf of Maine, on Georges Bank, and on the Scotian Shelf. Gulf of Maine herring migrate from summer feeding grounds along the Maine coast and on Georges Bank to southern New England and Mid-Atlantic areas during winter, with larger individuals tending to migrate farther distances (https://www.nefsc.noaa.gov/sos/spsyn/pp/herring/). Spawning in the Gulf of Maine occurs during late August-October and primary spawning locations are located on the Maine coast, Jeffreys Ledge, Nantucket Shoals, and Georges Bank.

<u>Sweden</u>

3.3.8. In Sweden (Baltic Sea), licence conditions have so far related to sound pressure limits / exposures of noise to harbour porpoises and not herring. Existing restrictions for harbour porpoise relate to avoiding activities during sensitive periods for reproduction, migration and foraging. However, it depends on a case by case basis on what level of restriction is applicable at each permission. The BIAS project (Baltic Sea Information on the Acoustic Soundscape) delivered a web based tool for planning, testing and evaluation of continuous underwater sound in the Baltic Sea. It includes layers on sensitive fish areas, like herring, collected from national and international monitoring programs and can be temporarily accessed upon request. A manual to support the tool is currently under development. It is hoped that a similar tool will be developed for the North Sea area through a new application for the EU-project JOMOPANS (https://biasproject.wordpress.com/tasks/tools/), but no further information is available on this project at this time.

3.3.9. A web based research exercise did identify that some of Sweden's wind farms are located within sensitive areas for reproducing fish, including herring and flounder (as well as migratory eel and salmon).

These species have been considered, for example at the Blekinge Offshore Wind Farm and information suggests that restrictions have been applied to avoid construction during sensitive reproductive periods for fish (Hemmingsson, 2013). Swedish offshore wind has the potential to impact upon various herring stocks including the Western Baltic, Central Baltic, Southern Bothnian and Northern Bothnian stocks.

Germany

3.3.10. In Germany, a similar finding has been recorded in that consultees have confirmed that spawning grounds are not present in close proximity to their OWF sites, and their main concern is underwater noise impacts upon marine mammals. The German Federal Maritime and Hydrographic Agency / Bundesamt für Seeschifffahrt und Hydrographie (BSH) provided information through a completed Consultation Proforma. Up to now, a total of 31 approvals have been given for OWFs in the German European Economic Zone (EEZ) in the North Sea and three approvals for wind farms in the German EEZ in the Baltic Sea. A total of 15 wind farms are now in operation and five under construction. In the German EEZ of the North and Baltic Sea no spawning areas for fish species have been identified up to now, with the key species being harbour porpoise. General mitigation is put in place to reduce underwater noise levels and the impact upon all species, however the mitigation primarily related to measures for marine mammals such as soft start piling, noise mitigation systems, deterrents and hammer energy levels.

Netherlands

3.3.11. The Netherlands (Rijkswaterstaat Zee & delta) also provided information through completion of the Consultation Proforma. The research completed here has focused on the larval stage of various fish species including sole, sea bass (*Dicentrarchus labrax*) and herring. The research reported no significant long-term effects on larvae from exposure to piling. However, piling restrictions have been put in place by the Dutch authorities forbidding pile driving of OWF foundations from January to June, in order to ensure that negative effects on prey availability for birds and marine mammals within Natura 2000 areas are minimised. The Dutch are also concerned about noise impacts upon harbour porpoise and have ongoing research in place to look at the modelling used for harbour porpoise within EIA. This is consistent with published literature by Bolle *et al*. (2014) which makes mention to pile-driving for the construction of offshore wind farms in the Netherlands being limited to the period July - December. This literature states that this precautionary management measure was installed partly because of potential adverse effects of pile-driving sounds on fish larvae.

3.3.12. Currently the latest research program in the Netherlands has started aiming at decreasing the uncertainty in the predictions of models which are used in the impact assessments for harbour porpoises. One of their key questions they are looking to address is whether the sound propagation predictions are accurate enough to base the impact assessment for marine mammals on them, and if not, how can they be improved to decrease the uncertainties.

3.3.13. In terms of uncertainty and fish populations and the current research program, the Dutch provide feedback that they have a series of areas of uncertainty that they are looking to address in the future. No further information on timescales for this future research is provided. These are identified as follows:

- What effects does masking (secondary sound overruling natural sounds) have on fish behaviour?;
- What effects does particle motion have on the behaviour of fish?;
- What effects does the additional sound pressure caused by passage of (recreational) vessels and OWF maintenance (service vessels) have on fish?; and
- Do OWFs attract fish?

3.3.14. For the Appropriate Assessment of Dutch offshore wind farms, a modelling study was carried out to estimate the effect of pile-driving sounds on the number of plaice (*Pleuronectes platessa*), common sole (*Solea solea*), and herring (*Clupea harengus*) larvae that reach the Dutch Natura2000 sites (Bolle *et al*., 2014; Bolle *et al*., 2016). For this, an existing larval transport model was expanded with an assumption on larval mortality caused by pile driving. Although it was recognised that insufficient scientific knowledge was available on the relationship between sound exposure and mortality, it was assumed that 100% mortality occurs up to a distance of 1 km from the pile-driving site. This assumption was based on interim guidelines developed by the US Fisheries Hydro-acoustic Working Group. The results of this modelling study indicated a reduction of 0-18% in the number of larvae that reach the Natura2000 sites due to pile driving on specific construction sites.

3.3.15. Subsequently, based on expert-judgment, the model results were extrapolated to other fish species and older life stages in an attempt to assess the effect of offshore pile-driving on the overall prey availability for birds and marine mammals in Natura2000 sites. This extrapolation indicated that a reduction of more than 5% might occur for seven important prey species: plaice, flounder, herring, sprat, cod, whiting and smelt. These findings contributed to the decision for implementing a mitigation rule on the period of the year in which pile driving is allowed.

3.3.16. Most recently, it would seem that there has been a move away from seasonal piling restrictions within the Netherlands as the most recent permits that have been issued have not included seasonal piling restrictions. Instead, seasonally differentiated noise thresholds have been applied to the permit requirements, which is in contrast to the earlier approach (Carbon Trust / Vattenfall *pers. comm*. 13/04/18).

<u>Belgium</u>

3.3.17. In Belgium, the species of interest to date in relation to underwater noise are cod and sea bass. No further information was obtained. As identified in Section 4.5, environmental monitoring has been undertaken on OWFs constructed in Belgium and there is a report that presents the monitoring findings (Degraer *et al.,* 2013). This report identifies cod and pouting (*Trisopterus luscus*) as being species of concern in the past, with monitoring requirements having been put in place for these species. The results conclude that the OWFs have not had any population effects upon these species (up to 2013). Herring are not identified as a species of concern.

<u>Denmark</u>

3.3.18. For Denmark, in relation to underwater noise and the regulation of offshore activities such as piling, these are targeted at the protection of marine mammals. There is a limited understanding on how noise affects fish at a population level, and therefore this is, as of now, not included in the national guidelines.

<u>France and Norway</u>

3.3.19. The French response was that they had very little background knowledge and information on herring and did not provide any further information. Similarly, Norway responded but had no information to provide.

UK and Republic of Ireland Consultation

3.3.20. A total of 11 UK / Republic of Ireland organisations were consulted. Responses were received from 10 consultees to date, with one response expected shortly from one other. Of the 10 organisations that responded:

- Two completed Consultation Proforma;
- Seven provided information; and

- One (SFF) directed the study to another organisation (SPFA).

3.3.21. Carbon Trust advised that engagement with SNH would take place through the expert panel.

Table 3-2: List of UK and Republic of Ireland Consultees.

Country	Consultee	Response
England (and Welsh / Scottish and Northern Ireland Offshore Waters)	Marine Management Organisation (MMO)	Response received Information provided
	The Centre for Environment, Fisheries and Aquaculture Science (Cefas)	Response received Information provided
	Joint Nature Conservation Committee (JNCC)	Response received Information provided
	Association of Inshore Fisheries and Conservation Authorities (IFCA)	Response received Consultation Proforma received
Northern Ireland	Department of Agriculture, Environment and Rural Affairs - The Marine and Fisheries Division & Agri-Food and Biosciences Institute (AFBI)	Response received Information provided
Scotland	Marine Scotland Licence Operations Team (MS-LOT)	Information provided via website[15]
	Marine Scotland Science (MSS)	Response received Comment and information provided
	Scottish Natural Heritage (SNH)	Engagement through expert panel (comments provided via MSS).
	Scottish Fishermen's Federation (SFF)	Response received Asked to consult with Scottish Pelagic Fishermen's Association (SPFA)
	SPFA	Response received Information provided
Wales	Natural Resources Wales (NRW)	Response received Consultation proforma received
Republic of Ireland	Marine Institute (MI)	Response received Information provided

3.3.22. The IFCA provided a completed proforma with information included on correspondence received from the fishing industry, primarily related to perceived reductions of numbers of tope (*Galeorhinus galeus*) around Gwynt y Mor and Burbo Bank OWFs after construction, reduced numbers of flat fish and round fish (particularly sea bass) around Walney 1, Walney 2, Walney Extension, West of Duddon Sands,

[15] http://www.gov.scot/Topics/marine/Licensing/marine/scoping

Ormonde and Barrow OWFs during construction / piling (considered due to the use of ADDs), increased numbers of smooth hound around Walney Extension at the start of construction (considered due to displacement), and increased numbers of mackerel around Ormonde after construction (considered due to presence of structures). No specific information was provided on herring in the Consultation Proforma and, at the time of consulting, no correspondence has been received by the IFCA regarding herring or spawning herring.

3.3.23. Natural Resources Wales (NRW) also provided a completed Consultation Proforma. For decision making on the effects of underwater noise on fish, the NRW use existing data for all fish species. Where models are not proven, additional survey information may be needed to validate predictions. In relation to offshore wind projects in Welsh waters, key concerns include direct effects of mortality / disturbance / displacement of fish populations, restrictions on use of important life stage habitats and energetic implications of sub-optimal feeding. Indirect effects on other species (e.g. mammals, birds) may occur due to changes in availability of fish as a prey resource. In terms of current mitigation that is applied, little mitigation was specified in relation to offshore wind projects off the North Wales coast (apart from elasmobranchs and cabling) at the time these applications were considered. Examples would typically include site specific measures including timing restrictions, soft starts and possible use of bubble curtains. Area closures are also used as a management tool, including for herring, but these aren't typically driven by development activities.

3.4. Review of OWF Construction Restrictions

3.4.1. The projects that have been identified as having such consent conditions and that have been reviewed to date are presented in Table 3-3, along with a summary of the restriction and the herring spawning component that was / is considered to be impacted upon. Figure 2-2 shows the location of herring stocks / stock components in relation to offshore wind developments.

3.4.2. A total of 19 OWF projects have been identified to date as having herring restrictions or other mitigation requirements for this species associated with marine licences. These have been set out within a detailed spreadsheet which presents the information in chronological order, from earliest consent permissions to later / latest consents and applications.

Table 3-3 List of OWFs identified as having herring restrictions or other mitigation requirements for herring.

Date of Consent	OWF	Type of Licence Condition	Herring Spawning Component
June 2004	Gunfleet Sands 1 (Round 1)	Surveys throughout the spawning period.	Thames Blackwater
December 2006	Thanet (Round 2)	Piling seasonal restriction - mid February and the end of April.	Thames Blackwater
February 2007	Greater Gabbard (Round 1)	Piling seasonal restriction – October to February inclusive	Downs
2008	Gunfleet Sands 2 (Round 1)	Surveys throughout the spawning period.	Thames Blackwater
August 2008	Sherringham Shoal (Round 2)	Surveys throughout spawning period (Beginning October to mid November)	Banks
November 2011	Westermost Rough (Round 2)	Piling seasonal restriction -mid August to end of November	Banks
April 2012	Gunfleet Sands 3 (Demonstration)	Piling seasonal restriction – February to April inclusive	Thames Blackwater
July 2012	Race Bank (Round 2)	Piling seasonal restriction – beginning October to mid November	Banks

Date of Consent	OWF	Type of Licence Condition	Herring Spawning Component
July 2012	Dudgeon (Round 2)	Piling seasonal restriction – beginning October to mid November	Banks
February 2013	Kentish Flats Extension (Round 2.5)	Piling seasonal restriction – mid February to end of May	Downs
May 2013	Galloper (Round 2.5)	Piling seasonal restriction – November and December inclusive, unless otherwise agreed with MMO	Downs
July 2013	Triton Knoll (Round 2)	Piling seasonal restriction – beginning of September to end of October, unless otherwise agreed with MMO	Downs
March 2014	Beatrice (Scottish Territorial Waters (STW))	Herring larvae surveys every year during August and September (from consent date to commencement of development) followed by submission of mitigation plan. If mitigation not agreed with MS-LOT then restriction to piling for 16 day period during August and September.	Buchan / Shetland
March 2014	Moray East – Stevenson, McColl and Telford (Round 3)	Herring larvae surveys every year during August and September (from consent date to commencement of development) followed by submission of mitigation plan. If mitigation not agreed with MS-LOT then restriction to piling for 16 day period during August and September.	Buchan / Shetland
July 2014	Rampion (Round 3)	Piling seasonal restriction (wind farm array only and not the export cable corridor) - 20 November to mid-January, unless otherwise agreed with MMO	Downs
October 2014	Seagreen Alpha and Bravo	Consideration of underwater noise effects upon herring in Piling Strategy	Buchan / Shetland
November 2014	Walney Extension (Round 2.5)	Piling seasonal restriction – mid September to mid November, but areas of restriction to be agreed and identified by noise modelling results.	Manx
December 2014	Hornsea Project One (Round 3)	Grab survey and Particle Size Analysis (PSA) in order to determine habitat suitability for herring spawning.	Banks
August 2016	Hornsea Project Two (Round 3)	Grab survey and Particle Size Analysis (PSA) in order to determine habitat suitability for herring spawning	Banks

3.4.3. The reasons given, by the Consenting Authorities, for the need to include piling restrictions and other mitigation for herring within marine licences is consistent across the UK, as set out within Marine Licences, Development Consent Orders and other Planning Inspectorate documentation. The reason being an understanding that the impacts of piling noise (for both wind turbine and substation foundations) will potentially affect spawning adult herring and / or their behaviour. The conditions are not related to potential effects of piling noise on herring larvae, principally because of the limited range of noise levels considered to pose any risk to eggs or larvae as demonstrated through modelling and the resultant minimal extent of any risk thus posed (Bolle *et al*., 2014).

3.4.4. The type of condition that is included within marine licences seems to vary both, as a result of the consenting authorities approach and also with the passing of time in the offshore wind industry. The first conditions for herring were included under the FEPA consenting regime by DECC, subsequently being transposed into Marine Licences / deemed Marine Licences issued by MMO / MS-LOT under the Marine and Coastal Access Act (2009) and the Marine (Scotland) Act (2010) respectively.

3.4.5. In Scotland, three developments have been subjected to licence conditions involving herring. Two of these are within the same location (the Beatrice OWF and the Moray East OWF in the Moray Firth) and the other comprises the Seagreen Alpha and Bravo OWFs, located in the Outer Firth of Forth. All of these projects potentially affect the same herring spawning component (Buchan / Shetland).

3.4.6. The condition requirement set by MS-LOT for Beatrice OWF in the Moray Firth is for further herring larvae surveys to be undertaken in order to determine the need for further mitigation. This approach is different to that generally applied in English waters and seems to have worked well on this occasion, as further surveys were completed over two years, with no further mitigation (such as piling restriction) being required. The majority of herring larvae were found (via back-calculations of larvae age) to have drifted down from the well-established spawning grounds in the Orkney and Shetland area, indicating that spawning activity was much further to the north of the Beatrice OWF. If, however, the larvae surveys had reported spawning taking place within, or closer to, the wind farm boundary then there would likely have been a need for piling restrictions to be enforced and / or other mitigation measures to protect the spawning herring. As such, this type of consent condition can be seen as being open ended with respect to being a constraint on a project, as the level of work required to discharge the consent may increase significantly and potentially result in a temporal, spatial or technical constraint. The same condition is in place for Moray East, which is yet to proceed to construction. Similar to other conditions and mitigation, there is an additional cost encountered by developer and regulator to undertake these surveys and this cost would rise if surveys determined spawning was taking place within the modelled noise impact zone.

3.4.7. For Seagreen Alpha and Bravo, the conditions relate to ensuring that, within the Piling Strategy, the effects of exposure to and / or the effects of underwater noise have been mitigated in respect of herring (and other species). As this project is not yet under construction, no further detail on the interpretation of this condition is available. The condition again is rather open ended with respect to what the developer is required to do to meet the condition requirement. However, it is presumed that this condition is recognising the distance of the Seagreen developments from the Buchan spawning component (at its closest point the edge of the Buchan stock component is 6.9 km from Seagreen Alpha) and as a result the aim is to ensure that noise impacts upon herring remains under consideration. The eventual interpretation of this condition should recognise that potential impacts from the Seagreen developments will not be as significant as the potential impacts within the Moray Firth.

3.4.8. The setting of consent restrictions and conditions in Scotland is primarily driven by the adoption of a design envelope for describing the design parameters of OWFs at application stage. It is also driven by the marine policies that are in place, along with the consideration of sensitive species that require particular conservation measures, such as PMFs like herring. Further information on UK policies and marine planning is presented in Section 4.4.

3.4.9. In English waters, there has been a temporal change in the type of condition requirements that are set, although the type of condition does appear to depend upon the spawning component being potentially affected. The earliest consented developments have conditions to either undertake surveying during spawning periods or they have a blanket piling restriction during the perceived key spawning periods (which differ depending on the stock under consideration). Latterly, there has been some flexibility added into this piling restriction clause which allows for further information to be provided to the MMO to have the restriction period altered, lifted or limited to a certain part of the development site. As such, from the beginning of 2013 there was some recognition by the Planning Inspectorate that restrictions can be minimised / lifted or refined through further technical assessment post-consent and that this should be catered for in deemed Marine Licences. However, in the most recent dML's (e.g. Walney Extension) the wording 'unless otherwise agreed with the MMO' (or similar statements) no longer appears, which means that lifting or alteration of a 'piling restriction' consent condition may be more difficult to undertake, especially if formal consultation with numerous organisations needs to take place as part of the variation process, rather than the more limited process of agreeing with the MMO only[16]. The approach of not including this wording would place the emphasis back on having to have the correct restriction or mitigation put in place pre-consent, rather than providing the opportunity to present new or revised information and assessment post-consent that will protect fish stocks while reducing restrictions upon offshore wind developers.

3.4.10. Most recently at Hornsea One and Two (2014 – 2016), conditions implementing piling restrictions have not been applied to consents, with the conditions requesting further surveying to be undertaken. The surveying requests are focused on habitat types and determining whether suitable habitat is present on site, which is similar to the approach adopted by MS-LOT. This type of condition is unlikely to be desk-based and will usually require the completion of site-specific particle size analysis (PSA) surveys unless suitable data and site coverage already exists. The PSA approach is essentially acknowledging the limitations of spawning maps and requesting the developer to improve the accuracy of the maps. However, the inclusion of conditions requesting further surveying can lead to opportunities for indecision or disagreement on what happens once this surveying is completed (e.g. are restrictions required or not) as well as the level of surveying that is needed to fulfil the condition requirements, or whether this condition can actually be addressed through desk based research, data analysis and literature review rather than through surveys. In the event that PSA data already exists for the relevant area, then it should be straight forward to determine if these data are sufficient, or if further sampling is required.

3.4.11. The conditions that have been applied for the Thames Blackwater stock (Gunfleet Sands 1, 2 & 3 and Thanet) are different in nature as this stock had been known to have collapsed and vacated its spawning grounds. Conditions were therefore more focused on determining the population and spawning status of the stock on a regular basis and hence why surveying features as part of the conditions rather than piling restrictions.

3.4.12. There is therefore evidence to suggest that original 'blanket' piling restrictions that were initially applied across developments have slowly become more focused and flexible in recent years with the ability for OWF developers to now enter further discussion with consenting authorities regarding restrictions or for conditions to be applied to certain areas of a development (e.g. array only, export cable route only or part of the array only). This does, however, lead to an associated cost for OWF developers and consenting authorities with having to undertake this further post-consent survey and consenting work which often also includes additional noise modelling. For original 'blanket' piling restrictions, the costs for developers would potentially have been far more significant, with piling activities often having to be put on hold for long periods of time (e.g. two or three months). This was due to uncertainty in exact spawning times (which are now understood, from site-specific studies and other literature / research,

[16] Where the wording "in agreement with the MMO" is included in a condition, the MMO may still choose to consult with others in relation to a variation of any condition on a licence.

to peak over a relatively narrow time period (two week period)). Developers will, however, need to be in the position to be able to identify when the peak spawning period is, as this will vary by site, and also potentially by year. This may not always be possible from only a literature review of existing information for a given area.

3.4.13. While reviewing documentation to record herring requirements, other key fish species associated with a project were recorded as they were encountered, along with any restriction or mitigation requirement. This was undertaken on an 'as encountered' basis as the scope of the current work did not allow for a more detailed investigation of other fish species. Most of these restrictions are associated with seasonal piling restrictions during key spawning periods or are in relation to salmonid[17] migration or potential effects of electromagnetic fields (EMF). Other key species encountered to date include: Black bream (*Acanthopagrus butcheri*), sole (*Solea vulgaris*), cod, salmon, sea trout, sandeel spp., cuttlefish spp., seahorse spp., flatfish in general and elasmobranchs in general (but also lesser spotted dogfish [*Scyliorhinus canicular*], thornback ray [*Raja clavata*] and starry smooth-hound [*Mustelus asterias*] in particular).

3.5. Implications of Uncertainty

3.5.1. The above review of consenting conditions for herring has identified that due to the adoption of a design envelope approach and the uncertainty included within the design of OWF at the application stage, along with uncertainty on the exact location of spawning beds for herring, these uncertainties have clearly led to the inclusion of consenting restrictions on marine licences. This seems particularly true for the Round 2 and 2.5 / Demonstration OWFs, which were consented between 2011 and early 2013. During this period it seems that the potential effects of underwater noise upon herring (and other species) was becoming an area of concern for consenting authorities, but the level of impact was not fully understood. In response to this, recognition was given to the potential presence of spawning herring, through reference to available fish sensitivity maps (Coull *et al*., 1998) and as there was uncertainty over the actual timing or exact location of spawning, a piling restriction was put in place for the whole development site which covered the whole duration of the perceived spawning period. This was often a piling restriction which lasted between 1.5 to 2 months. For Greater Gabbard, which would appear to be the second OWF to have a herring piling restriction put in place (2007), this restriction covered a period of five months.

3.5.2. It is also clear, from reviewing documentation and decisions made during the DCO process, that this uncertainty was recognised by the Planning Inspectorate around 2013. This occurred initially with Galloper, where, during the issue specific hearings, it was questioned whether there was any form of instrumentation that could be used to measure in real time the state of herring spawning, rather than just having these blanket prohibitions. Condition requirements involving piling restrictions were therefore specifically altered to include the ability for an OWF developer to discuss the need for a piling restriction further with MMO and Cefas. They were also given the opportunity to present supporting information (such as further survey work; additional noise modelling or up to date (or 'as built') design information) in order to demonstrate justification for the removal or reduction of restrictions. This has since been undertaken on various wind farms including Race Bank (Banks stock component), Triton Knoll and Rampion (both Downs stock component). As noted previously however, this flexibility and ability to discuss and potentially reduce conditions post-consent seems to have been removed from the most recent dML's that have been issued, which may re-introduce an element of uncertainty pre-consent once again and lead back to blanket or over-precautious piling restrictions. The reasons for removal of the flexibility to further discuss and potentially remove or reduce restrictions in more recent licences (Hornsea 1 and 2) is not clearly defined, but appears to be due to a different reason being in place for

[17] A fish of the salmon family, such as Atlantic salmon (*Salmo salar*) or sea trout (*Salmo trutta*).

the restriction (concern that dredging and disposal may impact upon herring spawning habitats, rather than an underwater noise and behavioural change impact). It will be interesting to see if such flexibility appears again in future herring restriction conditions.

3.5.3. The scope of this study does not allow for detailed discussion on implications that the restrictions have for industry (in terms of construction delays and monetary implications) but some consultees have presented useful comment and raised concern regarding the additional costs of demobilising and remobilising a piling vessel to comply with the types of piling restrictions that applied to OWFs such as the Rampion OWF (which had two piling restrictions in their marine licence, 20 November to 15 January for herring spawning and 15 April to 30 June for black bream) or Greater Gabbard. The introduction of some type of method to allow consenting authorities and developers to undertake some type of cost / benefit comparison when these restrictions are applied might help alleviate the implications of uncertainty in these instances.

3.5.4. As identified, one area of uncertainty is the exact location where herring spawn (spawning beds). Section 2.2 explains how the IHLS data confirms larvae presence, rather than where the eggs were laid and Section 2 also details how herring are particular about where they spawn, requiring a specific sediment type, although other environmental factors such as water temperature at the time of spawning activity need to be taken into consideration. To date, the challenge therefore is to use moving larvae to predict the location of the fixed, specific sediment type that comprises a spawning bed. Larvae are a good indicator of spawning areas and grounds, but there is a gap in knowledge between where the eggs are laid versus where the larvae have drifted to on the currents by the time they were sampled.

3.5.5. Attempts to undertake back-calculations of where larvae may have drifted from based upon published prevailing water current information, larvae age and growth rates have been undertaken (e.g. Beatrice Offshore Wind Farm Limited, 2016; Brown and May Marine, 2007) but these reports show how broad the resulting conclusions are, with very large areas being cited as potential spawning beds and no exact identification available due to estimates of current conditions. Marine Space (2013) also looked at this within the aggregate dredging industry for the BMAPA (Section 2.2) and concluded that of all methods that can be used to determine spawning beds, the IHLS data was the best indicator and is a direct measure of spawning where fish of length 0 – 11mm were caught. From a review of literature, there is only one instance where the exact location of a spawning bed has been identified (Ballantray Bay in the Clyde) and this was via grab sampling, where herring eggs were incidentally located on the seabed (Parrish *et al*., 1959). It has been recognised since 1959 that due to changing environmental conditions and spawning beds being discrete pockets of suitable habitat (which can change from year to year) within a spawning ground or area, it is extremely difficult to identify the exact location of spawning beds unless they are recorded through grab sampling or by drop down video surveys.

3.5.6. The use of larvae to determine these main spawning areas and grounds has been the adopted approach with the highest confidence levels, as confirmed through the use of IHLS data by commercial fisheries, fish sensitivity maps, BMAPA. This study has found that by using current, up to date IHLS data spanning a 10 year period to create heat mapping, while also using historical fish sensitivity maps and sedimentary data, it is possible to refine historical data to identify the key larvae areas that indicate key spawning areas, providing an update on the historical data that is currently used. The study concludes that, even through the application of back-calculation of larvae to spawning grounds, it would not be possible to identify exact spawning beds.

3.6. Consent Management

3.6.1. Through the more recent addition to the Marine Licences of the opportunity to discuss piling restriction conditions with MMO and Cefas (through the inclusion of the phrases 'unless the Licensing Authority provides written confirmation that works may take place…' and 'unless otherwise agreed in writing'), it is now possible to manage these consent conditions to a certain degree. This, however, is at the additional expense of both the OWF developer (e.g. undertaking further surveys or data reviews and preparing justifications) and the consenting authorities / scientific advisors (e.g. additional time involved in reviewing new data / information submissions and processing variations). Further discussions that have taken place to reduce, minimise or remove piling restrictions have all relied upon additional technical information being submitted in support of marine licence variation requests submitted by OWF developers, along with additional resourcing from the consenting authorities and their advisors during the further consultative and condition review stages.

3.6.2. A combination of changing project design information, additional noise modelling, further survey work and new research identified during desk based studies have been used to support variation requests. The key element here is the ability to re-define the final design of the OWF at this point and reduce the uncertainty that comes from adopting a design envelope at application stage.

3.6.3. Using a realistic worst case scenario approach (or design envelope) during the EIA process and application stage means that often what is actually built at an OWF is often substantially refined in comparison to that consented due to advances in the technology between the period of consent being granted, finance being secured, strike prices / electricity tariffs being agreed and construction taking place. As a result, the likely significant impacts are usually less than those expected and there is therefore opportunity for licence conditions to be varied. One example of this that has been identified is Race Bank, where supporting information was submitted post-consent which included a combination of more detailed knowledge about the construction of the Project (including the particular foundations that would be installed during the current restriction window) as well as changes to assumptions made in cumulative assessment which lead to reductions in the significance levels of effects. Another example was Rampion where further technical assessment work was provided in relation to more recent baseline information (such as bathymetry data) and revised noise propagation modelling (reflecting the actual construction activities being undertaken rather than those predicted) which resulted in the relaxation of piling restrictions. For Triton Knoll, Innogy Renewables UK Limited are also going through a similar process to have piling restrictions removed through presentation of detailed IHLS data analysis using heat mapping, analysis of IBTS data and interpretation of Humber cumulative impact assessment sediment data and seabed characterisation assessment which formed part of the Marine Aggregate Regional Environmental Assessment (MAREA) (ERM, 2013).

3.6.4. It is important to recognise that regulators are required to make decisions according to the development that the applicant applies for and the information that is available at that time. If the design envelope is unrealistically broad, the assessment of impacts may therefore be greater than what would emerge in reality. The onus is on the applicant/developer to make their design envelope as realistic as possible which, in turn, allows any necessary restrictions to be applied at a proportionate level.

3.7. Summary

3.7.1. A review of marine licences and other available consenting documentation has allowed the production of a detailed list of OWFs to be drawn up that have specific herring conditions included on marine licensing, along with the type of restriction that has / is being applied. In addition, it has been possible to look at how these restrictions or other mitigation requirements have been discussed further with the aim of reducing or removing them (successfully or otherwise) within a UK context. It is also possible to look at how these conditions have evolved over time and why they have been implemented for a particular project. A total of 19 projects have been identified to date and there is information available for projects around the UK.

3.7.2. Within the international context, it is apparent that herring have not been identified as such a vulnerable species within the other countries that have been consulted. This is not due the species being considered insignificant, but more that key spawning grounds have not been identified as being present within or around their OWF sites. These countries that have not experienced co-locations of proposals with spawning areas would appear to have been fortunate to avoid key spawning areas, as opposed to the developments being spatially planned so as to avoid these sensitive areas.

4. Regulations and Guidance

4.1. Introduction

4.1.1. It is important to understand how different UK countries approach the issue of herring sensitivity to noise within their regulations and guidance. In order to do this, there needs to be an understanding of the marine planning systems and the policies within each country and how these are used to influence decision making and consenting processes. In addition to this, it is also important to determine how this compares with other European and international countries with active offshore wind industries and what their policies, regulations and guidance requires.

4.1.2. The aim of this WP was to identify relevant guidance where it exists, including advice provided by statutory bodies. A high-level review was then carried out to summarise the mitigation guidance identified and relevance to herring spawning during periods of piling.

4.2. Approach

4.2.1. To gather information and inform an understanding, consultation has taken place with the key consenting authorities in the UK and Republic of Ireland. As well as consulting within the UK and Republic of Ireland, consultation has taken place with a range of other countries, including via the issue of a consultation proforma specifically asking about regulations and guidance. The details of these consultees are presented in more detail within Section 2.5.

4.3. UK Regulations and Guidance

4.3.1. Within the UK, there are no specific regulations or guidance in relation to the EIA process and the consideration of herring within the UK offshore wind industry.

4.3.2. In terms of commercial fishing regulations, there is specific legislation in place for the protection of herring within the Isle of Man. The 'Sea-fisheries (technical Measures) Bye-laws, 2000 (Isle of Man Government, 2000) introduces restrictions on fishing for herring between the 21 September and 15 November in any given year, within a stipulated area of the territorial sea (referred to as the 'herring box'). These are set out within Part III Special Provisions Relating to Fishing for Certain Sea-Fish and introduce seasonal, gear and catch size restrictions. Section 4.4 discusses the marine planning system of the Isle of Man in more detail.

4.3.3. The following list of UK regulations and other documents have been identified as being of relevance to EIA and fish in general and their guidance and advice is generally applied to the industry.

Regulations

4.3.4. UK Regulations that apply in general include:

- HMSO (2017). Statutory Instrument 2017 No. 115. The Marine Works (Environmental Impact Assessment) (Scotland) Regulations 2017;
- HMSO (2007). Statutory Instrument 2007 No. 1518. The Marine Works (Environmental Impact Assessment) Regulations 2007 (as amended).
- Various country-specific regulations transposing Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora ('Habitats Directive'; Official Journal of the European Communities, 1992). These include:
    - HMSO (1994). Conservation (Natural Habitats &c.) Regulations 1994 (as amended);
    - HMSO (2010). The Conservation of Habitats & Species Regulations 2010 (as amended);

- The Stationery Office (2011). Statutory Instruments. S.I. No. 477 of 2011. European Communities (Birds and Natural Habitats) Regulations 2011; and
- Department of Environment (1995). Statutory Instrument 1995 No. 380. The Conservation (Natural Habitats, etc.) Regulations (Northern Ireland) 1995.

4.3.5. Several UK Acts of legislation apply to the general consenting process including (but not limited to): Marine and Coastal Access Act 2009, Marine (Scotland) Act 2010, Wales Act 2017 and The Marine Act (Northern Ireland) 2013. Fisheries legislation also exists that protects certain commercial fisheries in key areas for certain periods. Species specific measures are also applied through the Salmon Act 1986 & Eels Directive and related Eels Regulations in England, Scotland and Wales.

4.3.6. In terms of herring and commercial fishing, fishing in the EU is regulated through the Common Fisheries Policy (CFP). ICES are the body that advises upon the exploitation of commercial fish stocks, which include the North Sea herring stocks. There is an expert working group, the ICES Herring Assessment Working Group for the Area South of 62ºN (HAWG), which provides scientific advice on the herring stocks in the North Sea and the adjacent areas spanning from the Celtic Sea to the Western Baltic. HAWG advise the ICES Advisory Committee (ACOM) on the annual quota for herring. The key guidance issued by ICES / HAWG includes:

- ICES (1951). Fisheries of the North East Atlantic. Herring Atlas. Fishing Ground, Landing Ports and Quality;
- ICES (2015). ICES Advice on fishing opportunities, catch, and effort. Greater North Sea Ecoregion. Published 29 May 2015 (Section 6.3.12); and
- ICES (2017). Herring Assessment Working Group for the Area South of 62 deg N (HAWG). ICES HAWG Report 2017. ICES Advisory Committee. ICES CM 2017/ACOM:07. Ref. ACOM.

4.3.7. The most recent advice from ICES regarding the management of herring stocks appears in each of the ICES division guidance documents for herring (e.g. ICES, 2017c) and these state that:

- ICES advises, under precautionary considerations, that activities that have an impact on the spawning habitat of herring should not occur, unless the effects of these activities have been assessed and shown not to be detrimental.

Guidance

4.3.8. Within the UK, there are no specific regulations or guidance in relation to the EIA process and the consideration of herring within the UK offshore wind industry. The following regulations and other documents have been identified as being of relevance to EIA and fish in general and contain guidance and advice:

- Popper, A.N., Hawkins, A.D., Fay, R.R., Mann, D.A., Bartol, S., Carlson, T.J., Coombs, S., Ellison, W.T., Gentry, R.L., Halvorsen, M.L., Løkkeborg, S., Rogers, P.H., Southall, B.L., Zeddies, D.G.,Tavolga, W.N. (2014). ASA S3/SC1.4 TR-2014. Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. January 2014;
- Cefas (2004). Offshore Wind Farms: Guidance Note for Environmental Impact Assessment in Respect of FEPA and CPA Requirements. Prepared by Cefas on behalf of the Marine Consents and Environment Unit (MCEU). June 2004;
- Cefas (2009). Strategic Review of Offshore Wind Farm Monitoring Data Associated with FEPA Licence Conditions. Fish. Contract ME1117.

- Cefas (2011). Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects. Draft for Consultation issued 10th March 2011. Cefas contract report: ME5403 – Module 15;
- Coull, K.A., Johnstone, R., and S.I. Rogers. (1998). Fisheries Sensitivity Maps in British Waters. Published and distributed by UKOOA Ltd;
- Ellis, J.R., Milligan, S.P., Readdy, L., Taylor, N. and Brown, M.J. (2012). Spawning and nursery grounds of selected fish species in UK waters. Science Series Technical Report no. 147;
- Chartered Institute of Ecology and Environmental Management (CIEEM) (2010). Guidelines for Ecological Impact Assessment in Britain and Ireland. Marine and Coastal. Final Document. 2010; and
- CIEEM (2016). Guidelines for Ecological Impact Assessment in the UK and Ireland. Terrestrial, Freshwater and Coastal. Second Edition. January 2016.

4.3.9. Most recently, guidelines on fish sound exposure levels were developed in 2014 following a review by a Working Group specifically set up to address this issue. These sound exposure guidelines (Popper *et al.,* 2014) are based on the best scientific data available to date and as more research is completed, the guidelines will be updated to reflect this. The document determines broadly applicable sound exposure guidelines for fishes and sea turtles, defined by the way the animals detect sound. Specific guidelines are presented for pile driving. These suggest the following guidelines apply to herring (fish with a swim bladder involved in hearing (primarily pressure detection)):

- Mortality and potential mortal injury - 207 dB re 1 µPa2·s SEL_{cum} or >207 dB re 1 µPa peak;
- Impairment: recoverable injury – 203 dB re 1 µPa2·s SEL_{cum} or >207 dB re 1 µPa peak;
- Impairment: TTS – 186 dB re 1 µPa2·s $SEL_{cum;}$
- Impairment: masking – Near distance = High risk, Immediate distance = High risk, Far distance = Moderate risk; and
- Behaviour - Near distance = High risk, Immediate distance = High risk, Far distance = Moderate risk.

4.3.10. The Cefas Offshore Wind Farms: Guidance Note for Environmental Impact Assessment in Respect of FEPA and CPA Requirements (Cefas, 2004) is used as reference by developers during the completion of EIA and Environmental Statements and by consenting authorities during the determination stages of applications. Although published to align with the pre-2010 marine licensing systems, this document is still valid for the current system and assists in identifying the key issues that need to be assessed and addressed within EIA. For fish, this document contains a full section describing what aspects of fish ecology are important and provides advice on fish surveys. This document identifies herring as a 'primary species of concern' due to them depositing eggs on the sea floor. It states:

- The peak egg-laying/spawning seasons should be avoided during construction and cable laying, and work should ensure that those aspects of the sedimentary environment required for spawning are maintained in the development site and adjacent areas. Herring spawning grounds, for example, are typically comprised of coarse sand, coarse shelly sand, gravel, and large unbroken shell fragments overlying gravel, and such habitats should retain their physical integrity; and
- The identification of herring spawning grounds can be achieved using grab sampling and/or underwater camera/video.

4.3.11. The Strategic Review of Offshore Wind Farm Monitoring Data Associated with FEPA Licence Conditions. (Cefas, 2009) presents information on the review of FEPA licence conditions that were applied to offshore wind farms in the past and assesses whether they have been successful or not, or need strengthening or not. This is a useful document for both developers and consenting authorities to make reference to as it may help identify the level of fish data that may need to be included within an Environmental Statement / EIA Report or will indicate what level of post-consent survey may be required in the future and therefore included in future licences.

4.3.12. The fisheries sensitivity maps produced by Coull *et al*. (1998) are recognised as a key decision-making tool in the EIA process for identifying the likely presence of spawning and nursery grounds for sensitive fish species. These are widely used to date, alongside the Ellis *et al*. (2012) spawning and nursery maps to identify sensitivities in order to ensure they are fully considered during both the application and determination stages. In terms of spawning herring, the Ellis *et al.* (2012) mapping did not update the spawning maps as presented within Coull *et al*. (1998), although they did update many of the other species spawning information. From the findings of this study, we would recommend that these fisheries sensitivity maps could potentially be further updated based on the current IHLS data available.

4.3.13. The CIEEM has published guidelines on how to undertake ecological impact assessment (EcIA) for marine and coastal developments (CIEEM, 2010). These set out the environmental issues that should be considered along with the methodology that should be applied when completing EcIA and assessing significance. This document is guidance and is used by developers as a guide on how to undertake a robust and comprehensive assessment. It is only guidance and is implemented as such as opposed to being adopted in any formal capacity.

4.3.14. Other guidance and advice applied in Wales includes: Marine Noise Registry: (http://naturalresources.wales/permits-and-permissions/marine-licensing/marine-noise-registry/?lang=en, research reports published by Collaborative Offshore Wind Research into the Environment (COWRIE) during the early stages of OWF development, and the use of National Physical Laboratory guidelines and metrics within EIA to promote consistency and good practice (http://www.npl.co.uk/ultrasound-and-underwater-acoustics/underwater-acoustics/research/underwater-noise).

4.4. Policy and Decision Making

4.4.1. Within the UK, there has been a UK wide Marine Policy Statement in place since 2011 (HM Government, 2011). This policy statement contributes to the achievement of sustainable development in the marine area and sets out the framework for preparing marine plans and taking decisions affecting the marine environment. Each of the UK countries has then produced a Marine Plan in accordance with UK policies.

Scotland

4.4.2. A National Marine Plan was put in place by the Scottish Ministers in 2015, under the Marine (Scotland) Act 2010. Embedded within this National Marine Plan, there is a sectoral plan for offshore wind. This sets up a system for which marine planning and policy in Scotland is set. The plan covers the management of both Scottish inshore waters (out to 12 nm) and offshore waters (12 to 200 nm). The Plan sets out the strategic policies for which management decisions will be made across the main marine sectors including sea fisheries and offshore wind and marine renewable energy. Local policies are then set out within Regional Marine Plans. As the Regional Marine Plans are not yet in place, the National Marine Plan is implemented. A set of General Planning Policies are set, along with Sectoral Policies for specific marine sectors. In addition, the National Marine Plan sets out the regional policies that should be considered within the Regional Marine Plans.

4.4.3. As these are strategic level policies, there are no specific policies in relation to herring, however within the Sea Fisheries section of the National Marine Plan, there are policies for the:

- Protection for vulnerable stocks (in particular for juvenile and spawning stocks through continuation of sea area closures where appropriate);
- The potential impact (positive and negative) of marine developments on the sustainability of fish and shellfish stocks and resultant fishing opportunities in any given area; and
- The environmental impact on fishing grounds (such as nursery, spawning areas), commercially fished species, habitats and species more generally.

4.4.4. Within the Offshore Wind and Marine Renewables section of the National Marine Plan, there is a policy stating that:

- Marine planners and decision makers must ensure that renewable energy projects demonstrate compliance with Environmental Impact Assessment and Habitats Regulations Appraisal legislative requirements.

4.4.5. There is also a general policy on natural heritage (GEN 9) that is applicable in terms of priority marine features (PMFs). This general policy states that development and use of the marine environment must:

- Comply with legal requirements for protected areas and protected species;
- Not result in significant impact on the national status of PMFs; and
- Protect and, where appropriate, enhance the health of the marine area.

4.4.6. Scotland has identified a list of 81 PMFs for which the Atlantic herring is one, protected in all waters, but with a focus on the juvenile and spawning adults within territorial waters (Tyler-Walters *et al*., 2016). These are species of conservation importance that are specifically considered within nature conservation planning and decision-making.

England

4.4.7. A total of 11 marine plan areas in England will be covered within six Marine Plans. These plans are currently being developed for the North East, North West, South East and South West (covering inshore and offshore areas). A plan is in place for the South but is currently undergoing consultation, while a plan is approved and in place for the East. The timeline for approval and adoption of these plans will depend upon the consultation and development progress of each individual plan and until a Marine Plan is adopted, the principles within the UK Marine Policy Statement are adopted. Once a Marine Plan is adopted, these plans will be consulted upon during the decision-making and consenting process (and subsequent identification of conditions).

Wales

4.4.8. The Welsh National Marine Plan is currently being developed in line with the UK Marine Policy Statement although a draft plan was produced in November 2015 and is available. Similar to the Scottish National Marine Plan, the document sets out general policies, along with sectoral policies, including Fisheries and Low Carbon Energy.

4.4.9. Policy GOV-07 makes reference to considering the potential impacts of proposals on other sectors and should, where appropriate, ensure that proposals demonstrate that they will, in order of preference: a) avoid adverse impacts on existing and, where relevant, planned activities of other sectors; b) minimise them where they cannot be avoided; c) mitigate them where they cannot be minimised. Specific mention is made to the fact that disturbance of the marine habitats or species in one area may have consequences in distant areas, e.g. damage to spawning area of commercial fish species may disrupt fishing hundreds or even thousands of miles away.

4.4.10. Policy Fisheries (FIS) 02 states that decision making authorities should ensure that proposals in and affecting important fish feeding, breeding (including spawning and nursery) and migration areas for important species and their associated habitat, demonstrate that they will, in order of preference a) avoid adverse impacts on spawning and nursery areas and the associated habitat b) minimise impacts where they cannot be avoided c) mitigate impacts where they cannot be minimised d) present the case for proceeding where (a-c) are not possible. This policy guidance makes specific reference to the spawning and nursery maps by stating:

- Important species includes those of commercial, conservation, ecological or recreational importance. Information for some lifecycle stages is better than others, e.g. spawning and nursery grounds for some species are reasonably well defined (see http://cefas.defra.gov.uk/media/29947/sensi_maps.pdf and http://www.cefas.defra.gov.uk/publications/techrep/TechRe p147.pdf) but that for feeding and migration areas is less well understood; and that
- A range of indicative information is available in report form, on the Welsh Government Marine Portal and from industry and regulators to assist the identification of important spawning / nursery areas and established commercial fishing areas.

4.4.11. Policy Energy Low Carbon (ELC) 04 also makes a similar statement to that of FIS 02 and suggests that suitable mitigation to minimise potential adverse effects includes measures to amend the design or construction methods, e.g. temporal restrictions on pile-driving during fish spawning; use of marine mammal observers and shut down to avoid adverse effects.

Northern Ireland

4.4.12. The Department of Agriculture, Food and Environment is currently developing one Marine Plan for Northern Ireland, under The Marine Act (Northern Ireland) 2013, which will cover the inshore waters and offshore waters. The draft plan is currently under review and updating and the supporting NI Marine Mapviewer is being developed. Until the Marine Plan is in place, the UK Marine Policy Statement is applicable.

Isle of Man

4.4.13. For the Isle of Man, The Department of Infrastructure is the lead organisation within the Isle of Man Government that has the responsibility for marine planning and consenting. New marine legislation is currently being put in place, with a consultation exercise underway on the proposed new legislation that will lead to a single consenting process for the Isle of Man territorial waters. However, the current legislative system is quite complex with several acts and regulations being applicable to the marine environment. The Department of Environment, Food and Agriculture also has a consenting remit under some of this legislation e.g. Fisheries Act, 2012.

4.4.14. As well as the bye-law regulations described in Section 4.3, the Manx Marine Environmental Assessment (Isle of Man Government, 2013) is used to provide environmental information on the species and habitat constraints that may be applicable to a marine development application and this is used as initial guidance for the decision-making process.

4.4.15. There is also a guidance document that sets out the Isle of Man Governments approach and requirements to the consideration of marine consent applications and the EIA process (Isle of Man Government, 2014). This outlines the different requirements under each of the current legislative processes. There is specific guidance within this document that states that:

- Potential environmental impacts should be considered, including possible impacts on herring spawning and marine megafauna; and

- The effects upon the herring spawning area (Douglas Bank) could potentially be mitigated but this is dependent on specific details of both the site and the proposed development.

Republic of Ireland

4.4.16. The Republic of Ireland does not currently have a system of marine spatial planning, however development of the coast is governed by current legislation. It is unknown whether a system for marine spatial planning will be implemented or when.

4.5. International Regulations and Guidance

USA

4.5.1. Within the USA, the consenting process is split between state waters and federal water, for which each has its own sets of legislation and regulations. To summarise, the state waters cover the 0 – 3 nm waters with state laws applying (which differ from state to state). The federal waters cover the territorial waters from 3 nm – 12 nm, as well as covering the contiguous waters (up to 24 nm) and the EEZ up to 200 nm. The federal waters are overseen by the Bureau of Ocean Energy Management (BOEM) and National Oceanic and Atmospheric Administration (NOAA), while state waters are overseen by state authorities.

4.5.2. BOEM has developed a number of national and regional guidelines for renewable energy activities on the Outer Continental Shelf, although none of these specifically address spawning fish. There are guidelines for providing information on fisheries social and economic conditions for renewable energy development (BOEM, 2015), but these focus on commercial fishing interests. There are also guidelines for the completion of surveys, including fish populations (https://www.boem.gov/Survey-Guidelines/).

4.5.3. Consultation with the BOEM did not identify any further relevant regulations or guidance for inclusion within this study.

European Countries

4.5.4. For the European countries contacted, the following guidance has been identified during consultation as applicable:

- In the Netherlands, consultation with the Licensing Department of Rijkswaterstaat Zee en Delta identified that site decision plots (Borselle and Hollandse Kust Zuid) are applied. https://www.officielebekendmakingen.nl/stcrt-2016-14428.html. General regulations concerning underwater sound generation have been implemented based on precautionary principles and these sound generation decisions are used as mitigation and shown on the site decision plots. Most recently however, seasonal piling restrictions have not been part of permit requirements, with seasonally differentiated noise thresholds being applied to recently granted permits.
- For Sweden, no information on regulations or guidance was received during consultation. From an internet review, decisions regarding offshore wind appear to come from the Swedish Government (Ministry of Enterprise, Energy and Communications), the Swedish Energy Agency and/or the Land and Environment Court. The planning and policy assessment rules are set out within the 'Environmental Code' (Ministry of Environment and Energy, 1999; www.government.se/legal-documents/2000/08/ds-200061/) rather than within legal standards and these give guidance, albeit this is described as being 'vague' guidance. Two permits are required for offshore wind; a permit for environmental hazardous activity (Permit for EHA) and a permit for hydraulic (water) operations (Permit for WO). These permits are supported by an EIA (Soderholm et. al., 2010). The Swedish Environmental Protection Agency also provides guidance documents on environmental work including species protection,

noise, environmentally hazardous activities and environmental quality standards (http://www.swedishepa.se/Guidance/Guidance/) as does the Swedish Agency for Marine and Water Management;

- For Belgium, no information on regulations or guidance was received during consultation. From an internet review, the decisions regarding offshore wind appear to come from both regional governments and federal government, but the Scientific Service Management Unit of the Mathematical Model of the North Sea, of the OD Nature is responsible for decisions on wind farms at sea. The Law on the Protection of the Marine Environment (Belgian Official Journal, 1999) is adhered to for the licensing process. The consequences of the installation of wind turbines on the marine ecosystem are monitored in accordance with the environmental permit, with the results reported in Degraer *et al.* (2013. This document mentions herring but this is restricted to acknowledgement of its sensitive hearing. The document also comments on spawning interests but this is primarily related to cod and pouting, for which the report states that there has been no significant effect upon in terms of wind farm effects upon regional populations. Herring do not seem to be of a concern);
- In Germany, the German Federal Maritime and Hydrographic Agency / Bundesamt für Seeschifffahrt und Hydrographie (BSH) is responsible for consenting of offshore wind farms. Fish and underwater noise has to be considered by the developers in the course of EIA prior to the approval. Possible impacts and mitigation measures are evaluated by the licensing agency in the framework of the environmental assessment taking into account the scientific comments given by the Federal Agency for Nature Conservation. The Standard Investigation of the impacts of offshore wind turbines on the marine environment (StUK4) edited by BSH (BSH, 2013) are followed and applied by developers to fish surveys. Harbour porpoise is the key concern to Germany and other guidance documents that are applied to the industry are:
  - Maritime Spatial Planning for the German EEZ in the North Sea (2009): Wind farm installation and operation are excluded from protected areas (Natura 2000 sites);
  - Incidental clauses in the approvals given by the Federal Maritime and Hydrographic Agency for offshore construction sites (e.g. offshore wind farms): Limitation of underwater sound emission during the erection of offshore installations by given thresholds; and
  - Sound protection concept for harbour porpoises by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (2013).
- In Denmark, the Danish government (Danish Energy Agency) is responsible for the deployment of offshore wind farms. The consultation responses received from the Ministry of Environment and Food in Denmark stated that the regulation of offshore piling activities is mainly targeted the protection of marine mammals. There is a limited understanding on how noise affects fish at a population level and therefore, as of now, this is not included in the national guidelines;
- For France, no information on regulations or guidance was received during consultation. Consenting would seem to follow the requirements of the Environmental Code (file:///Z:/Projects/0089%20ORJIP%20Piling%20Study/Technical%20Data/WP3/fr197en.pdf) and require supporting EIA to be submitted in a similar manner to the UK. The consenting authority is the French Government; and
- For Norway, no information on regulations or guidance was received during consultation. From a web based review, Norway has previously undertaken a strategic assessment of offshore wind in 2013 (Norwegian Water Resources and Energy Directorate, 2013), but then placed development of offshore wind on hold. More recently due to the success of Statoil off the coast of Scotland with floating wind technology, the Norwegian Government is revisiting this potential industry and is proposing to open some development zones up to wind demonstration projects (https://www.windpoweroffshore.com/article/1452871/norway-opens-offshore-wind). Any future development in Norway does have potential to influence

herring stocks, particularly the North Sea, Western Baltic, Norwegian and some local coastal stocks and their spawning areas. Due to the early stages of the industry in Norway there are no specific regulations or guidance currently in place in relation to the consenting process, but the Offshore Energy Act is applicable.

4.6. Understanding of Regulations and Guidance

4.6.1. Within the UK there is a clear and collaborative system in place with respect to marine strategic planning across the UK, through the application of a common UK Marine Policy Statement and the ongoing implementation of regional policies (which may differ between regions) via the application of the National and Regional Marine Plans (some of which are still in progress). The current legislation and regulations that apply to the decision-making process make consistency across the consenting processes relatively streamline. Within this system, it is fairly clear that the sensitivities of fish need to be considered, as set out within the UK Marine Policy Statement where there is specific reference to renewable energy development and potential adverse impacts on marine fish.

4.6.2. The international understanding is slightly more vague within Europe due to limited information being provided during the consultation stage of this study. It would appear that regulations and guidance are in place but that these refer to marine mammals, and particularly harbour porpoise, as opposed to fish. Very similar mitigation is referred to, and applied, across Europe for marine mammals, such as use of 'soft start', ADD's, sound exposure thresholds and seasonal restrictions.

4.6.3. In the US, the offshore wind farm industry is in its early stages and development has to date been restricted to the east coast. The consenting authorities in the US are in a similar position to their European counterparts in that marine mammals have been the feature of focus to date, but there has been interest in learning lessons from the UK and Europe in terms of the sensitivities of fish species.

4.6.4. The key driver to the limited consideration of herring to date within the US and the other European countries consulted would appear to be related to the Baltic and Atlantic herring populations not having spawning grounds within reach of the currently proposed, consented or constructed offshore wind farm developments in the waters of these countries to date. For example, Norway has potential to have an impact upon spawning herring stocks within the Baltic and North Seas but the industry is yet to be progressed to consenting level and so this issue has not yet had to be dealt with by the Norwegian offshore wind industry. For some European countries (e.g. Germany) other fish species have been identified as being of interest (for example cod and pouting) in this regard but no related guidance appears to be present. It is expected that for many of these countries herring stocks may well become a concern with future development and will need guidance and assessment methods established in due course.

5. Study Conclusions and Recommendations

5.1. Population Information and OWFs

5.1.1. A review of literature and herring data sources has illustrated that there is a good understanding of the main spawning areas for the different herring stocks that are present within UK waters and that a broad-based identification of the key areas is possible. It is also possible to identify more specific spawning areas for most of these stocks through the use of historical fish sensitivity maps, more recent IHLS and IBTS data and predicted seabed habitat types along with other specific seabed habitat data. Through review of this combined information, the main spawning areas can be discerned. A notable outcome of the assessment of recent IHLS data (covering the last ten years), through analysis on a year to year basis as well as cumulatively, shows that by comparing this recent data with historical fish sensitivity maps produced by Coull *et al*. (1998), it is possible to achieve some refinement of the historical data. This may provide more confidence during EIA for both developers and regulators in assessing potential impact.

5.1.2. This study suggests that there is an ability to identify areas within the historical mapping (Coull *et al*., 1998) where spawning activity is focused within more defined spawning grounds. Even when considering larval data that hasn't been back-calculated to a specific location, it is possible to demonstrate that the historical spawning areas are not evenly used (i.e. many areas are not utilised) and that there are specific locations (spawning grounds) where spawning activity is focused, although it is recognised that there is some slight inter-annual variation in the focal point of spawning activity in each spawning ground. This is illustrated well by the 'hot spots' in the heat mapping.

5.1.3. The specific, discrete pockets of spawning beds that herring use are, however, not so easily identified as they can change from year to year. This is due to the specific habitat and environmental conditions that herring require to enable successful spawning to take place. The literature review confirms that without undertaking intrusive grab sampling surveys during spawning periods, or using drop down video surveying, it is difficult to locate or identify exact spawning bed locations (only identifiable through the presence of mats of eggs). As such, there are gaps in the current knowledge of where specific spawning beds are located for all of the stocks.

5.1.4. The use of the IHLS data to identify spawning grounds has been questioned due to larvae freely drifting away from spawning beds on the prevailing currents and so the confidence that the larval surveys are identifying actual spawning areas is reduced. However, the use of larvae to determine spawning areas has been accepted since 1957 (Parrish *et al.*, 1957) and most recently the use of larvae was reviewed within the aggregate dredging industry for the BMAPA (Section 2.2) by MarineSpace (MarineSpace, 2013) where it was concluded that of all methods that can be used to determine spawning beds, the IHLS data was the best indicator and is a direct measure of spawning where fish of length 0 – 11 mm were caught. This study concluded that the methodology of using IHLS data to produce heat maps of spawning areas is widely accepted. Indeed, using this method to support further discussions on reducing herring restrictions for OWFs has recently been accepted in the UK by consenting authorities. Being able to take drift rates and apply back-calculation to larvae to identify spawning beds would provide an ability to be more precise in the location of spawning beds. There are limitations with this method however. Attempts to undertake back-calculations of where larvae may have drifted from based upon published prevailing water current information, larvae age and growth rates have been undertaken (e.g. Beatrice Offshore Wind Farm Limited, 2016; Brown and May Marine, 2007) but these reports show how broad the resulting conclusions are, with very large areas being cited as potential spawning beds and no exact identification available due to estimates of current conditions. From a review of literature, there is only one instance where the exact location of a spawning bed has been identified (Ballantray Bay in the Clyde) and this was via grab sampling, where herring eggs were incidentally located on the seabed (Parrish et al., 1959). It has been recognised since 1959 that due to changing environmental conditions and spawning beds being discrete pockets of suitable habitat (which can change from year to year) within a spawning ground or area, it is extremely difficult to identify the exact location of spawning beds unless they are recorded through grab sampling or by drop down video surveys.

5.1.5. There is a need to be proportionate in terms of risks posed by OWF developments that do not appear to affect the main spawning grounds within the Coull et al., 1998 mapping area, as refined by the heat mapping 'hot spots' versus the OWF developments that clearly do affect the 'hotspots'. Given that the noise modelling undertaken for EIA is precautionary and that the fish sensitivity maps are also precautionary, then balanced consideration needs to be given to the level of potential effects that may result from OWF developments located on the fringes of spawning areas illustrated on the fish sensitivity maps and what the benefit of restricting piling at such developments might be in terms of safeguarding a herring population.

5.1.6. Although the herring stocks around the UK are identified within various scientific papers and within ICES advisory documents, there remains some uncertainty regarding the status of the West of Scotland and West Irish stocks and whether they are in fact components of one stock, or are genetically separate stocks (ICES, 2015). A review of literature (ICES, 2017e) suggests that genetic testing is underway to determine the status of these stocks, along with the relationship between the different stock components of the West of Scotland stock. This genetic testing is part of an industry initiative, and is being undertaken in collaboration with the Pelagic Advisory Council (PELAC). It has involved completion of a genetic research programme during 2016 / 2017 to provide new stock separation information. Genetic and morphometric samples of the two stocks are also being collected during 2017 for further analysis (ICES, 2017e). The results of these studies are not yet available but are expected to be made available in 2018.

5.1.7. The perceived impacts of piling on herring focus on spawning herring as opposed to other life stages such as eggs, larvae and juveniles. Perceived impacts are related to underwater sound pressure and particle motion, with there being more understanding of sound pressure and the potential effects upon herring than particle motion. Several studies have identified specific sound exposure criteria for fish and specific thresholds do exist for herring (Popper *et al*. 2014). There are no thresholds currently identified in terms of particle motion. The main impacts are perceived to be behavioural changes that arise as a result of piling activities, with there being less concern regarding physiological effects due to the localised extents to which actual injury from levels of noise extends (a very small area around the piling so the risk of population level effect is minimal). Furthermore, sound pressure is considered to be of greater concern for herring as they are considered 'hearing specialists', with their swim bladder linked to the inner ear and involved in hearing (Popper *et al*., 2014).

5.1.8. There is limited understanding of how behavioural changes affect herring populations (and other fish populations in general) and at what point the behavioural changes become significant and are unacceptable. Most research into this topic has been undertaken in laboratory or confined conditions and have not necessarily reflected conditions in the open sea.

5.1.9. While consideration of predator-prey relationships are typically considered in EIAs, there is limited understanding of what impacts on herring from pile driving might mean for their trophic interactions (specifically, how important are herring as a predator of smaller fish, and what are the spatial and temporal variations of this importance?). This could be a relevant factor when establishing an appropriate level of precaution during consenting decisions, i.e. within a risk-based approach to achieving proportionality.

5.2. Understanding Consenting Restrictions

5.2.1. A total of 19 OWF projects have been identified to date as having herring restrictions or other mitigation requirements for this species associated with marine licences. The reason that piling restrictions are applied is due to the potential effect of piling upon spawning adult herring and / or their behaviour. The conditions are not related to potential effects of piling noise on herring larvae, principally because of the limited range of noise levels considered to pose any risk to eggs or larvae.

5.2.2. Initially within England, blanket piling restrictions were put in place due the use of a 'design envelope' approach for EIAs supporting consent applications due to limited information on the actual final design of the OWFs being available at that time, leading to uncertainty in the actual level of potential impact risk associated with the individual projects and the consequent application of a precautionary approach to ensure protection of spawning herring. Such restrictions would have caused considerable additional expense to developers at the time. As the offshore wind industry became more established, a more evidence based approach was adopted by The Planning Inspectorate, during the DCO process, to piling restrictions with the introduction of flexibility within consent requirements and conditions to reduce or remove these restrictions, subject to the provision of further information and agreement with the MMO and their advisors. As a result of this, further discussions to reduce or remove restrictions have taken place in more recent years, with new evidence being submitted to support these discussions. This evidence has included further seabed sediment and habitat analysis, further specific herring larvae surveys and more refined engineering design information on what will actually be constructed at the OWF. However, the most recent licences to be granted for OWF (for example Hornsea Projects One and Two) have reverted back to not including this flexibility to further discuss removal of restrictions, but have gone on to request further sediment grab sampling to identify whether suitable spawning habitat is present or not in order to determine the need for further restrictions or mitigation for herring. For these two developments at Hornsea, the concern has changed from one of potential impacts from piling activity to potential impacts from dredging and disposal activities. The area of concern, however, still remains the determination of the extent of suitable herring spawning ground habitat.

5.2.3. Within Scotland, the herring is listed as a PMF and is given special consideration in line with the National Marine Plan. Three OWFs in Scottish waters have had herring conditions included within their marine licence. These conditions are for further herring larvae surveys to be undertaken in order to determine the need for further mitigation. This approach is different to that generally applied in English waters and for Beatrice Offshore Wind Farm, herring larvae surveys were undertaken post-consent along with the application of back calculations to determine that spawning grounds were not located within the modelled noise impact zone and subsequently MS-LOT determined that no further mitigation would be required for herring.

5.2.4. It is important to recognise that regulators are required to make decisions according to the development that the applicant applies for and the information that is available at that time. If the design envelope is unrealistically broad, the assessment of impacts may therefore be greater than that which would arise in reality. The onus is on the applicant/developer to make their design envelope as realistic as possible which, in turn, allows any necessary restrictions to be applied at a proportionate level.

5.3. Regulations and Guidance

5.3.1. Through international and European consultation and literature review, it would appear that spawning herring have not been a concern for OWF development in other countries to date, with the main concern being related to the effects of underwater noise on marine mammals, particularly harbour porpoise in a European context. This limited concern seems to be related to the absence of herring spawning areas close to OWFs and this would appear to be by chance, rather than through strategic assessment of proposed OWF lease areas in relation to fish spawning grounds. As such, there is no specific guidance or regulations in place specifically to address herring.

5.3.2. In the UK and the Republic of Ireland, there are some general regulations and guidance that relate to spawning fish populations as well as to sound exposure criteria and thresholds. In addition, the UK has a Marine Policy Statement in place, which sets out the process for UK countries to form and adopt National and Regional Marine Plans. It is through these Marine Plans that specific policies are / will be set for adoption during determination of OWF applications. For example, in Scotland, herring is listed as a PMF (with specific mention to spawning adults) and therefore its conservation needs to be considered during the decision-making process.

5.4. Recommendations

5.4.1. The method of undertaking heat mapping of IHLS data (and IBTS data) to identify herring larvae hotspots and therefore determine the main herring spawning grounds is promoted in order to enable a more up to date appraisal of spawning grounds than that presented within the historical Coull *et. al* (1998) fish sensitivity maps. By using the heat mapping technique alongside the historical data, while overlaying seabed sediment and habitat information, the previous approach of relying upon the Coull *et al*. mapping can be further refined and modernised to provide more up to date information. This approach can be kept up to date each year through using the most recent 10 years of IHLS data (or five years worth of IBTS data if there are no IHLS data available). This novel approach fits well when compared with the historical fish sensitivity maps and is an all-encompassing approach using all available evidence base as opposed to a series of older spawning maps. The technique can also be used for any fish species of conservation interest where larvae (or egg) surveys are undertaken and are available over a suitable time series. One example would be for cod (Figure 5-1). For this all-encompassing approach to be most effective, and in recognition of the changing budgets and priorities of government bodies, there is a need to ensure survey data (both from the developer and public funded surveys) is provided in a publicly accessible area so that future offshore wind developments can have unrestricted access to the latest data.

5.4.2. One area of uncertainty is identification of the exact location where herring spawn (spawning beds). Attempts to undertake back-calculations of where larvae may have drifted from based upon published prevailing current information, larvae age and growth rates have been undertaken (e.g. Beatrice Offshore Wind Farm Limited, 2016; Brown and May Marine, 2007) but these reports show how broad the resulting conclusions are, with very large areas being cited as potential spawning beds and no exact identification available due to estimates of current conditions. Marine Space (2013) also looked at this within the aggregate dredging industry for the BMAPA (Section 2.2) and concluded that of all methods that can be used to determine spawning beds, the IHLS data was the best indicator and is a direct measure of spawning where fish of length 0 – 11 mm were caught. From a review of literature, there is only one instance where the exact location of a spawning bed has been identified (Ballantray Bay in the Clyde) and this was via grab sampling, where herring eggs were incidentally located on the seabed (Parrish *et al*., 1959)).

5.4.3. It is recommended that the undertaking of back-calculations is examined in more detail as part of a future study. The approach to undertaking this exercise should be assessed in detail and build upon the earlier work undertaken for the Beatrice and Thanet Offshore Wind Farms. It is recommended that further review of the previous method used is undertaken and that this is built upon to provide a more robust methodology of back-calculation. This should include specific prevailing current modelling (e.g. Scottish Shelf Model) for the stock / stock component being analysed rather than using generic prevailing current information, which leads to a wider possible area of distribution being identified for drifting larvae. A thorough review of larval growth rates and also the movement of larvae within the water column should be undertaken, along with consideration of possible temporal (diurnal) components such as determining the times of the day that larvae tend to move.

5.4.4. By undertaking this more detailed back-calculation and then applying the IHLS heat mapping technique in combination with provision of seabed habitat data, it may be possible to further refine the historical fish sensitivity maps that are currently used to assist with licence determination and the identification of licence restrictions and other consent conditions.

Further Studies

5.4.5. Prior to being able to undertake the back-calculations to a high degree of accuracy, it would be necessary to undertake further research to refine the existing knowledge of the current speed and direction in the water around the spawning grounds. This would ideally occur in conjunction with the known spawning periods for the different stocks and with a reasonably high resolution of sampling locations. The data gained from this would allow accurate back-calculations to occur and would also raise the possibility of determining the distance from the spawning grounds at which herring larvae are first able to affect their direction to avoid noisy activities.

5.4.6. As little research or understanding is available regarding herring behaviour in response to pile driving, particularly with respect to spawning herring which may potentially demonstrate increased tolerance towards noise, it is recommended that detailed studies on the impact from piling noise on spawning herring would be appropriate. A study like this would help expand upon the limited knowledge of whether piling noise does affect spawning activity and at what levels and duration of piling noise would displacement from spawning grounds and changes in spawning behaviour occur at.

5.4.7. In addition, an examination of the efficacy of ADDs on specific fish species may also provide important information in relation to the effects of currently used mitigation measures. A study such as this could advise both on the response of a hearing specialist fish such as herring to ADDs (i.e. if ADDs cause fish to swim away from the noise source and how far) and also how behaviour might change during spawning or feeding. Although ADD's could reduce the risk of injury from piling noise, they may cause behavioural effects such as displacement (including displacement from spawning grounds / beds, which is not a desirable effect). Additional knowledge of the response of fish to ADDs would allow a more robust assessment of both physical injury and behavioural impacts to fish from piling through an understanding of whether ADDs act as an effective mitigation measure to piling noise as they have been demonstrated to be for marine mammals (McGarry *et al*., 2017), or whether they are not an effective mitigation measure by causing displacement of fish from spawning grounds / beds.

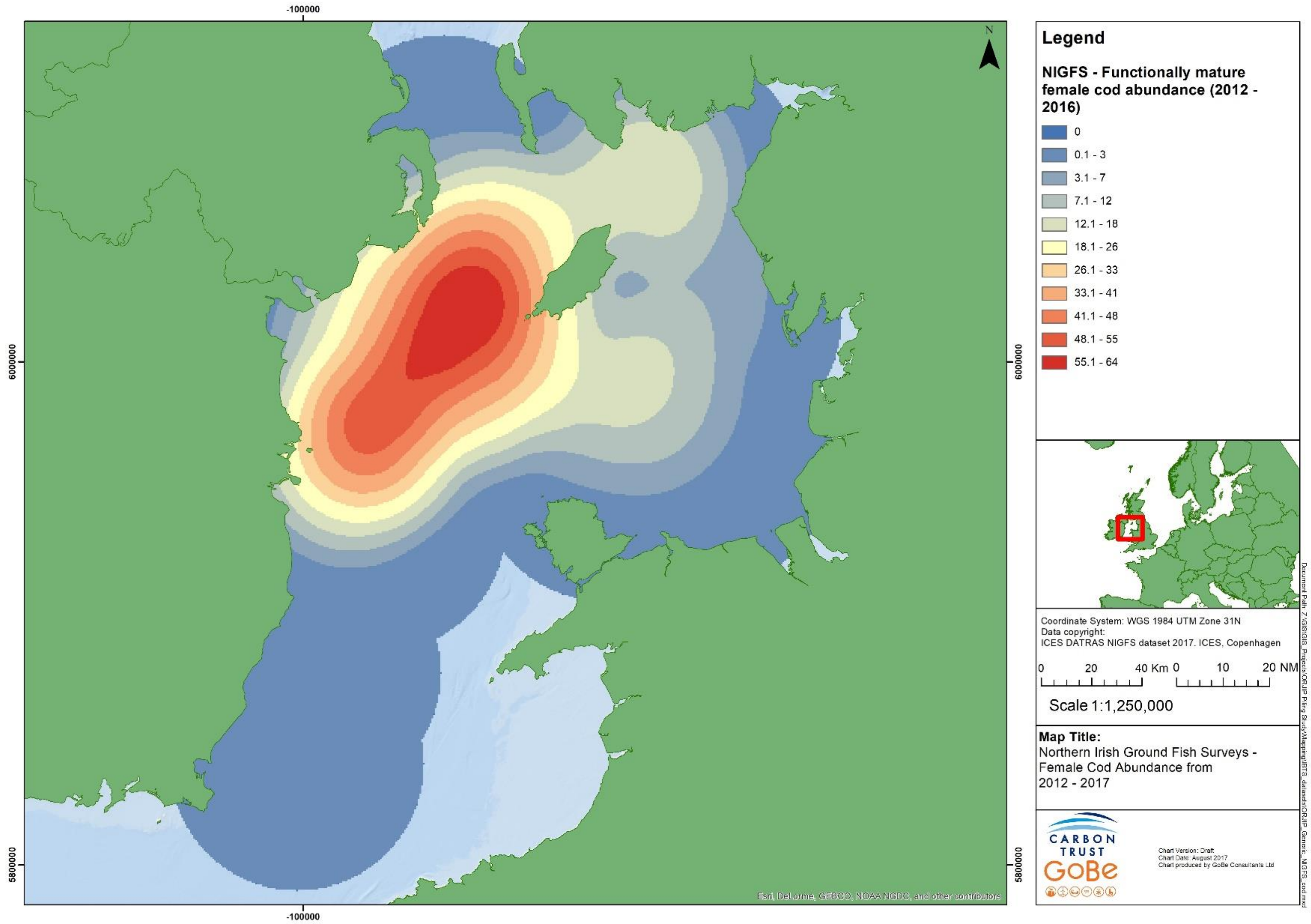

Figure 5-1: Northern Irish Ground Fish Surveys – Female Cod Abundance from 2012 – 2017.

6. Applying Study Findings to an OWF Test Case

6.1. Introduction

6.1.1. From the study findings it has been demonstrated that, while using the fish sensitivity maps provided by Coull *et. al.* (1998) along with predictive habitat mapping (Emodnet, 2017) to assist with the setting of marine licence conditions for spawning herring, it is possible to further refine the understanding of where key herring spawning grounds are, through the application of IHLS survey data and heat mapping.

6.1.2. The aim of this section is to use the additional tool of heat mapping to show how this can be interpreted for a specific (theoretical) offshore wind farm array and used to further inform, or refine, the current decisions that are made during the marine licensing process (and also be included within the current EIA reporting process). The results of this type of exercise will, however, vary depending on the specific site being assessed and on other information such as hammer energy and noise modelling outputs.

6.2. Overview

6.2.1. For this exercise, a fictitious OWF array ("OWF X") has been created and positioned approximately 25 km from the Yorkshire coast (Figure 6.1). This location has been selected for the following reasons:

- The area is not currently zoned as a OWF development area and does not currently have an Agreement for Lease (AfL) in place;
- The area selected is not currently the focus of known future OWF development;
- The area has been carefully selected and positioned for impartiality. It avoids any crossover with proposed, consented or developed OWFs which may currently be, or have recently been exposed to Marine Licence conditions or discussions regarding the presence of herring spawning grounds; and
- The OWF X is within an area identified as herring spawning grounds (Banks stock component) according to the fish sensitivity maps (Coull *et. al.,* 1998) and so would likely have some form of seasonal, temporal or technical restriction included within Marine Licence conditions.

6.2.2. The assumption for the purposes of OWF X is that, in a similar vein to the developed OWFs located within the spawning areas for the Banks stock component (e.g. Race Bank, Dudgeon, Triton Knoll), there is a seasonal restriction for pile driving in place, set out within a Marine Licence. This condition prevents pile driving occurring between 1st September and 31st October to protect the herring spawning grounds surrounding OWF X. This seasonal restriction is similar to real restrictions that have been applied to OWFs in relation to the Banks stock component (Figure 6-1).

6.2.3. For the purposes of this test case using OWF X, it is assumed that the maximum piling hammer energy is 4,000 kJ and to allow the presentation of noise contours for OWF X, the mean distances for the noise contours of a recently modelled OWF (using a 4,000 kJ hammer energy on a 8.5 m monopile) have been utilised to create example noise contours for OWF X. It is acknowledged that this approach is limited and will not provide site specific information with regard to the bathymetric influence on the noise contours. However, it provides sufficient information for the purposes of this demonstration test case as only the methodology described in Section 2.2 of the main report would be used for an OWF under development with site specific noise modelling used in place of this mean distances used here.

6.2.4. This outcome is due to the position of OWF X in relation to the Coull *et al*. (1998) spawning areas and the sediments within and surrounding OWF X being deemed as suitable habitat for herring spawning through a review of predictive habitat mapping data / site specific benthic surveys.

6.2.5. The noise contours have been overlain onto the heat mapping created (as described in Section 2.2 of this document) to compare the extent of the contours relative to the hotspots for the Banks stock component.

6.2.6. The example noise modelling used within this test case is focused on the unweighted metrics from Popper *et. al.* (2014). Specifically, the following metrics have been used to assess the potential impacts on both adult herring and larvae:

- 207 dB SPL_{peak} - damage to eggs and larvae; and
- 186 dB SEL_{cum} - disturbance to adults.

6.2.7. These two metrics cover the primary impacts of concern most likely to impact on the reproduction of herring: damage to the eggs and larvae preventing their development; and disturbance to the adult herring while engaged in spawning activity, potentially reducing the spawning success.

6.3. Results

6.3.1. The noise modelling using the 4,000 kJ hammer resulted in the following spatial extent for the two metrics identified above:

- 207 dB SPL_{peak} - 205 m; and
- 186 dB SEL_{cum} - 15.4 km.

6.3.2. Figure 6-2 shows the IHLS data for the Central North Sea (CNS) dataset (i.e. Banks stock component) for all years between 2007/08 and 2016/17. Figure 6-2 clearly shows that during the period of 2007/08 - 2016/17, the most important spawning ground for this section of the North Sea is located to the north and east of Flamborough Head, to the south of OWF X.

6.3.3. To investigate the inter-annual variation in the location of the highest density of eggs and larvae, the data for each individual year were also assessed and are presented in Figure 6-3 to Figure 6-12. These year by year graphics show that there is some slight inter-annual variation in egg and larval density, although with the exception of 2010/11 (Figure 6-6), the highest density of eggs and larvae is consistently located either in line with, or slightly north of, Flamborough Head, rather than being even across all of the spawning areas defined by Coull *et. al.* (1998). Figures 6-3 to 6-12 clearly show a low occurrence, if any, of larvae in the region around OWF X.

6.3.4. As demonstrated in graphics (Figure 6-3 to Figure 6-12), it is clear that the abundance of herring larvae varies significantly from year to year, with very high abundances observed in some years (i.e. 2008/09 and 2011/12) and very low abundances observed in others (i.e. 2007/08 and 2012/13). However, in all years, the sampling points in the vicinity of OWF X recorded very low densities or zero larvae.

6.3.5. From analysing the annual data, there appears to be no discernible or reliable correlation with respect to survey year and abundances of larvae. Consequently, even if pile driving were to occur in a peak year for larvae production, it is unlikely that there would be any population level impacts as regardless of the overall larval abundance, the peak larval abundance in any given year is always located around Flamborough Head and so not in the vicinity of OWF X.

6.3.6. Finally, analysis of the data has also been undertaken in order to ensure that particular hotspots do not hide areas of lesser importance at the regional scale but nonetheless still important at the sub-regional scale. The hot spot analysis has the potential to 'mask' areas of lesser importance due to the data scaling, however the data have been interrogated to ensure this is not occurring within the region surrounding OWF X by examining the point data used to generate the heatmaps. The point data (for the area around OWF X) was checked to confirm the low importance that the heatmap had attributed to these locations was correct for all trawls and not just based on the average. This approach should therefore have prevented the potential for areas important at a sub-regional scale to be overlooked.

6.3.7. Using the point data which underpins the heatmaps (Table 6-1 to Table 6-3), it can be seen that the point data collected within the limits of OWF X only recorded larvae in two years; 2014/15 and 2016/17 with the maximum larvae density recorded as 28 m-2 in 2014/15. In all other years, no larvae were identified in OWF X. The point data within the noise contours was also examined: larvae were recorded in the south east contour in 2011/12 and 2013/14 - 2016/17, with the highest density of 685 m^{-2} recorded in 2013/14 with all other years not exceeding 300 m^{-2}; larvae were recorded in the north west contour in 2008/09, 2009/10, 2015/16 and 2016/17, with the highest density of 206 m^{-2} recorded in 2008/09 and all other years did not exceed 7 m^{-2}. By way of context, the areas of highest density of eggs and larvae around Flamborough Head during the same period peak at >77,000/m^2.

6.3.8. Furthermore, it is evident that even during the years with the high abundance of larvae recorded, the noise impacts from pile driving at OWF X do not extend into the areas of greatest importance for herring spawning.

6.4. Conclusions

6.4.1. The data analysis and figures presented show that OWF X is not located within the vicinity of any peak herring spawning grounds, based on the abundance of eggs and larvae collected during the IHLS trawls. While OWF X falls partially within one spawning area and between two other spawning areas defined Coull *et. al.* (1998), these areas were defined based on relatively coarse-scale seabed sediment maps and historical fishing data, in addition to IHLS and other survey data.

6.4.2. As detailed above, the low abundance of herring eggs and larvae collected during the IHLS trawls throughout the period of 2007/08 - 2016/17 around the limits of OWF X indicate that this area is not one of importance for spawning herring, with this trend seen across all survey years analysed. The maximum density of larvae within OWF X and indicative noise contours in a single trawl was 685 m^{-2} and this only occurred in one year (2013/14) with no other trawls recording densities above 300 m^{-2}. For two of the years (2007/08 and 2010/11), no larvae were recorded in OWF X or in the noise contour areas, with larvae only recorded in OWF X during two years (2014/15 and 2016/17).

6.4.3. The very small numbers of eggs and larvae recorded within all surveys, over all years, suggests that there is a clear case for the full removal of the seasonal restriction on pile driving at OWF X with respect to spawning herring.

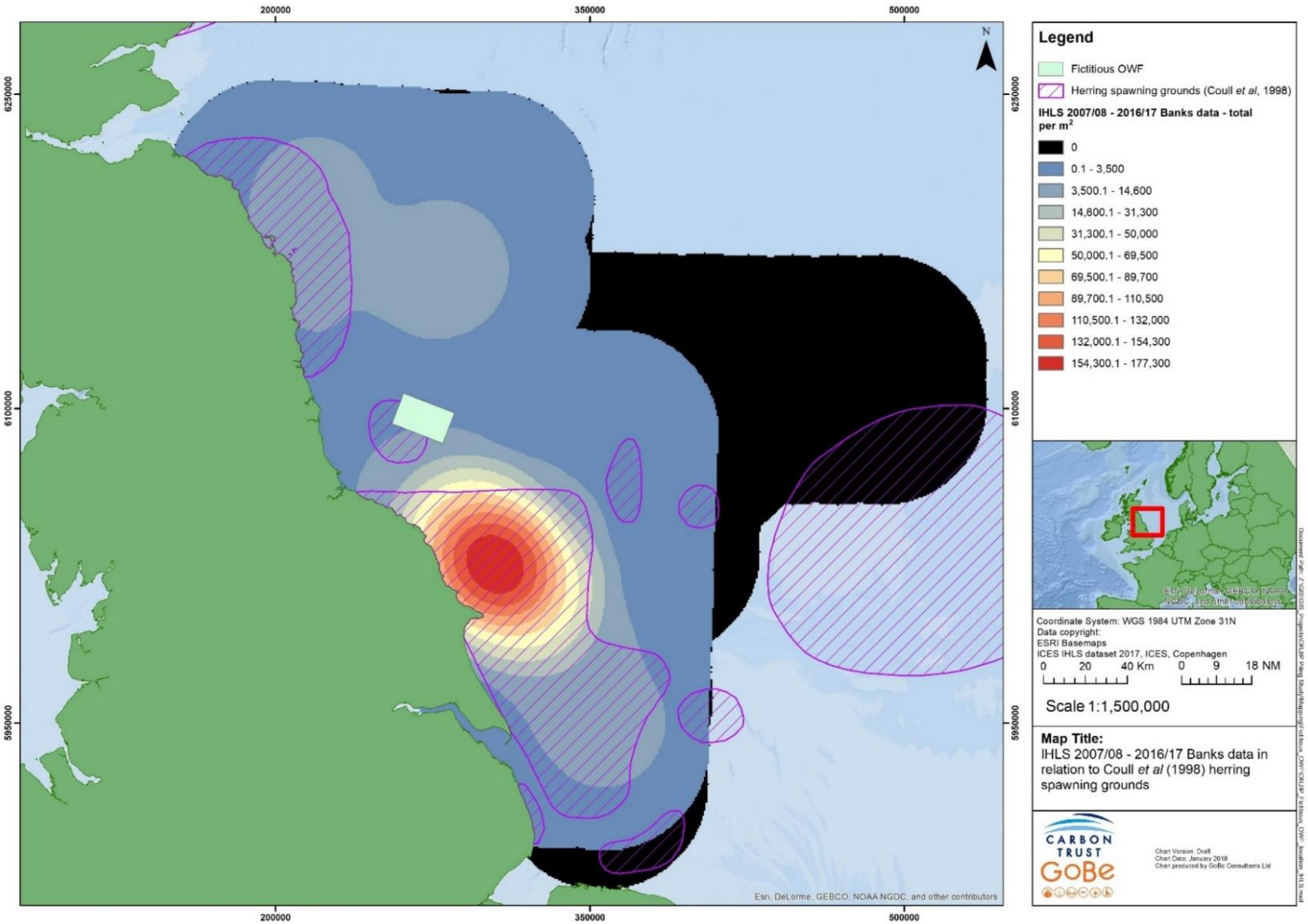

Figure 6-1: IHLS 2007/8 – 2016/17 Banks data in relation to Coull *et. al*. (1998) herring spawning grounds.

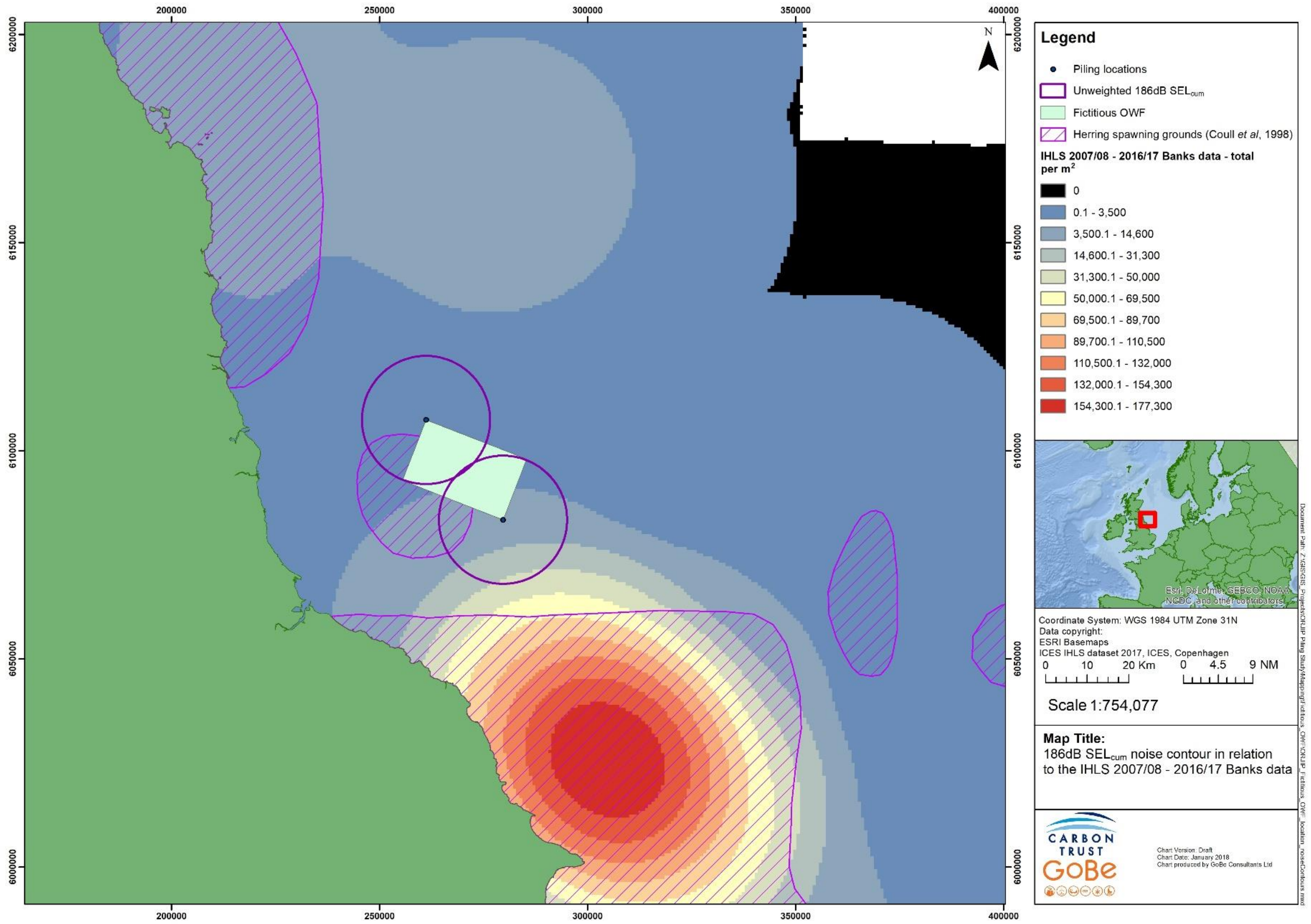

Figure 6-1: 186 dB SEL$_{cum}$ noise contour in relation to IHLS 2007/8 – 2016/17 Banks data.

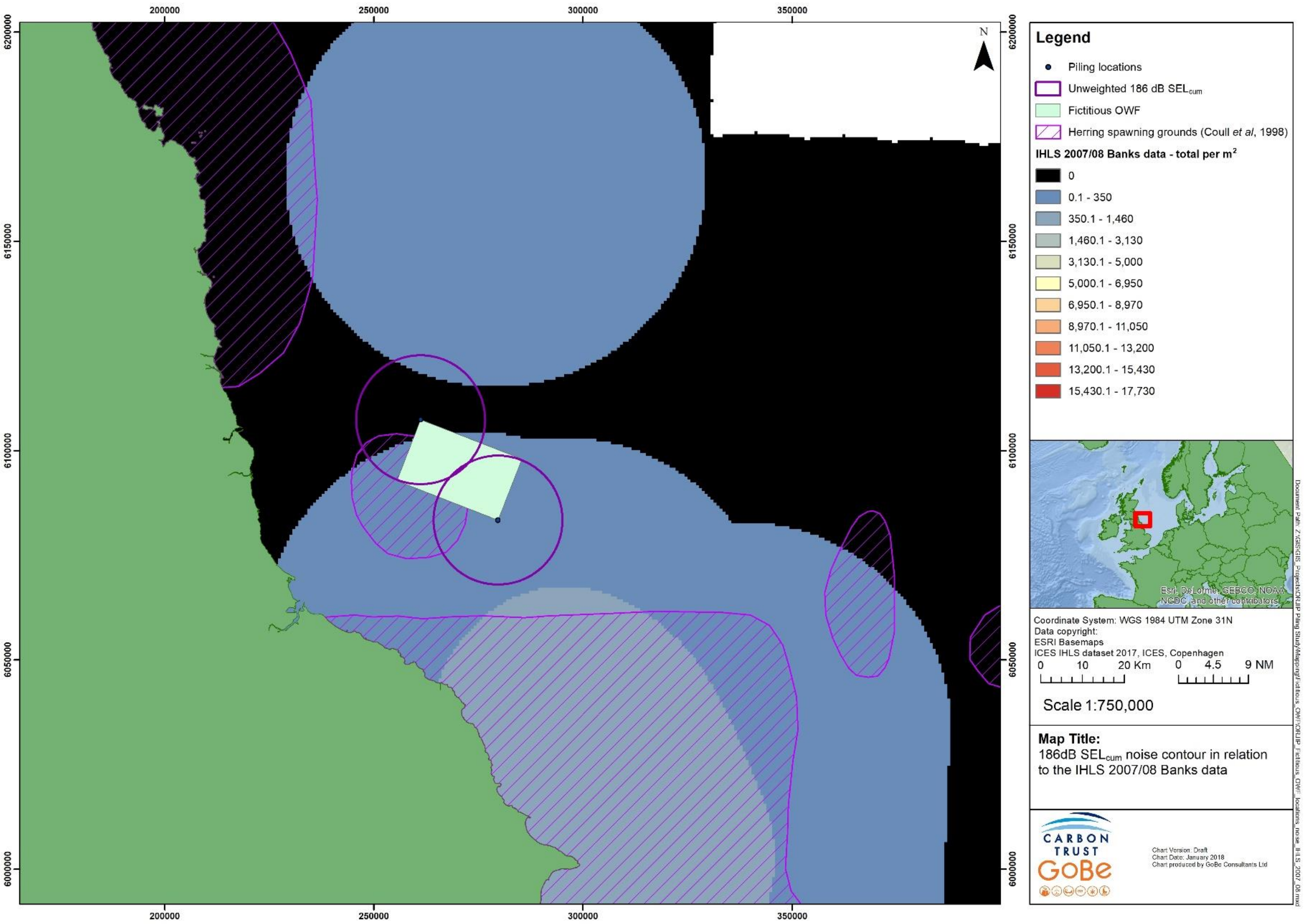

Figure 6-2: 186 dB SEL$_{cum}$ noise contour in relation to the IHLS 2007/08 Banks data

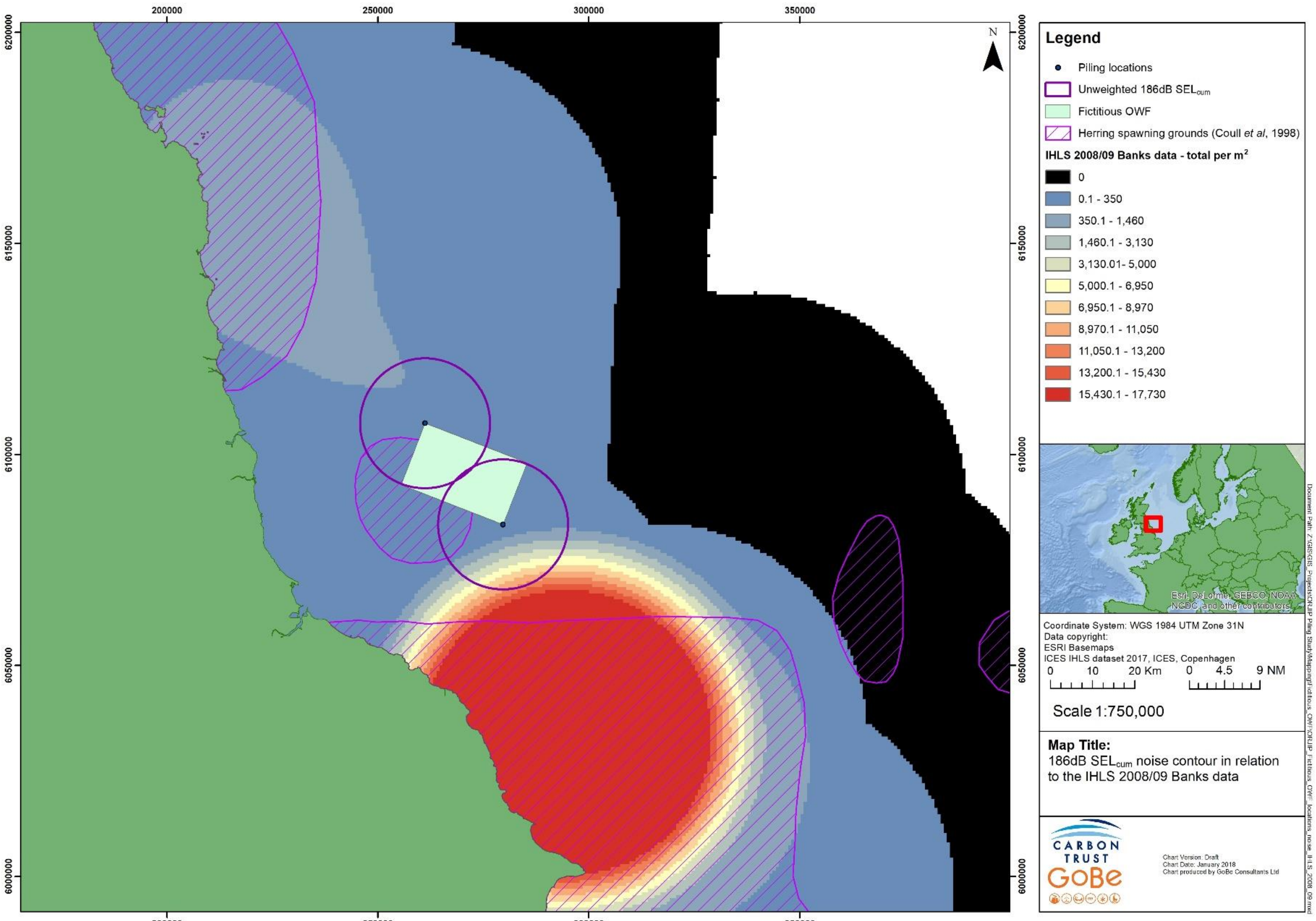

Figure 6-3: 186 dB SEL_{cum} noise contour in relation to IHLS 2008/09 Banks data.

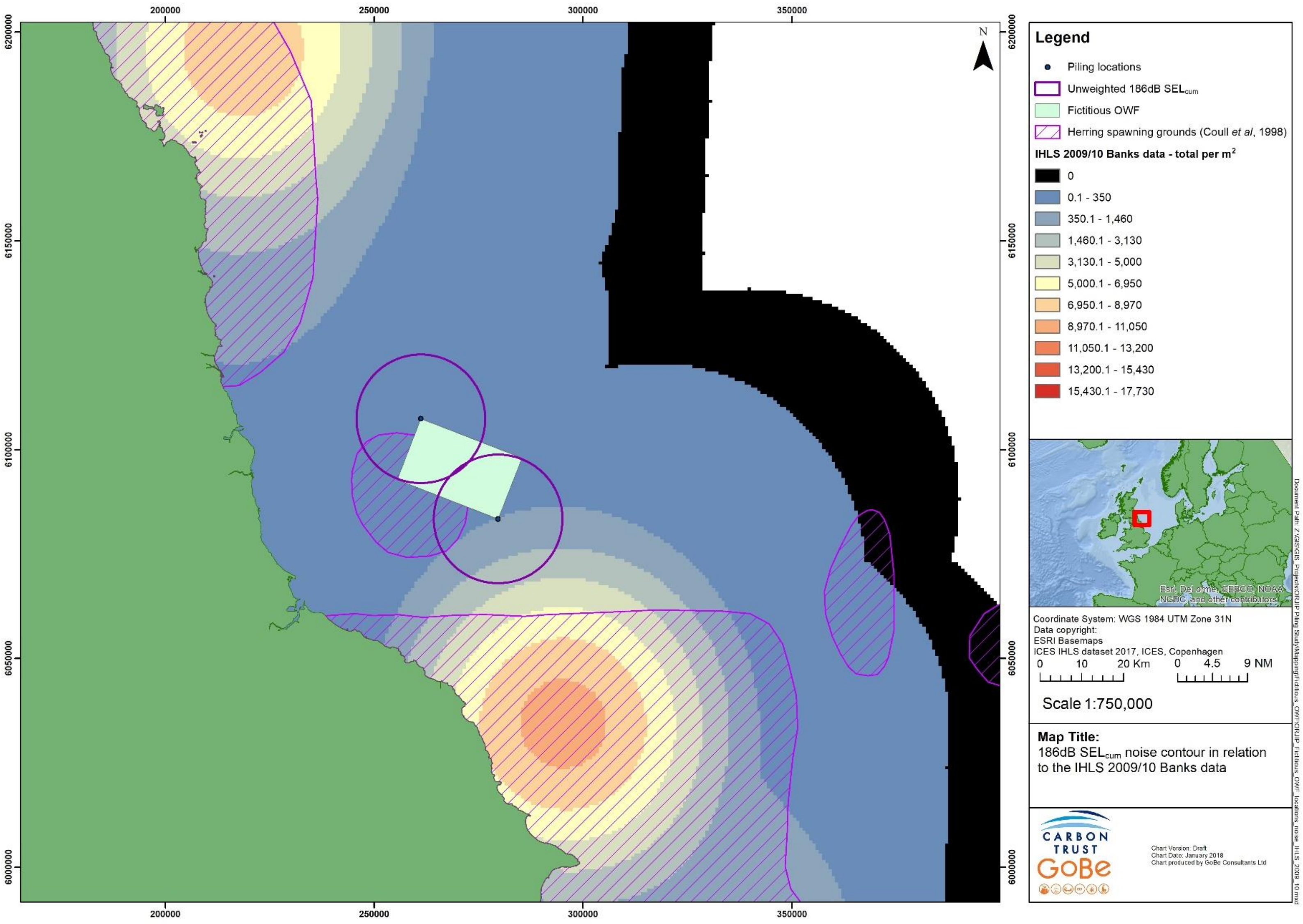

Figure 6-4: 186 dB SEL$_{cum}$ noise contour in relation to IHLS 2009/10 Banks data.

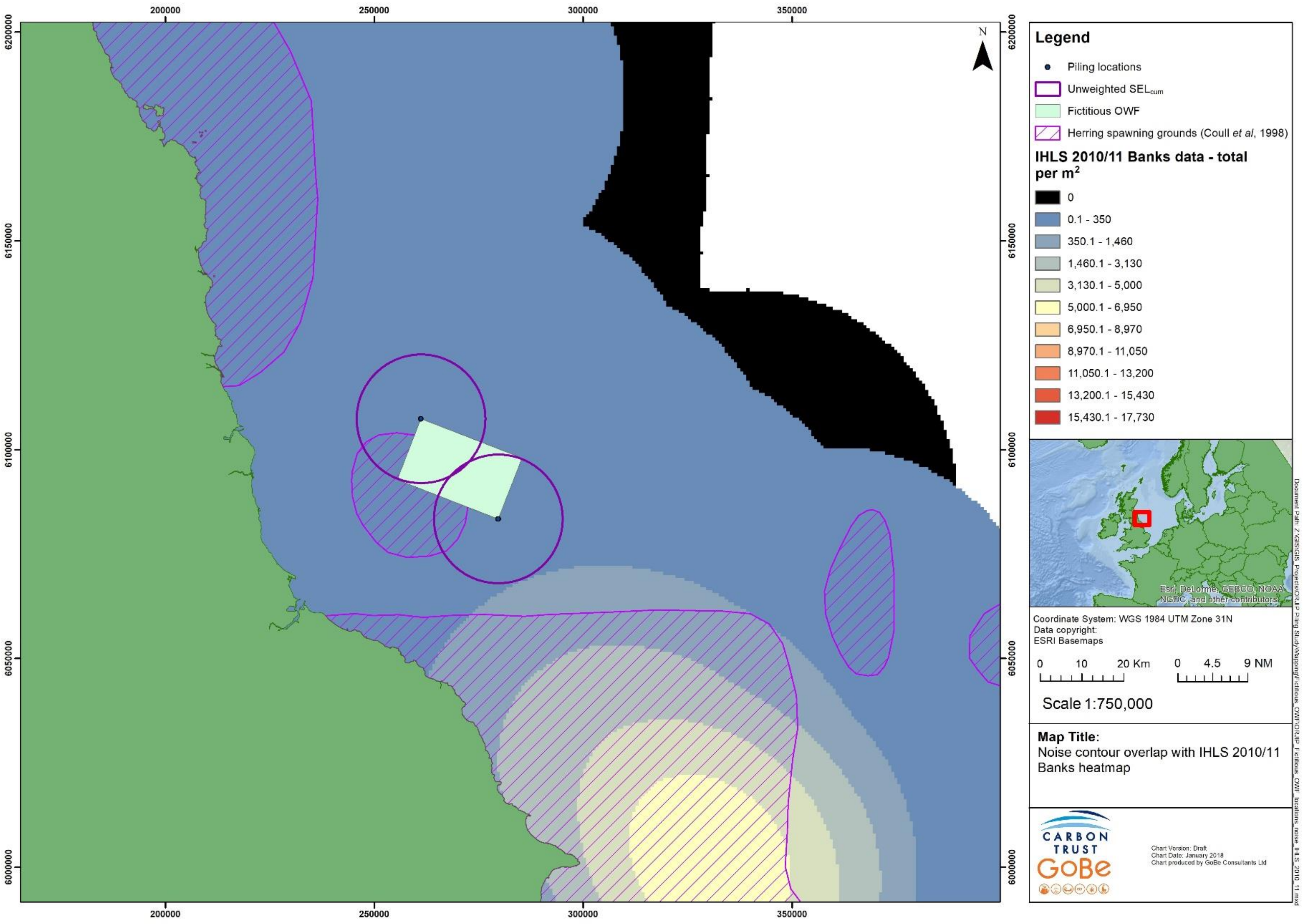

Figure 6-5: 186 dB SEL_{cum} noise contour in relation to IHLS 2010/11 Banks data.

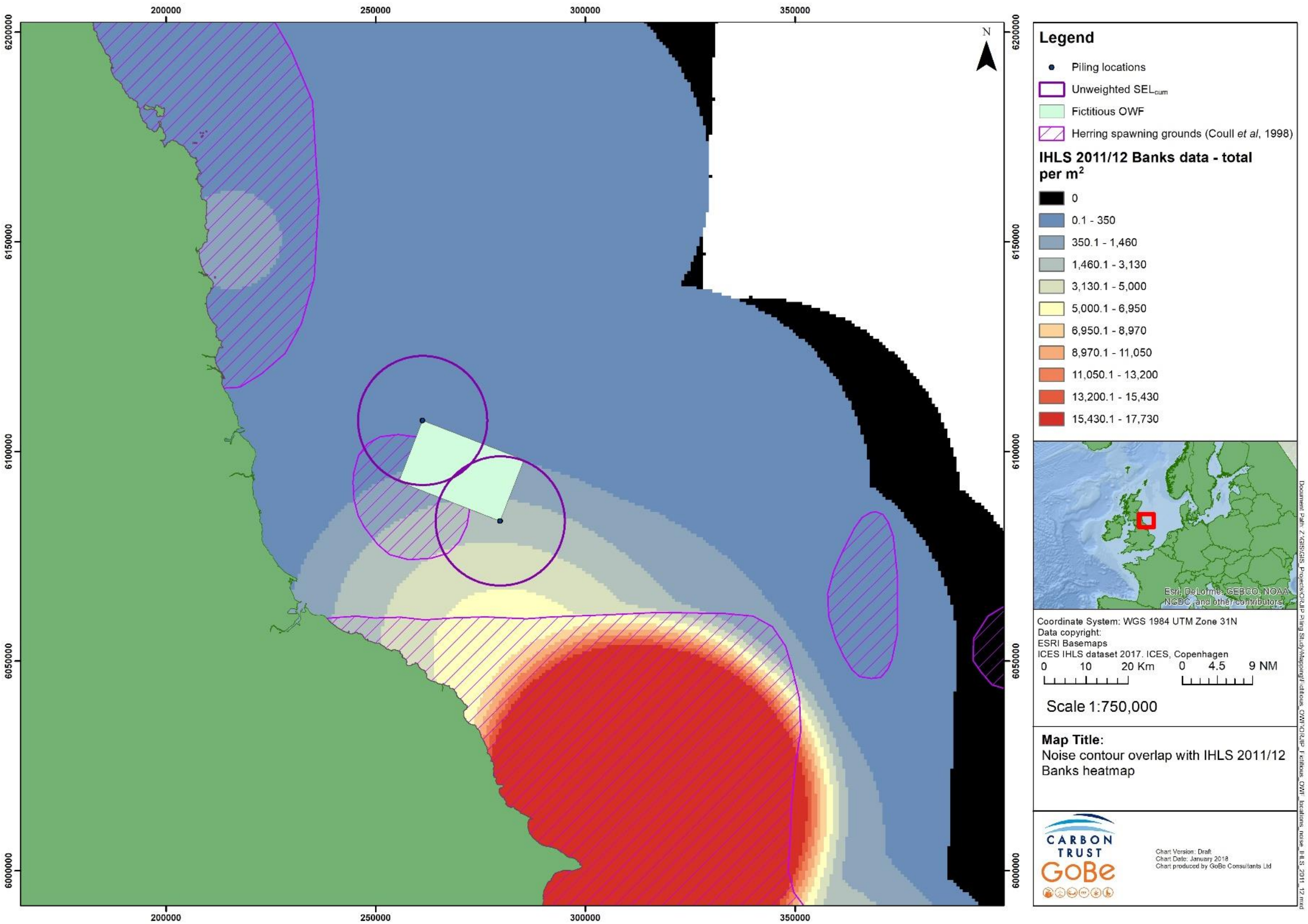

Figure 6-6: 186 dB SEL$_{cum}$ noise contour in relation to IHLS 2011/12 Banks data.

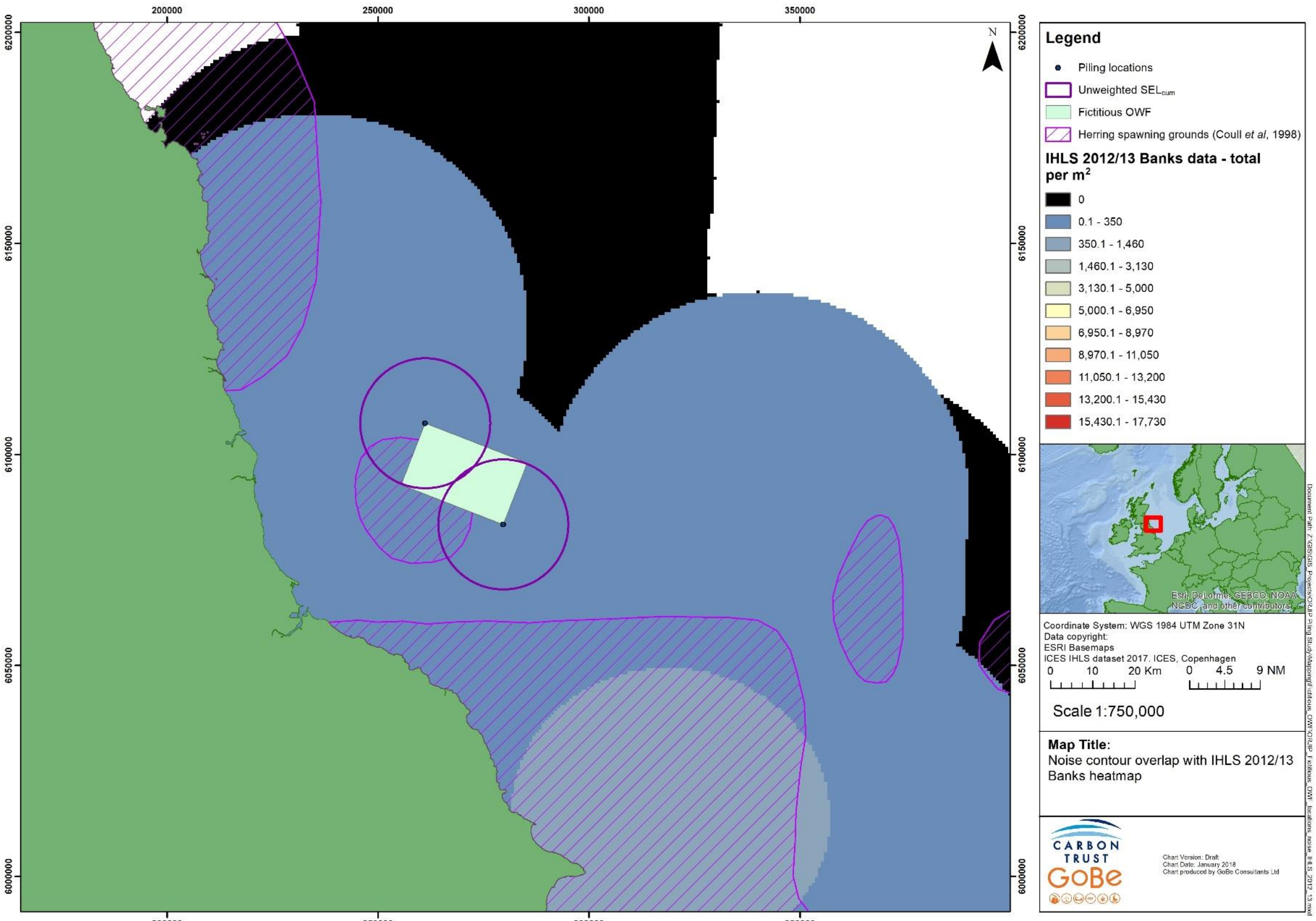

Figure 6-7: 186 dB SEL_{cum} noise contour in relation to IHLS 2012/13 Banks data.

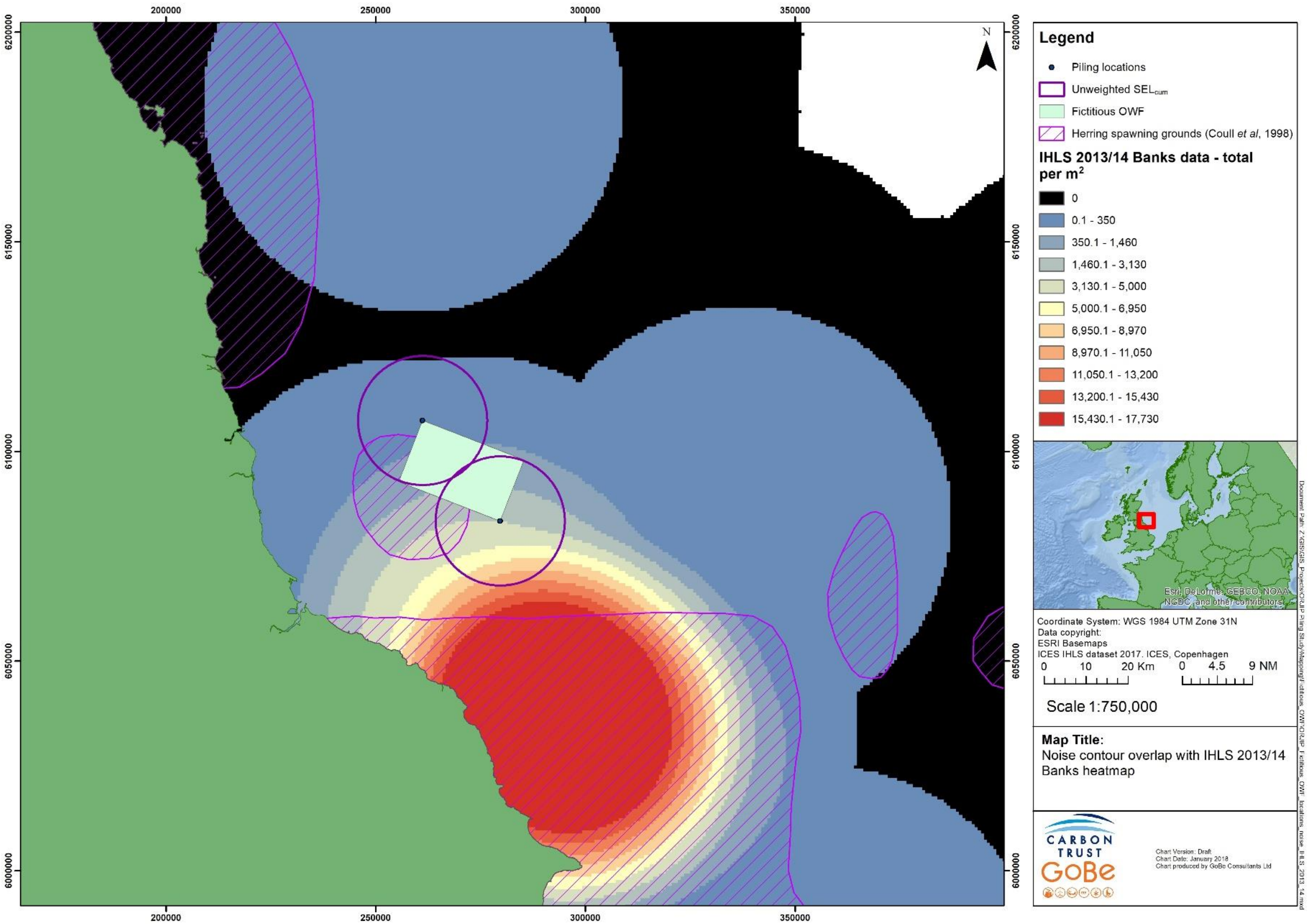

Figure 6-8: 186 dB SEL$_{cum}$ noise contour in relation to IHLS 2013/14 Banks data.

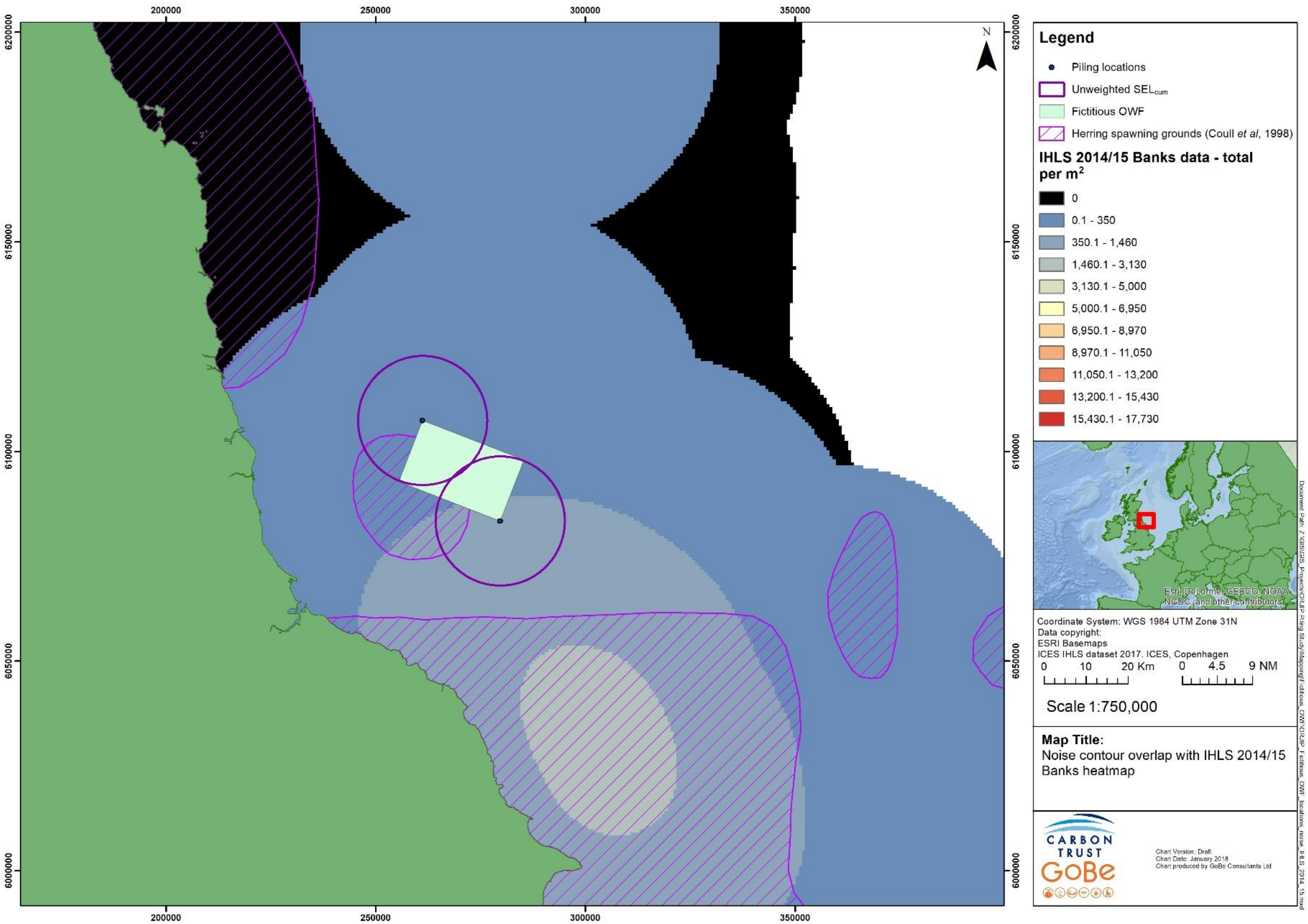

Figure 6-9: 186 dB SEL_{cum} noise contour in relation to IHLS 2014/15 Banks data.

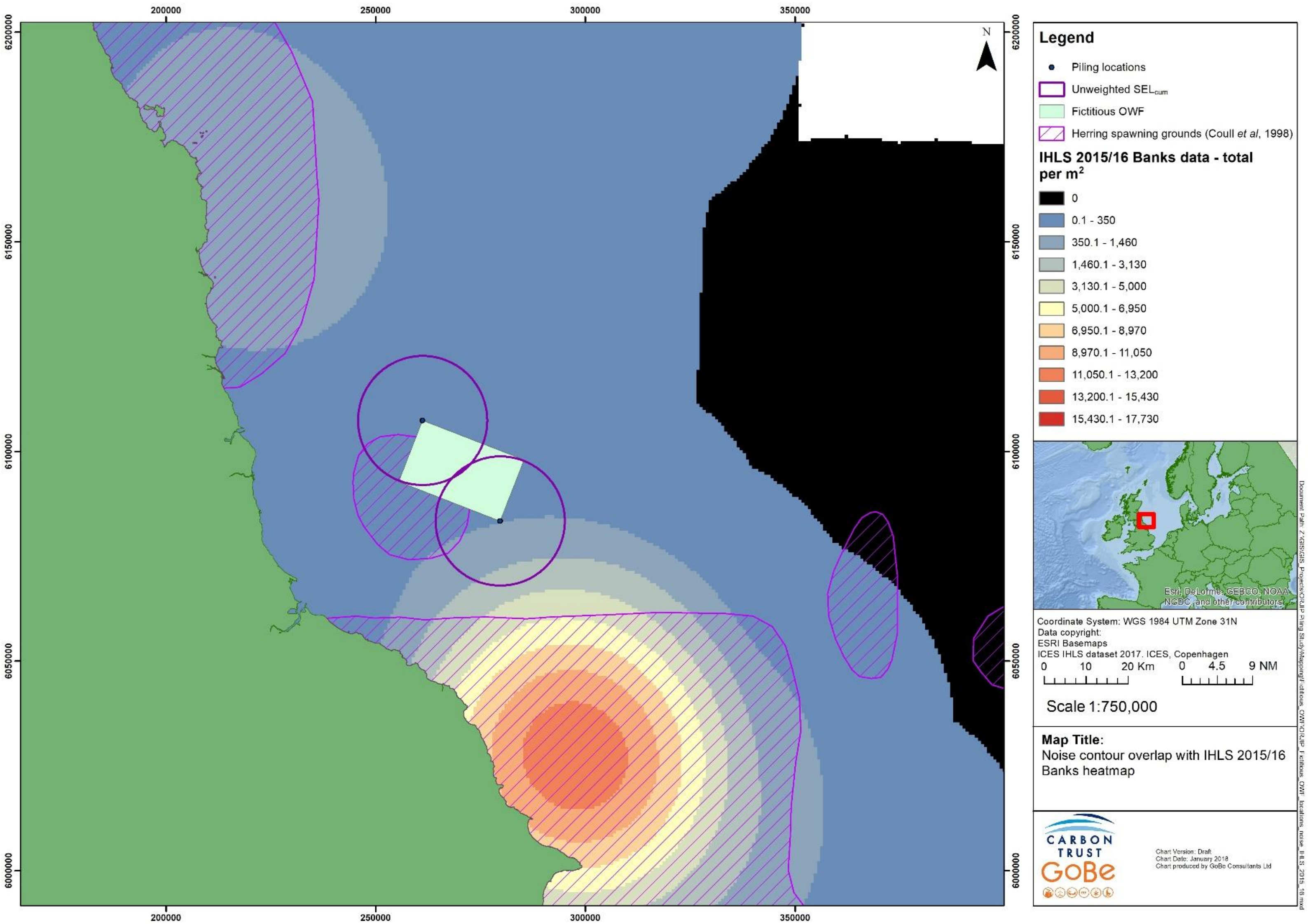

Figure 6-10: 186 dB SEL_{cum} noise contour in relation to IHLS 2015/16 Banks data.

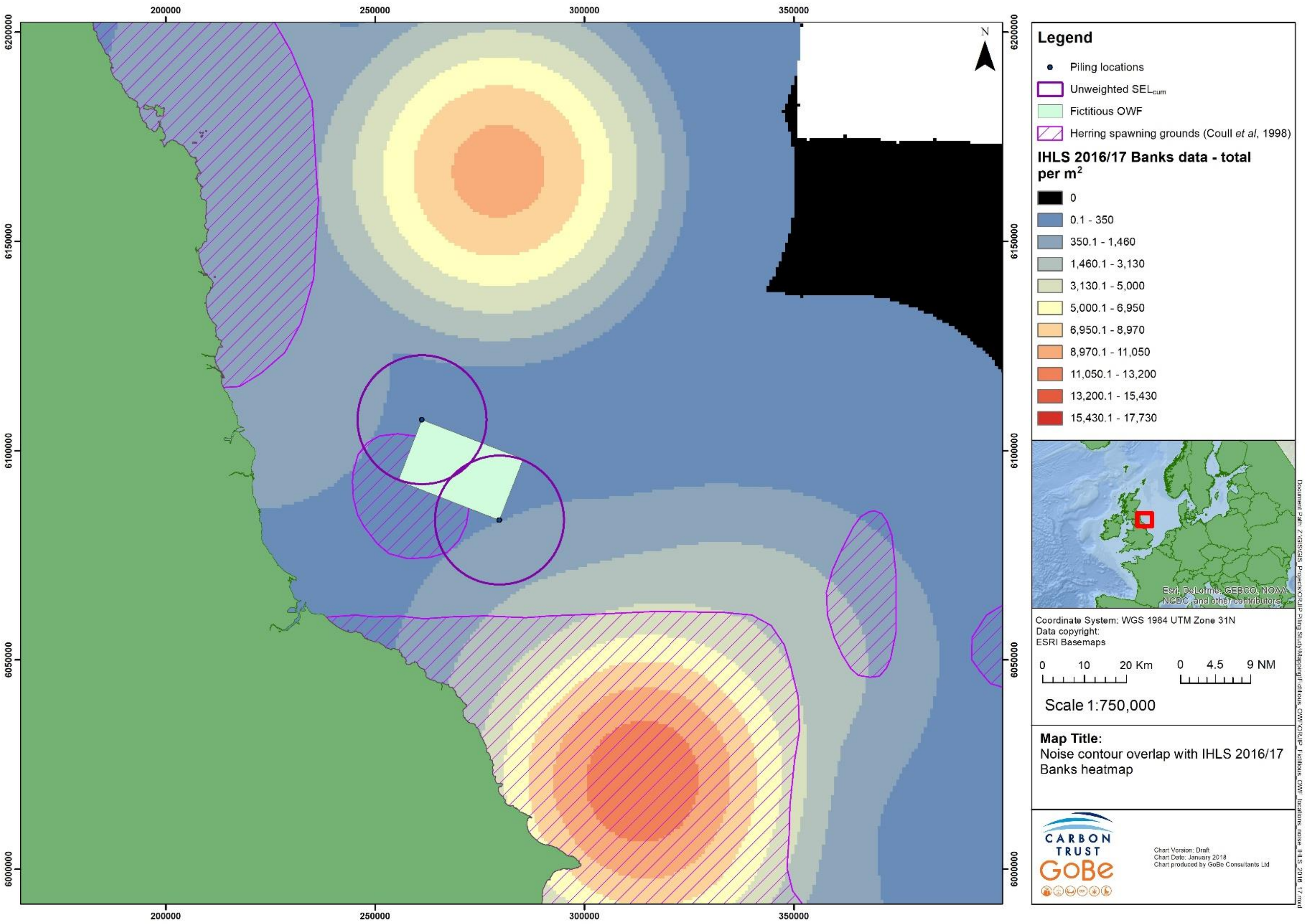

Figure 6-11: 186 dB SEL_{cum} noise contour in relation to IHLS 2016/17 Banks data.

Table 6-1: Larval Densities in the Fictitious OWF Boundary

Season	Latitude	Longitude	Haul No	Sample No	Country	Water Depth	Total Per m²
2007/08	54.92	-0.5	1323146	992050	Netherlands	68	0
2008/09	54.92	-0.5	1323511	988277	Netherlands	72	0
2009/10	54.92	-0.5	1325694	991283	Netherlands	68	0
2010/11	54.92	-0.5	1326323	991672	Netherlands	68	0
2011/12	54.92	-0.5	1329289	996312	Netherlands	68	0
2012/13	54.92	-0.5	1379176	1325325	Netherlands	68	0
2013/14	54.92	-0.5	1381513	1332345	Netherlands	64	0
2014/15	54.92	-0.5	1425453	1394663	Netherlands	65	28
2015/16	54.92	-0.5	1425853	1395070	Netherlands	68	0
2016/17	54.92	-0.5	1519857	1424964	Netherlands	65	5
2016/17	54.92	-0.5	1519939	1425344	Netherlands	65	5

Table 6-2: Larval Densities in the South East Noise Contour

Season	Latitude	Longitude	Haul No	Sample No	Country	Water Depth	Total Per m²
2007/08	54.92	-0.5	1323146	992050	Netherlands	68	0
2007/08	54.75	-0.5	1323175	994484	Netherlands	62	0
2008/09	54.92	-0.5	1323511	988277	Netherlands	72	0
2008/09	54.75	-0.5	1323623	988537	Netherlands	63	0
2009/10	54.92	-0.5	1325694	991283	Netherlands	68	0
2009/10	54.75	-0.5	1325809	991309	Netherlands	61	0
2010/11	54.92	-0.5	1326323	991672	Netherlands	68	0
2010/11	54.75	-0.5	1328975	998384	Netherlands	63	0
2011/12	54.92	-0.5	1329289	996312	Netherlands	68	0
2011/12	54.75	-0.5	1329399	997567	Netherlands	64	297

Season	Latitude	Longitude	Haul No	Sample No	Country	Water Depth	Total Per m^2
2012/13	54.92	-0.5	1379176	1325325	Netherlands	68	0
2012/13	54.75	-0.5	1379167	1325425	Netherlands	64	0
2013/14	54.75	-0.5	1381514	1332346	Netherlands	61	685
2013/14	54.92	-0.5	1381513	1332345	Netherlands	64	0
2014/15	54.75	-0.5	1425452	1394661	Netherlands	61	121
2014/15	54.90	-0.5	1425453	1394663	Netherlands	65	28
2015/16	54.75	-0.5	1425838	1395055	Netherlands	63	60
2015/16	54.92	-0.5	1425853	1395070	Netherlands	68	0
2016/17	54.75	-0.5	1519856	1424963	Netherlands	63	9
2016/17	54.75	-0.5	1519938	1425343	Netherlands	63	9
2016/17	54.92	-0.5	1519857	1424964	Netherlands	65	5
2016/17	54.92	-0.5	1519939	1425344	Netherlands	65	5

Table 6-3: Larval Densities in the North West Noise Contour

Season	Latitude	Longitude	Haul No	Sample No	Country	Water Depth	Total Per m^2
2007/08	55.03	-0.83	1323142	986802	Netherlands	67	0
2008/09	55.08	-0.83	1323618	988302	Netherlands	68	206
2009/10	55.08	-0.83	1325804	991307	Netherlands	68	6
2010/11	55.08	-0.83	1328969	995964	Netherlands	69	0
2011/12	55.08	-0.83	1329392	1004365	Netherlands	63	0
2013/14	55.07	-0.83	1381509	1332341	Netherlands	65	0
2014/15	55.08	-0.82	1425447	1394666	Netherlands	68	0
2015/16	55.08	-0.83	1425851	1395068	Netherlands	66	2
2016/17	55.08	-0.83	1519841	1424948	Netherlands	66	7
2016/17	55.08	-0.83	1519923	1425328	Netherlands	66	7

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APPENDIX A

WP1 – Literature and Data Sources Summary Spreadsheet

Data Name / Owner	Data Source	Use of Data	Data Span	Summary of Key Findings Relevant to this study
Main Sources of Data				
International Herring Larvae Surveys (IHLS)	International Council For Exploration of the Seas (ICES) WGIPS Group. http://www.ices.dk/marine-data/data-portals/Pages/Eggs-and-larvae.aspx	Primary data source. Used to generate the heatmaps for the North Sea and central/eastern English Channel (will need to use the HAWG reports to outline the methodology behind these surveys and the justification for the areas of focus (i.e. herring of lesser importance to Irish Sea and western English Channel) and should also contain the start of the info for the literature review on herring).	1967 - current Data downloadable from 1972	Heatmaps provided displaying data.
Northern Ireland Ground Fish Surveys (NIGFS)	DATRAS https://datras.ices.dk/Data_products/Download/Download_Data_public.aspx	Use of the data to generate heatmaps of the distribution of adult fish to use as proxies for potential spawning ground (i.e. fish caught in these surveys are classified into maturity groups and we then defined ‘functionally mature’ groupings and ‘functionally immature’ groupings and then used the distribution of the ‘functionally mature’ females to represent likely spawning areas). previously used for the Walney Extension cod seasonal restriction variation but also currently using this for herring for the Triton Knoll seasonal restriction variation request.	1992 - current	Heatmaps provided displaying data.

Quarter 1 Scottish Ground Fish Survey	DATRAS https://datras.ices.dk/Data_products/Download/Download_Data_public.aspx	Age frequencies are constructed for herring. Indices of abundance at age are calculated and these data are made available for the Herring Assessment Working Group.	1981 - current	Heatmaps provided displaying data.
Quarter 4 Scottish Mackerel Survey	DATRAS https://datras.ices.dk/Data_products/Download/Download_Data_public.aspx	Surveying was extended in 1995 to include herring. Data will be assessed and used if relevant.	1995 - current	Heatmaps provided displaying data.
North Sea - International Bottom Trawl Surveys (IBTS)	DATRAS https://datras.ices.dk/Data_products/Download/Download_Data_public.aspx	Targets a number of commercial finfish species including herring, with the objective to provide recruitment and distributional data of target species within the ICES study area. The IBTS surveys began in 1991 with quarterly surveys conducted across ICES Area IV (the North Sea) until 1996 using a semi-pelagic bottom trawl. From 1997 survey effort was reduced and conducted biannually with only Quarter 1 and Quarter 3 surveys being undertaken. More recent data may be assessed and used if relevant.	1991 - current (effort differences across the years)	Heatmaps provided displaying data.
Predictive Habitat Information / Prevailing currents				
Predictive European Nature Information System (EUNIS) seabed habitats.	European Marine Observation and Data Network (EMODnet) (2017). Coltman et al. (2008).	Predictive broad scale benthic habitat mapping of seabed habitat types across the Mapping European Seabed Habitats (MESH) area. Uses data collected across Europe between 2009 and 2012 and updated with additional data in 2013 – 2016. To be used in comparison / ground truthing heat maps, although this	2017	Used for mapping, along with heatmaps

		ORJIP study will focus on actual data rather than predictive data.		
The Scottish Shelf Model. Part 1: Shelf-Wide Domain. Scottish Marine and Freshwater Science Vol 7 No 3 J Wolf, N Yates, A Brereton, H Buckland, M De Dominicis, A Gallego, R O'Hara Murray (2016).	http://data.marine.gov.scot/sites/default/files/SMFS%20Vol%207%20No%203.pdf	Report providing detail on prevailing currents based on GIS data	2016	Useful information on general currents.
Prevailing currents around the UK	https://www.nodc.noaa.gov/General/current.html ? https://www.bodc.ac.uk/data/bodc_database/nodb/ ?	Provide information on potential for larvae to drift and would also be useful for discussions with Cefas regarding the survey methodology for the IHLS data not necessarily capturing the youngest larvae/eggs which tend to remain below the depth at which the IHLS trawls are undertaken (~2m above the seabed). Maps as a separate layer that can be used as required.	2017	Primarily surface current data, use of this data would require discussion with the expert panel. Would need to gain agreement of expert panel on methodology to be used for any predictions of actual spawning locations.
General Population Information				
Spawning and nursery grounds of selected fish species in UK waters	Ellis J.R., Milligan S.P., Readdy L., Taylor N., and Brown M.J., (2012) Spawning and nursery grounds of selected fish species in UK waters. Sci. Ser. Tech. Rep., Cefas Lowestoft, 147, 56 pp.	Pelagic and demersal fish species spawning and nursery ground data in a regional and national context.	2012	Ellis *et al*. did not update the boundaries for herring spawning locations from the Coull *et al*. areas, only updated the nursery grounds. Did note that Coull was

				correct when stating "spawning distributions are under continual revision, it follows that these maps should not be seen as rigid, unchanging descriptions of presence or absence". This is the basis for using the heatmaps of the IHLS data to try and refine the boundaries of the Coull et al spawning grounds as the heatmapping data shows the data from the last 10 years rather than relying on data from more than 20 years ago.
Spawning and nursery mapping dataset.	Ellis *et al*. (2010).	Mapping of spawning and nursery areas of species to be considered in MPAs (Marine Conservation Zones (MCZs)). Final Report on development of derived data layers for 40 mobile species considered to be of conservation importance.	2010	Ellis et al. did not update the boundaries for herring spawning locations from the Coull et al. areas, only updated the nursery grounds. Shapefiles not used in this study.
Fish maps	International Council for Exploration of the Seas (ICES) (2006). http://www.ices.dk/marine-data/maps/Pages/ICES-FishMap.aspx	An atlas of North Sea fish, including fact sheets of key species and distribution maps.	2006	Generic information on herring, low on details.
Fishery Sensitivity Maps.	Coull K.A., Johnstone R., and Rogers S.I. (1998) Fisheries Sensitivity Maps in British Waters. Published and distributed by UKOOA Ltd. https://www.cefas.co.uk/media/52612/sensi_maps.pdf http://marine.gov.scot/information/fisheries-sensitivity-maps	Fishery sensitivity maps for British Waters. Maps have been compiled from data collected and collated by Fisheries Research Services (FRS) and Centre for the Environment, Fisheries and Aquaculture Science (Cefas).	1998	Identified spawning grounds for multiple fish species around the UK, including for herring. The study used multiple data sources but did use the IHLS data (up to 1996) to aid in the delineation of the spawning grounds.

ICES international North Sea herring acoustic survey - HERring Acoustic Survey (HERAS)	ICES Planning Group for Herring Surveys www.clupea.net/contact/index.html	Herring acoustic surveys are used by ICES to identify distribution, abundance and biomass of herring in the North Sea	1979 - Present	This data is not particularly relevant to this study as it is based upon adult abundance of the North Sea stock for policy and ICES advice on stock biomass. However, it provides good information on stock productivity and population abundance information. The website is also designed to hold various reports on herring of interest to researchers and public. There is also a similar industry acoustic survey being put in place for the West Coast herring (for 6a-7bc herring).

APPENDIX B

Note on the Project Approach to Use of Survey Data

Impacts on Fish from Piling at Offshore Wind Sites: Collating Population Information, Gap Analysis and Appraisal of Mitigation Options - Study for the Offshore Renewables Joint Industry Programme (ORJIP)

Project Approach to Use of Survey Data

Purpose of Note

As part of the project kick-off meeting with the Steering Committee (DPSC) and the expert panel, feedback was received on the following two points:

- A query from an expert on the pros and cons of using empirical survey data in preference to predictive habitat mapping; and
- A question as to whether there were differences between year to year IHLS surveying that would need consideration as part of the mapping exercise.

Considering these queries, this note presents GoBe's rationale for their approach to use of survey data with the overall objective of seeking consensus on this project approach from the experts.

Use of Empirical Survey Data

Within GoBe's tender submission, the approach being applied to Work Package (WP) 1 for the generation of heat maps was to use empirical data as the key source, with ground-truthing of the outputs through the application of existing predictive habitat mapping, other historical data (e.g. Coull and Ellis fish sensitivity maps) and literature review. This approach is preferred, as from GoBe's scientific industry experience there is a risk of over predicting actual herring distribution through habitat modelling and as such it is the view of GoBe that the emphasis should be placed on mapping generated through use of data such as that provided in the IHLS. Feedback received from an expert identified that '*there is a risk however, of under-estimating using the empirical data due to the limited number of surveys undertaken. Both methods have their pros and cons*'.

GoBe Rationale

GoBe believes the deliverables of this study should be based on the best available data and make best use of this data and current knowledge to promote understanding and informing of piling impacts upon herring.

- While the predictive habitat mapping data that is available through EUNIS is very useful, this habitat mapping is predictive and broad scale in nature, with the biotope classification identified at a high level. The mapping uses low resolution maps and models to predict seafloor habitat types. These maps are generated using measurements such as water depth, sediment type and light levels amongst others, then using statistical analysis and Geographical Information System (GIS) modelling. Thus, interpretation of the potential effects upon spawning herring is understandably overinterpreted as a precautionary measure and can cover a large area of seabed perceived to be suitable for herring spawning.
- By using empirical data as the key source of information, the element of prediction is reduced as the survey data collected by IHLS, Scottish and North Sea IBTS and NIGFS is real-time data collected over a period of time. These datasets extend over a relatively long period, with between 20 to 50 years worth of datasets available (ICES IHLS dating back to 1967). Such long-term data are considered to be the best available data to be used in heat mapping.

- For the IHLS data we propose to utilize the most recent 10 years of data. A heat map will be produced based on the dataset for each year, which will show where the 'hotspots' occur within each year. Subsequently, a composite (cumulative) illustration of the full ten years of data will be produced to show the maximum extent of larvae presence for each of the spawning stocks present around the UK. GoBe are content that 10 years of data gives a good and adequate amount of data to base findings on and addresses the concern of 'limited' data being used as well as ensuring the most contemporary information is employed, which is important in informing decision making for proposals being brought forward in the present day. That said, a larger data set is obviously available if 10 years of data was felt to be too temporally limited.

- We are also using the last five years of data for the IBTS data. This dataset has been limited to 5 years due to the size of the datasets; a 10 year download of the North Sea IBTS dataset is too large to hold in an excel sheet and manage within the expectations of this study. This data gives more weight to the IHLS data which is more robust, with the IBTS data (which is only adults) either filling in the gaps or comprising additional evidence.

- In recognition of the value of the predictive habitat mapping, we will then use the existing most recent EUNIS data to verify/compare/ground truth the survey data findings. This will be presented as a different GIS layer which can be overlaid on to the heat maps as required.

- GoBe also consider that there is value in illustrating the prevailing currents within UK waters. If such publicly available GIS data can be sourced, we will provide this as a separate additional informative layer, to overlay with the other GIS data if required.

<u>Differences in Year to Year Collection of IHLS Data</u>
Comment has been made during project discussions that there could be differences between survey methods and data collation which would need to be considered within the study.
GoBe Rationale
As with any survey monitoring programme, GoBe appreciate that there may be differences in the way in which data has been collected between years, during surveys. There are also differences in how the IHLS data has been classified over the years, but care will be taken to either standardise or or specifically note/accommodate any such variations and we are confident that this can be managed appropriately to ensure that this does not compromise the outcomes of the mapping exercises if caveated appropriately to explain how data can and cannot be directly compared.

- Surveying locations – these have often varied slightly from year to year. The sampling locations are based on the evidence and advice provided by the Herring Advisory Working Group (HAWG) at ICES identifying where the most likely spawning locations are, based both on historical IHLS surveys and other available data and literature. The reason for this is so the survey effort is focused on the areas that have the most potential for herring larvae. This results in herring focused surveys as far as possible.

- Classification of development stages of adult herring – Adults are now classified into six maturity classes: juvenile/immature (1); maturing (2); spawning (3); spent (4); resting/skip of spawning (5); and abnormal (6). For the purposes of the heat mapping, GoBe propose to separate these into two classes, functionally mature and functionally immature. Classes 3 (spawning) and 4 (spent) are identified as functionally mature in that they are/have been reproductively active in the sampling year. Classes 1 (juvenile), 2 (maturing), 5 (resting) and 6 (abnormal) are all classed as functionally immature in that they have not been reproductively active in the sampling season.

- Differences in survey methodologies and equipment – in order to address this the data sets for IHLS and the different IBTS area surveys will be treated individually and illustrated as separate datasets.

APPENDIX C

Heat Mapping

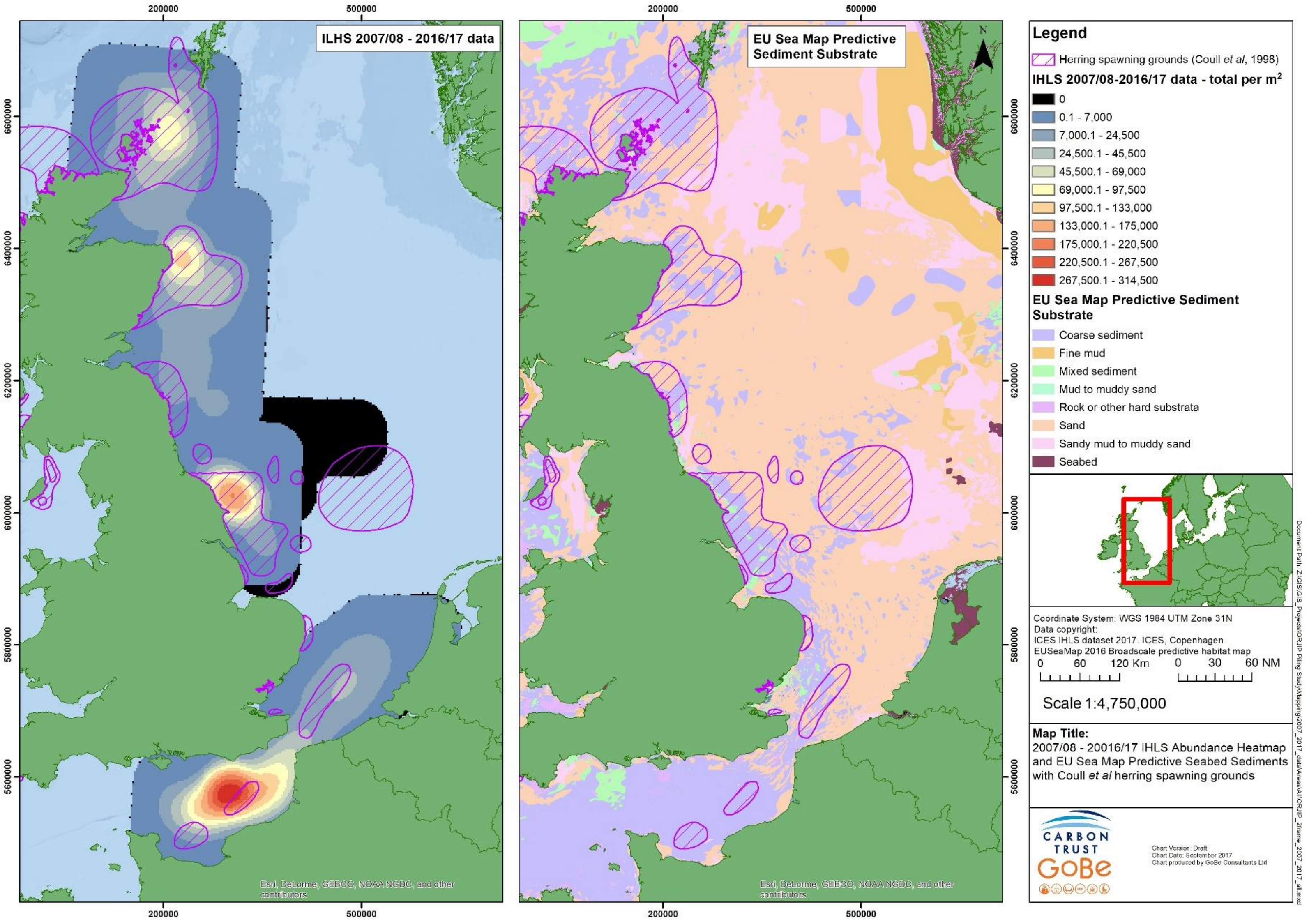


Figure C-1 2007/08 – 2016/17 IHLS Abundance Heatmap (All)

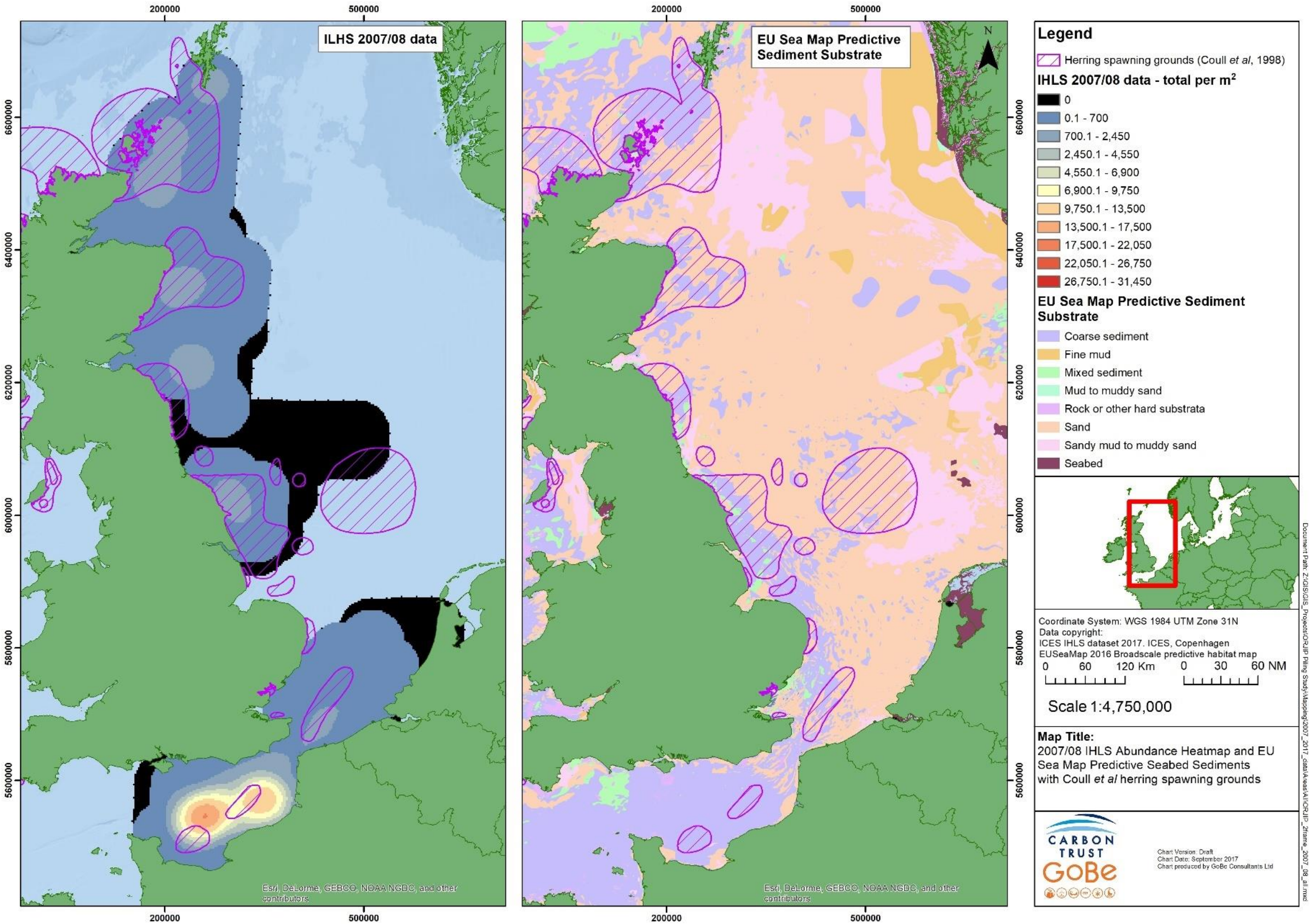


Figure C-2 2007/08 IHLS Abundance Heatmap (All)

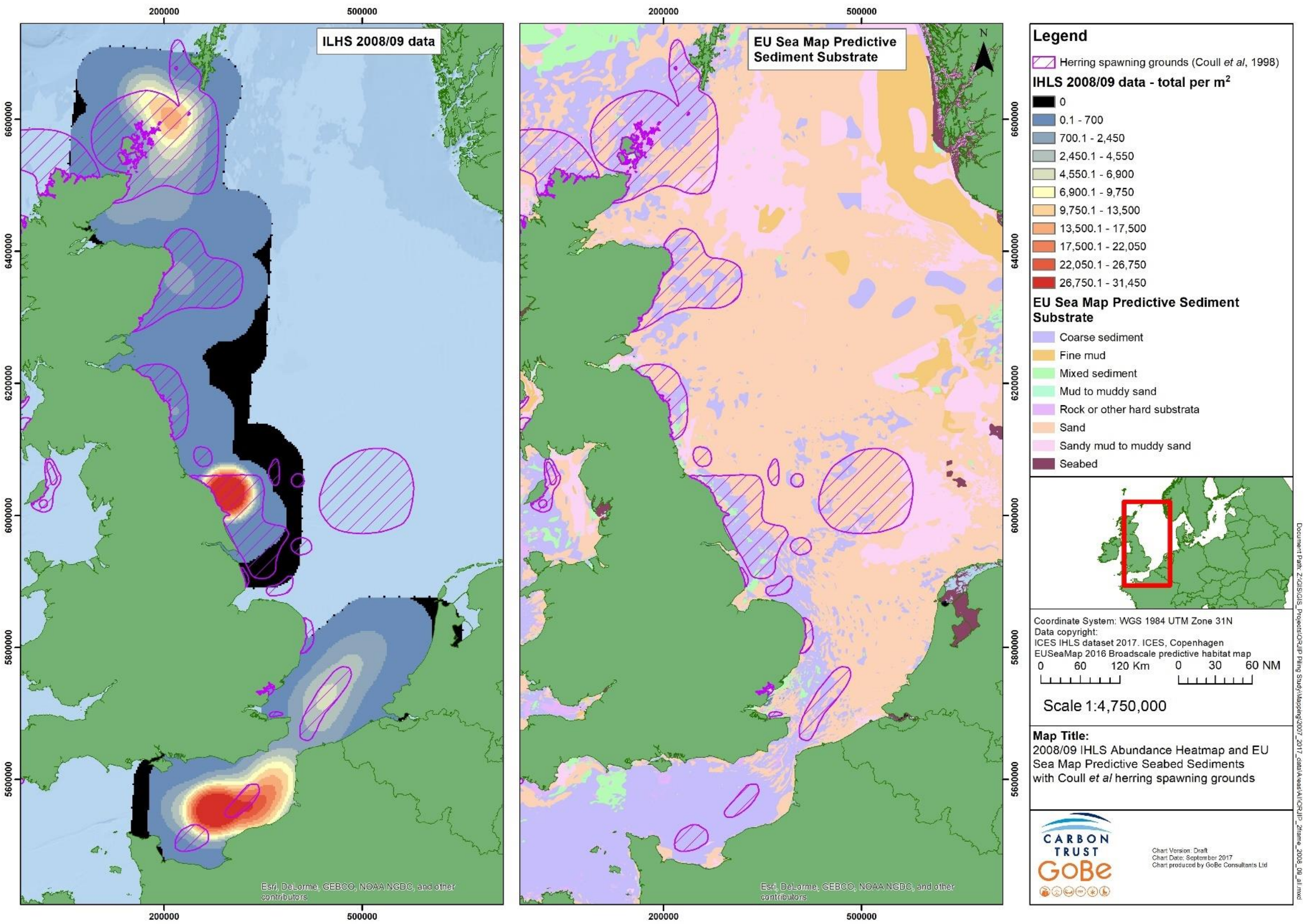


Figure C-3 2008/09 IHLS Abundance Heatmap (All)

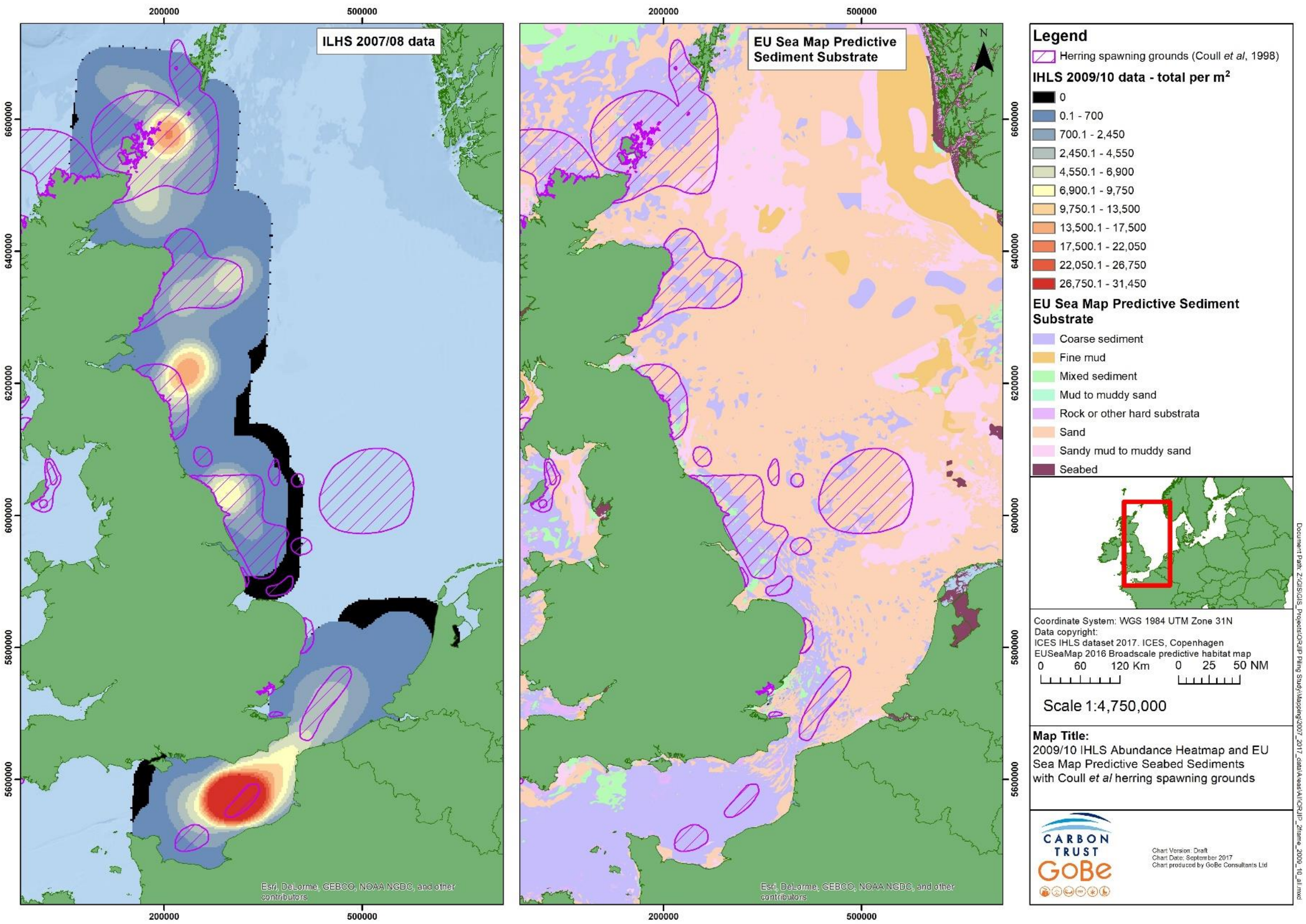


Figure C-4 2009/10 IHLS Abundance Heatmap (All)

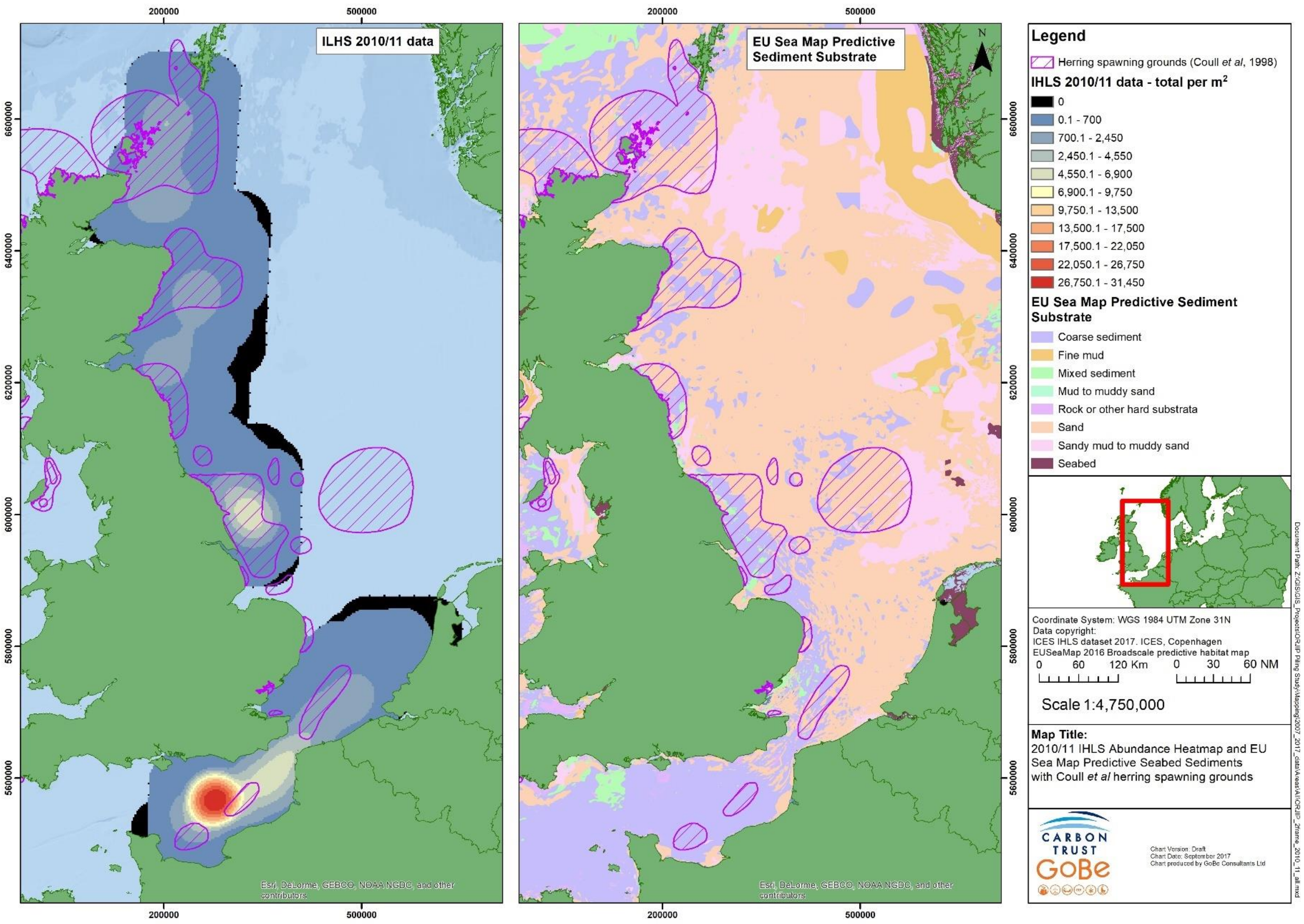


Figure C-5 2010/11 IHLS Abundance Heatmap (All)

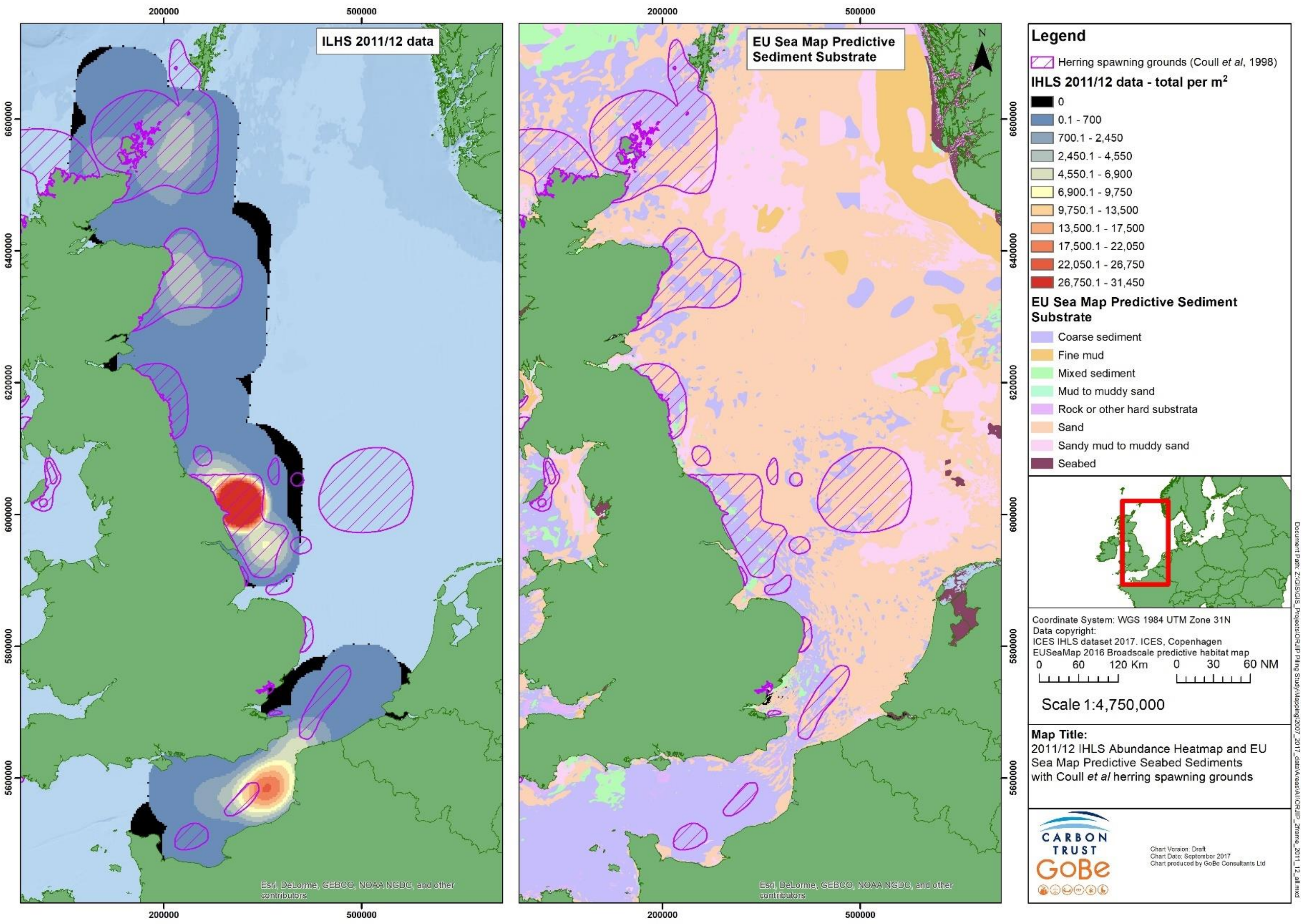


Figure C-6 2011/12 IHLS Abundance Heatmap (All)

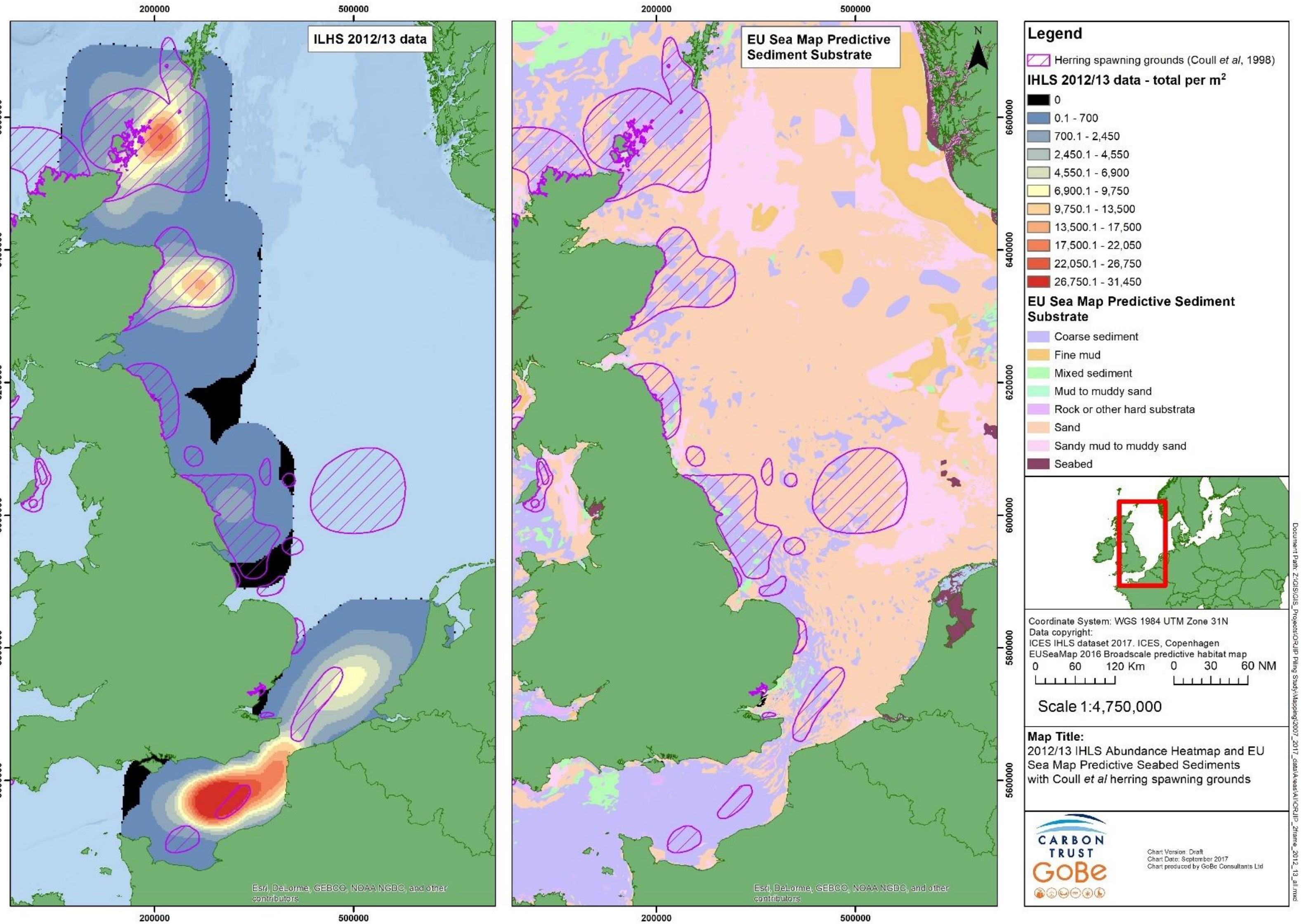


Figure C-7 2012/13 IHLS Abundance Heatmap (All)

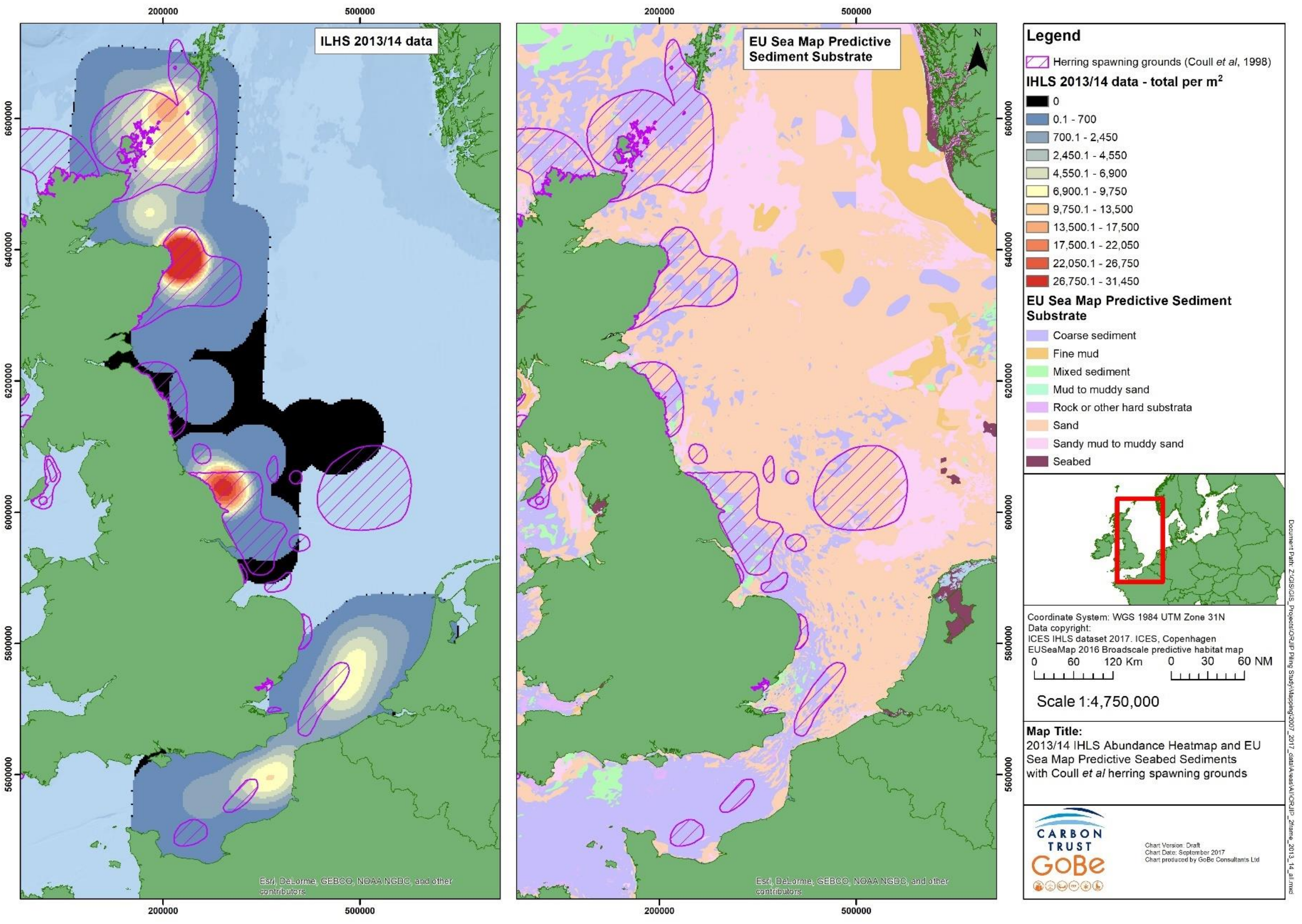


Figure C-8 2013/14 IHLS Abundance Heatmap (All)

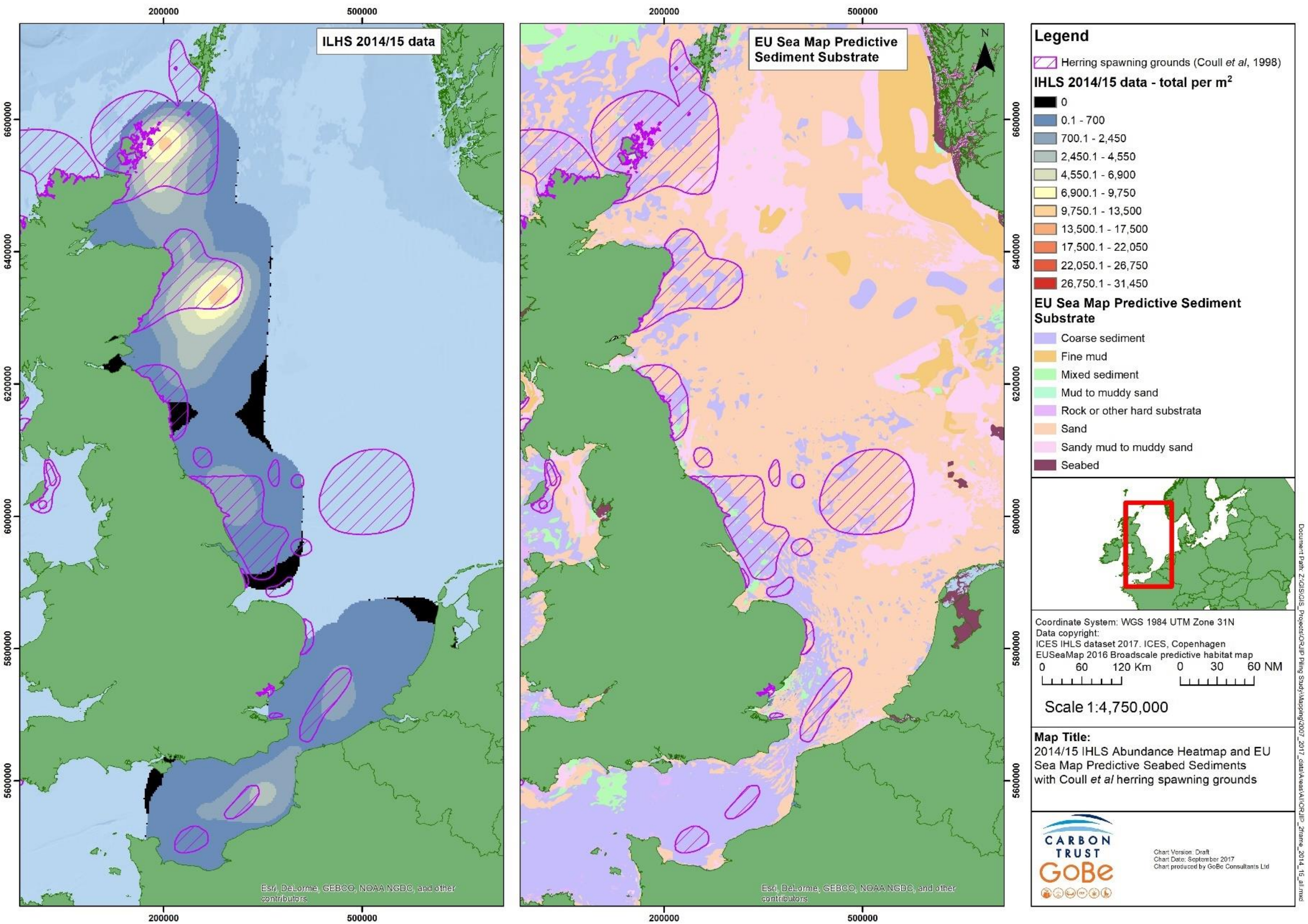


Figure C-9 2014/115IHLS Abundance Heatmap (All)

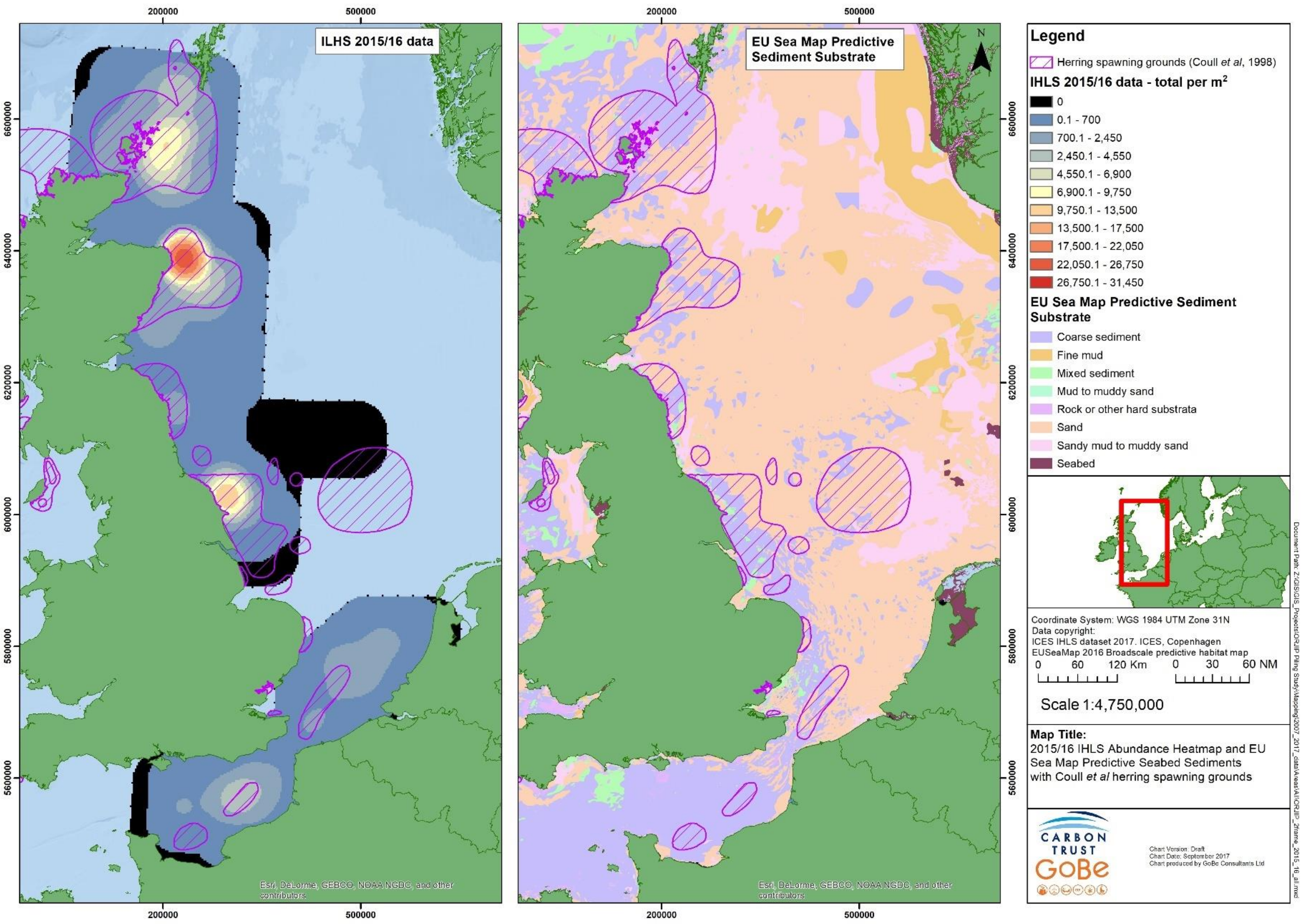


Figure C-10 2015/16 IHLS Abundance Heatmap (All)

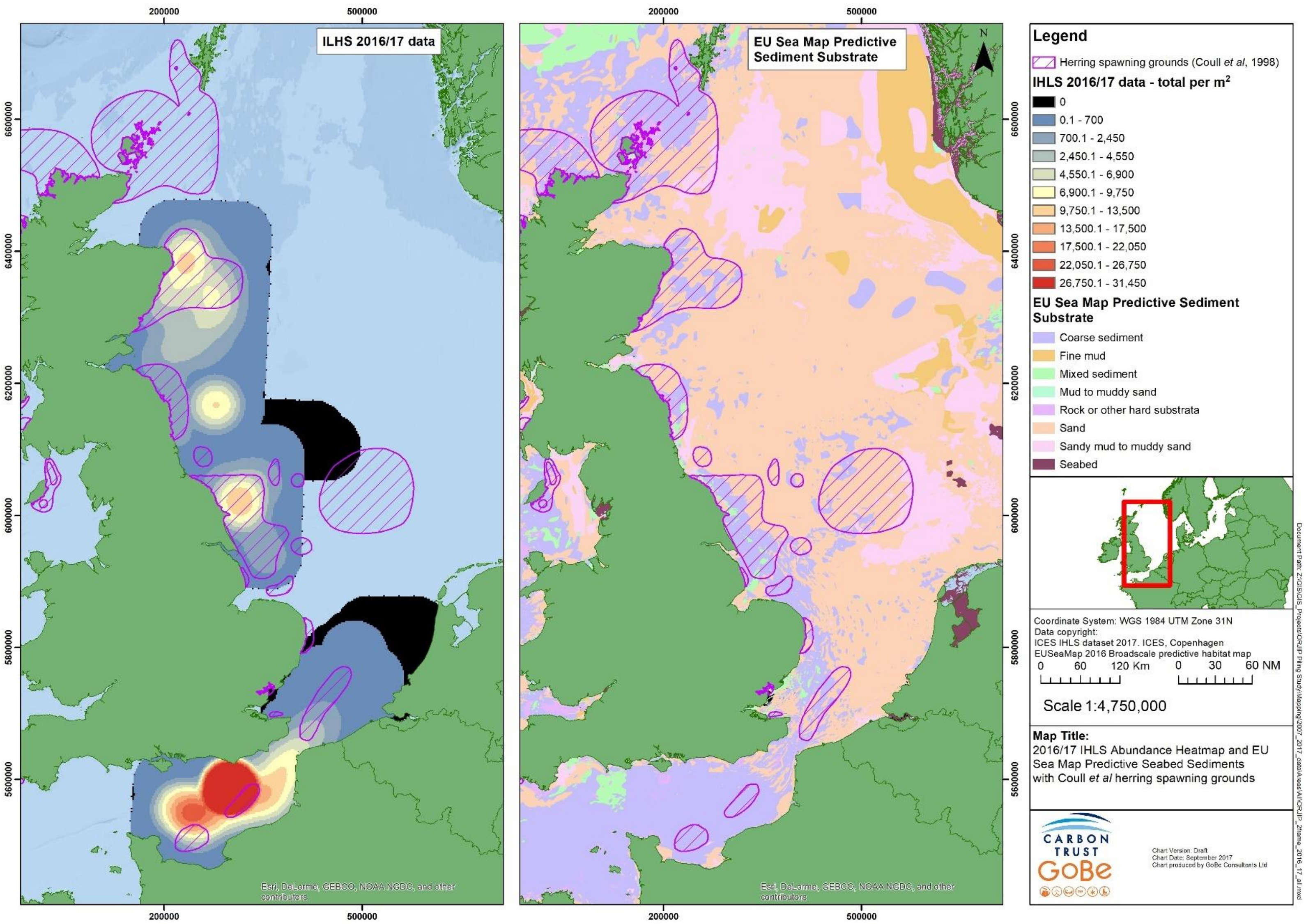


Figure C-11 2016/17 IHLS Abundance Heatmap (All)

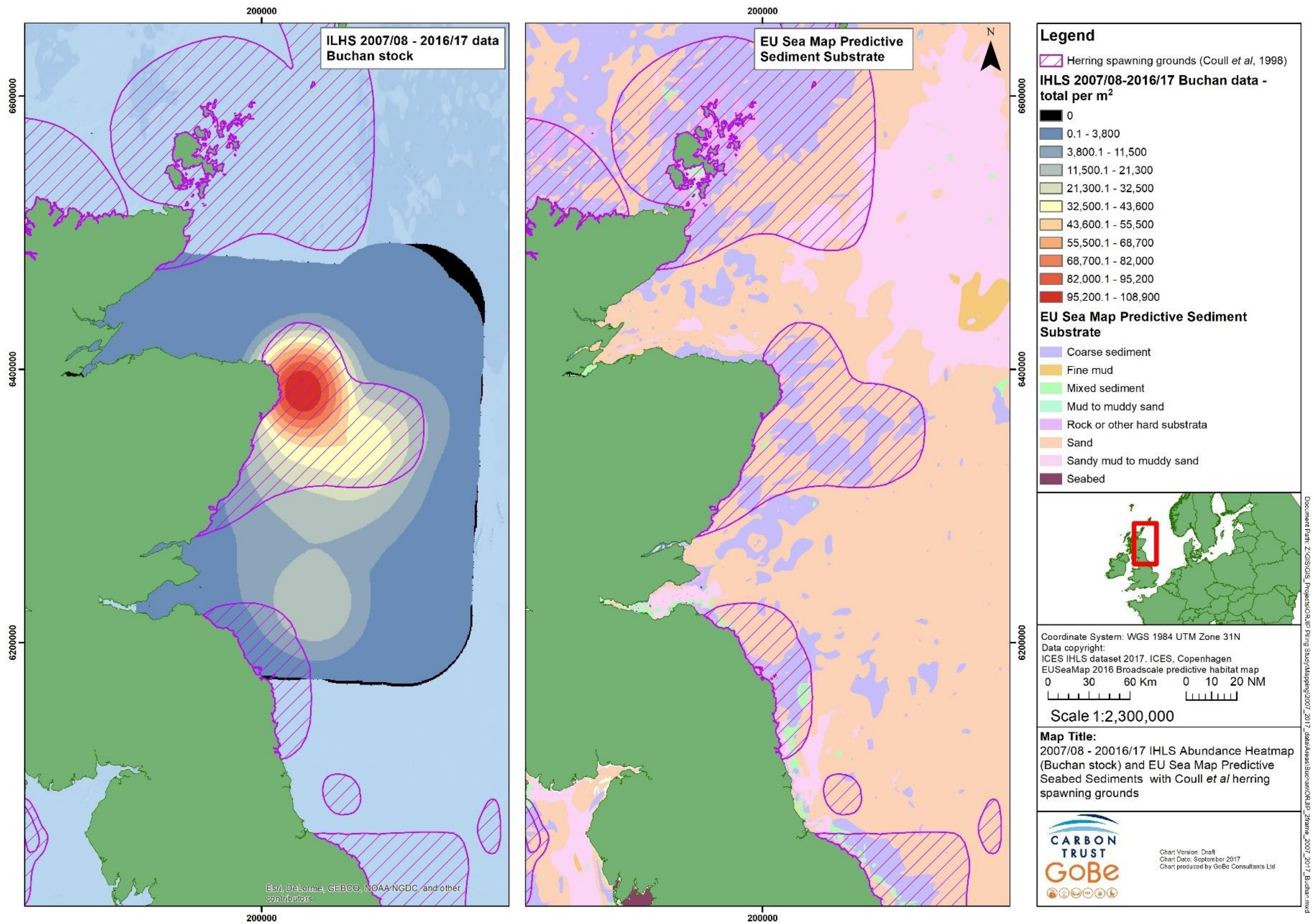


Figure C-12 2007/08 - 2016/17 IHLS Abundance Heatmap (Buchan)

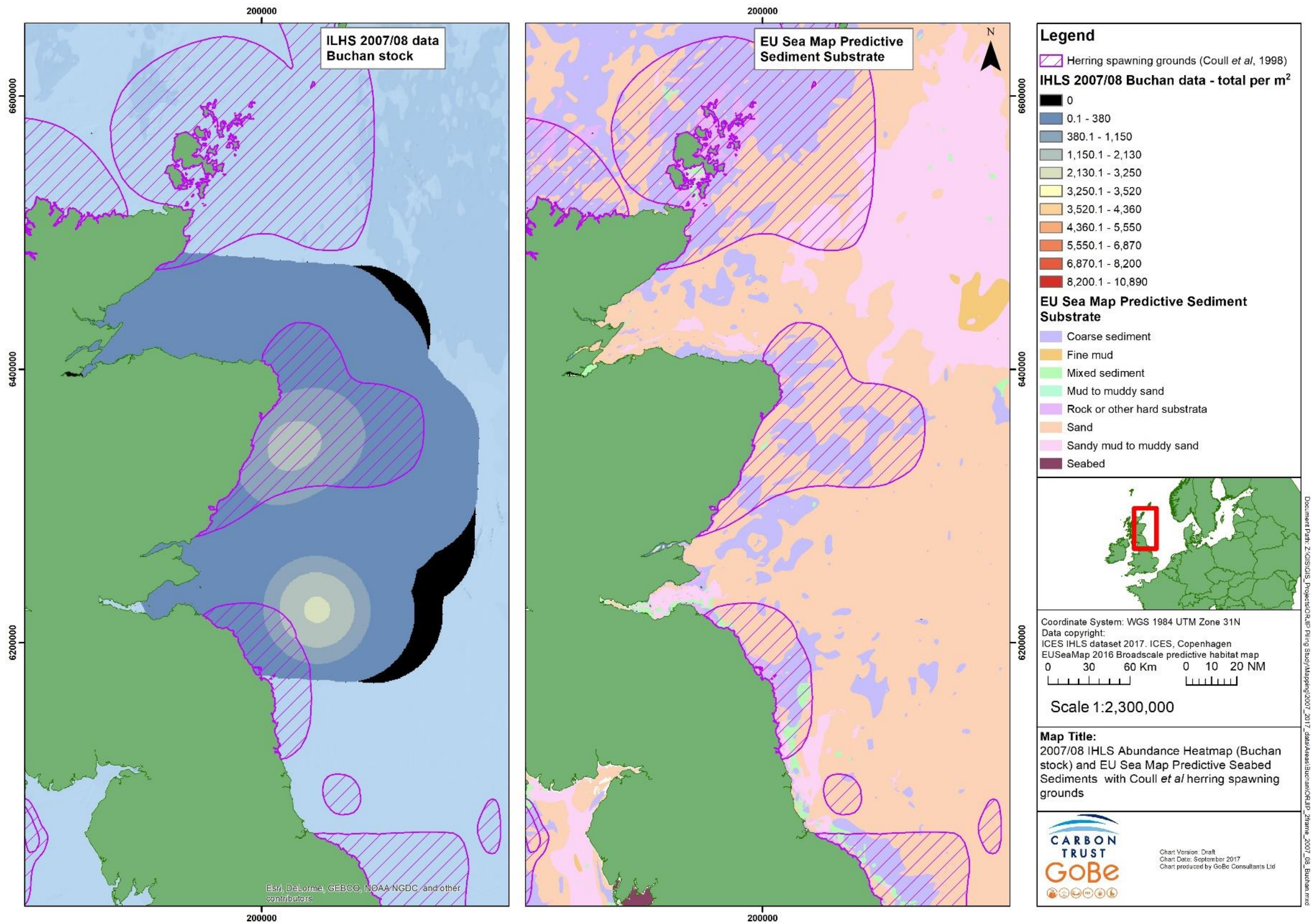


Figure C-13 2007/08 IHLS Abundance Heatmap (Buchan)

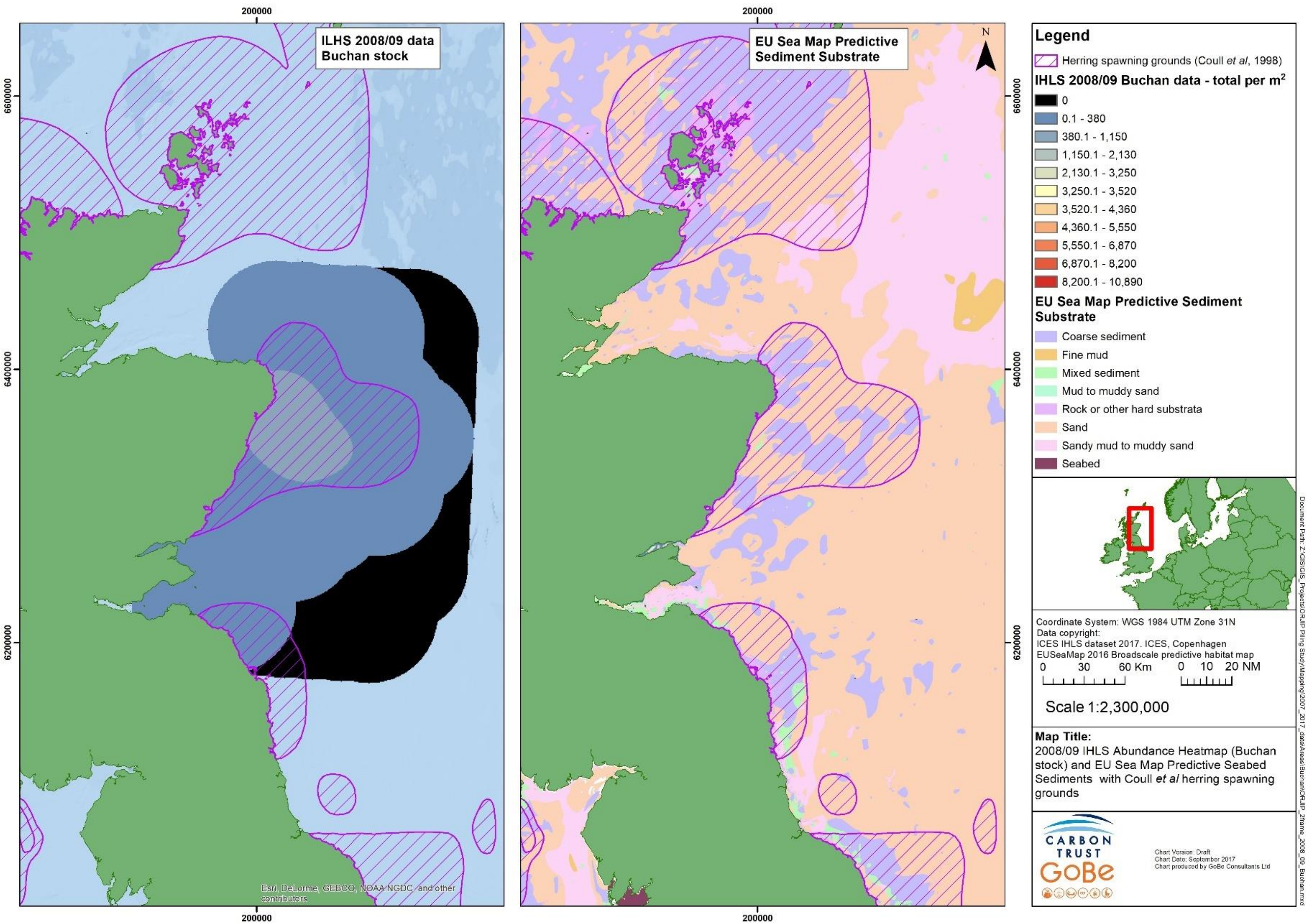


Figure C-14 2008/09 IHLS Abundance Heatmap (Buchan)

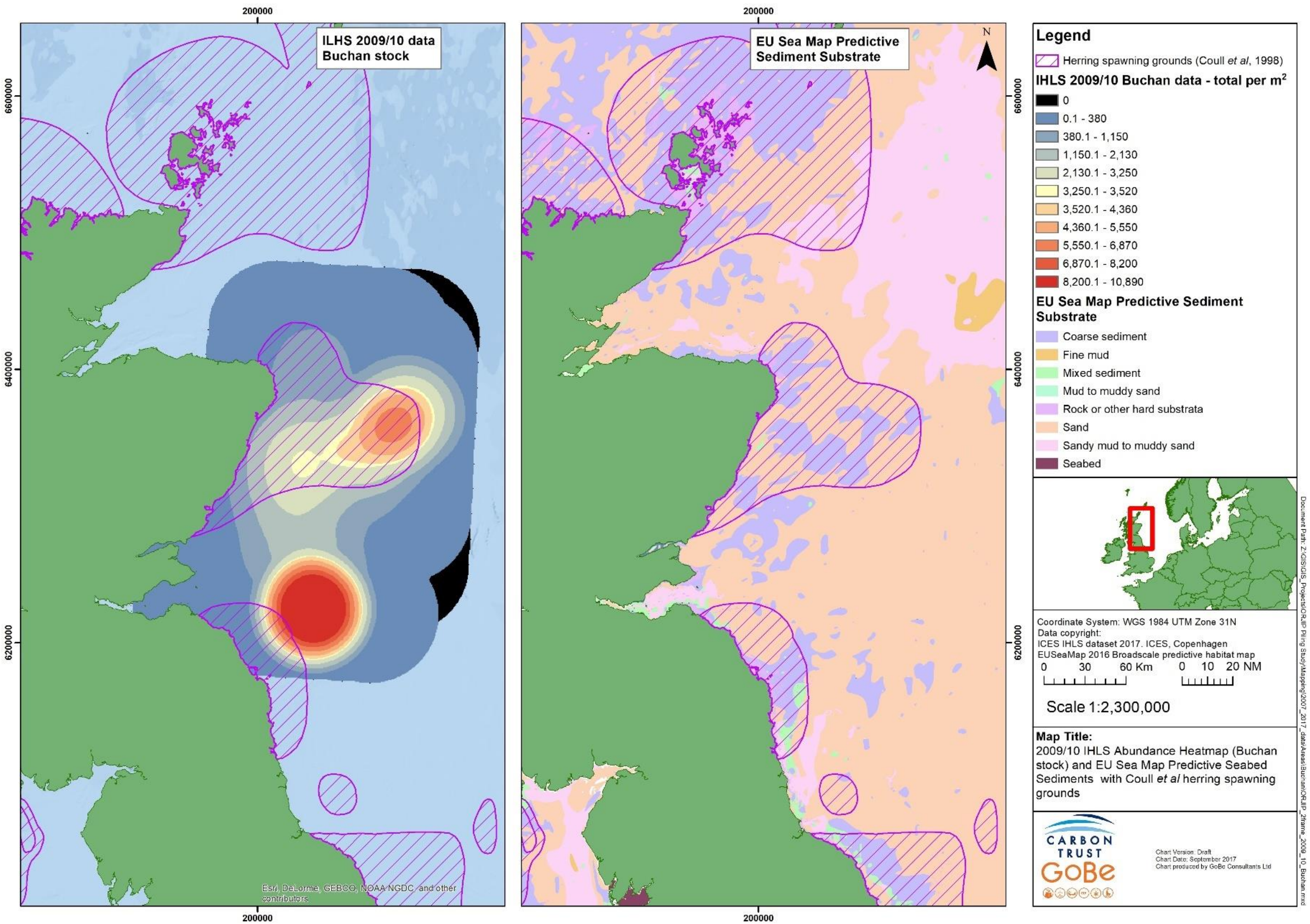


Figure C-15 2009/10 IHLS Abundance Heatmap (Buchan)

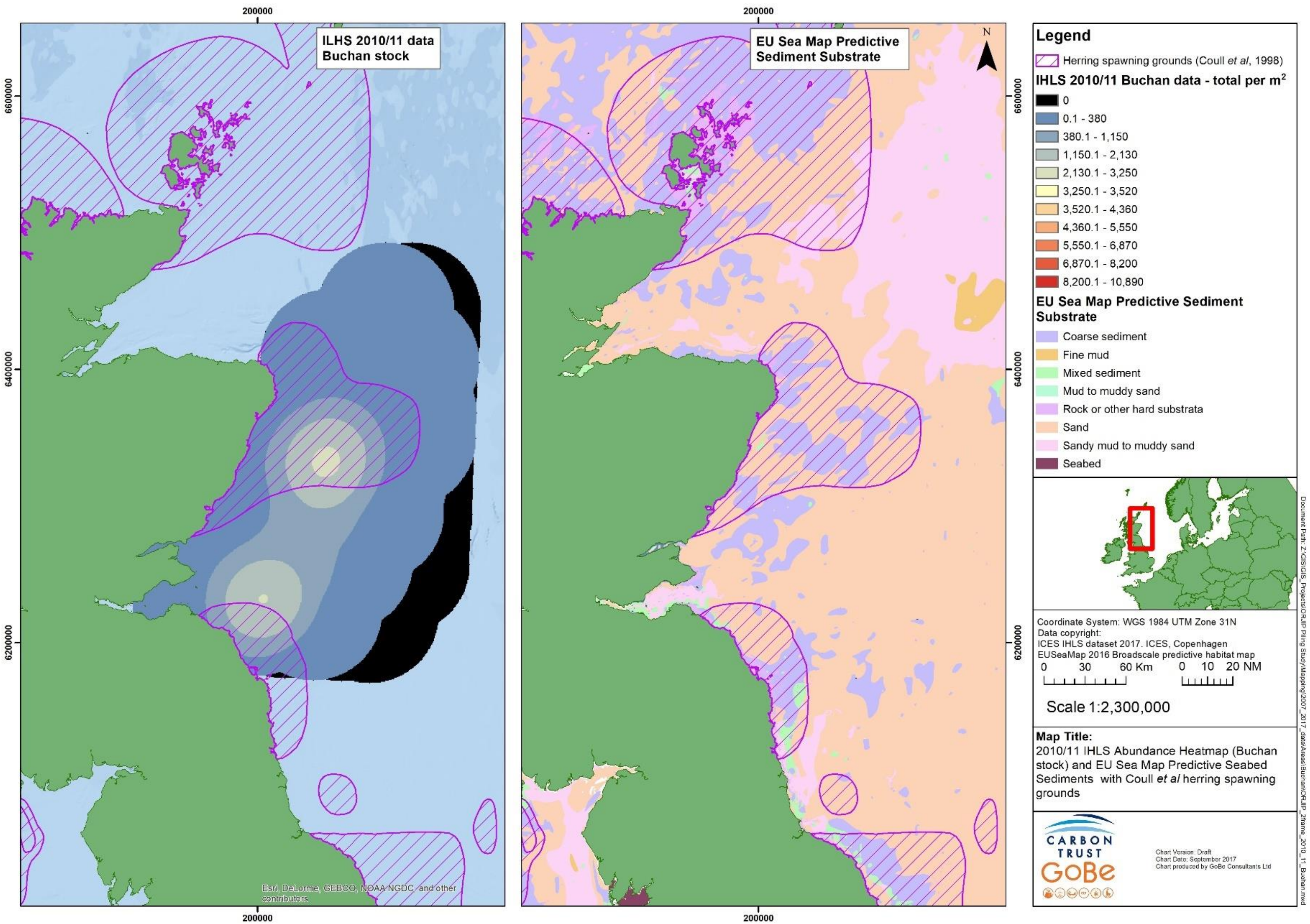


Figure C-16 2010/11 IHLS Abundance Heatmap (Buchan)

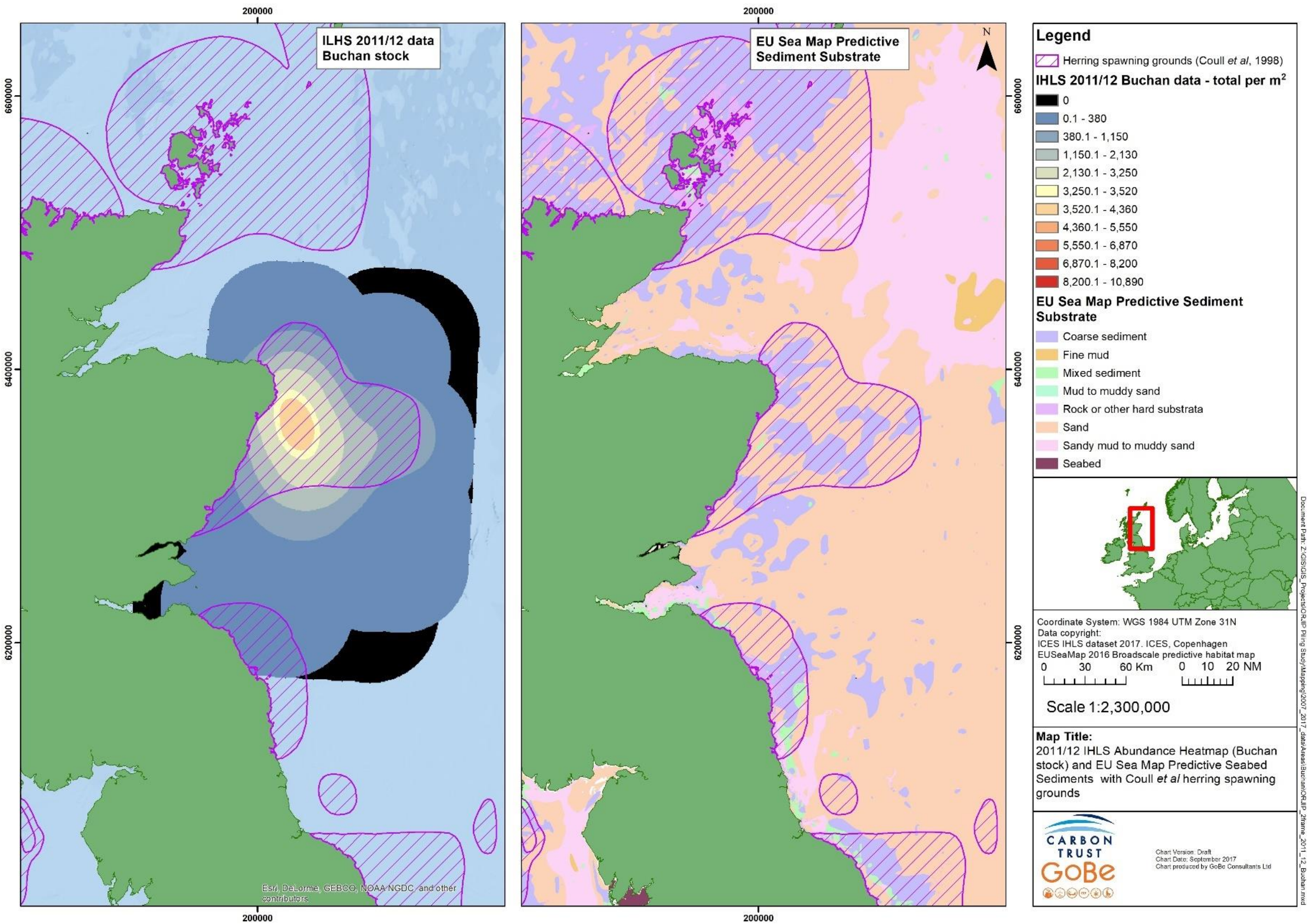


Figure C-17 2011/12 IHLS Abundance Heatmap (Buchan)

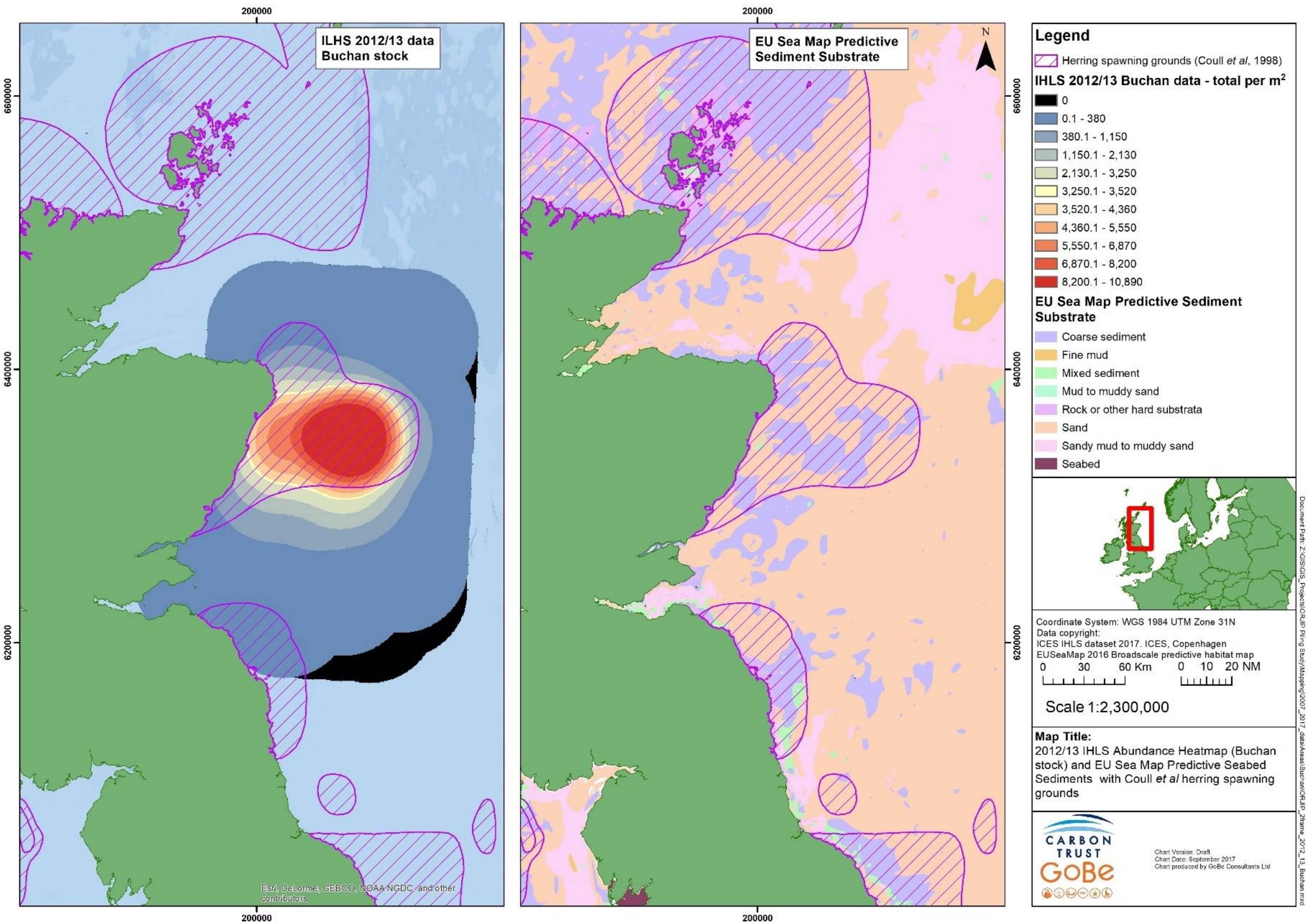


Figure C-18 2012/13 IHLS Abundance Heatmap (Buchan)

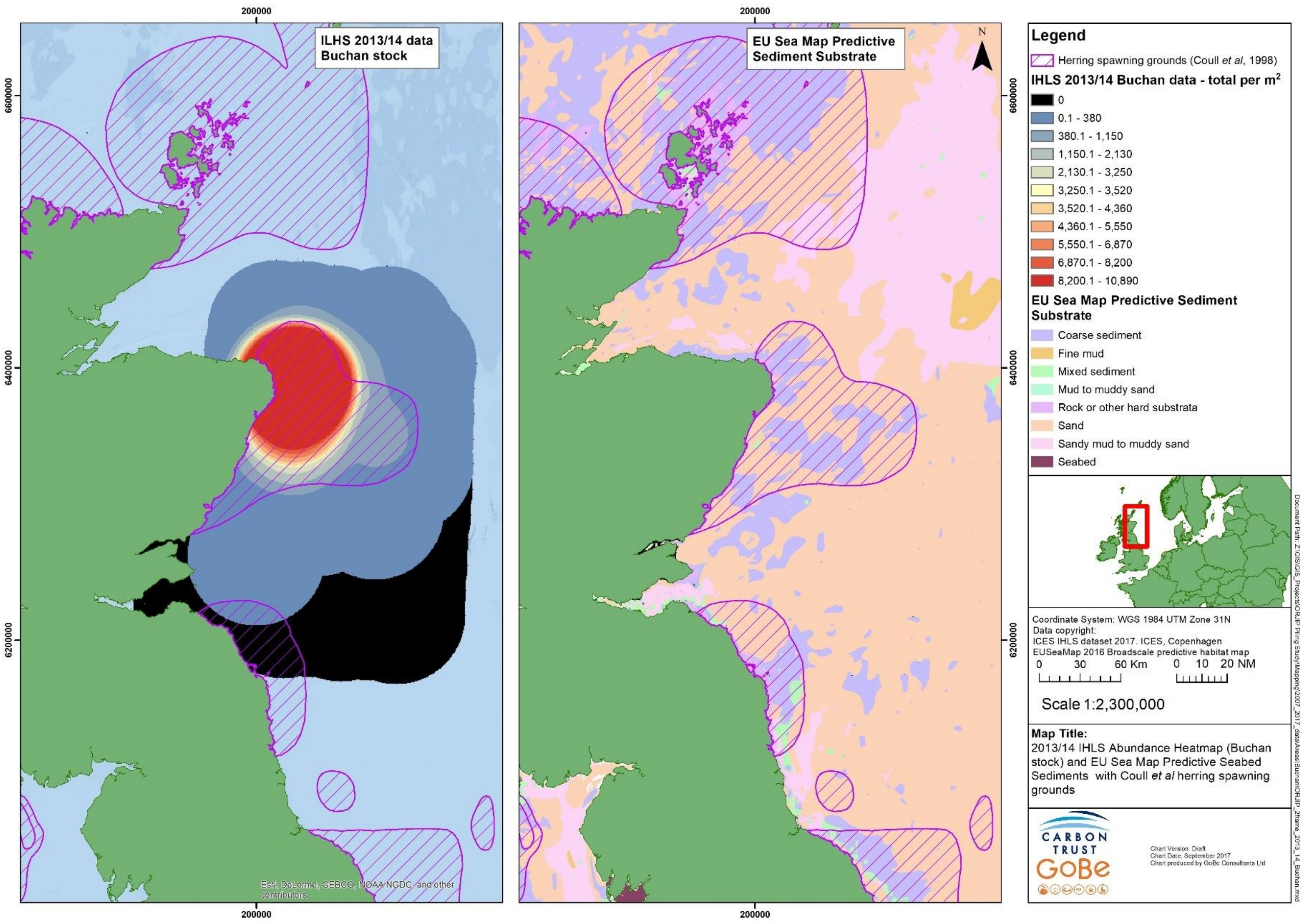


Figure C-19 2013/14 IHLS Abundance Heatmap (Buchan)

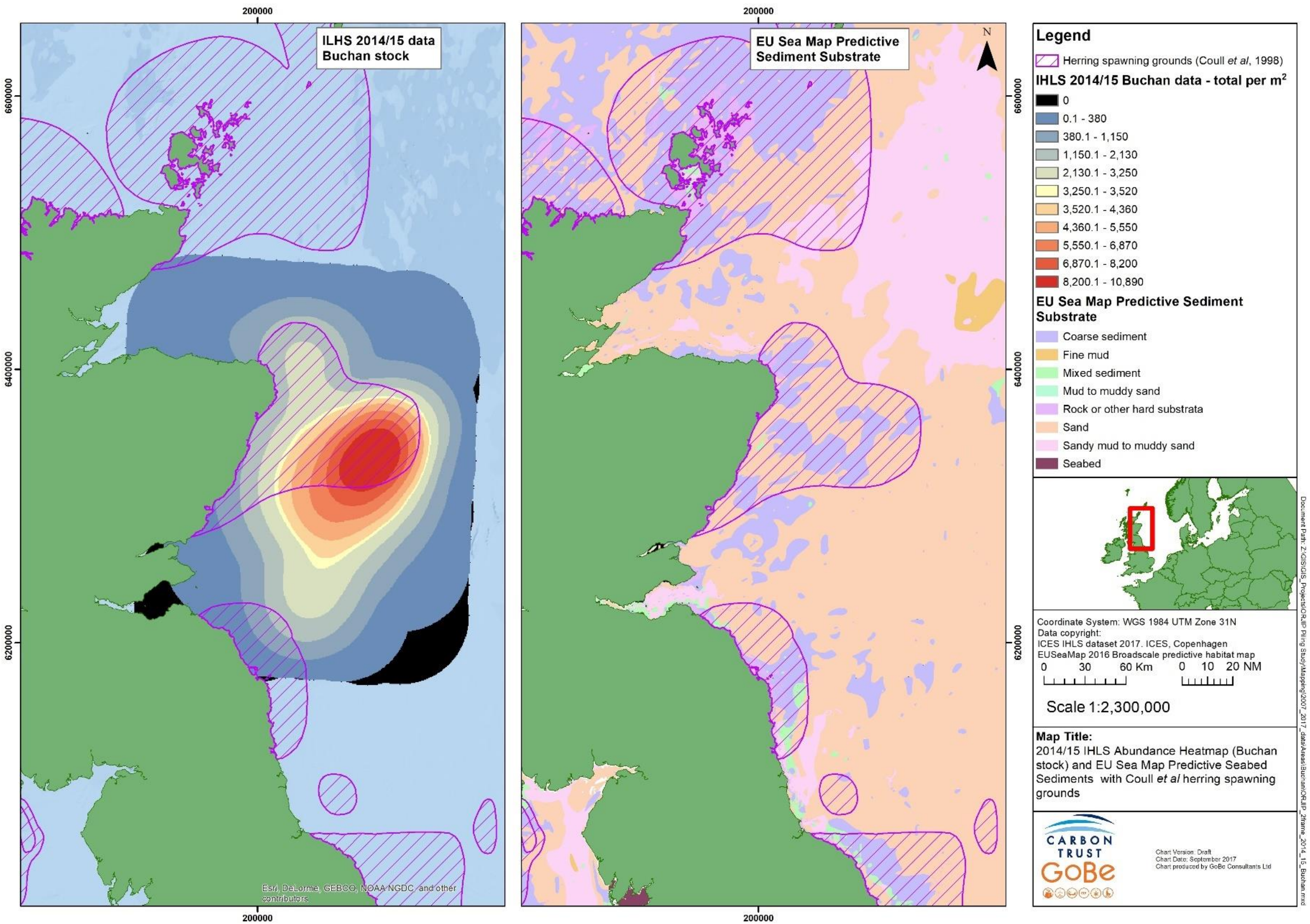


Figure C-20 2014/15 IHLS Abundance Heatmap (Buchan)

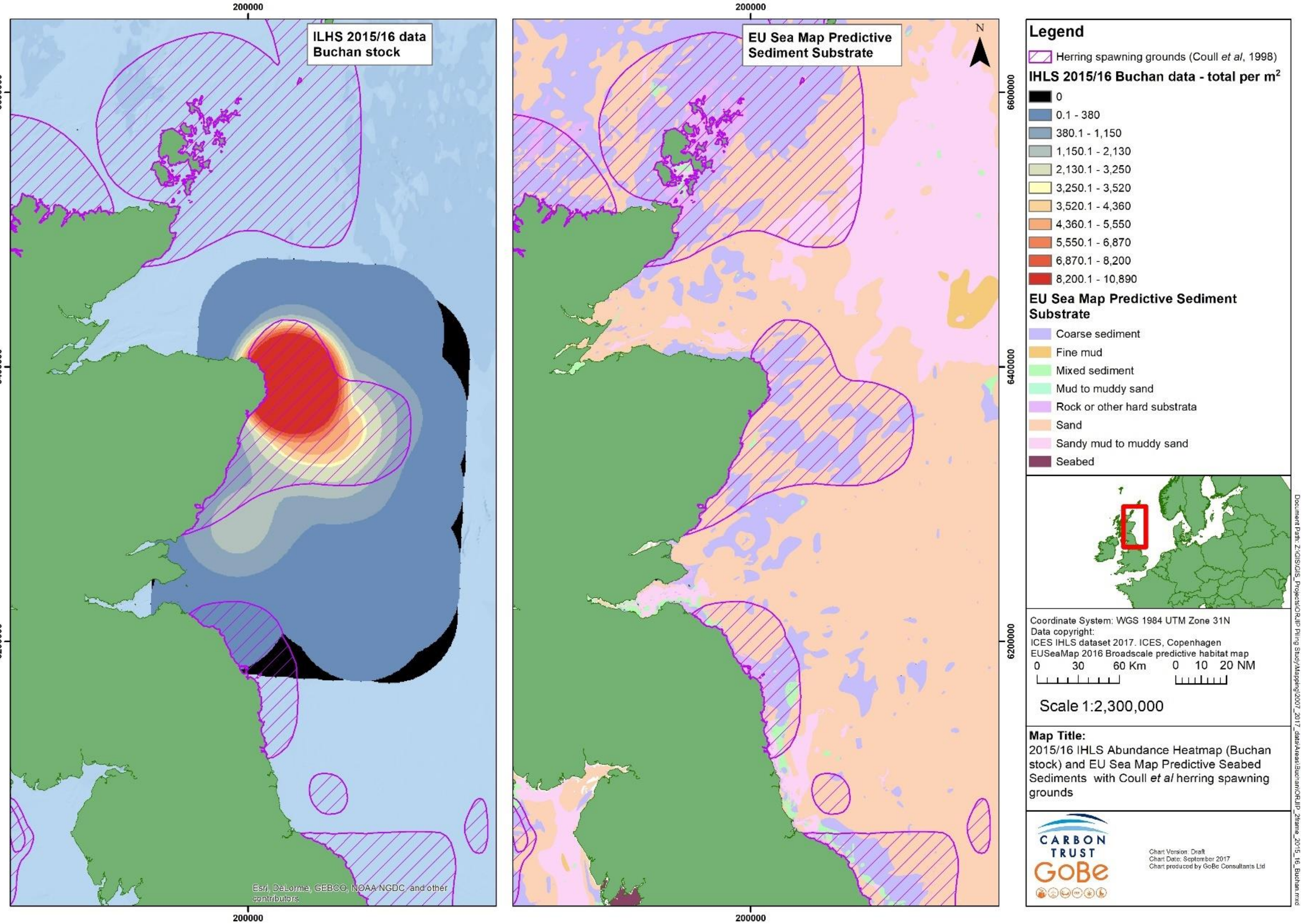


Figure C-21 2015/16 IHLS Abundance Heatmap (Buchan)

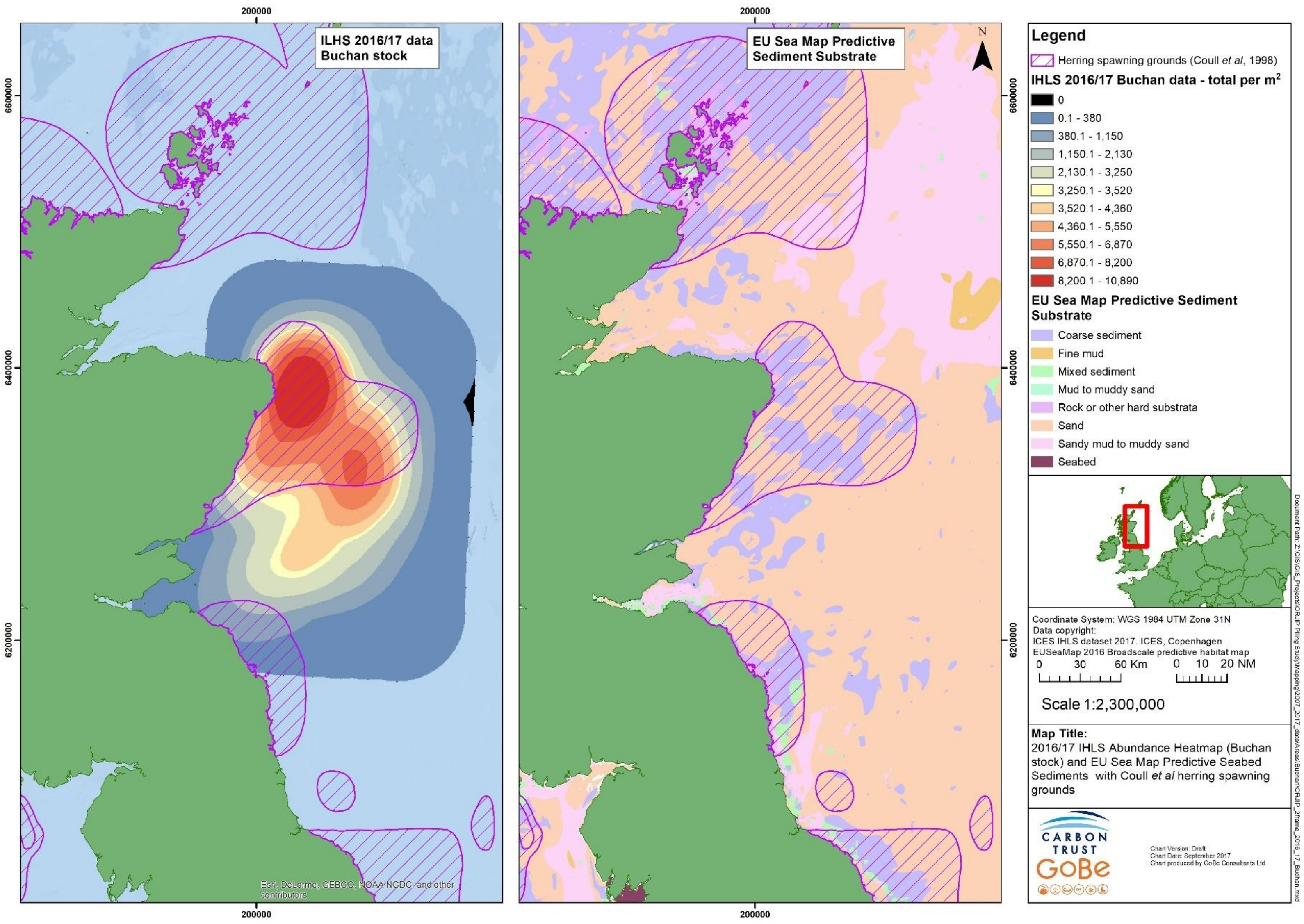


Figure C-22 2016/17 IHLS Abundance Heatmap (Buchan)

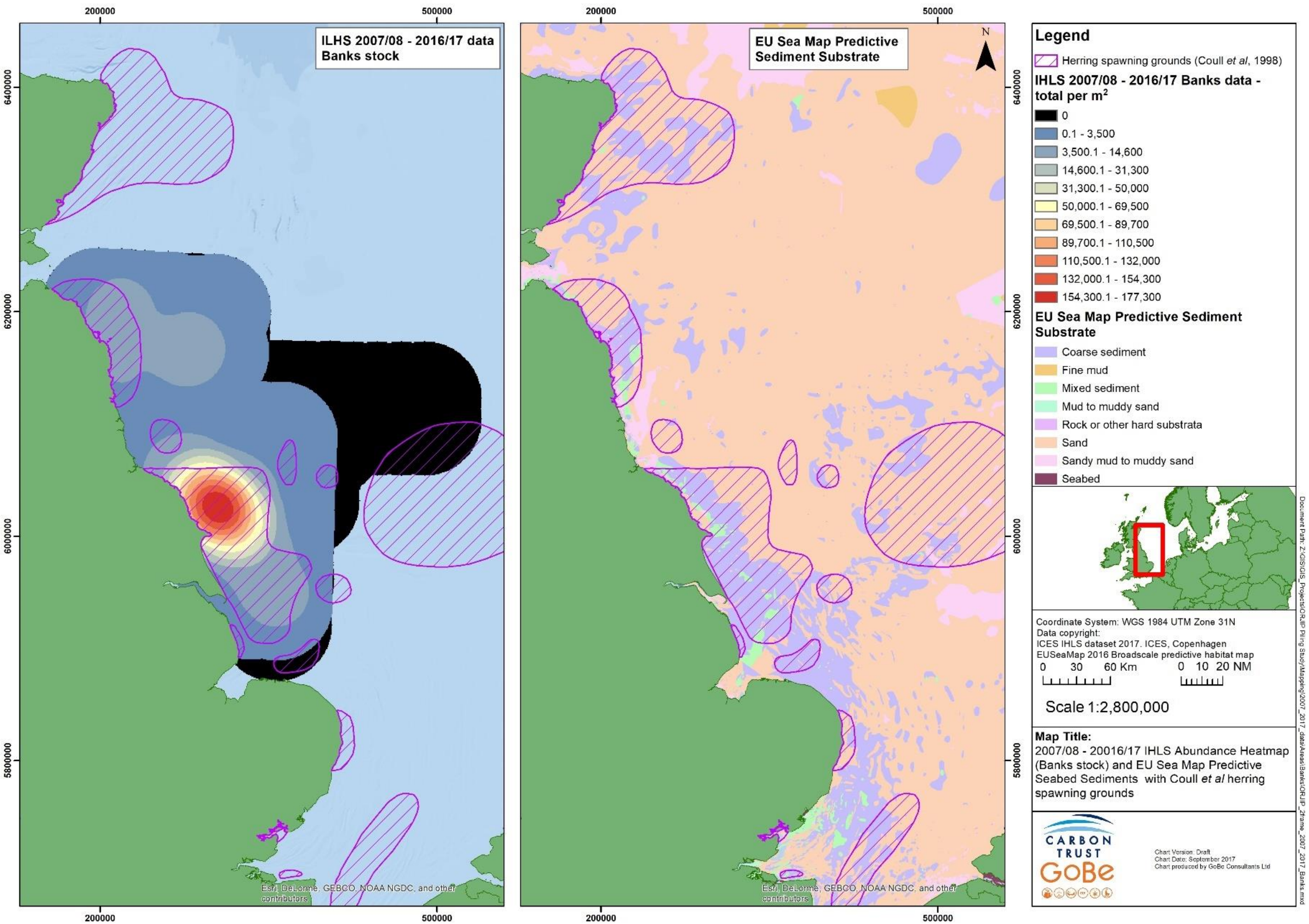


Figure C-23 2007/08 – 2016-17 IHLS Abundance Heatmap (Banks)

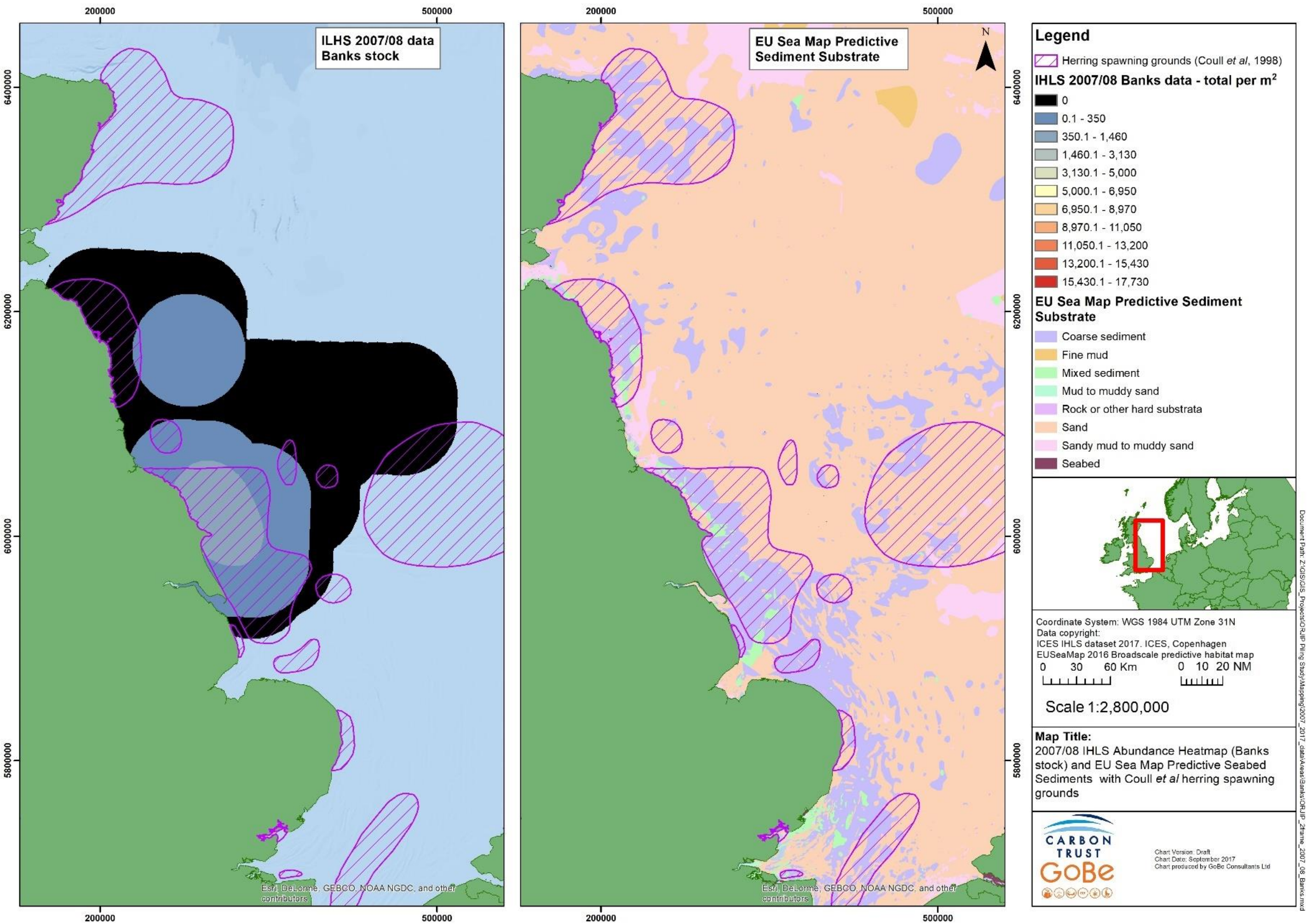


Figure C-24 2007/08 IHLS Abundance Heatmap (Banks)

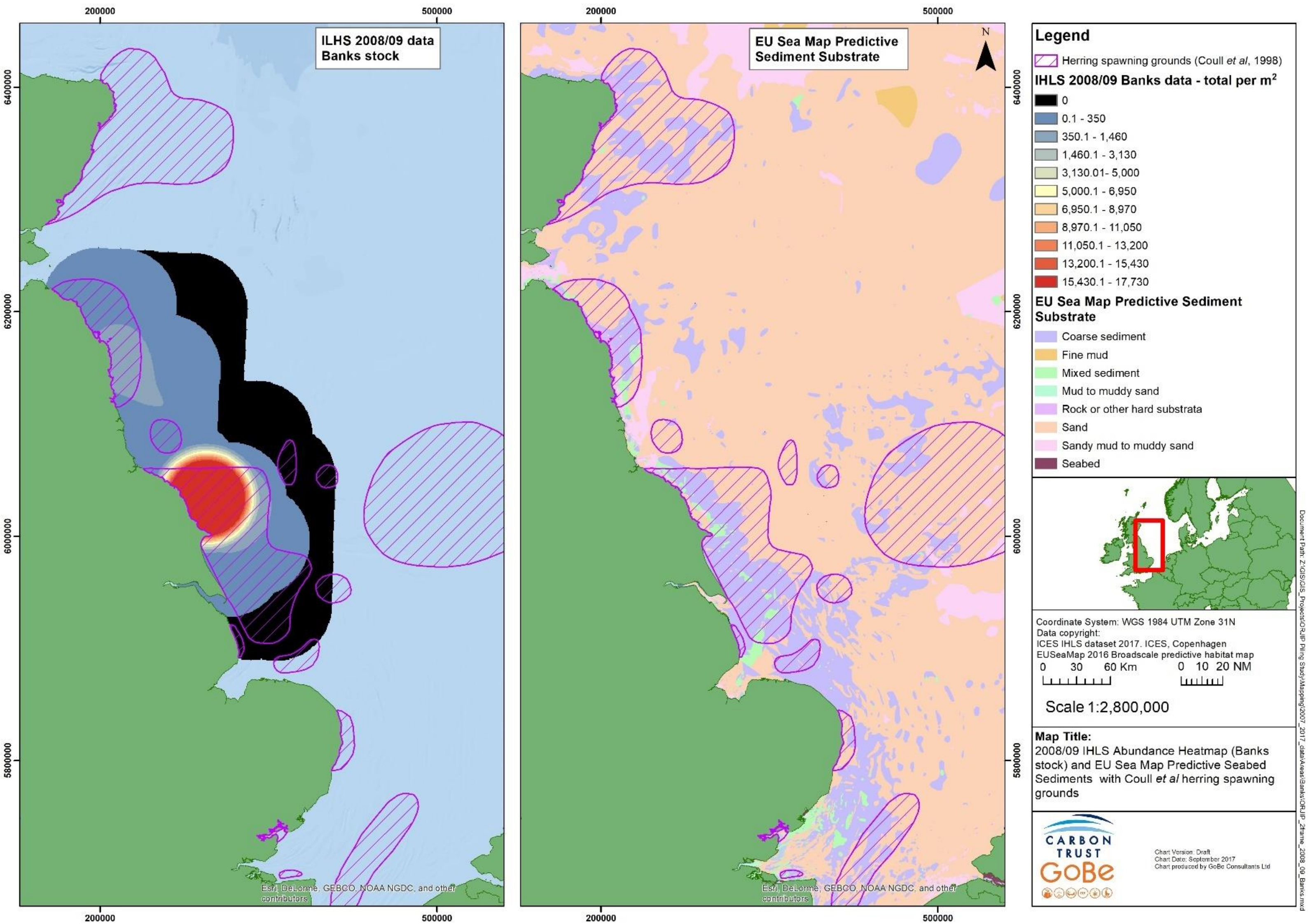


Figure C-25 2008/09 IHLS Abundance Heatmap (Banks)

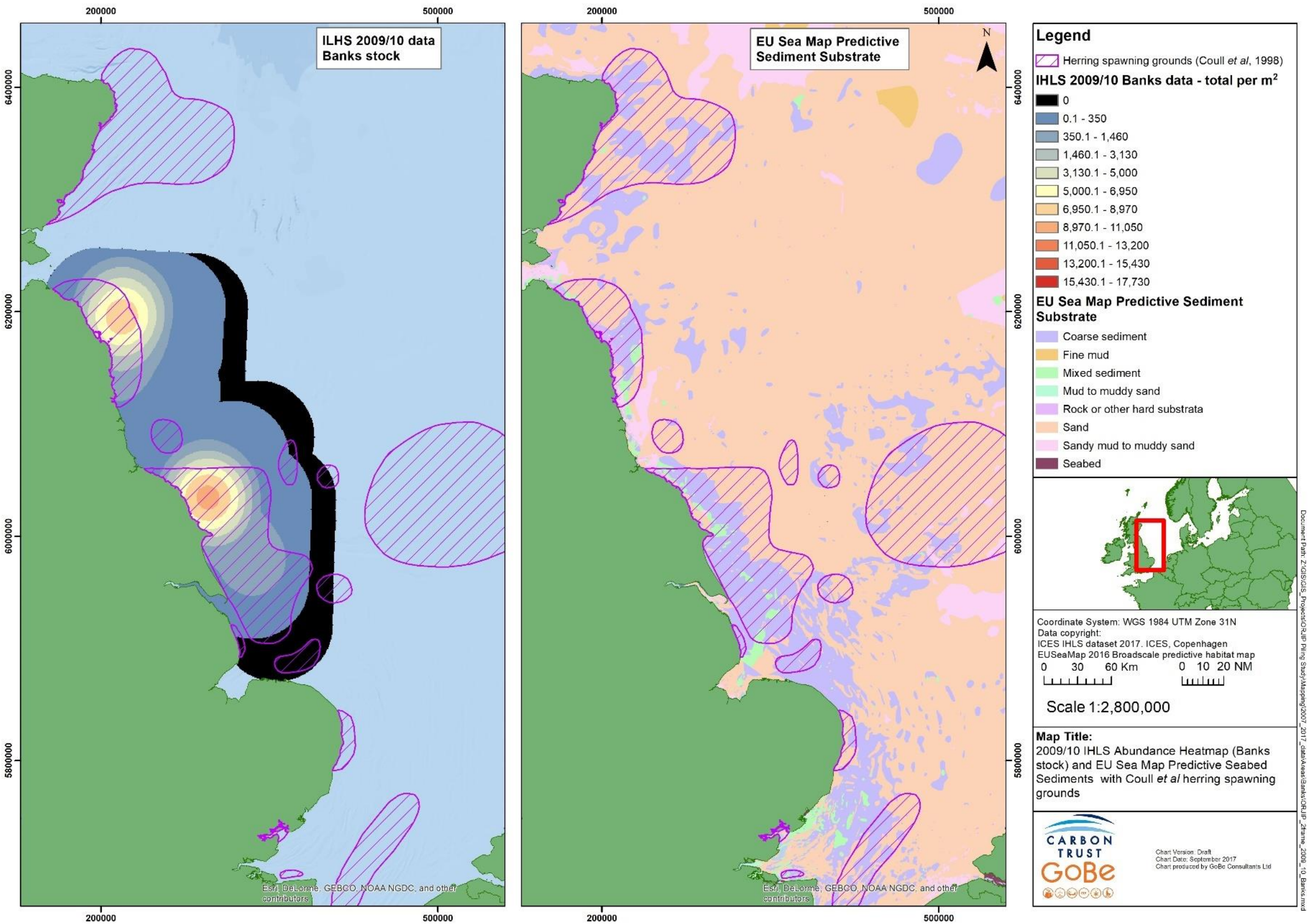


Figure C-26 2009/10 IHLS Abundance Heatmap (Banks)

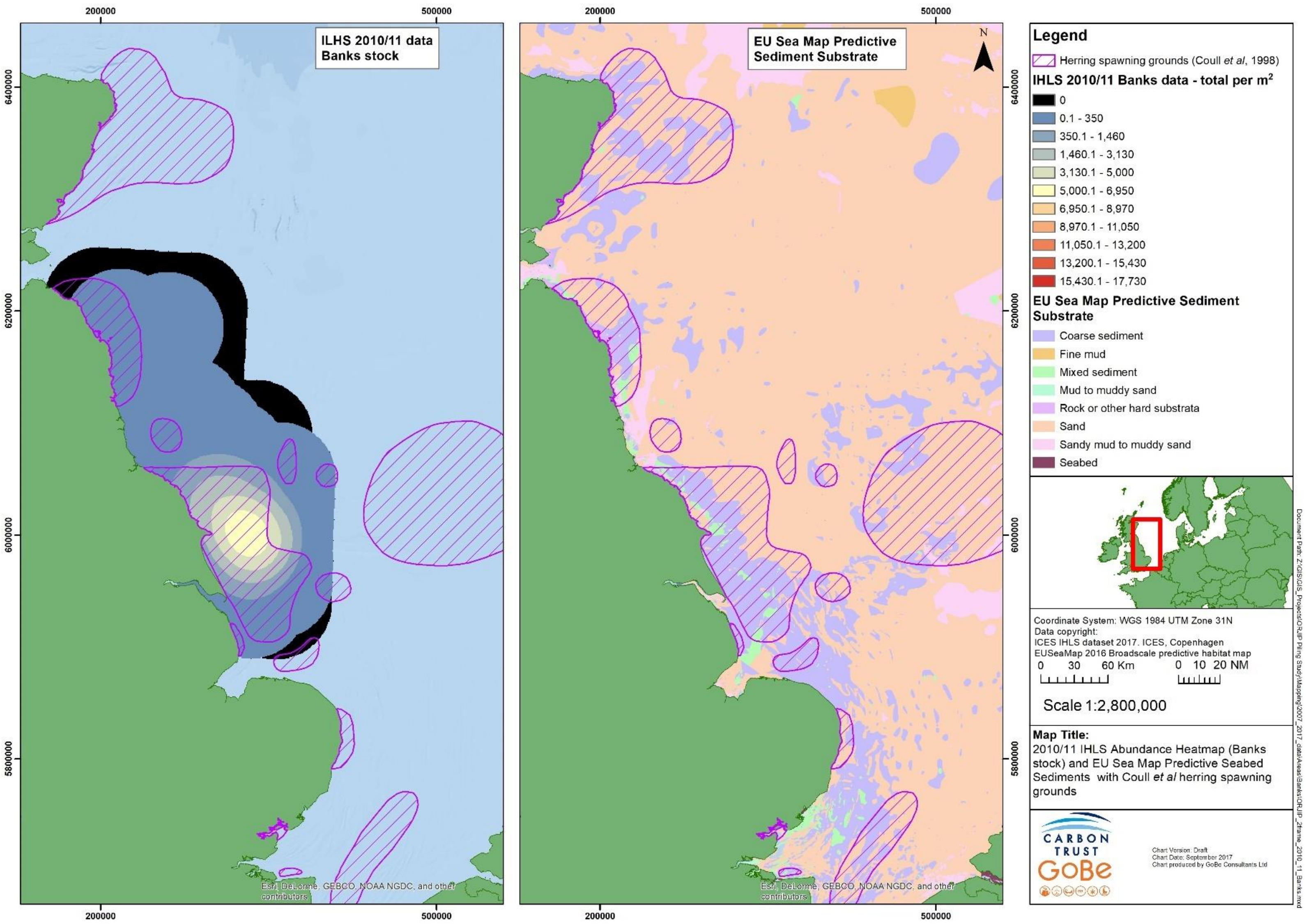


Figure C-27 2010/11 IHLS Abundance Heatmap (Banks)

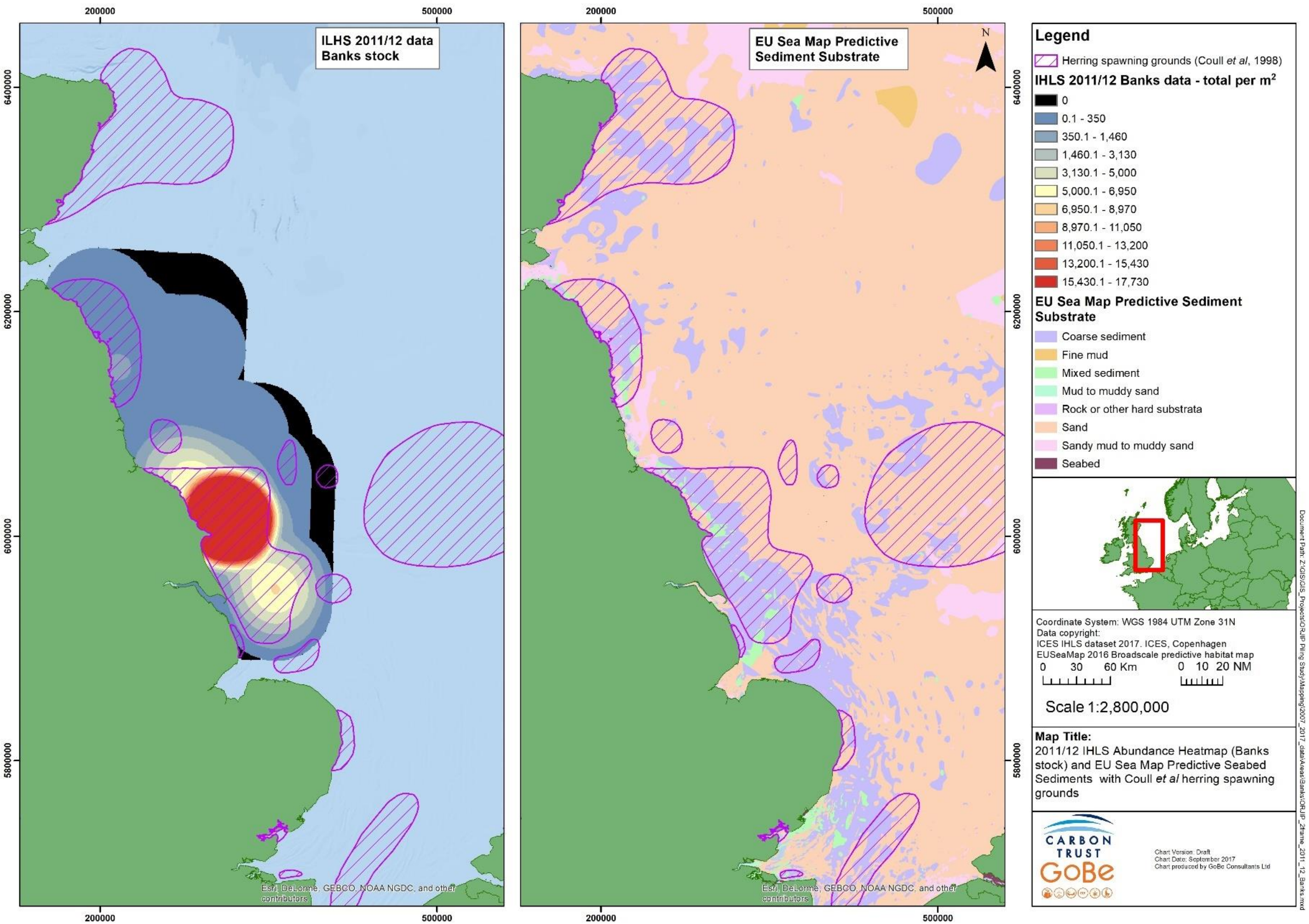


Figure C-28 2011/12 IHLS Abundance Heatmap (Banks)

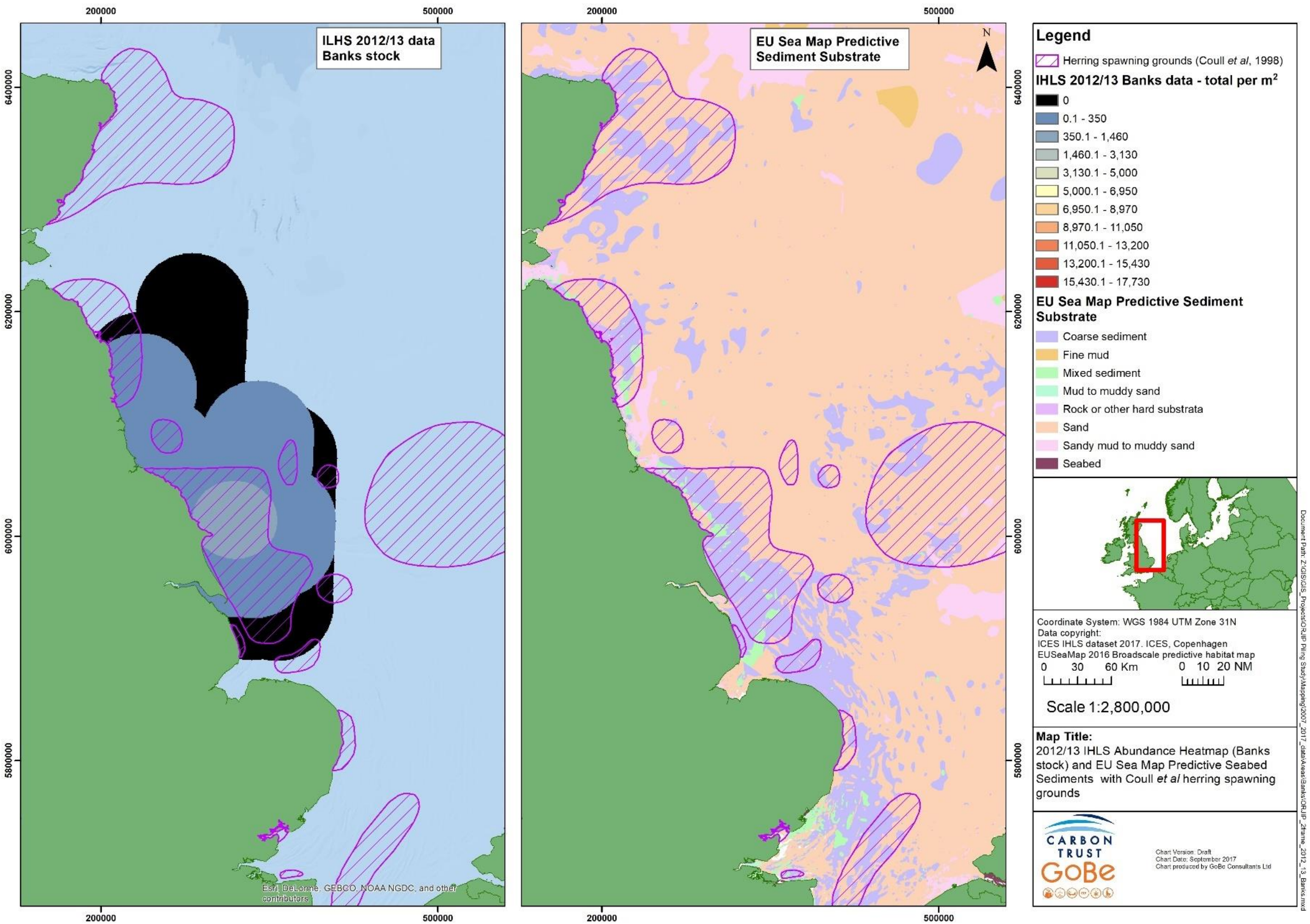


Figure C-29 2012/13 IHLS Abundance Heatmap (Banks)

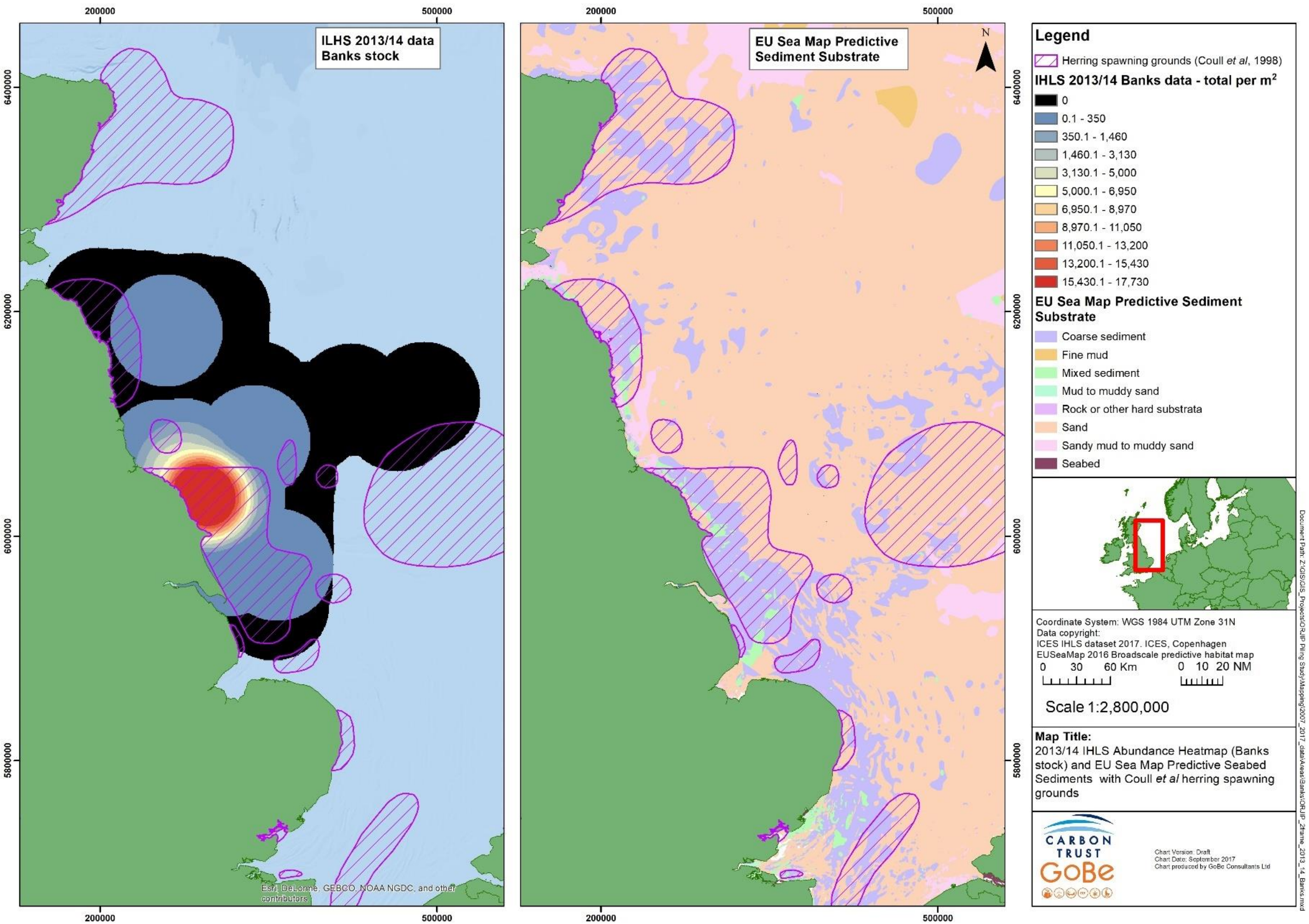


Figure C-30 2013/14 IHLS Abundance Heatmap (Banks)

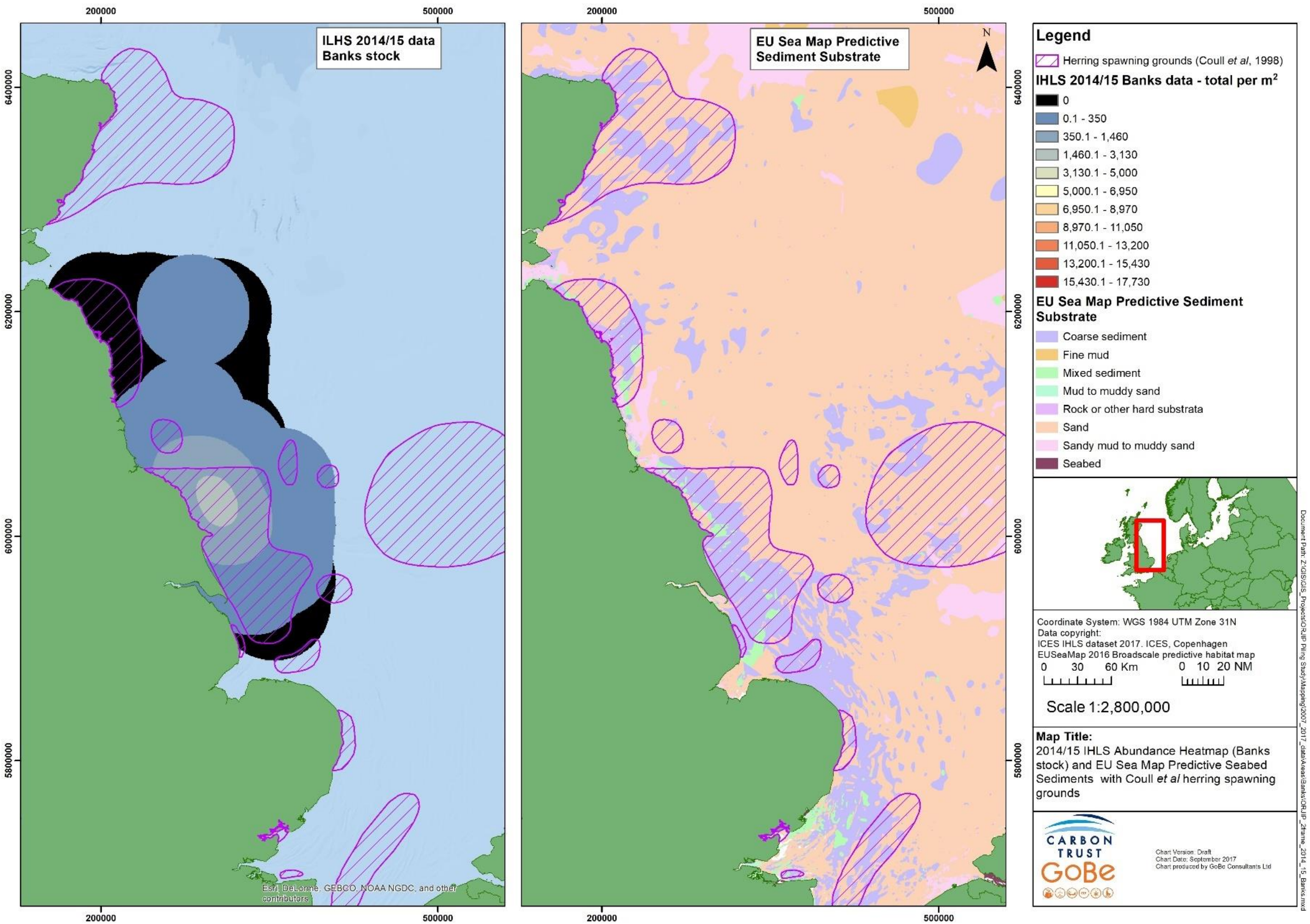


Figure C-31 2014/15 IHLS Abundance Heatmap (Banks)

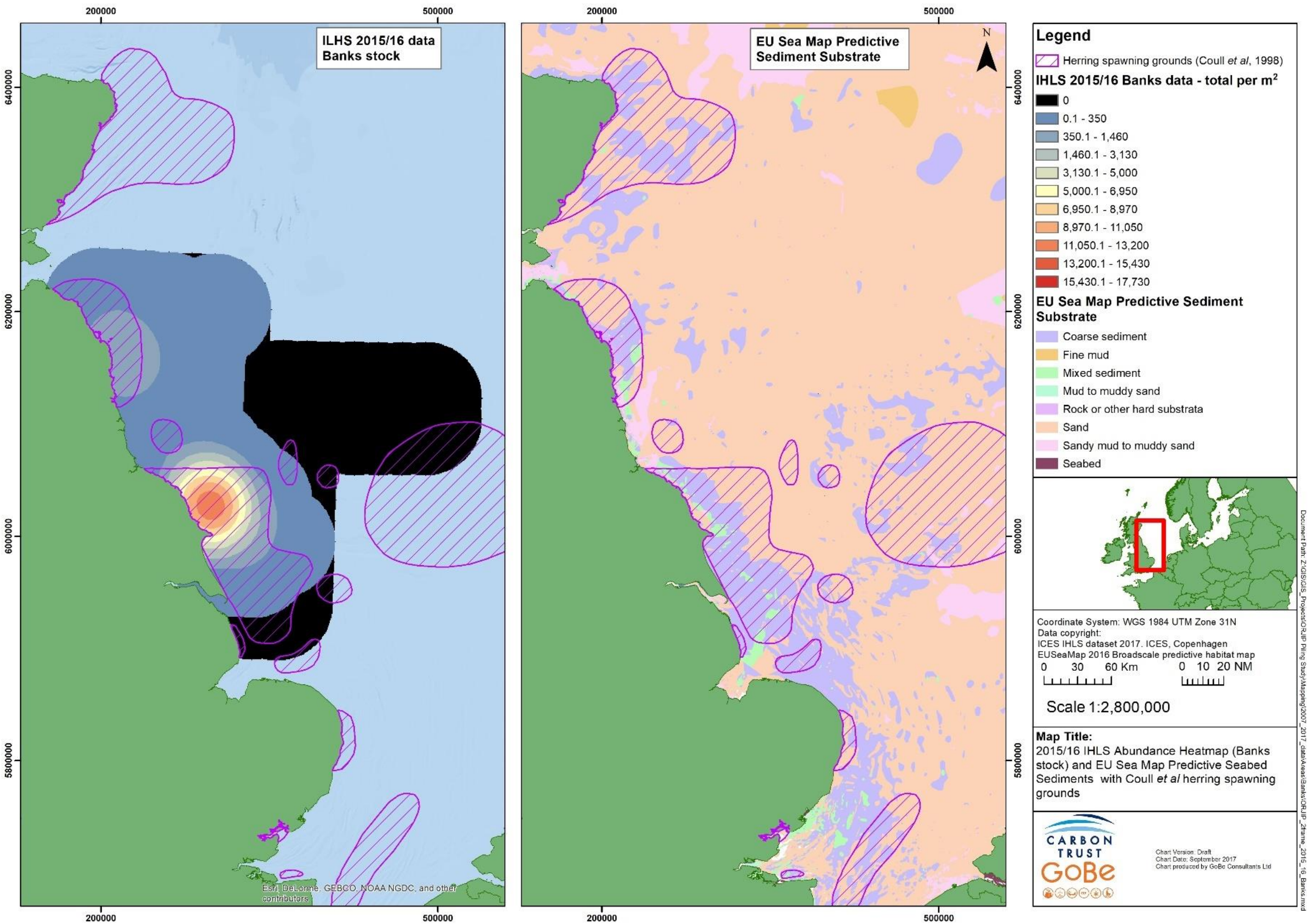
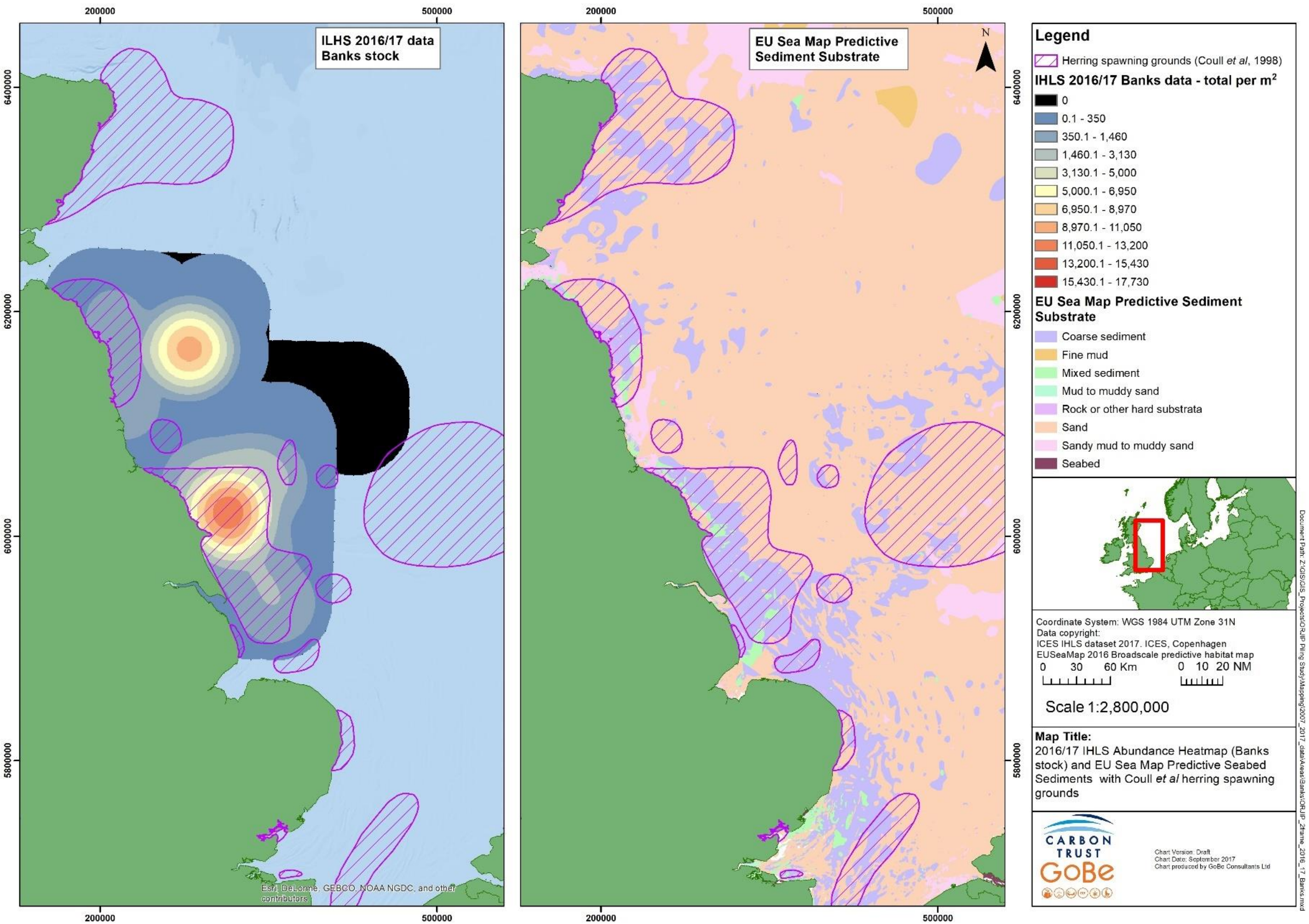


Figure C-32 2015/16 IHLS Abundance Heatmap (Banks)



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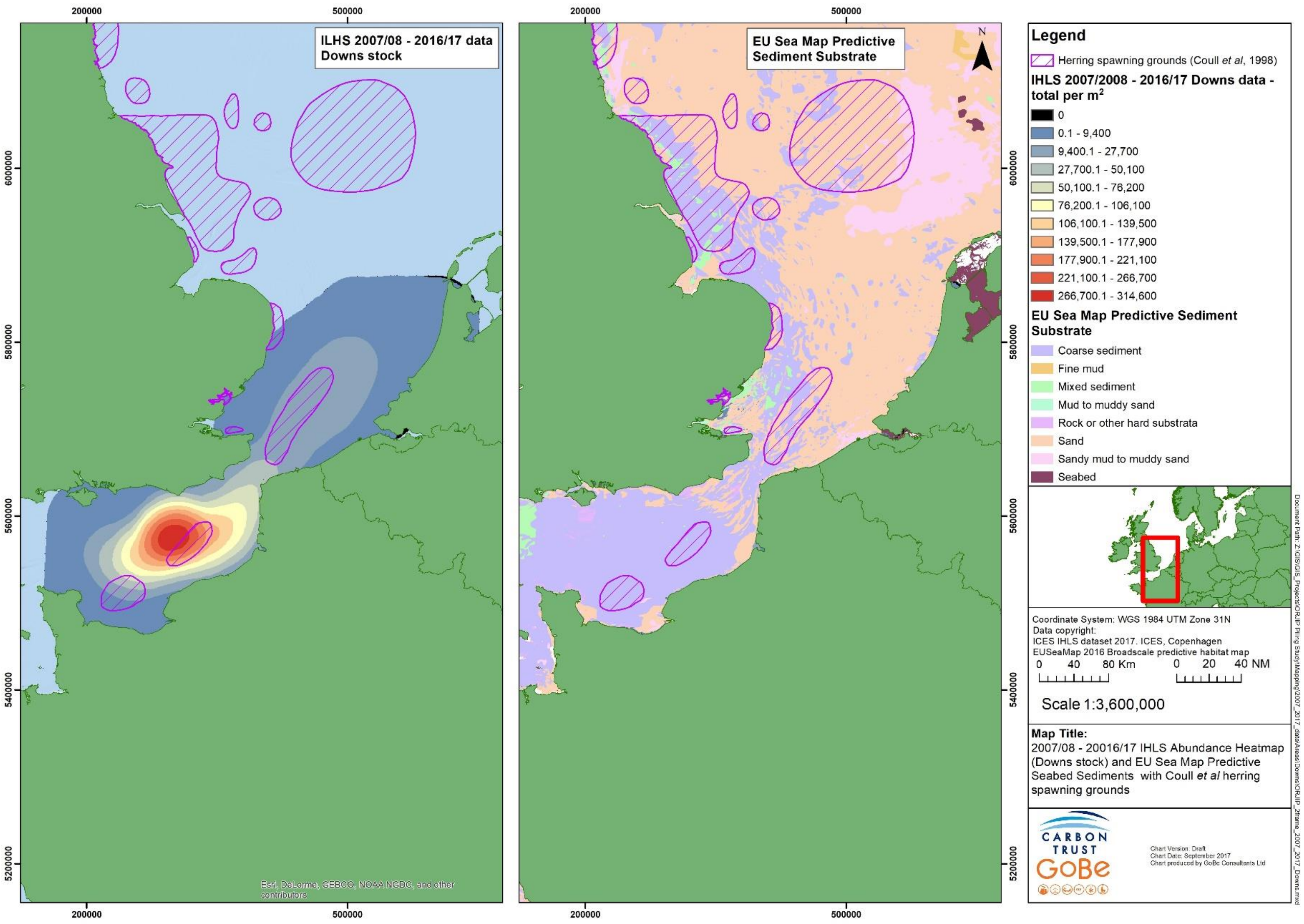


Figure C-34 2007/08 - 2016/17 IHLS Abundance Heatmap (Downs)

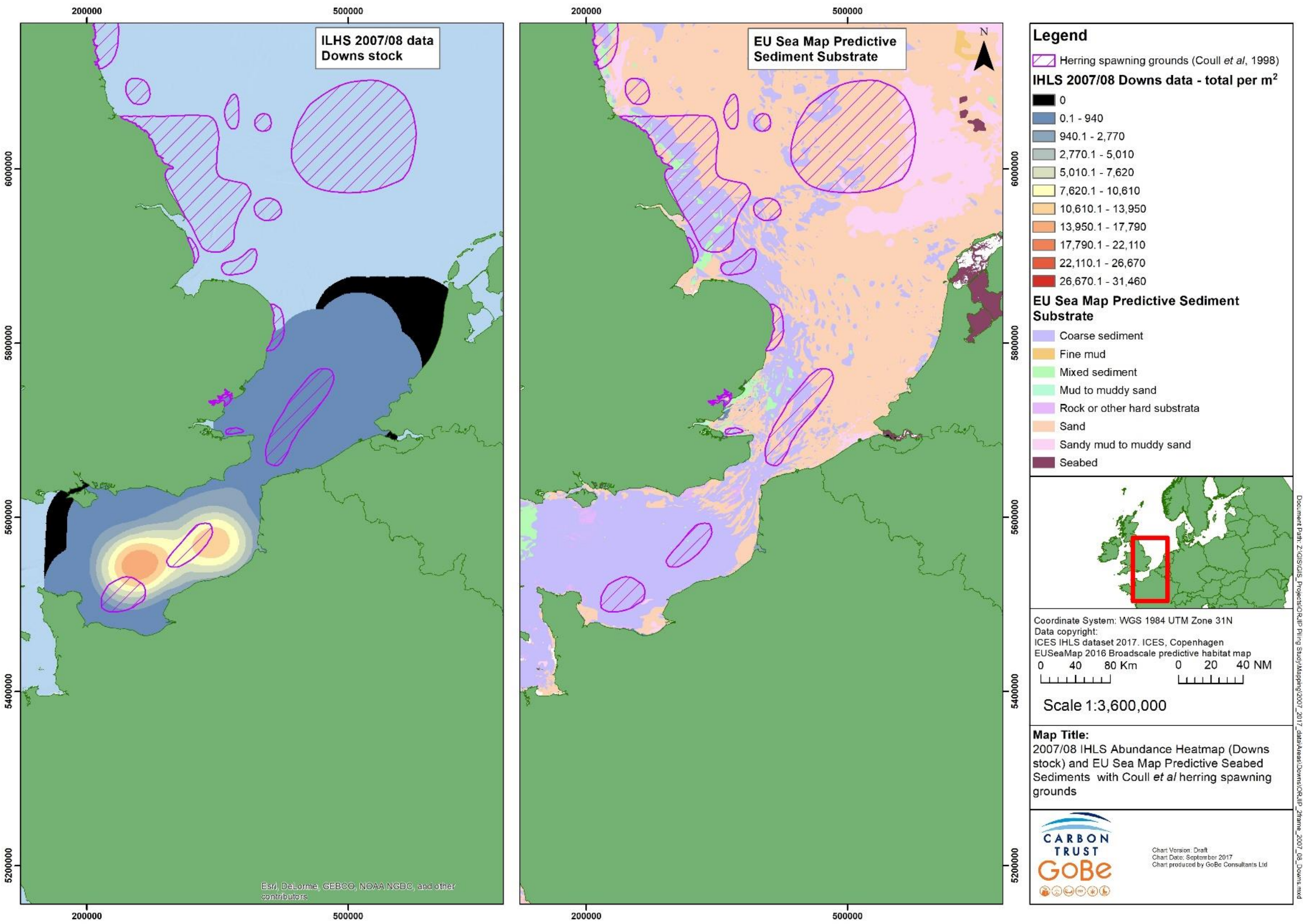


Figure C-35 2007/08 IHLS Abundance Heatmap (Downs)

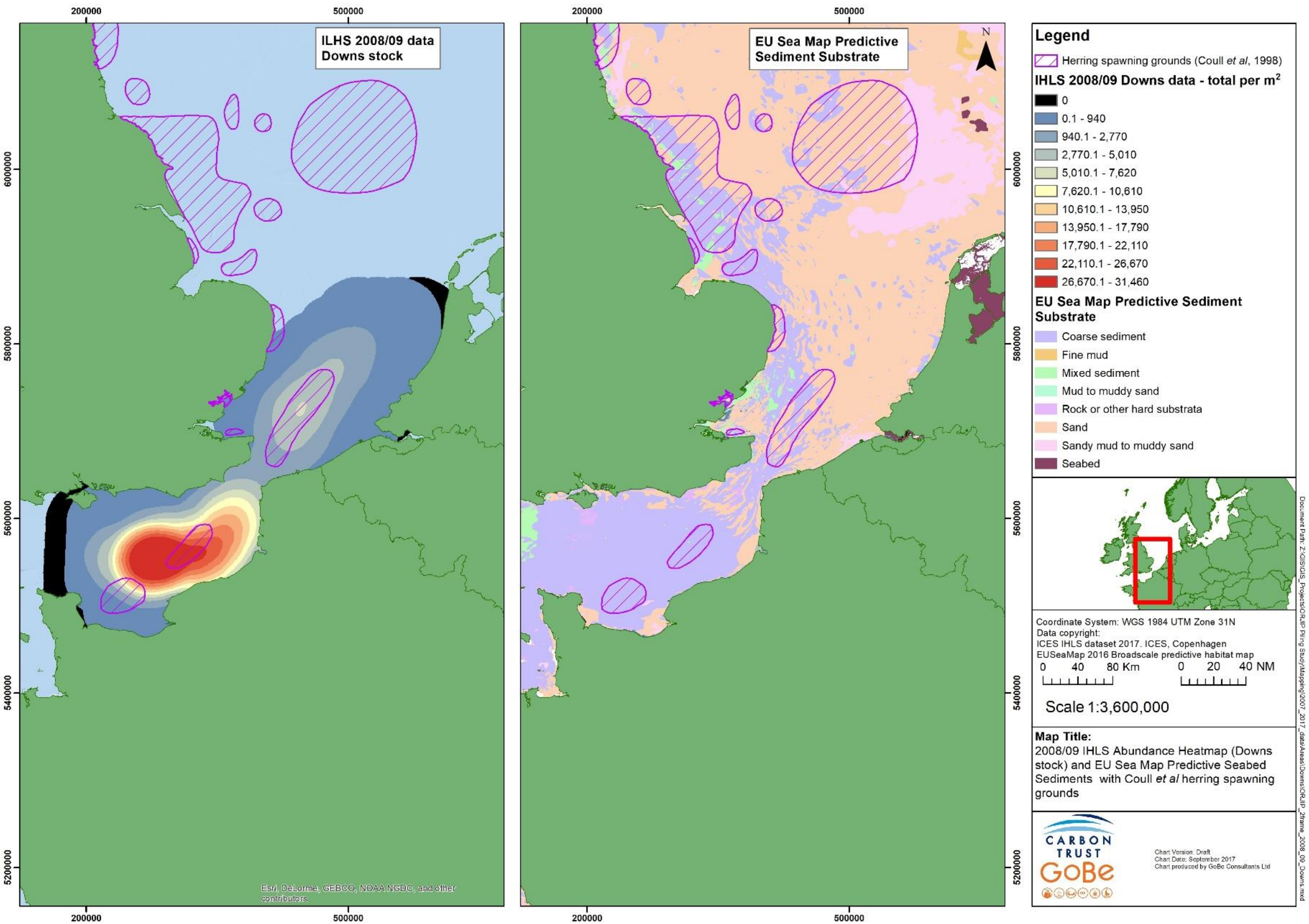
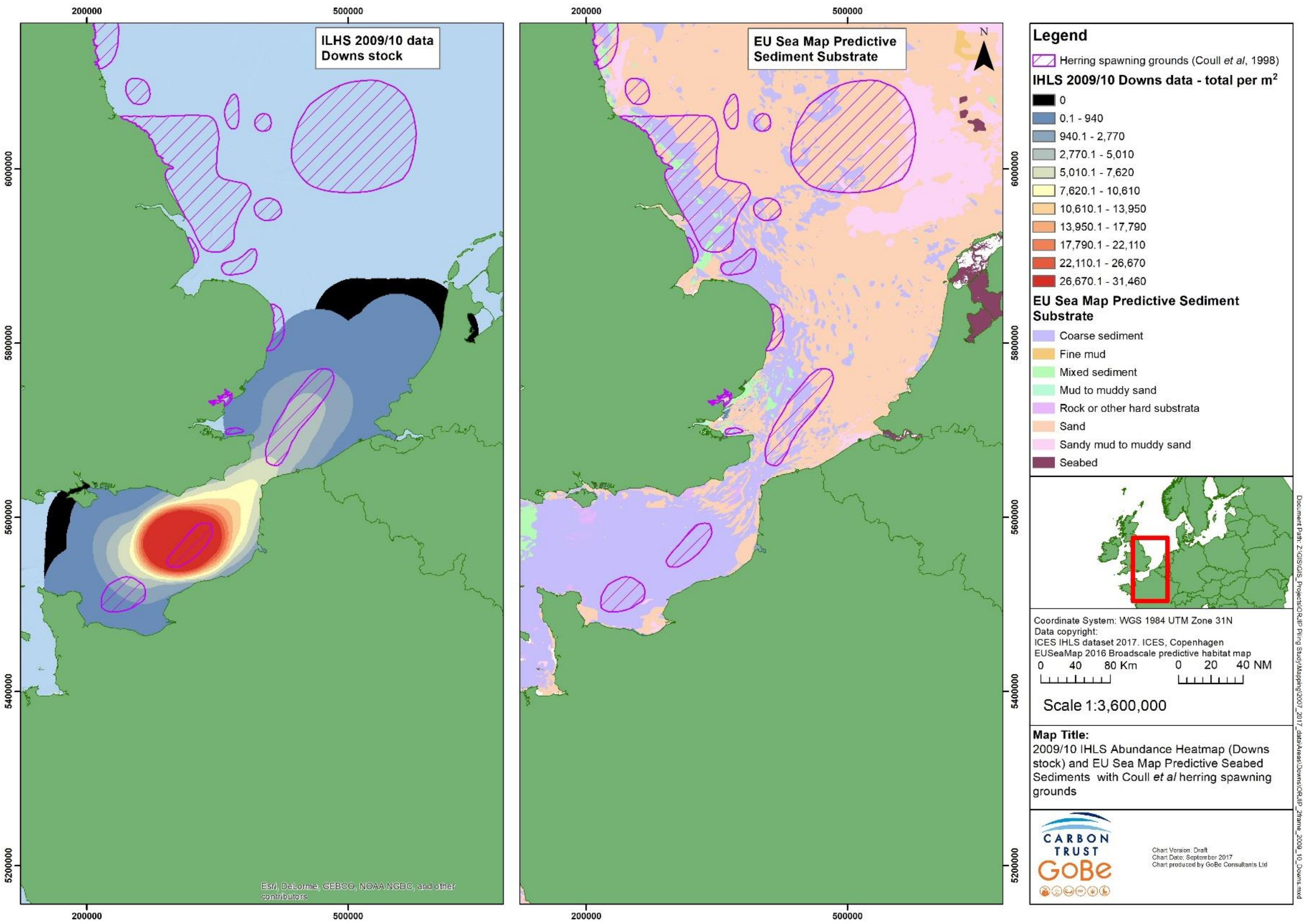


Figure C-36 2008/09 IHLS Abundance Heatmap (Downs)



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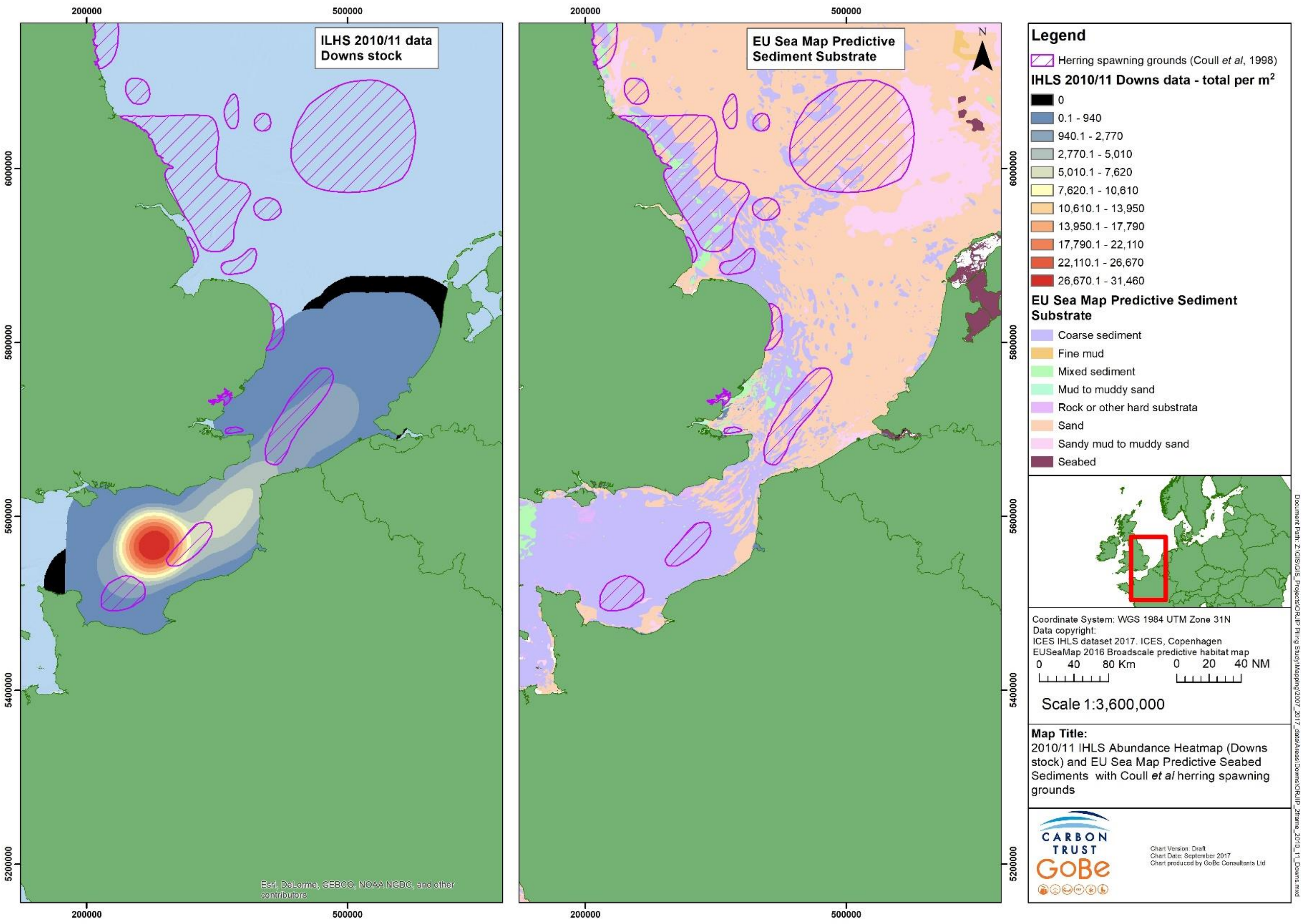

Figure C-38 2010/11 IHLS Abundance Heatmap (Downs)

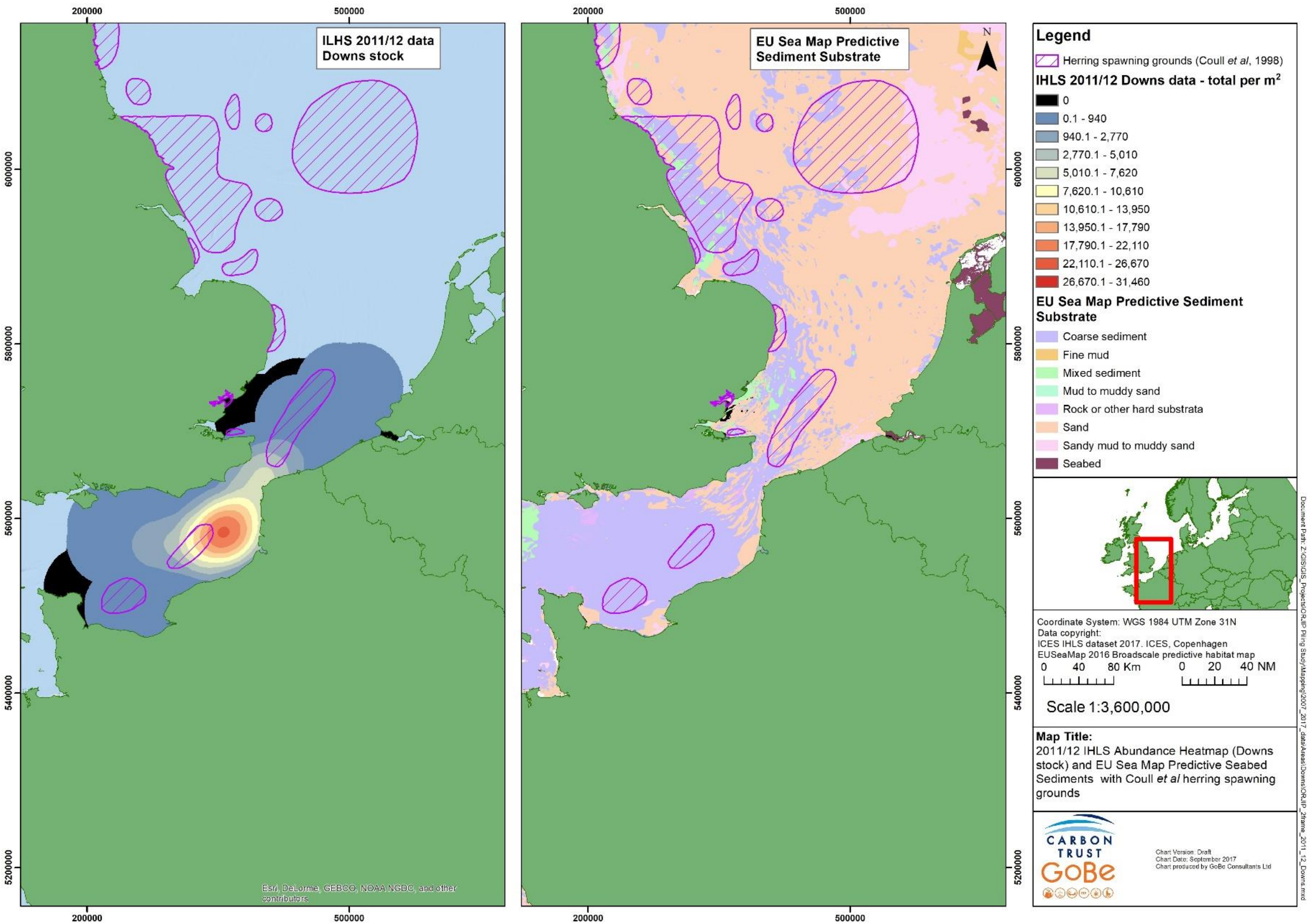

Figure C-39 2011/12 IHLS Abundance Heatmap (Downs)

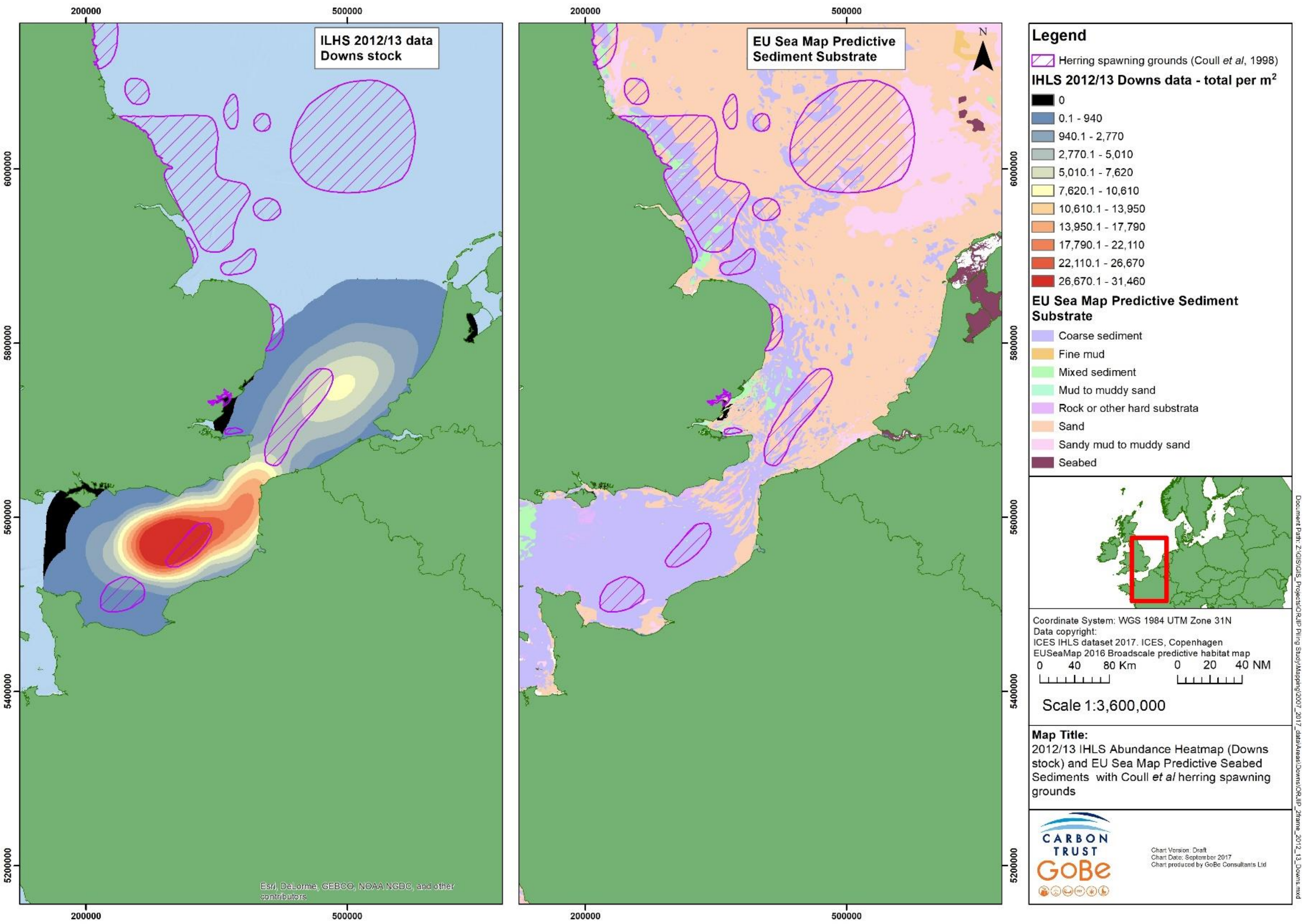

Figure C-40 2012/13 IHLS Abundance Heatmap (Downs)

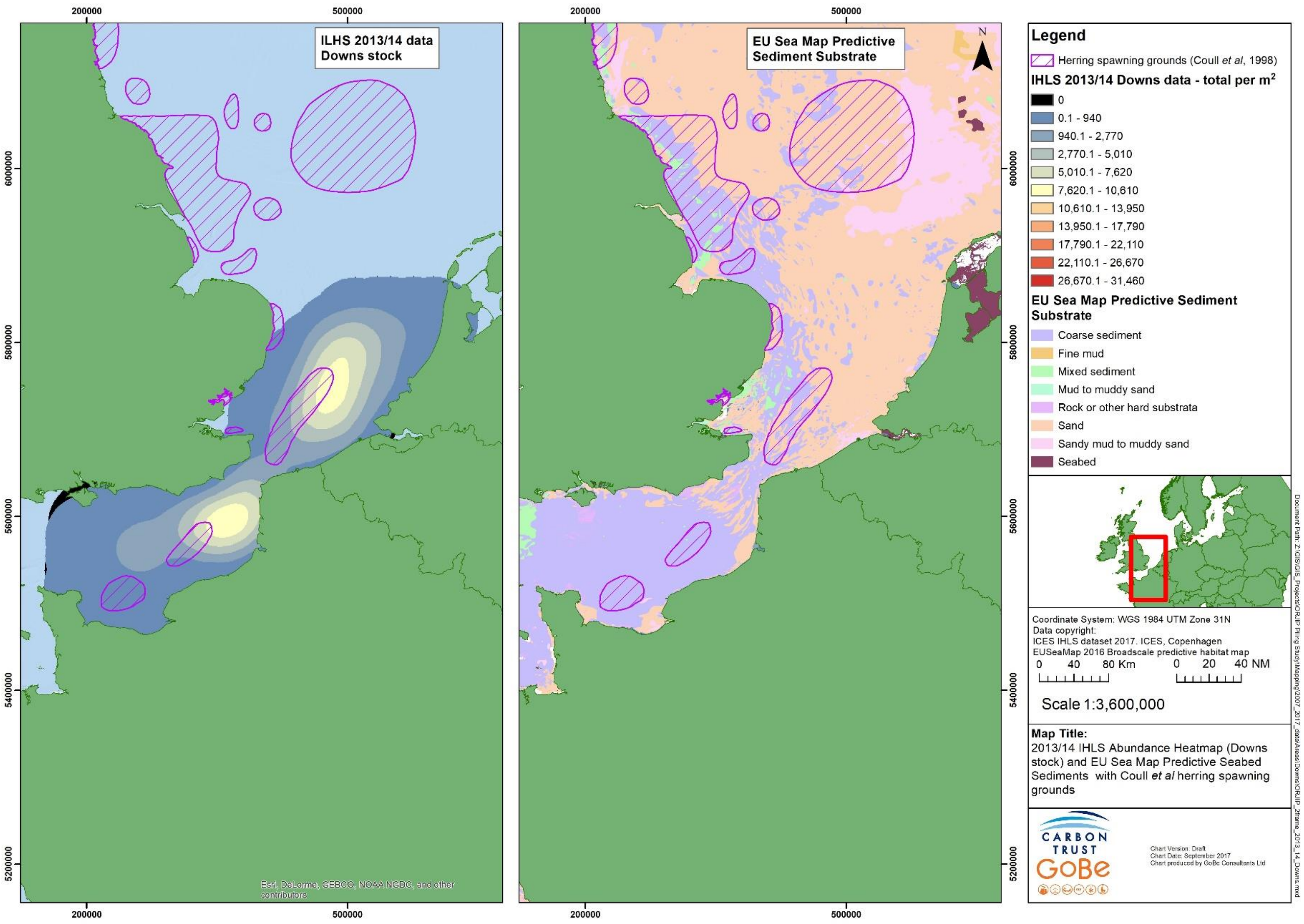

Figure C-41 2013/14 IHLS Abundance Heatmap (Downs)

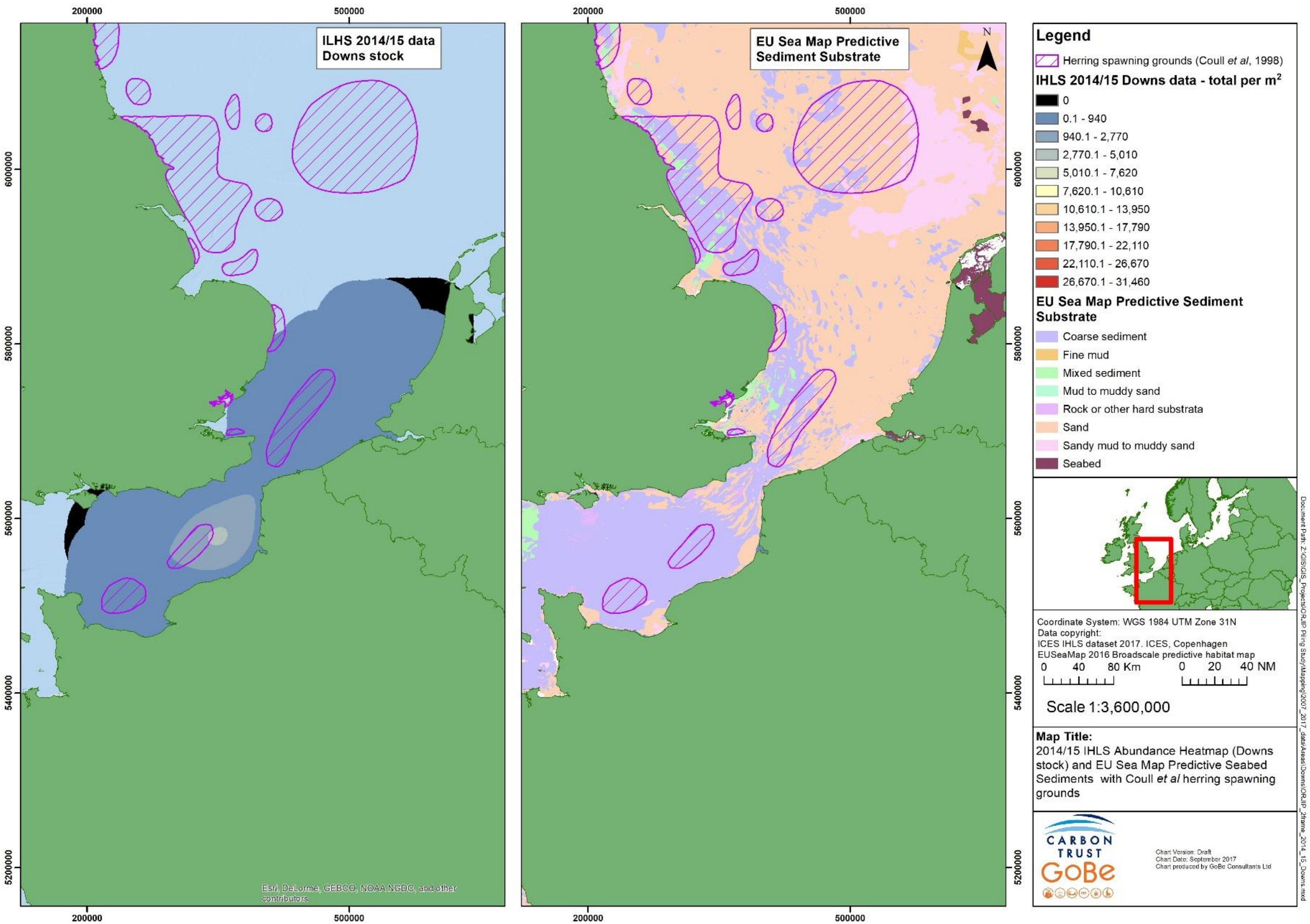

Figure C-42 2014/15 IHLS Abundance Heatmap (Downs)

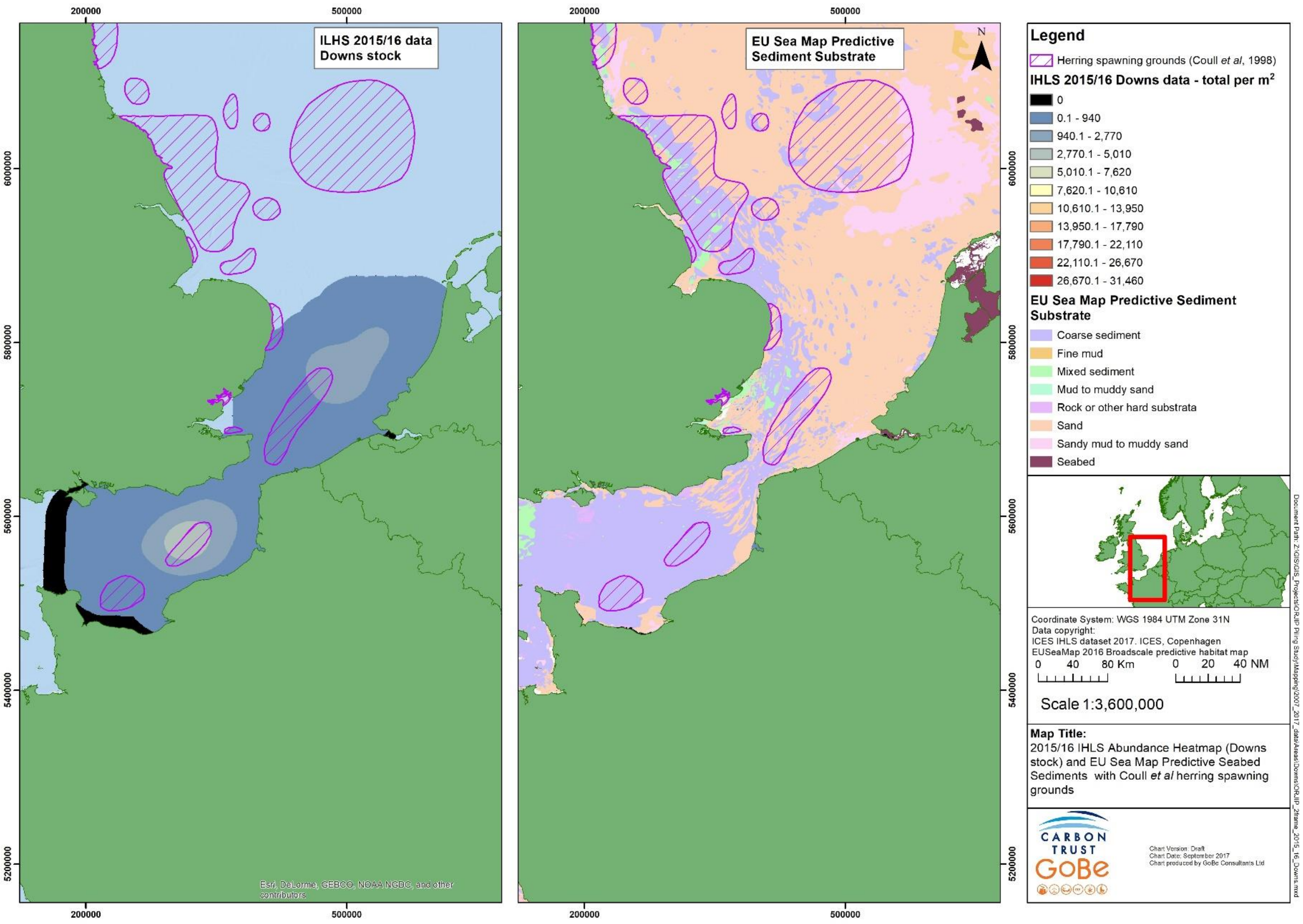

Figure C-43 2015/16 IHLS Abundance Heatmap (Downs)

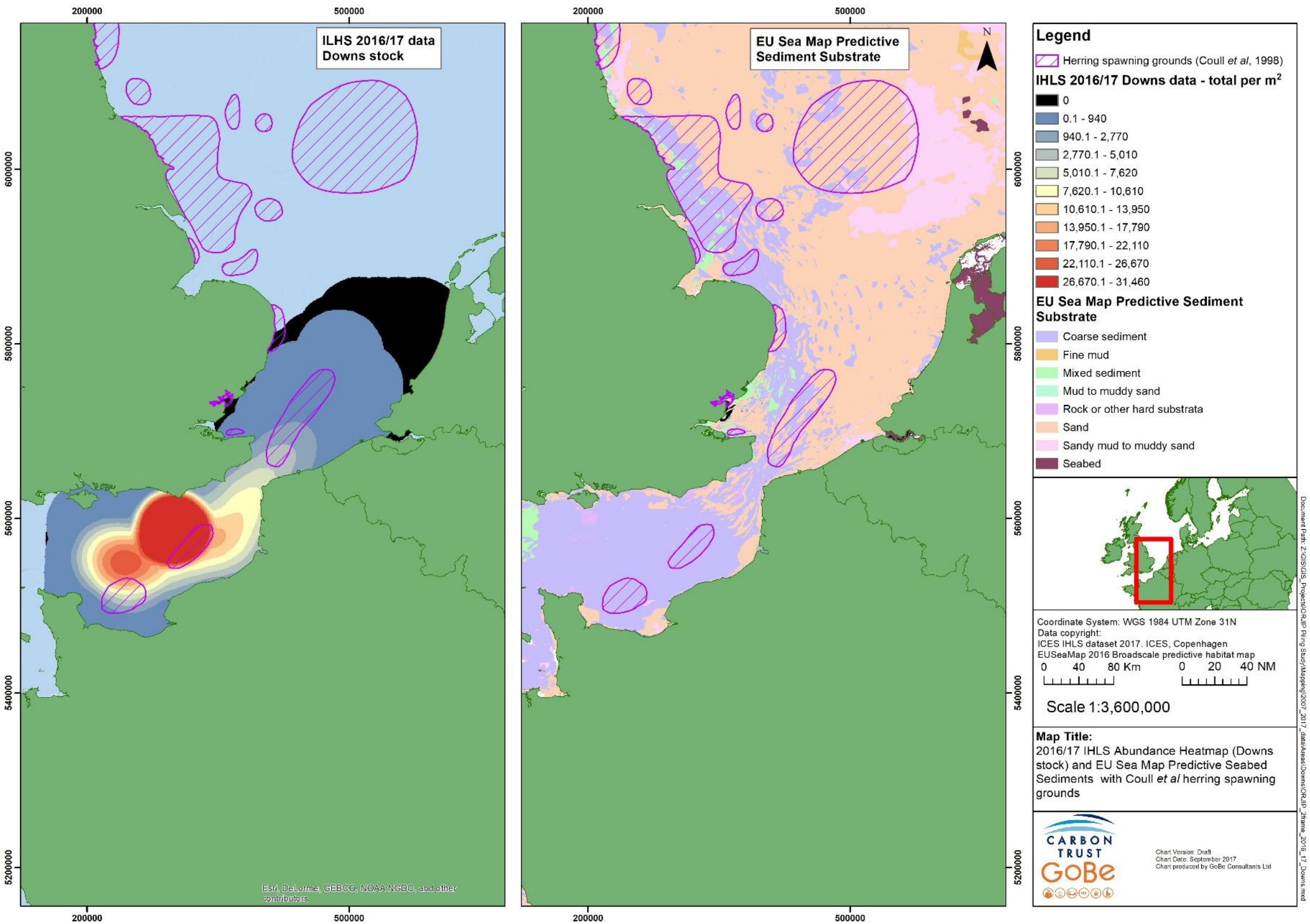

Figure C-44 2016/17 IHLS Abundance Heatmap (Downs)