Welsh Marine Invasive Non-Native Species Pathways Assessment

NRW Evidence Report No. 459

About Natural Resources Wales

Natural Resources Wales' purpose is to pursue sustainable management of natural resources. This means looking after air, land, water, wildlife, plants and soil to improve Wales' well-being, and provide a better future for everyone.

Evidence at Natural Resources Wales

Natural Resources Wales is an evidence based organisation. We seek to ensure that our strategy, decisions, operations and advice to Welsh Government and others are underpinned by sound and quality-assured evidence. We recognise that it is critically important to have a good understanding of our changing environment.

We will realise this vision by:

- Maintaining and developing the technical specialist skills of our staff;
- Securing our data and information;
- Having a well resourced proactive programme of evidence work;
- Continuing to review and add to our evidence to ensure it is fit for the challenges facing us; and
- Communicating our evidence in an open and transparent way.

This Evidence Report series serves as a record of work carried out or commissioned by Natural Resources Wales. It also helps us to share and promote use of our evidence by others and develop future collaborations. However, the views and recommendations presented in this report are not necessarily those of NRW and should, therefore, not be attributed to NRW.

Report series:	NRW Evidence report
Report number:	459 (version 2)
Publication date:	September 2020 (version 1), December 2021 (version 2)
Contract number:	P21018-0023
Contractor:	ABPmer
Contract Manager:	Kate Griffith, Chloe Powell Jennings
Title:	Welsh Marine Invasive Non-Native Species Pathways Assessment
Author(s):	Dewey, N., Pack, K., Williamson, D, Walsh, A.
Technical Editor:	Hull, S.
Peer Reviewer(s):	Kate Griffith, Chloe Powell Jennings, Gabrielle Wyn, Maggie Hatton-Ellis, Jim Evans (WFA), Mark Gray (WFA), James Wilson (WFA)
Restrictions:	None

Distribution List (core)

NRW Library, Bangor	2
National Library of Wales	1
British Library	1
Welsh Government Library	1
Scottish Natural Heritage Library	1
Natural England Library (Electronic Only)	1

Recommended citation for this volume:

Dewey, N., Pack, K, Williamson, D, Walsh, A. 2020. Welsh Marine Invasive Non-Native Pathways Assessment NRW Evidence Report No: 459, 90pp, Natural Resources Wales, Bangor

Contents

List of Figures

List of Tables

1. Crynodeb Gweithredol

Caiff dau i dri o rywogaethau anfrodorol eu cyflwyno i'r Môr Celtaidd (sy'n cynnwys dyfroedd Cymru ac Iwerddon) bob blwyddyn (Asiantaeth yr Amgylchedd Ewrop, 2015; 2019a). Mae nodi ardaloedd o'r arfordir ble mae rhywogaethau estron goresgynnol yn fwy tebygol o gael eu cyflwyno yn offeryn gwerthfawr a fydd yn helpu i ganolbwyntio ar reoli a nodi ardaloedd sensitif lle gallai'r risg fod yn uwch. Gall mapio dwysedd gweithgareddau llwybrau cyflwyno gynorthwyo â'r broses o nodi'r ardaloedd hyn lle mae'r risg yn uwch.

Mae'r adroddiad hwn yn darparu diweddariad ar y gwaith a gyflawnwyd gan Tidbury *et al*. yn 2014, a ystyriodd y posibilrwydd y gallai rhywogaethau estron goresgynnol gael eu cyflwyno i ardaloedd arfordirol y DU ac Iwerddon gan ddefnyddio grid o 50 x 50 km. Mae'r astudiaeth hon yn canolbwyntio ar ddyfroedd Cymru'n unig, ac ar gydraniad gofodol uwch na'r astudiaeth wreiddiol. Roedd nodau'r asesiad hwn fel a ganlyn:

1. Llunio mapiau gwres ar gyfer y llwybrau cyflwyno canlynol, sy'n dangos ardaloedd yn nyfroedd Cymru sydd â risg uwch o achosion o gyflwyno rhywogaethau estron goresgynnol:
    - Morgludiant masnachol
    - Hamddena ar gychod
    - Safleoedd casglu / cynhyrchu pysgod cregyn
    - Gweithgareddau ar y môr

2. Llunio map gwres cyffredinol er mwyn amlygu ardaloedd sy'n debygol o fod â'r risg uchaf o oresgyniad.

3. Troshaenu’r safleoedd dynodedig ar fap gwres y llwybrau cyfunedig cyffredinol er mwyn darparu arwydd o ardaloedd dynodedig sydd â risg uwch o achosion o gyflwyno rhywogaethau estron goresgynnol morol.

Defnyddiodd y dull a gafodd ei gymhwyso yn yr astudiaeth hon ddata a gasglwyd o ffynonellau â thrwydded agored, hawdd eu cyrchu, lle'r oedd hynny'n bosibl. Cafodd grid hecsagonol, wedi'i docio yn ôl hyd a lled ardal cynllunio morol Cymru, ag iddo faint cell o 5km^2, ei greu yn ArcGIS, a chafodd hwn ei gyfuno'n ofodol â haenau data a fewnbynnwyd, a oedd yn cynrychioli'r llwybrau cyflwyno, er mwyn llunio mapiau gwres. Cafodd cyfres o fapiau gwres ei chreu ar gyfer pob un o'r llwybrau cyflwyno, gan ddefnyddio dull sgorio graddfa. Cafodd map gwres cyfunedig terfynol o'r holl lwybrau cyflwyno ei greu hefyd drwy gymhwyso pwysoliadau i'r llwybrau cyflwyno gwahanol. Cynhyrchwyd ffigurau ar gyfer yr holl fapiau gwres, yn ogystal â ffigurau ar gyfer safleoedd dynodedig sy’n troshaenu’r map gwres cyfunedig terfynol er mwyn dangos y safleoedd oedd â risg uwch o bosib o achosion o gyflwyno rhywogaethau estron goresgynnol morol.

Mae'r asesiad hwn yn darparu mewnwelediad gwerthfawr i'r ardaloedd sydd â risg uchel ar gyfer pob llwybr cyflwyno posibl a gynhwysir yn yr adroddiad, yr ardaloedd lle mae'r prif ardaloedd sydd mewn perygl yn gorgyffwrdd ar gyfer y llwybrau gwahanol, a ble maent yn gorgyffwrdd ag ardaloedd gwarchodedig. Nid oedd digon o ddata i gynnwys pysgota masnachol yn yr adroddiad hwn.

Aberdaugleddau a Chaergybi yw'r prif ardaloedd arfordirol y mae mapiau'n dangos eu bod â'r risg uchaf o achosion o gyflwyno rhywogaethau estron goresgynnol morol gan y llwybr cyflwyno morgludiant masnachol. Yr ardaloedd arfordirol o gwmpas Ynys Môn, o gwmpas Penrhyn Llŷn, Aberdaugleddau, Abertawe ac Aber Hafren sydd â'r risg uchaf gan y llwybr cyflwyno hamddena ar gychod. Aber afon Dyfrdwy, afon Menai ac aber afon Llwchwr yw'r ardaloedd sydd â'r risg uchaf gan y llwybr cyflwyno casglu / cynhyrchu pysgod cregyn. Aberdaugleddau yw'r brif ardal arfordirol sy'n wynebu risg gan y llwybr cyflwyno pysgota masnachol. Aber afon Dyfrdwy, ardaloedd i'r gorllewin o Ynys Môn, Penfro ac ardal i'r de o Gasnewydd yn Aber Hafren yw'r prif ardaloedd arfordirol sydd â'r risg uchaf o safbwynt gweithgareddau ar y môr.

Mae ardaloedd gwarchodedig sydd â'r risg uchaf o bosib o achosion o gyflwyno yng Nghymru, yn seiliedig ar ystyried llwybrau cyflwyno yn unig, wedi'u lleoli yn bennaf yn agos at faeau cysgodol, cilfachau a phorthladdoedd a harbwrs mawr. Mae hyn yn gyson â dwysedd cymharol y llwybrau cyflwyno y maent wedi'u cydnabod fel fectorau dylanwadol o safbwynt cyflwyno. Mae ardaloedd allweddol ble ceir gorgyffwrdd â safleoedd dynodedig yn cynnwys yng nghyffiniau aber afon Dyfrdwy, ar hyd arfordir gogleddol Cymru ac o gwmpas Ynys Môn, yn Aberdaugleddau, Bae Caerfyrddin, Bae Abertawe ac arfordir de-ddwyreiniol Cymru.

Mae'r llwybrau cyflwyno a ystyrir yn yr asesiad hwn yn annhebygol o newid yn sylweddol yn y tymor canolig (20-50 o flynyddoedd), ac eithrio gweithgareddau ar y môr a safleoedd casglu / cynhyrchu cregyn pysgod, o bosib. Yn ogystal, lle mae newidiadau o'r fath yn digwydd, yn arbennig lle mae trwydded forol yn ofynnol, mae'n ofynnol cwblhau asesiad risg bioddiogelwch fel arfer. Felly mae nodi'r ardaloedd sydd â risg uchel, a ble y maent yn gorgyffwrdd â safleoedd dynodedig, yn darparu arwydd ar lefel uchel o ardaloedd gwarchodedig a allai fod â'r risg mwyaf gan rywogaethau estron goresgynnol. Gallai'r safleoedd hyn fod yn ffocws ar gyfer rhaglenni monitro a dargedir er mwyn sicrhau bod rhywogaethau estron goresgynnol yn cael eu canfod yn gynnar, ac o ganlyniad yn hwyluso'r gwaith o gael gwared ar rywogaethau estron goresgynnol, neu eu rheoli, cyn iddynt ledaenu ymhellach.

Dylid nodi, fodd bynnag, fod yr adroddiad hwn yn llinell sylfaen ar gyfer mapio'r gweithgareddau hyn yng Nghymru ac y bydd yn cael ei ddefnyddio fel rhan o becyn cymorth ar gyfer cynlluniau bioddiogelwch. Mae'r mapiau gwres a gynhyrchir ar gyfer asesu risg, nid rheoli risg. Roedd hwn yn ymarfer mapio ar raddfa genedlaethol yn seiliedig ar setiau data sydd ar gael am ddim yn unig, sydd â chyfyngiadau ac anghywirdebau posibl eu hunain oherwydd cofnodion anghyflawn, yn amserol ac yn ofodol. Mae'r sgoriau a gymhwysir i'r setiau data mewnbwn a'r pwysoliadau a gymhwysir i'r llwybrau cyflwyno hefyd yn seiliedig ar y llenyddiaeth sydd ar gael a barn arbenigol. Bydd gweithgareddau ac amodau sy'n benodol i safleoedd bob amser yn ystyriaeth bwysig, yn ogystal ag amrywiadau o ran amser. Mae'n werth nodi hefyd, ynghyd ag eithrio pysgota, nad yw'r adroddiad hwn yn cwmpasu pob llwybr cyflwyno fel abwyd byw, sbwriel morol a rhyddhau bwriadol gan fod hyn y tu hwnt i gwmpas y prosiect ac nad oes digon o ddata ar gael i'w mapio.

Gan ystyried y cyfyngiadau hyn a ffactorau dylanwadol eraill, mae'r mapiau gwres yn darparu asesiad defnyddiol, ar raddfa genedlaethol, o effaith gymharol y risg o gyflwyno INNS drwy'r llwybrau a asesir. Gall allbynnau'r asesiad hwn fod yn sail i gynlluniau bioddiogelwch. Gallai gwaith ymchwil pellach i nodweddion hanes bywyd INNS targed a thueddiadau o ran natur mewn llwybrau cyflwyno helpu i ddeall y tebygolrwydd o oresgyniad gan INNS penodol a syniad o gyfnodau lle bydd goresgyniadau ar eu hanterth. Ymchwiliodd yr astudiaeth hon i lwybrau cyflwyno ar lefel Cymru gyfan. Ar gyfer risgiau ar raddfa fwy lleol, fel safleoedd gwarchodedig, gallai data â chydraniad uwch sy'n benodol i'r ardal dan sylw, wella rhagfynegiadau o'r risgiau o gyflwyno rhywogaethau estron goresgynnol morol.

2. Executive Summary

The Celtic Sea (including Welsh and Irish waters) has approximately two to three new introductions of non-indigenous species every year (European Environment Agency (EEA), 2015; 2019a). Identifying coastal areas where invasive non-native species (INNS) are more likely to be introduced is a valuable tool which will help to focus management efforts and identify sensitive areas which may be at a higher risk. Mapping the intensity of introduction pathway activities can aid the identification of these higher risk areas.

This report provides an update to the work carried out by Tidbury *et al.* in 2014, which considered the potential for the introduction of INNS in coastal areas of UK and Ireland using a 50 km x 50 km grid. The current study focuses only on Welsh waters and at a higher spatial resolution than the original study. The aims of this assessment were to:

1. Produce heatmaps for the following introduction pathways indicating areas in Welsh waters with a higher risk of INNS introduction:
    - Commercial shipping
    - Recreational boating
    - Shellfish gathering/ production sites
    - Offshore Activities

2. Produce an overall heatmap to highlight key areas which are likely most at risk from invasion.

3. Overlay the designated sites on the overall combined pathway heatmap to provide an indication of designated areas at increased risk of marine INNS introduction.

The approach applied in this study, used data acquired from readily available, open licence sources where possible. A hexagonal grid, clipped to the extent of the Welsh marine planning area, with cell size of 5 km^2 was created in ArcGIS and this was spatially joined to input data layers, representative of the introduction pathways, to create heatmaps. A series of heatmaps were created for each of the introduction pathways, using a scaled scoring method. A final combined heatmap of all introduction pathways was also created by applying weightings to the different pathways. Figures of all heatmaps were created, as well as figures of designated sites overlying the final combined heatmap to show sites at potentially greater risk from the introduction of marine INNS.
This assessment provides a valuable insight into hotspots related to each potential pathway of introduction included in the report, the areas where the main areas of risk overlap for the different pathways and their overlap with protected areas. There was insufficient data to include commercial fishing in this report.

The main coastal areas mapped as being at highest risk from introductions of marine INNS from the commercial shipping introduction pathway are Milford Haven and Holyhead. For the recreational boating introduction pathway, the coastal areas at highest risk are around Anglesey, around the Llyn Peninsula, Milford Haven, Swansea and the Severn Estuary. For the shellfish gathering/ production sites introduction pathway, the areas at highest risk are the Dee Estuary, Menai Straits and Loughor Estuary. For offshore activities, the main coastal areas at highest risk are the Dee

Estuary, areas to the west of Anglesey, Pembroke and an area south of Newport in the Severn Estuary.

Protected areas with potentially the highest risk of introduction in Wales, based on consideration of the introduction pathways alone, are predominantly located close to sheltered bays, inlets and major ports and harbours. This is consistent with the relative intensity of the introduction pathways recognised as dominant vectors of introduction. Key areas of overlap with designated sites include in the vicinity of the Dee Estuary, along the north coast of Wales and around Anglesey, Milford Haven, Carmarthen Bay, Swansea Bay and along the south-east coast of Wales.

The introduction pathways considered within this assessment are unlikely to change substantially in the medium term (20-50 years), possibly with the exception of offshore activities and new shellfish gathering/production sites. In addition, where such changes do occur, particularly where a marine licence is required, a biosecurity risk assessment is typically required. The identified high-risk areas and their overlap with designated sites therefore provides a high-level indication of protected areas that could be at most risk from INNS. These sites could be a focus for targeted monitoring programmes to ensure the early detection of INNS and, therefore, facilitate the eradication or control of INNS before further spread.

It should be noted, however, that this report is a baseline for mapping these activities in Wales and will be used as part of a toolkit for biosecurity planning. The heatmaps produced are for risk assessment, not risk management. This was a national scale mapping exercise based only on freely available datasets, which themselves have limitations and possible inaccuracies due to incomplete coverage, both temporally and spatially. The scorings applied to the input datasets and weightings applied to the introduction pathways are also based on available literature and expert judgement. Site-specific activities and conditions will always be an important consideration, as well as temporal variations. It is also worth noting that along with excluding fishing, this report does not cover all introduction pathways such as live bait, marine litter and deliberate release as this was out of the scope of the project and there is not enough data available to map them.

Taking these limitations and other influencing factors into consideration, the heatmaps provide a useful, national scale, position of the relative intensity of risk of introduction of INNS through the pathways assessed. The outputs from this assessment can form the basis to underpin biosecurity planning. Further investigation of target INNS life-history traits and temporal trends in introduction pathways could aid in understanding the likelihood of invasion by particular INNS and an idea of peak periods of invasions. This study investigated introduction pathways at a Wales-wide level. For risks at a more localised scale, such as protected sites, higher resolution data specific to the area of interest may improve predictions of the risks of introduction of marine INNS.

3. Introduction

3.1. Background

Marine Invasive Non-Native Species (INNS) are recognised by the Convention on Biological Diversity (CBD) as one of the greatest drivers of biodiversity loss and ecosystem service change. INNS can have negative environmental and socio-economic impacts and the risk they impose may be increasing in line with increasing global trade, transport and climate change. INNS can have a negative impact on native species and habitats through smothering, predation and outcompeting native species for space and food and bio-engineering which may ultimately alter ecosystem functioning (Ruiz *et al*., 1997, Manchester and Bullock, 2000, Wallentinus and Nyberg, 2007). The Marine Strategy Framework Directive (MSFD) Descriptor 2 outlines indicators to assess Good Environmental Status regarding INNS, highlighting the need for the monitoring and assessment of INNS abundance, spread and impact.

Commercial shipping, recreational boating and shellfish gathering/ production activities are recognised as key pathways for the potential anthropogenic introduction of marine INNS (Bax *et al*., 2003, Minchin *et al*,. 2009). For example, it is understood that the Chinese mitten crab (*Eriocheir sinensis*) was transported to the UK through ballast water, the Pacific oyster (*Magallana gigas*) through deliberate introduction for aquaculture and the Carpet sea squirt (*Didemnum vexillum)* through hull fouling (Griffith *et al*., 2009). After their initial introduction, INNS can establish self-sustaining populations and further spread to new areas through natural dispersal or by further anthropogenic transportation.

It is widely accepted that preventing introduction is the most effective approach to reduce the impacts of INNS. If prevention fails, early detection, rapid response and eradication should follow (CBD, 2002). Biosecurity measures can help prevent the introduction and spread of INNS and reduce the likelihood of a species entering an area; such measures are particularly important for marine ecosystems, where eradication and control techniques have been shown to be less effective and expensive.

Natural Resources Wales (NRW) has been successful in gaining European Maritime and Fisheries Fund (EMFF) funding for a project entitled “Marine Biosecurity Planning for Pen Llŷn a’r Sarnau Special Area of Conservation (PLAS SAC)”. The project began in April 2019 and will run for a duration of three years. This EMFF project involves working with key stakeholders to develop a biosecurity plan for PLAS SAC to reduce the risk of introduction and spread of marine INNS. It will act as a template for developing cost-effective biosecurity for Wales’ network of Marine Protected Areas (MPAs).

In this context the MPA network in Wales constitutes a number of sites of European and international importance which include SPAs, SACs and Ramsar Sites. The nationally designated sites within the MPA network include MCZs and SSSIs with coastal or marine features. The MPA network in Wales covers approximately 50% of Welsh waters (Welsh Government, 2018).

3.2. Previous pathway assessment

The Celtic Sea (including Welsh and Irish waters) has approximately two to three new introductions of non-indigenous species every year (European Environment Agency (EEA), 2015; 2019a). Identifying coastal areas where INNS are more likely to be introduced is a valuable tool which will help to focus management efforts and identify sensitive areas which may be at a higher risk. Mapping the intensity of introduction pathway activities can aid the identification of these higher risk areas.

Work commissioned by the Marine Pathways Project has already mapped the intensity of activities across the UK for the introduction pathways listed below (Cefas report C5955 by Tidbury *et al.* 2014) (hereinafter referred to as the 'Cefas Study'):

- Commercial shipping
- Recreational boating
- Aquaculture
- Natural dispersal – ocean currents
- Natural dispersal – offshore structures

The Cefas Study determined the intensity of activity associated with the above introduction pathways in coastal areas of the UK and Ireland using a 50 km x 50 km grid. These pathway intensity scores were then plotted as heatmaps to enable visualisation of the relative intensity of activity of each introduction pathway in different coastal regions. It was concluded that the pathway assessment identified high risk locations specific to each individual pathway which could aid in targeting development and implementation of risk-based monitoring programmes.

3.3. Objectives

This report provides an update to the work carried out for the Cefas Study, however, this assessment focusses on Welsh waters and at a higher resolution. The report is a baseline that will be used as part of a toolkit to inform biosecurity planning. It is not an end product and will be updated as more data becomes available.

The aims of this assessment were to:

1. Produce heatmaps for each introduction pathway indicating areas in Welsh waters with a higher risk of marine INNS introduction;
2. Produce an overall combined pathway heatmap to highlight key areas which are likely to be most at risk of marine INNS introduction; and
3. Overlay the designated sites on the overall combined pathway heatmap to provide an indication of areas at increased risk of marine INNS introduction.

To provide this information this report is structured as follows:

Section 4: Methodology – describes the processing steps applied during the study, the associated rationale and data limitations;

Section 5: Results – describes the combined heatmaps for each introduction pathway, the final heatmap output of the study, and where high-risk areas overlap with designated sites;

Section 6: Discussion – contains conclusions and discussion about limitations of and improvements to the methodology;

Section 7: Conclusion

Appendix A: Contains the results and heatmaps for individual data layers and grouped data layers created for each introduction pathway; and

Appendix B: Describes the issues with incorporating ports, harbours and marinas data into the commercial shipping and recreational boating heatmaps.

4. Methodology

The data inputs, descriptions, limitations and methodology for production of the heatmaps for Welsh waters are described in the sections below. This has been undertaken for each of the following marine INNS introduction pathways.

- Commercial shipping
- Recreational boating
- Shellfish gathering/ production sites
- Offshore Activities

It should be noted that the principles of the overall approach applied within this project were, as far as possible, similar to the methodology that was used in the Cefas Study.

4.1. Outline of approach

The following description provides an outline of the steps taken in the analysis for this study and are summarised in the flow chart in Figure 1. All data processing was carried out using ArcGIS and the output heatmaps were provided as gridded polygons in an ArcGIS geodatabase.

Step 1 - Agreed overall approach and data sources with NRW

At the request of NRW, input data were acquired from readily available sources and were open licence, where possible. Recreational data sourced from the Royal Yachting Association (RYA) was the only dataset used in the study that required a data licence agreement. More up-to-date datasets similar to those used in the Cefas Study were investigated, however, it was not always possible to obtain data with comparable data attributes, features and format. In these cases, the methodology was adapted to take account of the differences in the input data whilst maintaining a similar processing method.

Commercial fishing was originally included as an introduction pathway, however, this pathway was later removed due to insufficient data to accurately map fishing activity in Wales.

A more detailed description of the data inputs and overarching principles of the approach for each of the main introduction pathways is provided in Sections 4.2 to 4.6.

Step 2 - Developed a standardised hexagonal grid

A hexagonal grid with cell size of 5 km^2 was created in ArcGIS using the fishnet tool and then clipped to the extent of the Welsh marine planning area. The grid was used to map and combine the various input data layers in a consistent way and enabled the creation of relative intensity heatmaps for each of the introduction pathways at a consistent scale.

At NRW's request, a second, finer resolution hexagonal grid was also created to enable heatmaps to be generated at a scale of 2 km x 2 km. These heatmaps were produced in GIS format only for use in future planning at the MPA scale (and not used to create figures within this report).

Step 3 – Created a series of heatmaps for each introduction pathway

A series of heatmaps were created for each of the introduction pathways based on the standardised grid created above. The following subtasks were carried out to produce the heatmaps:

- Collated and prepared input datasets for each introduction pathway;
- Developed an ArcGIS model to spatially join the defined input data layer and calculate the values for the heatmap outputs;
- Produced individual heatmaps for the respective data layers using scoring methods agreed with NRW (as detailed in Sections 4.2 to 4.6) and scaled to the same range (Section 4.1.1);
- Combined individual heatmaps to create an overall heatmap for each impact pathway and, for the commercial shipping introduction pathway only (Section 4.2), additional heatmaps of sub-groupings of input datasets;
- Combined overall heatmaps from each introduction pathway using the weightings agreed with NRW (Section 4.7) to create a final heatmap for all introduction pathways across Welsh waters; and
- Created figures of all heatmaps (summarised in Table 6) as well as figures of designated sites overlying the final combined heatmap.

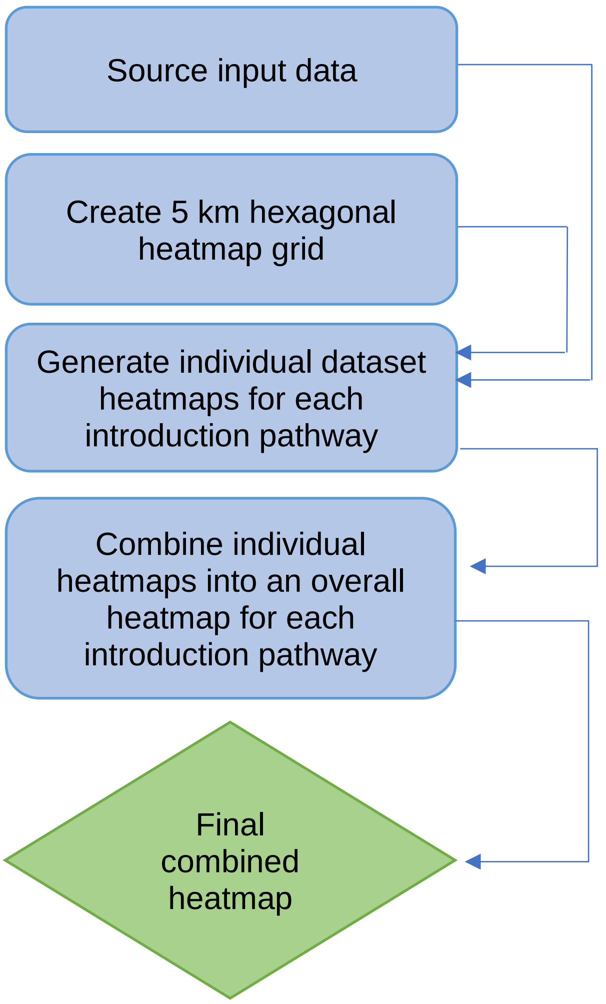

Figure 1 Flow chart of simplified methodology

4.1.1. Scaling values for heatmaps

Since each pathway grid contained varying ranges of scores dependent on the source data, these required normalising to the same scale (i.e. 0 to 100) to allow comparison of relative values across the different pathways and to allow the combining of individual pathways into an overall risk density grid. A similar approach to the Cefas Study was used, as described by the following equation:

$$\text{Scaled } xi = ((xi - Xmin)/(X \text{ Range})) * 100$$

where:

xi = Variable x in i^{th} row
Xmin = Minimum value of the variable X
XRange = Maximum value of variable X - Minimum value of the variable X

4.2. Commercial shipping

International, regional and local shipping are the dominant vectors for the introduction and movement of INNS and have been attributed to the majority of introductions in Europe (EEA, 2019b). It is estimated that approximately half of the INNS introduced in to Europe since the 1950s have been through hull fouling and the release of ballast water (EEA, 2019b). Harbours and ports are recognised as hotspots for marine INNS due to the high number of species transported via shipping and the sheltered, artificial structures which promote establishment (Griffith *et al*., 2009; Mineur *et al*., 2012; Ferrario *et al*., 2017).

The input data used in the production of the commercial shipping introduction pathway heatmaps are listed in Table 1.

Table 1 Commercial shipping data

Data Layer	Data description	Comparison with Cefas Study
UK AIS Density Grid 2017	**Source: Marine Management Organisation** (MMO)/ABPmer (2018) Vessel densities for UK based on 12 weeks of AIS data from 2017. ABPmer Route Density data provides weekly and annual average number of vessel transits (routes) per 2 km^2 for the following ship types: • Port Service • Non-port service • Dredging & underwater ops	Cefas used AIS data for 6 months from 2012. The data provided information on shipping traffic including port connections, number of ships and number of voyages for vessels categorized as large (>50 m) or small (<50 m). The latest freely available AIS datasets (MMO, EMODNet, EMSA) do not include information on originating or destination ports therefore, the Cefas method could

	• Military/Law • High Speed Craft • Passenger • Cargo • Tanker • Fishing • Recreational • Unknown Heatmaps for the above ship type groups have been included in the analysis, except for recreational vessels (Section 4.3) and fishing vessels (Section 4.5) which use alternative data. .	not be replicated. However, the latest AIS datasets do include categories based on ship type group.
Ports and Harbours of the UK	**Source:** Ports.org.uk/ABPmer (2018) Dataset of over 900 ports and harbours around the UK classified into three categories: • Major port • Minor port • Harbour Port location data was considered for use in this study (since the available AIS data does not include information on port connections), but due to difficulties in applying an automated method this was not possible (Appendix B). Instead, port locations were added to the commercial shipping heatmap figures.	Ports and harbours data were not used in the Cefas Study, however, information on originating and destination port was included in the AIS data used in that analysis.

International vessels are more likely to introduce new INNS to an area, however, regional and local vessels are just as likely to introduce INNS from other nearby regions, i.e. to act as secondary introduction pathways. Therefore, the total number of vessel movements is the most important factor when considering the risk of INNS introduction by commercial shipping.

However, it is also useful to differentiate shipping according to the risk of global ('primary') versus regional/local ('secondary') introduction pathways and to compare risk between individual ship type groups. Since the latest available AIS data included information on ship type category, it was possible to compare ship types for this study. Therefore, the following heatmaps were produced:

- Heatmap for each ship type, based on the maximum weekly average number of vessel transits from the UK AIS density grid;
- Heatmap for ship types groups considered as global (unknown ship type, military/law enforcement vessels, cargo vessels and tankers), regional (high speed craft and passenger vessels) or local (port service vessels, non-port service vessels, dredgers and vessels engaged in underwater operations), based on the maximum weekly average number of vessel transits from the AIS density grid; and

- Heatmap for all vessel movements combined, based on the maximum weekly average number of all transits for all ship type groups from the AIS density grid.

The values in the individual and combined heatmaps from the AIS data were normalised to the same scale, in order to compare different introduction pathways and combine all pathways together to create an overall heatmap, following the method described in Section 4.1.

The following ship types were excluded from the analysis for this introduction pathway as they are dealt with separately:
- The recreational ship type group were excluded from these heatmaps as this is covered in the Recreational Boating introduction pathway (Section 4.3).
- The fishing ship type group was excluded from these heatmaps

4.3. Recreational boating

Recreational vessels are increasingly recognised as an important pathway for the introduction of INNS, most likely via hull fouling (Clarke Murray *et al*., 2011). They are often anchored/moored in marinas or sheltered inlets for a prolonged period of time which would increase the likelihood of an INNS becoming established if present on the vessel (Minchin *et al*., 2006; Tidbury *et al*., 2014).

The input data used in the production of the recreational boating introduction pathway heatmaps are listed in Table 2.

Table 2 Recreational boating data

Data Layer	Data description	Comparison with Cefas Study
Intensity of Recreational Boating	**Source:** RYA Atlas of Recreational Boating (2016) Density grid (0.25 km x 0.25 km) of recreational boating intensity based on AIS-B data from the summers (May to September) of 2014 to 2017. AIS dataset is limited as it only represents recreational vessels that carry AIS transponders (around 1 in 6 vessels). In areas where there is no AIS coverage, this does not mean no recreational boating, therefore, the RYA also supply a polygon of general boating areas to complement the AIS data.	The Cefas Study used the probable cruising routes data from the earlier version of the RYA Atlas of Recreational Boating (2008) and also cruising route data obtained from the Irish Sailing Club. The RYA data comprised likely lines of light, medium and heavy cruising routes. Cefas complimented this with information obtained from personal correspondence. The routes were not based on actual vessel movements.
General Boating Areas	**Source:** RYA Atlas of Recreational Boating (2016) Areas around the coast where general recreational boating activities are likely to take place, used to compliment the AIS Intensity data.	The polygons of general boating areas were not included in the Cefas Study.

Marinas	**Source:** NRW (created by Blue-C-Ecology/Cloud-BasePro Ltd, 2019) NRW provided point data of locations of marinas around Wales, including number of berths, freshwater/marine and identified risk level associated with INNS. Due to difficulties in applying an automated method which gave sensible results, it was decided to exclude marinas from the final methodology (Appendix B). Instead, marina locations were added to the recreational boating heatmap figures.	Marinas were not included in the Cefas Study, however, due to the more recent focus on marinas as an important vector in the introduction of INNS, the use of marina data was considered in this study.

The following recreational boating heatmaps were produced:

- Heatmap for recreational boating intensity, based on the maximum intensity value from the Intensity of Recreational Boating datalayer;
- Heatmap for general boating areas, based on the presence (*value = 100*) or absence (*value = 0*) of a boating area polygon; and
- Heatmap for recreational boating intensity and general boating areas combined.

The values in the heatmaps from the different recreational data inputs were normalised to the same scale, in order to combine and compare all introduction pathways, following the method described in Section 4.1.

4.4. Shellfish gathering/ production sites

Aquaculture is recognised as a key vector for the introduction of INNS globally (ICES, 2005, EEA, 2019b). There are two main processes by which species are introduced, either intentionally for cultivation purposes, such as the Pacific oyster, or unintentionally by accidental release of species ‘hitchhiking’ on the target species (Grosholz *et al*., 2015). Due to the available data and for the purpose of this report, we have used the term ‘shellfish gathering/ production’ since some of the data used is not ‘aquaculture’, yet it is still an INNS introduction pathway.

The input data used in the production of the shellfish gathering/ production introduction pathway heatmaps are listed in Table 3.

Table 3 Shellfish gathering/ production sites

Data Layer	Data description	Comparison with Cefas Study
Shellfish Waters (Wales)	**Source**: Magic.defra.gov.uk Protected areas of Shellfish Waters around the Welsh	The Cefas Study used live shellfish imports data for 2012 from Cefas’ Live Fish Movement Database. Data were in the form of Excel

	coastline. This list constitutes that which is referred to under ‘ The Water Environment (Water Framework Directive) (England and Wales) (Amendment) Regulations 2016’ which came into force on 3 March 2016.	spreadsheets including details of aquaculture imports such as date, source and destination of import and species imported.
Several & Regulating Orders	**Source**: Welsh Government Marine Planning Portal Data layer This data layer comprises operational mussel, oyster and clam shellfisheries in Wales. No information is provided as to the type of culture, therefore, this cannot be considered in the scoring.	
Cockle gathering sites (2012)	**Source:** NRW Distribution of Fisheries Habitats and Fishing Activity Project Fishing activity data for this project were based upon Fishing Atlas activity layers. Some of this data may be out of date therefore datasets are indicative rather than definitive.	

It was not possible to obtain information on live shellfish imports (as used in the Cefas Study) or details about the type of shellfish gathering/ production i.e. bivalve harvesting techniques, for use in this project. Therefore, a general approach was taken for this introduction pathway, focussing on the presence or absence of a shellfish water or Several Regulating Order. The following shellfish gathering/ production site heatmaps were produced:

- Heatmap for shellfish waters, presence (*value = 100*) or absence (*value = 0*) of a shellfish water polygon;
- Heatmap for Several Regulating Orders, based on the presence (*value = 100*) or absence (*value = 0*) of a Several Regulating Order polygon;
- Heatmap for cockle gathering sites, based on the presence (*value = 100*) or absence (*value = 0*) of cockle gathering site polygon; and
- Heatmap for shellfish waters, Several Regulating Orders and cockle gathering sites combined.

The values in the heatmaps from the shellfish gathering/ productiondata were subsequently normalised to the same scale, in order to compare all introduction pathways, following the method described in Section 4.1.

4.5. Commercial fishing

Commercial fishing represents a pathway of introduction through the potential biofouling on gear such as mobile or static nets and pots. Some non-indigenous species have been observed to survive on damp recreational angling gear for several days to weeks between uses and locations (Smith *et al*., 2020). Although there is little published information on commercial fishing as a vector for introductions, a similar pathway may exist.

The commercial fishing data listed in table 4 were looked at but it was decided that the data was inaccurate and insufficient to map. The data sources identified in table 4 predominately focus on vessels over 15 meters which represent a small percentage of the Welsh fishing fleet. The new inshore vessel monitoring system will provide very accurate data for vessels under 12 metres in the future.

Table 4 Commercial fishing data

Data Layer	Data description	Comparison with Cefas Study
National Inshore Fishing Data Layer (NIFDL)	**Source:** Cefas (2014) Fishing activity intensity within 12 nm of the English and Welsh coast derived from sightings data from IFCAs and the MMO. Data are presented by gear classes: mobile, static, dredging, trawling, potting, netting and lining & commercial angling. Data from 2010 to 2012 and is gridded onto a grid approx. 5.5 by 5 km. Since the fishing intensity is based on sightings data, it may not accurately reflect fishing intensity where there were few or no fisheries enforcement vessels carrying out sightings, however, it is a useful dataset for inshore waters where no other data is available.	Commercial fishing was not included in the analysis of INNS introduction pathways in the Cefas Study.
Fishing Activity for UK Commercial Fishing Vessels 15 m and Over in Length (2017)	**Source**: MMO (2018) The fishing activity data for 2017 is categorised into aggregated gear groups (e.g. mobile, static) and by gear type. Positional data were extracted from GPS-derived VMS and gridded on 0.05 degree ICES sub-rectangle grid (approx. 5 km x 9 km). Data is provided by: • Number of vessels; • Time (minutes);	

	• Effort in kW Hours (time fishing in hours multiplied by engine power); • Quantity (tonnes) of live weight fish; and • Value (£) of live weight fish landed.	
UK AIS Density Grid 2017	**Source:** MMO/ABPmer (2018) Vessel densities for UK based on 12 weeks of AIS data from 2017. ABPmer Route Density data provides weekly and annual average number of vessel transits (routes) per 2 km^2 for all ship types listed in Table 1 including: • Fishing	

4.6. Offshore activities

The threat offshore activities pose for the introduction of INNS is relatively under-studied. Offshore structures are vectors which have been shown to facilitate the spread of INNS (De Mesel *et al*. 2015). These structures may aid natural dispersal via ocean currents, acting as stepping stones between locations on which larvae can settle (Adams *et al*., 2013). The area around the north of Wales has a high concentration of offshore structures which may aid the introduction of INNS on the prevailing current from Ireland (Tidbury, *et.al*, 2014).

There is little discussion in published papers about the risk of introducing INNS from the dredging and aggregate industry. Dredge and disposal sites present areas where material is transported from one place to another which has the potential to move INNS to new locations. Biosecurity plans are typically produced to manage these risks as part of the respective licensing requirements (Payne *et al*., 2015).
In the Cefas Study, offshore structures associated with the UK oil and gas industry were considered, however, as there are no oil and gas structures within Welsh waters, this information was not included in the analysis.

The input data used in the production of the offshore activities introduction pathway heatmaps are listed in Table 5.

Table 5 Offshore activities data

Data Layer	Data description	Comparison with Cefas Study
Offshore wind	**Source:** The Crown Estate (19/02/2019) Dataset of polygons of offshore wind farms in UK waters at different stages of development	The Cefas Study included offshore wind farm structures in operation at that time.

	from planning to fully operational. Data was filtered by status 'Active/In Operation' or 'Consented' or 'Under construction' for use in the analysis.	
Wave and tidal	**Source:** The Crown Estate (19/02/2019) Dataset of UK wave and tidal energy site polygons.	The Cefas Study did not include wave and tidal energy sites.
Aggregate extraction	**Source:** The Crown Estate (19/02/2019); NRW (2019) Dataset of aggregate extraction activity area polygons.	The Cefas Study did not include aggregate extraction activity.
Dredging Activiti es Dredge spoil dumping	**Source**: Lle.gov.uk Marine licence application data downloaded from Lle. Polygon data was filtered by application type 'Dredge and/or Disposal' for use in the analysis.	The Cefas Study did not include dredging activity.
Disposal Sites	**Source:** Cefas (2019) and Lle.gov.uk Data on UK disposal sites. Polygon data were filtered by status 'Open' for use in the analysis.	The Cefas Study did not include disposal sites.
Tidal Currents	**Source**: Atlas of UK Renewable Resources, ABPmer (2014) Gridded data (resolution approx. 1.8 km) for wave, tide and wind covering the UK Continental Shelf. For tidal currents, spring and neap peak flows are included, but no information on direction. This was not used in the final heatmaps for the reasons highlighted in the adjacent cell.	The Cefas Study mapped important prevailing currents into and between UK regional waters. Consideration was therefore given to using the tidal current data in this study. However, it was unclear how this dataset could be used in the overall pathway heatmap, since locations of high-speed current flow do not necessarily correlate with high risk of the presence of INNS; areas where the current is very low may be more favourable for high populations of INNS. The current will contribute to the spread of any INNS along the coast, but data was not available to this study which included direction of flow. Similarly, spatial data on fronts and coastal cells was not available to this project. Therefore, currents were not included in this pathway or in the overall risk heatmap.

The following offshore activities heatmaps were produced:

- Heatmap for offshore wind sites, presence (*value = 100*) or absence (*value = 0*) of an offshore wind site;
- Heatmap for wave or tidal energy sites, presence (*value = 100*) or absence (*value = 0*) of a wave or tidal energy site;
- Heatmap for aggregate extraction sites, presence (*value = 100*) or absence (*value = 0*) of an aggregate extraction site;
- Heatmap for dredging activities, presence (*value = 100*) or absence (*value = 0*) of a marine licence application site;
- Heatmap for open disposal sites, based on the presence (*value = 100*) or absence (*value = 0*) of a disposal site; and
- Heatmap for all offshore activities combined.

The values in the heatmaps from the offshore activities data were subsequently normalised to the same scale, in order to compare all introduction pathways, following the method described in Section 4.1.

4.7. Combining heatmaps for all introduction pathways

A heatmap of the risk of INNS introduction was created across all of the introduction pathways considered within this project, by combining the overall heatmaps for each introduction pathway.

4.7.1. Weighting introduction pathways

It was not appropriate to give equal weighting to all pathways as this would only give an indication of where pathways overlap, but not necessarily areas at higher risk to introduction of INNS. Where scores are scaled between 0 and 100 for all pathways, comparison of activity intensity scores between pathways was problematical given that the same score may represent a different level of activity for each pathway and scores are based on data of different resolution. For example, a score of 100 for the commercial shipping pathway represents much higher activity than a score of 100 for the recreational boating pathway (Tidbury *et al*., 2014).

In practice, the main risk factors are considered to be shipping (international and recreational) and aquaculture, both accounting for approximately 80% of primary and secondary introductions (EAA, 2019b). Therefore, a comparative weighting system was applied to allow a distinction between the relative risks from the different introduction pathways.
The following weightings were used in this study to produce the combined introduction pathway heatmap (Figure 6). These weightings were adapted from the EEA (EEA 2019b) metadata table which identified the percentage of non-indigenous species introductions associated with different pathways of introduction in the Celtic Sea. This percentage has been used as a proxy for the comparative risk between different introduction pathways. The EEA recognises shipping, including recreational boating, as the main vector of introduction, therefore commercial shipping and recreational boating have been combined for the purposes of this heatmap. The metadata table did not provide a separate weighting for offshore activities, however, weightings have been based on the EEA (2019b) “Transport stowaway” breakdown

detailing the number of introductions associated with offshore oil and gas platforms, dredging and angling or fishing equipment.
.
- Commercial shipping and recreational boating (combined) = 55.6%
- Shellfish gathering/ production = 34.6%
- Offshore activities = 1.1%

4.7.2. Summary of combined heatmaps

Table 6 summarises the heatmaps produced for each introduction pathway and shows how they were combined to produce the final heatmap for all introduction pathways.

The overall pathway heatmaps and the final combined heatmap are presented in Section 5; all individual data layer and grouped data layer heatmaps are in Appendix A. The final combined heatmap is also presented in Section 5.7 with nature designations overlaid to show which designations may be at greater risk from introduction of a marine INNS.

Table 6 Summary of introduction pathway heatmaps

Pathways and Data layers	Data layer Heatmaps	Grouped Data layer Heatmaps	Overall Introduction Pathway Heatmaps	Final Combined Heatmap
Commercial shipping				All introduction pathways
UK AIS Density Grid 2017	Port Service	Local shipping	All shipping	
	Non-port service			
	Dredging			
	High Speed Craft	Regional shipping		
	Passenger			
	Military/Law	Global shipping		
	Cargo			
	Tanker			
	Unknown vessels			
Recreational boating				
Intensity of Recreational Boating	Intensity of Recreational Boating	n/a	All recreational boating	
General Boating Areas	General Boating Areas			
Shellfish gathering/ production				
Shellfish Waters	Shellfish Waters	n/a	Shellfish gathering/ production sites	
Several & Regulating Orders	Several & Regulating Orders			
Cockle Gathering Sites	Cockle Gathering Sites			
Offshore activities				
Offshore wind	Offshore wind	n/a	All offshore activities	
Wave and tidal	Wave and tidal			
Aggregate extraction	Aggregate extraction			
Dredging Activities	Dredging Activities			
Disposal Sites	Disposal Sites			

5. Results

The overall heatmaps for each introduction pathway are presented in this section along with descriptions of the areas of relatively high, medium or low risk of introduction of marine INNS. Where there is no activity shown in the heatmaps, this is assumed to be the areas of lowest risk, however, it may also be due to a data gap. A greater emphasis has been placed on the descriptions of the relative levels of risk of introduction in coastal waters in order to help focus management effort and identify sensitive areas which may be at a higher risk.

All the individual data layer heatmaps and grouped data layer heatmaps for each introduction pathway are presented in Appendix A.

5.1. Commercial shipping pathway

Figure 2 shows the heatmap of the combined commercial shipping pathway for all vessels (excluding recreational and fishing vessels). The heatmap shows that the coastal areas at the highest relative risk of introductions of marine INNS (scaled score of 50 or over) are located at:

- Milford Haven
- Holyhead

Areas of moderate risk (scaled score between 2 and 50) areas occur at:

- Mostyn
- Fishguard
- Swansea
- Neath
- Port Talbot
- Port of Barry
- Cardiff
- Penarth
- Newport
- St. Bride's Bay
- The north coast of Anglesey
- Bangor
- The coastline between Rhyl and the Dee Estuary

The remainder of the Welsh coastline are mapped as being of at relatively low risk of introductions of marine INNS (scaled score of less than 2) apart from isolated pockets of grid cells where no commercial shipping activity has been recorded.

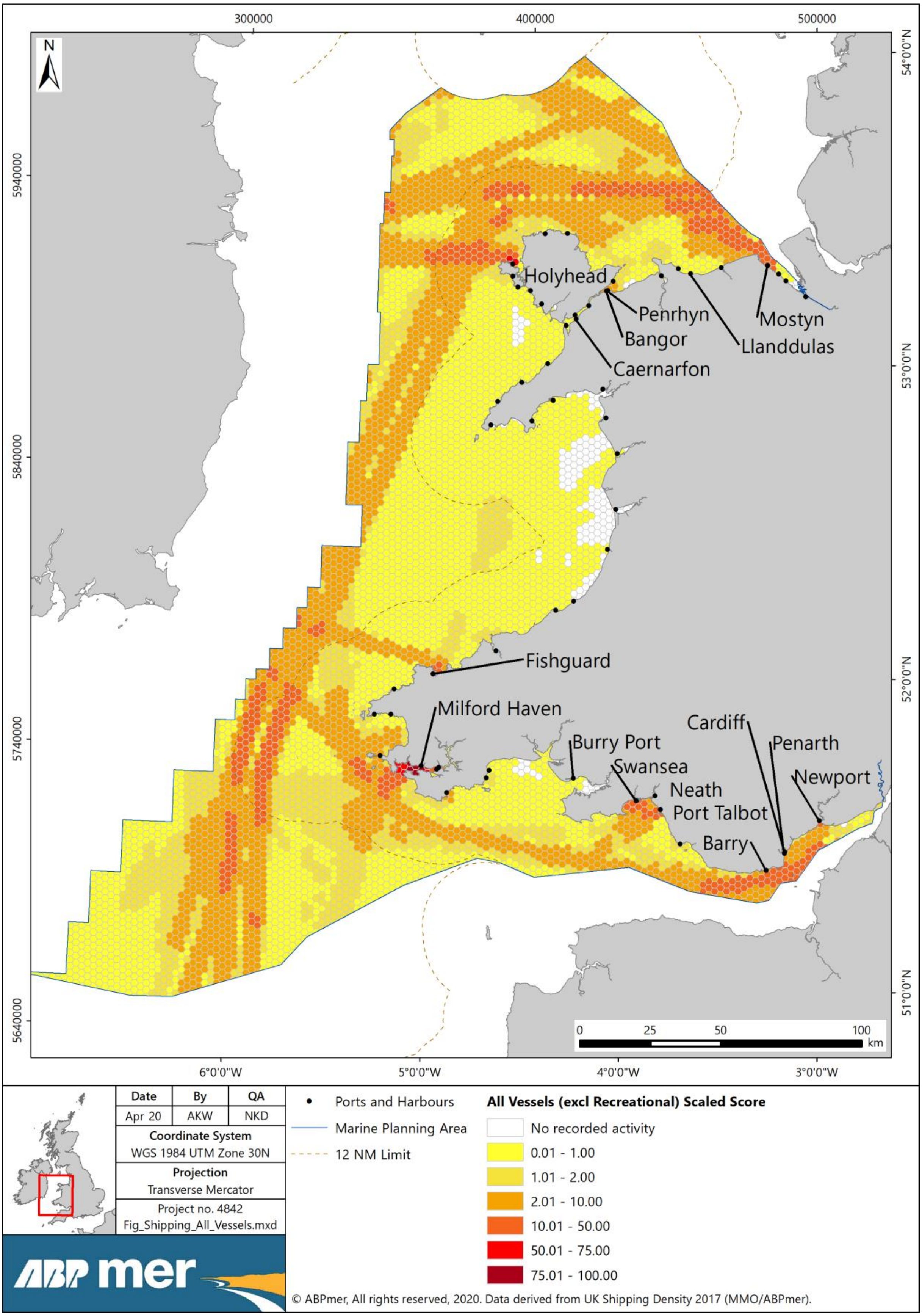

Figure 2 Combined commercial shipping heatmap

5.2. Recreational boating pathway

Figure 3 shows the heatmap for the combined recreational vessels introduction pathway.

Much of the Welsh coastline has been classified as being at high or moderate risk of introductions of marine INNS (scaled score of 10 or over), apart from areas with no recorded recreational boating activity. The highest risk areas (where the scaled score is greater than 50) occur at:

- Conwy
- The Menai Strait
- Almost the entire coastal area of Holyhead
- Porth Nefyn
- Pwllheli and westwards along the Llyn Peninsula
- Newport Bay
- Milford Haven
- Coastal areas on the west side of Swansea Bay
- Cardiff

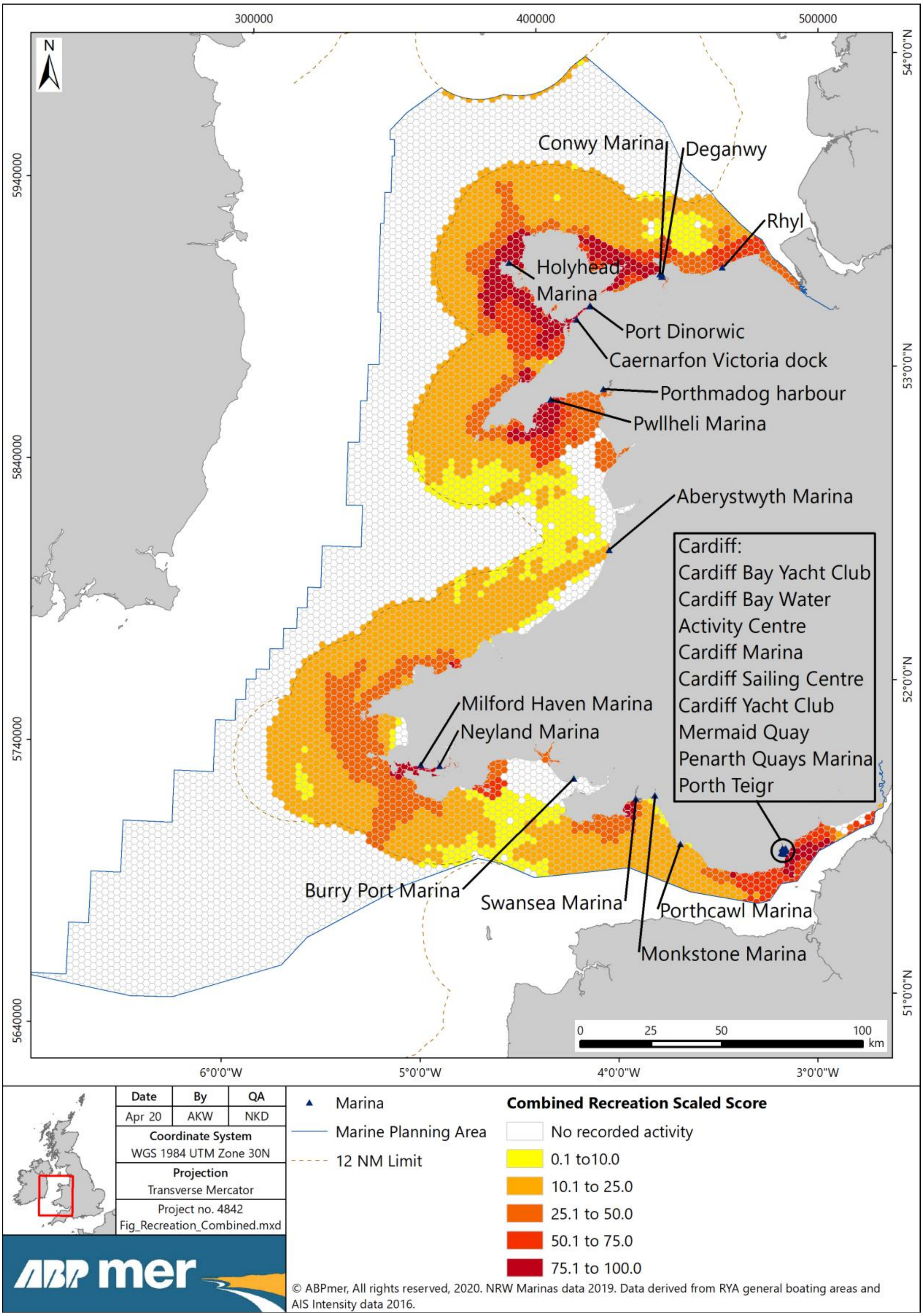

Figure 3 Combined recreational boating heatmap

5.3. Shellfish gathering/ production

Figure 4 shows the heatmap for the combined shellfish gathering/ production introduction pathway.

The areas of highest risk of introductions of marine INNS from shellfish gathering/ production (with a scaled score of 100) were identified at:

- North end of the Dee Estuary
- Parts of the Menai Strait (at the western and eastern ends)
- The Loughor Estuary

Areas of moderate risk (with a scaled score of 66.7) were found at the following locations:

- The Dee Estuary
- Throughout the Menai Strait
- Red Wharf Bay
- Cefni Estuary
- Dwyryd Estuary
- Mawddach Estuary
- Dyfi Estuary
- Cleddau Estuary
- Carmarthen Bay
- Outer Loughor Estuary
- Swansea Bay

The remainder of the Welsh coastline are mapped as being of at relatively low risk of introductions of marine INNS by this pathway. These are most extensive in Swansea Bay and at Porthcawl and there are more isolated low risk cells near Tenby, Milford Haven, and along the north coast.

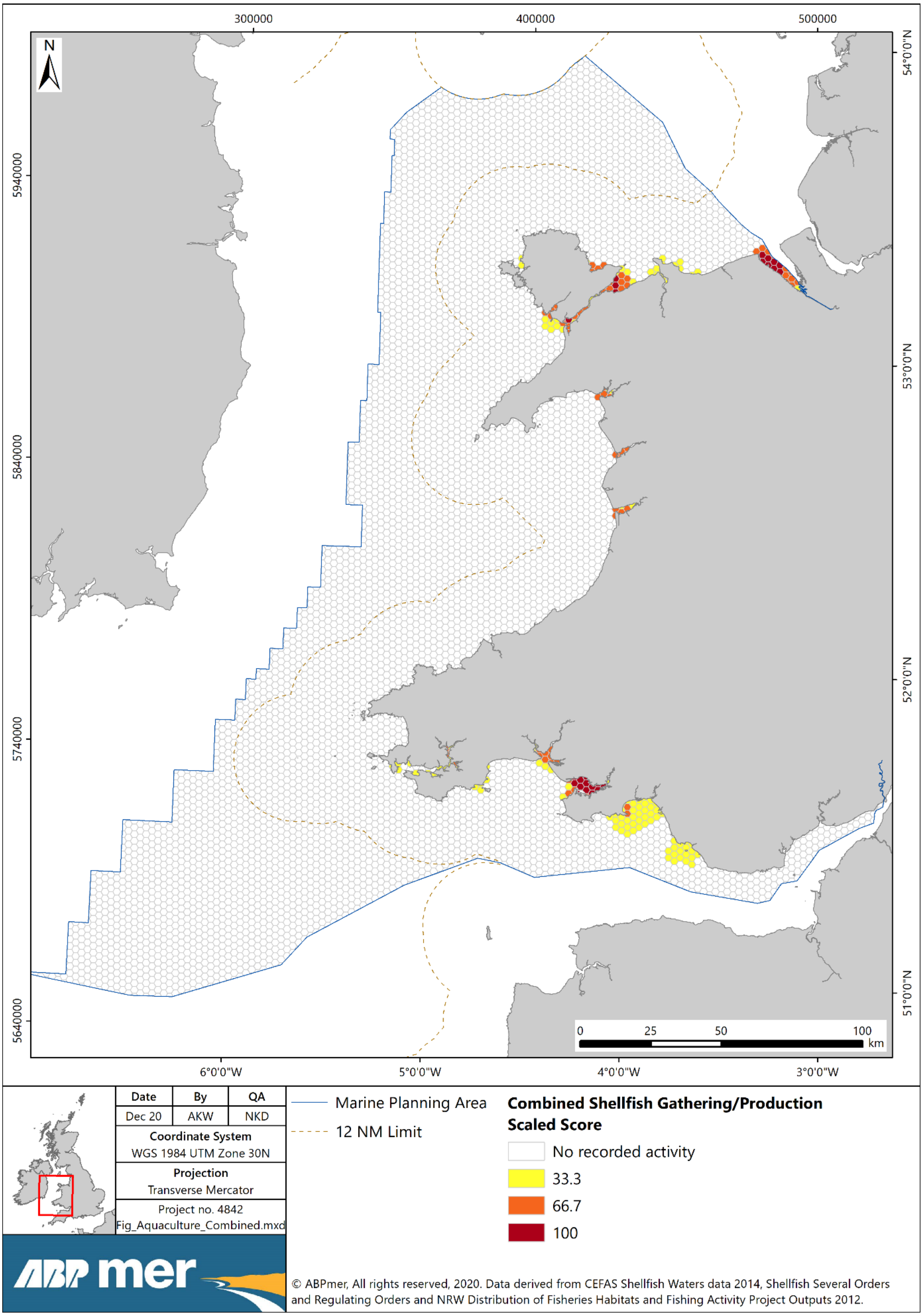

Figure 4 Combined shellfish gathering/production heatmap

5.4. Offshore activities pathway

Figure 5 shows the heatmap for the combined offshore activities introduction pathway. The areas of highest risk of introductions of marine INNS from offshore activities (scaled score greater than 50) occur at the following locations:

- Severn Estuary south of Newport
- Pembroke
- West of Anglesey
- Parts of the Dee Estuary and approaches to the port of Mostyn

Areas of moderate risk (scaled score 25 to 50) were identified in the Severn estuary, south and south-west of Milford Haven, West of Holyhead and off the north coast. Moderate risk areas occur closer to the coast at the following locations:

- Newport
- Cardiff
- Barry
- Neath
- Swansea
- Saundersfoot Bay
- Tenby
- Milford Haven
- Ramsey Island
- New Quay
- Aberaeron
- Holyhead
- Conwy
- Parts of the Dee Estuary

Low-risk areas (with scaled score less than 25) occur at the following locations:

- Alongside more high-risk areas off the north coast.
- In the Bristol Channel south of Carmarthen Bay.
- In the Severn estuary south of Newport.

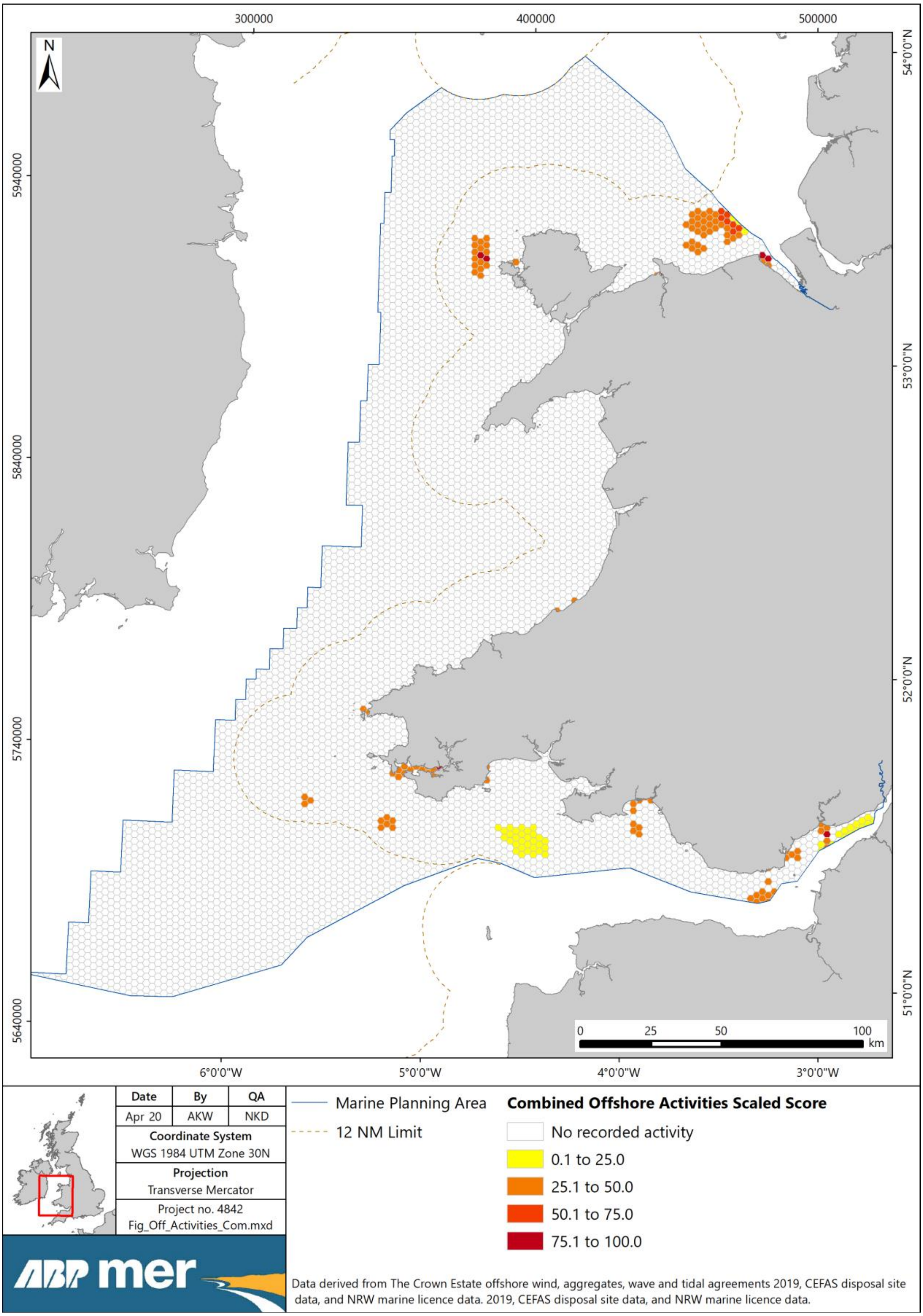

Figure 5 Combined offshore activities heatmap

5.5. Combined introduction pathways heatmap

The heatmap combined across all of the considered introduction pathways characterises the entire Welsh coast in terms of the risk of introductions of marine INNS. Figure 6 shows the heatmap for the overall combined introduction pathways, based on the weightings between pathways discussed in Section 4.7.

Areas at highest risk (with scaled score of 50 or over) were identified at the following coastal locations:

- The Dee Estuary
- Bangor
- Beaumaris
- Holyhead
- The Menai Strait
- Malltraeth Bay
- Milford Haven
- Pembroke Dock
- Llanelli and parts of the Loughor Estuary
- Swansea and parts of Swansea Bay

Areas at the next highest risk (with scaled scores between 25 and 50) were identified at the following coastal locations:

- Llanddulas
- Colwyn Bay
- Llandudno
- Conwy
- Penrhyn
- Porthmadog
- Barmouth
- Aberdyfi
- Fishguard
- Tenby
- Saundersfoot
- The Towy Estuary
- The Loughor Estuary
- Swansea Bay and westwards along the coast
- Port Talbot
- Porthcawl
- Barry
- Penarth
- Cardiff
- Newport

Coastal areas at moderate risk (with scaled scores of 5 to 25) were identified at the following locations:

- Along the north coast from the Dee Estuary, around Anglesey to the Llyn Peninsula
- The south coast of the Llyn Peninsula
- Porthmadog
- Barmouth
- At the coast east and west of Fishguard and along the coast to Milford Haven
- The coast east of Milford Haven
- West of Swansea Bay
- Interspersed with high-risk areas from the Gower Peninsula to Newport

Notable low risk coastal areas (with scaled scores less than 5) occur at the following locations:

- Large sections of Cardigan Bay
- St. Bride's Bay
- Carmarthen Bay

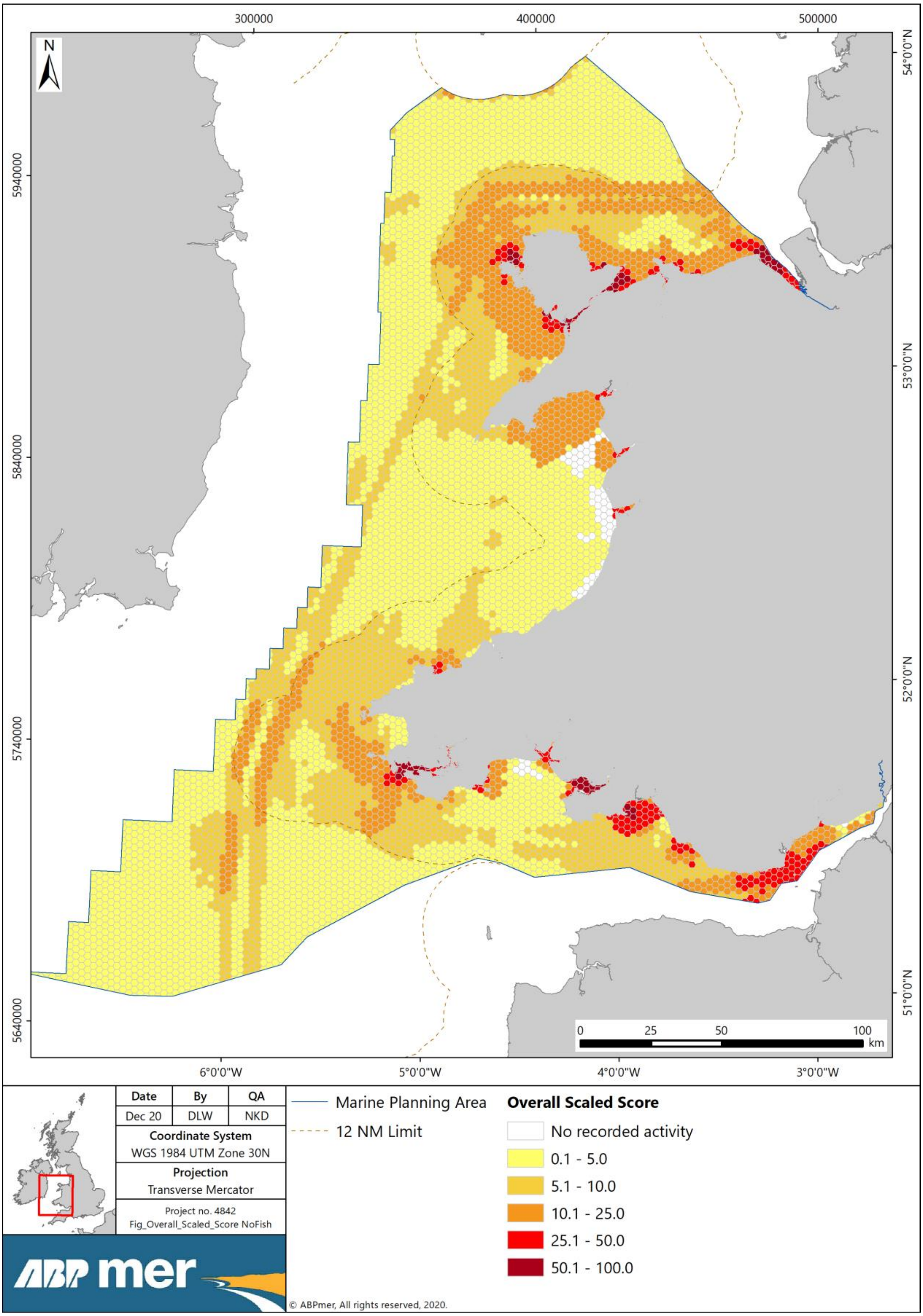

Figure 6 Combined introduction pathways heatmap

5.6. Designations and combined pathways heatmap

In Figure 7 the combined introduction pathways heatmap has been overlain with the designated sites (SACs, SPAs, Ramsar sites and MCZs) to determine which sites may be at higher risk from the introduction of marine INNS. Individual figures showing the combined introduction pathways heatmap with each designation type are included in Appendix A. Areas at highest risk are predominantly close to sheltered bays, inlets and major ports and harbours, in line with the pathways recognised as dominant vectors of introduction at the following coastal locations.

Higher risk areas overlap with the following SACs:

- The Dee Estuary SAC
- North Anglesey Marine SAC
- Menai Strait and Conwy Bay SAC
- Anglesey Coast Saltmarsh SAC
- West Wales Marine SAC
- Pembrokeshire Marine SAC
- Carmarthen Bay and Estuaries SAC
- Bristol Channel Approaches SAC
- Hafren SAC
- Limestone Coast of SW Wales SAC
- Severn Estuary SAC

Higher risk areas overlap with the following SPAs:

- The Dee Estuary SPA
- Anglesey Terns SPA
- Lavan Sands SPA
- Liverpool Bay SPA
- Skomer, Skokholm and the Seas off Pembrokeshire SPA
- Carmarthen Bay SPA
- Burry Inlet SPA
- Severn Estuary SPA

Higher risk areas overlap with the following Ramsar sites:

- The Dee Estuary Ramsar
- Burry Inlet Ramsar
- Severn Estuary Ramsar

The Skomer MCZ is located in an area of moderate risk.

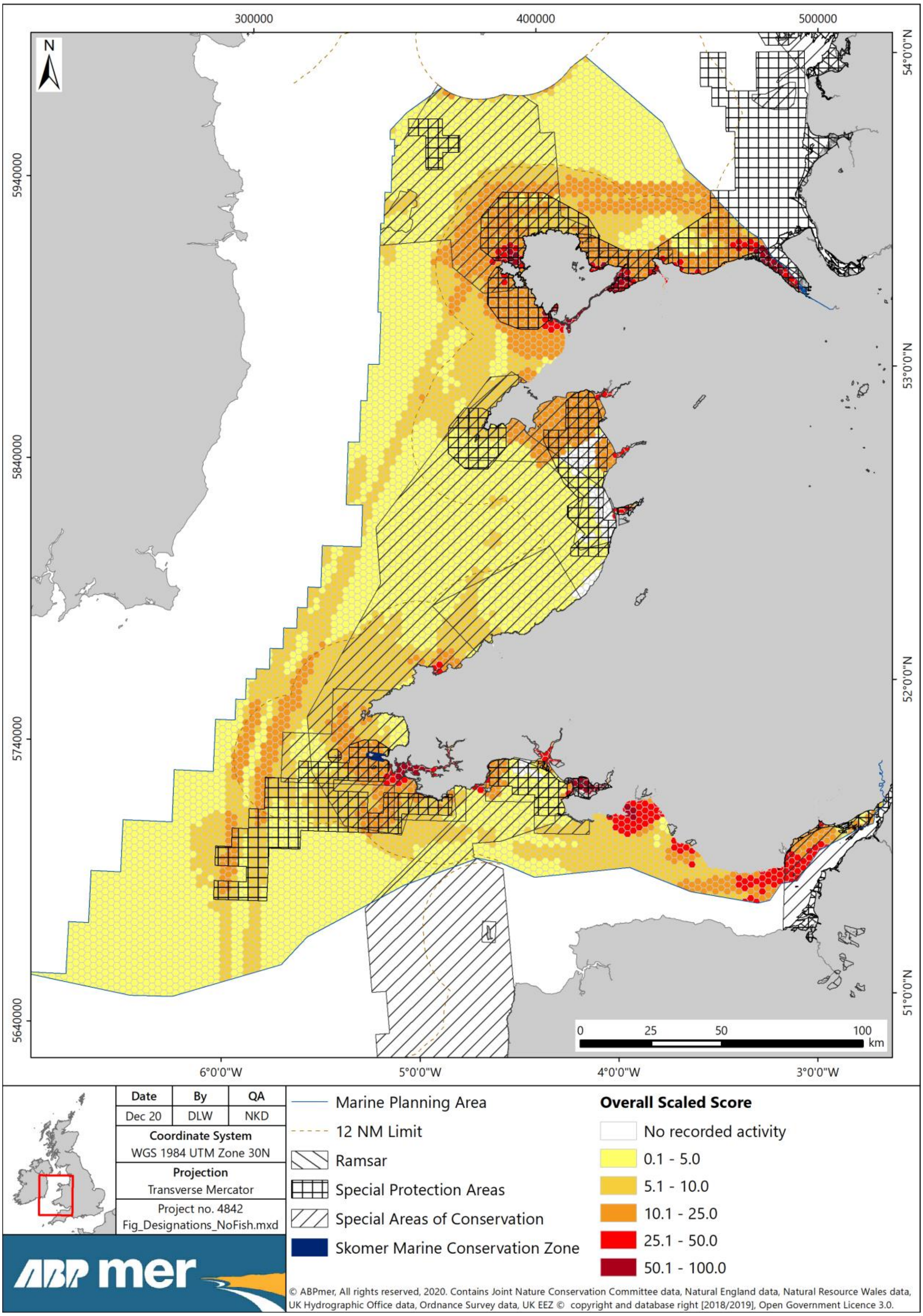

Figure 7 Combined introduction pathways and designations heatmap

6. Discussion

6.1. Introduction pathways

This assessment provides a valuable insight into hotspots related to each potential pathway of introduction included in this report (Figures 2-6), the areas where the main areas of risk overlap for the different pathways and their overlap with protected areas (Figure 7). The outputs from this assessment can help to form the basis on which to underpin biosecurity planning. It should be noted, however, that this was a national scale mapping exercise based only on freely available datasets, which themselves have limitations and possible inaccuracies due to incomplete coverage, both temporally and spatially. The scorings applied to the input datasets and weightings applied to the introduction pathways are also based on the available literature and expert judgement. Where there is no activity shown in the heatmaps, this is assumed to be the lowest risk of all, however, it may also be due to a data gap.

Aquaculture and shipping (including recreational vessels) are responsible for the majority of INNS introductions in the Celtic Sea (EEA, 2019b), therefore, the overall heatmap is heavily weighted towards these introduction pathways. Areas where these heavily weighted pathways overlap have resulted in hotspots of pressure where there is increased likelihood of introduction of marine INNS. Overall, key hotspots that have been identified around the Welsh coast include the Dee Estuary, Anglesey, and along the south coast including Milford Haven, Swansea Bay and Port Talbot.

The overall heatmap has provided a general overview of the areas of relatively high risk of introduction of INNS. However, the individual heatmaps provide a better representation of the risks associated with individual pathways. The individual pathway heatmaps should, therefore, be considered alongside the overall heatmap to best understand the associated risks and provide more specific detail on areas where management measures should be targeted. This is an important consideration when deciding on how best to manage risks associated with specific activities.

Ports and harbours are recognised as important areas for monitoring the early detection of introductions (Arenas *et al*., 2006) due to the high intensity of commercial vessels. Compared to commercial shipping, recreational vessels likely pose a greater risk of introduction to a wider area outside of ports and harbours. They can travel long-distances and anchor/moor for a prolonged period of time in shallow, sheltered coastal bays and marinas making them an ideal vector for both the primary and secondary introduction of INNS on local and regional scales (Minchin *et al*., 2006; Tidbury *et al*., 2014).

The risk of introduction from shellfish waters are mapped as being highest in sheltered bays and estuaries/inlets along the Welsh coastline, with some of the largest areas around the River Dee, Menai Strait, Loughor Estuary and around Carmarthen Bay and Swansea Bay. Given the open nature of shellfish gathering/ production sites, these areas might facilitate the spread of INNS once introduced. For example, hitchhiking species on aquaculture imports (including predators, pathogens and parasites) have been observed to establish populations outside aquaculture sites (Grosholz *et a*l., 2015). In Europe, Savini *et al*. (2010) found that the majority of hitchhiking species were introduced via bivalve aquaculture (mainly Pacific oysters and Manila clams), by fouling on shells and macroalgae used for packaging.

Other introduction pathways are relatively under studied compared to shipping and aquaculture. Some dredging and disposal programmes around the UK have monitored for non-indigenous species (Stebbing *et al*., 2014), however, more data are needed to assess the risks associated with these pathways. Studies on offshore structures have highlighted the ability for non-indigenous species to rapidly colonise new areas via natural dispersal (De Mesel *et al*., 2015). Monitoring of fouling on offshore wind structures found the first records of two non-indigenous amphipod species, *Jassa marmorata* and *Caprella mutica* in Denmark (Dong Energy *et al*., 2006). Similarly, De Mesel *et al*. (2015) found ten non-indigenous species on the foundations of wind turbines in the southern North Sea. Offshore wind farms and wave and tidal structures in north Wales overlap with areas of high shipping intensity, thus could act as an ideal location for the establishment of INNS. The Ecostructure Project (Ecostructure, 2020), as part of the Ireland-Wales Cooperation Programme (2014-2020), aims to research eco-engineering solutions to benefit marine plants and animals, including investigating the mechanisms by which artificial structures facilitate the introduction and spread of non-indigenous species around the Irish Sea. This project will increase overall understanding of the role artificial structures play in the introduction of non-indigenous species in Wales and may help with identifying tools and preventative measures to impede invasions.

6.2. Overlap with designated sites

Protected areas with potentially the highest risk of introduction in Wales, based on consideration of the introduction pathways alone, are predominantly those located close to sheltered bays, inlets and major ports and harbours. This is consistent with the relative intensity of the introduction pathways recognised as dominant vectors of introduction (Figures 2 to 4). Key areas of overlap with designated sites include in the vicinity of the Dee Estuary, along the north coast of Wales and around Anglesey, Milford Haven, Carmarthen Bay, Swansea Bay and along the south-east coast of Wales.

In the PLAS SAC, the main vectors of introduction are from recreational vessels, particularly around the Llŷn Peninsula, and shellfish gathering / production sites, predominantly in the estuaries and inlets. The risk associated with commercial shipping is low, largely due to the major ports being situated outside of the PLAS SAC. This is of course, not taking into account the pathways that weren’t included in this report such as tidal currents and live bait, etc.

Areas of high risk of introduction that overlap with protected sites could be a focus for targeted monitoring programmes to ensure the early detection of INNS and, therefore, facilitate the eradication or control of INNS before further spread in these locations. This could be combined, for example, with data collection that is undertaken to inform wider drivers for understanding the condition of designated sites and features.

The introduction pathways considered within this assessment are unlikely to change substantially in the medium term (20-50 years), possibly with the exception of offshore activities and new shellfish gathering/ production sites. In addition, where such changes do occur, particularly where a marine licence is required, a biosecurity risk assessment is typically required. The identified high-risk areas and their overlap with designated sites therefore provides a high-level indication of protected areas that could be at most risk from INNS. It should be noted, however, that this is based on national scale mapping and that site-specific activities and conditions will always be an important consideration.

Protected areas may need site-based prevention and detection efforts depending on the introduction pathways which overlap with these areas. Similarly, measures extended past the boundaries of the protected areas may further reduce the risk of introduction from outside these locations by secondary transfer or natural dispersal (Monaco and Genovesi, 2014). Biosecurity strategies should also be updated regularly, for example, when an INNS becomes established or knowledge of the pathways of introduction increases for a specific area (Simberloff *et al*., 2013).

6.3. Future considerations

Each introduction pathway examined in this report has been based on specific anthropogenic vectors of introduction where data are available at a national scale. However, further factors could have a large influence on both the estimated risk of introduction associated with individual pathways as well as the likelihood of successful establishment of INNS.

In practice, species specific biological tolerances would determine whether individual pathways provide a viable vector for the translocation of a particular INNS. This combined with the suitability of conditions in the new habitat would influence the likelihood of establishment. If particular species are of interest in biosecurity planning, consideration is therefore required of the biological traits of the respective INNS and the relationship with the different introduction pathways. This could include, for example, more detailed consideration of the ports of origins of vessels arriving in Welsh waters as well as the relative similarity of environmental conditions between the two locations.

The Cefas Study included data on the number of unique connections and number of voyages into ports from inside and outside the UK. This enabled the shipping pathway to be scaled so that the greater the number of connections/sources and number of voyages, the greater the likelihood of introduction. These data were not available for the present assessment; however, vessel density could be weighted by number of unique connections and provide a more detailed understanding of the likelihood of introduction per vessel.

Data on types of shellfish gathering/ production harvesting, which was not available to this study, would improve the analysis of the risk from this introduction pathway, as well as information on live shellfish imports.

Fishing was originally included in this report, however, it was decided that the limited data gave an inaccurate representation of the fishing activity in Wales and therefore, fishing was later removed. The inshore vessel monitoring system recently introduced to Wales will provide much more accurate data in the future for vessels under 12 metres. It would be useful to have the ability to differentiate between vessels in transit (to and from fishing grounds) and vessels deploying fishing gear, this would assist with identifying INNS introduction pathways further.

Natural dispersal of species, via ocean currents, was not explored as a pathway in this report, however, it is an important vector which promotes the spread of INNS (Tidbury *et al*., 2014). Natural dispersal between locations may also be facilitated by settlement on offshore structures as ‘stepping-stones’ (Adams *et al*., 2013) or on rafting objects such as plastic or natural debris (Rech *et al*., 2016). Other pathways such as deliberate release, live bait, etc. were also out of the scope of this project and the data is currently insufficient to map them.

Strategies to assess the full risk of introduction of INNS should also consider temporal patterns associated with introduction pathways. For example, recreational boating and shipping intensity fluctuates with season; the summer months have a significant increase in the number of vessels moving between locations than in the winter months (MMO, 2014). Propagule pressure (the number of individuals released into a new region) plays an important role in the likelihood that an INNS will establish at a particular time (Simberloff, 2009). An increase in shipping intensity may, therefore, lead to an increase in propagule pressure and increased risk of introduction (Johnston *et al*., 2009). Thus, temporal variation in the introduction pathways may change the likelihood of introduction by that pathway at different times of the year.

Taking these other influencing factors into consideration, the heatmaps provide a useful, national scale, position of the relative intensity of risk of introduction of INNS through the pathways assessed. Further investigation of target INNS life-history traits and temporal trends in introduction pathways could aid in understanding the likelihood of invasion by particular INNS and an idea of peak periods of invasions.

7. Conclusion

The Celtic Sea (including Welsh and Irish waters) has approximately two to three new introductions of non-indigenous species every year (European Environment Agency (EEA), 2015; 2019a). Identifying coastal areas where INNS are more likely to be introduced is a valuable tool which will help to focus management efforts and identify sensitive areas which may be at a higher risk. Mapping the intensity of introduction pathway activities can aid the identification of these higher risk areas.

This project has produced both individual and an overarching combined heatmaps for commercial shipping, recreational boating, shellfish gathering/ production and offshore activities introduction pathways. The heatmaps have also been overlapped with MPAs in Welsh waters to provide an indication of designated areas at increased risk of marine INNS introduction. It should be noted that this report is a baseline that will be used as part of a toolkit to inform biosecurity planning.

The main coastal areas mapped as being of highest risk of introductions of marine INNS from the commercial shipping introduction pathway are Milford Haven and Holyhead. For the recreational boating introduction pathway, the coastal areas at highest risk are around Anglesey, around the Llyn Peninsula, Milford Haven, Swansea and the Severn Estuary. For the shellfish gathering/ production introduction pathway the areas at highest risk are the Dee Estuary, Menai Straits and Loughor Estuary. For offshore activities, the main coastal areas at highest risk are the Dee

Estuary, areas to the west of Anglesey, Pembroke and an area south of Newport in the Severn Estuary.

Protected areas with potentially the highest risk of introduction in Wales, based on consideration of the introduction pathways included alone, are predominantly located close to sheltered bays, inlets and major ports and harbours. This is consistent with the relative intensity of the introduction pathways recognised as dominant vectors of introduction. Key areas of overlap with designated sites include in the vicinity of the Dee Estuary, along the north coast of Wales and around Anglesey, Milford Haven, Carmarthen Bay, Swansea Bay and along the south-east coast of Wales.

The introduction pathways considered within this assessment are unlikely to change substantially in the medium term (20-50 years), possibly with the exception of offshore activities and new shellfish gathering/ production sites. In addition, where such changes do occur, particularly where a marine licence is required, a biosecurity risk assessment is typically required. The identified high-risk areas and their overlap with designated sites therefore provides a high-level indication of protected areas that could be at most risk from INNS. These sites could be a focus for targeted monitoring programmes to ensure the early detection of INNS and, therefore, facilitate the eradication or control of INNS before further spread.

It should be, noted, however, that this was a national scale mapping exercise based only on freely available datasets, which themselves have limitations and possible inaccuracies due to incomplete coverage, both temporally and spatially. The scorings applied to the input datasets and weightings applied to the introduction pathways are also based on available literature and expert judgement. Site-specific activities and conditions will always be an important consideration, as well as temporal variations. Fishing was not included in this report due to insufficient data. The new inshore vessel monitoring system will provide much more accurate data in the future.

The heatmaps provide a useful, national scale, position of the relative intensity of risk of introduction of INNS through the pathways assessed. Further investigation of target INNS life-history traits and temporal trends in introduction pathways could aid in understanding the likelihood of invasion by particular INNS and an idea of peak periods of invasions. This study investigated introduction pathways at a Wales-wide level; for risks at a more localised scale, such as protected sites, higher resolution data specific to the area of interest may improve predictions of the risks of introduction of marine INNS.

Taking these limitations and other influencing factors into consideration, these outputs provide a valuable insight into hotspots related to each potential pathway of introduction, the areas where the main areas of risk overlap for the different pathways and their overlap with protected areas.

8. References

Adams, T.P., Miller, R.G., Aleynik, D. and Burrows, M.T. 2014. Offshore marine renewable energy devices as stepping stones across biogeographical boundaries. *Journal of Applied Ecology* 51 (2), 330-338.

Arenas, F., Bishop, J.D.D., Carlton, J.T., Dyrynda, P.J., Farnham, W.F., Gonzalez, D.J., Jacobs, M.W., Lambert, C., Lambert, G., Nielsen, S.E. and Pederson, J.A. 2006. Alien species and other notable records from a rapid assessment survey of marinas on the south coast of England. *Journal of the Marine Biological Association of the United Kingdom* 86 (6), 1329-1337.

Bax, N., Williamson, A., Aguero, M., Gonzalez, E. and Geeves, W. 2003. Marine invasive alien species: a threat to global biodiversity. *Marine Policy* 27 (4), 313-323.

Clarke Murray, C., Pakhomov, E.A. and Therriault, T.W. 2011. Recreational boating: a large unregulated vector transporting marine invasive species. *Diversity and Distributions* 17 (6), 1161-1172.

Convention of Biological Diversity (CBD). 2002. *Alien species that threaten ecosystems, habitats or species to which is annexed Guiding principles for the prevention, introduction and mitigation of impacts of alien species that threaten ecosystems, habitats or species.* The Hague: Sixth Conference of the Parties, Decision VI/23, 7-19.

Defra. 2018. Marine Protected Areas Network Report 2012-2018. Presented to Parliament pursuant to Section 124 of the Marine and Coastal Access Act 2009. pp87.

De Mesel, I., Kerckhof, F., Norro, A., Rumes, B. and Degraer, S. 2015. Succession and seasonal dynamics of the epifauna community on offshore wind farm foundations and their role as stepping stones for non-indigenous species. *Hydrobiologia* 756 (1), 37-50.

Dong Energy, Vattenfall, Danish Energy Authority, The Danish Forest, Nature Agency. 2006. *Danish Offshore Wind-Key Environmental Issues*. ISBN: 87-7844-625-0, 1-142.

Ecostructures, 2020. Ecostructures, climate change adaptation through ecologically-sensitive coastal infrastructure [online]. [Accessed April 2020]. Available at: hiip://www.ecostructureproject.eu/.

European Environment Agency (EEA). 2015. *Trends in marine non-indigenous species.* Indicator Assessment. Available at: hiips://www.eea.europa.eu/data-and-maps/indicators/trends-in-marine-alien-species-mas-2/assessment.

European Environment Agency (EEA). 2019a. *Trends in marine non-indigenous species.* Indicator Assessment. Available at: hiips://www.eea.europa.eu/data-and-maps/indicators/trends-in-marine-alien-species-mas-3/assessment.

European Environment Agency (EEA). 2019b. *Pathways of introduction of marine non-indigenous species to European seas.* Indicator Assessment – Data and maps.

Available at: hiips://www.eea.europa.eu/data-and-maps/indicators/trends-in-marine-alien-species-1/assessment.

Ferrario, J., Caronni, S., Occhipinti-Ambrogi, A. and Marchini, A. 2017. Role of commercial harbours and recreational marinas in the spread of non-indigenous fouling species. *Biofouling*, 33 (8), 651-660.

Griffith, K., Mowat, S., Holt, R.H., Ramsay, K., Bishop, J.D., Lambert, G. and Jenkins, S.R. 2009. First records in Great Britain of the invasive colonial ascidian *Didemnum vexillum* Kott, 2002. *Aquatic Invasions* 4 (4), 581-590.

Grosholz, E.D., Crafton, R.E., Fontana, R.E., Pasari, J.R., Williams, S.L. and Zabin, C.J. 2015. Aquaculture as a vector for marine invasions in California. *Biological Invasions* 17 (5), 1471-1484.

Herborg, L.M., Bentley, M.G. and Clare, A.S., 2002. First confirmed record of the Chinese mitten crab (*Eriocheir sinensis*) from the River Tyne, United Kingdom. *Journal of the Marine Biological Association of the United Kingdom*, 82 (5), 921-922.

Herborg, L.M., Rushton, S.P., Clare, A.S. and Bentley, M.G. 2005. The invasion of the Chinese mitten crab (*Eriocheir sinensis*) in the United Kingdom and its comparison to continental Europe. *Biological Invasions* 7 (6), 959-968.

ICES. 2008. Report of the ICES Advisory Committee, 2008. Book 6, North Sea. ICES, Copenhagen

Johnston, E.L., Piola, R.F. and Clark, G.F. 2009. *The role of propagule pressure in invasion success.* In: Rilov, G. and Crook, J.A. (eds.) Biological invasions in marine ecosystems, 133-151. Berlin: Springer.

Manchester, S.J. and Bullock, J.M. 2000. The impacts of non-native species on UK biodiversity and the effectiveness of control. *Journal of Applied Ecology* 37 (5) 845-864.

Marine Management Organisation (MMO). 2014. *Mapping UK Shipping Density and Routes from AIS.* A report produced for the Marine Management Organisation. MMO Project No: 1066. 1-35.

Minchin, D., Floerl, O., Savini, D. & Occhipinti-Ambrogi, A. 2006. *Small craft and the spread of exotic species.* In: Davenport, J.L. and Davenport J. (eds) The ecology of transportation: managing mobility for the environment. Berlin: Springer-Verlag, 99–118.

Minchin, D., Gollasch, S., Cohen, A.N., Hewitt, C.L. and Olenin, S., 2009. *Characterizing vectors of marine invasion.* In: Rilov, G. and Crooks, J.A. (eds) Biological invasions in marine ecosystems. Berlin: Springer, 109-116.

Mineur, F., Cook, E.J., Minchin, D. Bohn, K., MacLeod, A. and Maggs, C.A. 2012. Changing Coasts: Marine aliens and artificial structures. In: Gibson, R.N., Atkinson, R.J.A., Gordon, J.D.M. and Hughes, R.N. (eds) Oceanography and Marine Biology: an annual review, p 189-233.

Monaco, A. and Genovesi, P. 2014. European Guidelines on Protected Areas and Invasive Alien Species, Council of Europe, Strasbourg, Regional Parks Agency – Lazio Region, Rome

Natural Resources Wales (NRW). Undated. *Marine Protected Areas* [online]. [Accessed March 2020]. Available at: hiips://naturalresources.wales/guidance-and-advice/environmental-topics/wildlife-and-biodiversity/protected-areas-of-land-and-seas/marine-protected-areas/?lang=en.

Payne, R.D., Cook, E.J., Macleod, A. and Brown, S. 2014, edited by Natural England and Natural Resources Wales, 2015. *Marine biosecurity planning - Guidance for producing site and operation-based plans for preventing the introduction and spread of invasive non-native species in England and Wales.* Available at: hiips://cdn.naturalresources.wales/media/684349/marine_biosecurity_planning_guidance_for_wales_and_england_november_2015.pdf?mode=pad&rnd=131653365600000000

Rech, S., Borrell, Y. and García-Vazquez, E. 2016. Marine litter as a vector for non-native species: what we need to know. *Marine Pollution Bulletin* 113 (1-2), 40-43.

Ruiz, G.M., Carlton, J.T., Grosholz, E.D. and Hines, A.H. 1997. Global invasions of marine and estuarine habitats by non-indigenous species: mechanisms, extent, and consequences. *American zoologist* 37 (6), 621-632.

Savini, D., Occhipinti–Ambrogi, A., Marchini, A., Tricarico, E., Gherardi, F., Olenin, S. and Gollasch, S. 2010. The top 27 animal alien species introduced into Europe for aquaculture and related activities. *Journal of Applied Ichthyology* 26, 1-7.

Simberloff, D. 2009. The role of propagule pressure in biological invasions. *Annual Review of Ecology, Evolution, and Systematics* 40, 81-102.

Simberloff, D., Martin, J.L., Genovesi, P., Maris, V., Wardle, D.A., Aronson, J., Courchamp, F., Galil, B., García-Berthou, E., Pascal, M. and Pyšek, P. 2013. Impacts of biological invasions: what's what and the way forward. *Trends in Ecology & Evolution* 28 (1), 58-66.

Smith, E.R.C., Bennion, H., Sayer, C.D., Aldridge, D.C. and Owen, M. 2020. Recreational angling as a pathway for invasive non-native species spread: awareness of biosecurity and the risk of long distance movement into Great Britain. *Biological Invasions*, 1-25.

Stebbing, P., Murray, J., Whomersley, P. and Tidbury, H. 2014. *Monitoring and surveillance for non-indigenous species in UK marine waters*. A report for Centre for Environment, Fisheries & Aquaculture Science (Cefas). 1-58.

Tidbury, H., Taylor, N., Copp, G., Garnacho, E. and Stebbing, P. 2014. *Introduction of marine non-indigenous species into Great Britain and Ireland: Hotspots of introduction* *and the merit of risk based monitoring.* Lowestoft: Cefas Contract Report C5995 (Objective 1).

Wallentinus, I. and Nyberg, C.D. 2007. Introduced marine organisms as habitat modifiers. *Marine Pollution Bulletin* 55 (7-9), 323-332.

Welsh Government. (2018) *Marine Protected Area Network Management Framework for Wales 2018–2023* [Viewed: March 2020]. Cardiff: Welsh Government. Report by Marine Protected Area Management Steering Group. p. 61. Available at: hiips://gov.wales/sites/default/files/publications/2018-09/marine-protected-areas-network-management-framework-for-wales-2018-2023.pdf.

Wood, C. Bishop, J. and Yunnie, A. 2015. Comprehensive Reassessment of NNS in Welsh Marinas. A report funded by the Welsh Government Ecosystems Fund (REF), grant GU9430.

9. Acronyms

AIS	Automatic Identification System
CBD	Convention on Biological Diversity
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
EEA	European Environment Agency
EMFF	European Maritime and Fisheries Fund
EMODNet	European Marine Observation and Data Network
EMSA	European Maritime Safety Agency
GIS	Geographic Information System
ICES	International Council for the Exploration of the Sea
IFCA	Inshore Fisheries and Conservation Authority
INNS	Invasive Non-Native Species
MCZ	Marine Conservation Zone
MMO	Marine Management Organisation
MPA	Marine Protected Areas
MSFD	Marine Strategy Framework Directive
NIFDL	National Inshore Fisheries Data Layer
NRW	Natural Resources Wales
PLAS SAC	Pen Llŷn a'r Sarnau Special Area of Conservation
RYA	Royal Yachting Association
SAC	Special Areas of Conservation
SPA	Special Protection Area
TCE	The Crown Estate

10. Appendix A

This section contains the results of the heatmapping exercise for all individual data layer and grouped data layer heatmaps for all the introduction pathways considered in the study. The overall combined heatmaps and final combined introduction pathway heatmap are described in the Results section of this report (Section 5).

10.1. Commercial shipping pathway

The commercial shipping heatmaps are shown in Figures 10.1 to 10.12. High risk areas are defined as having scaled scores greater than 50, moderate risk as scaled scores between 2 and 50 and low risk as scaled scores less than 2.

10.1.1. Non-port service vessels heatmap

Areas identified at highest risk of introductions of marine INNS from the non-port service vessels were:

- East and west coasts of Anglesey, particularly at Holyhead
- The north coast of the Llyn Peninsula most likely associated with the lifeboat station at Porthdinllaen lifeboat station near Morfa Nefyn.
- Fishguard
- The headland near Porthdais
- Milford Haven
- Along the coast to Tenby
- The River Tywi Estuary
- Burry
- Swansea
- Neath
- Port Talbot
- Port of Barry
- Cardiff

Areas identified at moderate risk were:

- Dee Estuary
- Llandudno
- Pwllheli
- At the coast at Barmouth.

Low-moderate risk areas stretching across Cardigan Bay to Fishguard.

10.1.2. Port service vessels heatmap

Areas of high and moderate risk of introductions of marine INNS from port service vessels are limited to small number of port locations in the southern region. These are located at:

- Milford Haven
- Swansea
- Neath
- Port Talbot

- Port of Barry
- Cardiff
- Newport

Areas of low risk are associated with the shipping routes servicing these ports and further north at Fishguard, Anglesey and Mostyn.

10.1.3. Dredging/Underwater operations vessels heatmap

Areas of high and moderate risk of introductions of marine INNS areas associated with this vessel group are concentrated in the Bristol Channel near the following ports:

- Newport
- Penarth
- Cardiff
- Port of Barry
- Port Talbot
- Neath
- Swansea
- Burry
- Milford Haven

There are also moderate risk areas at Holyhead and the eastern end of the Menai Strait and on approach routes to the port of Mostyn.

Low risk areas are interspersed with the high and moderate risk areas and in the following locations:

- Bride’s Bay and
- Along the coast to Fishguard.
- A low risk route to the Llyn Peninsula along coastal areas to Anglesey

10.1.4. High speed craft heatmap

The largest concentration of areas at high-risk of introductions of marine INNS for this vessel category occurs at the following locations:

- The port of Mostyn
- The high-speed passenger ferry route from Holyhead to Dublin

Moderate risk areas were identified at Milford Haven.

Low risk areas are associated with:

- Traffic at the north coast
- The Menai Strait
- At coastal areas neighbouring Fishguard and Milford Haven.

10.1.5. Law/Military vessels heatmap

The areas of highest risk of introductions of marine INNS for this vessel group are centred on the ports of:

- Holyhead
- Fishguard
- Milford Haven

A band of moderate risk follows the entire coast from the eastern side of Anglesey round to the southern side of the Llyn Peninsula. Additional bands of moderate risk areas occur from Ramsey Island to Milford Haven and a stretch of coastline from Swansea to Cardiff.

There are areas of low risk at the following locations:
- Llandudno
- The Menai Strait
- Along routes in the south of Cardigan Bay
- Along the coast from Aberporth to Fishguard
- East of Milford Haven
- Across Carmarthen Bay

10.1.6. Passenger vessels heatmap

The areas at highest risk of introductions of marine INNS are confined to the passenger ferry routes in the Irish Sea and associated ports. These include the Holyhead to Dublin route and the Fishguard and Pembroke routes to Rosslare. There is also an area of high risk associated with movement of passenger vessels from Mostyn in an area adjacent to the Liverpool – Dublin ferry route.

A small area of moderate risk was identified at Cardiff.

The coastal areas of low risk occur at:
- Llandudno
- Around the coast of Anglesey
- The Menai Strait
- Where routes pass the end of the Llyn Peninsula
- At the coast by Cardigan

The remaining low-risk areas occur between the Rosslare ferry routes, south of Milford Haven, Swansea and along the coast at Port of Barry to Newport.

10.1.7. Cargo vessels heatmap

The areas of highest risk of introductions of marine INNS from cargo vessels are restricted to small groups of cells in the main shipping routes in the Irish Sea and also in the Bristol Channel close to the port of Barry.

The moderate risk areas also align with the main shipping routes but extend into the port areas at the following locations:
- Newport
- Cardiff
- Port of Barry
- Neath
- Swansea

- Port Talbot
- Milford Haven
- Anglesea
- The north coast by Llanddulas and Mostyn

Notable areas of low risk are found in Cardigan Bay, St. Bride's Bay and Carmarthen Bay.

10.1.8. Tankers heatmap

The areas of highest risk of introductions of marine INNS from tankers are associated with Milford Haven.

The areas of moderate risk are generally associated with the main shipping routes in the Irish Sea and the Bristol Channel. Closer to the coast moderate risk areas have been identified at the following locations:

- On the north coast of Anglesey and in particular at Holyhead.
- St. Bride's Bay and south towards Milford Haven.
- A small group of cells near Stockpole Quay.
- Coastal areas from the port of Barry to Cardiff.

Low risk areas are associated with tanker traffic to Fishguard and Port Talbot.

10.1.9. Unknown category vessels heatmap

Areas identified at highest risk of introductions of marine INNS from the unknown vessel category were:

- Milford Haven
- Mostyn

Areas identified at moderate risk were:

- Along almost all of the north Welsh coast and across the north coast of Anglesey.
- South of the Llyn peninsula
- Coastal areas from Aberaeron, Aberporth, Cardigan, and Fishguard
- Along the coast from Milford Haven to Stackpole Quay
- South coast of the Gower peninsula through to Newport
- More pronounced areas of risk at Swansea, Neath, and Port Talbot, Port of Barry and Cardiff

Areas identified at low risk were:

- On the north coast by Rhyl, Llanddulas, and Rhos-on-Sea
- The north of Cardigan Bay
- North coast of the Llyn peninsula towards the Menai Strait
- Between the moderate risk areas at Fishguard, Aberporth and Aberaeron and along routes to Aberystwyth & Barmouth and across St. Bride's Bay
- Saundersfoot Bay to Caldey Island and across Carmarthen Bay to the head of the Gower peninsula

10.1.10. Global vessels heatmap

The areas of highest risk of introductions of marine INNS from the global vessels category (unknown ship type, high speed craft, cargo vessels and tankers) have been identified at:

- Milford Haven
- Port of Barry

Moderate to high risk areas have been identified at:
- St. Bride's Bay
- Swansea
- The coastal area from Cardiff and Penarth to Newport.

The remaining areas have been classified as low risk from vessels in the global shipping category, or there was no recorded activity for global shipping activity.

10.1.11. Regional vessels heatmap

The areas of highest risk of introductions of marine INNS from the regional vessels category (military/law enforcement vessels and passenger vessels) were identified at the ports of:
- Mostyn
- Holyhead

Areas of moderate risk were identified at the following locations:
- Along the coast westward of the port of Mostyn
- Fishguard
- Milford Haven

Small pockets of moderate to low risk cells were identified at Llandudno, along the coast by Cardigan and off Ramsey island.

Low risk areas were identified at the following locations:
- On the coast of Anglesey.
- The Menai Strait
- At the end of the Llyn Peninsula.
- Sections of coastline between Cardigan, Fishguard, Milford Haven and Carmarthen Bay.
- The coastal areas near Swansea, Port of Barry, Cardiff, and Newport.

Much of Cardigan bay and Carmarthen bay show areas where there was no recorded activity for regional shipping activity.

10.1.12. Local vessels heatmap

The areas found to be at greatest risk of introductions of marine INNS from the local vessels category (port service vessels, non-port service vessels, dredgers and vessels engaged in underwater operations) were:

- Milford Haven
- Swansea
- Port Talbot
- Newport

Moderate risk areas were identified at:
- Holyhead
- Trearddur Bay
- Fishguard
- Neath
- Port of Barry
- Cardiff
- Penarth

The remainder of the Welsh coastline was classified as low risk for this vessel group or were areas without recorded activity.

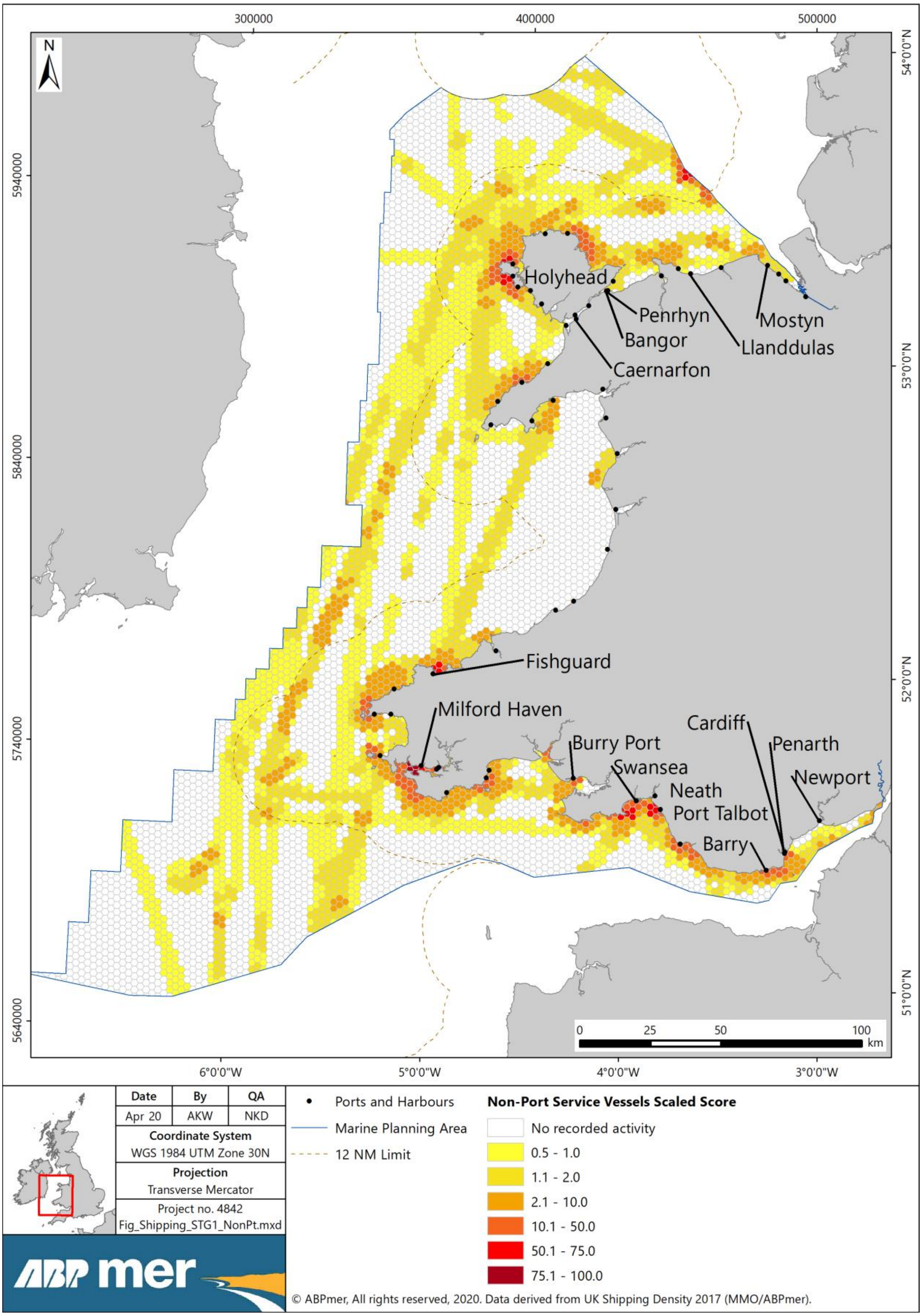

Figure 10.1 Non-port vessels heatmap

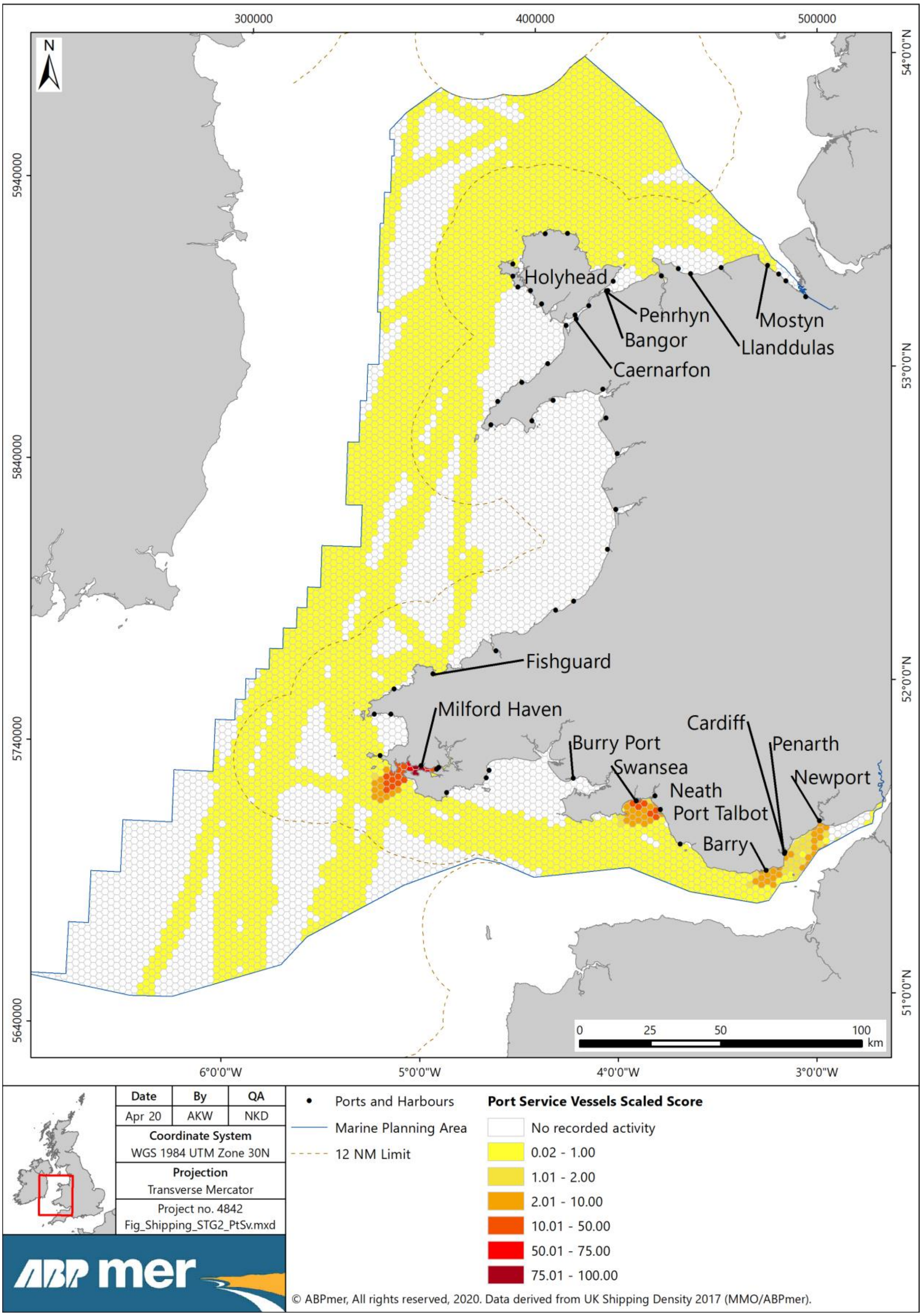

Figure 10.2 Port vessels heatmap

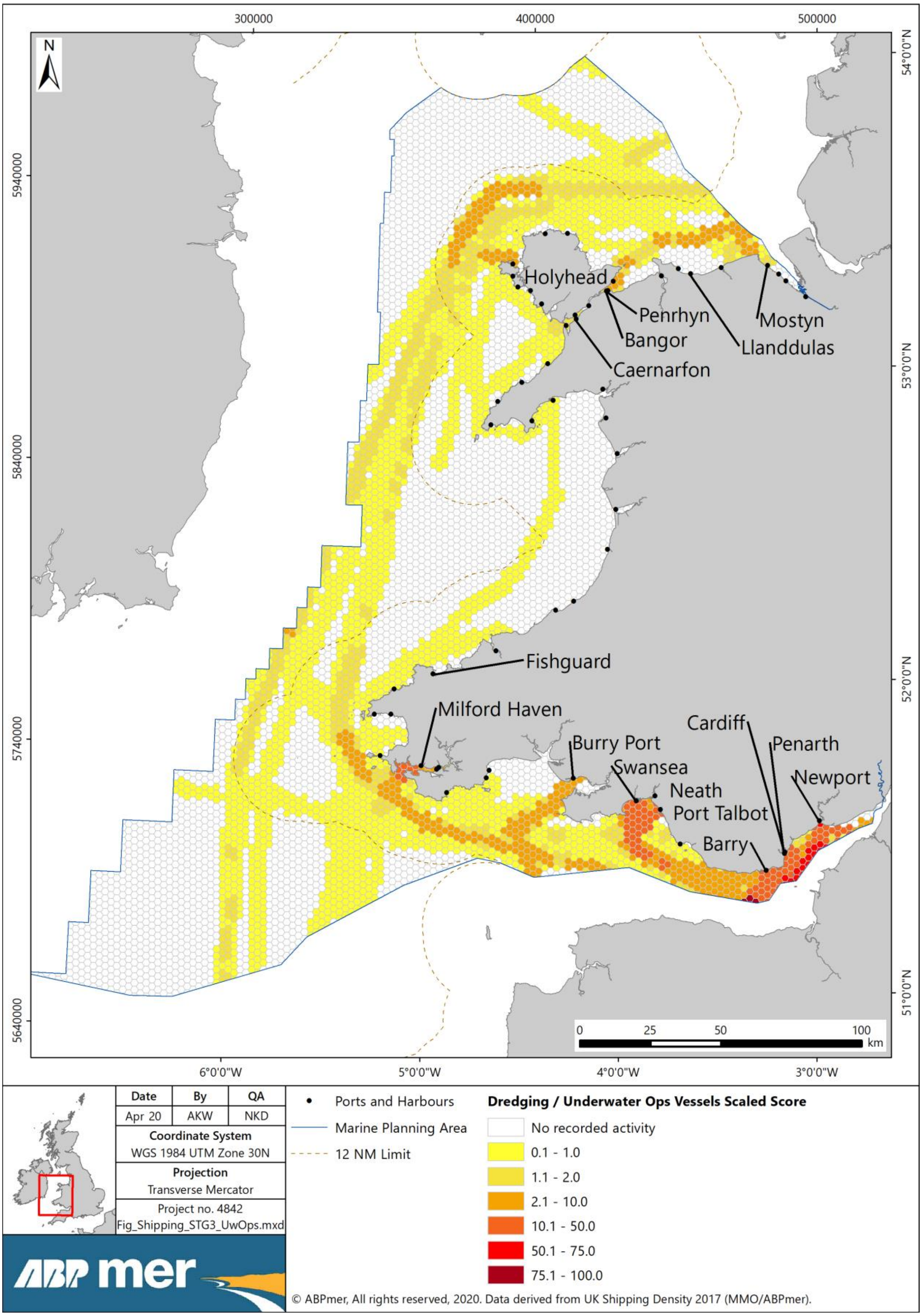

Figure 10.3 Dredging / Underwater operations vessels heatmap

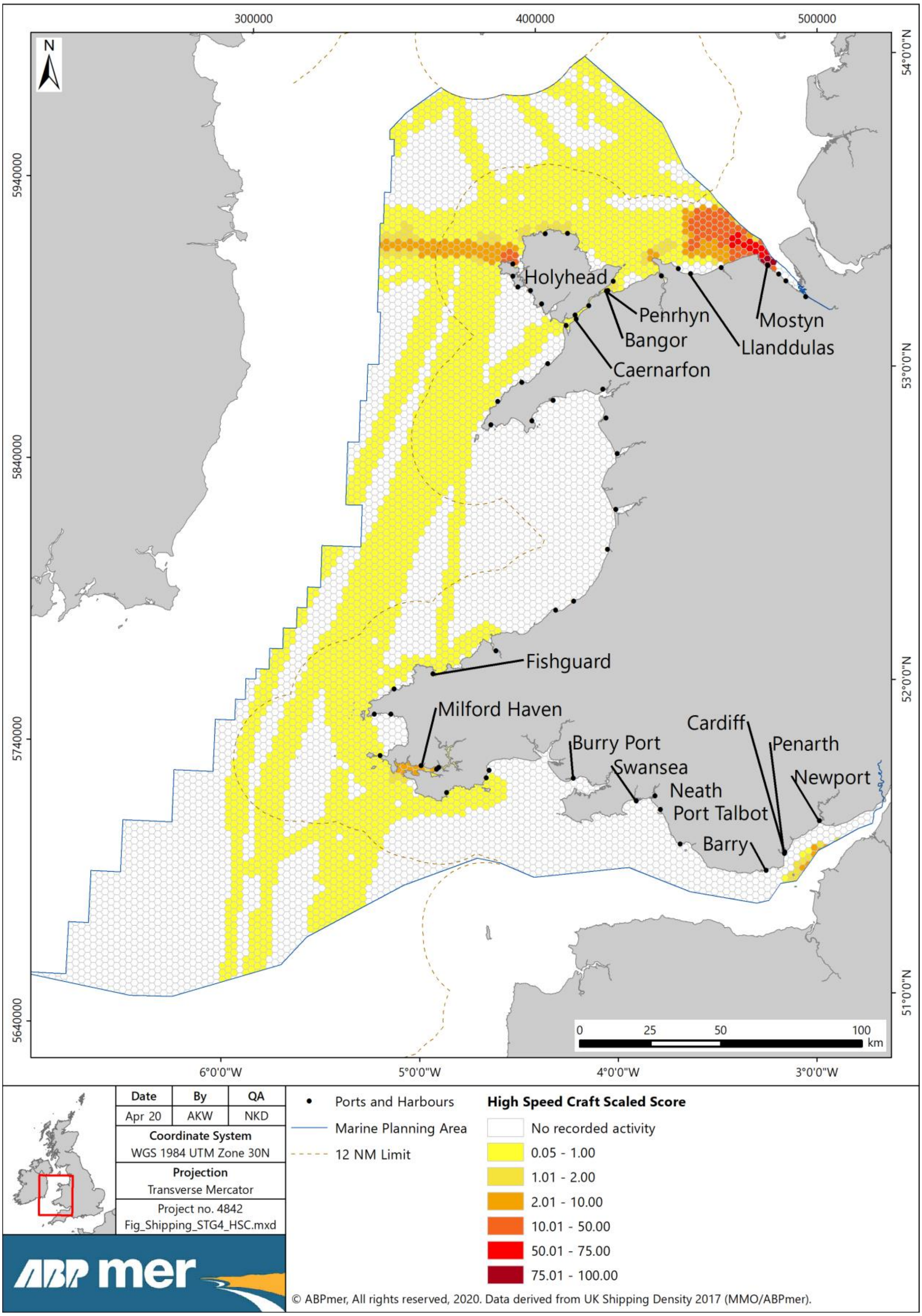

Figure 10.4 High speed craft heatmap

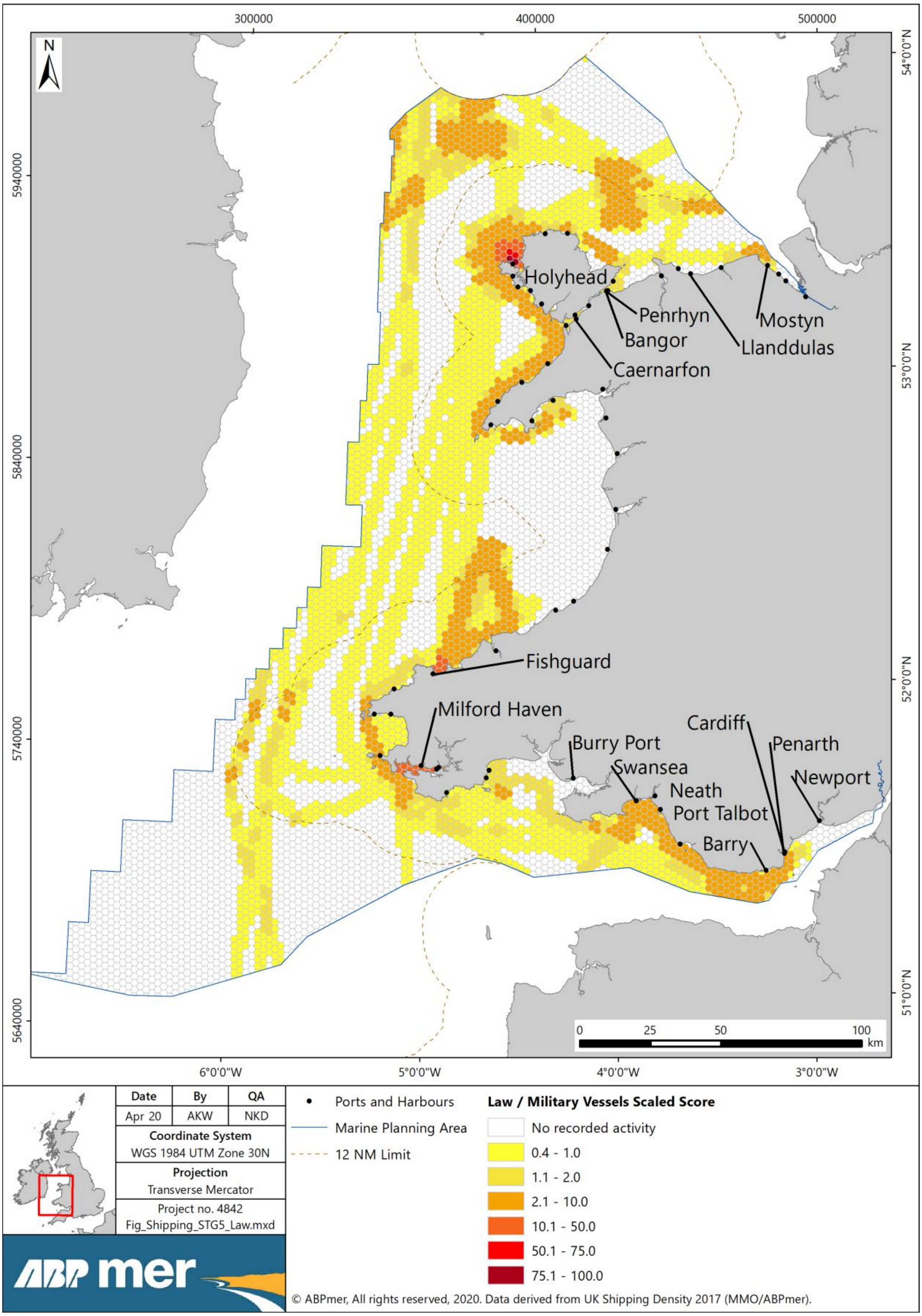

Figure 10.5 Military / Law enforcement vessels heatmap

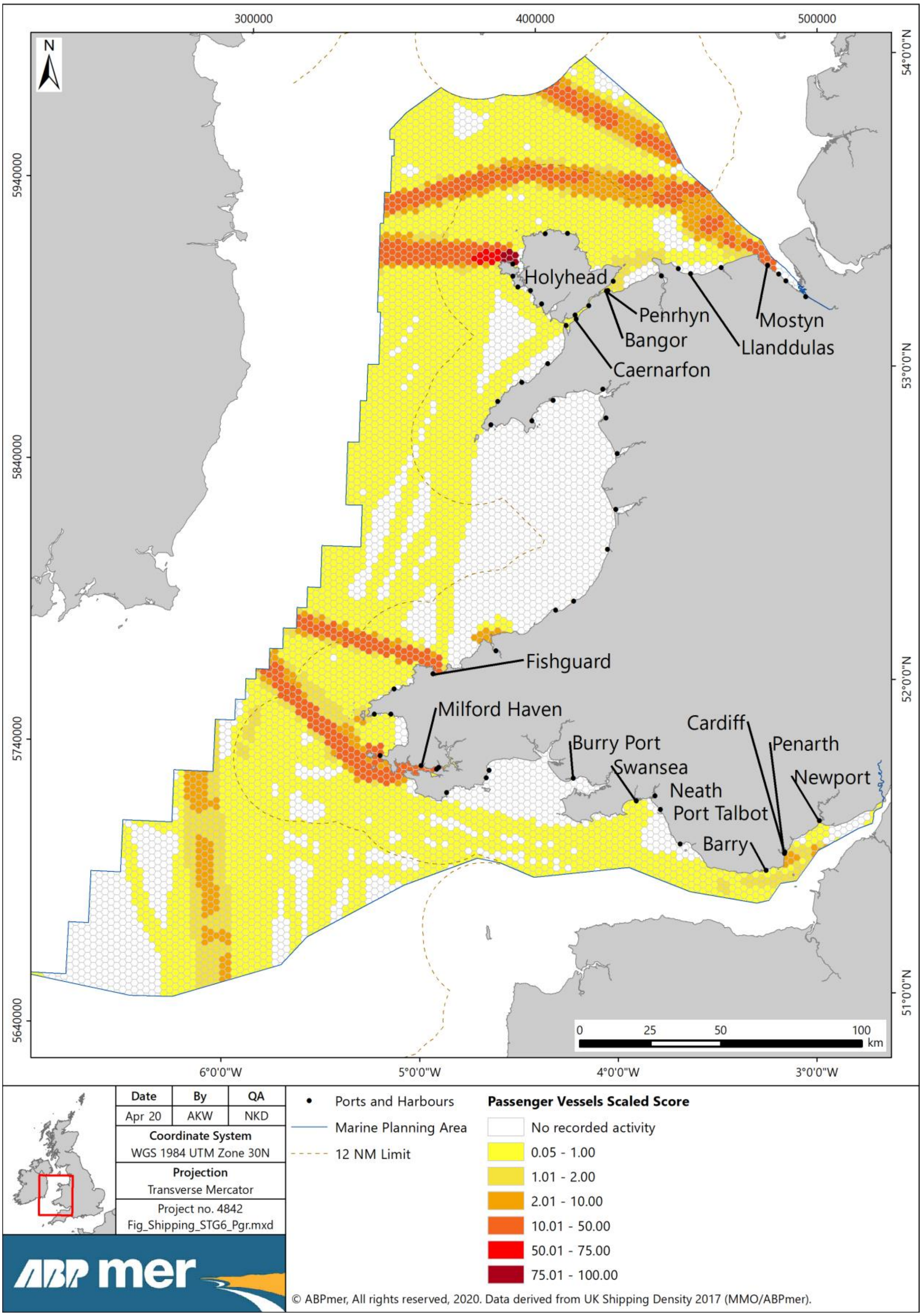

Figure 10.6 Passenger vessels heatmap

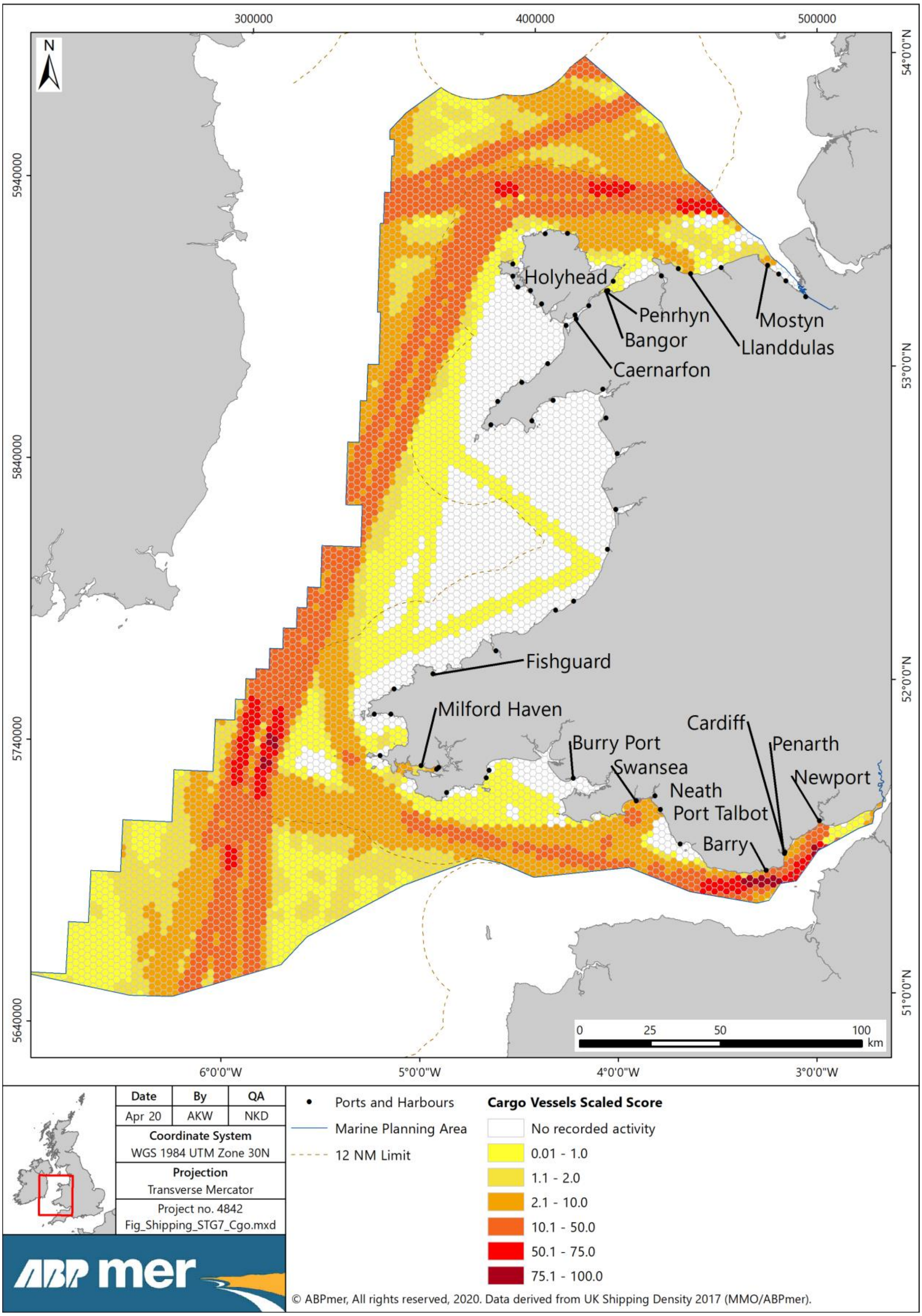

Figure 10.7 Cargo vessels heatmap

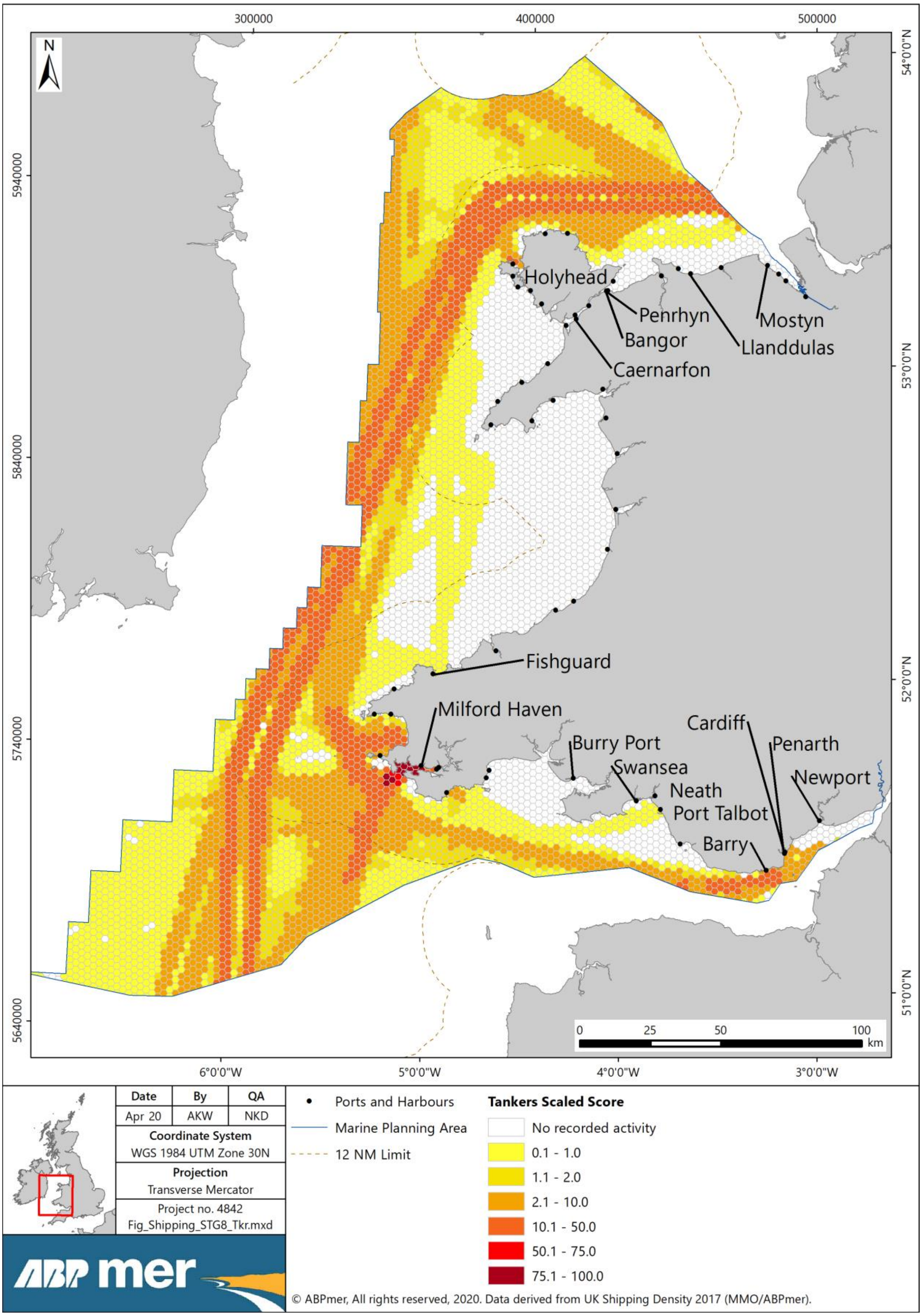

Figure 10.8 Tankers heatmap

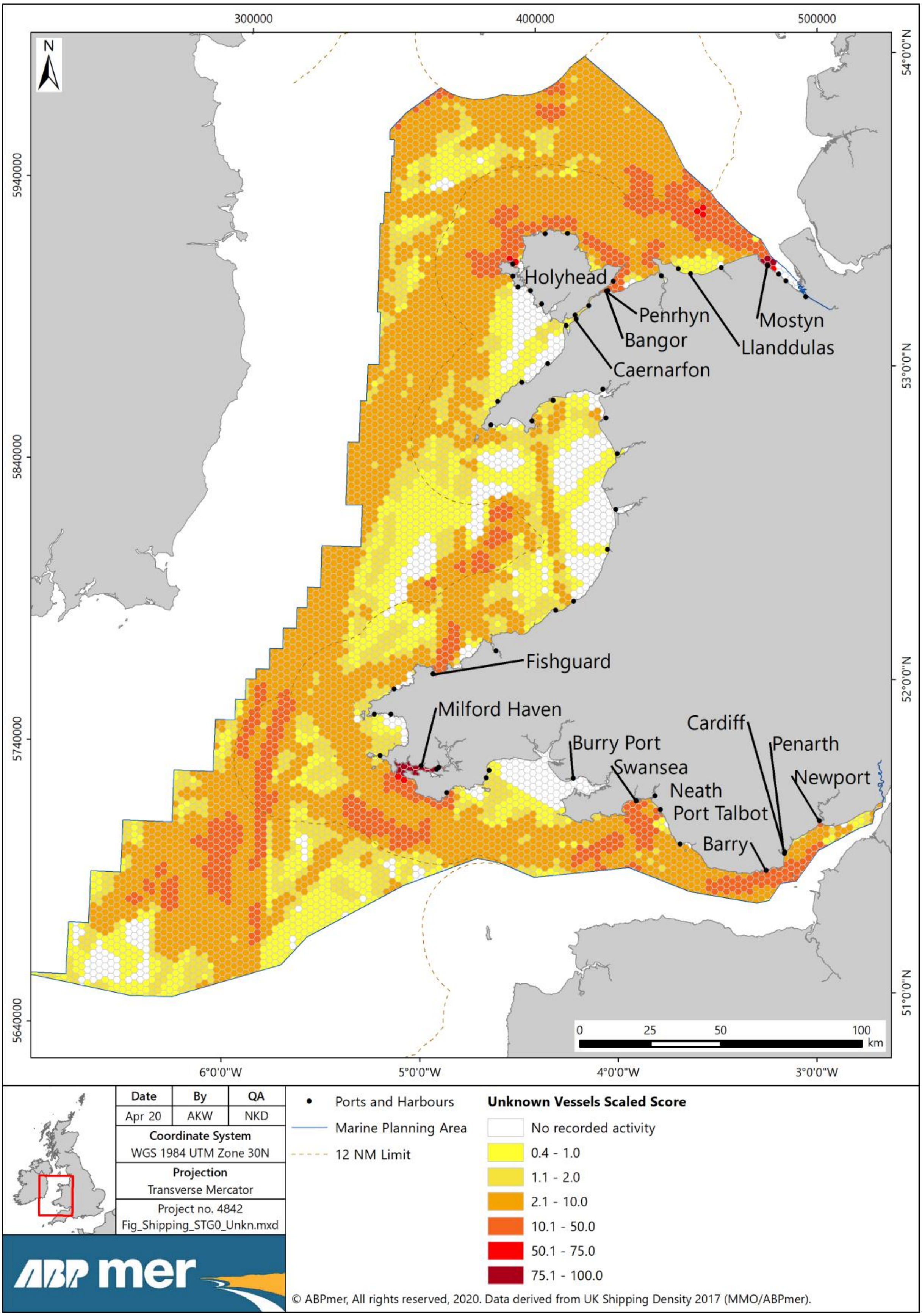

Figure 10.9 Unknown vessels heatmap

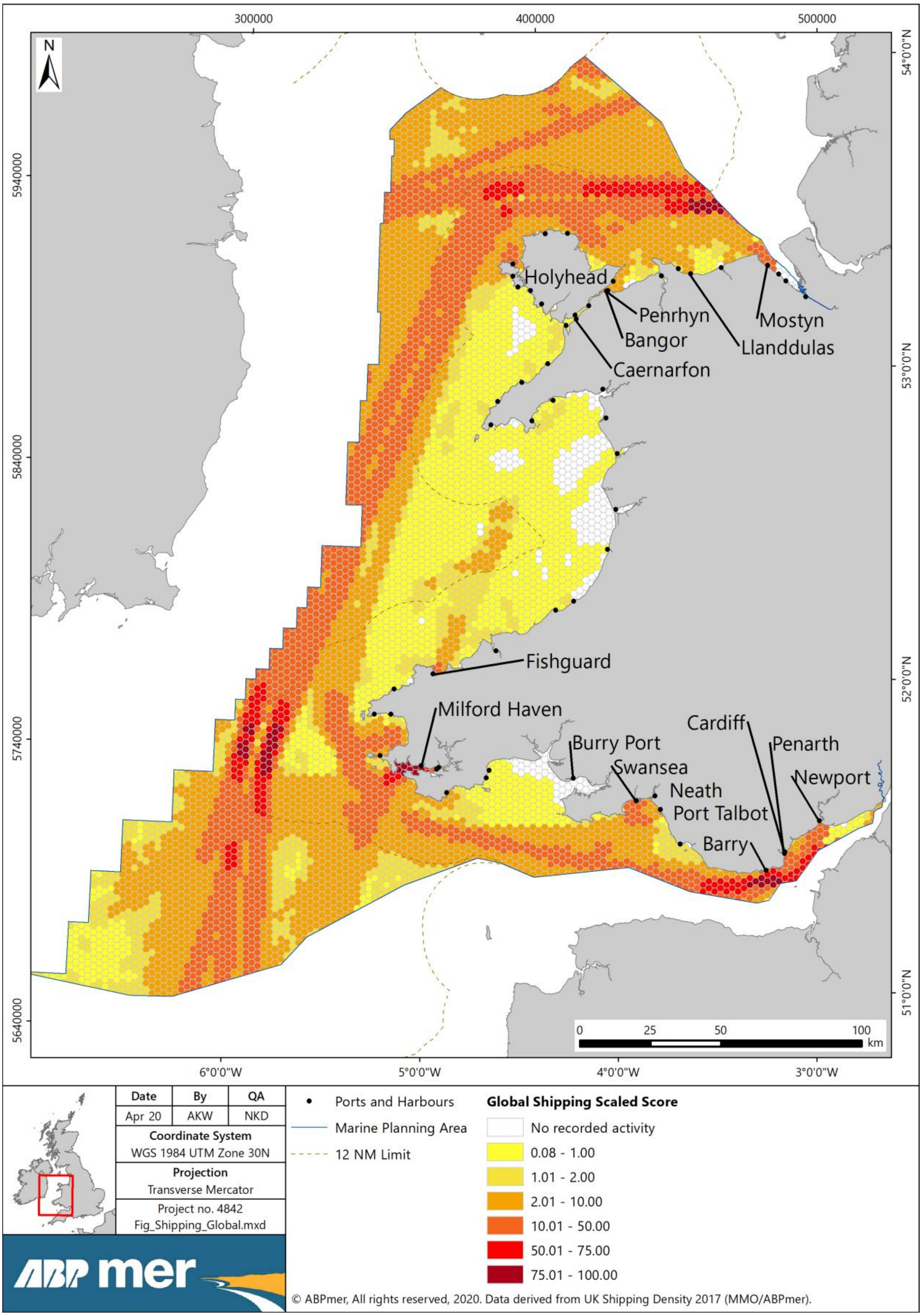

Figure 10.10 Global vessels heatmap

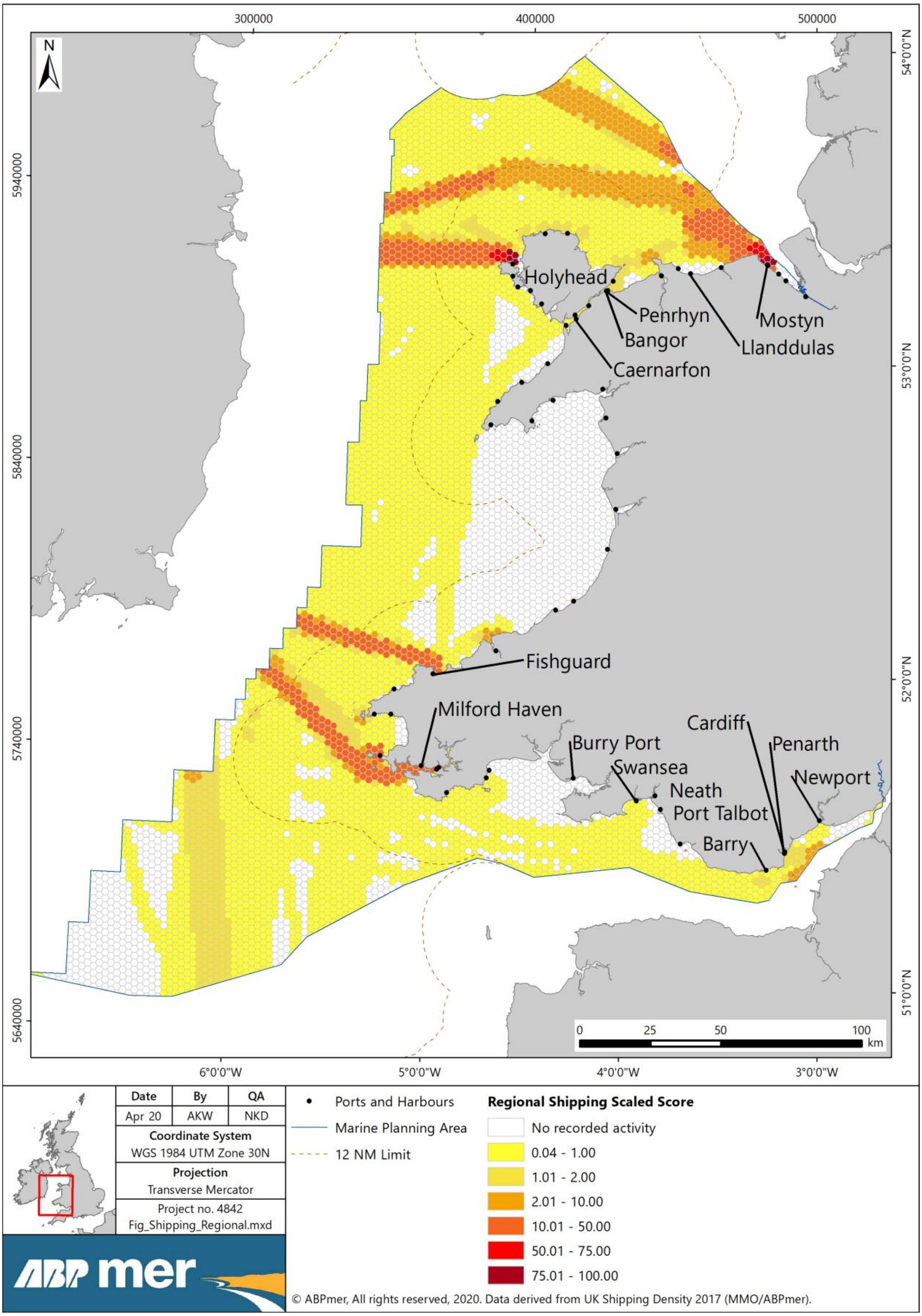

Figure 10.11 Regional vessels heatmap

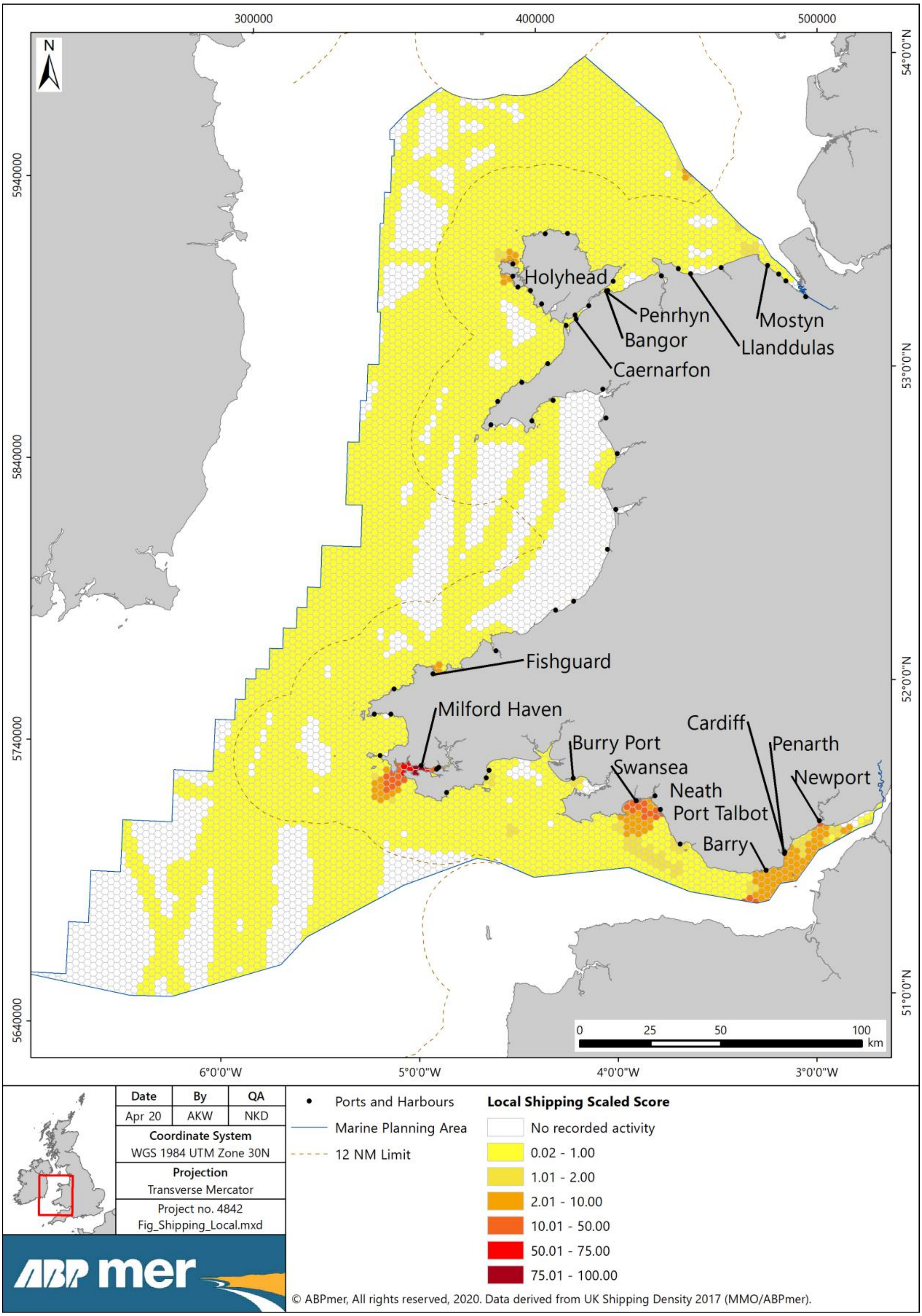

Figure 10.12 Local vessels heatmap

10.2. Recreational boating pathway

The recreational boating heatmaps are shown in Figures 10.13 to 10.14.

10.2.1. RYA recreational boating intensity heatmap

Much of the Welsh coastline has been identified as being associated with areas of moderate to high risk of introductions of marine INNS, except for lengths of coastline near Newport, Swansea Bay, St. Bride's Bay, Cardigan Bay, Colwyn Bay, and the Dee Estuary which do not show any recorded activity. The highest risk areas (with scaled scores greater than 50) occur at:

- Holyhead
- Milford Haven
- Swansea

10.2.2. RYA general boating areas heatmap

The classification of risk of introductions of marine INNS from general boating activity areas was determined on a presence or absence basis. Areas that were identified at risk (with a scaled score of 100) are:

- The entire north coast from the Dee Estuary to Holyhead
- The east and west coasts of Holyhead
- The Menai Strait
- Porth Nefyn
- The south coast of the Llyn Peninsula
- Porthmadog
- Barmouth
- East of Fishguard at Newport
- Milford Haven
- West Carmarthen Bay
- The river Towy Estuary
- West Swansea Bay
- Barry
- Cardiff
- Newport

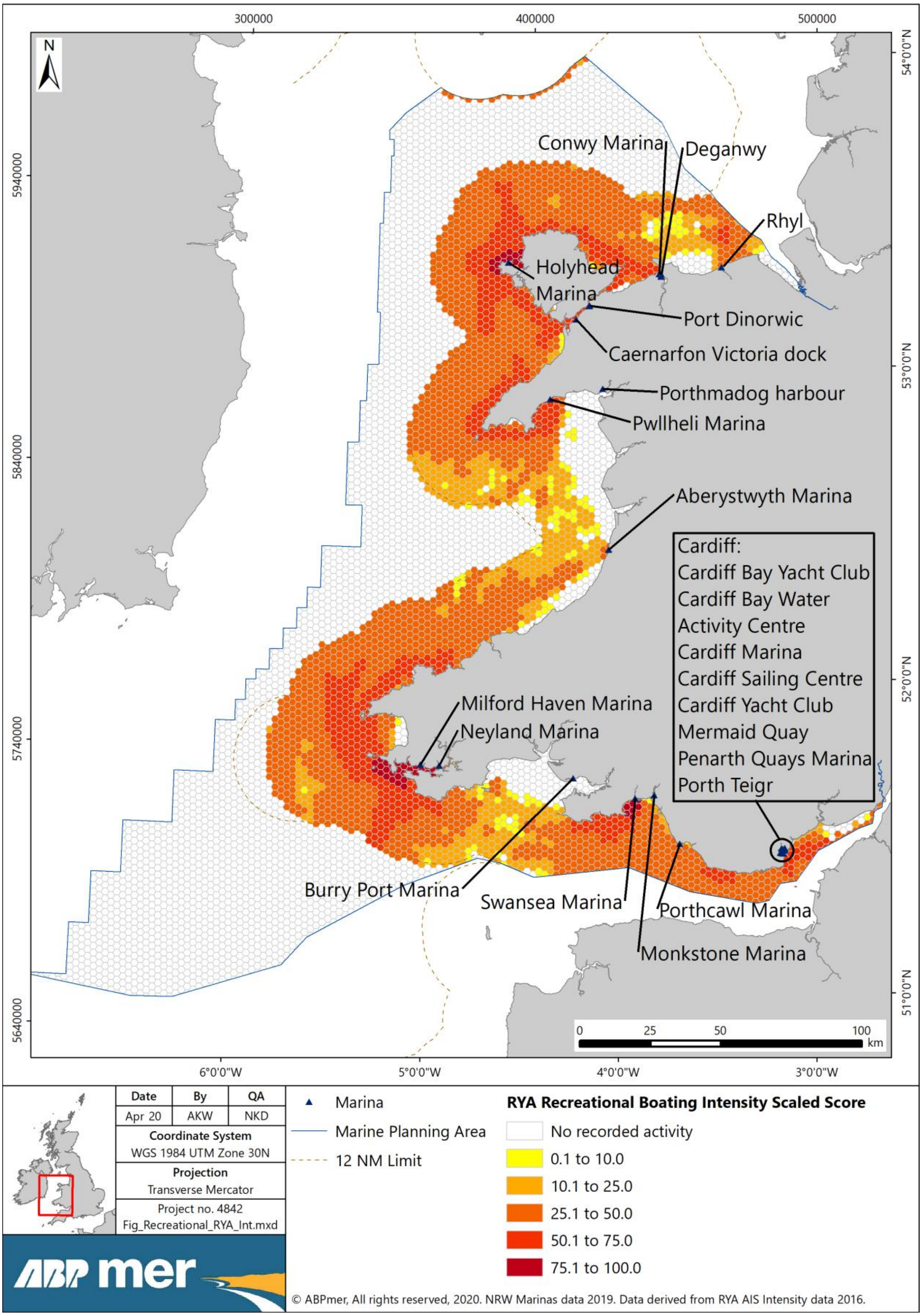

Figure 10.13 RYA Recreational boating intensity heatmap

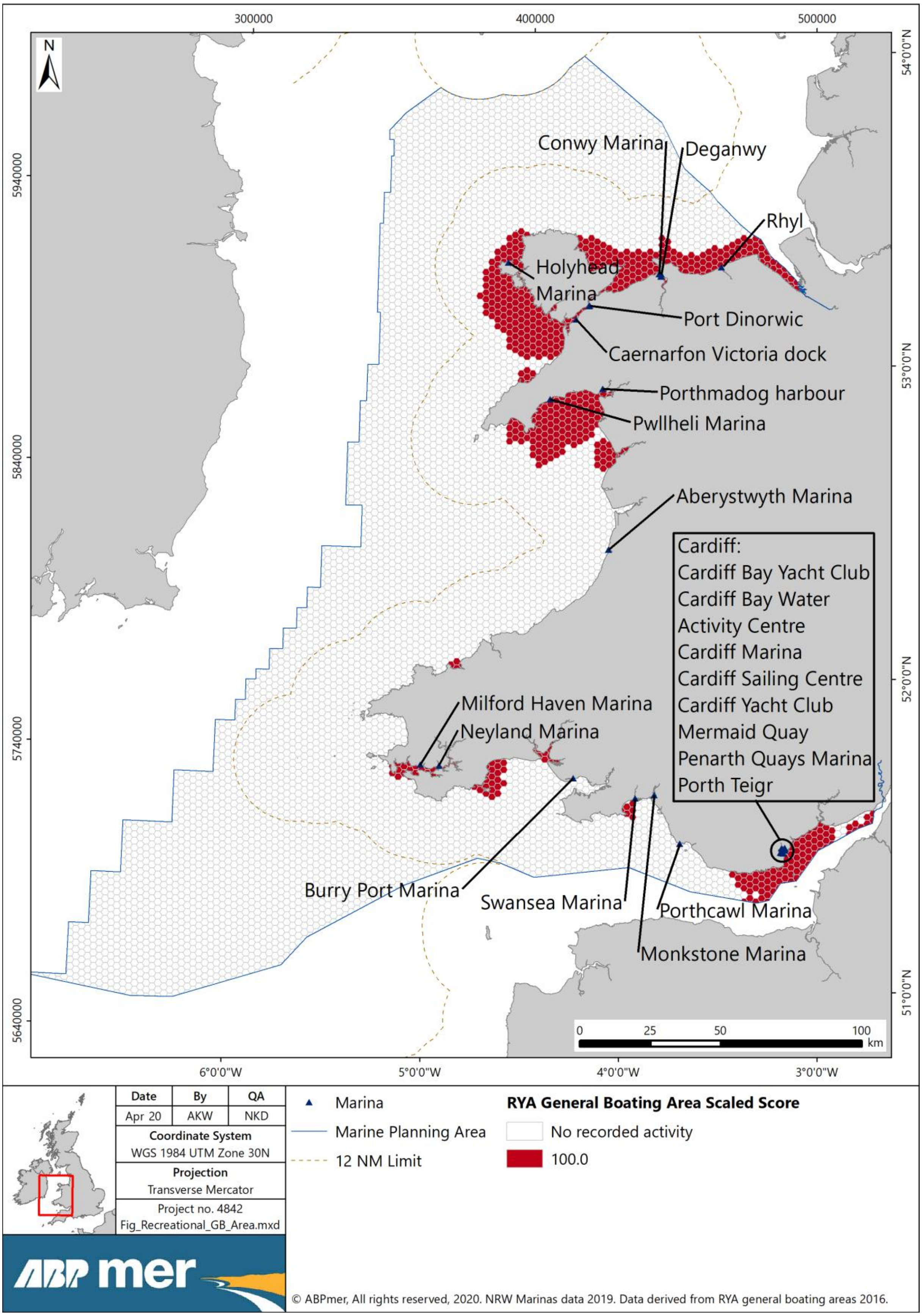

Figure 10.14 RYA General boating areas heatmap

10.3. Shellfish gathering/ production pathway

The shellfish gathering/ production heatmaps are shown in Figures 10.15 to 10.17. Areas at risk are defined as having scaled scores of 100.

10.3.1. Shellfish waters heatmap

The classification of risk of introductions of marine INNS from shellfish waters was determined on a presence or absence basis. Areas identified at risk are:

- The Dee Estuary
- Llandulas
- Rhos-on-Sea
- Llandudno
- Conwy
- Menai Strait and Foryd Bay
- Red Wharf Bay
- Maltreath Sands
- Llanddwyn Bay
- Cardigan Bay (Dwyryd and Glaslyn Estuaries, Mawddach Estuary and Dyfi Estuary)
- Milford Haven

10.3.2. Several Regulations Orders heatmap

The classification of risk of introductions of marine INNS from Several Regulating Orders was determined on a presence or absence basis. Areas identified at risk are:

- The Dee Estuary
- (West side of Conwy Bay) and Menai Strait
- Between Lydstep Haven and Caldey Island
- Burry Inlet and Loughor Estuary
- West side of Swansea Bay

10.3.3. Cockle Gathering Sites heatmap

The classification of risk of introductions of marine INNS from cockle gathering sites was determined on a presence or absence basis. Areas identified at risk are:

- The Dee Estuary
- Menai Strait and Foryd Bay
- Red Wharf Bay
- Holyhead Bay
- Maltreath Sands
- Cardigan Bay (Dwyryd and Glaslyn Estuaries, Mawddach Estuary and Dyfi Estuary)
- Milford Haven
- Parts of Carmarthen Bay, Burry Inlet and Loughor Estuary

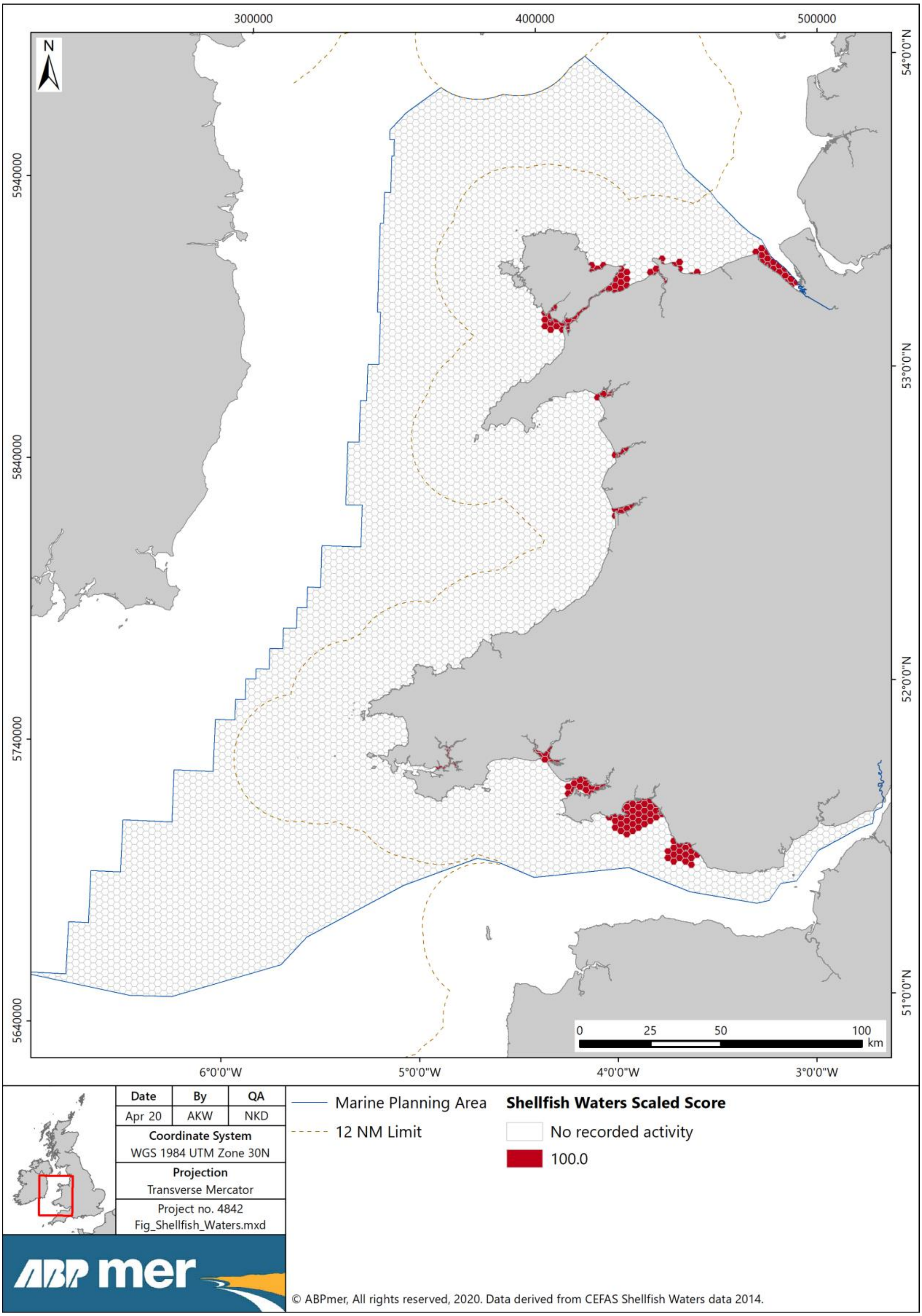

Figure 10.15 Shellfish waters heatmap

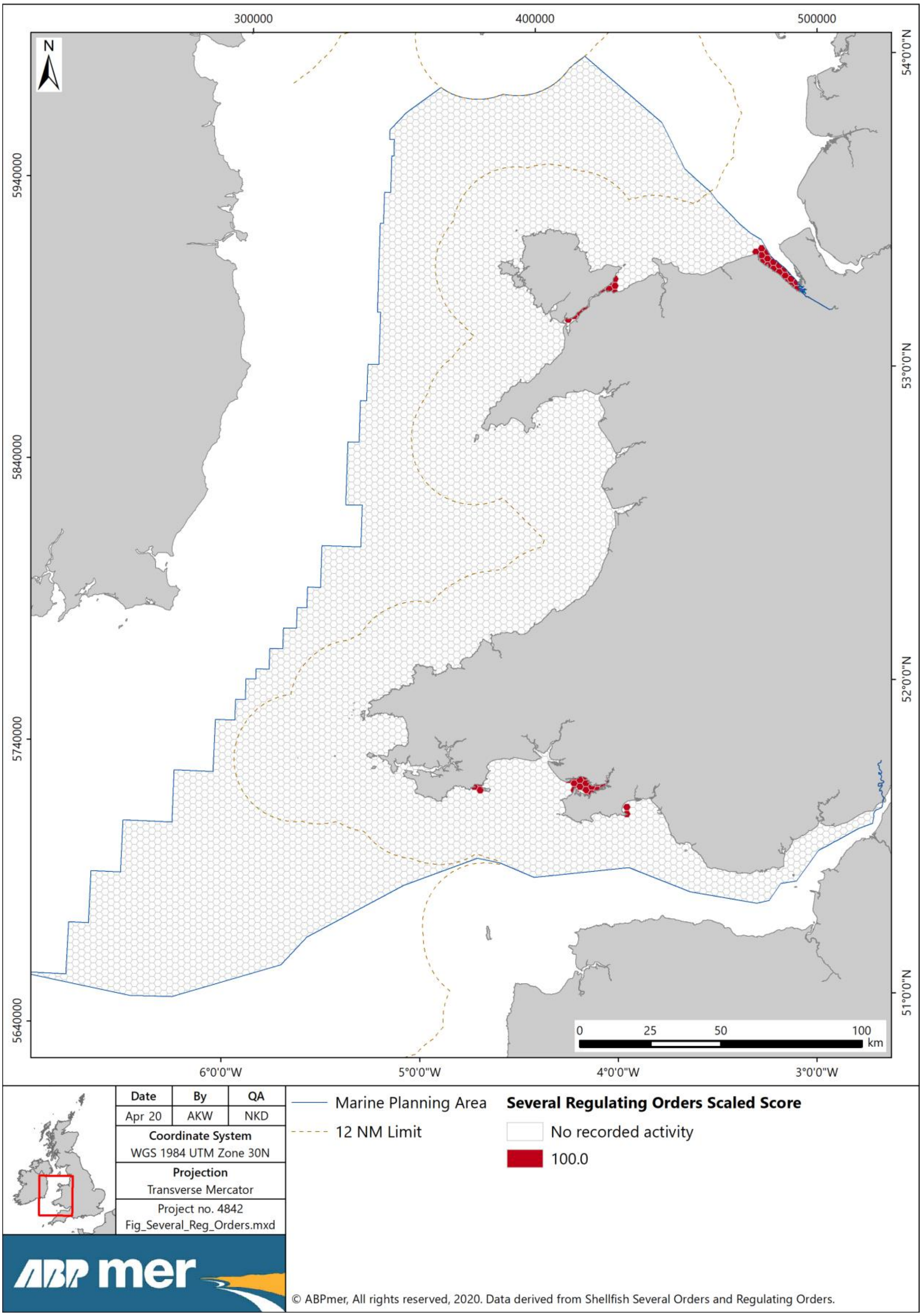

Figure 10.16 Several Regulating Orders heatmap

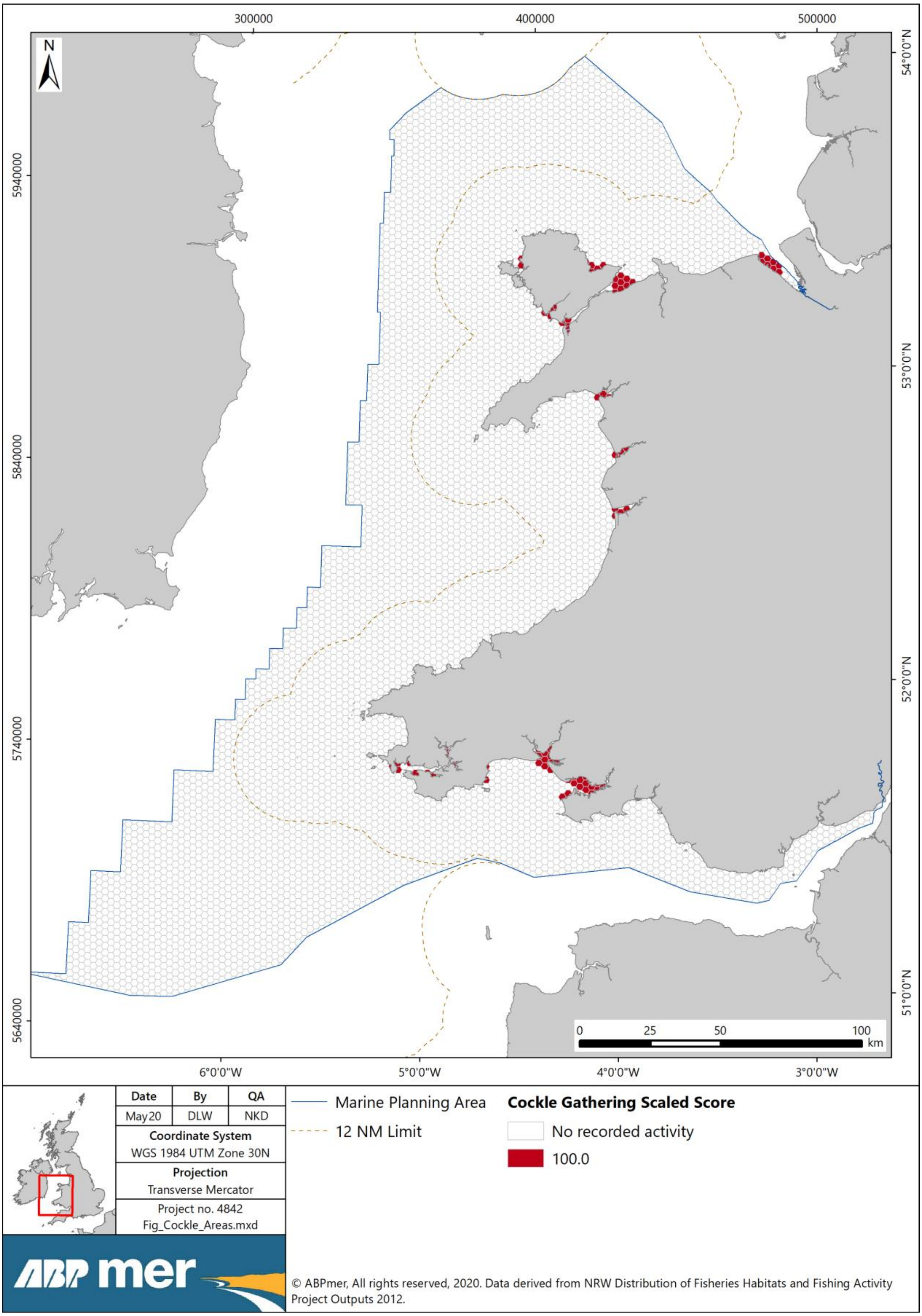

Figure 10.17 Cockle Gathering Sites heatmap

10.4. Offshore activities pathway

The offshore activities heatmaps are shown in Figures 10.18 to 10.22. Areas at risk are defined as having scaled scores of 100, except for the aggregates heatmap where the high risk areas are defined as having scaled scores greater than 50.

10.4.1. Offshore windfarm heatmap

The classification of risk of introductions of marine INNS from offshore wind farm infrastructure was determined on a presence or absence basis. Areas identified at risk are located off the north coast and are associated with the following offshore wind facilities:

- Gwynt y Mor
- Rhyl Flats
- North Hoyle

10.4.2. Wave/tidal energy heatmap

The classification of risk of introductions of marine INNS from wave/tidal energy infrastructure was determined on a presence or absence basis. Areas identified at risk are located west of Holy Island and Anglesey, and off Ramsey Island.

10.4.3. Aggregates heatmap

All areas identified at risk of introductions of marine INNS from aggregate extraction activities are at a distance from the coastline. An area of varying risk is located in the Severn estuary off the coast at Newport. An area of higher risk is located further to the west, south of the Port of Barry. An area of low risk was identified south-west of the Gower peninsula and area of moderate risk is located north-west of the Dee Estuary.

10.4.4. Dredging Activities heatmap

The classification of risk of introductions of marine INNS from dredging activities was determined on a presence or absence basis. Areas identified at risk are:

- Mostyn
- Conwy
- Holyhead
- Aberaeron
- Milford Haven
- Tenby
- Saundersfoot
- Swansea Bay
- Barry
- Penarth/Cardiff
- Newport

10.4.5. Offshore disposal heatmap

The classification of risk from offshore disposal sites was determined on a presence or absence basis. Areas identified at risk are located:

- In the Severn estuary between Newport and Port of Barry, and south of Swansea Bay.
- Pembroke
- At two sites south and south-west of Milford Haven.
- New Quay
- West of Anglesey
- Conwy
- The Dee Estuary

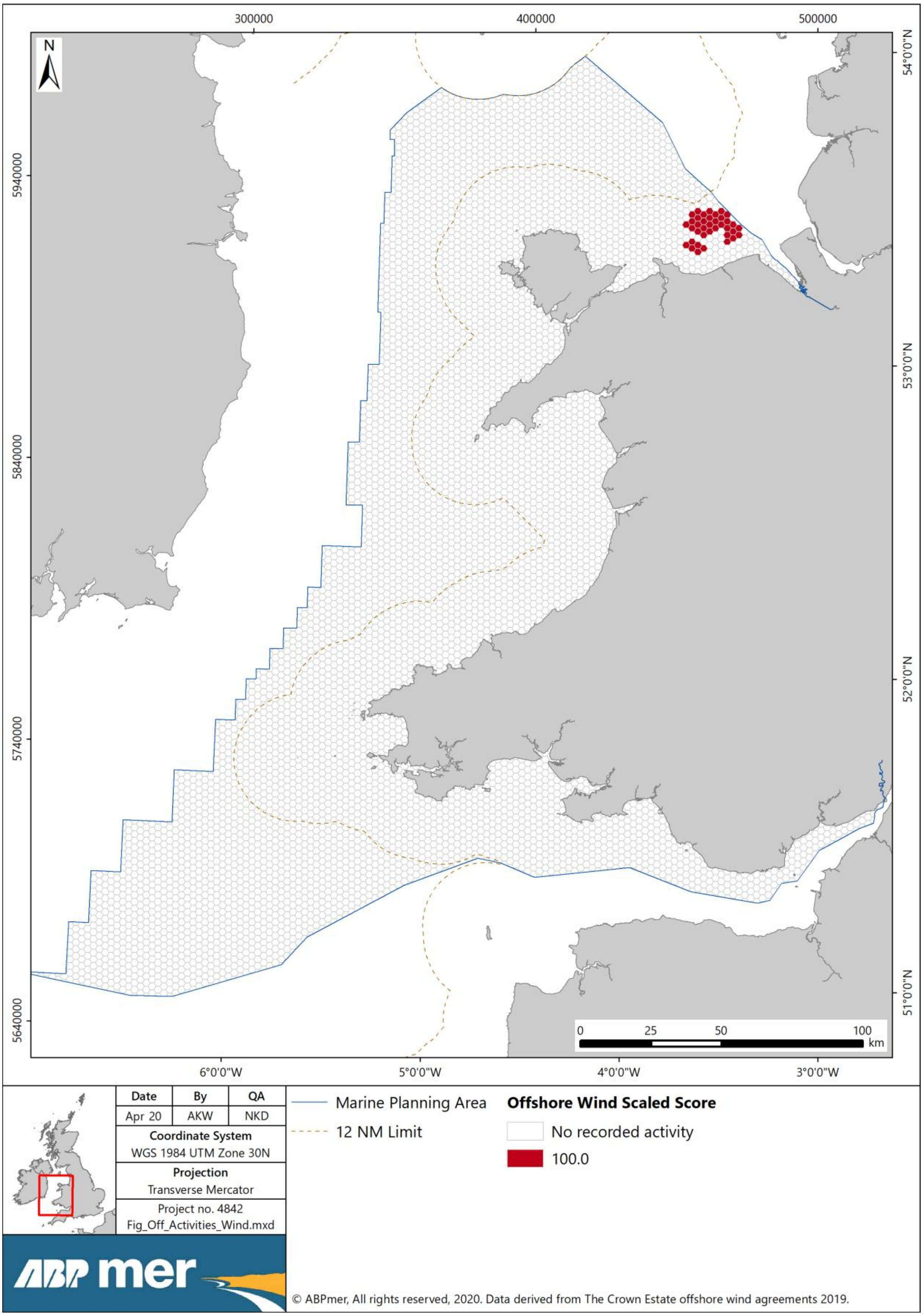

Figure 10.18 Offshore wind activities heatmap

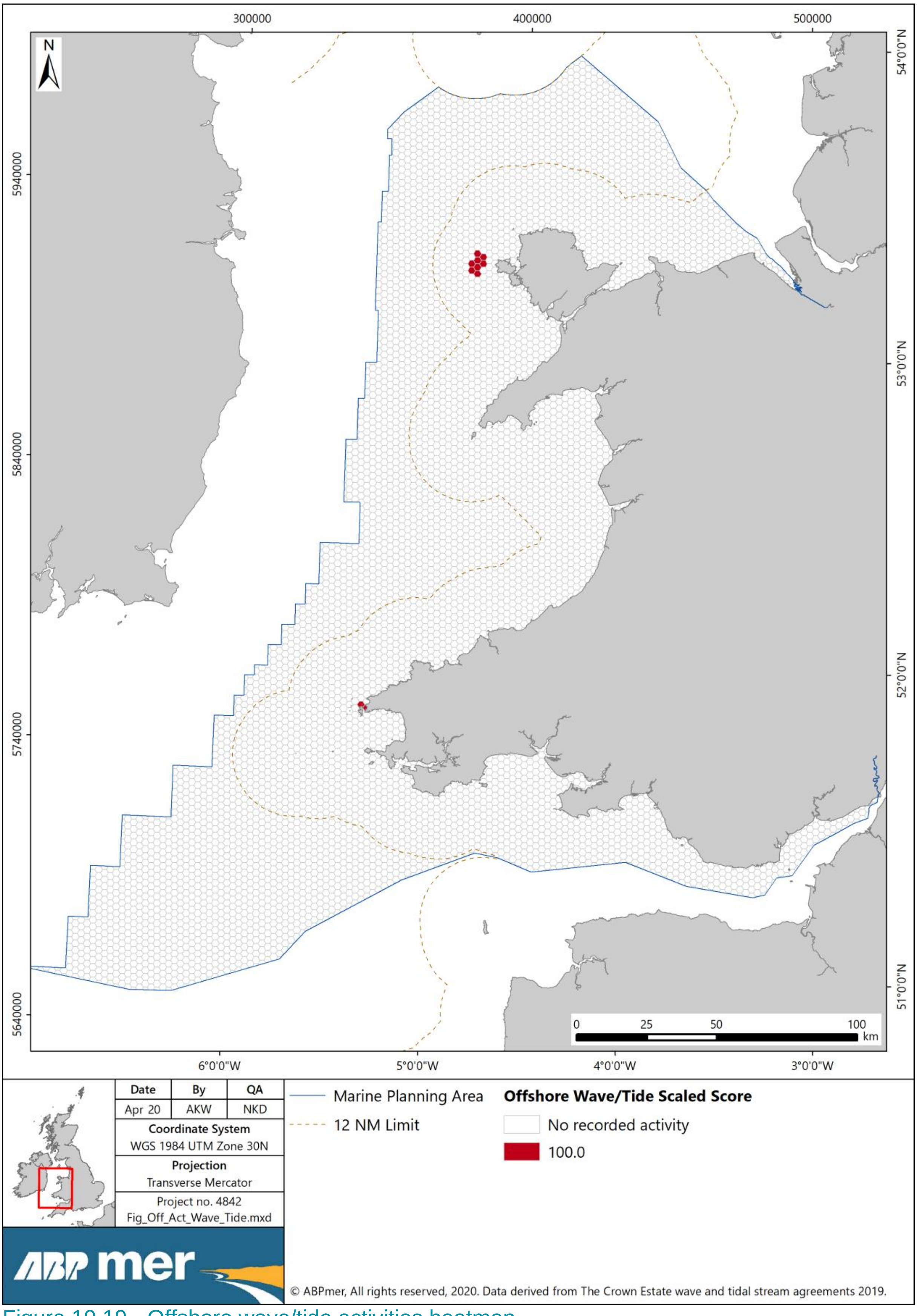

Figure 10.19 Offshore wave/tide activities heatmap

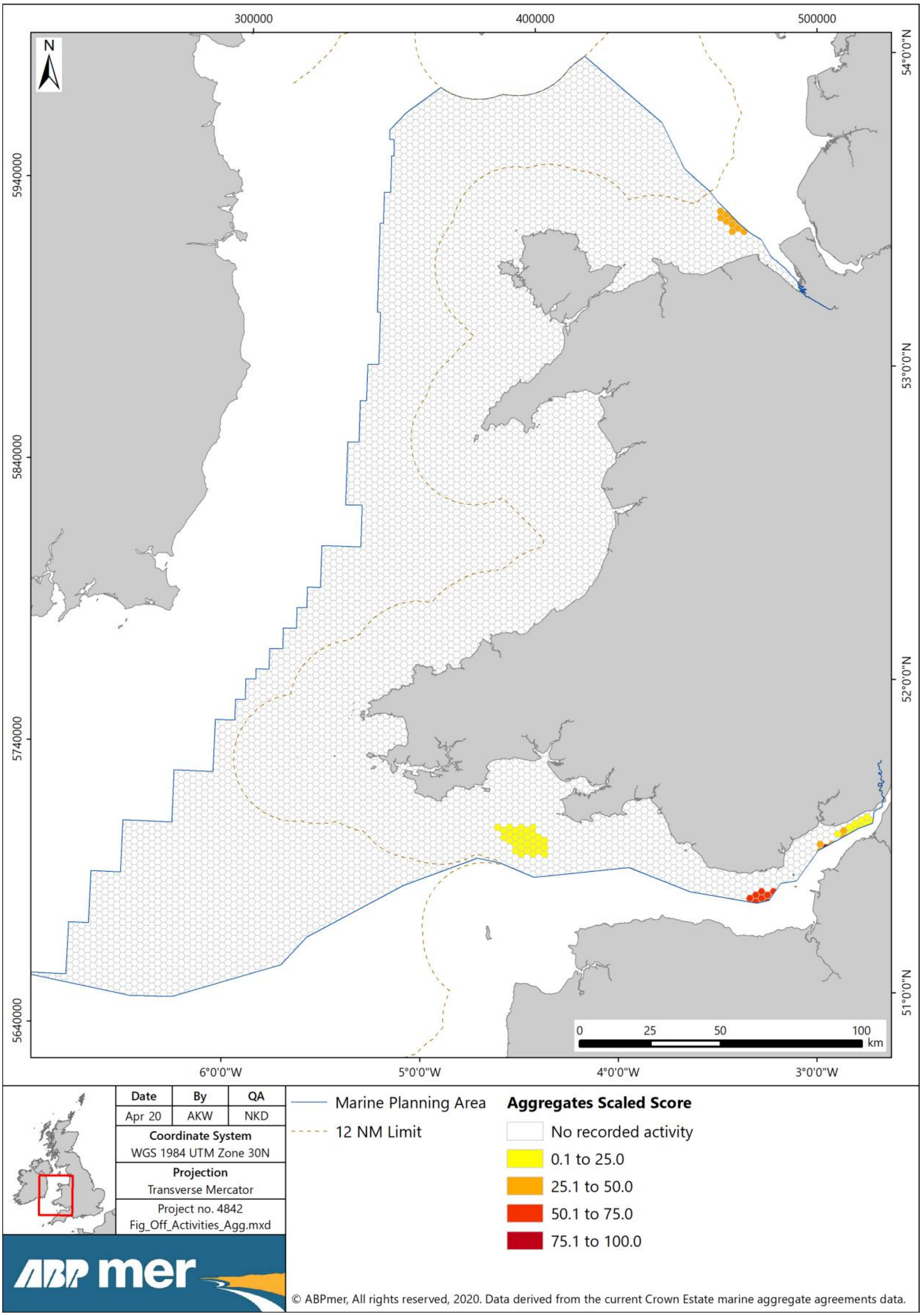

Figure 10.20 Offshore aggregate extraction activities heatmap

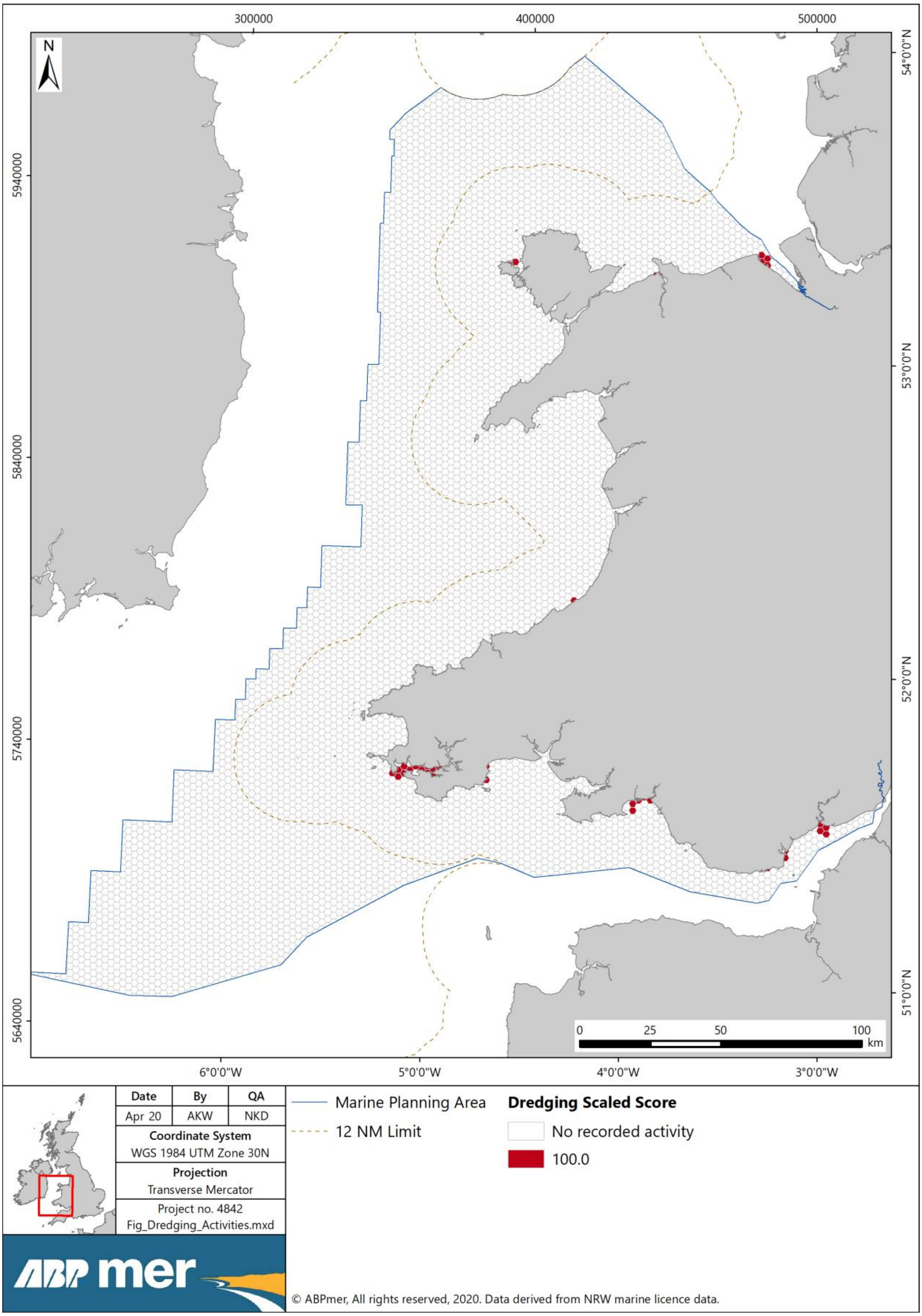

Figure 10.21 Dredging activities heatmap

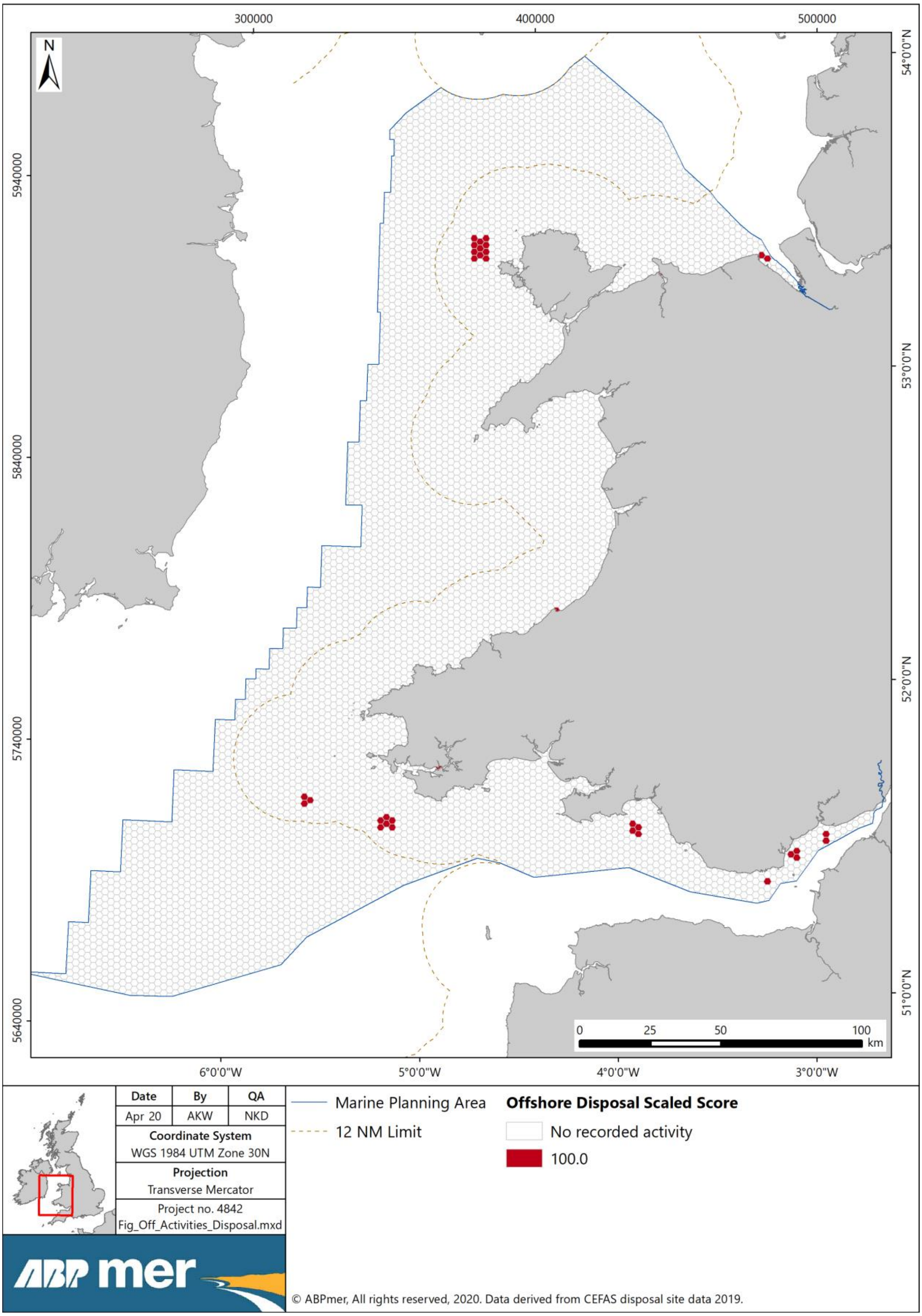

Figure 10.22 Offshore disposal activities heatmap

10.5. Designations and combined pathways heatmap

Figures 10.23 to 10.26 show the combined introduction pathways heatmap overlain with the designated sites (SACs, SPAs, Ramsar sites and MCZs, respectively) to determine which sites may be at higher risk from the introduction of marine INNS. Areas at highest risk are predominantly close to sheltered bays, inlets and major ports and harbours, in line with the pathways recognised as dominant vectors of introduction at the following coastal locations.

Higher risk areas overlap with the following SACs:

- The Dee Estuary SAC
- North Anglesey Marine SAC
- Menai Strait and Conwy Bay SAC
- Anglesey Coast Saltmarsh SAC
- West Wales Marine SAC
- Pembrokeshire Marine SAC
- Carmarthen Bay and Estuaries SAC
- Bristol Channel Approaches SAC
- Hafren SAC
- Limestone Coast of SW Wales SAC
- Severn Estuary SAC

Higher risk areas overlap with the following SPAs:

- The Dee Estuary SPA
- Anglesey Terns SPA
- Lavan Sands SPA
- Liverpool Bay SPA
- Skomer, Skokholm and the Seas off Pembrokeshire SPA
- Carmarthen Bay SPA
- Burry Inlet SPA
- Severn Estuary SPA

Higher risk areas overlap with the following Ramsar sites:

- The Dee Estuary Ramsar
- Burry Inlet Ramsar
- Severn Estuary Ramsar

The Skomer MCZ is located in an area of moderate risk.

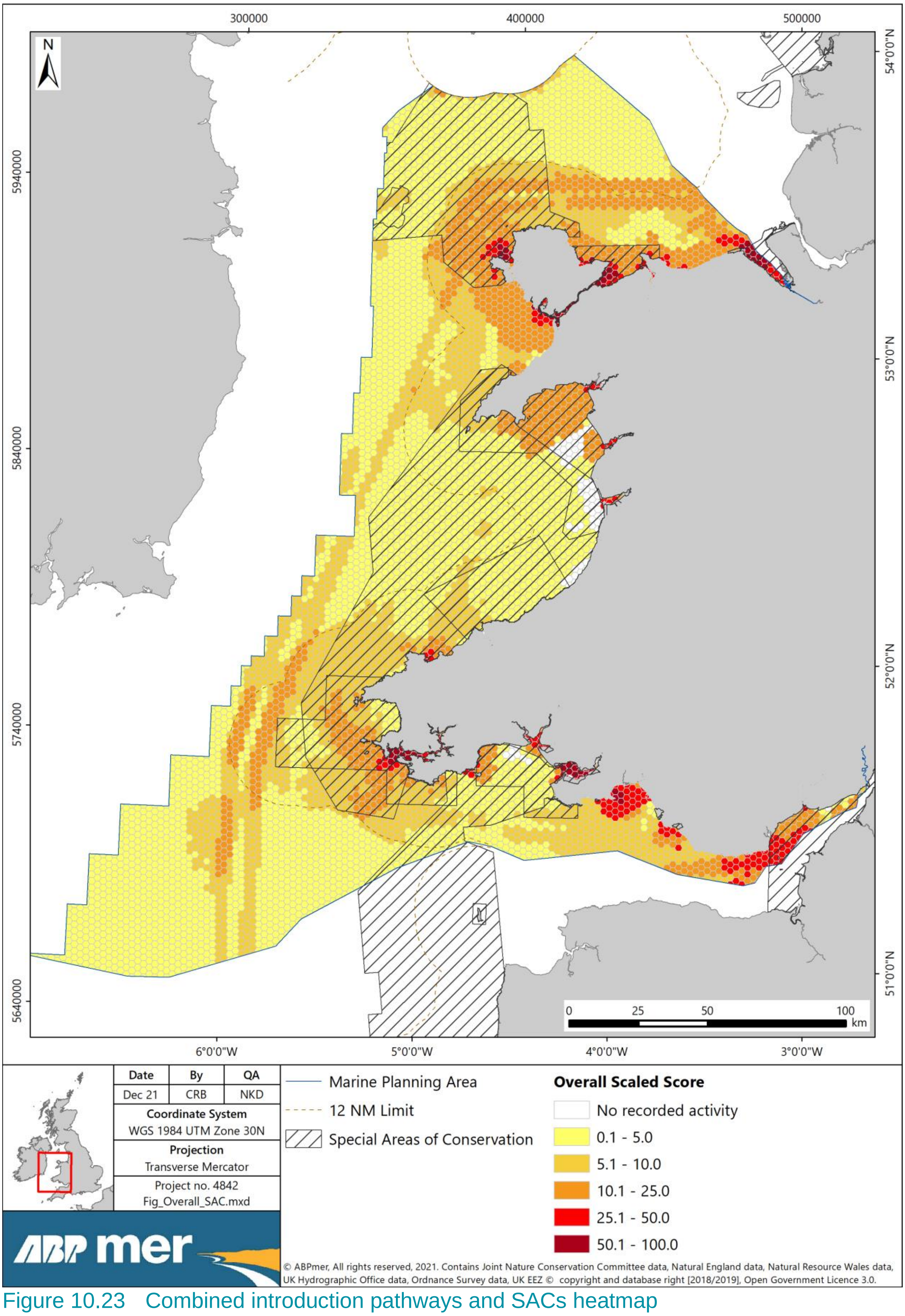

Figure 10.23 Combined introduction pathways and SACs heatmap

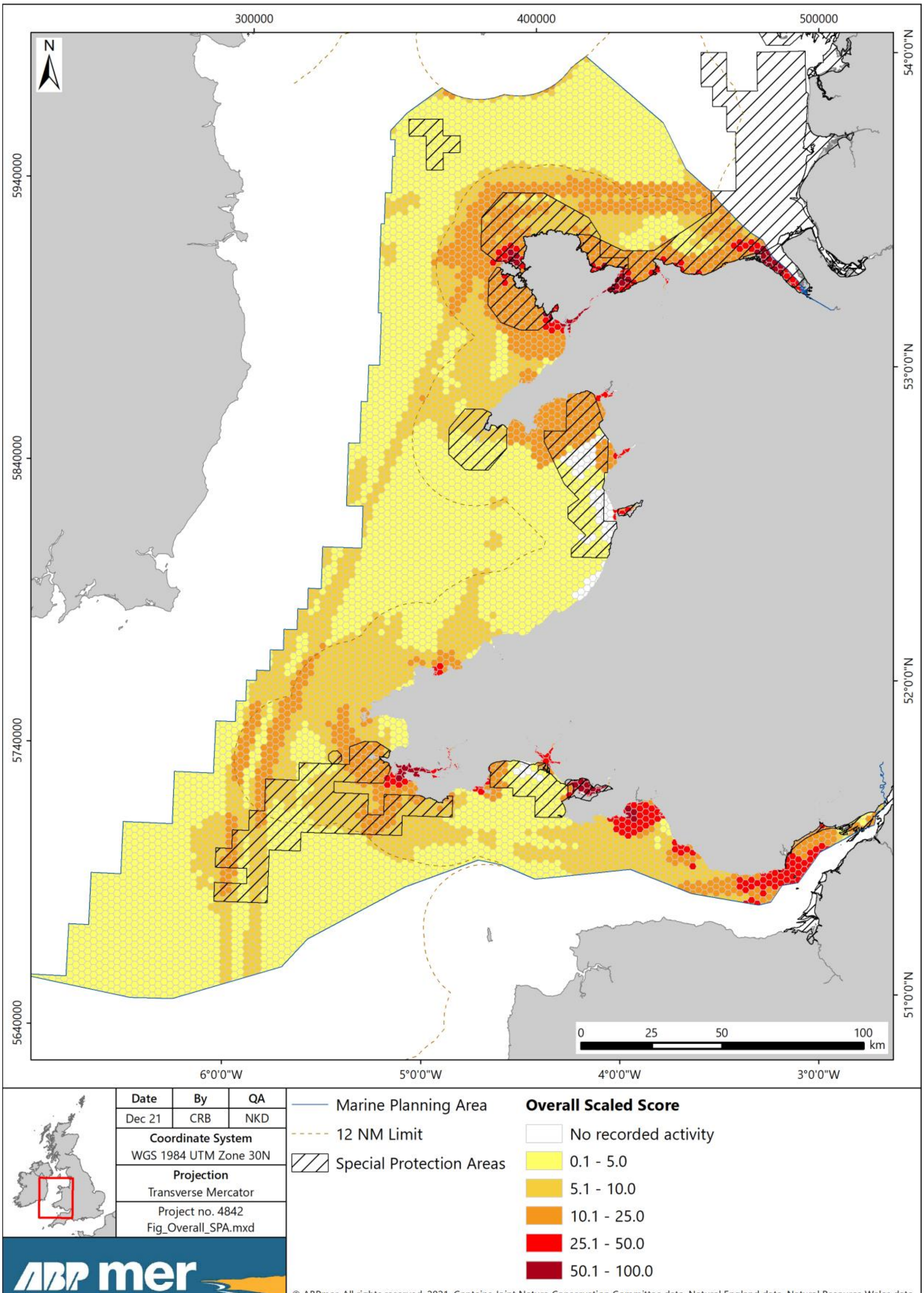

Figure 10.24 Combined introduction pathways and SPAs heatmap

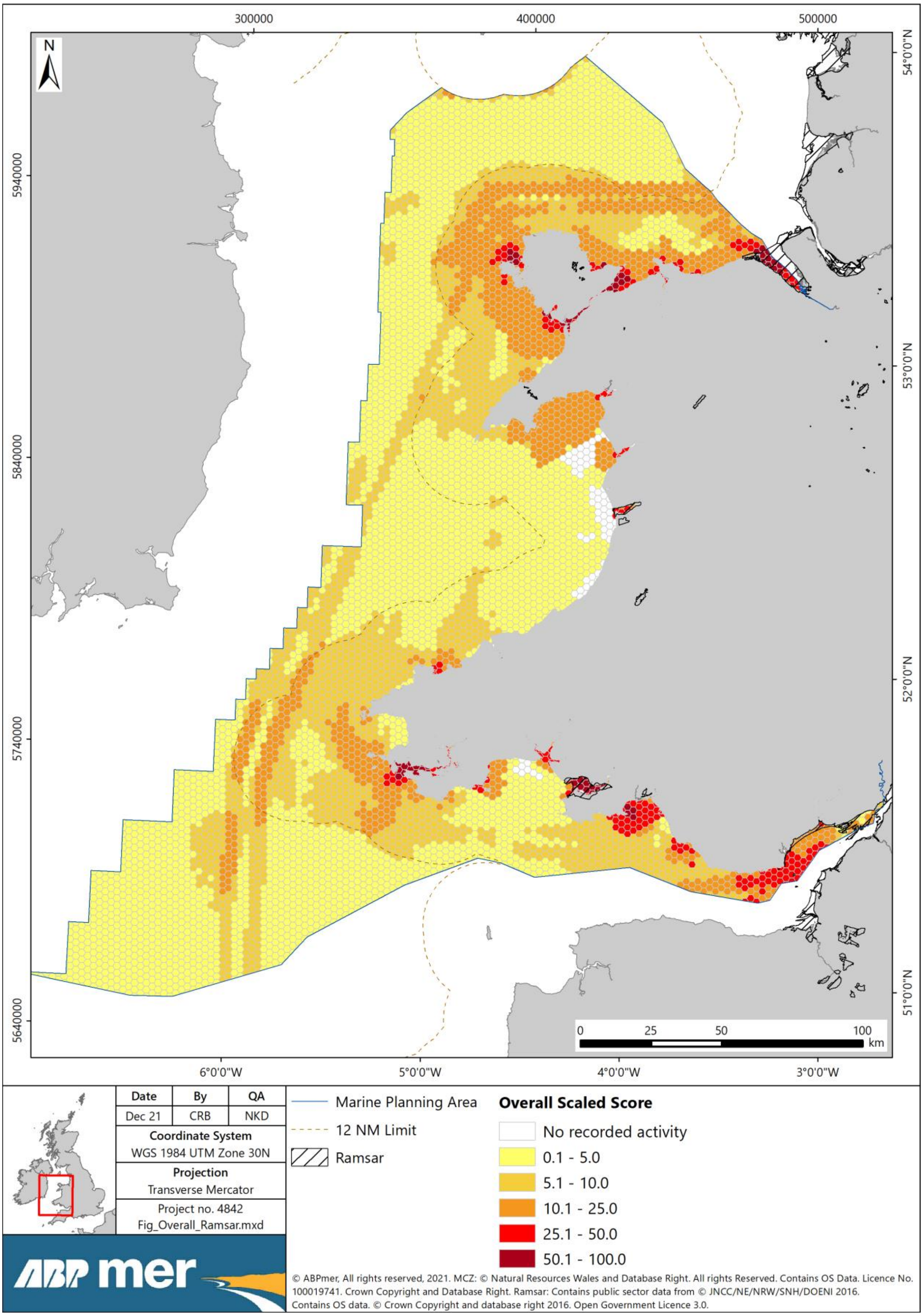

Figure 10.25 Combined introduction pathways and Ramsars heatmap

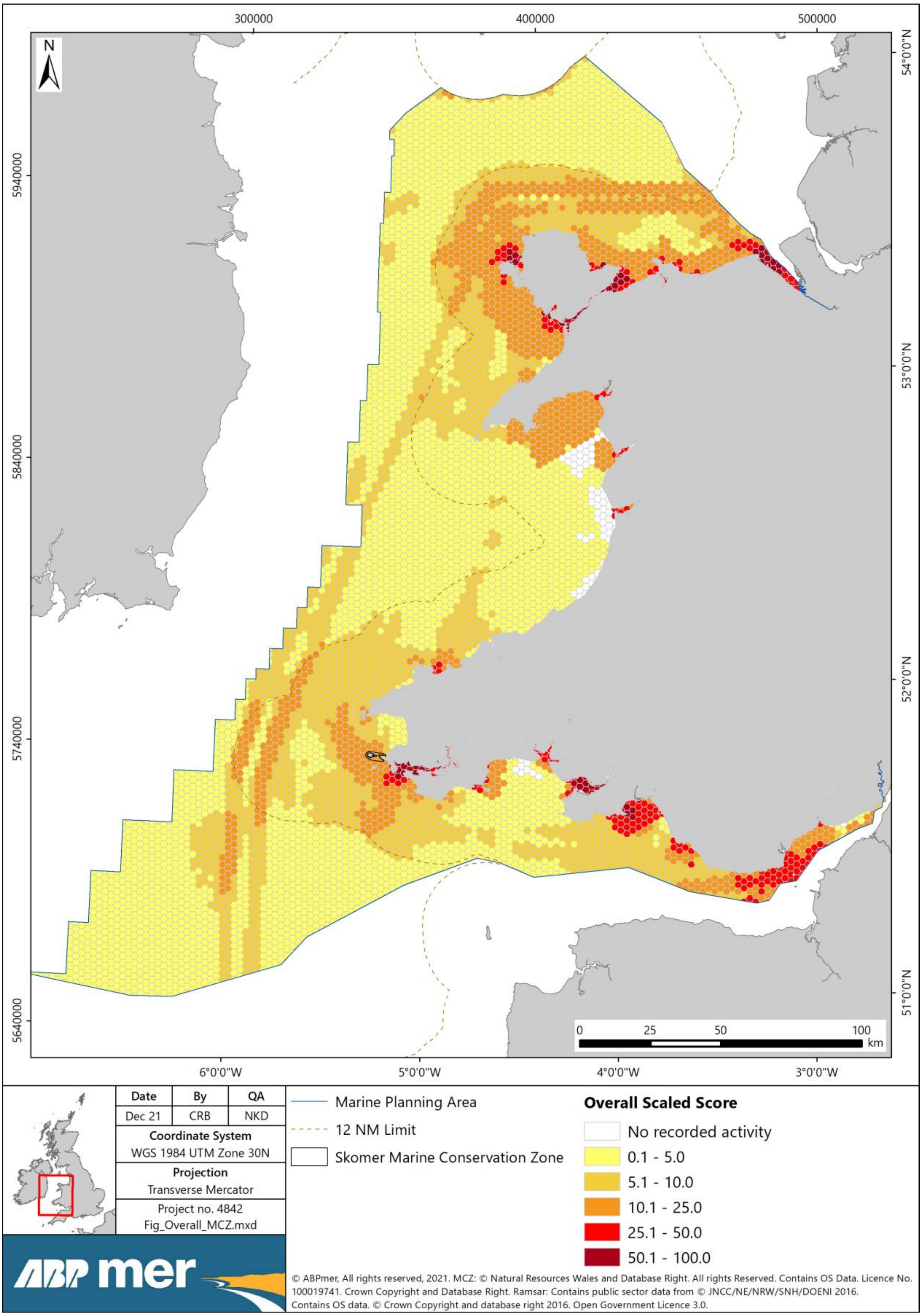

Figure 10.26 Combined introduction pathways and MCZ heatmap

11. Appendix B

Ports, harbours and marinas location data were considered for use in this study, due to the importance of these locations in assessing the risk of introduction of INNS. However, due to difficulties in applying an automated method this was not possible. Sections 11.1 and 11.2 describe the issues in more detail.

11.1. Ports and harbours data

Since the shipping data available to this study did not include information about destination port (section 4.2), consideration was given to including port and harbour locations in the commercial shipping heatmap instead, using either:

(a) a value to differentiate between major ports, minor ports or harbours assigned to a heatmap grid cell containing the port or harbour point location; or

(b) the maximum value from the AIS density grid for all ship type groups overlapping with the heatmap grid cell containing the port or harbour point location.

(c) assigning the value from option (a) or (b) to a buffered area around the point data, rather than the grid cell containing the port or harbour location only.

These approaches were all tested to establish their relative merit. However, the proposed methods did not give sensible results, since it was affected by the spatial position of the heatmap grid in relation to the port and harbour location. For example, if the grid cell in which the port was located, was clipped by the land, as shown in the example for Milford Haven (Figure 11.1), the spatial influence of the port appeared to be very small whereas minor ports may appear to have a larger spatial influence.

The method was adjusted to include a buffer around each port or harbour point location based on the following rule: major port = 2 km, minor port = 1 km, harbour = 100 m. Although this gave a better result for Milford Haven (Figure 11.2) it resulted in some more minor ports having a large spatial influence where several surrounding grid cells were selected. Additionally, some ports still had a small spatial influence depending where the point data fell.

This dataset was therefore not included within the heatmaps, instead, port and harbour locations were added as labels to the commercial shipping heatmap figures.

11.2. Marinas data

Consideration was also given to including marinas in the recreational boating heatmap (section 4.2), using the 'risk level' value for 15 marinas from Conwy to Cardiff, as reviewed in the report by Wood *et a*l. (2015). However, the location of the marinas within the heatmap grid cells affected the relative spatial influence of the marinas, as described above for the ports and harbours data, making it difficult to apply an automated approach to the methodology at the scale required for this study.

The marinas dataset was therefore not included within the heatmaps, instead, marina locations were added as labels to the recreational boating heatmap figures.

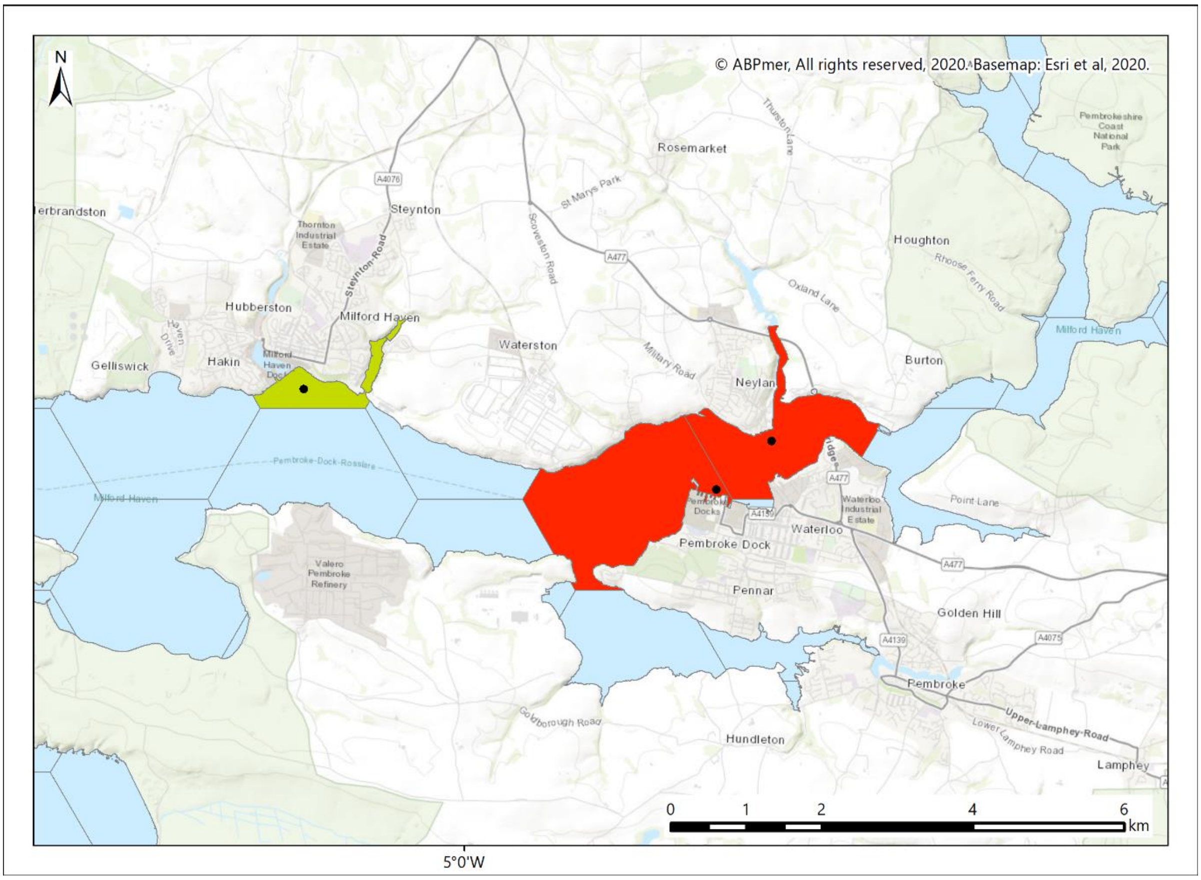

Figure 11.1 Position of Milford Haven and Pembroke Dock in relation to grid cells

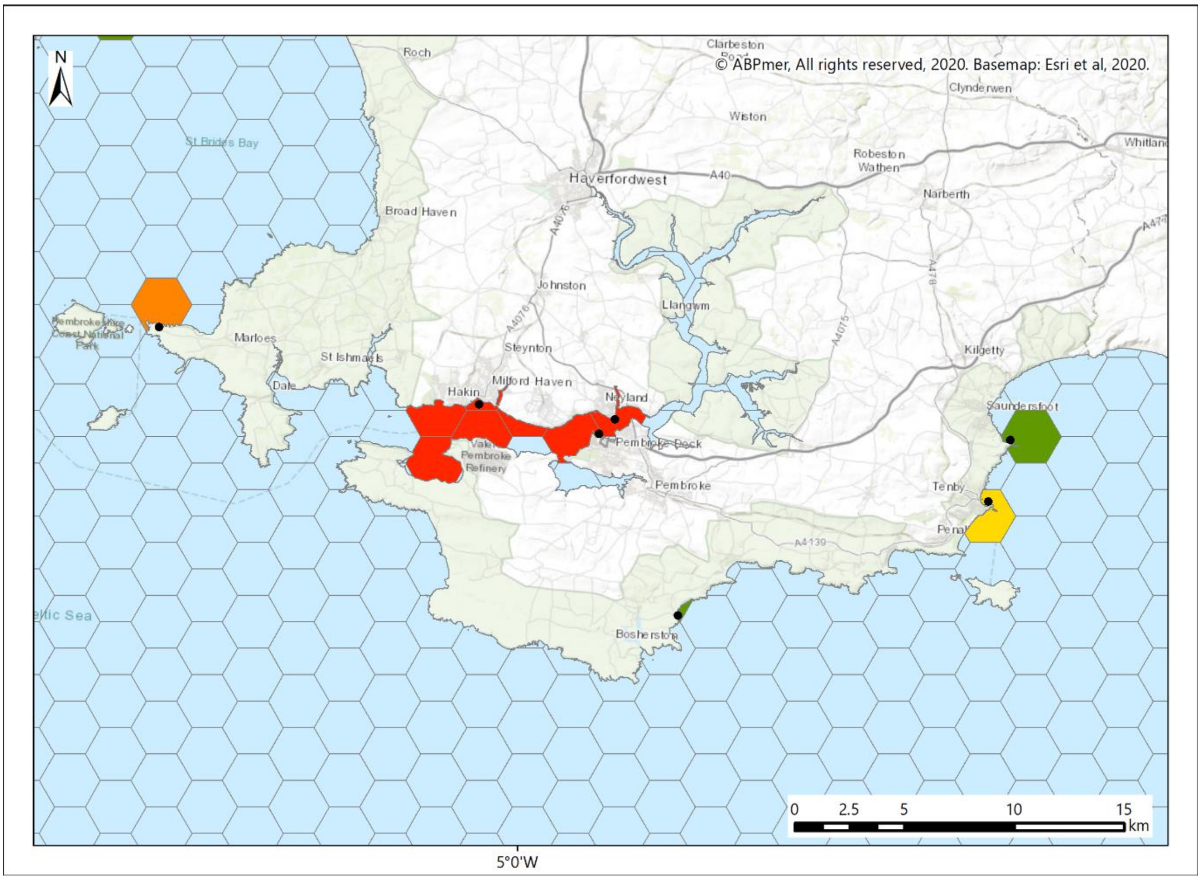

Figure 11.2 Comparison of buffered ports in heatmap grid

Data Archive Appendix

Data outputs associated with this project are archived on server–based storage at Natural Resources Wales.

The data archive contains:

[A] A series of GIS datasets including a combined heatmap for each introduction pathway and individual and grouped heatmaps for each introduction pathway

Metadata for this project is publicly accessible through Natural Resources Wales' Library Catalogue hiips://libcat.naturalresources.wales (English Version) and hiips://catllyfr.cyfoethnaturiol.cymru (Welsh Version) by searching 'Dataset Titles'. The metadata is held as record no 124807.

Published by:
Natural Resources Wales
Maes y Ffynnon,
Penrhosgarnedd,
Bangor,
LL57 2DW

0300 065 3000

Further copies of this report are available from:

Email: library@cyfoethnaturiolcymru.gov.uk