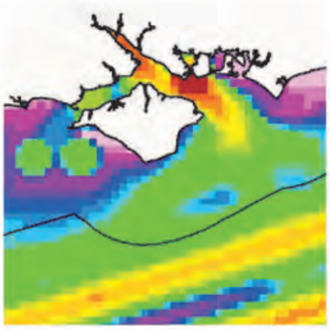
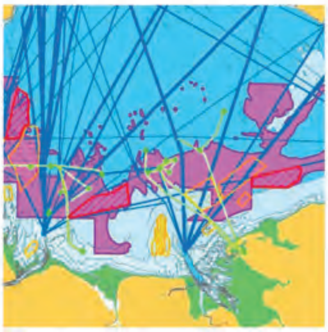
Crown Estate Scotland

Prospects and Opportunities for Large-scale Restorative Aquaculture in Scotland

Final Report

December 2021





Innovative Thinking - Sustainable Solutions

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		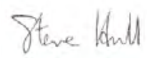

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Notice

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Executive Summary

The term regenerative aquaculture has been applied to the farming of seaweeds and bivalve shellfish as both taxa can provide beneficial ecosystem services whilst also having the potential to produce commercially valuable crops. The aim of this study was to identify areas off the south-west and east coasts of Scotland where it may be technically feasible to undertake large-scale cultivation of seaweed (kelp species) or mussels, in areas that are further offshore or more exposed compared to current developments. Technical feasibility was considered with respect to:

- The physical oceanographic conditions with respect to the equipment, farmed species and operator requirements;
- The environmental conditions that would be required for suitable growth of the farmed species;
- The marine spatial planning (MSP) constraints with respect to existing marine sector infrastructure and activity.

A further aim of the study was to explore the scope for mitigating deleterious interactions and promoting beneficial interactions and relationships with local fishing interests. As such, key fisheries stakeholders were consulted to obtain further information about the inshore fishing activities undertaken in the areas identified and gain their opinion on the potential compatibility of fisheries, in particular static gear fisheries (e.g., creeling) within aquaculture developments.

The three areas of specific interest were:

1. Scotland's North Sea coast between Berwick and Wick;
2. The Sound of Jura south of Loch Sween; and
3. Kilbrannon Sound and the south-east coastline of Arran south of Carradale.

Physical and environmental spatial data sets were mapped to identify 'potential resource areas' where offshore mussel or kelp farming may be suitable based on the natural resource requirements of the species to be cultivated and the physical conditions (in relation to tidal current and wave height) required for farm-related operations. A total of 24,295 km^2 of potential resource area for mussels between 20-100 m water depth were identified within the areas of interest (5,555 km^2 between 20-50 m water depth and 18,740 km^2 between 50-100 m water depth) and 25,742 km^2 for kelp (6,380 km^2 between 20-50 m water depth and 19,362 km^2 between 50-100 m water depth). The model outputs also enabled identification of potential resource areas which may be suitable for the cultivation of either or both farmed species, a total of 24,293 km^2; (5,555 km^2 between 20-50 m depth and 18,738 km^2 between 50-100 m water depth).

Further to identifying potential resource areas for mussels and kelps, the study also sought to assess the extent to which offshore aquaculture developments might be constrained within these areas due to existing marine sector activity or infrastructure. This analysis was necessarily high level and the resulting outputs from the spatial model do not indicate areas where mussel or kelp farms would be consented. Rather they indicate potentially feasible development areas, where interactions with, and impacts on, other marine sectors will require careful further consideration. For mussels, a total of 19,624 km^2 of potentially feasible development area was identified (3,641 km^2 between 20-50 m depth; 15,983 km^2 between 50-100 m depth). Of this, 2,896 km^2 was within 20-50 m depth and 6 NM of the coast (considered to be where developments are most likely). For kelp, 20,882 km^2 of potentially feasible development area was identified in the areas of interest (4,372 km^2 between 20-50 m depth; 16,510 km^2 between 50-100 m depth). The total potentially feasible development area which may be suitable for the cultivation of either or both farmed species was 19,624 km^2 (3,641 km^2 in 20-50 m depth; 15,983 km^2 in 50-100 m depth). Of this, 3,627 km^2 was within 20-50 m depth and 6 NM of the coast (considered to be where developments are most likely).

With regard to the scale of offshore farms, the study focus was on identifying areas of opportunity for:

i. Mussel farm developments of > 500 tonnes of annual production (an indicative minimum scale assumed likely to attract the required financial investment[1]); and
ii. Seaweed farm developments, of > 1 km² in extent (an indicative minimum area assumed to represent large-scale development for the purposes of this study).

Based on a generic farm design for mussel farms (an array of four columns of ten parallel 150 m longlines in 30 m water depth, each capable of producing just over 200 tonnes every two-year growing cycle), the indicative sea surface area required for the estimated production of 1,000 tonnes every two-year growing cycle was in the range of 5.46–7.26 km² (depending on the spatial grouping of the six arrays required). This represented 0.2–0.3 % of the potentially feasible development area identified for mussels within 20-50 m water depth and 6 NM of the coast (considered to be the most likely area for any developments) within the areas of interest.

Based on a generic farm design for kelp farms (an array of four columns of ten parallel 200 m longlines in 30 m water depth), the indicative sea surface area required for the estimated production of 40 tonnes of kelp every year was approximately 1.05 km² This represented 0.03 % of the potentially feasible development area identified for kelp within 20-50 m water depth and 6 NM of the coast (considered to be the most likely area for any developments) within the areas of interest.

Further to identifying potentially feasible development areas for cultivating mussels and kelp, key fisheries stakeholders were invited to discuss the fishing activity in these areas, the potential impacts of aquaculture developments on commercial fisheries and their opinions on the potential for some fishing activities to be able to continue within mussel or kelp farm installations (i.e. co-exist). Displacement of fishing vessels from key inshore fishing areas was the key impact of concern amongst the fisheries stakeholders consulted that even with an 'extensive' farm design (to potentially enable access and some fishing activity with the farms), entanglement of static gear such as creels with farm equipment was inevitable. As such, the consensus opinion from fisheries stakeholders was that these activities should be separated. It was also highlighted that the 'access channels' proposed in the generic farm design would encourage all vessels to transit through them making it even less practical for static gear fisheries to operate in them. Suggestions regarding farm design included that it would be preferable to have a more intensive farm design where feasible (i.e. producing higher volumes of mussels or kelp from a smaller sea area), that the activities should be kept separate (an opinion also expressed by one aquaculture stakeholder), with recognised separation distances. It was also queried whether such aquaculture development could occur within MPAs to reduce the competition for space with commercial fisheries outwith MPAs. The outcomes of this consultation highlight the importance of understanding the location of inshore fishing grounds as part of any site selection process and consultation with fisheries at a more local level.

It is important to note that the spatial model developed for this study was necessarily high level and there are numerous additional factors which would influence the technical feasibility of offshore mussel and/or kelp farming. Key amongst these is the economic viability of such developments (relating to capital investment and operational costs, market demand and the market value of the species produced). The economic viability in turn is influenced by operational factors such as the distance of the site from shore (influencing steaming time to and from site), the ability to access the farm site when required (influenced by physical conditions) and the presence and adequacy of shore side logistics (e.g., the availability of haulage, processing units for the potential production volumes etc). These are all factors that will require further detailed consideration in relation to assessing the potential opportunities for large-scale restorative aquaculture in Scotland.

[1] https://www.crownestatescotland.com/resources/documents/scottish-shellfish-critical-mass-study

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1 Introduction

1.1 Context

Aquaculture is an important industry for Scotland, helping to sustain economic growth in the rural and coastal communities. In 2020, the total value at first sale of all shellfish species farmed for table trade (consumption) was approximately £6.1 million, with mussels comprising the largest volume and value of shellfish produced in Scotland (approximately 5,661 tonnes (t) valued at approximately £5 million in 2020) (Marine Scotland Science, 2021).

The majority of mussel production occurs in the Shetland Islands (78% of the total mussel production in 2020), although mussel production also occurs in the Western Isles (5% of total production volume in 2020), and on the western coast of mainland Scotland in the Highlands (9%) and Strathclyde (8%) regions (Marine Scotland Science, 2021). Currently the majority of mussel farms are located in sheltered waters in lochs and voes, with the majority covering less than 20 hectares (ha; equivalent to 0.2 km^2) and the largest not exceeding 40 ha (0.4 km^2). Poseidon (2017) reported that fewer than 30% of mussel farms produce over 200 t per annum.

However, whilst mussel production has generally increased in the Shetland Islands in the past ten years, production on the mainland has mainly stagnated (Poseidon, 2017). Whilst multiple factors may be contributing to this lack of growth in the sector on the mainland, for example competition for space with other sectors, access to finance, regulatory hurdles etc, it has also been suggested that 'the right sites are not available' for example in relation to good spat supply or the ability to expand production (Poseidon, 2017).

There is ambition for the Scottish aquaculture industry to grow, given the socio-economic importance of the sector to Scotland, in addition to the potential to contribute to national and global food security and the provision of healthy nutritious food. In its vision for 2030, Scotland Food and Drink's 'Strategic plan for aquaculture growth to 2030' highlighted the ambition for growth of the shellfish farming sector across all regions of Scotland, referring to increasing the utilisation of consented areas but also the take up of efficient farming practices and improvements in finance availability:

"*production will be more balanced across the regions, with current low-volume production areas gaining critical mass to support new infrastructure in these locations. The current permitted capacity will be almost fully utilised….Highly efficient farming practices will be the norm and costs of farming will be well understood and competitive*".

One strategy for enabling larger-scale mussel production is to look to develop farms further offshore or more exposed locations, where competition for space with other marine sectors may be less compared to current inshore locations, enabling development at sites with 'optimal conditions' with respect to production capacity and at larger economies of scale. Although farming in more exposed locations will obviously provide additional technical challenges, the ability to successfully achieve this has been demonstrated in New Zealand as well as through the establishment of the UK's first offshore mussel farm (located between 3-6 miles NM off the coast) in Lyme Bay, Devon, with the latter farming sites covering a total area of 15.4 km^2, sufficient to support an estimated production capacity of approximately 10,000 t per annum once fully developed.

In addition to the established shellfish and finfish farming sectors in Scotland, there is an emerging seaweed farming sector. Scotland's current seaweed-based industry sector, which provides seaweed based food, nutraceutical and horticultural products to Scottish, UK and worldwide markets is almost exclusively based on harvesting wild seaweed. However, at least one commercial seaweed farm, and several trial sites, have been established in Scotland, and there is great interest in the development of this sector to enable expansion and diversification of the aquaculture industry to develop new markets and products.

The farming of seaweeds and bivalve shellfish such as mussels can be classified as restorative aquaculture as both groups have significant positive impacts on the marine environment through the provision of ecosystem goods and services whilst also having the potential to produce commercially valuable crops. Given the importance of this balanced approach, Crown Estate Scotland has commissioned this study to assess the prospects and opportunities that may exist for large-scale shellfish and seaweed farming in the following three areas:

1. Scotland's North Sea coast between Berwick and Wick;
2. The Sound of Jura south of Loch Sween; and
3. Kilbrannon Sound and the southeast coastline of Arran south of Carradale.

1.2 Objectives

The specific objectives of the project, as stated in the ITT are as follows:

1. Confirm the technical feasibility and identify associated opportunities for the following, within the 0 to 3 NM (0 – 6 NM where appropriate) zone of the three areas defined above:
    - mussel farm developments of > 500 tonnes of annual production, and
    - seaweed farm developments, of > 1 km² in extent

2. Undertake subsequent assessments of:
    - The scope for the co-cultivation of both mussels and seaweeds at single developments of >1 km² and associated implications for production volumes and stakeholder interaction mitigation compared to single species only farms; and
    - The scope and measures for mitigating deleterious and promoting beneficial interactions and relationships with local fishing interests. This should include prospective arrangements for access for static gear activity as well as contractual opportunities in operational and quayside requirements. Prospects for and value of one or more pilots of 'managed interactions' area should be included.

1.3 Scope of study

The scope of this study was to identify marine areas where it is potentially **technically feasible** to cultivate seaweed or mussels in areas that are further offshore and more exposed compared to current developments. Two study areas were defined, one of the West coast, and one on the East coast (Figure 1).

The criteria for technical feasibility were considered with respect to:

- The physical oceanographic conditions with respect to the equipment, farmed species and operator requirements;
- The environmental conditions that would be required for suitable growth of the farmed species; and
- The marine spatial planning (MSP) constraints with respect to existing marine sector infrastructure and activity.

It was confirmed that the seaweed species to be considered were the kelp species: *Saccharina latissima*; *Laminaria digitata* and *Alaria esculenta* (hereafter referred to as kelps). The shellfish species to be considered was the blue mussel, *Mytilus edulis*.

Whilst it is acknowledged that there are multiple factors beyond those listed above that will influence whether larger-scale kelp or mussel farms may develop in Scotland, it was not within the scope of this study to consider the following factors when assessing potential opportunities:

- The financial (capital and operational) cost or viability of such developments;
- The market demand or price for the species farmed;
- The impacts of COVID-19 or the UK's exit from the European Union (EU) on the seafood sector (producers and supply chain); or
- Climate change.

Furthermore, it was not within the scope of this study to assess the environmental or socio-economic impacts of any such future developments on other commercial marine sectors, marine users, local communities or other stakeholders. These are important issues that would need to be considered at a site-specific level for any proposed development through the existing consenting processes for seaweed and shellfish aquaculture, or at a regional or national level for regional marine plans or sectoral plans respectively. Examples of wider environmental and socio-economic concerns that were raised during consultation for this study are summarised in Appendix C.

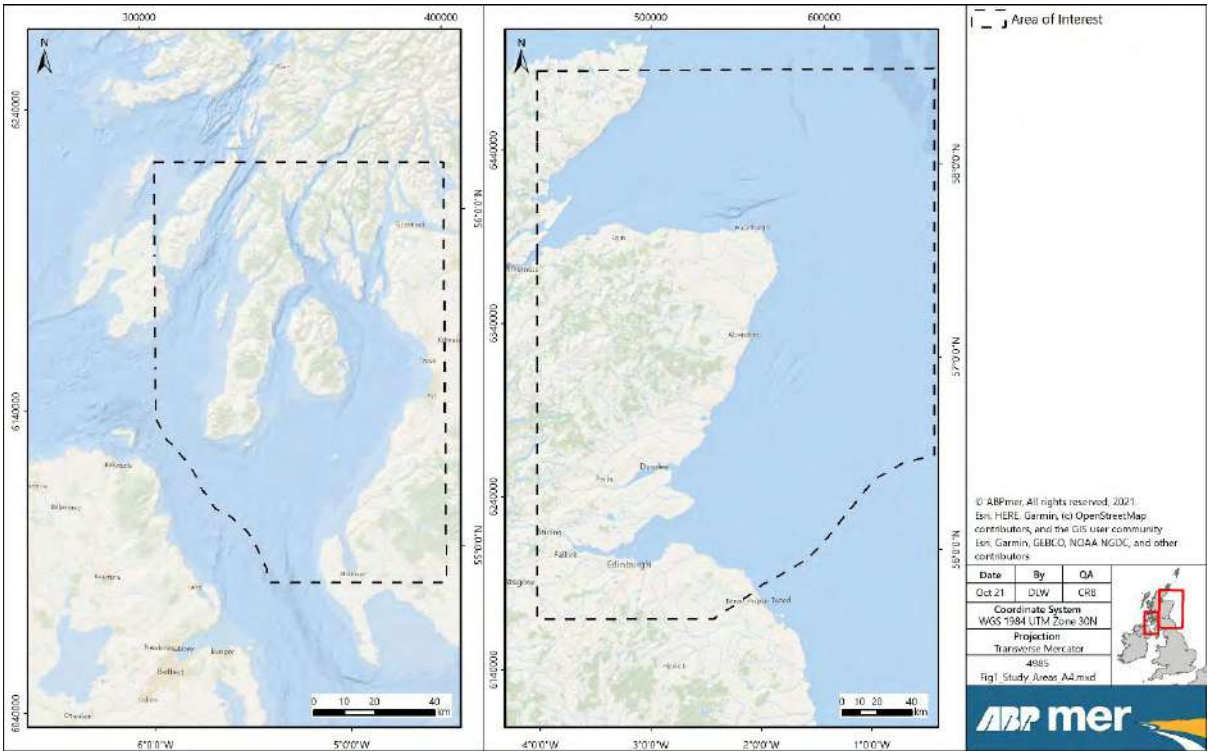


Figure 1. **Study areas**

1.4 Report structure

This report comprises the following sections:

Section 1: Introduction (this section);
Section 2: Development of the spatial model;
Section 3: Outputs of the spatial model;
Section 4: Scope and measures for promoting beneficial interactions with fisheries; and
Section 5: Key findings.

2 Development of the Spatial Model

In order to identify marine areas that that may be suitable for cultivating kelps or mussels, at a greater scale and in more exposed locations than the sector currently occupies (acknowledging seaweed cultivation is a nascent sector), a spatial model was developed.

This section provides a summary of the approach used to develop the spatial model, including the following:

- Current farming technology and practice;
- The physical and environmental parameters used to identify suitable resource areas for cultivation of mussels and/or kelp; and
- The constraints to development in these areas (i.e. other marine activity and infrastructure).

The full details of the methodology used, including the assumptions regarding the generic farm size and layout and the spatial data sources, parameters and thresholds applied within the spatial model, are presented in Appendices A and B respectively.

2.1 Farming technology and design

It was necessary to propose a generic design (equipment and layout) for mussel farms and kelp farms to enable calculation of the sea surface area and estimated production volumes within the spatial model. Expert stakeholder input was sought through consultation to try to ensure that the farm layouts used within the spatial model were potentially viable in more exposed offshore locations from the species requirements, equipment and operational perspectives.

Given the purpose of the study was to identify areas which could potentially support large-scale offshore farming operations, the initial generic design used in this study for both mussel and kelp farms have utilised a more extensive layout and thus should be considered as representing a minimum production capacity per unit area. This approach takes into account the limitations (in terms of resolution) of the available data used for the spatial model and the inputs of industry experts with respect to the need to address the following site-specific operational considerations:

- The potential for tangling of equipment (e.g. growing lines) to occur if there is inadequate spacing between parallel longlines in more exposed locations with higher tidal current flows (compared to semi enclosed lochs);
- The access and operational requirements of farm vessel(s) designed to be able to carry 20 tonnes of stock (e.g. the ability to turn the vessels around between longlines during maintenance or harvesting activities); and
- To potentially enable access through the farm by small vessels (e.g. creel fishers or recreational boat users).

Commercial fisheries and aquaculture stakeholder opinions on whether such a design could potentially enable the co-existence of some types of fisheries within such farm developments are presented in Section 4.

2.1.1 Mussels

In general, the current preferred suspended mussel farm systems are based around the more modern New Zealand continuous growing rope design attached to either a single or double headline, which is submerged below the sea surface and is supported by vertical buoys. For the purposes of this study, a single headline was chosen for the generic mussel farm design as it was assumed that such an approach would minimise the risk of rope or stock entanglement (compared to a double headline) in more exposed offshore locations. A summary of the equipment, layout and production capacity of the generic mussel farm designed for this study is shown in Table 1. A detailed explanation of the rationale underlying each aspect of the farm design is provided in Table A1, Appendix A.

Based on the layout chosen, it was estimated that one array of 40 x 150 m longlines may potentially produce approximately 230 tonnes of mussels per growing cycle (i.e. every two years). If it is assumed that the length of growing rope is reduced by 10% to enable deployment of spat collector ropes (as opposed to buying spat in and using the whole area for on-growing), the estimated production per array would decrease to approximately 207 tonnes per growing cycle. This estimate, which is indicative only (with low confidence), does not account for other factors that may reduce production volumes, for example, spat availability, natural mortality, growth rates (related to sea temperatures) or stock loss arising from extreme weather events, predation etc.

Table 1. Generic mussel farm design

Criteria	Design Assumption
Type of headline rope	Single
Length of headline	150 m
Position of headline in water	4 m subsurface
Type of growing rope	One continuous rope, attached to the headline rope every 1.5 m, with the loops extending to 10 m below the headline (see Image 1)
Length of growing rope per headline	c. 1.15 km (see Image 1)
Seeding method	Spat collector lines within the same array. Assume 10% of each array (4 longlines) needed for spat collection
Time to harvest	2 years (from re-socking[2] of mussel spat onto growing lines)
Type of anchor/seabed required	Screw anchors; suitable for any substratum except rock
Ratio distance: depth of mooring line	2.5 m horizontal distance: 1 m depth
Farm layout	4 columns of 10 parallel longlines (see Image 2) - 70 m between rows - 150 m between columns (at 30 m depth)
Farm area per array – sea surface	0.91 km^2 at 30 m depth (see Image 2)
Total length of growing rope per array	45.9 km
Yield per m growing line	5 kg / m
Estimated production tonnage per array per two year growing cycle	c. 230 tonnes every 2 years c. 207 tonnes every 2 years if 10% of the growing area is used for spat collection

2 Re-socking involves putting mussel spat into a continuous mesh tube which is then wrapped around the growing rope. The mussels then grow through the tubular sock and attach to the growing rope using their byssus thread.

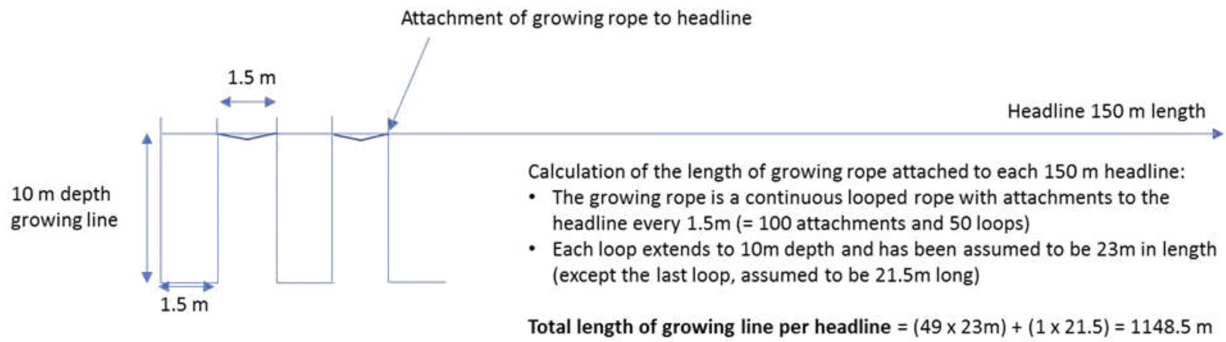


Image 1. **Schematic illustration of a continuous loop mussel growing line**

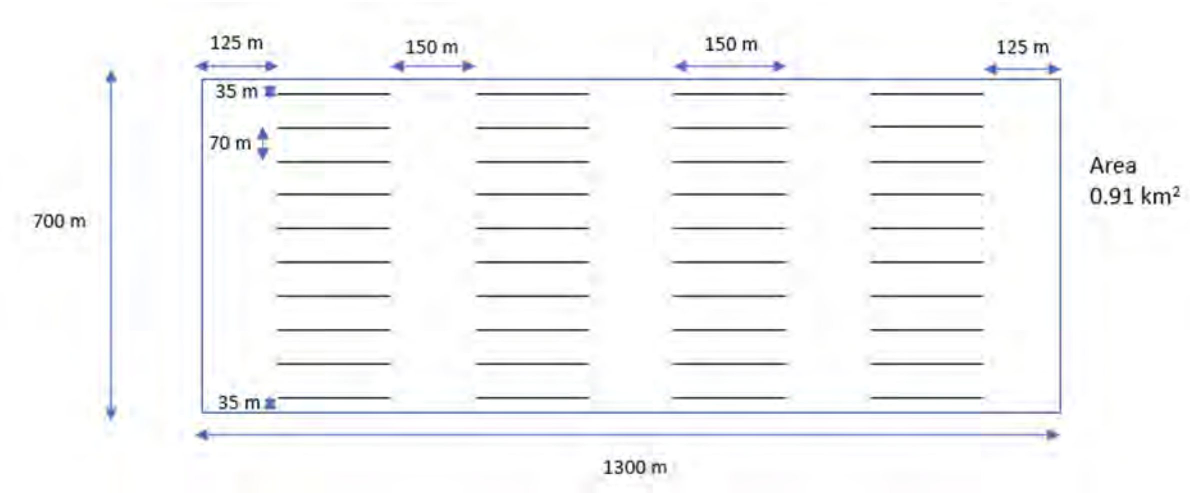


Image 2. **Schematic showing generic mussel farm design used in model**

As the water depth increases, the spacing between the columns of longlines would need to increase to prevent the anchor lines from overlapping. As such, the surface area of the array would increase with water depth as shown in Table 2, whilst the estimated production volume of mussels per array would remain constant (in this instance, an estimated 207 tonnes every two years).

Table 2. **Effect of water depth on surface area of arrays**

Water Depth	Distance Required Between Columns (m)	Total Sea Surface Area Within array(s) (km^2)
30	150	0.91
40	200	1.02
50	250	1.12

The UK's only offshore mussel farm is located in Lyme Bay, Devon. Once fully developed that farm will cover a total area of 15.4 km^2 and produce approximately 10,000 tonnes of mussels per year. Based on the estimated production volume of approximately 207 tonnes from one of the generic arrays designed for this study, approximately 48 arrays would be required to produce 10,000 tonnes every 2 years, covering an area of approximately 45 km^2 of sea area (at 30 m water depth), based on this extensive design, or 56 km^2 if production was achieved through 'blocks' of four arrays assuming a 250 m horizontal access channel between pairs of arrays; see Image 3). The reason for these differences in area required between the farm in Devon (15.4 km^2) and those predicted in this study (45-56 km^2) are likely to be due to the following factors:

- The spacing between parallel rows of longlines in our model was 70 m. In practice, this spacing could be significantly reduced dependent upon prevailing site-specific conditions (stakeholder input);
- Mussel farm yield (kg per metre of growing rope) is variable, for example, reaching levels of between 12 to 15 kg/m in New Zealand and 8 to 10 kg/m in the USA (stakeholder input). In general yields range between 5 to 8 kg/m in Scotland; a conservative yield of 5 kg/m was used in this model but higher yields may be possible;
- The growth rate of mussels is influenced by various factors with the two main ones being sea temperature and food availability. In this study it has been assumed that two years would be the required grow-out time starting from seeding the mussel spat onto the growing rope up until they reach a marketable harvest size. In contrast, grow out time at the Offshore Shellfish Ltd farm sites is 12 months or less (Offshore Shellfish Ltd, pers. comm.).

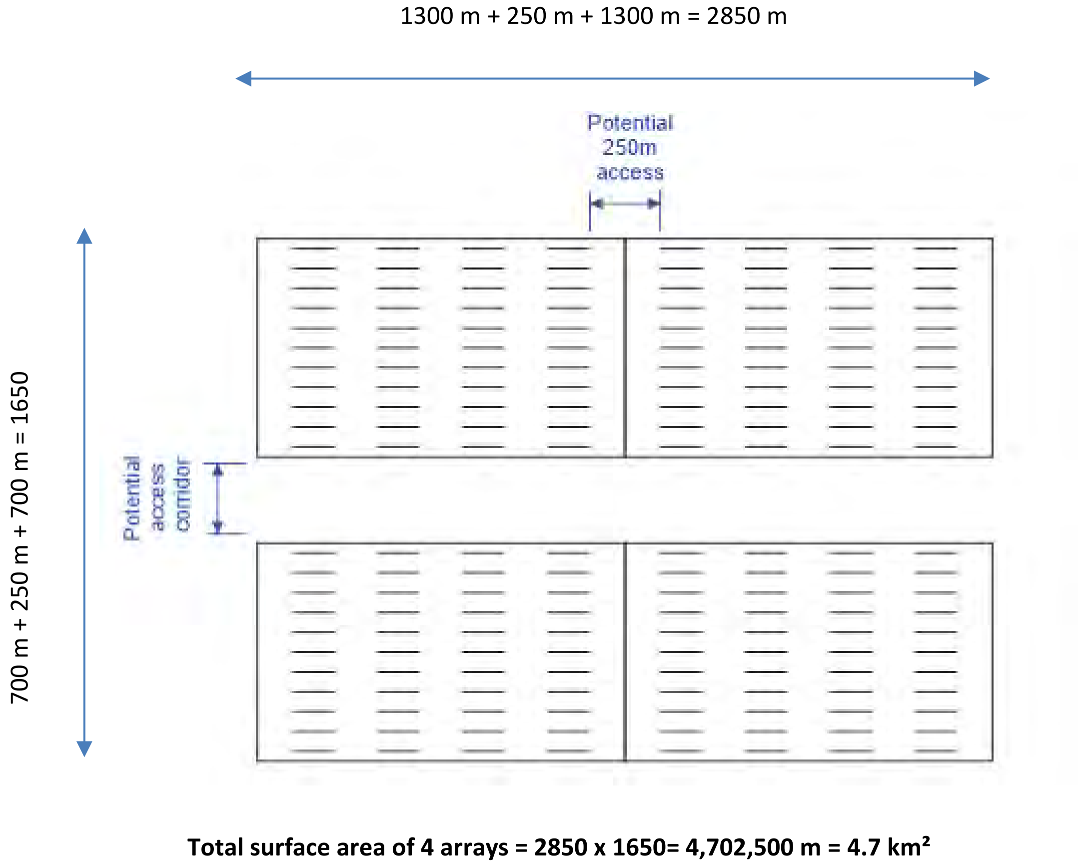


Image 3. Schematic showing a cluster of four arrays with an access channel in a mussel farm

2.1.2 Seaweed

For the purposes of this study, the seaweed species considered for cultivation were assumed to be the kelp species *Alaria esculenta*, *Saccharina latissima* and *Laminaria digitata*. It was confirmed with an expert stakeholder that the environmental requirements for these species are similar enough that it could be assumed that all three species could be farmed at the same site. As such, hereafter, the species of seaweed is just referred to as kelp.

Farmed kelp is a seasonal crop. Whilst there are small differences in the growing season between the three species (not considered further within this study), in general growing ropes are put out to sea in October and the seaweed is harvested between March to May if the seaweed is for use in human food applications, or possibly June if for use in non-human food applications (the difference relating to fouling of the stock after May).

In Scotland, as in the rest of the UK and Europe, seaweed farming is a relatively new and emerging industry. General seaweed farm designs may include grid systems, single longlines, modified mussel growing ropes or offshore cultivation rigs (see SAMS and IMANI, 2019). For this study, the generic design chosen for kelp farms was a single longline, which was considered to be a more efficient design for the harvesting of relatively high volumes of kelp and reduced the risk of entanglement of the stock (kelp fronds) compared to a 'grid' rope system. The length of single longlines used (or proposed) for seaweed farms in Scotland is variable; for the purposes of this study, the length of longlines was set at 200 m.

A summary of the equipment, layout and production capacity of the generic kelp farm designed for this study is shown in Table 3. A detailed explanation of the rationale underlying each aspect of the farm design is provided in Table A1, Appendix A.

Based on the layout chosen, it was estimated that one array of 40 x 200 m longlines may potentially produce approximately 40 tonnes of kelp per growing cycle (i.e. annually).

Table 3. Generic kelp farm design

Criteria	Design Assumption
Type of headline rope	Single
Length of headline	200 m
Position of headline in water	2 m subsurface
Type of growing rope	Use headline as growing rope
Length of growing rope per headline	Same as headline (200 m)
Seeding method	Direct seeding
Time to harvest	c. 8 months (lines out Oct; harvest Mar – May (food); June (non-food))
Type of anchor/seabed required	Screw anchors; any substratum except rock
Ratio distance: depth of mooring line	2.5 m horizontal distance: 1 m depth
Farm layout	4 columns of 10 parallel longlines (see Image 4) - 70 m between rows - 150 m between columns (at 30 m depth)
Farm area per array – sea surface	1.05 km^2 (at 30 m water depth) (see Image 4)
Total length of growing rope per array	8 km
Yield per m growing line	5 kg/m
Estimated tonnage per array per year	40 tonnes

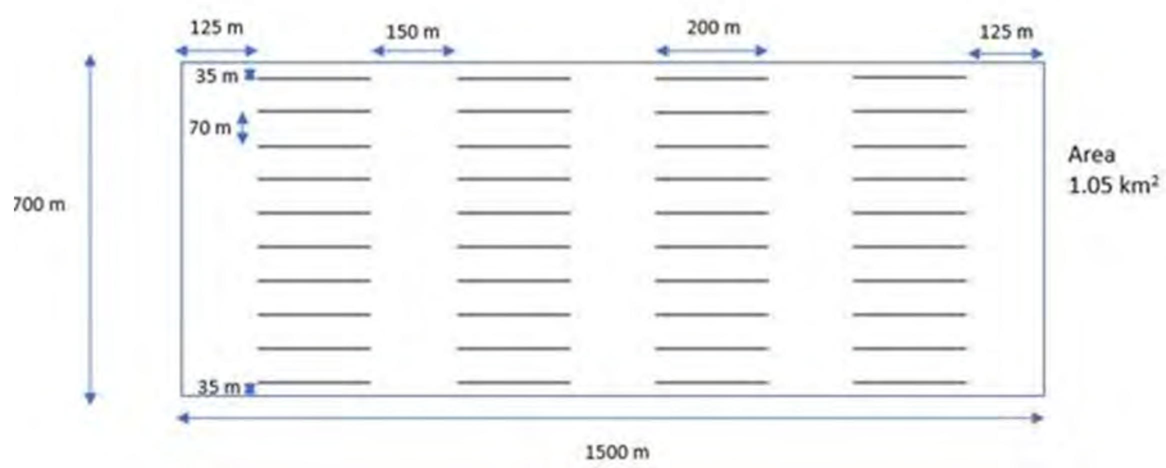


Image 4. Schematic showing generic kelp farm design used in model

As the water depth increases, the spacing between the columns of longlines would need to increase to prevent the anchor lines from overlapping. As such, the surface area of the array would increase with water depth as shown in Table 4 whilst the estimated production volume of kelp per array would remain constant (in this instance, an estimated 40 tonnes per year).

Table 4. Effect of water depth on surface area of arrays

Water Depth	Distance Required Between Columns (m)	Total Sea Surface Area Within Array(s) (km^2)
30	150	1.05
40	200	1.16
50	250	1.26

2.1.3 Access channels between arrays

In discussion with technical experts and to explore the potential for co-existence between mussel or kelp farms and static gear fisheries (e.g. creelers), it was proposed that where a theoretical development may exceed a sea surface area of 1 km^2 (i.e. more than one array), access channels could be placed between arrays to enable access to small vessels. Image 5 shows a generic design for incorporating 'access channels' between arrays, created for discussion with fisheries stakeholders regarding whether such a design may enable static gear fisheries to continue to operate within arrays. The outcomes of these discussions are presented in Section 4.

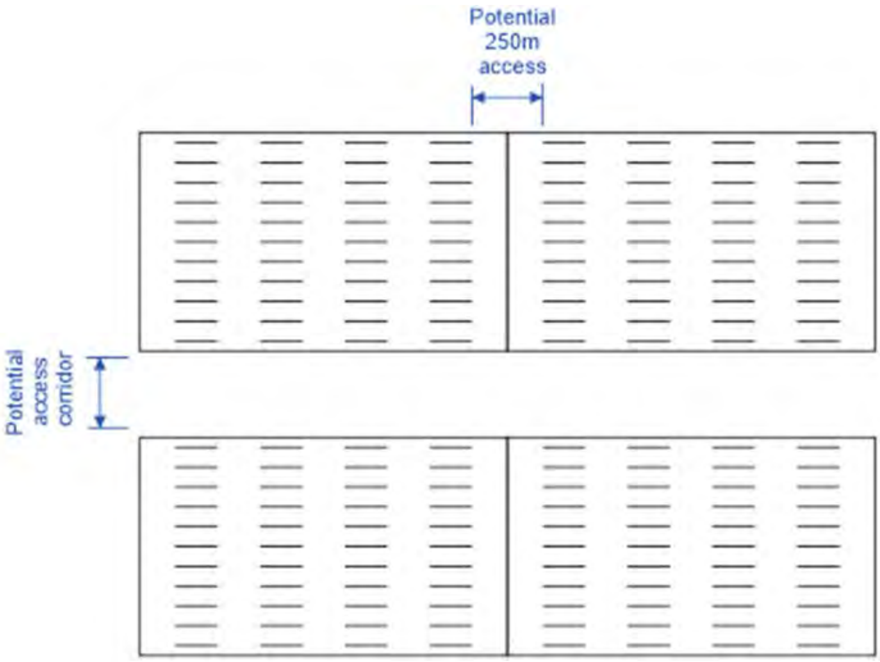


Image 5. Schematic showing potential access channels between arrays of a kelp farm

2.2 Identification of potential resource areas

The physical and environmental parameters and thresholds shown in Table 5 were used to identify areas in which the cultivation of kelp and mussels may be technically feasible ('potential resource areas'). The thresholds used are based on information regarding the natural resource requirements of the species to be cultivated, and the conditions required for operations, from the literature and stakeholder consultation.

The following parameters were not included in the model to identify potential resource areas as either they were not considered to be a constraint, or a suitable spatial data set was not sourced (i.e. they are identified as data gaps):

- Salinity – it was assumed that this parameter would not be a limiting environmental factor as long as there were no major freshwater inputs to the resource areas identified;
- Locations of recurrent harmful algal blooms (HABs) – although there are monitoring programmes and alert systems relating to HABs and algal toxins, these are only monitored in areas where bivalve molluscs are being farmed and thus a suitable long-term data set indicating any particular 'hotspot' areas for HABs was not sourced (data gap);
- Water quality – in general, only statutory monitoring is undertaken in coastal waters unless in response to a specific incident. Such monitoring is sparse and, in relation to microbial contamination focused on beaches and existing shellfish harvesting areas. As such, water quality with respect to microbiological contaminant levels cannot sensibly be incorporated into the spatial model due to its limited spatial distribution. Furthermore, the location of long sea outfalls (which would highlight potential point sources of microbial contamination) that could affect mussel farming in-particular, were not available within the timescale of the study (data gap).

With regard to water quality, which is a key influencing factor for shellfish farming, it was assumed that the water quality was not likely to be a constraint unless the potential resource areas identified were adjacent to:

- A shellfish harvesting area classified as C or X;
- A WFD waterbody that was classified as Moderate or Poor.

The outcome of this assessment is described in Appendix B.

Further detail regarding the assumptions and rationale underlying the thresholds applied, and data gaps are presented in Appendix B (see Table B1 and Table B3). The potentially resource areas for mussels and kelp based on the above parameters and thresholds are shown in Figure 3 and Figure 9 in Section 3.

It is also important to note, that the model developed for the purposes of this study was necessarily high level, and it is acknowledged there are other key physical and environmental factors that will influence the technical feasibility of offshore mussel or kelp farming. These factors would need to be considered further in detail in relation to site selection, farm design and the ability to access and operate at the farm site for the required number of days per year for the expected production volumes. The additional key factors influencing technical feasibility, raised by expert stakeholders, are listed below and discussed in further detail in Section B.1.1, Appendix B.

- **Tidal current** – influence on nutrient delivery, farm design (e.g. line spacing), yield and operational safety;

- **Tidal cycle and range** – influence on farm design (e.g. line spacing relating to changes in anchor line tension with changes in tidal height) and operational timings (e.g. timings for harvesting when vessel attached to farm equipment);
- **Wave exposure** – wave period and the 'shape' of waves (in turn influenced by seabed topography) as well as wave height (accounted for in model) influence the feasibility of operations at the farm site;
- **Wind** – influence on seastate conditions;
- **Turbidity (seaweed)** – winter storms could increase turbidity, reducing light penetration of the water column;
- **Spat availability (mussels)** – unreliable spat fall was raised as a key factor affecting the Scottish mussel industry, with variability both on a spatial and temporal scale;
- **Predation (mussels)** – eider ducks and golden eye were noted as a key issue in Scotland;
- **Fouling** – e.g. by hydroids and sea squirts can potentially impact spat settlement on spat collector lines (mussels) and tubeworms which can grow on mussel shells affecting stock quality; and
- **Disease status** (**mussels**) – e.g. if in a *Bonamia* area, can be an issue for exporting live bivalve molluscs.

Table 5. Parameters and thresholds used to identify potential resource areas for mussels and seaweed (kelp)

Parameter	Minimum	Maximum	Optimal	Rationale
Mussels				
Bathymetry (m)	20	100	20-50	Whilst it may be technically feasible to install a farm in water depth of > 50 m, it would be prohibitively expensive from a maintenance perspective (as too deep for commercial divers; stakeholder input). As such the optimal range was considered to be 20-50 m depth (consistent with Maritek, 2019 and MMO, 2019).
Significant wave height[3] (Hs; m)	0	2	< 2	It was assumed that the ability to safely conduct operations at a site would be the determining factor for Hs. A maximum value of 2 m was used based on stakeholder input.
Tidal current (m/s)	0.2	0.8	< 0.8	It was assumed that the ability to safely conduct operations at a site would be the determining factor of the maximum tidal current in the model. A maximum value of 0.8 m/s was set (based on judgement) with the assumption that lower current speeds for the majority of the time would be preferable (stakeholder input). The defined value for minimum current speed was based on the peak neap tidal current speed extracted from the location of an existing 'offshore' mussel farm in Lyme Bay, England. The flow speeds at the site were extracted from the in-house modelled ABPmer SEASTATES (www.seastates.net) hindcast database for hydrodynamics, covering the 41-year period from 1979 to 2020 inclusive.
Chlorophyll-a mean annual concentration (μg / l)	≥ 1	n/a	≥ 1	Based on information within MMO (2019) and stakeholder input.
Seabed substratum	n/a	n/a	Sedimentary	It was assumed that avoiding areas of rocky substratum[4] (which would be more costly and difficult to deploy screw anchors into) would enable avoidance of rocky reef species and habitats likely to be of concern to the statutory nature conservation body if located under an aquaculture development (e.g. in relation to abrasion from any deployed infrastructure, sedimentation etc).

3 Significant wave height (Hs) is defined as the average height of the highest one-third waves in a wave spectrum.

4 Rocky substratum was considered to be any habitat within the data set that started with the EUNIS code A3 (Infralittoral rock and other hard substrata), A4 (Circalittoral rock and other hard substrata) or A6 (Deep-sea rock).

Parameter	Minimum	Maximum	Optimal	Rationale
Kelp				
Bathymetry (m)	20	100	20-50	Same rationale as for mussels.
Significant wave height (Hs; m)	0	2	< 2	Same rationale as for mussels.
Tidal current (m/s)	0.1	0.8	< 0.8	It was assumed that the ability to safely conduct operations at a site would be the determining factor of the maximum tidal current in the model. A maximum value of 0.8 m/s was set (based on judgement) with the assumption that lower current speeds for the majority of the time would be preferable. The minimum tidal current was based on the lowest 'optimum' current requirement of the three kelp species of interest (MMO, 2019).
Photic depth (m)	5	n/a	n/a	It was assumed that the headlines would be 2 m below the sea surface and that the kelp species may grow to approximately 3 m in length prior to harvest. As such a photic depth of 5 m was considered to be the minimum required to ensure adequate growth conditions (based on stakeholder input).
Total oxidised nitrogen (TOxN; μM)	4	n/a	> 10	The minimum and optimum range were based on MMO (2019).
Seabed substratum	n/a	n/a	Sedimentary	Same rationale as for mussels.

2.3 Constraints to development in the resource areas

2.3.1 Operational constraints and economic viability of offshore aquaculture developments

Although it was beyond the scope of this study to assess the operational requirements for large-scale mussel or kelp farms in detail, or to consider the economic viability of offshore developments, the importance of these factors on the overall feasibility of establishing offshore developments was stressed by expert stakeholders. The key factors which will require further detailed consideration if the industry seeks to move offshore are briefly summarised below and described in more detail in Section B.1.2 in Appendix B.

- **The distance of the aquaculture development to the nearest land-based port or harbour facilities** – the further the distance from the shore the longer the transit time to and from the site, influencing the operational costs (with respect to fuel, vessel size requirements etc) and potentially the number of days per year the site can be accessed and worked. It was also noted that seaweed needs to be processed (dried or ensiled) within 24 hours of harvesting and hence transit time to shore will be an important factor;
- **The number of days per year access to the farm site is required** – the total number of days that the site will need to be accessed will be influenced by a range of factors including the overall size of the farm and the farm layout (e.g. if arrays are clustered), anticipated production volumes, the duration and efficiency of harvesting and the number and capacity of farm vessels;
- **Vessels** – the size and number of vessels required will depend on the farm size, estimated production volumes, and an appropriate farm layout will be required to enable vessels to manoeuvre between headlines if required;
- **Economic costs and viability** – factors that influence the economic viability of offshore developments will relate to the capital investment costs (required for initial site set up), operational costs (in turn influenced by the operational factors above) and market demand and value of the species farmed.

2.3.2 Other marine sectors and users

In addition to identifying potential resource areas for mussels and kelps, this study also sought to assess the extent to which such developments might be constrained within these areas due to existing marine sector activity or infrastructure. **It is important to stress that this exercise was based on the project team's judgement and that potential interactions with, and impacts of, any potential aquaculture development with other marine sectors (and indeed all receptors) would need to be considered at project level through the consenting process, or at a regional or national level through regional marine plans or a strategic sectoral plan respectively**.

For the purposes of this study, the analysis considered whether existing marine sector activity could affect the feasibility of developing a mussel or kelp farm. This judgement was made based on a range of considerations including the footprint, intensity and/or value of the existing activity, the presence of infrastructure, previous consenting issues and whether the activity/feature or infrastructure could be avoided by careful siting of the development within a potential resource area. This analysis is necessarily high level and **the resulting outputs from the spatial model do not indicate areas where mussel or kelp farms would be consented**, for the reasons stated above.

Table 6 describes the assumptions made regarding the feasibility of developing mussel or kelp farms within the potential resource areas identified by the spatial model (presented in Section 3). Where it was judged that an aquaculture development was not feasible due to existing activity or infrastructure, the areas in which the other sector activity or infrastructure occurred was removed from the potential resource areas previously identified, to create 'potentially feasible development areas'.

However, for the commercial fishing sector, it was not considered appropriate to exclude some areas (for example based on intensity or value of the activity; particularly given the data limitations described in Appendix B), and not others which may be considered of equal importance to the vessels and fishing communities which fish there. As such, no fishing areas were removed from the potential resource areas identified in the spatial model. Instead, the potential mussel and kelp resource areas identified were discussed with key fisheries stakeholders to obtain further information about the fishing activities in those areas and their opinion on the potential compatibility of fisheries, in particular, static gear fisheries (i.e. creeling) within aquaculture developments. The outcome of this consultation is described in Section 4.

Similarly given the relatively extensive nature of recreational boating activity in Scotland, and the known limitations of the underlying data, no areas of a given intensity were removed from the potential resource areas identified in the spatial model. Instead, this is noted as requiring further consideration.

The potentially feasible development areas for large-scale mussel and kelp farms are presented in Section 3.

Table 6. Assumptions applied to other marine sector-related constraints in the spatial model for mussel and kelp cultivation

Data Layer	Excluded From the Potential Resource Areas?	Assumption / Rationale
Military coastal firing ranges	Yes	Assumption: army coastal firing ranges (areas including a land and sea component) are associated with established land-based infrastructure that are not likely to be relocated. Hence these areas were removed from the identified resource areas. RAF and navy firing areas at sea were not excluded from the resource areas (as not associated with infrastructure) but would need to be considered at a site-specific level (i.e. during initial site selection).
Oil and Gas (O&G) platforms and pipelines	Yes and buffer zone applied	Rationale: There is a statutory 500 m safety zone for O&G surface infrastructure and a discretionary 500 m safety zone for subsurface infrastructure.[5]
Existing aquaculture lease/lease option areas	Yes	Assumption: The presence of existing finfish, shellfish or seaweed farms would exclude new aquaculture developments. Lease option areas were assumed to represent an area that would be developed and hence were also excluded from the identified resource areas.
Existing renewable lease/lease option areas	Yes	Assumption: The presence of existing marine renewable developments would exclude new aquaculture developments. Lease option areas were assumed to represent an area that would be developed and hence were also excluded from the identified resource areas.
Open waste disposal sites	Yes	Assumption: Vessel access to open waste disposal sites would be required, which would exclude new aquaculture developments in those areas.
Formal Anchorage areas	Yes	Assumption: Relatively large deep water anchorage areas would exclude new aquaculture developments. Note: anchorage 'points' located inshore were not excluded from the identified resource areas due to the high numbers and small footprint of these areas. However, informal anchorage area may require further consideration at a site-specific level (i.e. during initial site selection).

5 Marine Scotland: https://marine.gov.scot/information/oil-gas-field-infrastructure

Data Layer	Excluded From the Potential Resource Areas?	Assumption / Rationale
Shipping: IMO routeing measures; high intensity shipping routes (> 600 transits p.a.) and lifeline ferry routes	Yes	Commercial shipping is an important socio-economic sector. For the purposes of this study, 'major' shipping routes were identified as routes with over 600 vessel transits per annum (for tankers, cargo and passenger vessels) and these routes were excluded from the identified resource areas. It is acknowledged that there are key commercial shipping routes in Scottish waters with less than 600 transits per annum (e.g. vital services into smaller ports or harbours). As such, commercial shipping will require further consideration at site-specific level (i.e. during initial site selection). No buffers were applied to the major shipping routes identified however, it is noted that guidance produced by the Maritime and Coastguard Agency (Marine Guidance Note 654) states that for offshore windfarm developments a 3.5 NM minimum separation distance between turbines and a shipping route is broadly acceptable. Hence it is likely that such a separation distance may also be required for other marine sector developments.
Ferry routes	Yes and buffer zone applied	Regardless of the number of transits per annum, lifeline ferry routes were excluded from the resource areas and a 2.5 km buffer zone was applied to the route to allow for variation in the vessel route relating to tidal state and adverse weather.
Commercial fisheries	No	Commercial fisheries is an important socio-economic sector in Scotland. As such, it was not considered appropriate to exclude some fishing grounds (for example based on intensity or value of activity) from the identified resource areas, and not others which may be considered of equal importance to the vessels and communities which fish there. This approach appeared to be validated by the outcome of the fisheries consultation in which the importance of all fishing grounds within the identified resource areas was stressed (see Section 4). Instead the analysis presents a map of the indicative annual value* from fisheries in Scottish waters overlaid with the identified resource area boundaries. The outcome of the consultation with fisheries stakeholders regarding the types of fisheries in these areas, and the compatibility of aquaculture developments with these fisheries is presented in Section 4. Further consideration of interactions with, and impacts on, commercial fisheries would be required at regional and site-specific level (i.e. during initial site selection).

Data Layer	Excluded From the Potential Resource Areas?	Assumption / Rationale
Marine recreational boating activity	No	Recreational boating is an important socio-economic sector in Scotland. The analysis presents the RYA 'heatmap' of recreational boating activity in Scottish waters. Given the limitations of this data set* no recreational boating areas have been removed from the identified resource areas. Instead the analysis presents the heatmap overlaid with the identified resource area boundaries. Interactions with, and impacts on, recreational boating activity would need further consideration at the site-specific level (i.e. during initial site selection).
Priority Marine features (PMFs) and Marine Nature Conservation designations	Selected PMFs – Yes Nature Conservation (NC) designations - No	The potential for significant impact of any marine development on nature conservation designated sites and associated features is assessed by Competent Authorities during the consenting process. As such, for the purposes of this study it has not been assumed that the presence of a designated site would necessarily exclude a kelp or mussel farm, but that the ability to locate such a development in an MPA would be assessed through the consent process. Hence designated sites have not been removed from the identified resource areas. However, there are 11 Priority Marine Features (PMFs) which are assumed to be sensitive to pressures arising from mussel or kelp aquaculture developments (e.g. from sedimentation/smothering, shading etc.) and it was judged that consent for developments in the immediate vicinity of these features was unlikely. These PMFs are: blue mussel beds; fan mussel aggregations; flame shell beds; horse mussel beds; maerl beds; maerl or coarse shell gravel with burrowing sea cucumbers; native oysters; northern seafans and sponge communities, seagrass beds, serpulid aggregations and cold water coral reefs. Although the pressures arising from mussel farming and kelp farming will be different, as a precaution, the locations of all 11 PMFs (polygons or point data, with a 50 m buffer for point data) were excluded from the identified resource areas for both mussel and kelp farming. It is acknowledged that other PMFs (for example, burrowed mud with seapens) will be of concern to the statutory nature conservation body in Scotland and that other benthic habitat features will require further consideration at the site-specific level (i.e. during initial site selection).

Data Layer	Excluded From the Potential Resource Areas?	Assumption / Rationale
Subsea cables and pipelines	No	The presence of in-service subsea cables was judged by the project team to be likely to exclude the development of mussel or kelp farm based on the requirement for subsea cable owners or operators to be able to access the subsea cable for maintenance or repair. However, the footprint of subsea cables is relatively small compared to the size of the resource areas being explored. Hence subsea cables were not excluded from the potential resource areas identified. However, the location of subsea cables would need to be considered at the site-specific level (i.e. during initial site selection).
Historic protected wrecks	No	The presence of Historic Marine Protected Areas and protected wrecks (sites and vessels designated under the Protection of Military Remains Act 1986 ("war graves") was judged by the project team to exclude the development of mussel or kelp farms. However, the footprint of these designated areas is relatively small compared to the size of the resource areas being explored and it was assumed that such areas could be avoided at the site-specific planning level. Hence protected wrecks were not excluded from the potential resource areas identified but would need to be taken into consideration at the site-specific level (i.e. during initial site selection).
* The limitations of these data sets are described in Appendix B.		

3 Outputs of the Spatial Model

3.1 Areas of potential for mussel cultivation

This section presents the outputs of the spatial modelling exercise to identify areas potentially suitable for large-scale offshore mussel farming (potential resource areas) and the potential constraints within these areas relating to existing marine sector activity or infrastructure (potentially feasible development areas).

Figure 2 presents the areas identified as potentially suitable for mussel cultivation (with regard to the species growing and operational conditions required – the 'potential resource areas') based on the physical and environmental conditions. The figure differentiates between resource areas in water depths between i) 20 m and 50 m and ii) over 50 m to 100 m. The former represents the most likely depth range for development in the immediate future due to the cost that would be associated with installation or repair of farm infrastructure in locations with a water depth of over 50 m.

Figure 3 presents the remaining potentially suitable resource areas for mussels, once areas of other sector activity and infrastructure which were judged to make development of a mussel farm infeasible have been removed from the resource areas ('potentially feasible development areas'). Areas used for commercial fishing grounds and recreational boating and nature conservation designated areas were not removed from the resource areas for the reasons described in Table 6. Instead the overlap between the potentially feasible development areas for mussels and the value of fishing areas, intensity of recreational boating and the presence of nature conservation designations are shown in Figure 4, Figure 5 and Figure 6 respectively.

Other operational issues which influence the feasibility of the development of a large-scale mussel farms include the distance from the site to the nearest land-based port or harbour facilities. Based on stakeholder consultation, it was assumed that it would be preferable for large-scale mussel farms to be based within 10 km of land-based facilities. Figure 7 shows the potentially feasible development areas in relation to the 6 NM (c. 10 km) and 12 NM (c. 22 km) limits.

Table 7 presents the sea surface area within: i) the potential resource areas and ii) the potentially feasible development areas in the East and West coast study areas. However, it is important to note that there are additional marine sector activities, infrastructure, nature conservation designation and heritage designations that have not been excluded from the potentially feasible development areas. This is not because these constraints are of lesser social or economic importance but because the level of constraint and any interactions with or impacts on these receptors would need to be further considered and resolved through a strategic marine planning process at a regional or national level, or through the consenting process at a site-specific project level.

Table 7. Resource and potentially feasible development areas identified for mussel cultivation

Study Area	Resource Area	20-50 m Depth and Within 6 NM (km^2)	20–50 m Depth (km^2)	50–100 m Depth (km^2)	Total (20–100 m Depth) (km^2)
East	Potential resource area	2,668	4,681	17,953	22,635
East	Potentially feasible development area	2,217	2,962	15,359	18,320
West	Potential resource area	874	874	787	1661
West	Potentially feasible development area	679	679	625	1304

The focus in this study was on a mussel farm that could produce over 500 tonnes of mussels per annum. Based on the generic farm design developed (1 array covering 0.91 km^2 sea surface area in 30 m depth of water producing just over 200 tonnes per annum), six arrays would be required to grow over 1,000 tonnes per two year growing cycle (hence considered equivalent to over 500 tonnes per annum), covering an estimated area of between 5.46 km^2 (if six spatially distinct arrays were developed) or 7.26 km^2 if production was achieved through a cluster of six arrays assuming a 250 m horizontal access channel between the rows of arrays; see Image 6). Based on these assumptions, a mussel farm on the East coast would represent 0.2 % of the potentially feasible development area in the East for mussels between 20-50 m depth identified in the spatial model, or 0.2–0.3 % of the potentially feasible development area for mussels between 20-50 m depth within 6 NM of the coast (considered to be the most likely area for any developments). On the West coast, a mussel farm would represent 0.8–1.1% of the potentially feasible development area on the West coast (all of which lies within 6 NM). It should be noted that the sea surface area required for each array would increase as water depth increases (see Table 2; Section 2.1.1).

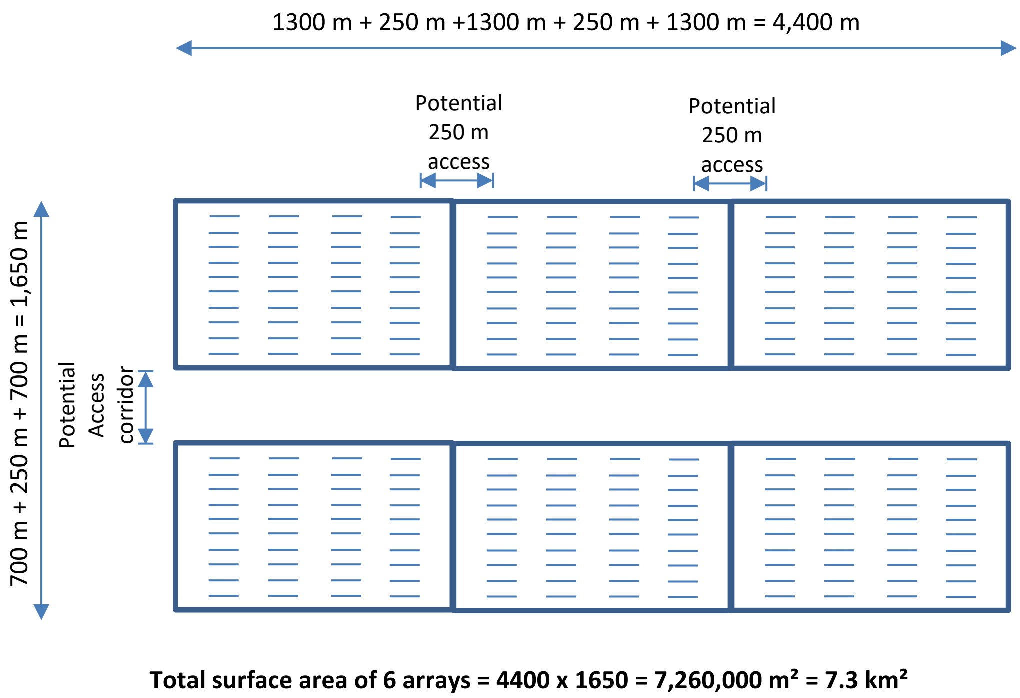


Image 6. Schematic showing a cluster of six arrays with a potential access channel

If an ultimate aim of the Scottish mussel industry was to reach similar production levels to those projected for the offshore mussel farm in Lyme Bay Devon once fully developed (10,000 tonnes per annum), the indicative estimate of required sea space to produce 10,000 tonnes every two-year growing season is around 45–56 km². Although there is some uncertainty concerning these estimates, which are significantly higher than the estimated required area for production of 10,000 tonnes p.a. at an offshore mussel farm in southern England (15.4 km²), assuming these estimates are reliable for Scottish waters, this area would represent 1.5–1.9% of the feasible development areas between 20-50 m depth identified in the spatial model on the East coast, or 2.0–2.5 % of those areas within 6 NM of the coast. On the West coast, this area would represent 6.6–8.2% of the potentially feasible development area between 20-50 m depth (all of which lies within 6 NM).

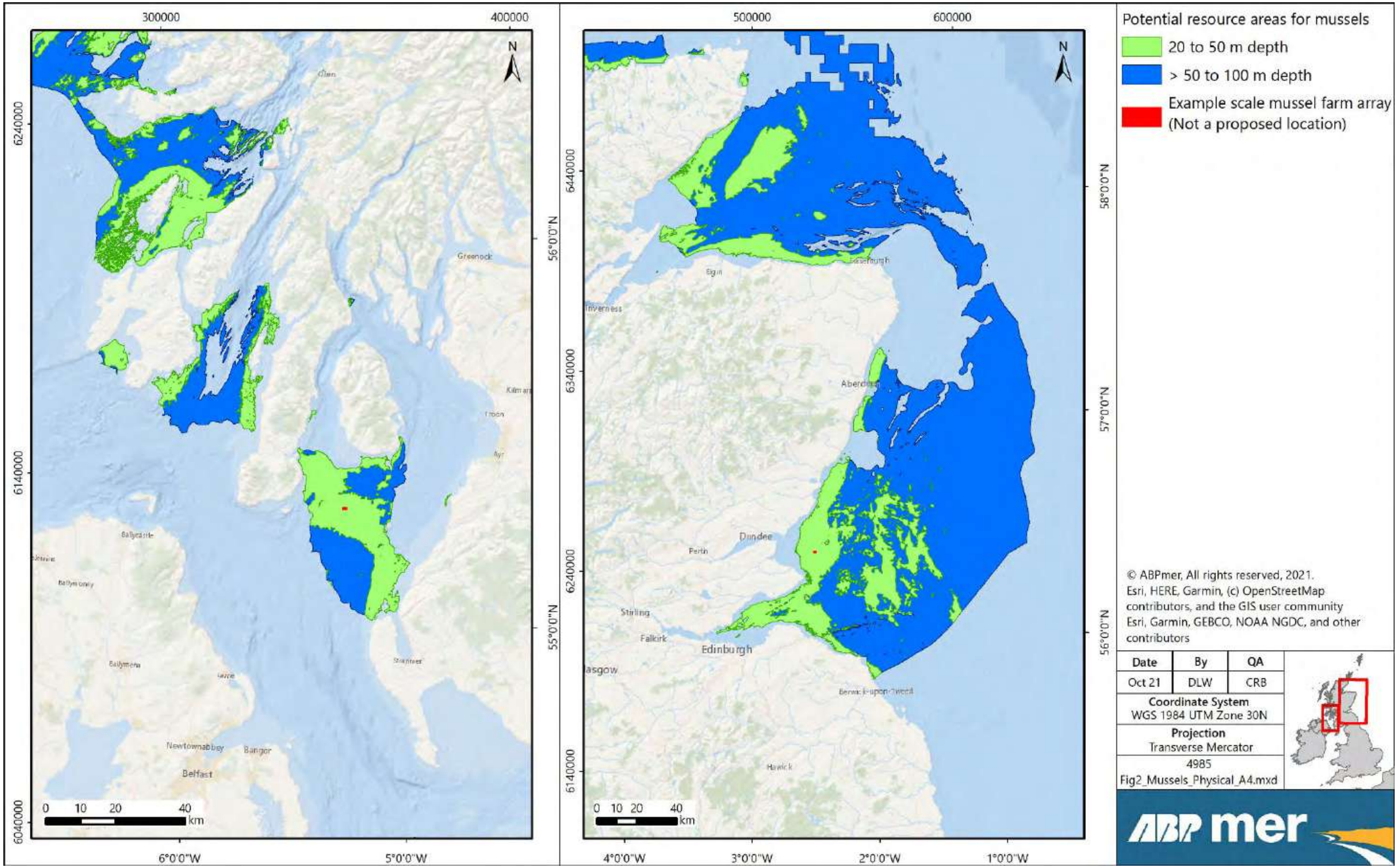


Figure 2. Potential resource areas for mussels

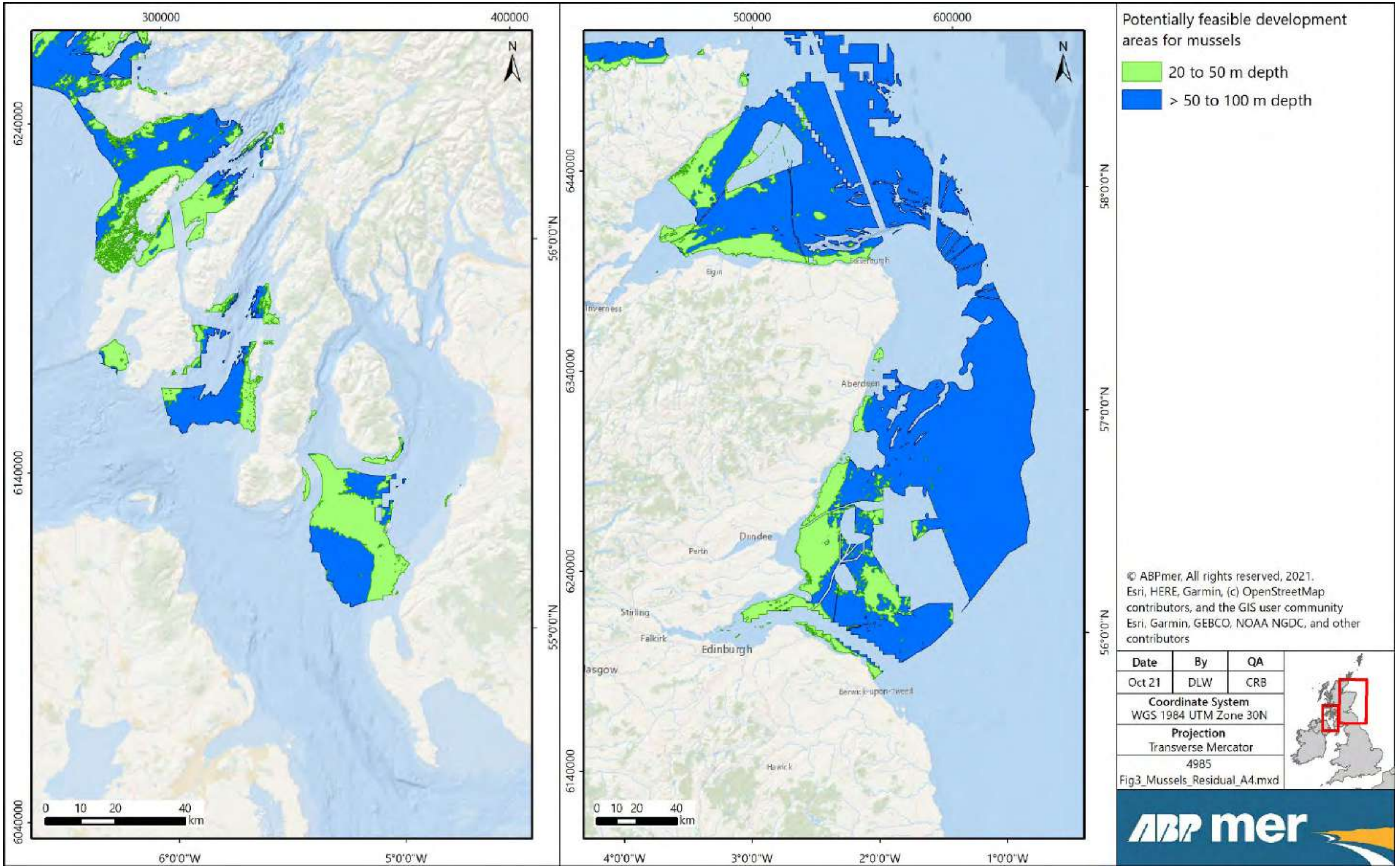


Figure 3. **Potentially feasible development areas for mussels**

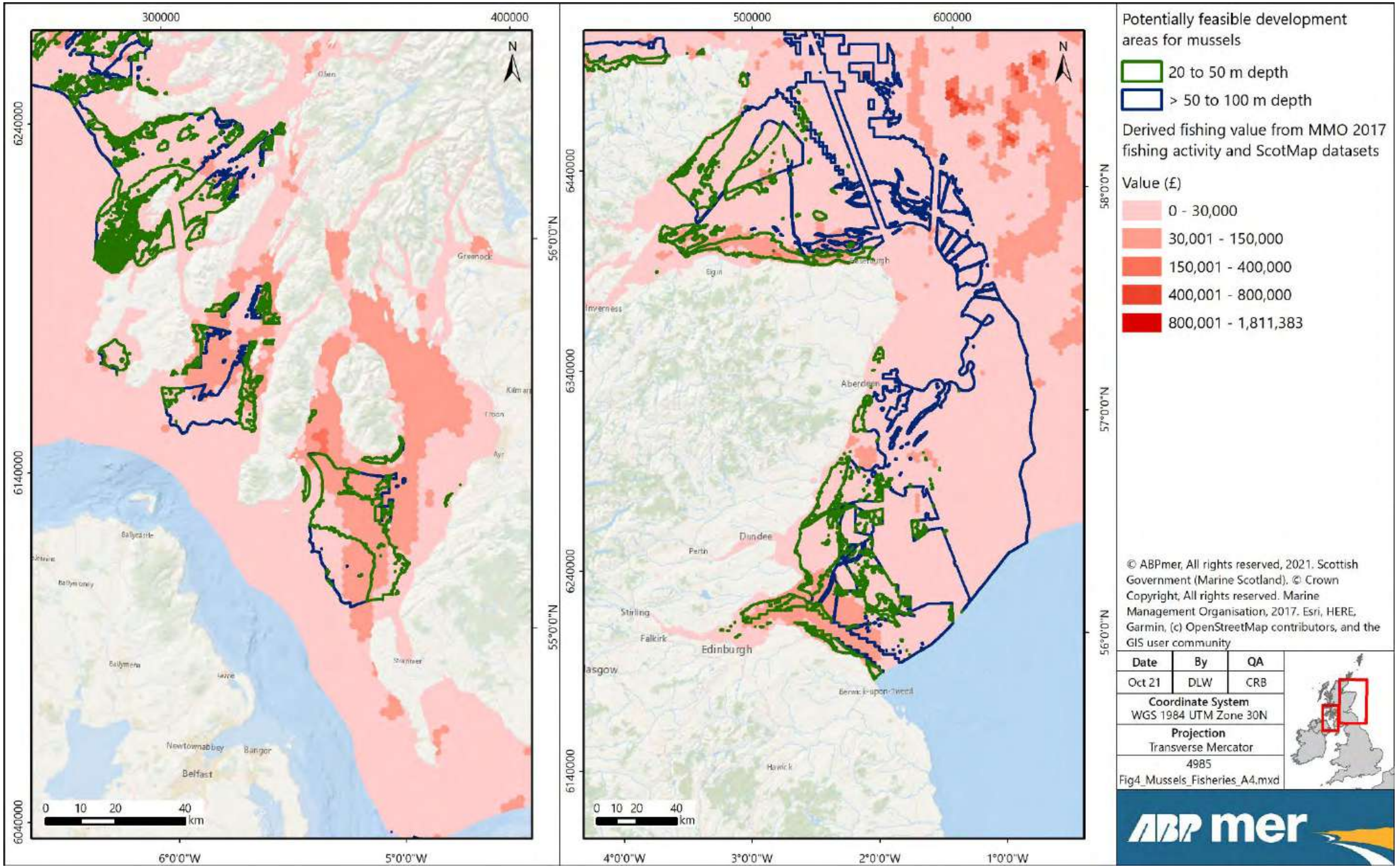


Figure 4. Indicative value of commercial fisheries (all vessel sizes and gear types) within the potentially feasible development areas for mussels

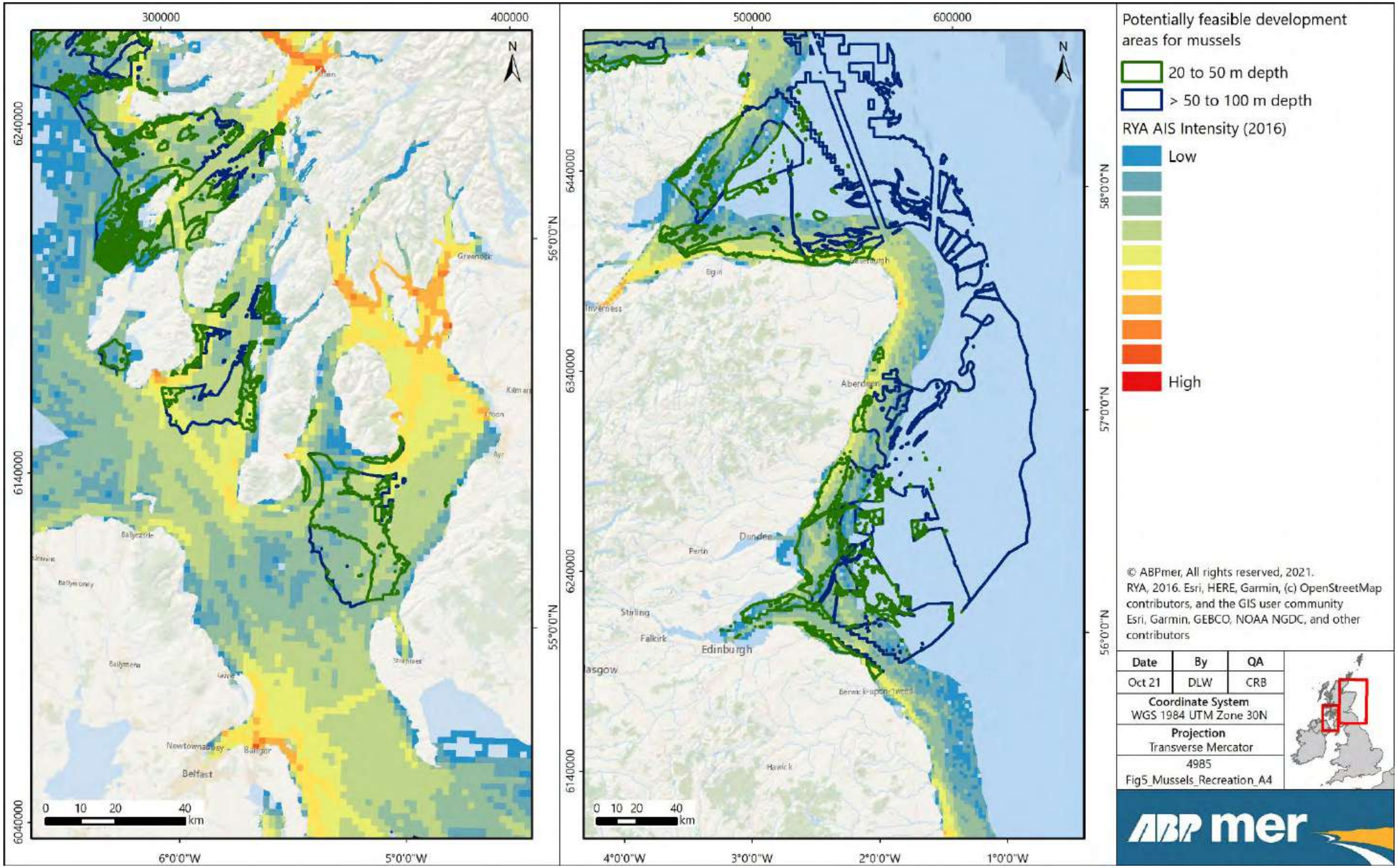


Figure 5. **Relative intensity of recreational vessels with AIS within the potentially feasible development areas for mussels**

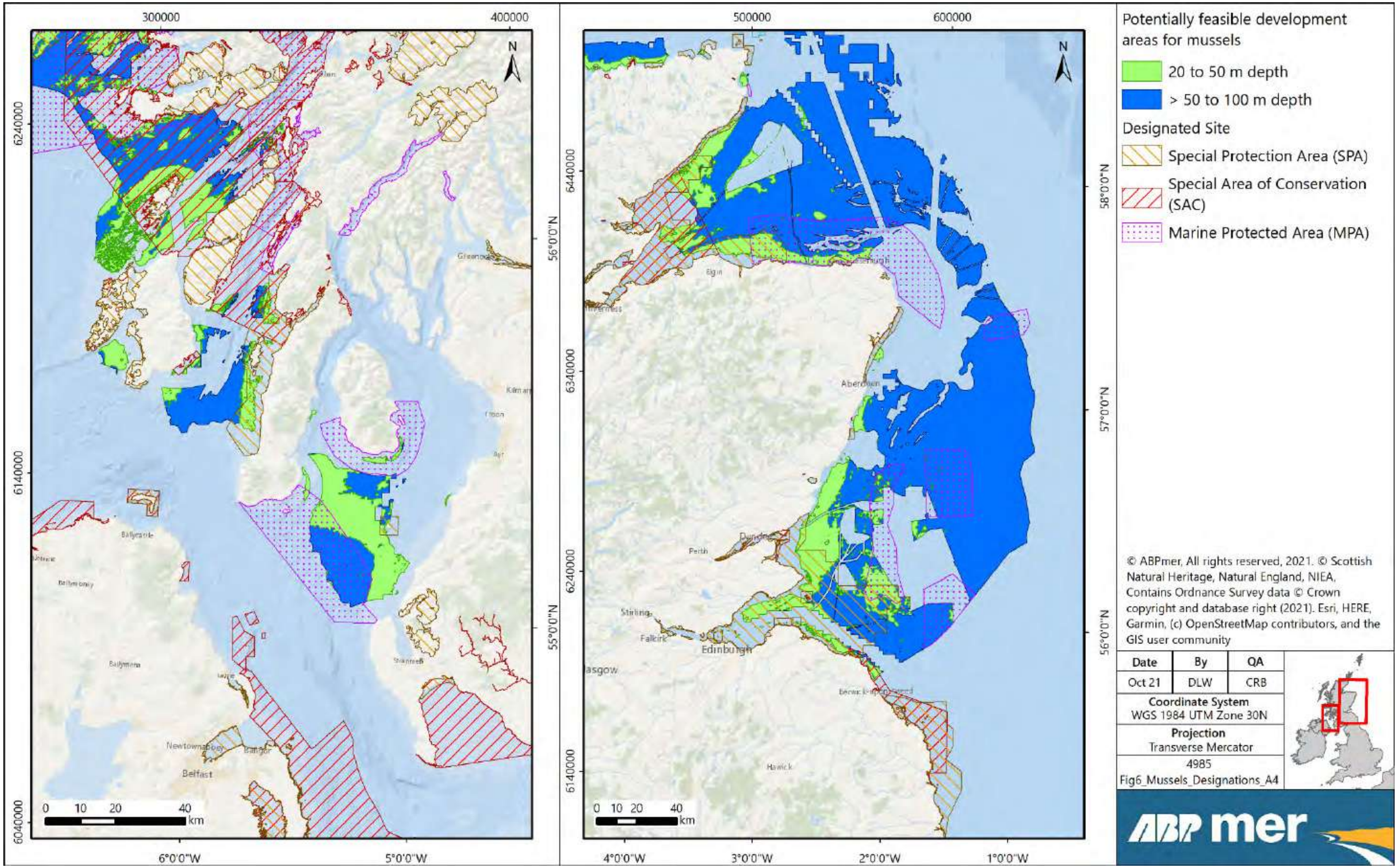


Figure 6. **Marine nature conservation designations within the potentially feasible development areas for mussels**

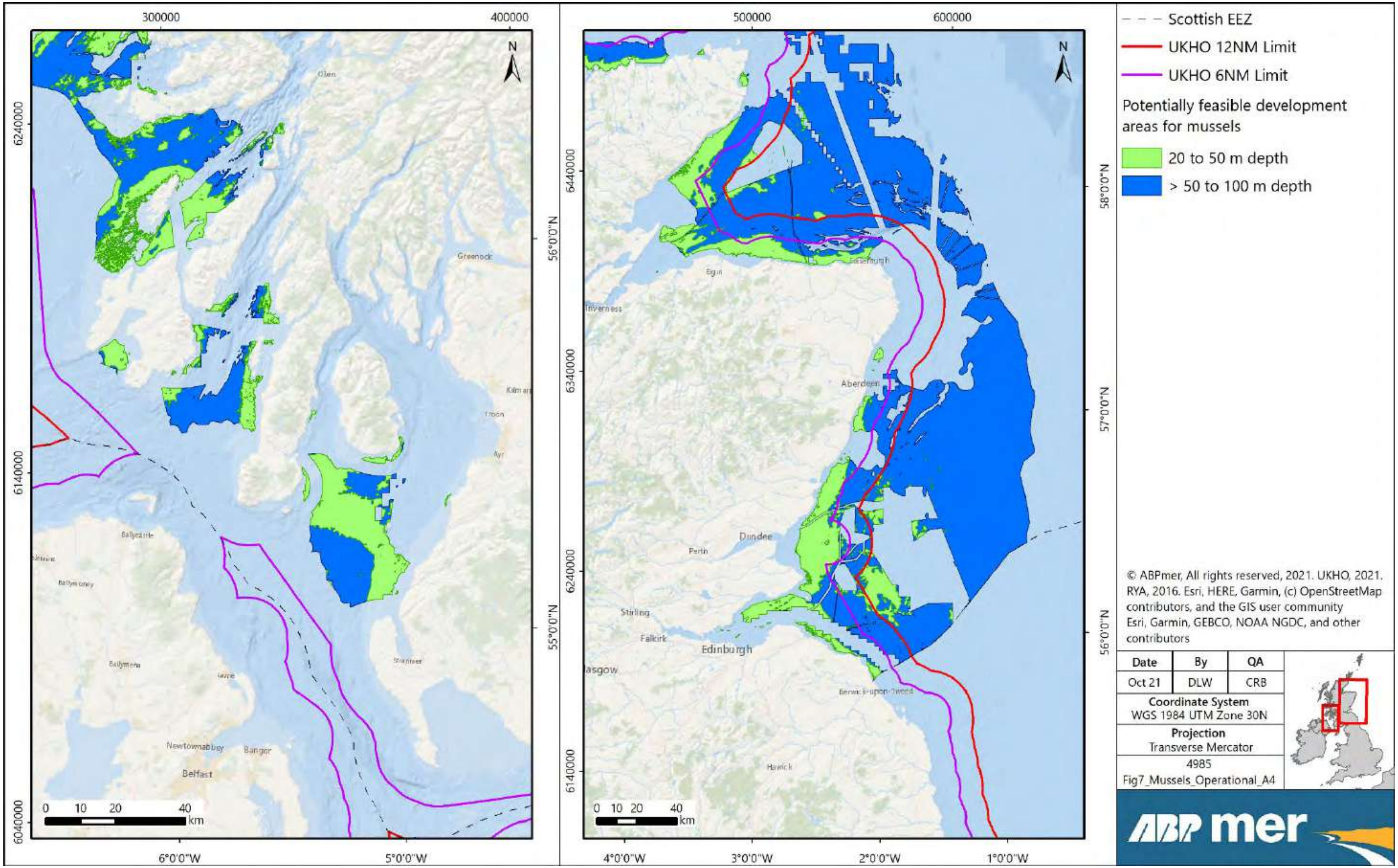


Figure 7. **Potentially feasible development areas for mussels in relation to the 6 NM and 12 NM limits**

3.2 Areas of potential for seaweed cultivation

This section presents the outputs of the spatial modelling exercise to identify areas potentially suitable for large-scale offshore kelp farming (potential resource areas) and the potential constraints within these areas relating to existing marine sector activity or infrastructure (potentially feasible development areas).

Figure 8 presents the areas identified as potentially suitable for kelp cultivation (with regard to the species growing and operational conditions required) based on the physical and environmental conditions. The figure differentiates between potential resource areas in water depths between i) 20 m and 50 m and ii) over 50 m to 100 m. The former represents the most likely depth range for development in immediate future due to the cost that would be associated with installation or repair of farm infrastructure in locations with a water depth of over 50 m.

Figure 9 presents the potentially feasible development areas for kelp, once areas of other sector activity and infrastructure which were judged to make development of a kelp farm infeasible have been removed from the resource areas ('potentially feasible development area'). Areas used for commercial fishing grounds and recreational boating and nature conservation designated areas were not removed from the resource areas for the reasons described in Table 6. Instead the overlap between the potentially feasible development areas for kelp and the value of fishing areas, intensity of recreational boating and the presence of nature conservation designations are shown in Figure 10, Figure 11 and Figure 12 respectively.

Other operational issues which influence the feasibility of the development of a large-scale kelp farm is the distance from the site to the nearest land-based port or harbour facilities. Based on stakeholder consultation, it was assumed that it would be preferable for large-scale kelp farms to be based within 10 km of land-based facilities. Figure 13 shows the potentially feasible development areas in relation to the 6 NM (c. 10 km) and 12 NM (cc. 22 km) limits.

Table 8 presents the sea surface area within: i) the potential resource areas and ii) the potentially feasible development areas in the East and West coast study areas. However, it is important to note that there are additional marine sector activities, infrastructure, nature conservation designation and heritage designations that have not been excluded from the potentially feasible development areas. This is not because these constraints are of lesser social or economic importance but because the level of constraint and any interactions with or impacts on these receptors would need to be further considered and resolved through a strategic marine planning process at a regional or national level, or through the consenting process at a site-specific project level.

Table 8. Sea area of the potential resource areas and potentially feasible development areas identified for kelp cultivation

Study Area	Resource Area	20-50 m Depth and within 6 NM (km^2)	20–50 m Depth (km^2)	50–100 m Depth (km^2)	Total (20–100 m Depth) (km^2)
East	Potential resource area	3,180	5,193	18,205	23,398
East	Potentially feasible development area	2,709	3,453	15,602	19,055
West	Potential resource area	1,187	1,187	1,157	2,344
West	Potentially feasible development area	919	919	908	1,827

The estimated production volume of kelp from one of the generic kelp farm arrays described in Section 2.1.2 is around 40 tonnes per year from approximately 1.05 km^2 of sea area (at 30 m water depth). This area would represent 0.03 % of the potentially feasible development areas on the East coast between 20-50 m depth identified in the spatial model, or 0.04 % of the feasible development areas between 20-50 m depth within 6 NM of the coast (considered to be the most likely area for any developments). On the West coast, this area would represent 0.11% of the potentially feasible development area between 20-50 m depth (all of which lies within 6 NM).

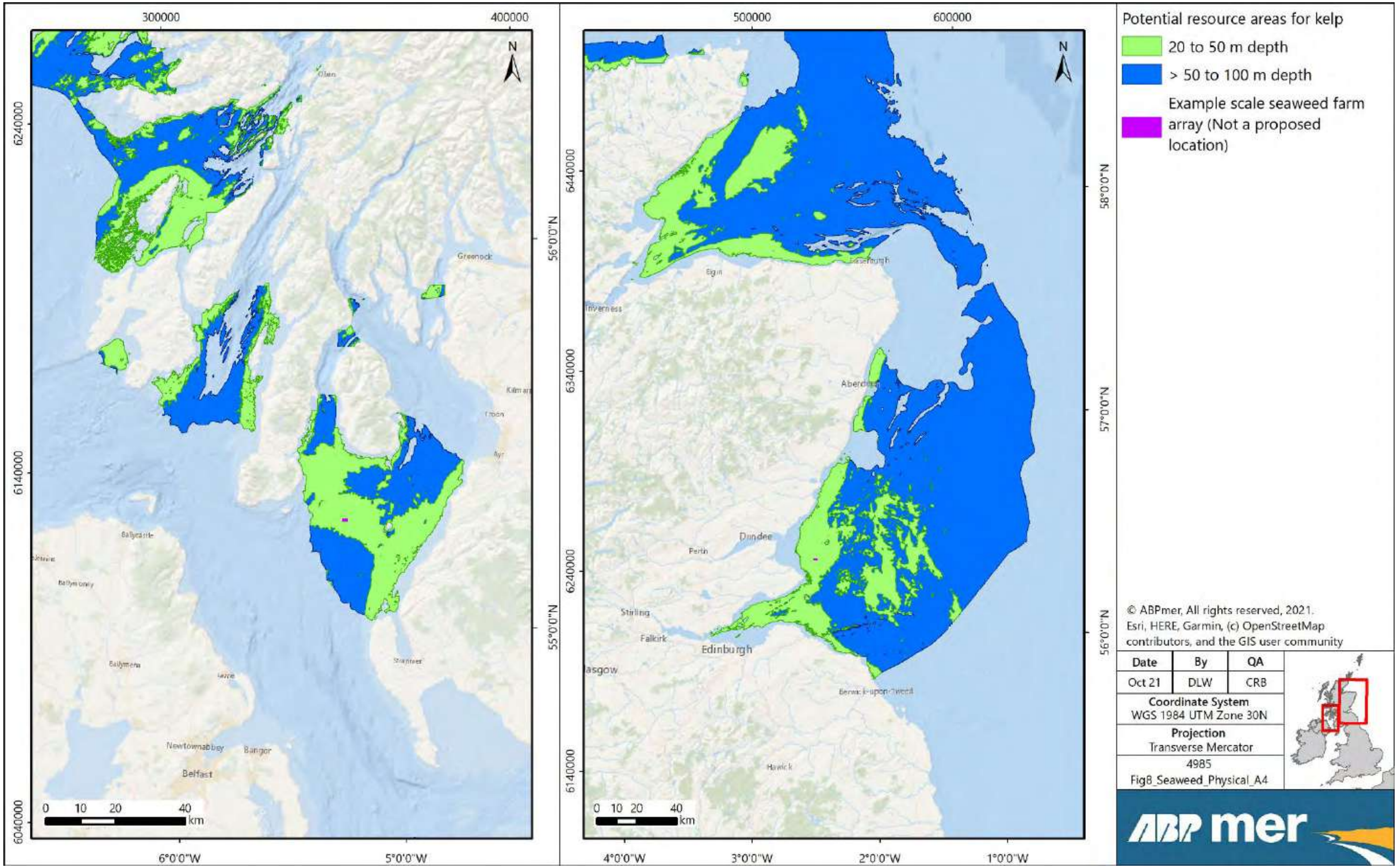


Figure 8. **Potential resource areas for kelp**

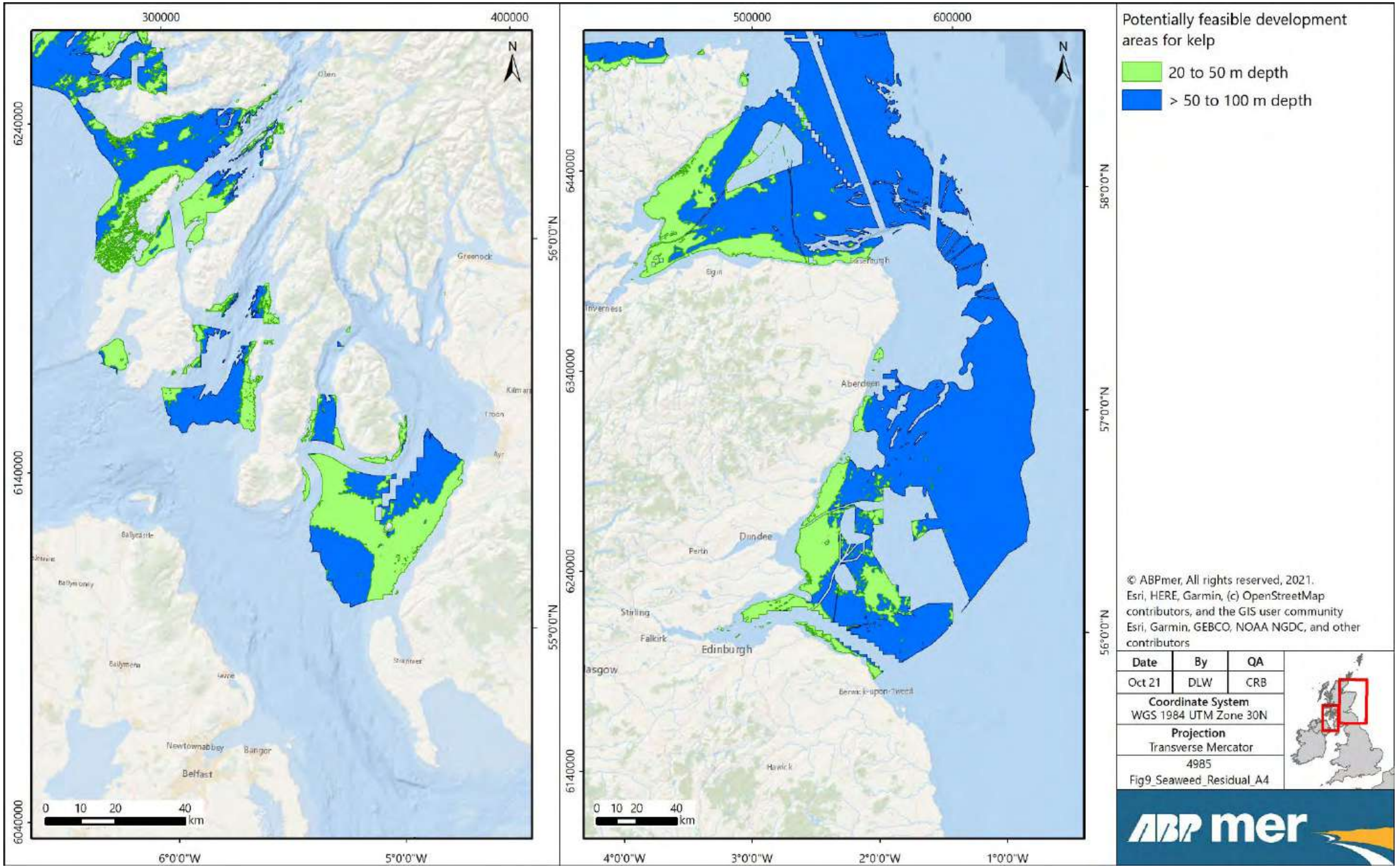


Figure 9. Potentially feasible development areas for kelp

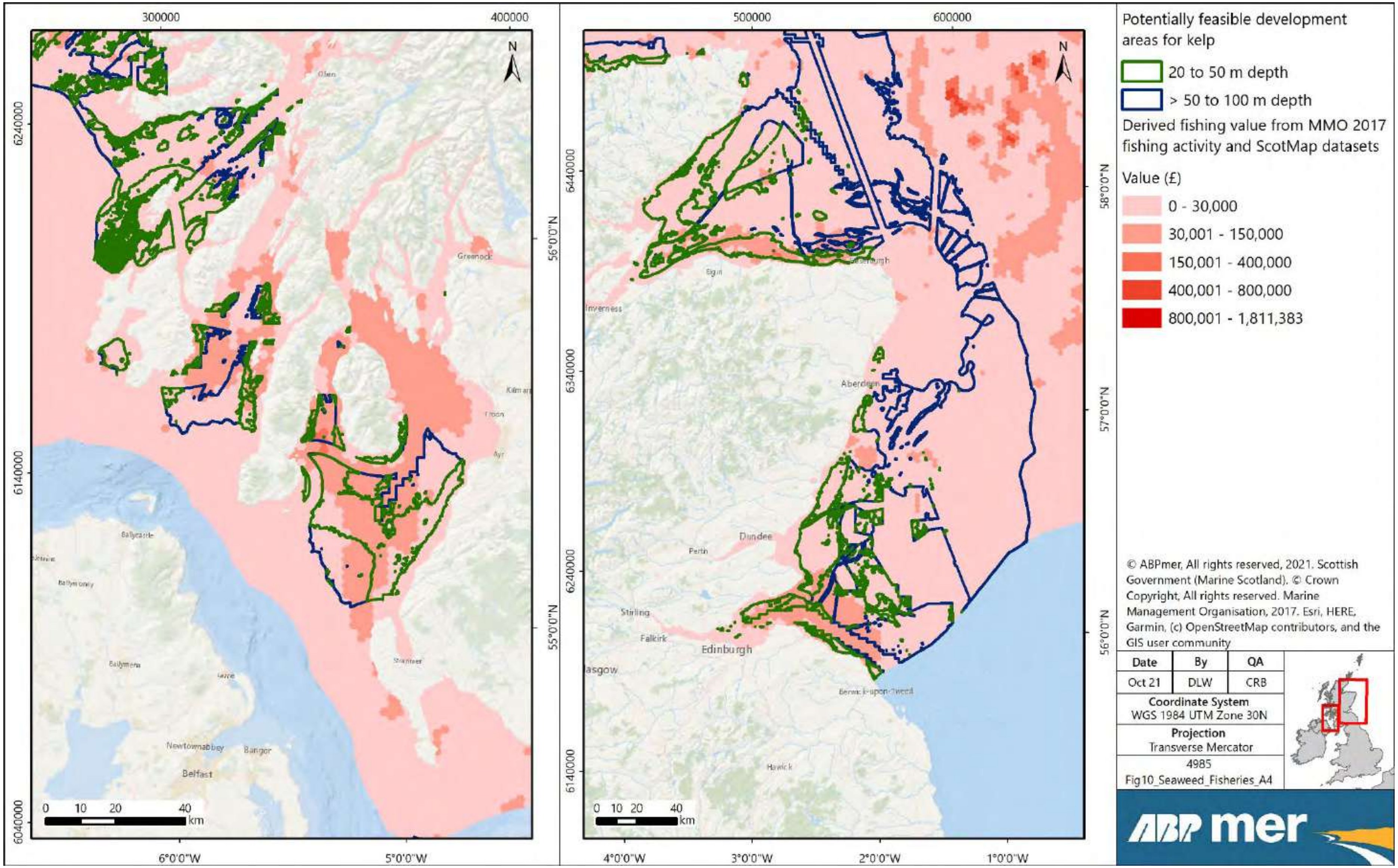


Figure 10. Indicative value of commercial fisheries (all vessel sizes and gear types) within the potentially feasible development areas for kelp

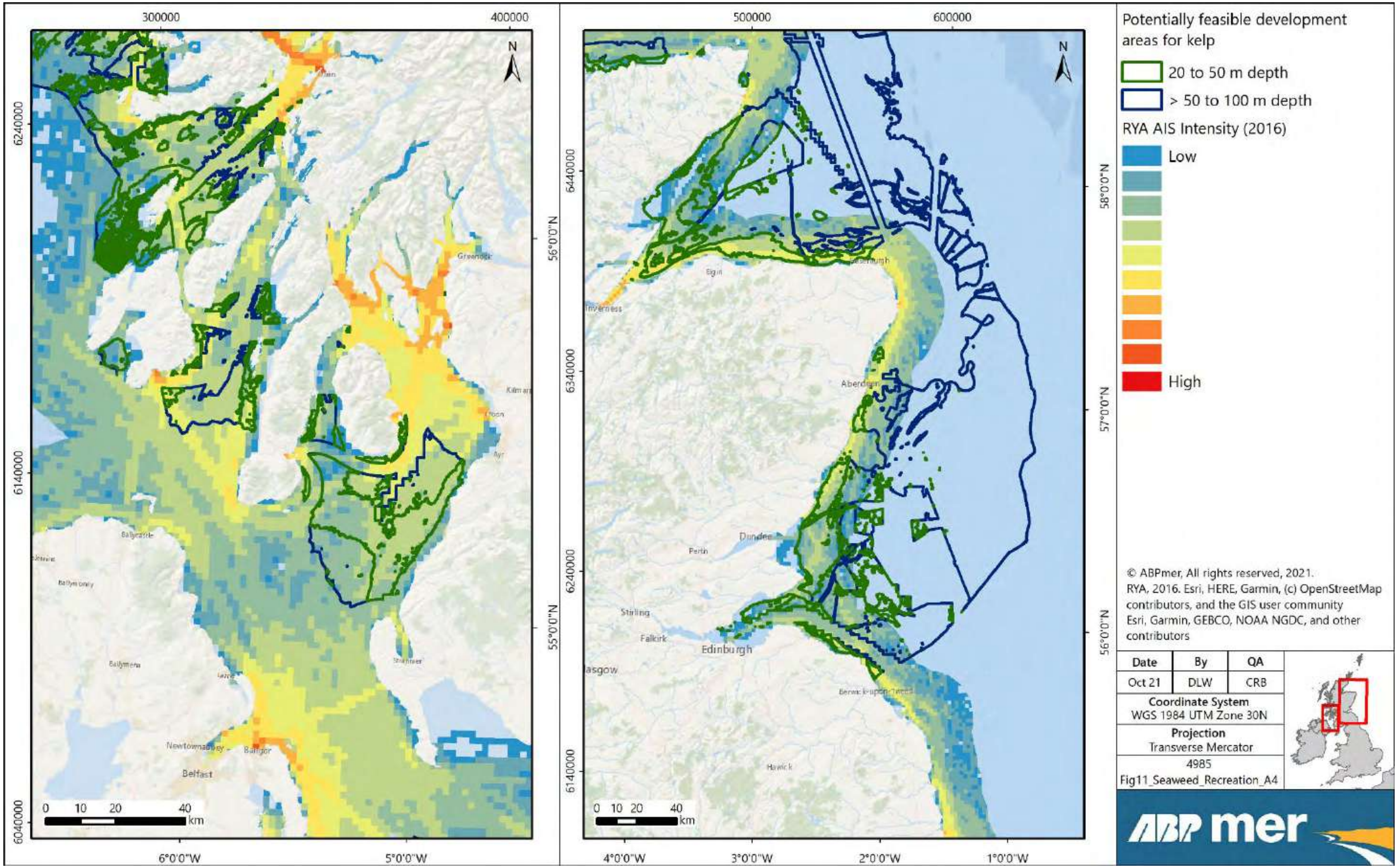


Figure 11. **Relative intensity of recreational vessels with AIS within the potentially feasible development areas for kelp**

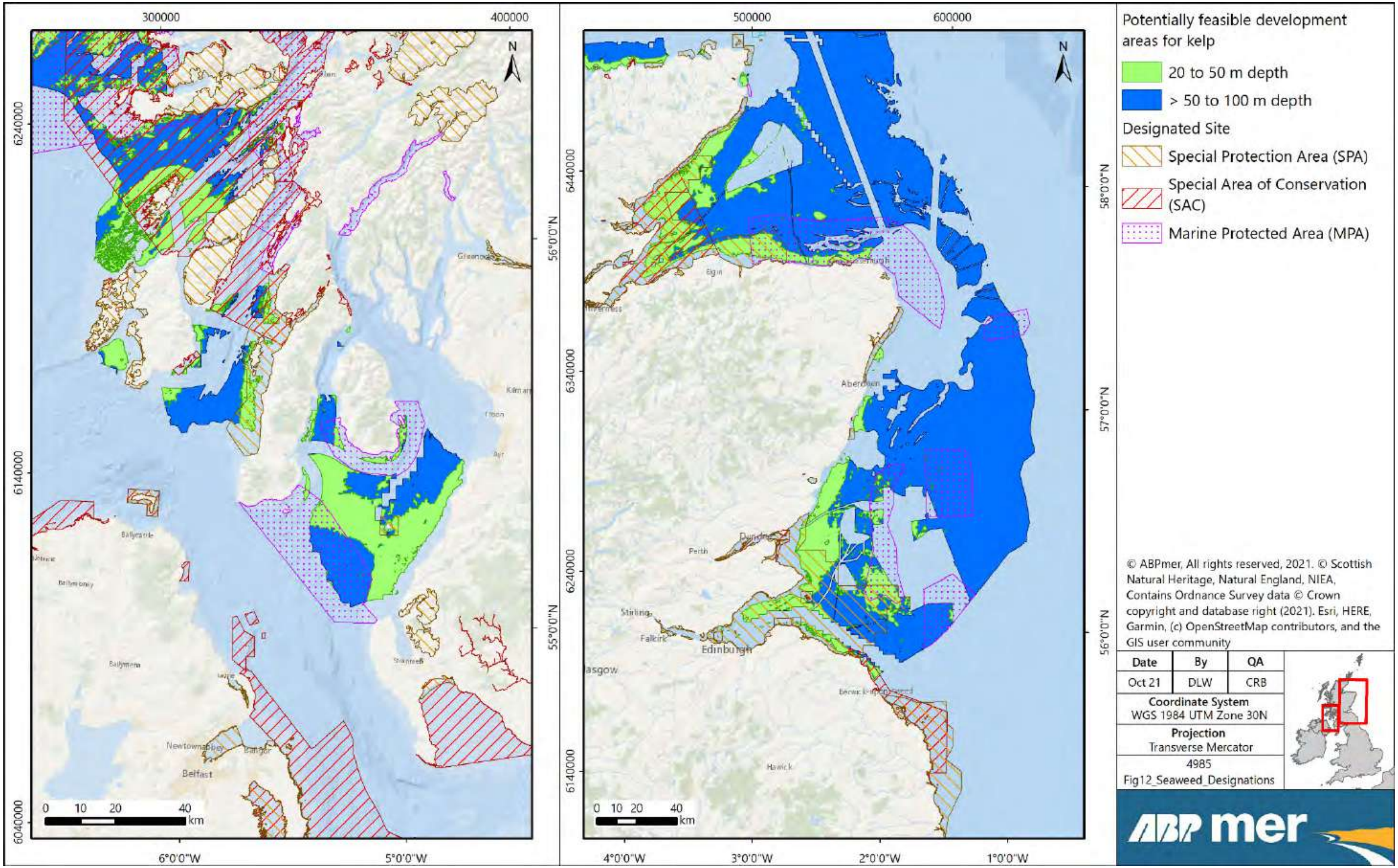


Figure 12. Marine nature conservation designations within the potentially feasible development areas for kelp

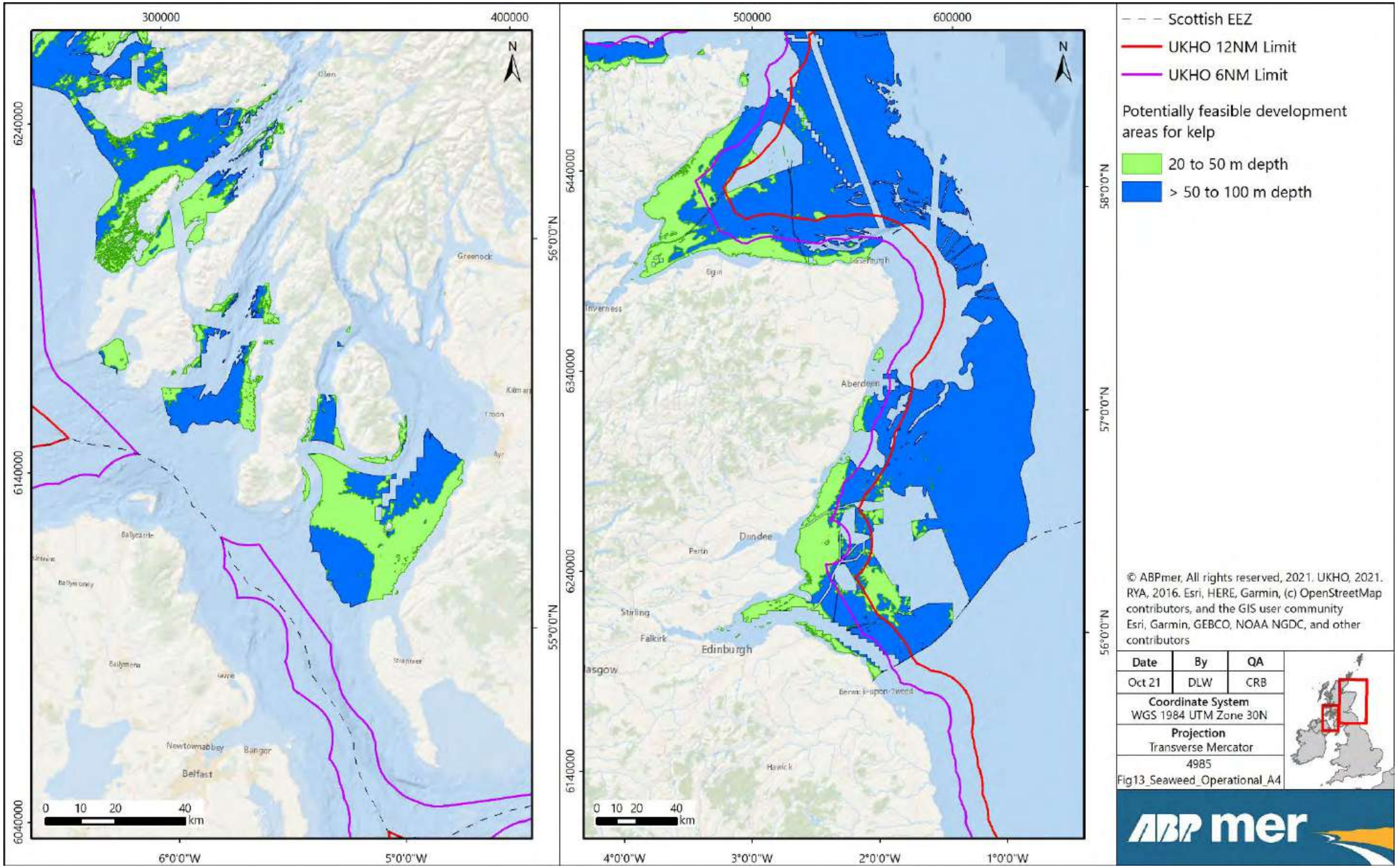


Figure 13. Potentially feasible development areas for kelp in relation to the 6 NM and 12 NM limits

3.3 Areas of potential for mussel or seaweed cultivation

A requirement of the project specification was to identify areas where the physical and environmental conditions may be suitable for the cultivation of both mussels and/or kelps i.e. areas where the requirements for both species were met. The original rationale behind identifying areas potentially suitable for cultivating both species was two-fold:

- Areas where both species could potentially be cultivated may represent a diversification opportunity, providing potential access to two different markets (shellfish and seaweed) and hence reducing investment risks; and
- In relation to the emerging interest in 'blue carbon' markets, for which the ability to cultivate both mussels and seaweed may be of interest.

However, further to the commissioning of this study, Crown Estate Scotland highlighted that their discussions with industry had suggested there was not much interest currently in combining mussel and seaweed farming at scale. As such no further stakeholder consultation on this issue was undertaken by the project team. Nonetheless, this section presents the outputs of the spatial modelling exercise to identify areas where cultivation of either or both species may be technically feasible and the potential constraints within these areas relating to existing marine sector activity or infrastructure.

Figure 14 presents the areas identified as potentially suitable for either or both types of cultivation. The figure differentiates between potential resource areas in water depths between i) 20 m and 50 m and ii) over 50 m to 100 m. The former represents the most likely depth range for development in immediate future due to the cost that would be associated with installation or repair of farm infrastructure for locations with a water depth of over 50 m.

Figure 15 presents the potentially feasible development areas for either or both types of cultivation, once areas of other sector activity and infrastructure which were judged to make development an aquaculture installation infeasible have been removed from the resource areas ('potentially feasible development area'). Areas used for commercial fishing grounds and recreational boating and nature conservation designated areas were not removed from the potential resource areas for the reasons described in Table 6. Instead the overlap between the potentially feasible development areas for both types of cultivation and the value of fishing areas, intensity of recreational boating and the presence of nature conservation designations are shown in Figure 16, Figure 17 and Figure 18 respectively.

Other operational issues which influence the feasibility of the development of a large-scale aquaculture development is the distance from the site to the nearest land-based port or harbour facilities. Based on stakeholder consultation, it was assumed that it would be preferable for large-scale farms to be based within 10 km of land-based facilities. Figure 19 shows the potentially feasible development areas for both types of cultivation in relation to the 6 NM (c. 10 km) and 12 NM (cc. 22 km) limits.

Table 9 presents the sea surface area within: i) the potential resource areas and ii) the potentially feasible development areas. However, it is important to note that there are additional marine sector activities, infrastructure, nature conservation designation and heritage designations that have not been excluded from the potentially feasible development areas. This is not because these constraints are of lesser social or economic importance but because the level of constraint and any interactions with or impacts on these receptors would need to be further considered and resolved through a strategic marine planning process at a regional or national level, or through the consenting process at a site-specific project level.

Table 9. Sea area of the potential resource areas and potentially feasible development areas identified for mussel or kelp cultivation

Study Area	Resource Area	20–50 m Depth within 6 NM (km^2)	20–50 m Depth (km^2)	50–100 m Depth (km^2)	20–100 m Depth (km^2)
East	Potential resource area	2,668	4,681	17,951	22,633
East	Potentially feasible development area	2,217	2,962	15,358	18,320
West	Potential resource area	874	874	787	1,661
West	Potentially feasible development area	679	679	625	1,304

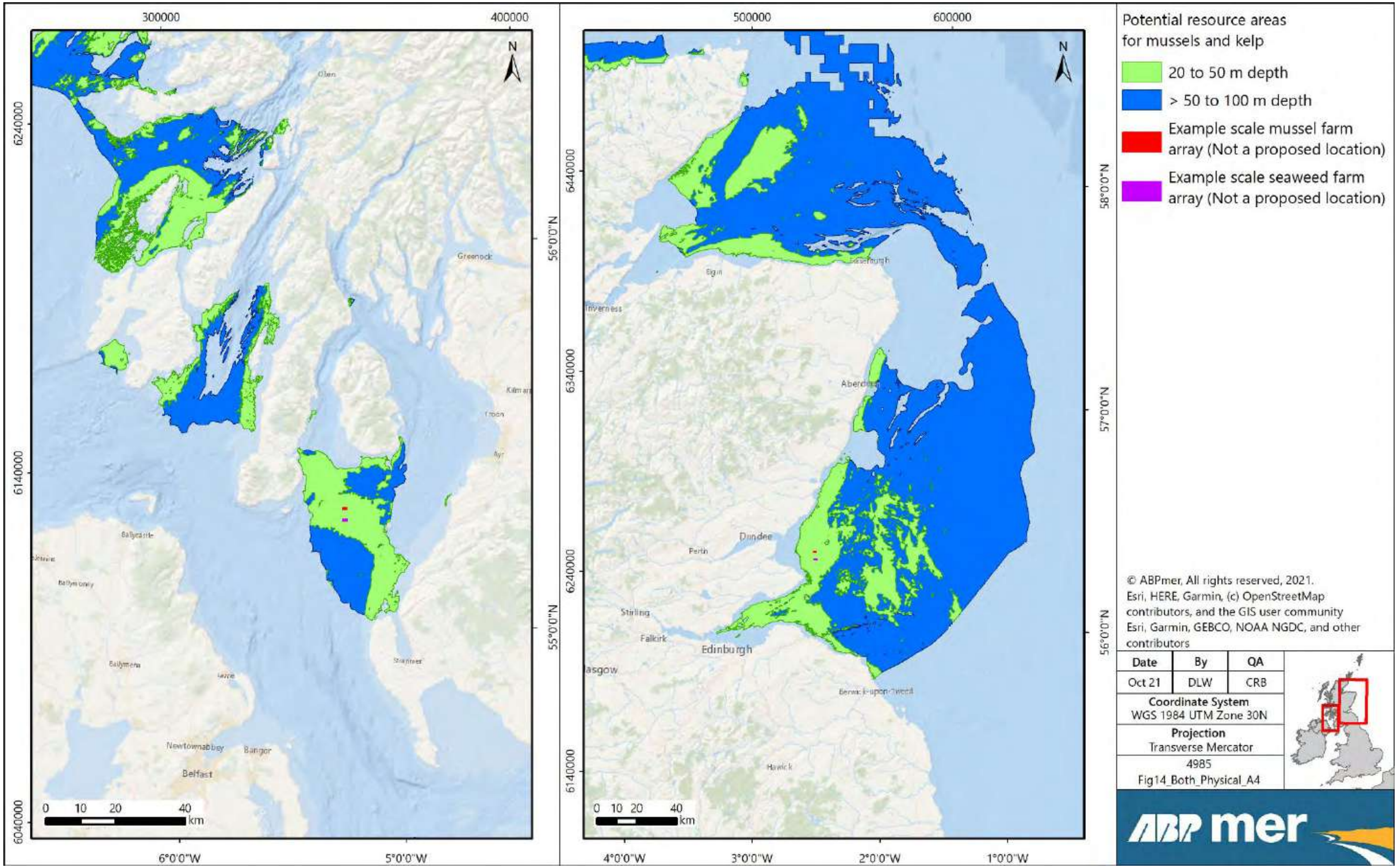


Figure 14. **Potential resource areas for mussels and kelp**

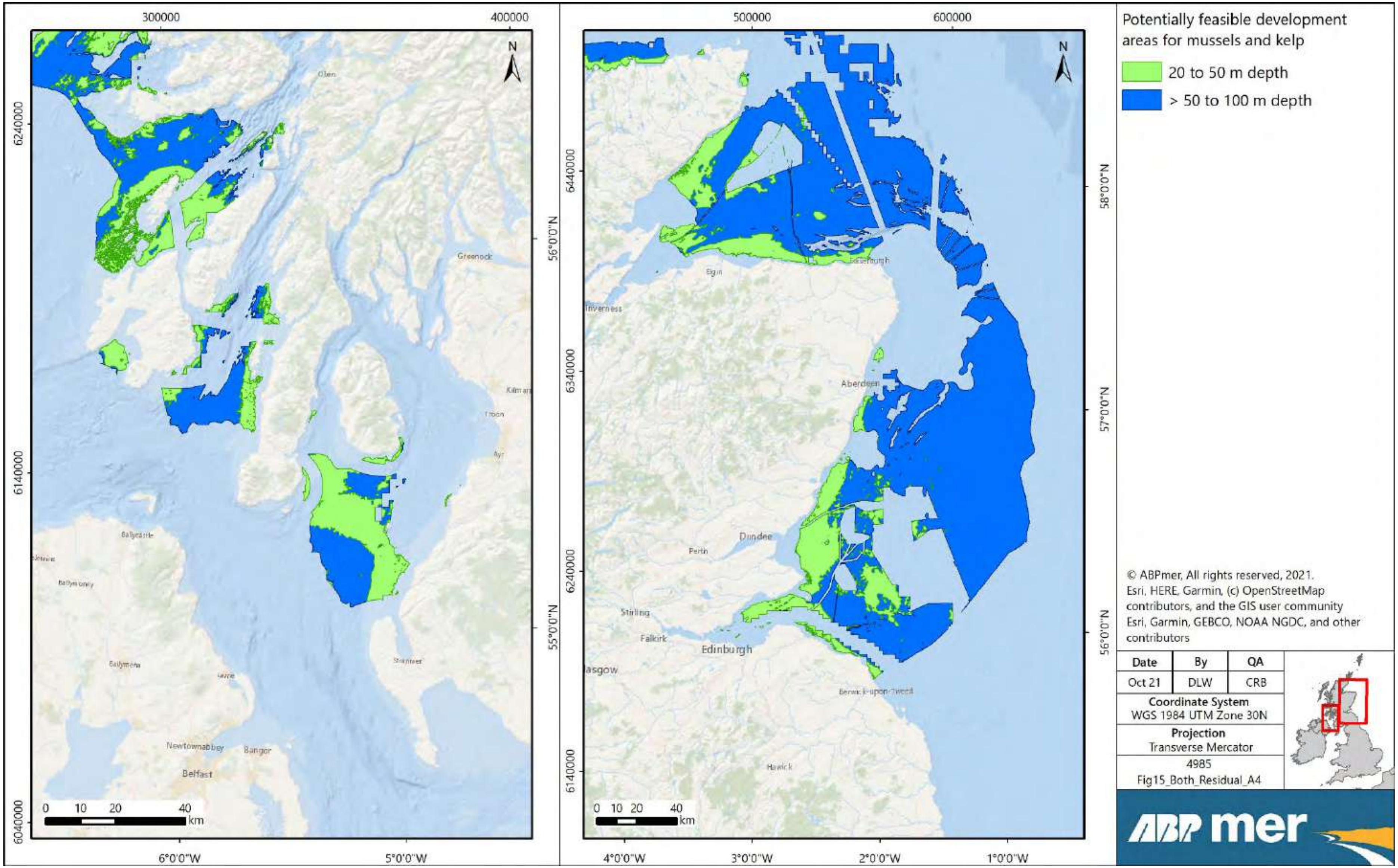


Figure 15. Potentially feasible development areas for mussels and kelp

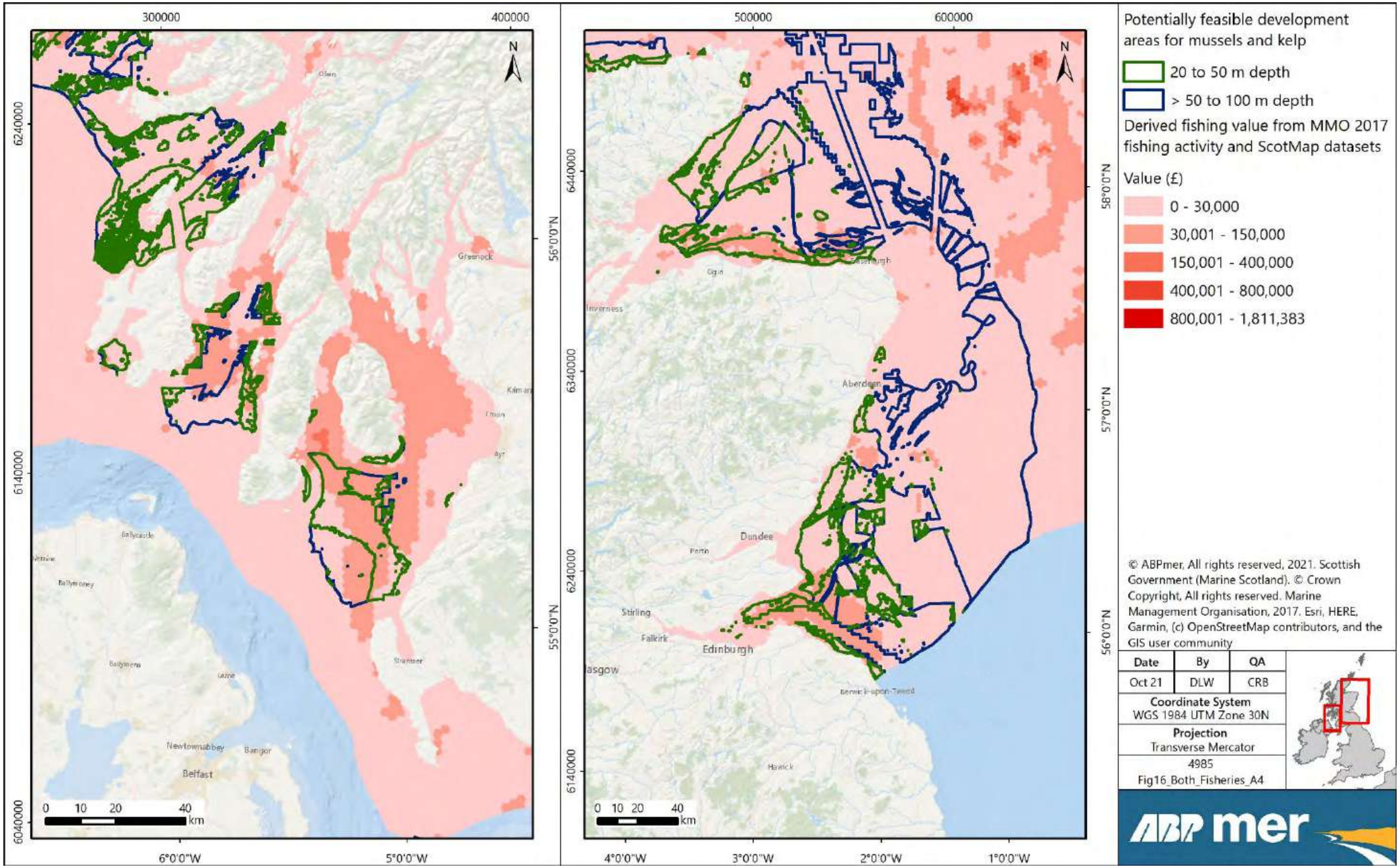


Figure 16. **Indicative value of commercial fisheries (all vessel sizes and gear types) within the potentially feasible development areas for mussels and kelp**

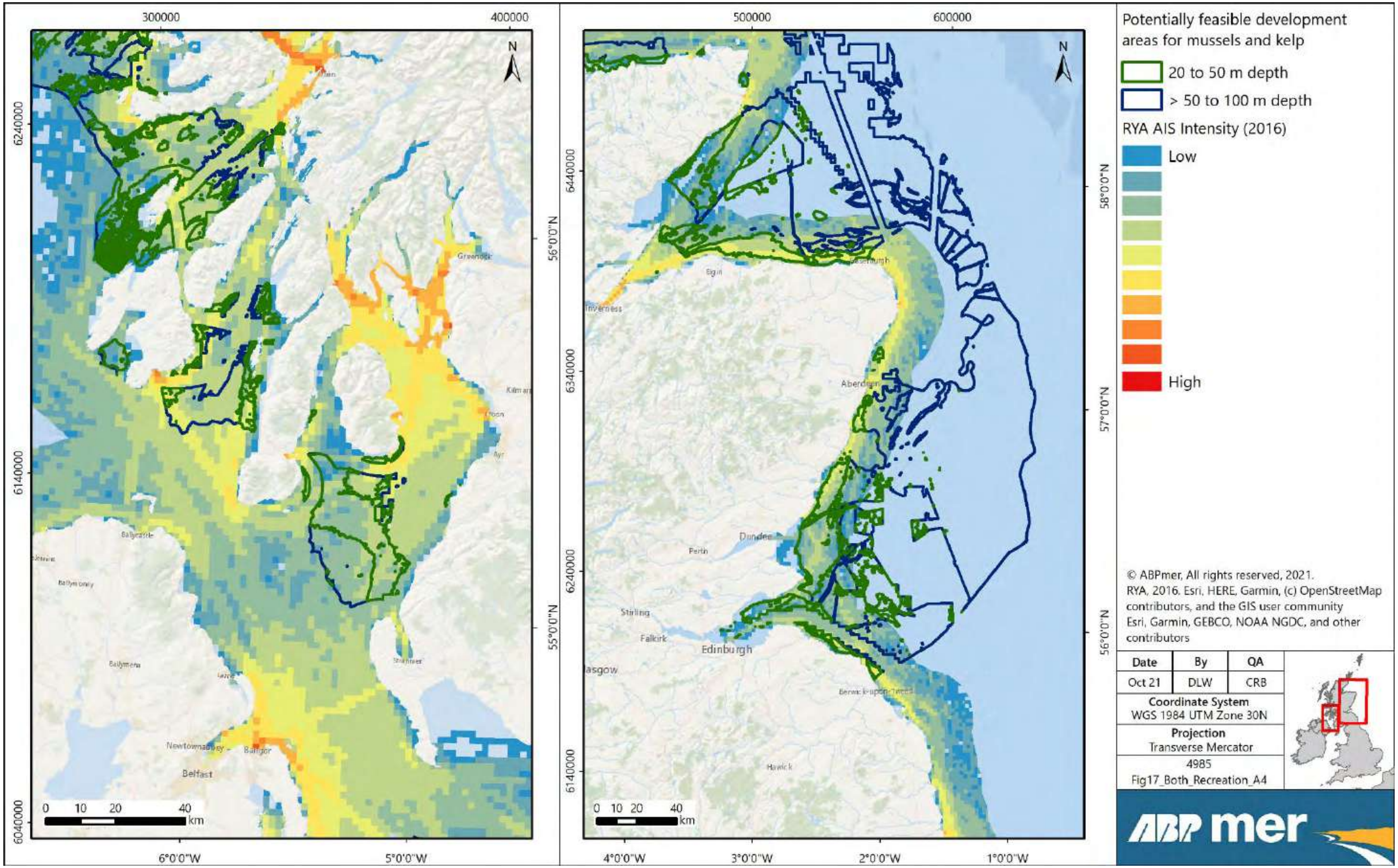


Figure 17. Relative intensity of recreational vessels with AIS within the potentially feasible development areas for mussels and kelp

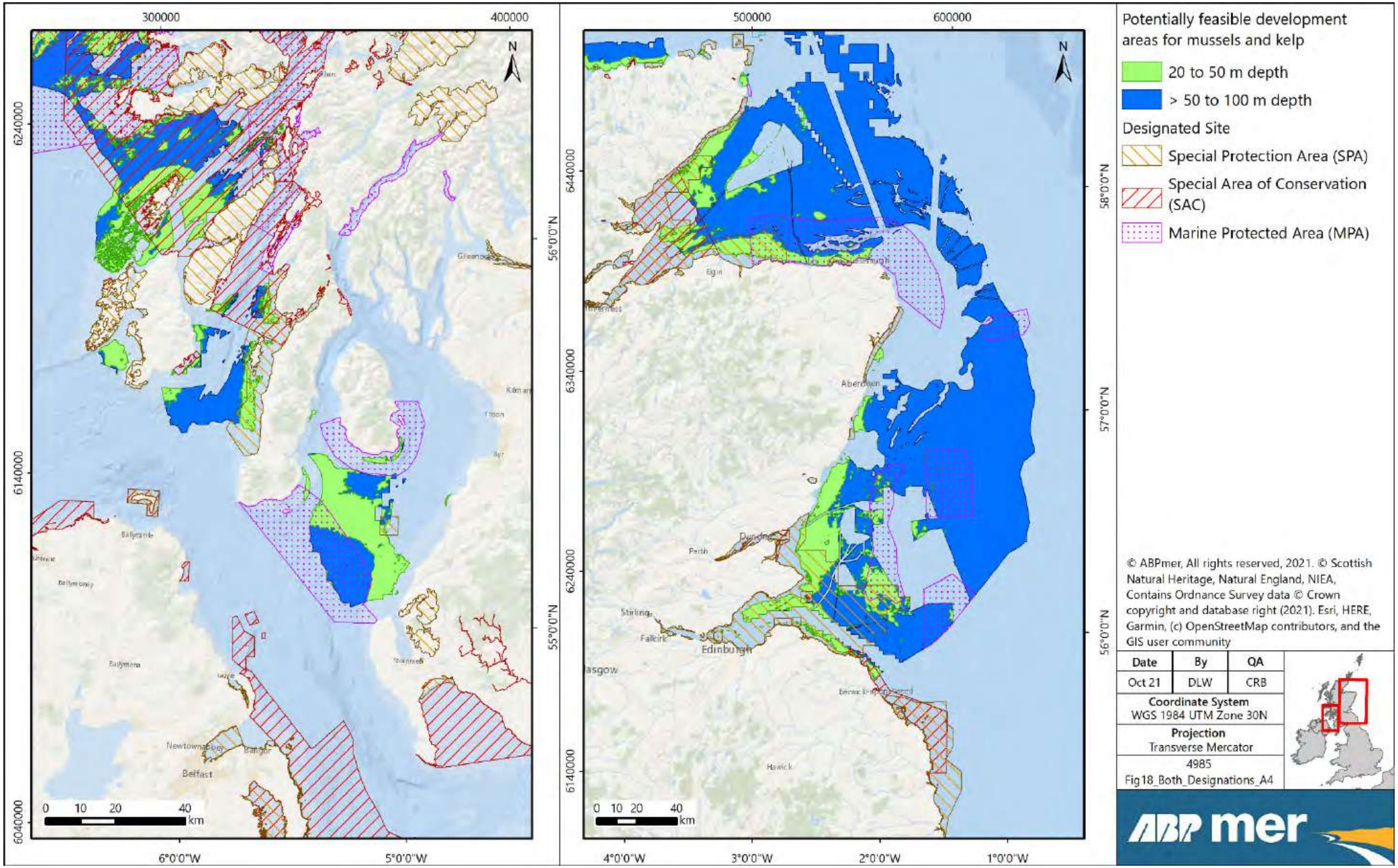


Figure 18. Marine nature conservation designations within the potentially feasible development areas for mussels and kelp

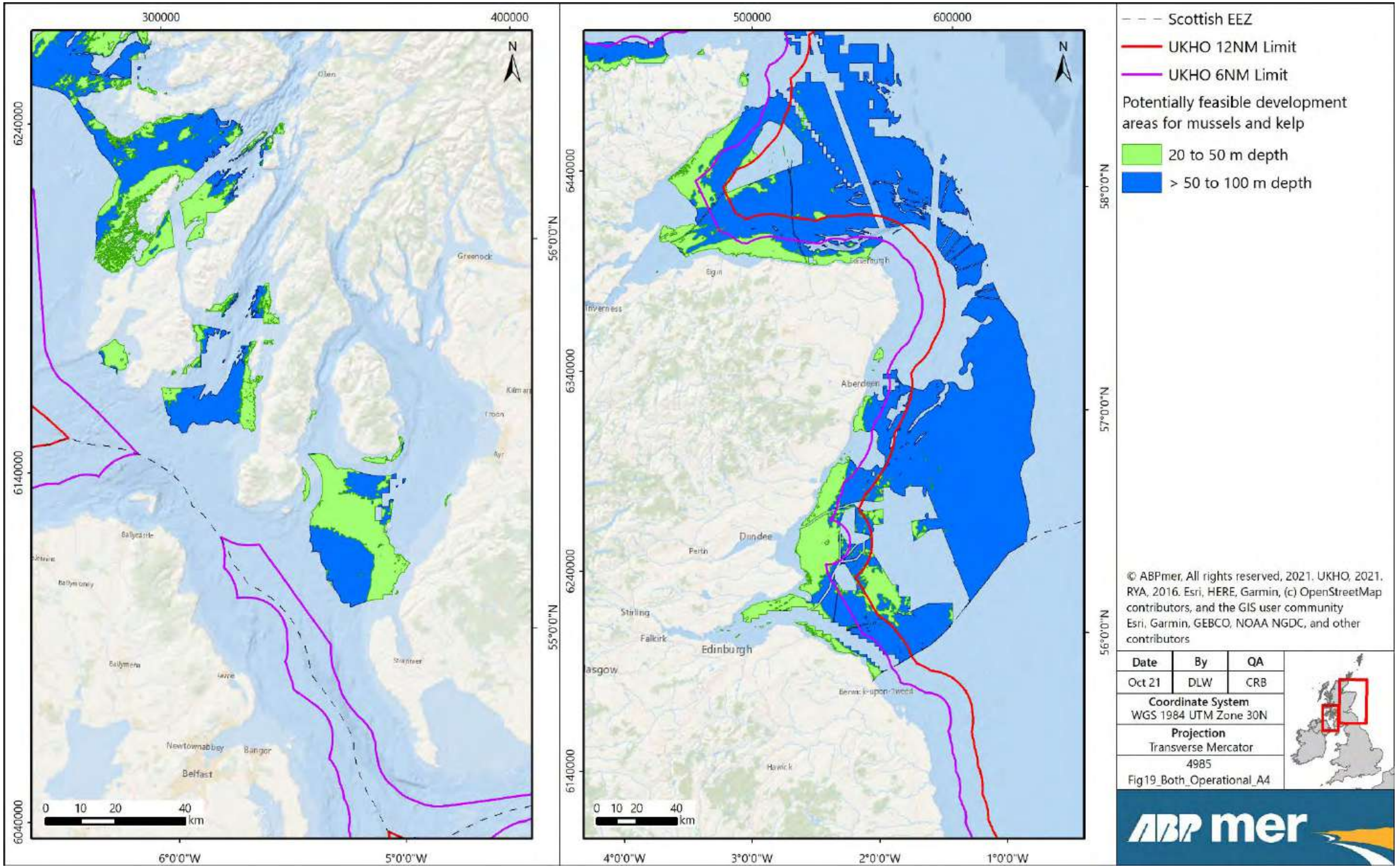


Figure 19. **Potentially feasible development areas for mussels and kelp in relation to the 6 NM and 12 NM limits**

4 Scope and Measures for Promoting Beneficial Interactions with Local Fishing Interests

As the aquaculture sector expands, the scope for aquaculture and wild capture fisheries sector (and particularly the inshore fishing fleets) to be able to co-exist needs to be explored to make best use of limited sea space.

It has been suggested that shellfish and seaweed aquaculture development could, in the long-term, potentially be beneficial to wild capture fisheries, for example through the provision of ecosystem services such as habitat and water filtration and/or acting as fish aggregating devices.

Although quantitative evidence to support this is currently sparse, developments such as the Offshore Shellfish Ltd mussel farm in Lyme Bay has enabled the impacts of such developments to be monitored (e.g. Mascorda Cabre *et al* 2021; Sheehan *et al*, 2019 and the University of Plymouth's ROPE project[6]).

A specific focus of this study was to assess the scope and potential for mitigating any potentially deleterious interactions with local fishing interests and promoting any potentially beneficial interactions and relationships.

As such, further, to identifying potential resource areas for cultivating mussels and kelp, key fisheries stakeholders were invited to review the potentially feasible development areas to discuss the fishing activity in these areas and their opinions on the potential for some fishing activities to be able to continue within mussel or kelp farm installations (i.e. co-exist).

Six interviews were conducted with commercial fishing representatives and other stakeholders with knowledge of the inshore fisheries in the potentially feasible development areas identified off the south-west and east coasts of Scotland. Interviewees were sent preliminary maps of these areas and schematics of the generic kelp farm layout and potential access channel arrangement to aid the consultation. During the interviews, the following aspects were discussed:

- The key fisheries that operate in the potential resource areas identified;
- The potential for static gear (creel) fisheries to continue to operate within mussel or kelp farms, specifically:
    - Potential negative impacts of shellfish/kelp farms on inshore static gear fisheries and any mitigation measures that could minimise or negate these impacts;
    - Potential positive impacts of shellfish/kelp farms on inshore static gear fisheries and any opportunities for developing synergies or maximising benefits to fishers;
    - The type of farm design or mitigations (if any) that would enable continued static gear fishing within such farms e.g. with respect to the layout of the longlines, distance between longlines, location and size of any access channels etc.

The following section provides a summary of the key messages from this consultation. Further detail is provided in Appendix C.

6 https://sheehanresearchgroup.com/rope/

4.1 Potential Interaction with fisheries in the study areas

In the west coast study are, and specifically in the Sound of Jura and wider Clyde area, the following key points were noted by fisheries' interests:

- All of the potentially feasible development areas are prime fishing areas on which coastal livelihoods depend;
- Key fisheries are: *Nephrops* trawling, scallop dredging, *Nephrops* creeling, crab creeling and scallop diving;
- The Clyde is unique in that many fishing grounds are shared by the static gear and trawl sectors (activities occur on different days);
- Creel fisheries operate in the more sheltered areas, so any aquaculture developments in sheltered areas will interact with these fisheries; and
- Around 200 pots can be deployed and left to soak for a few days.

Key fisheries off the east coast of Scotland were highlighted as:

- Squid fishery (within 1-2 NM; from north of Dundee into the Moray Firth);
- Lobster creeling (on hard ground);
- Scallop dredging (on soft ground); and
- *Nephrops* trawls (on softer grounds between 60-80 m deep).

It was noted that creelers deploy a higher number of creels over larger distances off the east coast compared to the west coast. Inshore fishing activity has been mapped off the east coast, and when these maps are available, they will help to improve future assessments and identify potential interactions with inshore fishing activity.

4.2 Potential negative interactions and mitigations

Displacement was the key impact of concern. It was highlighted that 75% of fishing vessels in Scotland operate within 6 NM of the shore and that fishermen have already been displaced from their fishing grounds by MPAs, offshore renewable developments and finfish farms (the latter on the west coast only).

Large-scale aquaculture developments in the potentially feasible development areas identified would therefore further displace fishermen from their remaining grounds. It was also stated that increased aquaculture-related vessel activity would also be an issue, especially in the Clyde area which is a busy maritime area (including military, commercial shipping and recreational vessel traffic).

4.3 Potential positive or beneficial interactions

There was a general consensus amongst fisheries stakeholders that it was difficult to see any positive or beneficial interactions. Whilst a few stakeholders noted the potential appeal of the idea that mussel or kelp farms may represent an area where static gear could be deployed without any competition from mobile fishing gears, in practice this was neither feasible (see below) nor desirable in areas where the seabed had been already been intensively dredged.

4.4 Farm design or mitigations that may enable continued static gear fishing within farms

There was consensus amongst all fisheries stakeholders that creeling activity within mussel or kelp farms was not feasible. This was due to the fact that creels move across the seabed as they are hauled in and that in rough weather, the creeling vessel may be dragged up to 1,000 m by the creels by the time all the creels have been recovered. As such it was agreed that entanglement was inevitable, even with an 'extensive' farm design with access channels. It was also highlighted that access channels would encourage all vessels to transit through them making it even less practical for static gear fisheries to operate in them. Suggestions regarding farm design included:

- it would be preferable to have an intensive farm design (i.e. producing higher volumes of mussels or kelp from a smaller sea area);
- the activities should be kept separate with recognised separation distances; and
- such aquaculture development could occur within MPAs hence reducing competition for space with commercial fisheries outwith MPAs.

5 Key Findings and Further Considerations

This study developed a spatial model to identify potential resource areas where it may be technically feasible to develop large-scale mussel or kelp farms based on their physical, environmental and operational requirements. Marine spatial planning factors relating to other marine sector activities, infrastructure and nature conservation were then considered to identify potentially feasible development areas for such installations.

However, it is stressed that the interactions with, and impacts of, any potential aquaculture development with all marine sectors (and indeed all receptors) would need to be considered at a site-specific level for any proposed development through the existing consenting processes for seaweed and shellfish aquaculture, or at a regional or national level for regional marine plans or sectoral plans respectively. In particular, potential interactions with and impacts on inshore fishing fleets and the communities that they support requires very careful consideration and discussion with both mobile and static gear sectors. The establishment of any plan option areas for offshore mussel or kelp farms should seek to safeguard existing fishing opportunities and activities wherever possible in line with the requirements of the National Marine Plan (and regional marine plans when these are adopted).

It is also important to note that the spatial data sets used in the model were those that were readily publicly available. There are known limitations for some of the data sets used, particularly with regard to the spatial distribution of fisheries value (which under-represents smaller inshore vessels) and the recreational boating intensity data (see Appendix B).

5.1 Key findings

5.1.1 Mussel farms

Key findings for mussel farms were:

- The potentially feasible development area for mussel farms within the 20 to 50 m depth range (the most likely area for developments) was 3,641 km^2 (of which 2,896 km^2 was within 6 NM of the coast). Of this, most was on the east coast (2,962 km^2), and 679 km^2 was on the west coast.
- Based on an extensive generic farm layout of 0.91 km^2 arrays, approximately 207 tonnes of mussels could be produced every two years (i.e. per growing cycle).
- To develop a farm that could produce the equivalent of 500 tonnes of mussels per annum (or in this instance 1,000 tonnes every two-year growing cycle), six arrays would need to be developed, estimated to cover an area of between 5.46–7.26 km^2, depending on the array clustering. This would represent:
    - 0.2–0.3 % of the potentially feasible area development areas identified between 20 to 50 m depth within 6 NM in the East coast study area;
    - 0.8–1.1 % of the potentially feasible area development areas identified between 20 to 50 m depth within 6 NM of the coast in the West coast study area;
- To scale production up (for example to a production of 10,000 tonnes), 48 arrays would be required covering a sea area of 45 to 56 km^2 (depending on array clustering). This represents:
    - 2.0–2.5 % of the potentially feasible development areas identified between 20 to 50 m depth within 6 NM of the coast in the East coast study area;
    - 6.6–8.2 % of the potentially feasible development areas identified between 20 to 50 m depth within 6 NM of the coast in the West coast study area.

5.1.2 Kelp farms

Key findings for kelp farms were:

- The potentially feasible development area for kelp farms within the 20 to 50 m depth range (the most likely area for developments) was 4,372 km^2 (of which, 3,627 km^2 was within 6 NM of the coast). As with mussels, the largest proportion was on the east coast (3,453 km^2) and 919 km^2 on the west coast.
- Based on an extensive generic farm layout of 1.05 km^2 arrays, approximately 40 tonnes of kelp could be produced annually. This area would represent:
  - 0.04 % of the potentially feasible area development areas identified between 20 to 50 m depth within 6 NM of the coast in the East coast study area;
  - 0.11 % of the potentially feasible area development areas identified between 20 to 50 m depth within 6 NM of the coast in the West coast study area.

5.1.3 Areas suitable for mussel or kelp

The potentially feasible development areas which were identified as potentially suitable for either or both types of cultivation within the 20 to 50 m depth range (the most likely area for developments) was 3,641 km^2 (of which 2,896 km^2 was within 6 NM of the coast). All areas suitable for mussels are also suitable for kelp, and there are some additional areas that are suitable only for kelp and not mussels.

5.1.4 The potential for co-existence between static gear fisheries and mussel or kelp farms

Key points relating to co-existence between static gear fisheries and mussel or kelp farms were:

- There was consensus amongst the fisheries stakeholders consulted that even with an 'extensive' design, including the provision of access channels, that entanglement of static gear (for the purpose of this study creels were specifically discussed) was inevitable.
- It was suggested that an intensive design to minimise sea and seabed area may be preferable to minimise competition for space with fishermen.
- The importance of engagement with fisheries stakeholders was stressed.

5.2 Further considerations

The spatial model developed for this study to identify potentially feasible development areas for offshore large-scale mussel and kelp farming was necessarily high level and there are numerous additional factors which would influence the feasibility of offshore mussel and/or kelp farming (see Section 2.2 and Section 2.3.1). Key amongst these is the economic viability of such developments (relating to capital investment and operational costs, market demand and the market value of the species produced). The economic viability in turn is influenced by operational factors such as the distance of the site from shore (influencing steaming time to and from site), the ability to access the farm site when required (influenced by physical conditions) and the presence and adequacy of shore-side logistics (e.g. the availability of haulage, processing units for the potential production volumes etc). These are all factors that will require further detailed consideration in relation to assessing the potential opportunities for large-scale restorative aquaculture in Scotland.

6 References

ABPmer, 2013. SEASTATES Wave Hindcast Model: Calibration and Validation Report. ABPmer Report R.2145, August 2013.

ABPmer, 2017. SEASTATES North West European Continental Shelf Tide and Surge Hindcast Database: Model Validation Report. ABPmer Report R.2784, March 2017.

Marine Scotland Science (2021). Marine Scotland Science Scottish Shellfish Production Survey 2020. Published by the Scottish Government, June 2021. Available online at: https://www.gov.scot/publications/scottish-shellfish-farm-production-survey-2020/

Maritek (2019). Shellfish Critical Mass Development Plan Pilot – Clyde. Final report submitted to Crown Estate Scotland (Interim Management), September 2019. Available online at: **Error! Hyperlink reference not valid.**

Mascorda Cabre, L., Hosegood, P., Attrill, M.J., Bridger, D., Sheehan, E.V. (2021). Offshore longline mussel farms: a review of oceanographic and ecological interactions to inform future research needs, policy and management. Reviews in Aquaculture (2021) 13, 1864–1887.

MMO (2019). Identification of Areas of Aquaculture Potential in English Waters, A report produced for the Marine Management Organisation by Centre for Environment Fisheries and Aquaculture Science, MMO Project No: 1184, May 2019, 107 pp. Available online st: https://www.gov.uk/government/publications/identification-of-areas-of-aquaculture-potential-in-english-waters-mmo1184

Poseidon Aquatic Resource Management (2017). Scottish Shellfish Development Critical Mass Model. Report submitted to Crown Estate Scotland and Association of Scottish Shellfish Growers (ASSG) November 2017. Available online at: https://www.crownestatescotland.com/resources/documents/scottish-shellfish-critical-mass-study

SAMS and IMANI (2019). Seaweed farming feasibility study for Argyll & Bute. November 2019. Available online at: https://www.argyll-bute.gov.uk/sites/default/files/seaweed_farming_feasibility_study_for_argyll_and_bute_report_1012019.pdf

Sheehan, EV, Bridger D, Mascorda Cabre L, Cartwright, A, Cox D, Rees S, Holmes L, Pittman SJ. 2019. Bivalves boost biodiversity. Food Science and Technology 33. Available online at: https://ifst.onlinelibrary.wiley.com/doi/10.1002/fsat.3302_5.x

Websites

http://marine.gov.scot/maps/700
https://marine.gov.scot/information/oil-gas-field-infrastructure
https://marine.gov.scot/marine-licence-applications
https://marine.gov.scot/sma/assessment/winter-nutrient-concentrations#links
https://offshoreshellfish.com/about-us/
http://www.seastates.net
https://sheehanresearchgroup.com/rope/

7 Abbreviations/Acronyms

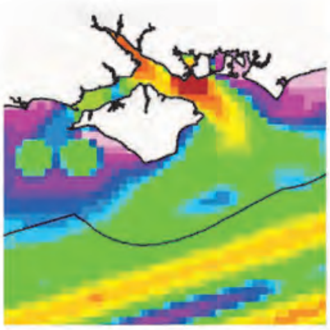
AIS	Automatic Identification System
ASSG	Association of Scottish Shellfish Growers
Cefas	Centre for Environment, Fisheries and Aquaculture Science
COVID	Coronavirus COVID-19
DAAC	Distributed Active Archive Center
EEZ	Exclusive Economic Zone
EMODnet	European Marine Observation and Data Network
EU	European Union
EUNIS	European Nature Information System
GEBCO	General Bathymetric Chart of the Oceans
GeMS	Geodatabase of Marine Features Adjacent to Scotland
GIS	Geographic Information System
HAB	Harmful Algal Bloom
HPMA	Highly Protected Marine Area
ICES	International Council for the Exploration of the Sea
IMANI	IMANI Developments
IMO	International Maritime Organisation
ITT	Invitation to Tender
KIS-ORCA	Kingfisher Information Service – Offshore Renewable & Cable Awareness project
LAT	Lowest Astronomical Tide
MCA	Maritime and Coastguard Agency
MD	Maryland (USA)
MMO	Marine Management Organisation
MODIS	Moderate Resolution Imaging Spectroradiometer
MPA	Marine Protected Area
MS	Microsoft
MSP	Marine Spatial Planning
n/a or N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NC	Nature Conservation
NGDC	National Geoscience Data Centre
NIEA	Northern Ireland Environment Agency
NM	Nautical Mile
NMPi	National Marine Plan Interactive
NOAA	National Oceanic and Atmospheric Administration
O&G	Oil and Gas
OB	Ocean Biology
OGA	Oil and Gas Authority
PAR	Photosynthetic Available Radiation
PMF	Priority Marine feature
RAF	Royal Air Force
ROPE	Response of predators to Protection and Enhancement
RYA	Royal Yachting Association
SAC	Special Area of Conservation
SAMS	Scottish Association for Marine Science
Scotmap	Inshore Fisheries Mapping Project in Scotland
SEPA	Scottish Environment Protection Agency
SNH	Scottish Natural Heritage (now NatureScot)

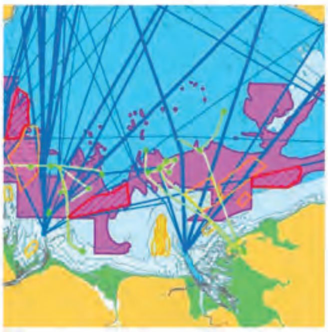
SPA	Special Protection Area
SST	Sea Surface Temperature
T	Tonnes
TOxN	Total Oxidised Nitrogen
TSS	Traffic Separation Scheme
UK	United Kingdom
UKHO	UK Hydrographic Office
USA	United States of America
UTM	Universal Transverse Mercator
VMS	Vessel Monitoring System
WFD	Water Framework Directive
WGS	World Geodetic System

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

Appendices




Innovative Thinking - Sustainable Solutions

A Farm Design and Production Capacity Assumptions

The project specification defined the size of seaweed and mussel farm developments that should be considered in the assessment as:

- Mussel farm developments of > 500 tonnes of annual production; and
- Seaweed farm developments, of > 1 km^2 in extent.

Furthermore, it was specified that the assessment of technical feasibility for establishing mussel or kelp farms in more exposed 'offshore' locations, should be based on current farming technology and practise. As such, for the purpose of this study it was necessary to make assumptions regarding the type of equipment that would be used, the farm design and the production capacity for a generic seaweed and mussel farm within the spatial model. These generic designs were based on the project team's knowledge of mussel and seaweed cultivation technologies, information available in the literature (peer-reviewed or grey literature sourced via an internet search) and through consultation with technical experts.

For both the mussel and the kelp farm design, an 'extensive' layout, as opposed to an 'intensive' farm layout was chosen for three reasons:

i) To minimise the risk of lines and/or stock tangling in areas of relatively strong tidal currents and wave exposure;
ii) The access and operational requirements of farm vessel(s) designed to be able to carry for example 20 tonnes of stock (e.g. the ability to turn the vessels around between longlines during maintenance or harvesting activities); and
iii) To theoretically enable access for some marine users (e.g. creeling vessels) to transit through or operate within the farm.

The following sub-sections describe the generic farm designs that were developed for use within the spatial model. Commercial fisheries stakeholder opinions on the potential for static gear fisheries (creels specifically) to continue within such a farm are presented in Appendix C and summarised in Section 4 of the main report.

A.1 Mussel farming

A.1.1 Species and production cycle

The shellfish species of interest for cultivation in this study was *Mytilus edulis* (blue mussel).

Mussel cultivation is dependent on a supply of mussel spat (juvenile mussels) for on-growing to a marketable size. Mussel spat is collected using spat collector ropes, deployed to coincide when mussel larvae are present in the water, providing a substrate for the mussel larvae to attach to and develop into spat. Once the spat reaches a certain size, they are re-socked onto mussel growing ropes.

It is beyond the scope of this study to provide detail on the technicalities of mussel spat collection for on-growing, except to note that for the purposes of this study, it has been assume that 10% of any mussel farm area will need to be dedicated to spat collection. It is also important to note that expert stakeholder input highlighted the highly variable nature of spat settlement both temporally and spatially, with some areas of Scotland experiencing very low spat settlement rates. As such, this is noted as a potential constraint for the development of large-scale mussels farms in Scotland which will need further consideration beyond the remit of this study.

The on-growing time for mussels to reach marketable size is dependent on the sea temperature, with slower growth occurring at lower temperatures. For the purposes of this study, it has been assumed that the grow out phase, further to the spat being re-socked onto the growing ropes, is two years.

A.1.2 Technology and farm design assumptions

Mussel farming is an established sector in Scotland. In general, farm designs include single or double headlines, often submerged below the sea surface, to which growing ropes (droppers) or a continuous looped growing rope are attached.

For this study, a single headline, of 150 m length, was chosen for the generic mussel farm design as it was assumed that single headline ropes would minimise the risk of rope or stock entanglement (compared to a double headline) in more exposed offshore locations. The full set of assumptions made regarding the equipment layout and production capacity of the generic mussel farm designed for this study is shown in Table A1.

The assumptions made regarding the natural resource requirements for farming mussels (with respect to physical and environmental conditions) and operational conditions (e.g. with respect to distance from land-base, wave and tide conditions etc) are presented in Appendix B.

Table A1. Assumptions regarding the equipment and design of mussel farms

Criteria	Design Assumption	Rationale
Type of headline rope	Single	Single headlines are less likely to result in tangling in more exposed conditions compared to a double headline.
Length of headline	150 m	Based on length of headline used by Offshore Shellfish Ltd (see https://offshoreshellfish.com/about-us/).
Position of headline in water	4 m subsurface	So theoretically small boats could transit over headlines
Type of growing rope	One continuous rope, attached to the headline rope every 1.5 m, with the loops extending to 10 m below the headline.	Continuous looped growing rope used to maximise efficiency during harvest. See Image A1.
Length of growing rope per single headline	1,148.5 m	See Image A1.
Seeding method	Spat collector lines within the same array.	Assume spat collector lines deployed in spring/summer, spat collected approx. 3 months later then re-socked onto growing lines within the array.
Time to harvest	2 years	Dependent on sea temperature. Indicative time of 2 years for the on-growing of spat once re-socked onto growing ropes has been assumed.
Type of anchor/seabed required	Screw anchor / sediment	Screw anchors are inserted into the substratum as opposed to placed onto the substratum (e.g. like a catenary mooring). It is more difficult and expensive to place screw anchors into rock, hence sedimentary substratum is preferable with the benefit of avoiding any rocky reef habitats/species of potential conservation concern (noting that other benthic habitat features will need to be considered at the site-specific level i.e. during initial site selection).
Ratio distance: depth of mooring line	2.5 m horizontal distance: 1 m deep	Based on stakeholder input. For example, the anchor line distance would be 75 m at a site 30 m deep. Hence this distance will change with changes in water depth. See Image A2 and Table A2.
Farm layout	4 columns of 10 parallel longlines - 70 m between rows - 150 m between columns	150 m longlines can 'bow' substantial distances as the tide ebbs and flows, and can bow in different directions as the tide turns, increasing the potential for tangling of lines and/or stock. Hence a 70 m distance was chosen between parallel longlines to minimise this risk. A 150 m distance between columns of longlines was chosen (at 30 m depth), based on the 75 m horizontal distance of the anchor line at each end of the longline. See Image A3.

Criteria	Design Assumption	Rationale
Farm area per array – sea surface	0.91 km^2 (at 30 m depth)	See Image A3.
Total length of growing rope per array (km)	45,940	Based on 40 longlines each with 1,148.5 m of growing rope attached. See Image A1.
Yield per m growing line	5 kg / m	A conservative estimate. In practice, yields may be higher.
Estimated tonnage per array per two year growing cycle (not	c. 230 tonnes every 2 years	Based on 5 kg / m growing rope and 45,940 m growing rope per array. Note, this assumes the whole array is used for mussel grow-out.
Estimated tonnage per array per two year growing cycle accounting for spat collection	c. 207 tonnes	This calculation assumes that 10% of the array (in this instance 4 of the 40 headlines) are utilised for spat collector lines.
Access channel size / location	For discussion with stakeholders	Where a theoretical development may exceed a sea surface area of 1 km^2 (i.e. more than one array), access channels could be placed between arrays to enable access or transit for small vessels. The generic design of the mussel array would provide a distance of 250 m between two arrays side by side (see Image A4) whilst the size of access channel between parallel arrays was left open to discussion with fisheries stakeholders (see Appendix C).

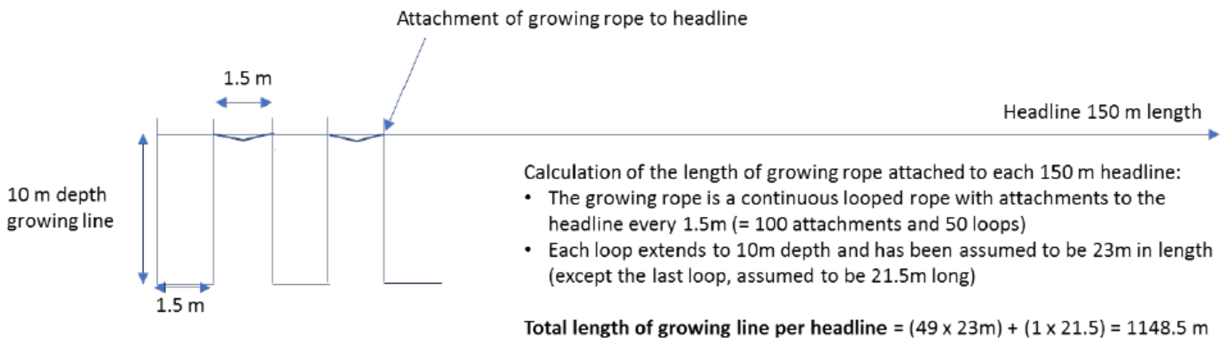


Image A1. Schematic showing continuous loop mussel growing rope

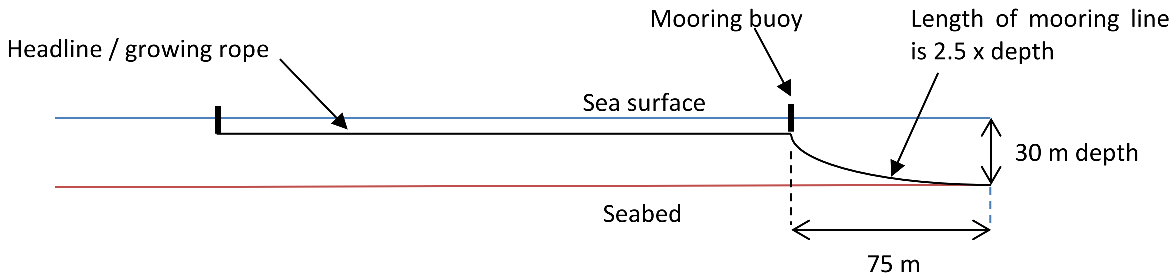


Image A2. Schematic showing mooring line length at 30 m water depth

Table A2. Horizontal distance of mooring line and sea surface area per mussel farm array between depths of 30 – 100 m

Depth (m)	Distance to Anchor	Total Sea Surface Area Within Array (km^2)
30	75	0.91
40	100	1.02
50	125	1.12
60	150	1.23
70	175	1.33
80	200	1.44
90	225	1.54
100	250	1.65

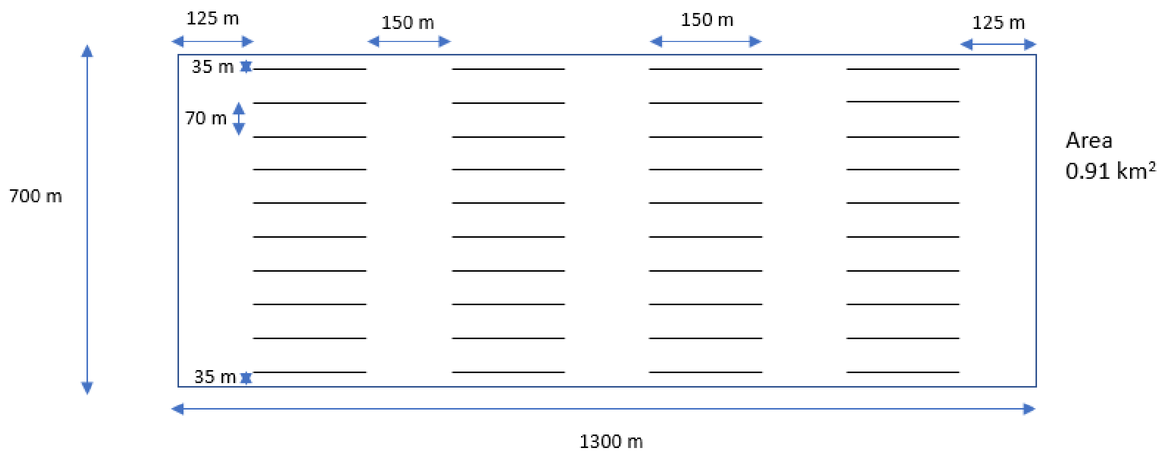


Image A3. Schematic showing generic mussel farm design used in model

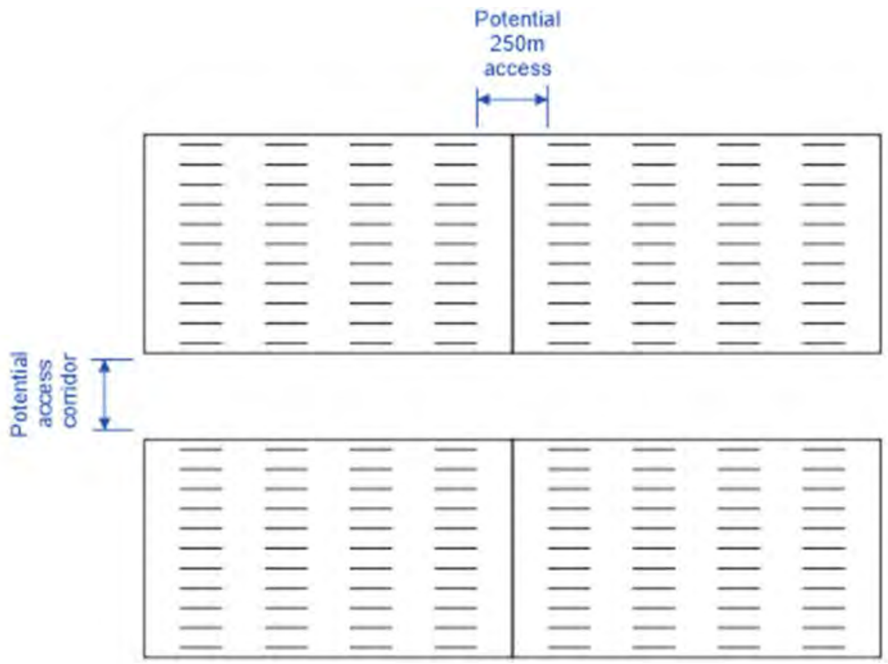


Image A4. Schematic showing potential access channels between arrays

A.2 Seaweed farming

A.2.1 Species and production cycle

For the purposes of this study, the species of seaweed for cultivation was assumed to be the kelp species *Alaria esculenta; Saccharina latissima;* and *Laminaria digitata*. It was confirmed with an expert stakeholder that the environmental requirements for these species are similar enough that it could be assumed that all three species could be farmed at the same site. As such, hereafter, the species of seaweed is just referred to as kelp.

Farmed kelp is a seasonal crop. Whilst there are small differences in the growing season between the three species (not considered further within this study), in general growing ropes are put out to sea in October and the seaweed is harvested between March to May if the seaweed is for use in human food applications, or possibly June if for use in non-human food applications (the difference relating to fouling of the stock after May). Although it does not influence the outcomes of the spatial modelling exercise, for the purposes of this study is has been assumed that the 'direct seeding' method of growing lines[7] would be more efficient for a large-scale farm rather than the alternative method of twinning (for further details regarding these different approaches, please refer to SAMS and IMANI, 2019).

A.2.2 Technology and farm design assumptions

In Scotland, as in the rest of the UK and Europe, seaweed farming is a relatively new and emerging industry. There is currently at least one commercial farm producing seaweed for the supply chain in Scotland, in addition to several trial sites cultivating seaweed, and nine sites where a marine licence has been consented for a seaweed farm development[8].

General seaweed farm designs may include grid systems, single longlines, modified mussel growing ropes or offshore cultivation rigs (see SAMS and IMANI, 2019). For this study, the generic design chosen for seaweed farms was a **single longline**, which was considered to be a more efficient design for the harvesting of relatively high volumes of seaweed and that there was less chance of entanglement of the stock (seaweed fronds) on a single headline rope, compared to a 'grid' rope system. The length of single longlines used (or proposed) for farming seaweed is variable, for example, 75 m longlines are used in Norway, whilst the length of longlines to be installed at consented sites in Scotland range between 100 m to 500 m in length[9]. The length of longlines to use in this study was set at **200 m**. The full set of assumptions made regarding the equipment layout and production capacity of the generic seaweed farm designed for this study is shown in Table A3.

The assumptions made regarding the natural resource requirements for farming seaweed (with respect to physical and environmental conditions) and operational conditions (e.g. with respect to distance from land-base, wave and tide conditions etc) are presented in Appendix B.

7 Kelp juveniles are grown in tumble culture, detached from any surface, rather than on twine. The juveniles are then mixed with a binder or bioglue and applied directly onto the cultivation surface (in this instance rope), which can then be immediately deployed into the sea (SAMS and IMANI, 2019)

8 Based on information from the Marine Scotland Marine Licence Application webpage: https://marine.gov.scot/marine-licence-applications [accessed April 2021]

9 information obtained from the Marine Scotland marine licence application website (https://marine.gov.scot/marine-licence-applications) [accessed 27 July 2021]

Table A3. Assumptions regarding the equipment and design of seaweed farms

Criteria	Design Assumption	Rationale
Type of headline rope	Single	Less likely to result in tangling in more exposed conditions compared to a double headline (used in mussel farming to increase production capacity) and more efficient for harvesting compared to a grid system (e.g. 50 m ropes in a grid formation; see SAMS and IMANI, 2019).
Position of headline in water	2 m below the sea surface	To avoid the wave energy at the sea surface.
Type of growing rope	Use headline as growing rope	The headline is used as the growing line rather than dropper ropes to minimise the risk of rope/stock tangling.
Seeding method	Direct seeding	Assumed to be most effective method for 200 m longlines (compared to the seeded twine method, although seeded twine can be purchased ready for use from third parties), plus denser growth and hence increased biomass from direct seeding (stakeholder input).
Time to harvest	c. 8 months (October to May)	Based on available information and stakeholder input.
Length of each growing rope	200 m	The length of single headlines proposed at consented sites in Scotland varies between 30 m and 230 m. Rope is generally supplied in 210 m length units, hence a 200 m longline was chosen.
Type of anchor / seabed required	Screw anchor / sediment	Screw anchors are inserted into the substratum as opposed to placed onto the substratum (e.g. like a catenary mooring). It is more difficult and expensive to place screw anchors into rock, hence sedimentary substratum is preferable with the benefit of avoiding any rocky reef habitats/species of potential conservation concern (noting that other benthic habitat features will need to be considered at the site-specific level i.e. during initial site selection).
Ratio distance: depth of mooring line	2.5 m horizontal distance: 1 m deep	Based on stakeholder input. For example, the anchor line distance would be 75 m at a site 30 m deep. Hence this distance will change with changes in water depth. See Image A2 and Table A4.
Farm layout	4 columns of 10 parallel longlines - 70 m between rows - 150 m between columns	200 m longlines can 'bow' up to 30 m as the tide ebbs and flows, and can bow in different directions as the tide turns, increasing the potential for tangling of lines and/or stock. Hence a 70 m distance was chosen between parallel longlines to minimise this risk. See Image A5.
Farm area per array – sea surface	1.05 km^2	See Image A5.

Criteria	Design Assumption	Rationale
Total length of growing rope per array	8,000 m	Based on 40 longlines, each 200 m long per array.
Yield per m growing line	5 kg / m	A conservative estimate. In practice, yields may be higher.
Estimated tonnage per array per annum (p.a.)	40 tonnes	Based on 5 kg / m growing rope and 8,000 m growing rope per array.
Access channel size / location	For discussion with stakeholders	Where a theoretical development may exceed a sea surface area of 1 km^2 (i.e. more than one array), access channels could be place between arrays to enable access or transit for small vessels. Similar to the mussel farm, the size of access channel between parallel arrays was left open to discussion with fisheries stakeholders (see Appendix C).

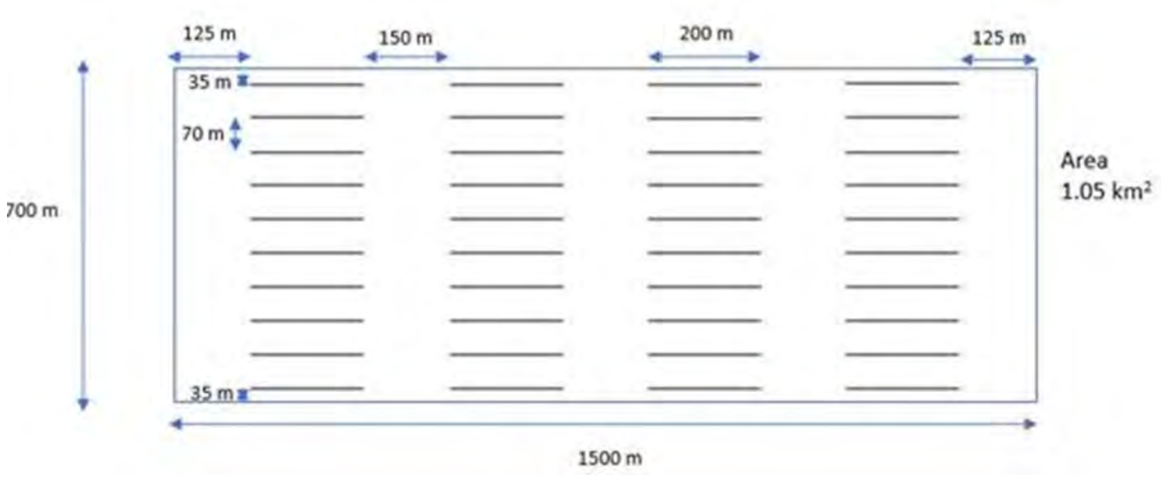


Image A5. Schematic showing generic seaweed farm design used in model

Table A4. Seabed area per seaweed farm array between depths of 30 – 100 m

Depth (m)	Distance to Anchor	Sea Surface Area (km^2)
30	75	1.05
40	100	1.16
50	125	1.26
60	150	1.37
70	175	1.47
80	200	1.58
90	225	1.68
100	250	1.79

B Development of the Spatial Model

This appendix describes in detail the methodological approach to identifying marine areas where development of large-scale seaweed or mussel farms may be technically feasible.

As noted in the main report, technical feasibility was considered with respect to the following:

- Current farming technology and practice;
- The physical and environmental parameters used to identify potentially suitable growing areas for seaweed and mussels (referred to as 'potential resource areas'); and
- The constraints to development in these areas (i.e. other marine activity and infrastructure; referred to as Marine Spatial Planning (MSP) constraints).

Identification of potentially suitable areas based on physical and environmental conditions and marine spatial planning (MSP) constraints was undertaken through the development of a spatial model, using publicly available spatial data layers. Section B.1 describes the component spatial data layers that were available to incorporate into the spatial model, highlighting data gaps and limitations. Section B.2 describes the rules and assumptions applied to each of these data layers within the model.

B.1 Spatial data sources and gaps

B.1.1 Physical and environmental data

Table B1 shows the data layers that were included in the spatial model. These data layers are presented in Figure B1 to Figure B8. The rules and assumptions applied to each physical and environmental data layers within the model to identify potential resource areas are described in Section B.2.

Model limitations - Table B2 shows the parameters for which a suitable spatial data set was not sourced and hence that are considered to be data gaps in the current model.

It is also important to note, that whilst for the purposes of this study the spatial model was necessarily high level, there are other key physical and environmental factors that will influence the technical feasibility of offshore mussel or kelp farming, which would need to be considered in detail at a site-specific level. Additional considerations for farm design (e.g. number, spacing, length and orientation of headlines) and operational feasibility are briefly described below (informed by expert stakeholder input).

- **Tidal current** – sufficient tidal current is required for the delivery of nutrients throughout the farm, although the current speed and associated shear forces will also determine aspects such as stocking densities on growing ropes (for mussels) and the potential for stock loss from the growing ropes through 'drag'. In turn, on mussel farms, as the shellfish grow, the weight of the stock on the growing ropes will alter the current flow through the farm, for example creating current and plankton shadows behind the lines.
- **Tidal cycle and range** - anchor lines will be taught at high tide and with less tension at low tide, which can result in the headlines 'bowing' (up to 30 m in some instances for a 200 m long headline) and headlines will also move as the tide changes direction (usually in the same direction but sometimes in different directions as the tide changes direction). A tidal range of less than 5.5 m was suggested for feasibility.
- **Wave exposure** - wave period and the 'shape' of waves (in turn influenced by seabed topography) and the resulting wave energy imparted onto vessels will be a key determining

factor in the ability to undertake operations on site. Shorter wave periods and steeper waves are more of an issue compared to a higher wave height with a longer wave period. During operations such as harvesting, vessels are attached to the lines which increases the structural loads on the farm equipment, hence modelling of wave height and period for farm siting is likely to be necessary. For seaweed, wave conditions may also be an issue with respect to disturbing seabed sediments and hence increasing turbidity (see above);

- **Wind** – will affect operational safety including through influence on seastate conditions;
- **Light availability (seaweed)** – turbidity and the potential for increased turbidity at specific times of the year and/or in areas where there is sedimentary seabed could reduce light penetration of the water column and hence the suitability of resource areas identified. In practice the optimum depth of the growing line for seaweed will be determined through trial and error with respect to being at a depth that reduces the impact of surface wave energy and allows sufficient light penetration throughout the growing period (approximately October to June). It was queried whether the turbidity off the east coast of Scotland would potentially be an issue;
- **Spat availability (mussels)** – unreliable spat fall was raised as a key factor affecting the Scottish mussel industry, with variability both on a spatial and temporal scale. This appears to be validated by the Shell-volution project in which the number one issue cited by mussel farmers surveyed for that project was spat availability;
- **Predation (mussels)** – eider ducks and golden eye were noted as a key issue in Scotland;
- **Fouling** – it was noted that being in an offshore location does not stop fouling (e.g. by hydroids, sea squirts) which can potentially impact e.g. spat settlement (mussels) and stock quality; and
- **Disease status** (**mussels**) – can be an issue for exporting live bivalve molluscs.

B.1.2 Operational limitations and economic viability

It is important to note that whilst consideration of the financial cost or viability of offshore mussel or kelp farms was outwith the scope of this study, the importance of these factors on the feasibility of such developments was stressed by expert stakeholders. A summary of the influence of these factors (based on stakeholder input) is briefly described below.

- **The distance of the aquaculture development to the nearest land-based port or harbour facilities** – the further the distance from the shore the longer the transit time will be to and from the site. The transit times must be suitable in relation to the number of days per year required for operational activities within the site (see below). Longer transit times will increase operational costs (e.g., fuel costs). Transit time to the nearest suitable port or harbour facilities and transport logistics into the supply chain may be a particular issue for seaweed, which needs to be processed (dried, freeze dried or ensiled) within 24 hours of harvest. For the current study a maximum distance from shore of approximately 10 km was considered likely to be feasible; for context, the Offshore Shellfish Ltd farm in Lyme Bay Devon comprises three sites, of which the farthest away from shore is over 20 km (Offshore Shellfish Ltd, pers. comm.)
- **The number of days per year access to the farm site is required** – operational activities within farm sites include setting out equipment (e.g., deploying seeded lines (kelp) or re-socking spat onto growing lines), maintenance of equipment (e.g. cleaning lines, inspecting navigational markers etc) and harvesting activity. The total number of days that the site will need to be accessed will be influenced by a range of factors including the overall size of the farm and the farm layout (e.g. if arrays are clustered), anticipated production volumes, the duration and efficiency of harvesting the stock and the number and capacity of farm vessels. For seaweed cultivation it will also be influenced by the ability to mechanise the deployment of seeded lines and harvesting (which could potentially increase the efficiency of deploying seeded line from 1 km per day by hand to approximately 8-10 km per day with mechanisation).

- **Vessels** – the size and number of vessels required will depend on the farm size, estimated production volumes, and an appropriate farm layout will be required to enable vessels to manoeuvre between headlines if required. It may be necessary for vessels to have accommodation facilities to minimise time lost to transiting from the land-base to the farm site and maximise operational flexibility.
- **Economic costs and viability** – factors that influence the economic viability of offshore developments will relate to the capital investment costs (required for initial site set up), operational costs (in turn influenced by the operational factors above) and market demand and value for the species farmed.

B.1.3 Marine spatial planning data

Table B3 shows the MSP data layers, relating to other marine sector activity, infrastructure and nature conservation designations that were included in the spatial model to enable the potential constraints to mussel or seaweed farm developments in the suitable growing areas to be identified.

These data layers are presented in Figure B9 to Figure B17, except the following layers which are presented in Section 3 of the main report in further detail:

- The indicative value of commercial fisheries per 1/200th of an ICES rectangle within the study area (see Figure 4, Figure 10 and Figure 16 in Section 3 main report);
- The RYA AIS intensity heat maps representing recreational boating activity in the study area – see Figure 5, Figure 11 and Figure 17 in Section 3 main report);
- The Nature Conservation Designations in the study area – see Figure 6, Figure 12 and Figure 18 in Section 3 main report).

The rules and assumptions applied to each MSP data layer within the spatial model is described in Section B.2.

Table B1. Physical and environmental data layers used to identify suitable growing areas

Parameter Type	Parameter	Data Source	Date	Resolution	Processing
Physical	Bathymetry (m; Lowest Astronomical Tide)	EMODnet	Current	500 m x 900 m	n/a
	Significant wave height (m)	ABPmer inhouse SEASTATE model (ABPmer, 2013)	1979-2020	500 m	n/a
	Tidal current (m/s)	ABPmer inhouse SEASTATE model (ABPmer, 2017)	1979-2020	500 m	n/a
	Seabed substratum	EMODnet	Current	Polygons	n/a
	Photic depth (m)*	NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group. Moderate-resolution Imaging Spectroradiometer (MODIS) Aqua Euphotic Depth Data; 2018 Reprocessing. NASA OB.DAAC, Greenbelt, MD, USA. doi: data/10.5067/AQUA/MODIS/L3M/ZLEE/2018.	2010-2020	4 km	10 year average during growing months (October to June)
Environmental	Total oxidised nitrogen (TOxN)*	Modelled salinity normalised total oxidised nitrogen, Marine Scotland Science (https://marine.gov.scot/sma/assessment/winter-nutrient-concentrations#links)	2017-2019	~ 660 m x 1 km	Average mean winter concentration (from October to March)
	Chlorophyll-a concentration (mg/m^3) **	NASA (NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group. Moderate-resolution Imaging Spectroradiometer (MODIS) Aqua Chlorophyll Data; 2018 Reprocessing. NASA OB.DAAC, Greenbelt, MD, USA. doi: data/10.5067/AQUA/MODIS/L3M/CHL/2018.)	2010-2020	4 km	10 year average
	Temperature	NASA Giovanni data portal - Aqua MODIS Global Mapped 11 µm Daytime Sea Surface Temperature (SST) Data	2020	4 km	Not incorporated into spatial model – see Table B4 and Table B5 for rationale
	WFD Dissolved oxygen classification ***	WFD dissolved oxygen classification, Marine Scotland NMPi (http://marine.gov.scot/maps/700)	2018	Waterbody	n/a

Parameter Type	Parameter	Data Source	Date	Resolution	Processing
	Shellfish harvesting area classifications***	Supplied by Food Standards Scotland	2021	Classified harvesting areas	n/a
	Overall WFD classification***	WFD Water Body Classification 2007-2017, Marine Scotland NMPi	2007-2017	Waterbody	n/a

* Only applied to identify potentially suitable growing areas for seaweed; ** Only applied to identify potentially suitable growing areas for mussels.
Data layers shaded grey were not incorporated into the spatial model; *** Used as stand-alone data sets on which to base assumptions on the water quality status of adjacent 'offshore' waters.

Table B2. Physical and environmental spatial data gaps

Parameter	Detail	Assumption / Recommendation
Salinity	No spatial data layer with a suitable coastal resolution was identified (**data gap**). However, given the wide range of salinities in which the seaweed species of interest and blue mussels naturally occur, the assumption was made that as long as any suitable areas identified were not likely to be impacted by major freshwater inputs, salinity was not likely to be a key influencing parameter.	Assumption: Salinity would not be a limiting environmental factor where there were no major freshwater inputs.
Harmful algal blooms	Although there are monitoring programmes and alert systems relating to harmful algal blooms (HABs) and marine biotoxins in inshore waters where there are classified shellfish harvesting areas, a long-term data set indicating any particular 'hotspot' areas for HABs was not sourced. As such, the influence of HABs on potentially suitable growing areas could not be incorporated into the spatial model. This has been identified as a **data gap**.	Recommendation: HABs are an important consideration for mussel farming particularly, that will need further consideration at a more site-specific level.
Water quality	Whilst there are various statutory water quality monitoring requirements in relation to the Water Framework Directive; Bathing Waters Directive, the Marine Strategy Framework Directive and food safety regulations (with respect to shellfish entering the food chain), in general, water quality monitoring is undertaken in inshore waters unless in response to a specific incident. As such, water quality with respect to microbiological contaminant levels could not be incorporated into the spatial model. Furthermore the location of long sea outfalls, which would highlight potential point sources of microbial contamination that could affect mussel farming in-particular, were not available from SEPA during the timescale of the study. This has been identified as a **data gap**.	Assumption: Water quality was assumed not to be a constraint unless: ▪ Adjacent to a shellfish harvesting area classified as C or X; or ▪ Adjacent to a WFD waterbody that was classified as Moderate or Poor. In 2021, there were no shellfish harvesting areas classified as C or X. There were two shellfish harvesting areas classified as B/C: at Campbeltown Loch and Loch Riddon. Of these Campbeltown Loch is the only site located in the main area of interest in this study (i.e. The Sound of Jura south of Loch Sween, Kilbrannon Sound and the southeast coastline of Arran south of Carradale). Only two coastal waterbodies in the areas of interest in the south west or the east coast had a classification below high or good: Irvine Bay in the south west of Scotland (2017 classification moderate) and Leith Docks to Port Seton (2017 classification poor).

Parameter	Detail	Assumption / Recommendation
		The implications for water quality in waters adjacent to these areas is not known. However, none of the potentially feasible development areas identified (see Figure 2 in the main report) were located in the vicinity of either of these areas. Recommendation: Water quality is an important consideration for mussel farming, and potentially seaweed farming depending on its end use, that will need further consideration at a more site-specific level.
Wave period	Consultation with technical experts indicated that wave period as well as wave height (and the resulting wave energy) was a key factor influencing whether it would be feasible to conduct operations on site. However, it was beyond the scope of this study to model the combinations of wave height and period that would create conditions unsuitable for operations.	Recommendation: Further consideration of how to incorporate this factor into a spatial model would enable further refinement of potentially suitable areas.

Table B3. MSP data layers included in model

Parameter	Data Source	Data	Resolution/Data Format	Data Processing
Military coastal live firing ranges	Oceanwise Marine Themes Vector dataset*	Current	Polygons	Filtered by military practice areas with the term 'range'
Oil and Gas platforms and pipelines	Oceanwise Marine Themes Vector dataset*	Current	Points/Polylines	Filtered only active pipelines. 500 m buffer applied to surface infrastructure and 250 m to pipelines
Shipping routes and International Maritime Organisation Traffic Separation Schemes	ABPmer, MCA, MMO, and UKHO	2017	2 km	Filtered data for cells containing $\geq$ 600 passenger, cargo and tanker transits per annum to represent 'high intensity' shipping routes
Lifeline ferry routes	Scottish Government	2020	Polyline	2.5 km buffer applied to all ferry routes
Existing aquaculture lease/lease option areas	Crown Estate Scotland data portal	Current	Polygons	n/a
Existing renewable lease/lease option areas	Crown Estate Scotland data portal	Current	Polygons	n/a
Waste disposal sites	Cefas	Current	Polygons	Filter only open disposal sites
Formal anchorage areas	Oceanwise Marine Themes Vector dataset*	Current?	Anchorage area polygons extracted from this dataset were considered to represent formal anchorage areas.	n/a
Priority Marine Features	GeMS	Current	Points/Polygons	Data filtered for subset Priority Marine Features and 50 m buffer added to each data point
Commercial fisheries	ABPmer in-house data layer estimating fishing value from MMO VMS data and Scotmap	2017 (VMS data) 2007-2011 (Scotmap)	1/200th of an ICES rectangle	An estimate of the value of landings from all fishing vessels and fishing gears around Scotland obtained through combining the monetary values from 2017 annual fisheries statistics (providing information from vessels over 15 m in length that have VMS) and

Parameter	Data Source	Data	Resolution/Data Format	Data Processing
				Scotmap (which provides information on the spatial distribution of value from vessels under 15 m in length from a study conducted between 2007 and 2011) The value estimates are indicative only and the data limitations are described in detail in Section B.1.4 below
Recreational boating activity	Royal Yachting Association (RYA) AIS intensity heatmap	2016	~3 km x 3.5 km	n/a
Subsea cables and pipelines	KIS-ORCA, Crown Estate Scotland data portal, and Oceanwise Marine Themes Vector dataset*	Current	Polylines/Polygons	n/a
Historic protected wrecks	UKHO, and Marine Scotland Historic Marine Protected Areas	Current	Points/Polygons	n/a

* Oceanwise Marine Themes data was supplied under licence by Crown Estate Scotland. Data layers shaded grey were not incorporated into the spatial model (see Table B6 for rationale).

B.1.4 Marine spatial planning data limitations

For the purpose of this study, readily available data sets were used to represent MSP constraints within the model. It is important to note the limitations of the following data sets:

Commercial fisheries

The dataset described in Table B3 was an available spatial data set that had been previously created by ABPmer to present an overview of the spatial distribution of the value of seafood caught in Scottish waters from all vessels using all types of fishing gears. The purpose of the data set in this study was to enable the distribution and relative indicative values of fisheries throughout the areas of interest and how the potentially feasible development areas identified overlapped with these fisheries areas. However, it is important to note the limitations associated with this dataset which are as follows:

- The data layer does not contain the most recent fisheries data for vessels over 15 m;
- Although VMS has been mandatory on vessels over 12 m since 2013, the data only represents the value from vessels of 15 m and over;
- VMS data does not capture the value of fish caught in UK waters by non-UK vessels;
- The Scotmap data was collated over the time period 2007 to 2011 and hence may not represent current inshore fishing activity;
- The value of the Scotmap data in this processed layer was not uprated to 2017 values.

Recreational boating

Data limitations of the RYA AIS heatmap include:

- The data are limited to only those vessels carrying AIS transponders (generally larger vessels) and hence may underestimate recreational boating activity;
- The AIS technology used by recreational vessel users (AIS-B; Class B) is a lower power solution than the AIS technology carried by commercial vessels[10] and may therefore have limitations in range and reception (which may result in activity being underestimated).

[10] International voyaging ships with Gross Tonnage of 300 or more tonnes and all passenger ships regardless of size

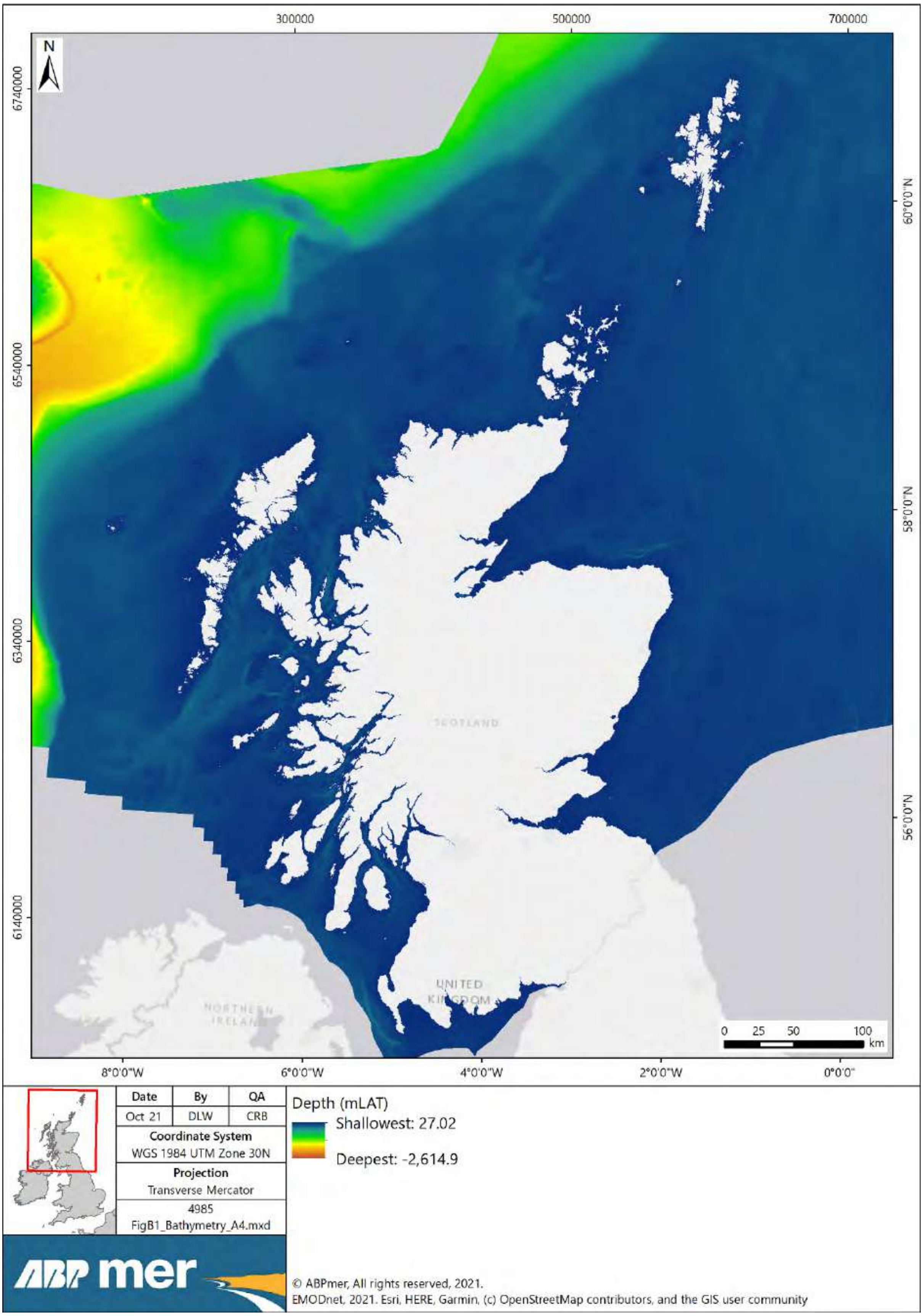


Figure B1. Bathymetry

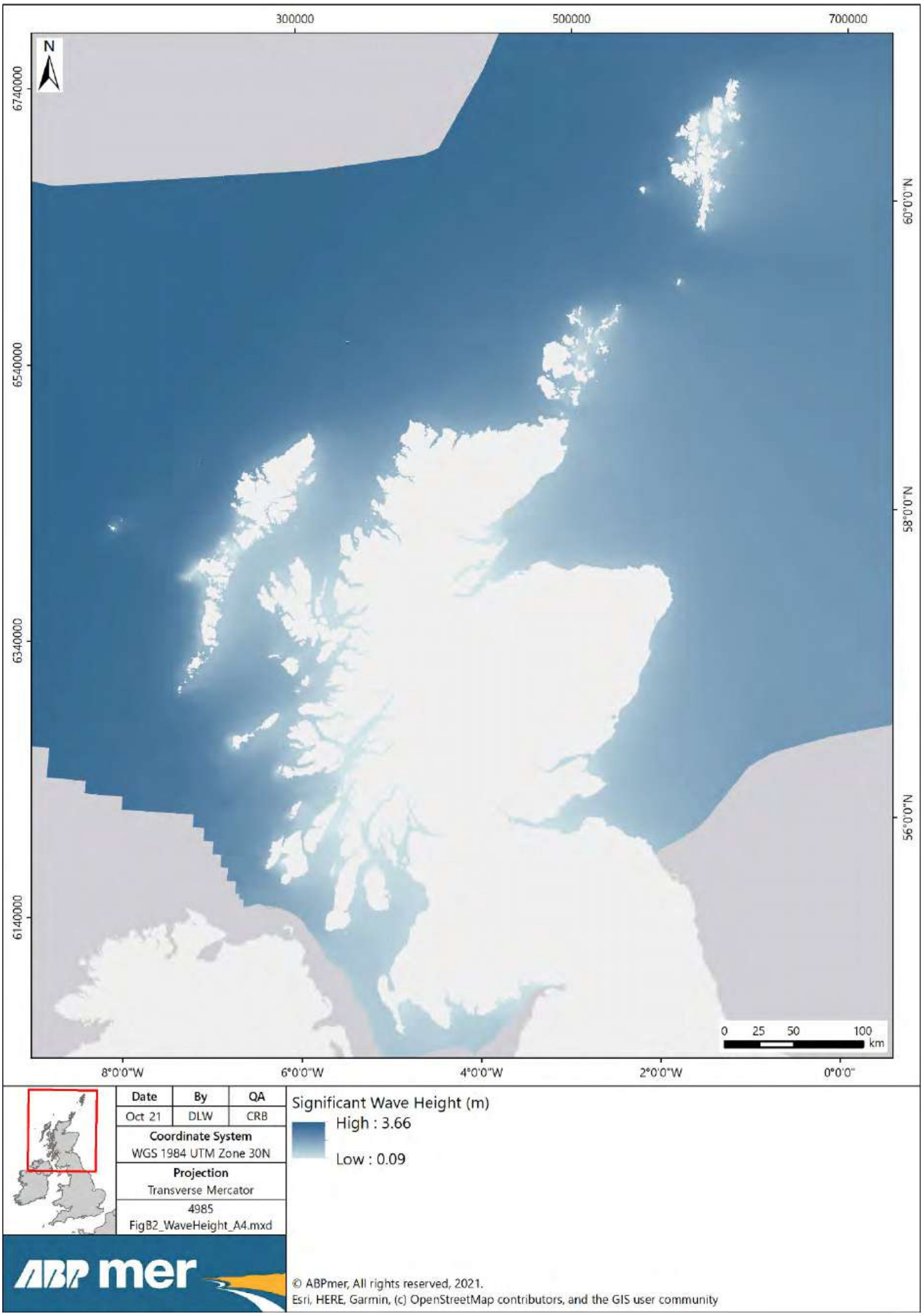


Figure B2. Significant wave height

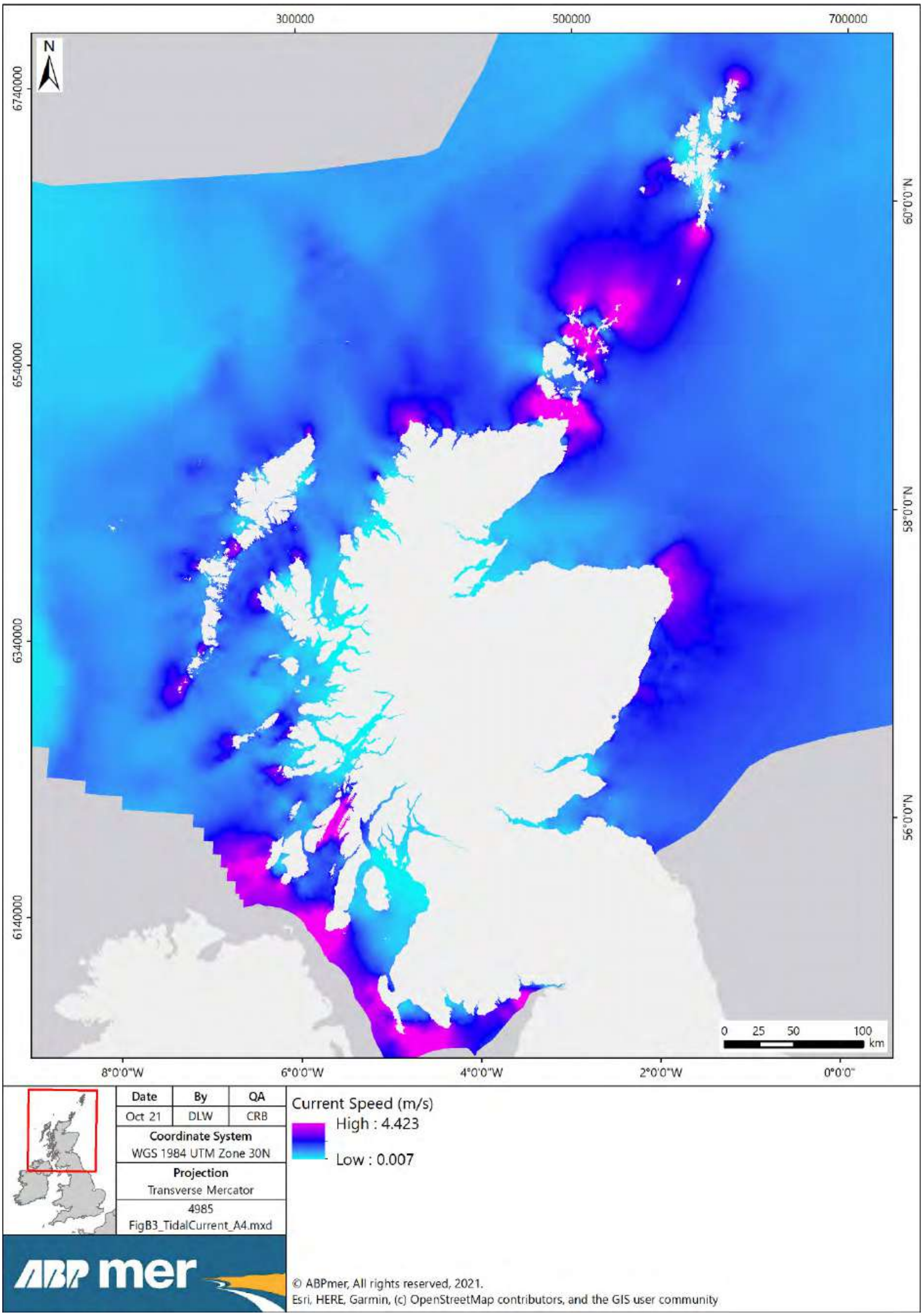


Figure B3. **Tidal current**

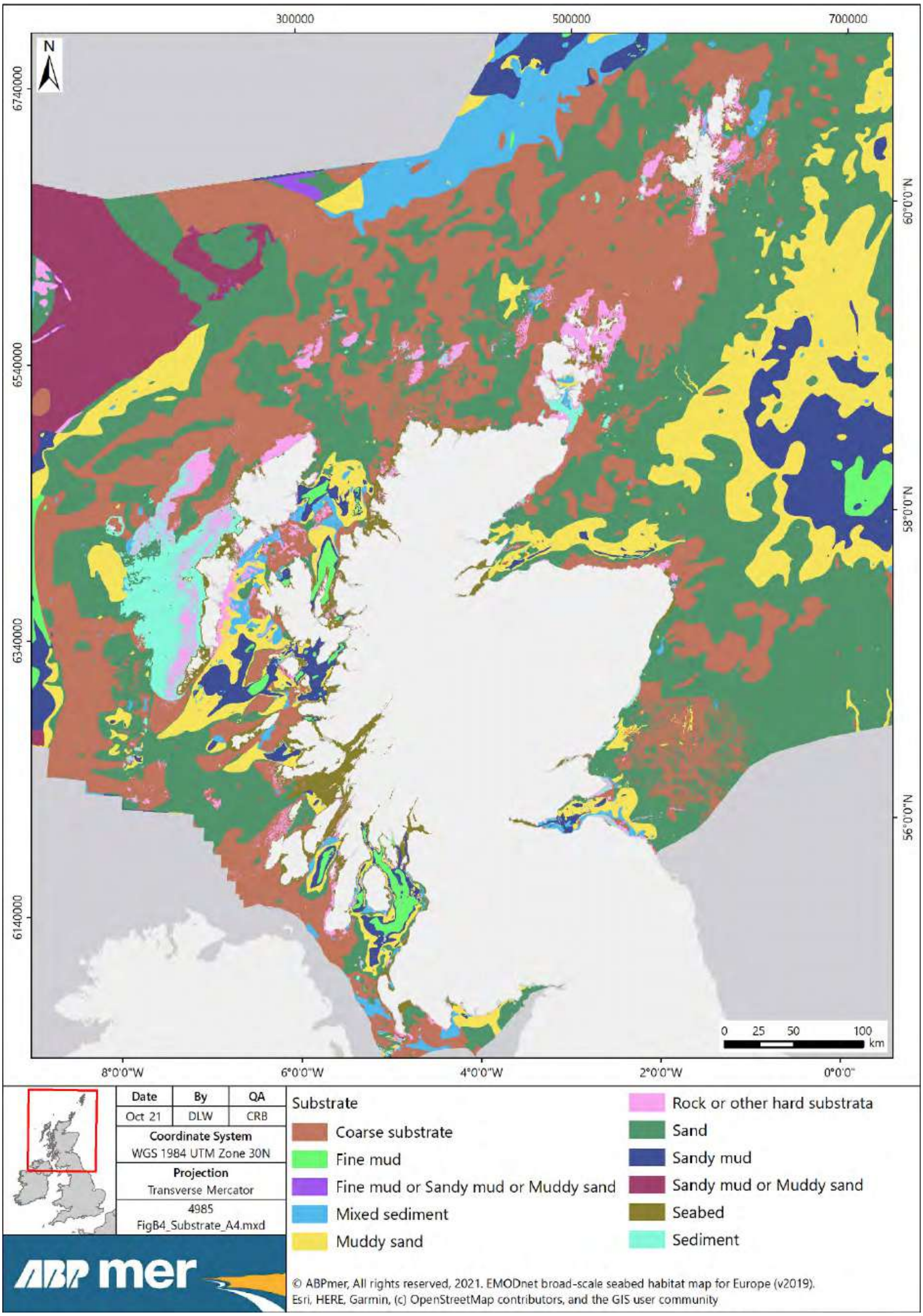


Figure B4. Seabed substratum

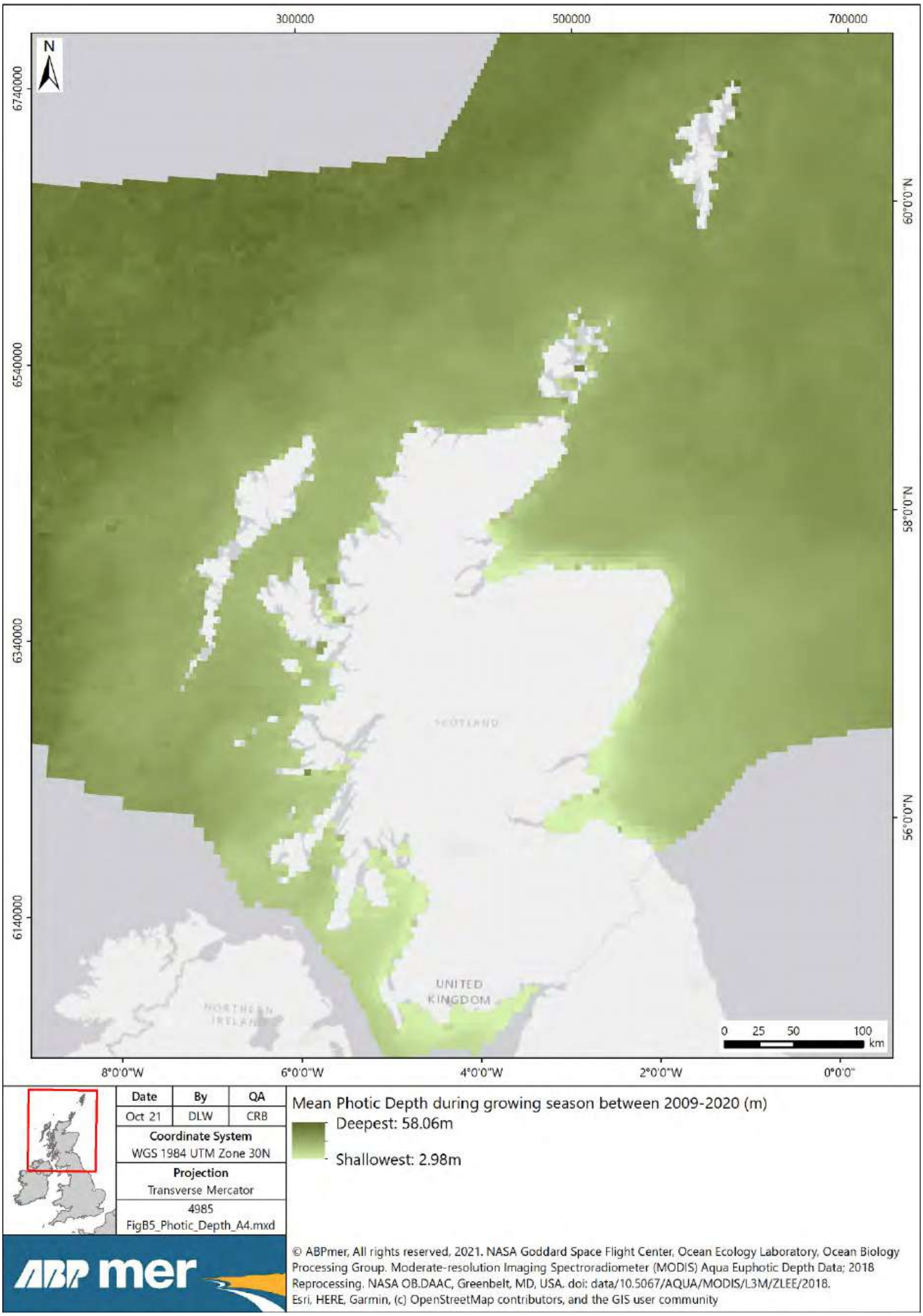


Figure B5. Photic depth

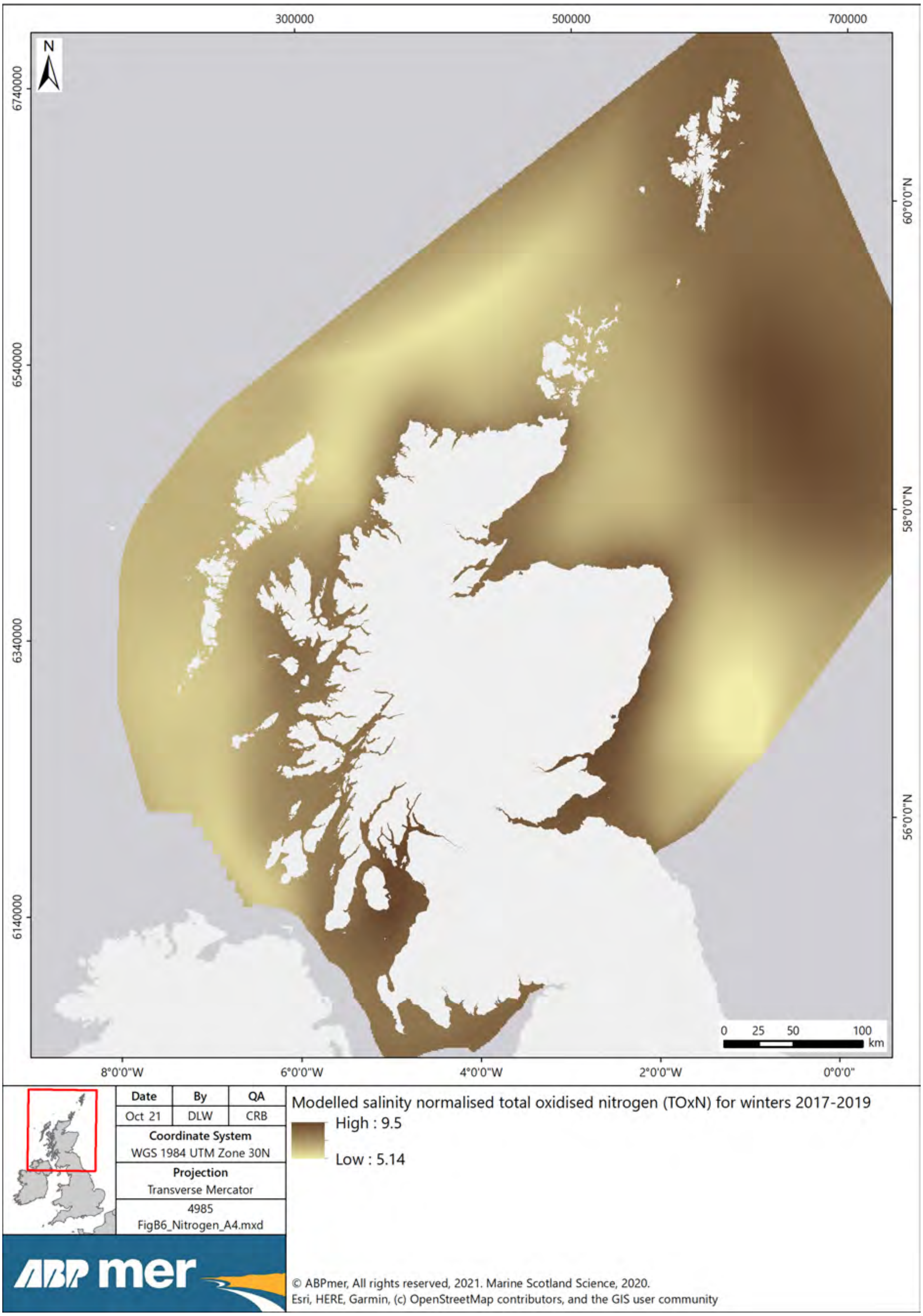


Figure B6. **Total oxidised nitrogen concentration**

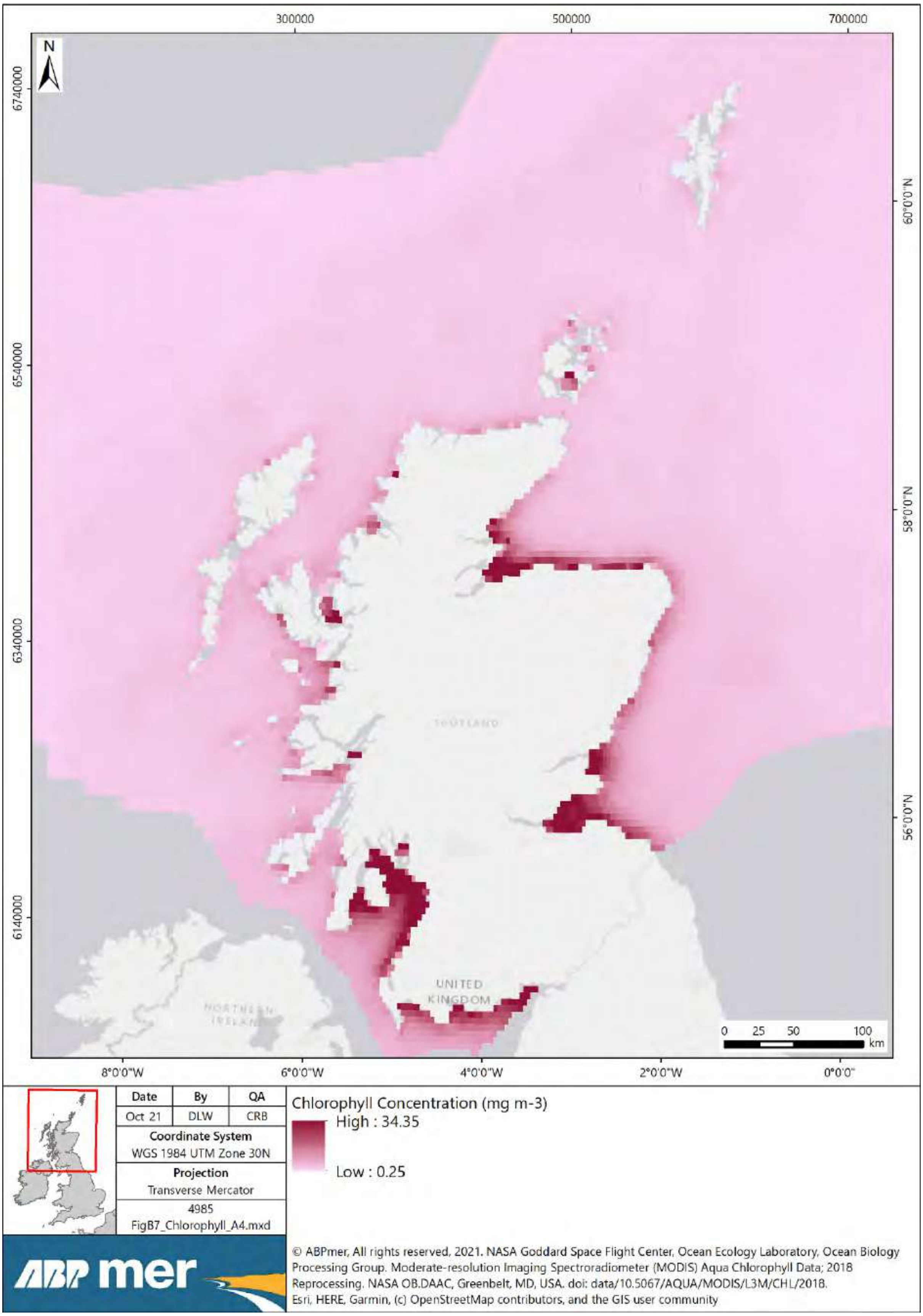


Figure B7. Chlorophyll-a concentration

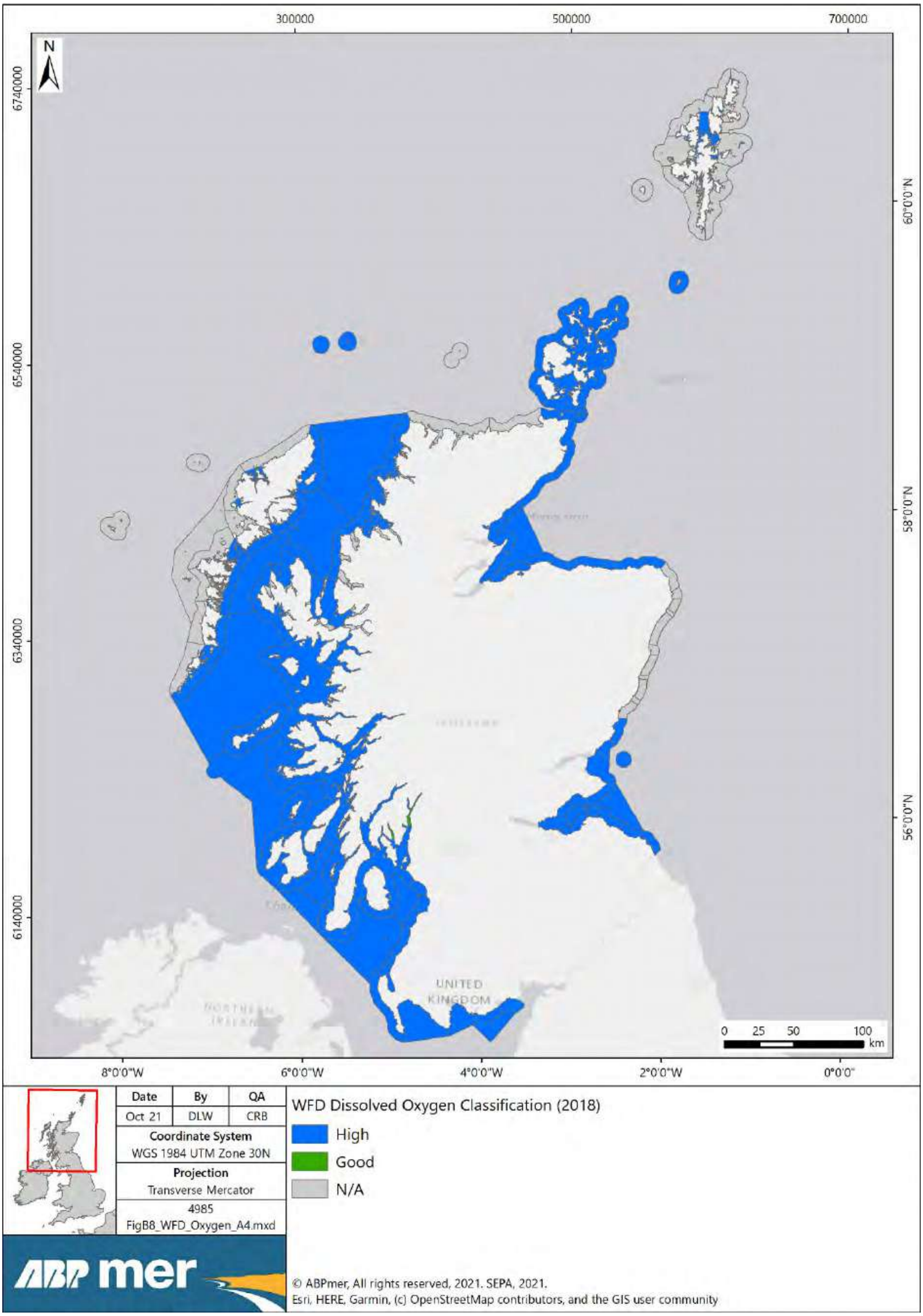


Figure B8. **Water Framework Directive dissolved oxygen classification**

B.2 Identification of potential resource areas

Table B4 and Table B5 show the thresholds (minimum and maximum) that were applied to each physical and environmental parameter within the spatial model to identify potentially suitable areas for cultivating seaweed and mussels respectively. An optimum range for some parameters is also shown where this information could be used to further refine the areas identified, for example, to highlight sub-areas which are considered likely to be the initial focus for any interested parties in relation to engineering costs, etc.

Table B4. Natural resource and operational limits applied in the spatial model for seaweed cultivation

Parameter	Min	Max	Optimal Range	Rationale
Bathymetry (m)	20	100	20-50	Stakeholder input indicated that whilst it may be technically feasible to install a farm in water depth of > 50 m, it would be substantially more difficult than within the range 20–50 m, and prohibitively expensive (particularly from a maintenance perspective as the depth would be over the limit at which commercial divers could operate). As such the optimal depth for any developments in the short-term future at least, was considered to 20-50 m depth, which was also in line with several previous studies assessing potential suitable locations in Scotland (Maritek, 2019) and England (MMO, 2019).
Significant wave height* (Hs; m)	0	2	0-2	It was assumed that the ability to safely conduct operations at a site (deployment of equipment, maintenance or harvesting) would be the determining factor of the maximum significant wave height in the model. Based on information obtained through consultation, an indicative value of 2 m has been set as the maximum Hs for identifying technically feasible areas.
Tidal current ($m.s^{-1}$)	0.1	0.8	< 0.8	It was assumed that the ability to safely conduct operations at a site (deployment of equipment, maintenance or harvesting) would be the determining factor of the maximum tidal current in the model. Based on information obtained through consultation, an indicative value of 0.8 m/s has been set as the maximum current for identifying technically feasible areas, with the assumptions that lower current speeds for the majority of the time would be preferable. Seaweed cultivation requires current to supply nutrients to the seaweed and the minimum current speed used was based on the tidal current requirement of the three kelp species from MMO (2019), from which the lowest 'optimum' current of the three kelp species was selected.

Parameter	Min	Max	Optimal Range	Rationale
Photic depth** (m)	5	n/a	n/a	For the purpose of the model, and based on information from the consultation, it was assumed that the headlines would be 2 m below the sea surface and that the seaweed species may grow to approximately 3 m in length prior to harvest. As such a photic depth of 5 m was considered to be the minimum required to ensure adequate growth conditions. It was assumed that 'shading' of sea areas caused by shadows from terrestrial features, e.g. mountains, would not be an issue for 'offshore' areas identified in the model. However, this is a potential issue that would require further consideration at a site-specific level.
Total oxidised nitrogen (TOxN; μM)	4	n/a	> 10	The minimum and optimum range were based on information in MMO (2019).
Seabed substratum	n/a	n/a	Sedimentary	It was assumed that avoiding areas of rocky substratum[11] would facilitate avoiding rocky reef species and habitats likely to be of concern to the statutory nature conservation body if located under an aquaculture development (e.g. in relation to anchors, sedimentation etc). Furthermore, whilst consultation indicated that it is possible to place screw anchors into rock, this is more difficult and costly compared to placing screw anchors into sedimentary substratum.
Temperature	n/a	n/a	n/a	Given the range of temperatures that the seaweed species of interest (*Alaria esculenta, Laminaria digitata* and *Saccharina latissima*) can tolerate, as long as any suitable area identified was not located within a loch system which may develop a thermocline in the summer, it was assumed that temperature was not likely to be a key influencing parameter.

* Significant wave height (Hs) = the mean wave height of the highest third of the waves; ** The Euphotic zone depth is defined as the depth where photosynthetic available radiation (PAR) is 1% of its surface value. For the purposes of this study this has been termed the 'photic depth'. Greyed row indicates that the data set was not used in the spatial model to identify suitable growing areas.

[11] Rocky substratum was considered to be any habitat within the data set that started with the EUNIS code A3 (Infralittoral rock and other hard substrata), A4 (Circalittoral rock and other hard substrata) or A6 (Deep-sea rock).

Table B5. Natural resource and operational limits applied in the spatial model for mussel cultivation

Parameter	Min	Max	Optimal	Rationale
Bathymetry (m)	20	100	20–50	Stakeholder input indicated that whilst it may be technically feasible to install a farm in water depth of >50 m, it would be substantially more difficult than within the range 20–50 m, and prohibitively expensive (particularly from a maintenance perspective as the depth would be over the limit at which commercial divers could operate). As such the optimal depth for any developments in the short-term future at least, was considered to 20–50 m depth, which was also in line with several previous studies assessing potential suitable locations in Scotland (Maritek, 2019) and England (MMO, 2019).
Significant wave height (Hs)	0	2	0–2	It was assumed that the ability to safely conduct operations at a site (deployment of equipment, maintenance or harvesting) would be the determining factor of the maximum significant wave height in the model. Based on information obtained through consultation, an indicative value of 2 m has been set as the maximum Hs for identifying technically feasible areas.
Tidal current ($m.s^{-1}$)	0.2	0.8	< 0.8	It was assumed that the ability to safely conduct operations at a site (deployment of equipment, maintenance or harvesting) would be the determining factor of the maximum tidal current in the model. Based on information obtained through consultation, an indicative value of 0.8 m/s has been set as the maximum current for identifying technically feasible areas, with the assumptions that lower current speeds for the majority of the time would be preferable. The defined value for minimum current speed was based on the peak neap tidal current speed extracted from the location of an existing 'offshore' mussel farm in Lyme Bay, England. The flow speeds at the site were extracted from the in-house modelled ABPmer SEASTATES (www.seastates.net) hindcast database for hydrodynamics, covering the 41-year period from 1979 to 2020, inclusive.
Chlorophyll-a concentration (µg / l mean annual concentration)	$\geq$ 1	n/a	n/a	Based on information within MMO (2019) and stakeholder input.

Parameter	Min	Max	Optimal	Rationale
Dissolved oxygen	n/a	n/a	n/a	It was assumed that dissolved oxygen levels would not be an issue in surface layers in 'offshore' locations. This assumption was considered to be reasonable if the WFD dissolved oxygen status of any adjacent inshore waterbody was classified as Good or High.
Seabed substratum	n/a	n/a	Sedimentary	It was assumed that avoiding areas of rocky substratum[12] would facilitate avoiding rocky reef species and habitats likely to be of concern to the statutory nature conservation body if located under an aquaculture development (e.g. in relation to anchors, sedimentation etc).
Temperature	n/a	n/a	n/a	Given the range of temperatures that *Mytilus edulis* can tolerate, as long as any suitable area identified was not located within a loch system which may develop a thermocline in the summer, it was assumed that temperature was not likely to be a key influencing parameter.
Greyed row indicates that the data set was not used in the spatial model to identify suitable growing areas.				

12 *Ibid*

B.3 MSP constraints to development within the identified growing areas

Exclusion areas were applied where the project team judged that there was an incompatibility between seaweed or mussel farming and existing marine sector infrastructure or activity. These exclusion areas were removed from the identified potential resource areas. The remaining areas are referred to as 'potentially feasible development areas'.

It is important to note that **any marine areas where activities, infrastructure or heritage features have not been excluded from the growing areas, does NOT imply that there are no potential constraints.** For example, areas used by commercial fisheries or recreational boaters have not been removed from the growing areas, however, **interactions with, and impacts on, these socio-economically important activities (and all potential receptors, including coastal communities) will need to be carefully considered through a strategic marine planning process at the national or regional level and through the consenting process at project level**. At project level, depending on the size of the proposed mussel or seaweed farm development, pre-application consultation may be a statutory requirement. However, even if it is not a statutory requirement, pre-application consultation with stakeholders from these sectors and the wider communities will be vital to ensure that any conflicts are minimised as far as possible when considering any development.

In order to start this dialogue, the potential impacts of seaweed or mussel farm developments on mobile and static gear commercial fisheries in the identified growing areas was investigated further through stakeholder consultation with commercial fisheries representatives. The outputs and key messages from this consultation are described in detail in Appendix C.

Table B6 describes how all of the MSP data layers presented in Table B3 were applied within the spatial model during identification of potential growing areas for mussel and seaweed farming developments. The outputs of applying the above marine spatial planning constraints to the identified growing areas are shown in Figure 2 to Figure 19 in the main report.

Table B6. Assumptions applied to other marine sector-related constraints in the spatial model for mussel and seaweed cultivation

Data Layer	Excluded from Growing Areas	Assumption / Rationale
Military coastal firing ranges	Yes	Assumption: army coastal firing ranges (areas including a land and sea component) are associated with land-based infrastructure that may not be relocated. RAF and navy firing areas at sea were not excluded from the resource areas (as not associated with infrastructure) but would need to be considered at a site-specific level.
Oil and Gas (O&G) platforms and pipelines	Yes. Buffer zones also applied.	Rationale: There is a statutory 500 m safety zone for O&G surface infrastructure and a discretionary 500 m safety zone for subsurface infrastructure.[13]
Existing aquaculture lease/lease option areas	Yes	Assumption: The presence of existing finfish, shellfish or seaweed farms would exclude new aquaculture developments. For the purpose of this study lease option areas were assumed to represent an area that would be developed and hence were also excluded from the identified resource areas.
Existing renewable lease/lease option areas	Yes	Assumption: The presence of existing marine renewable developments would exclude new aquaculture developments. For the purpose of this study lease option areas were assumed to represent an area that would be developed and hence were also excluded from the identified resource areas.
Open waste disposal sites	Yes	Assumption: Vessel access to open waste disposal sites would be required, which would exclude new aquaculture developments in those areas.
Formal Anchorage areas	Yes	Assumption: Relatively large deep water anchorage areas would exclude new aquaculture developments. Hence these were excluded from the identified resource areas. Note: anchorage 'points' located inshore were not excluded from the growing areas due to the high numbers and small footprint of these areas. However, anchorage points would require further consideration at the site-specific level (i.e. during initial site selection).
Shipping: IMO TSS; high intensity shipping routes (> 600 transits p.a.) and lifeline ferry routes	Yes	Commercial shipping is an important socio-economic sector. For the purposes of this study, 'major' shipping routes were identified as routes with over 600 vessel transits per annum (for tankers, cargo and passenger vessels) and these routes were excluded from the identified growing areas. Where lifeline ferry routes were identified (regardless of the number of transits per annum), a 2.5 km buffer was applied to the route to allow for differences in the route relating to tidal state and adverse weather.

13 Marine Scotland: https://marine.gov.scot/information/oil-gas-field-infrastructure

Data Layer	Excluded from Growing Areas	Assumption / Rationale
		No buffers were applied to the major shipping routes identified however, it is noted that guidance produced by the Maritime and Coastguard Agency (Marine Guidance Note 543) states that for offshore windfarm developments a 3.5 NM minimum separation distance between turbines and a shipping route is broadly acceptable. Hence it is likely that such a requirement may also be applied to other marine sector developments. It is acknowledged that there is likely to be key commercial shipping routes with less than 600 transits per annum (e.g. vital services into smaller ports or harbours). As such, commercial shipping will require further consideration at site-specific level (i.e. during initial site selection).
Commercial fisheries – mobile and static gear fishing grounds	No	Given the socio-economic importance of the commercial fisheries sector, it was not considered appropriate to exclude some fishing grounds (for example based on intensity or value of activity), and not others which may be considered of equal importance to the vessels and communities which fish there. This approach was validated by the outcome of the fisheries consultation in which the importance of all fishing grounds within the identified growing areas was stressed; see Section 4 of the main report). Instead the analysis presents an indicative map of fisheries value in Scottish waters overlaid with the identified growing area boundaries. The outcome of the consultation with fisheries stakeholders regarding the fisheries in these areas, and the compatibility of aquaculture developments with these fisheries is presented in Section 4 of the main report.
Marine recreational boating activity	No	Recreational boating is an important socio-economic sector in Scotland. The analysis presents an indicative map of fisheries value in Scottish waters overlaid with the identified growing area boundaries. The intensity of recreational boating activity would need further consideration at the site-specific level (i.e. during initial site selection).
Priority Marine features (PMFs) and Marine Nature Conservation designations	Selected PMFs – Yes NC designations - No	The potential for significant impact of any marine development on nature conservation designated sites and associated features is assessed by the Competent Authorities involved during the consenting process. As such, for the purposes of this study it has not been assumed that the presence of a designated site would necessarily exclude a seaweed or mussel farm, but that the ability to locate such a development in an MPA would be assessed through the consent process. Hence designated sites have not been removed from the identified growing areas. However, there were 11 PMFs which were assumed to be sensitive to pressures arising from mussel or seaweed aquaculture developments (e.g. from sedimentation/smothering, shading etc.) and hence consent to farm in the immediate vicinity of these features was judged to be unlikely. These PMFs are:

Data Layer	Excluded from Growing Areas	Assumption / Rationale
		blue mussel beds; fan mussel aggregations; flame shell beds; horse mussel beds; maerl beds; maerl or coarse shell gravel with burrowing sea cucumbers; native oysters; northern seafans and sponge communities, seabrass beds, serpulid aggregations and cold water coral reefs. Although the pressures arising from mussel farming and seaweed farming will be different, as a precaution, the locations of all 11 PMFs (polygons or point data, with a 50 m buffer for point data) were excluded from the identified growing areas for both mussel and seaweed farming. It is acknowledged that other PMFs (for example, burrowed mud with seapens) will be of concern to the statutory nature conservation body in Scotland and that this parameter will require further consideration at the site-specific level (i.e. during initial site selection).
Subsea cables and pipelines	No	The presence of in-service subsea cables was judged by the project team to be likely to exclude the development of mussel or seaweed farm based on the requirement for subsea cable owners or operators to be able to access the subsea cable for maintenance or repair. However, the footprint of subsea cables is relatively small compared to the size of the areas being explored. Hence for the purposes of this study, subsea cables were not excluded from the potential growing areas identified. However, this the location of subsea cables would need to be taken into consideration at the site-specific level (i.e. during initial site selection).
Historic protected wrecks	No	The presence of Historic Marine Protected Areas and protected wrecks (sites and vessels designated under the Protection of Military Remains Act 1986 ("war graves") was judged by the project team to exclude the development of mussel or seaweed farm. However, the footprint of these designated areas is relatively small compared to the size of the growing areas being explored and it was assumed that such areas could be avoided at the site-specific planning level. Hence for the purposes of this study, subsea cables were not excluded from the potential growing areas identified. However the location of such sites would need to be taken into consideration at the site-specific level (i.e. during initial site selection).

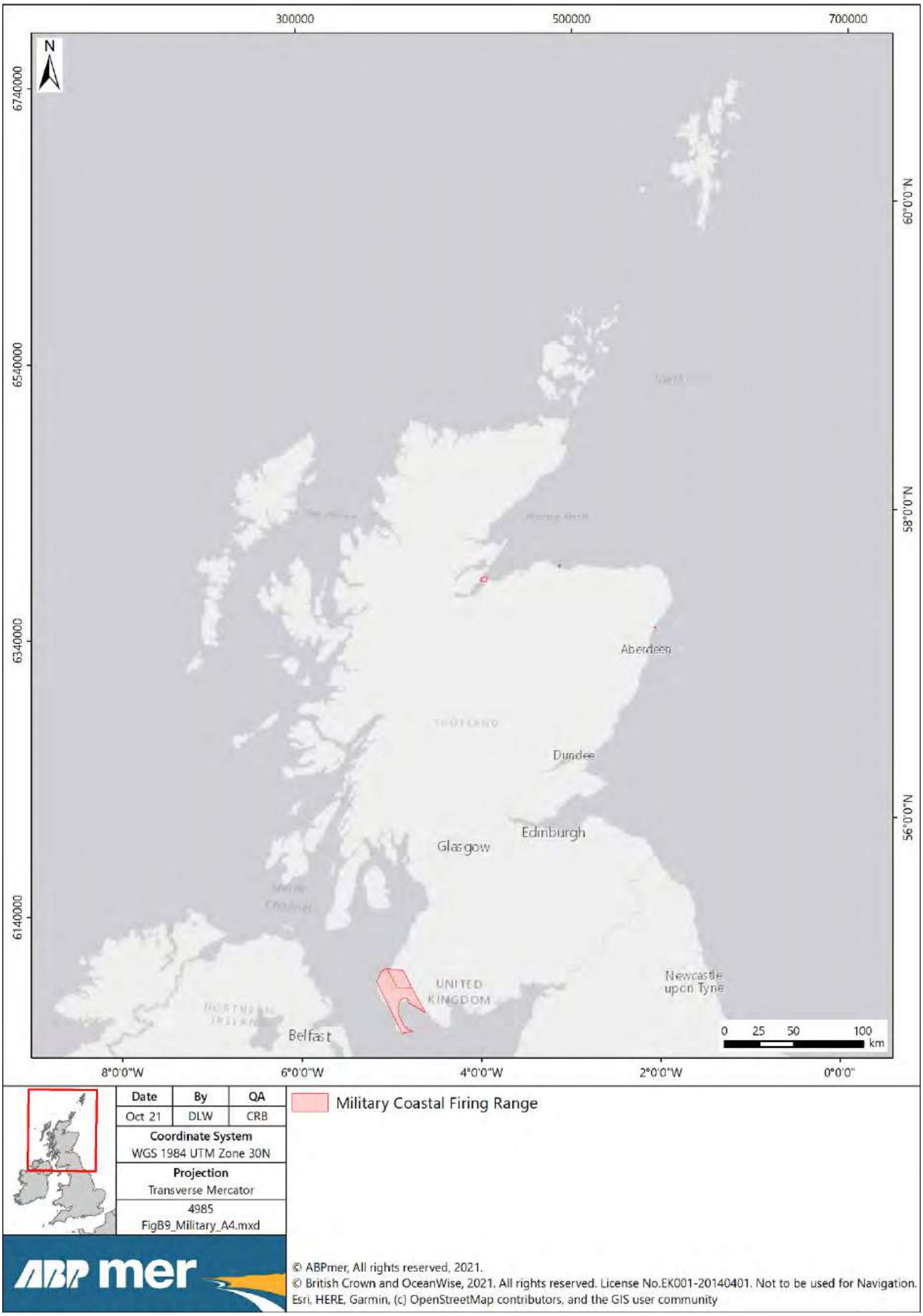


Figure B9. **Military coastal firing ranges**

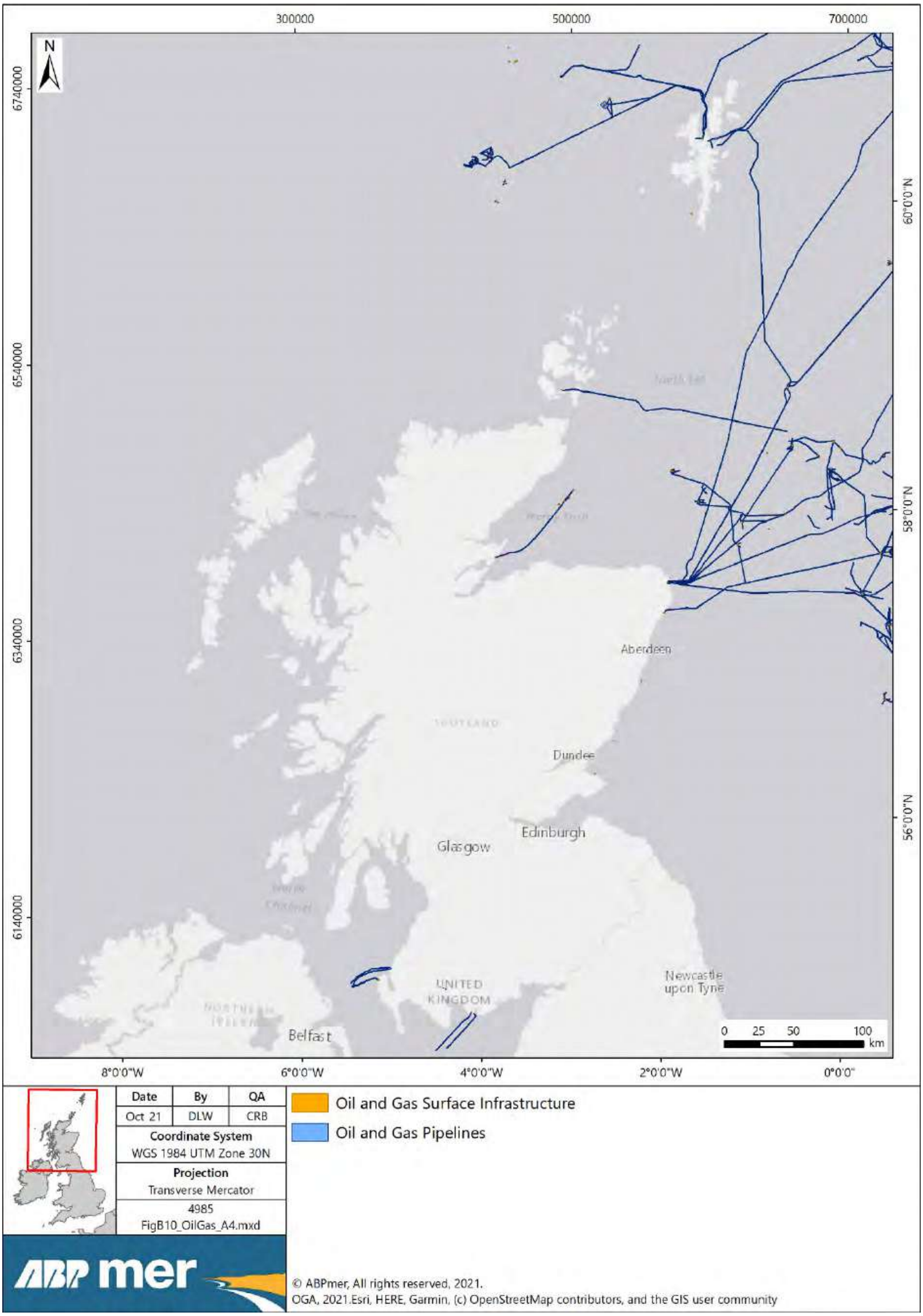


Figure B10. Oil and gas surface infrastructure and piplines

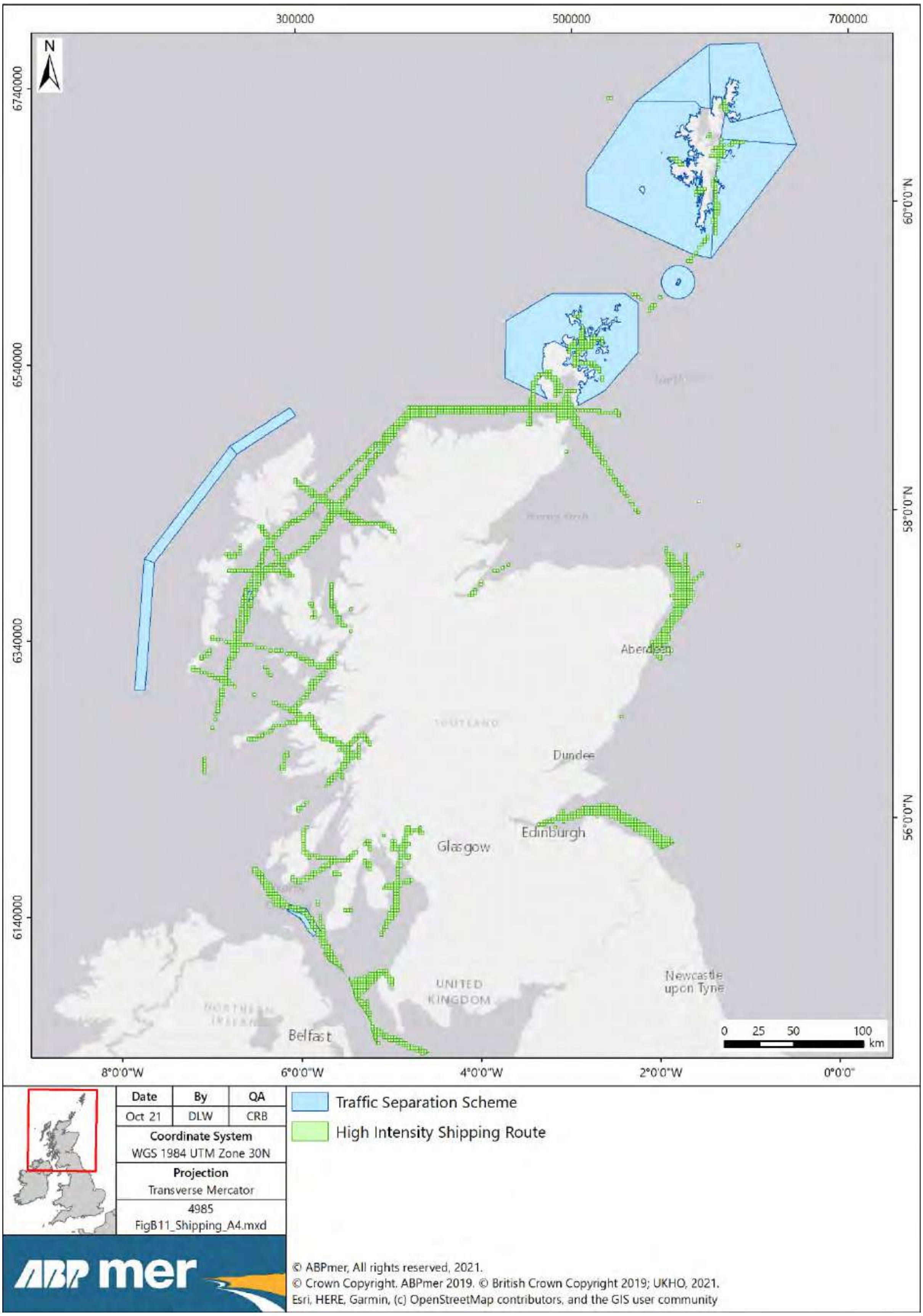


Figure B11. **Traffic Separation Schemes and high intensity (>600 transits per annum) shipping routes**

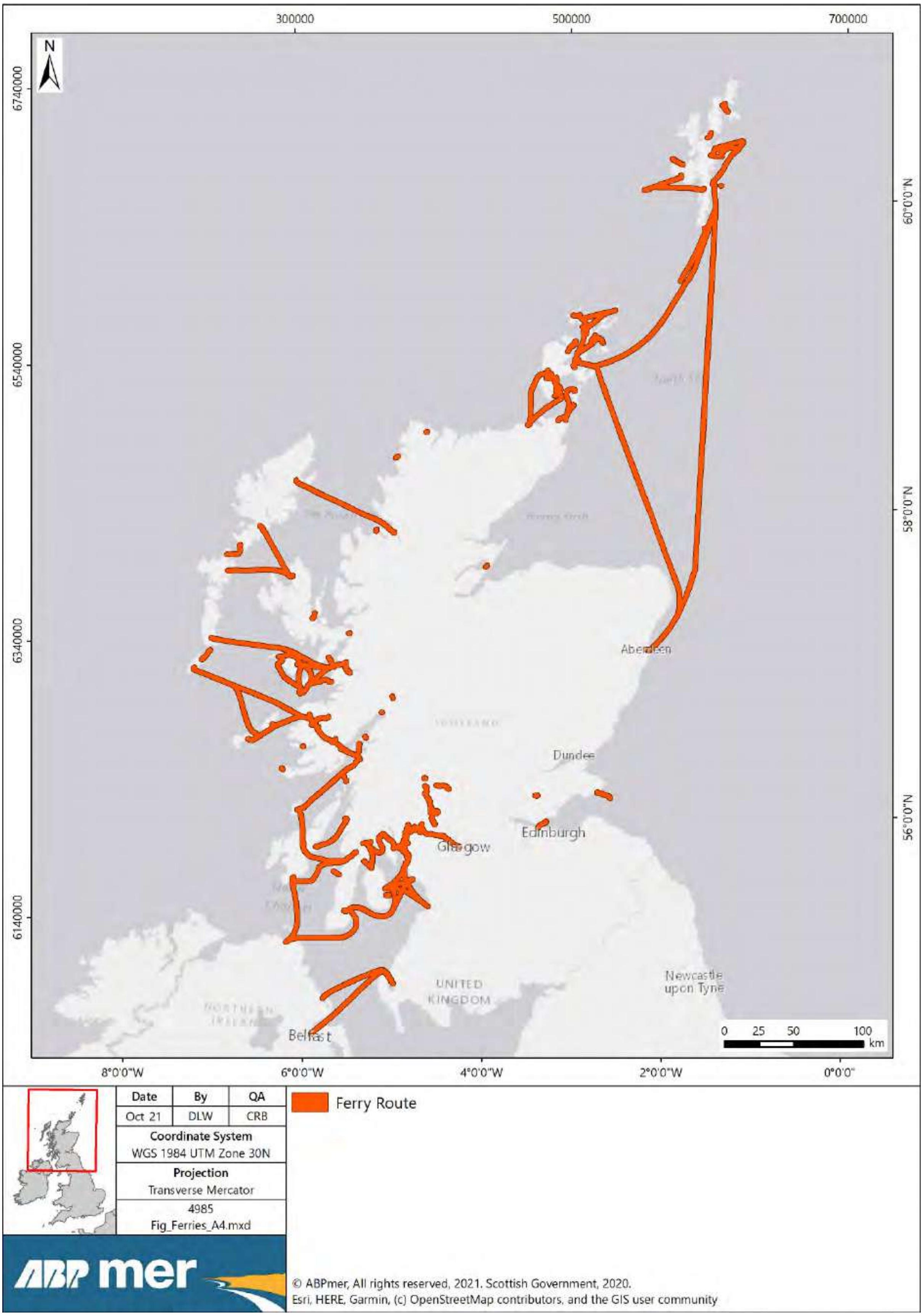


Figure B12. **Ferry routes**

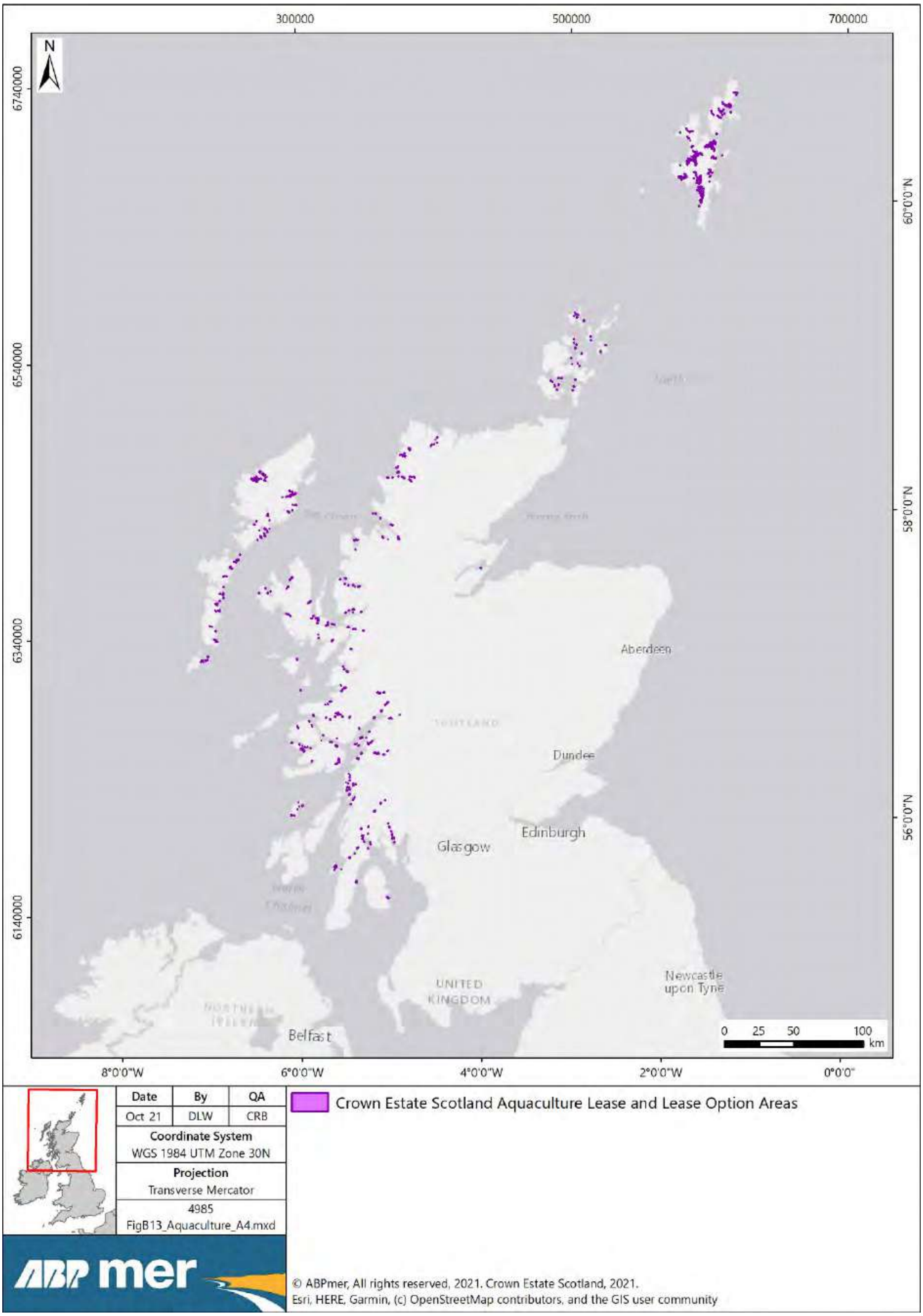


Figure B13. **Aquaculture lease and lease option areas**

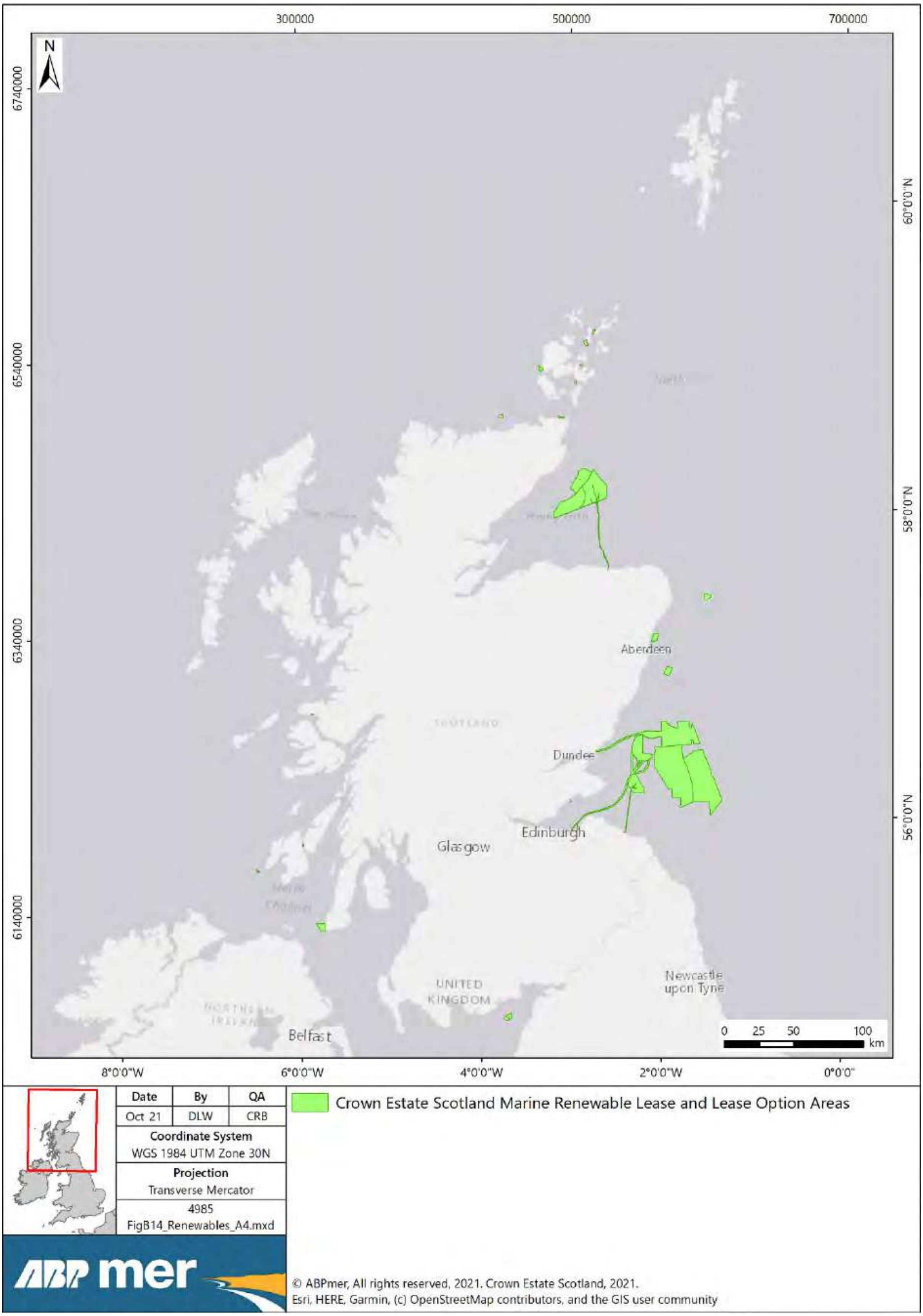


Figure B14. Marine renewables lease and lease option areas

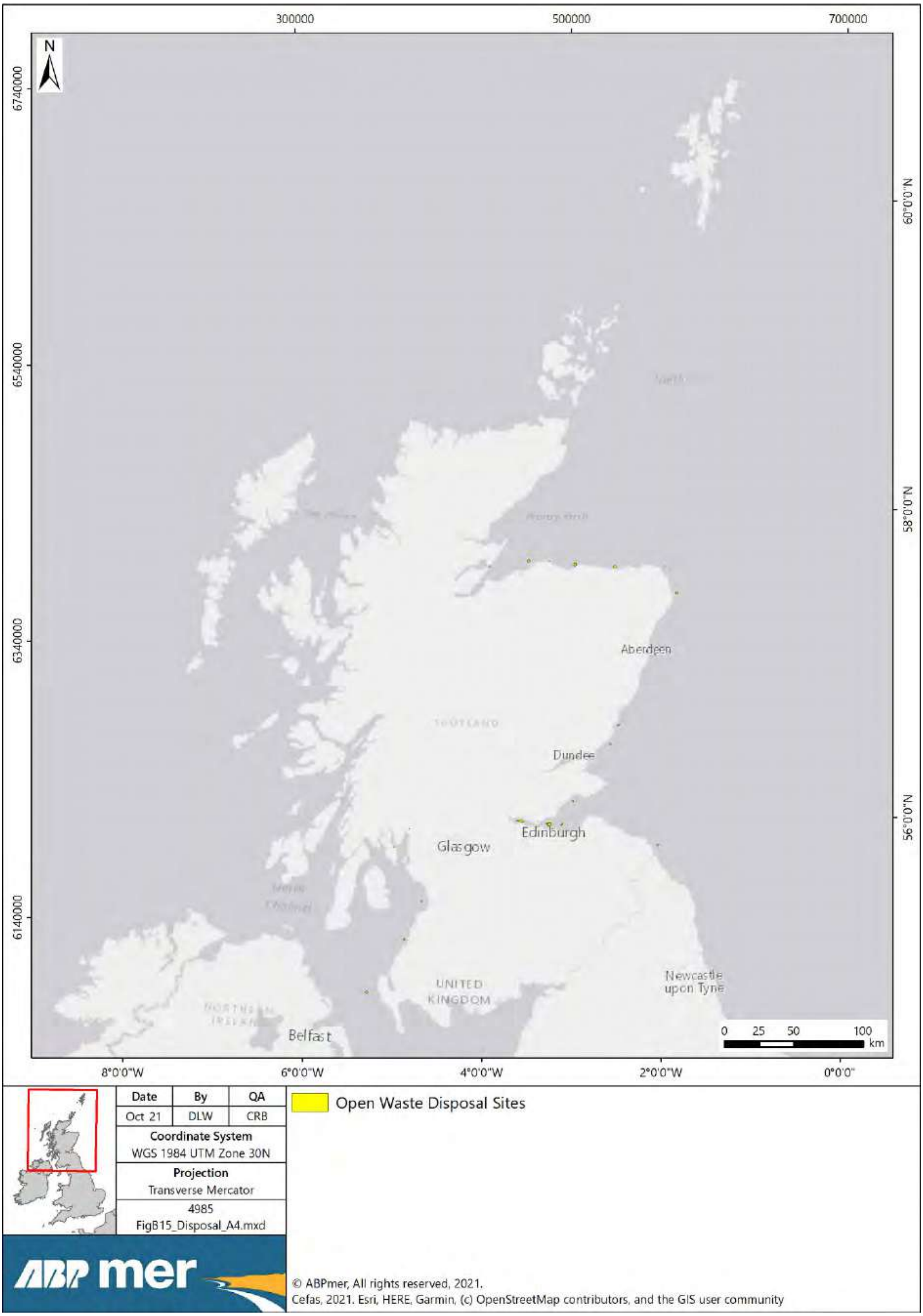


Figure B15. Open waste disposal sites

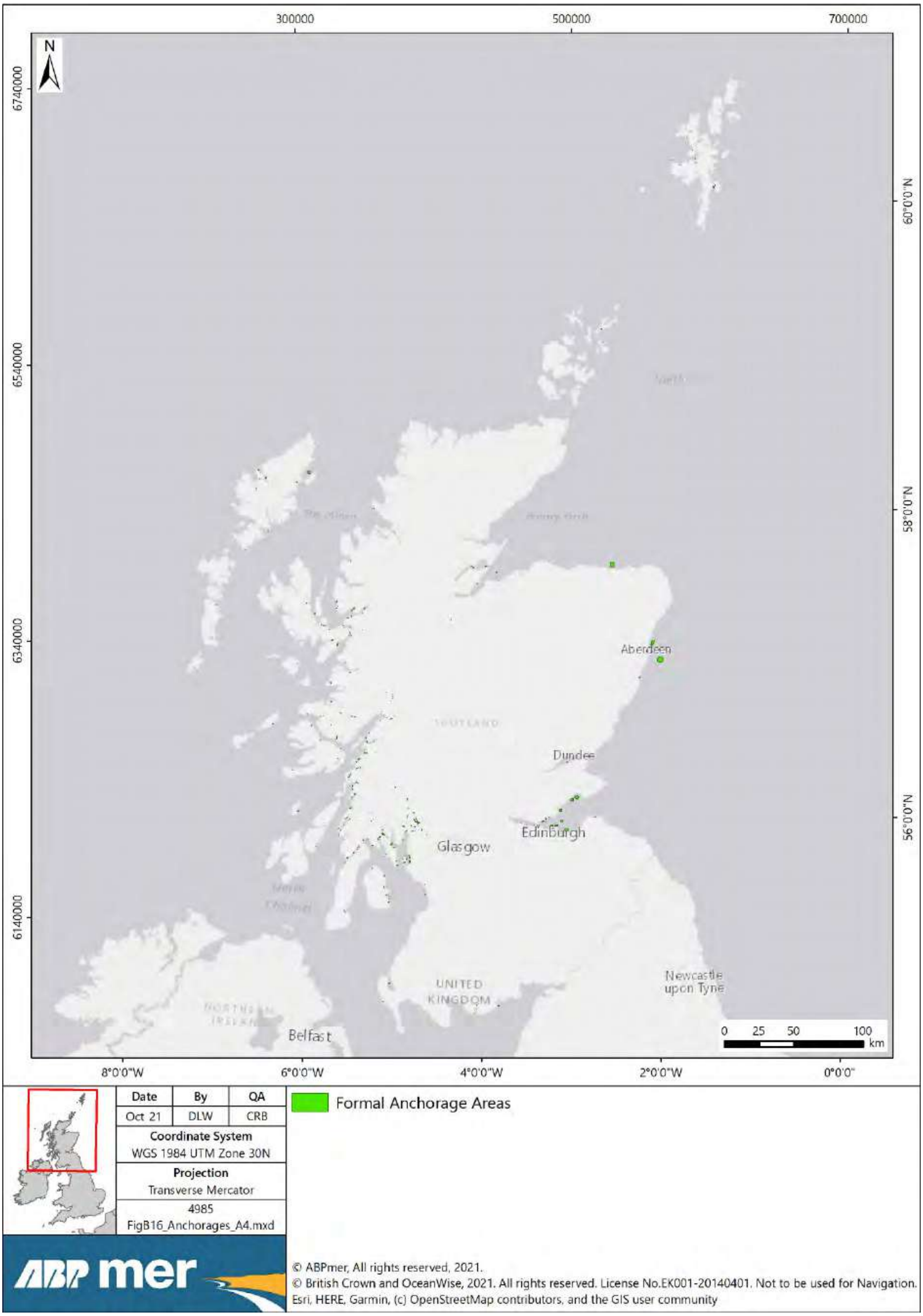


Figure B16. Formal anchorage areas

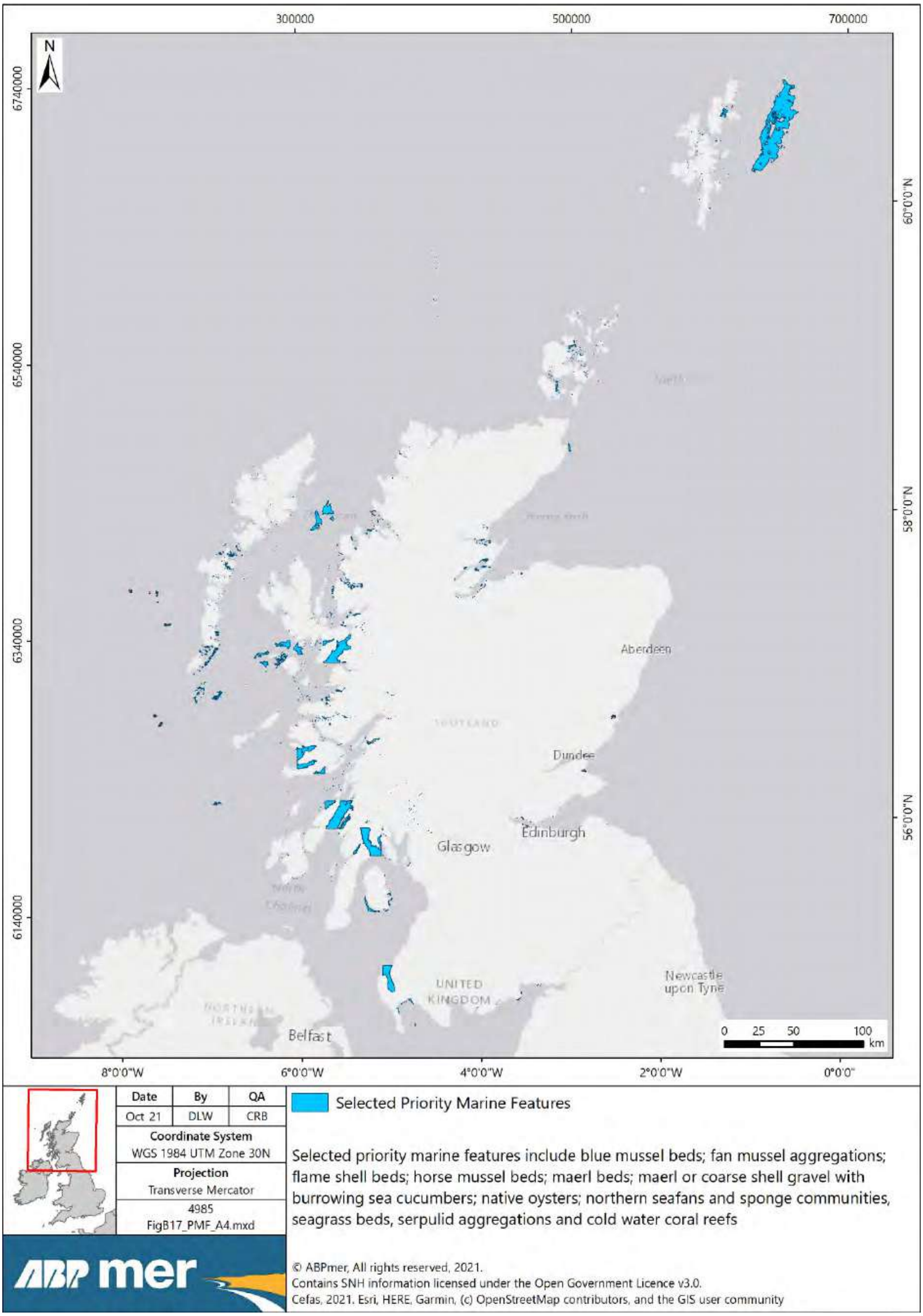


Figure B17. Selected priority marine features

C Commercial Fisheries Consultation

A specific focus of this study was to assess the scope and potential for mitigating any potentially deleterious interactions with local fishing interests and promoting any potentially beneficial interactions and relationships.

As such, further to identifying potential resource areas for cultivating mussels and kelp, key fisheries stakeholders were invited to review the potentially feasible development areas to discuss the fishing activity in these areas and their opinions on the potential for some fishing activities to be able to continue within mussel or kelp farm installations (i.e. co-exist).

In total eight stakeholders were contacted and six interviews were conducted via MS Teams. The stakeholders comprised commercial fishing representatives and other stakeholders with knowledge of the inshore fisheries in the general areas of interest (south-west Scotland and the east coast of Scotland). Interviewees were sent preliminary maps of the potentially feasible development areas identified and schematics of a generic farm layout with 40 x 200 m headlines and potential access channel arrangements to aid the discussion. During the interviews, the following aspects were discussed:

- The key fisheries that operate in the potential resource areas identified;
- The potential for static gear (creel) fisheries to continue to operate within mussel or kelp farms, specifically:
  - Potential negative impacts of shellfish/seaweed farms on inshore static gear fisheries and any mitigation measures that could minimise or negate these impacts?
  - Potential positive impacts of shellfish/seaweed farms on inshore static gear fisheries and any opportunities for developing synergies or maximising benefits to fishers?
  - What type of farm design or mitigations (if any) would enable continued static gear fishing within such farms e.g. with respect to the layout of the longlines, distance between longlines, location and size of any access channels etc?

The key messages from the consultation are summarised in Section 4 of the main report. This appendix contains further detail regarding the issues and points raised by the six stakeholders consulted (Table C1).

Table C1. Summary of key messages from fisheries stakeholders

Topic	Summary of Responses
Key fisheries in the wider Clyde region and Sound of Jura potential resource areas	*General*: ▪ Suitable [aquaculture] areas identified are all key fishing grounds on which coastal livelihoods depend. If developed it will take fishermen's remaining space ▪ Not one inch of areas selected that aren't used ▪ In the Clyde – static and mobile fishers share many grounds *Creeling*: ▪ 3 Creelers on Arran ▪ Will be creelers in Sound of Jura in more sheltered areas (have been displaced by salmon farms) ▪ Can put down 200 pots and leave for few days with long ropes on seabed (leading to issue with trawlers) ▪ Developments in sheltered areas inshore will interact with the creelers *Other fishing activity* ▪ Scallop dredging, *Nephrops* trawling, *Nephrops* creeling, crab creeling, scallop diving ▪ South east Arran – lot of *Nephrops* trawling and scallop dredging ▪ See Figure C1
Key fisheries off the east coast of Scotland	*Creeling* ▪ Lay out more pots on east coast over larger distance c.f. west coast *Other fishing activities*: ▪ Squid fishery within 1-2 NM, from approx. Montrose [?] and Elgin [Lossiemouth] ▪ Lobster fishery – on any hard ground ▪ Scallop dredging on any soft ground ▪ Prawn trawls on softer grounds between 60-80 m deep ▪ Not much demersal or pelagic trawling for finfish ▪ See Figure C2
Potential negative impacts on inshore static gear fisheries and any mitigation measures that could minimise these?	▪ The Clyde is a busy area ▪ Fishermen have already been displaced e.g. by MPAs ▪ Increased aquaculture farm vessel activity would also be an issue

Topic	Summary of Responses
Potential positive impacts on inshore static gear fisheries and any opportunities for developing synergies or maximising benefits to fishers?	▪ Hard to see any positive impacts/interactions ▪ Creelers not likely to want to place creels within farms as seabed already disturbed [impacted] by scallop dredgers
What type of farm design or mitigations (if any) would enable continued static gear fishing within such farms	*Creeling in farms* ▪ Very difficult in exposed areas ▪ Creels – don't go straight up and down – rope at angle when hauling so creel dragged across seabed before it is lifted to surface (n=3). In poor weather vessel could be dragged 1000 m by pots by time all hauled ▪ Main problem is ropes [long lines of rope on seabed between pots] if activities too close ▪ Entanglement inevitable. Even with 'extensive' design, inevitable that ropes/creels will get tangled (n=3) ▪ Think probably a one or other [activity] scenario *Opinions on co-existence* ▪ Best if have growing lines as tight as possible [i.e. intensive c.f. extensive] ▪ [Activities] need to be separated ▪ If have access channel – everyone will go through there, not just creelers ▪ Need a recognised separation distance between creelers, scallop divers and seaweed farmers ▪ Even if can steam through on surface, seabed [infrastructure] is the concern ▪ Cannot design farm to enable mobile gear to operate in farm. Trawl requires 100-200 m on seabed *Suitability of suitable areas identified* ▪ From a seastate perspective – hard to see how it could be done [in areas highlighted]. Location of salmon farms (west coast) a good indication of where aquaculture developments are feasible ▪ Don't think east coast suitable (due to tide as well as exposure) ▪ Think longline would need to be at least 20 m under surface [to withstand conditions]

<table>
<tr><th>Topic</th><th>Summary of Responses</th></tr>
<tr><td>Other issues or concerns raised</td><td>Data and limitations
▪ Data sets do not capture the < 12 m vessel activity [known limitation]
▪ MPAs have already displaced fleet into different areas
▪ West & east – could probably map different fishery areas by habitat e.g. burrowed mud good proxy Nephrops fishing grounds
▪ There is a fisheries management plan for the east coast
▪ Consider required distance between salmon farms [may need to add to buffer]

Conditions
▪ East coast less protected, shallower, get big swells. If north easterly/easterly gale get huge surge/swell. Weather more of a problem c.f. west coast. Think will be a problem

Other sector activity / interactions
▪ Clyde an extremely busy area with military, shipping and recreational vessel activity
▪ Have we considered aquaculture developments in MPAs?
▪ Not just MPAs that an issue, also PMFs and HPMAs
▪ Damage to offshore mussel farm in UK recently shows problems of offshore developments
▪ Other sectors to consider: tourism (visual impacts), recreational boating, anglers? MPA features, marine mammals, basking sharks, seabirds

Other factors to consider:
▪ Plankton blooms, disease outbreaks
▪ Climate change</td></tr>
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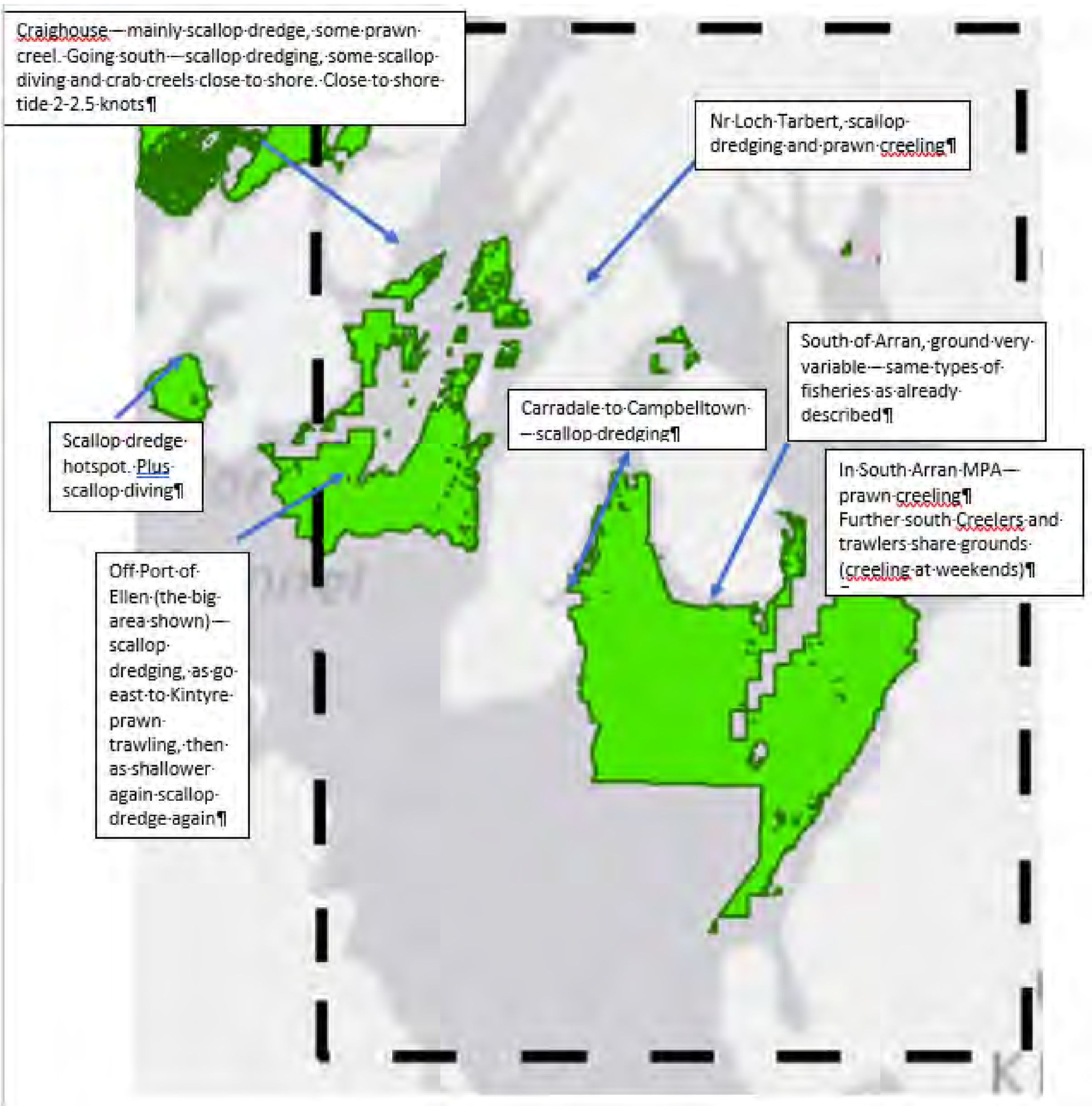

Figure C1. **Information from consultation regarding fisheries in the south west area of interest**

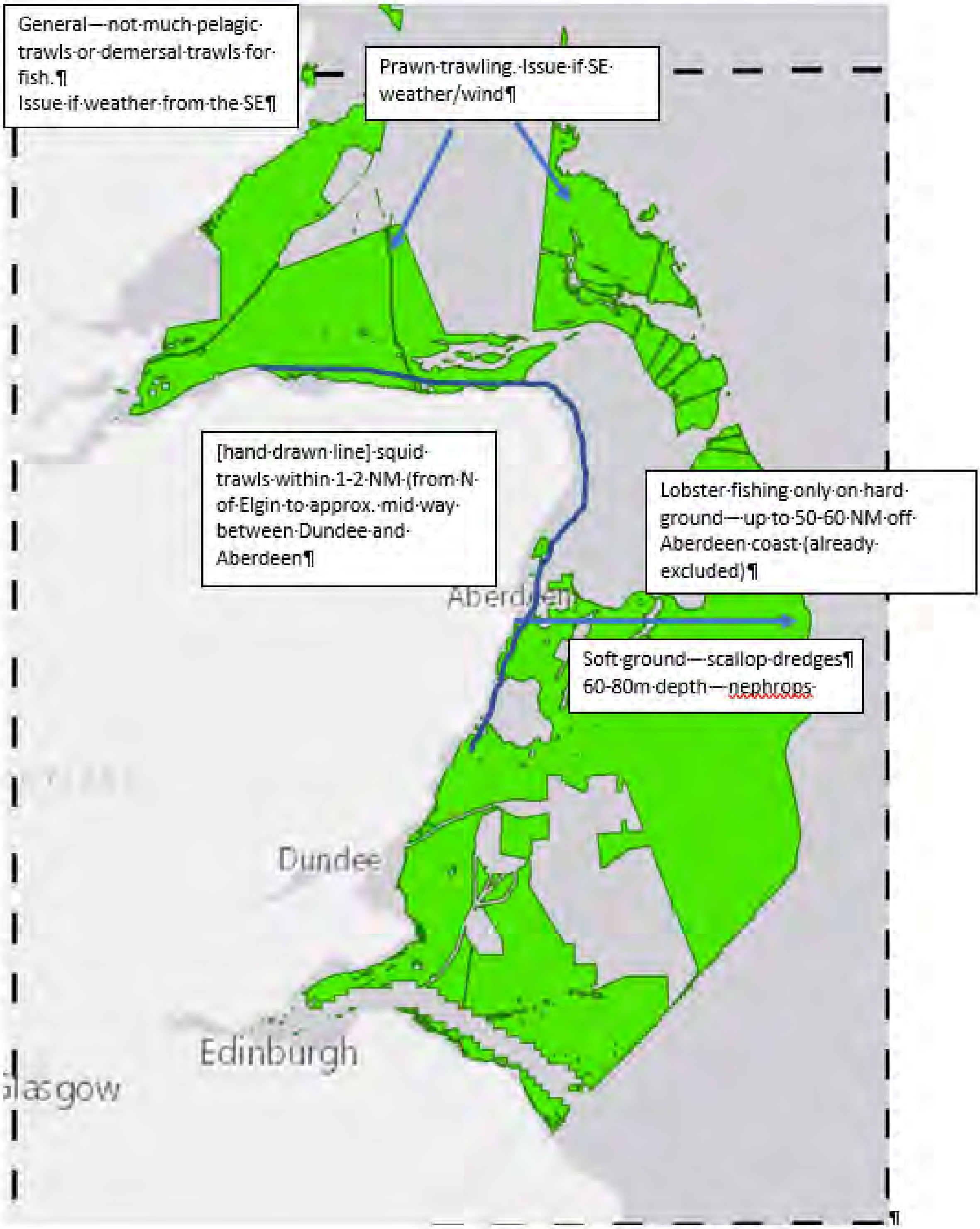

Figure C2. Information from consultation regarding fisheries in off the east coast

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