Developing Essential Fish Habitat maps for fish and shellfish species in Scotland Report

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Developing Essential Fish Habitat maps for fish and shellfish species in Scotland

Report

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Client

The Scottish Government (Marine Scotland Directorate)

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Project Personnel and Roles

Dr Anita Franco (Independent Estuarine & Marine Ecological Consultant): Project Management and Project lead. Project design. Literature review (fish). Data collation, analysis, modelling and interpretation. Habitat proxy assessment. Stakeholder consultation. Reporting.

Dr Shona Thomson (Thomson Geospatial ltd): GIS lead. Data layers collation, analysis and mapping. Reporting.

Dr Katie Smyth (independent consultant): Shellfish lead. Literature review (shellfish). Habitat proxy assessment. Reporting.

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Acronyms

BTS - Beam Trawl Surveys

CPUE – Catch Per Unit Effort

CUR - Kinetic energy of currents at seabed

CV – coefficient of variation

DATRAS –online Database of Trawl Surveys

Dist – Distance from coast (high water level)

EFH – Essential Fish Habitat

EVHOE - Evaluation Halieutique Ouest Europeen

GOV - *Grande Ouverture Verticale* bottom trawl

IBTS - International Bottom Trawl Surveys

ICES - International Council for the Exploration of the Seas

IE-IGFS - Irish Ground Fish Survey

MEGS - Mackerel and Horse Mackerel Egg Survey

MLT - Mixed layer thickness

MMO – Marine Management Organisation

NPPV - Net Primary Production (per unit volume of seawater)

NS-IBTS - North Sea International Bottom Survey

Q1, Q2, Q3, Q4 – Quarter 1 (January-March), Quarter 2 (April-June), Quarter 3 (July-September), Quarter 4 (October-December)

SandbH01 - Presence of Sandbank Habitat

SBT– Sea Bottom Temperature

SCOROC - Scottish Rockall Survey

SCOWCGFS - Scottish West Coast Groundfish Survey

SIAMISS - Scottish-Irish anglerfish and megrim industry-science survey

SLR – Sea Level Rise

SMALK - Spawning Maturity Age-Length Keys

SSS – Sea Surface Salinity

SST – Sea Surface Temperature

StructH01 - Presence of Structured Habitats

Subst – Substratum type (category)

VegH01 - Presence of Vegetated Habitats

WAV - Kinetic energy of waves at seabed

WCDF (survey) – West Coast of Scotland Demersal Fish (survey)

Executive Summary

Essential Fish Habitats (EFH), i.e. “those waters and substrata necessary to fish for spawning, breeding, feeding, or growth to maturity”, are amongst the marine assets for which uncertainty exists regarding their spatial distribution. The Scottish Government commissioned this project with the aim of developing the evidence base on EFH to inform future planning and project level assessments in Scottish waters, with consideration to providing outputs that can also assist with wider UK planning and project assessments. The results of this study will help the regulators to understand where further work is required to inform consenting decisions.

EFH in this project were identified as those habitats that function as refuge for individuals of a species, as nursery for its juvenile stages or as spawning ground for the spawning adults and the spawn products (eggs) (‘functional habitats’), and where these individuals are present in higher abundance (aggregations) compared to other habitats where they also occur. Two separate approaches were applied to the EFH assessment in offshore and inshore waters (distinguished by the 12 nautical miles limit): EFH data-based modelling and a semi-quantitative assessment (habitat proxy), respectively. The lower data availability in inshore waters (due to higher survey fragmentation, lower method standardisation and coverage gaps) prevented the application of EFH modelling in this region.

In offshore waters, Decision Tree models were calibrated based on catch data from broad-scale fish surveys (within the selected study period 2010 – 2020) and the associated environmental conditions (derived from publicly available data layers). These EFH models identified the set of environmental conditions where aggregations of a species/life stage were more likely to occur. Data layers for the environmental predictors of the model (derived as mean environmental conditions over the study period) were then used to extrapolate and map the UK-wide spatial distribution of the species/life stage aggregations, considered as indicative of EFH. A confidence value was calculated for each EFH model as a whole and its spatial prediction by combining model performance (statistical confidence) and confidence estimates for the input data used to calibrate and predict the model. The spatial output provided the integrated results on the prediction of the distribution of EFH and the associated confidence.

In inshore waters, habitat proxies for species/life stages that may have their EFH inshore were identified and mapped based on data layers for pre-defined habitat types (EUNIS habitat classification). A literature review on the species-habitat associations relevant to key EFH functions, and expert assessment by the project team and consulted external experts were used to score the habitat types according to their ability to provide EFH function to a species. As the evidence used for this assessment was most often based on mere species-habitat association, rarely accounting for abundance, the habitat proxies thus identified were used as indicators of the wider ‘functional habitat’ of a species, which is also likely to include EFH. A confidence level (low/medium/high) was allocated to the habitat scoring

based on the expert assessment of the supporting evidence/knowledge. Due to time limitations in the project, habitat proxy maps were produced for the west coast of Scotland for most of species as a demonstration site for the application of the approach and to ensure that the detail of biotopes at the EUNIS habitat Level 4 could be viewed at the appropriate scale. Only for herring spawning grounds, habitat proxy maps were produced covering all Scottish inshore waters. The spatial outputs integrated the information about the habitat scores and the confidence level.

Details on the methods used for both EFH models and habitat proxy assessments (including the confidence assessment) are in the main report.

EFH models were developed for 16 species/life stages in offshore waters, including: lesser sandeel and Norway lobster refugia; juveniles of plaice, lemon sole, common sole, anglerfish, whiting, blue whiting, hake, sprat, mackerel, and long finned squid; spawning adults of whiting, cod, Norway pout; and mackerel eggs. Habitat proxies were assessed for 19 species/life stages in inshore waters, including: small sandeel refugia; spawning herring; juvenile plaice, common sole, whiting, cod, saithe, sprat, spotted ray, European lobster, and brown crab; spawning grounds/egg nursery for thornback ray and spurdog; generic habitat for velvet crab, common cockle, dog cockle, razor clam, common whelk, and dog whelk. Some species, which were initially considered, could not be modelled (offshore) or assessed (inshore) due to insufficient data and/or evidence on the species-habitat association from the literature obtained in the project (common skate and sandy ray, inshore and offshore; queen and king scallops and surf clam, offshore).

The spatial products thus obtained were validated by comparison with additional actual observations of the species/life stages in survey catches, where these data could be obtained. The maps were also shared with the Project Steering Group and additional external experts for review to obtain feedback on possible EFH areas that were not adequately represented by the model maps. These additional validation results were graphically incorporated into the final spatial products, of which they constitute an integral part, along with the model/assessment predictions and confidence. However, due to time limitations in the project, the feedback received was often limited and in some cases validation survey data and stakeholder feedback could not be obtained (e.g. for most of the inshore habitat proxy maps). A summary of the results and validation of the individual spatial outputs is given in section 3.1.30.

The spatial products of this study represent a step forward for an evidence-based understanding of the EFH distribution in UK inshore and offshore waters and the confidence associated with it. However, further validation is required before they can be used in assessments (as discussed in sections 4.4, 4.5 and 4.7). Further engagement with stakeholders from the fishery industry would be particularly valuable in supporting this.

This study also allowed to identify important data and knowledge gaps that need further work, including the species mentioned above and for which the EFH could not be modelled, as well as other species for which the obtained results had a low confidence due to poor available knowledge for inshore waters (thornback ray, spotted ray, spurdog, sprat, common sole, saithe, cod, whiting, European lobster, brown and velvet crabs). Data gaps were also identified for shellfish inshore and offshore, and fish and habitat maps inshore. These gaps were relevant to both the calibration and application of EFH models, as well as the validation of both EFH model and habitat proxy maps. As some of these gaps were due to the time-limited data collation in this project, possible additional data sources that could not be obtained in this project but that could help in filling these gaps were identified.

Based on the limitations identified for the different spatial outputs produced in this study (e.g. factors affecting model confidence, spatial gaps in the map/data coverage, etc), and the data and knowledge gaps mentioned above, recommendations were made to provide more robust and validated models (see section 4.7). In summary, the recommendations were around:

A. The correct use of the overall (integrated) spatial outputs produced in this project.
B. The improvement of the overall (integrated) spatial outputs produced in this project.
C. The improvement of EFH models and their prediction maps.
D. Improvement of habitat proxy assessment and the resulting maps.

Finally, in light of the possible influence of climate change on the distribution of fish and shellfish populations (through changes in the environmental conditions and effects on the fish physiology, behaviour etc.), the sensitivity of EFH model predictions to changes in environmental predictors that are of the same scale and direction as those from climate predictions was explored. Although this was not by any mean an accurate assessment of climate change effects, it showed that these may potentially have variable influence on the distribution of EFH in Scottish waters, depending on the species, the environmental variable subject to change and its importance as environmental predictor of the species' EFH. The appropriate interpretation and use of results are further discussed in the report, where also the general implications of climate change for EFH distribution in inshore and offshore Scottish waters are briefly reviewed and discussed (see sections 2.5, 3.2 and 4.6).

1. Introduction

1.1 Background

Marine spatial planning is essential to the management of the activities, resources and assets in marine waters to ensure sustainable development in the marine environment. One of the aims of marine planning is to identify 'areas of preference' for development, so that projects can be sited appropriately while avoiding conflicts with areas of high value to existing users (including fishing) and to conservation interests.

Marine spatial planning is of particular relevance in light of the likely substantial expansion of the offshore wind industry in Scotland over the next decade and beyond. Offshore wind is expected to play a large role in meeting the Scottish and UK Governments' commitments towards clean energy and climate change targets, and a green economic recovery. Marine Scotland Directorate, as Planning Authority for Scotland's Seas, has developed a Sectoral Marine Plan for Offshore Wind Energy (SMP) that has identified geographical areas as sustainable options (Plan Options) for future commercial scale offshore wind developments (Figure 1). The Scottish Marine Energy Research (ScotMER) Programme has been established by Marine Scotland Directorate to identify and address scientific uncertainties when assessing the potential impact of offshore renewable developments on the marine environment and other users of the sea, to de-risk the consenting process, and support the sustainable development of Scotland's waters.

A robust understanding of the distribution of the resources and assets provided by the marine environment, at the appropriate spatial resolution and with enough confidence, is key to this process. This would also benefit the management of other sectors which use the marine environment and the resources it provides (e.g. fisheries, oil and gas industry), as well as support consideration of nature conservation measures. This includes the understanding of the distribution of ecologically important habitats, which support key phases of fish (or shellfish) life history (e.g. spawning and nursery grounds), thus ensuring the viability of wild populations and provision of the associated ecosystem services. These are commonly known as Essential Fish Habitats.

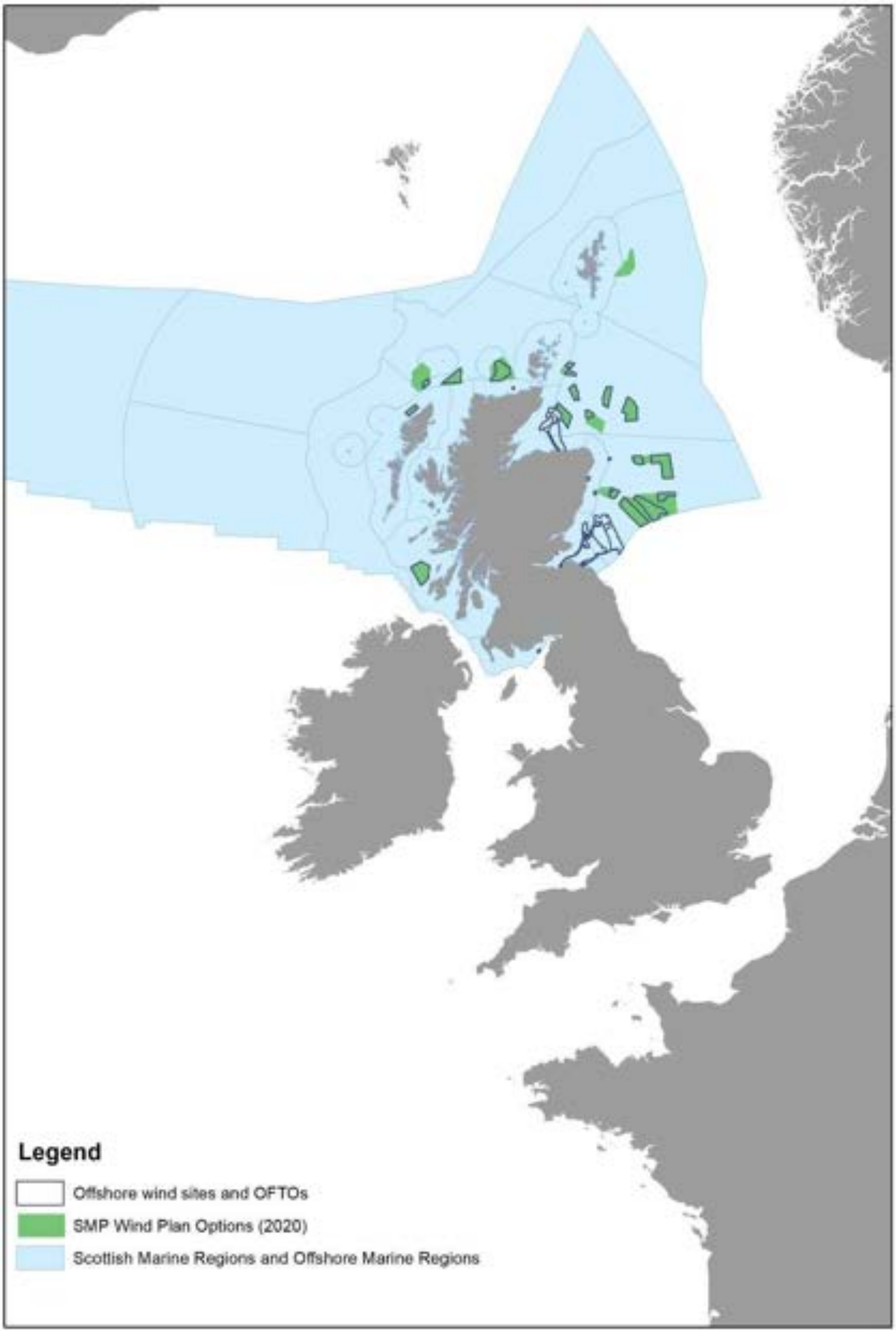


Figure 1. Offshore wind development areas in Scottish waters, including SMP areas referred to in the text and lease areas (Offshore wind sites and Offshore Transmission Owner agreements at various stages of development).

1.2 Essential Fish Habitat

The term Essential Fish Habitat (EFH) was first used in US legislation to identify "...those waters and substrata necessary to fish for spawning, breeding, feeding, or growth to maturity" (U.S. Magnuson-Stevens Fishery Conservation and Management Act 1976). This has been integrated as a tool for marine fisheries management in current U.S. legislation (U.S. Sustainable Fishery Act 1996; EFH Regulatory guidelines, NMFS / NOAA Rule 2002).

In this context, 'habitat' may be intended in its widest meaning as the combination of environmental conditions (e.g. physico-chemical and hydrodynamic characteristics, but also including biotic conditions) and structural components (e.g. substratum and habitat types), which characterise an area (in general or at a certain point in time). A conceptual representation of EFH of a species, and how it differentiates from other habitats used by the species, is given in Figure 2. This reflects the EFH concept as applied in this project.

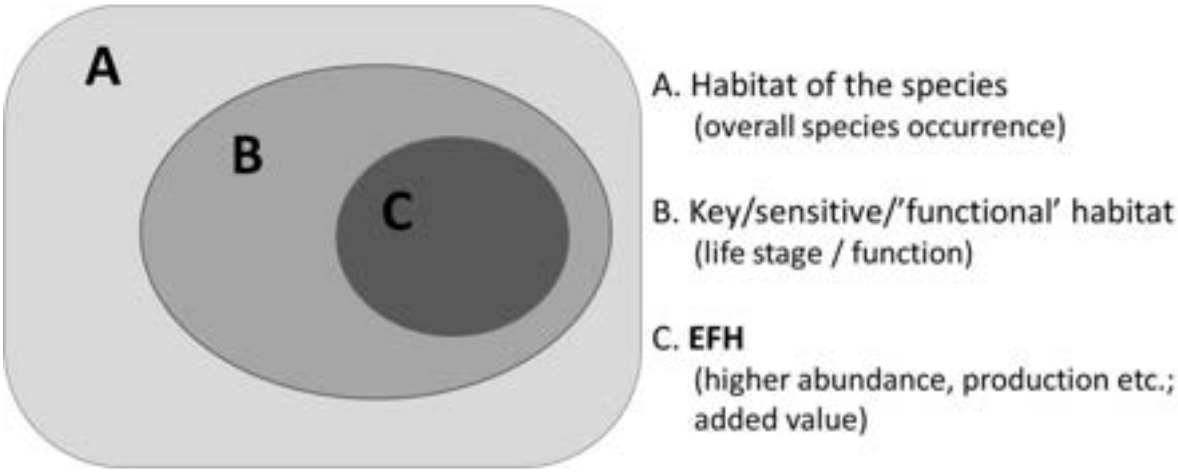


Figure 2. Conceptual representation of the habitats of a species. A habitat is intended as the set of environmental/ biotic/ ecological conditions (ecological niche) for: (A) where a species may occur as a whole; (B) a subset of A, where a species may occur as a specific key/sensitive life stage (e.g. juvenile habitat) or to perform a specific function (e.g. spawning habitat, refugia); (C) EFH, a subset of B, providing added value to the occurring life stage/function through e.g. higher abundance, enhanced survival, increased growth and production.

EFH is often associated with the function it performs for key phases of a species life history. Between species, it may have variable degrees of overlap (environmental and spatial) with the habitat (or habitat mosaic) used by the species throughout its whole life cycle due to ontogenetic changes in environmental tolerance ranges and optima (Rijnsdorp et al. 2009, Freitas et al. 2010). For example, nursery habitats provide food and space (shelter) to juveniles of a species, thus enhancing their survival and growth before they recruit back into the adult population. In marine migrant fish (e.g. some flatfish and gadoids), these habitats are distinct from the adult habitats, with nursery grounds mostly occurring in estuaries and shallow, enclosed coastal bays, whereas adult habitats are mostly at sea (Franco et al. 2008, Potter et al. 2015). Spawning grounds provide optimal conditions for reproduction, e.g. favouring egg/spawn survival and their successful transport into nursery areas. Similarly, habitats with a particular role in sheltering a species, e.g. from predators (refuge function), may also be considered as EFH (the refuge function being inherent in the nursery habitat definition when only juveniles directly benefit from it).

The mere association of a habitat with a life stage is not enough to identify it as an EFH. For example, Beck et al. (2001) distinguished between habitats where juveniles occur (see habitat B in Figure 2) and nursery grounds, the latter having an added value in their greater contribution (per unit area) to the production of individuals that recruit into adult populations (see habitat C in Figure 2). This added value is reflected, for example, by the increased density of juveniles, their enhanced survival or reduced mortality, increased growth rates and biomass production (Beck et al. 2001), as also found in other studies (e.g. Kraus and Secor 2005, Franco et al. 2010, Ciotti et al. 2013). Habitat connectivity is also a key element that ensures that the benefit gained locally within the EFH site is extended into the wider population (e.g. through successful export of the juvenile biomass from nursery grounds into marine adult populations; Gillanders et al. 2003, Able et al. 2022).

Therefore, to fully identify EFH, information on the species (or the relevant life stage) is needed at multiple levels of detail, from presence/absence to density, growth, reproduction, survival and production rate (NMFS and NOAA 2002). This type of data can be derived from survey catch data (e.g. size-frequency distribution analysis, as in Franco et al. 2010), although in some cases additional specialist analyses may also be needed (e.g. otolith microchemistry analysis, as in Gillanders et al. 2003 and Kraus and Secor 2005; RNA and DNA concentrations, as in Ciotti et al. 2013). A trade-off exists between the level of detail and availability of such data, and the operational application of the EFH concept for management purposes (EFH designation) often relies on more widely available but lower-level information (Level 1 and Level 2 in Figure 3; NMFS and NOAA 2002).

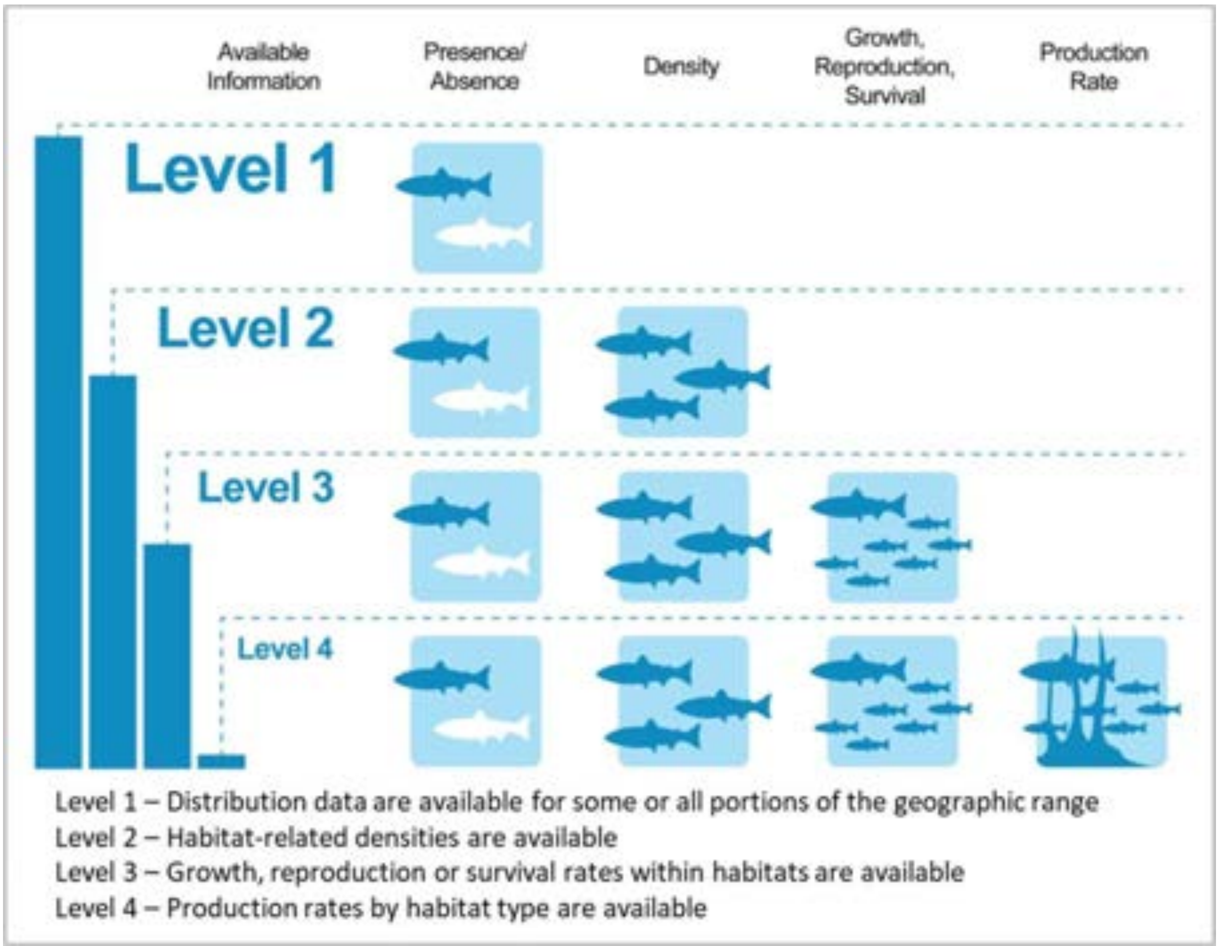


Figure 3. Four-tier approach for organizing information used to designate EFH based on the type of information available (from: NOAA 2022).

1.3 Aims and objectives

Understanding where essential fish habitats are located is vital to support effective habitat protection and healthy fish and shellfish populations, as well as predicting how habitats and resultant effects on fish and shellfish population may change (e.g. with climate change). However, evidence gaps in the knowledge base have been identified for Scotland (within ScotMER) as well as widely for UK waters (Marine Management Organization[1]).

Studies on EFH and their spatial distribution have been produced over the years, but available EFH models and maps may be outdated and/or insufficiently resolved (e.g. ICES[2]rectangle) for the use in marine planning (e.g. Coull et al. 1998, Ellis et al. 2012, Aires et al. 2014), or they do not cover Scottish waters (e.g. Franco et al. MMO 2013, 2016, AFBI 2021, Katara et al. 2021). Furthermore, there is a data gap for inshore waters, despite these areas holding ecologically important habitats and habitat complexes for fish and shellfish

[1] R088 - Spatial identification and categorisation of areas of particular importance to fish populations - GOV.UK (www.gov.uk)
[2] The International Council for the Exploration of the Seas.

(e.g. seagrass and saltmarsh, estuaries). EFH assessments and maps for inshore waters are scarce for the whole UK, and they are generally produced for local areas (e.g. Elliott et al. 2017 in Scottish waters) thus limiting their wider applicability.

As a result, the Scottish Government commissioned this study with the aim of developing the evidence base on EFH to inform future planning and project level assessments in Scottish waters, thus pulling together all available evidence to assist with wider UK planning and project assessments. The results of this study will help the regulators to understand where further work is required to inform consenting decisions (they will not be used to identify conservation measures as this would require a greater degree of robustness).

Specific objectives of this study are:

1. To identify, collate and standardise existing fishery and environmental data sources to develop high quality EFH models and GIS maps for relevant fish and shellfish species in Scotland (also including identification of data gaps and future data collection requirements).
2. To develop high quality EFH models and maps to deliver a national coverage (covering Scottish waters, UK-wide where possible) for relevant species with defined statistical confidence.
3. To explore viable alternative ways of mapping EFH for inshore waters through a systematic literature review, to identify habitat proxies for EFH functions, their applicability and with defined confidence.
4. To consider how climate change may affect EFH and give recommendations on how to take this into account for future planning and project level assessments.

1.4 General approach

In order to account for the variable data availability between species and inshore and offshore areas[3], a two-fold approach was applied to the identification of essential fish habitats.

Species distribution models (specifically Decision Tree models) were calibrated where broad-scale fish survey data were available for the study period 2010 - 2020 and correspondent environmental conditions could be derived from environmental layers based on survey locations and timings. The spatial distribution of the potential EFH for the species was then predicted based on the mapped environmental conditions under a selected environmental scenario (mean conditions over the ten-year study period). A confidence assessment was associated with the models and their spatial prediction taking into account the model performance (upon statistical validation of model predictions against a test dataset), and confidence estimates for the input data used to calibrate and predict the models (fish survey

[3] The boundary of Scottish (and UK) territorial waters (at the 12 nautical miles limit) is considered to be the inshore/offshore boundary for this study.

and environmental layers). As the data used in this approach were mostly available for marine areas offshore, the resulting maps provided poor coverage of inshore waters.

Data availability in inshore areas may be limited, e.g. due to a higher fragmentation (multiple, localised surveys undertaken by different bodies and for different reasons, e.g. ecological monitoring, impact assessment) and lower standardisation of surveys. Identifying, collating and harmonising these survey data (if made available by the respective providers) would require longer time than was available in this project. In addition, spatial coverage of environmental layers required for the modelling can be limited, especially in internal waters that are often poorly covered by broad scale environmental maps. Therefore, for inshore waters, a semi-quantitative assessment was applied to identify potential habitat proxies for EFH. The approach was similar to the one used in Amorim et al. (2017) to assess habitat attractiveness for estuarine fish communities. Different habitat types (identified based on EUNIS habitat classification) were scored according to their ability to provide EFH function to a species, with the habitat types with higher scores being used as proxies for EFH. The scoring was based on expert assessment as informed by a literature review and complemented through expert consultation. A confidence was allocated to each scoring based on the supporting evidence/knowledge.

For both approaches, examples of their spatial implementation (maps) were compared with survey data (where available) and, where possible, subjected to external examination by stakeholders for additional validation.

1.5 Report content

The report provides the main information on the methods, results and discussion of the findings and is supported by annexes as detailed below.

Section 2 reports on the methods applied, from the literature review, to the data collation and processing, modelling and habitat proxy assessment, the mapping procedure for both approaches, map validation via data and stakeholder feedback. The methodology used to assess the implications of climate change of EFH distribution (as required by objective 4) is also reported in this section. Additional specific details have been provided in separate technical annexes:

- Annex 1 provides details on the literature review methodology and the tabulated results.
- Annex 2 provides details on the data-based modelling approach used in the study and guidance on how to interpret and apply them for predicting the potential distribution of aggregations of a species/life stage.
- Annex 3 gives details on the methodology used to estimate confidence for the models and associated spatial predictions presented in the main report.

Section 3 reports on the main results obtained. The habitat assessment tools (decision tree model and habitat proxy matrix) and the resulting spatial implementation (maps) are presented by species, and for their relevant life stage(s), i.e. the life stage(s) associated to a specific EFH function relevant to the species. Interpretation and discussion of the specific results is included in this section, also accounting for the map validation via comparison with survey data and stakeholder feedback. The results of the assessment of the implications of climate change of EFH distribution are also reported in this section.

Section 4 provides a general discussion of the outputs of this project, also identifying gaps and recommendations for use of the outputs and their possible improvement.

2. Methodology

2.1 Literature review

A literature review was undertaken to inform the species selection, the data processing choices (e.g. body size and seasonality relevant for the identification of life stages) and the identification of the habitat proxies (i.e. habitat types with which the species is known to associate, in general or at particular stages of its life cycle). The literature review aimed at identifying which environmental characteristics and habitat types were important for each species under consideration, particularly exploring habitat association, preferences or requirements in relation to specific relevant EFH functions (e.g. as refugia, nursery, spawning grounds).

The literature search was structured by species and EFH function, and the review examined the available literature to characterise the association of different life stages with different habitats and their environmental characteristics accounting for their potential functioning as EFH. This included the examination of literature regarding, for example:

- Habitats associated with the presence (and, where possible, abundance) of spawning individuals or spawn products (e.g. eggs) or juveniles;
- The seasonality of use of the habitat;
- Habitat structure/characteristics granting shelter/protection from predators (e.g. submerged vegetation, shallow depth), local retention of spawn/juveniles (e.g. low hydrodynamic conditions), rapid growth of juveniles (e.g. abundance of food resources available to juveniles);
- Specific substrata required by a species (e.g. sediment characteristics) and environmental tolerances for the different life stages, where known.

The relevance of the different EFH functions (e.g. nursery, spawning, refuge function) to a species was also compiled. For example, the refuge function was not considered relevant for species that do not use refugia, or the nursery function was not considered relevant for species that do not show specific habitat requirements (other than those where the species normally occurs) for the survival and growth of juvenile stages.

The literature search was performed through online search engines (Google, Google Scholar, Scopus, ISI Web of Science) using combinations of keywords identifying the species (common and/or scientific name) and the EFH function (e.g. nursery, spawning, refuge). Results were selected for relevance using a hierarchical filtering approach, by screening first the title, then the abstract/summary, and, lastly, the text of the document as a whole. Although most of the searched evidence was recent (published after the year 2000), older literature was also considered where particularly relevant to inform the review. Where further literature sources deemed particularly relevant to the review were cited in the collated documents, they were also obtained and included in the assessment, where possible. The literature review considered scientific and grey literature, also including licensing or policy documents/reports and local by-laws, where available and relevant.

The review was compiled in a tabular format to aid the consultation and extraction of relevant information throughout the project. This included references to the relevant literature sources from which the information was obtained. Further details on the literature review and the resulting tables are given in Annex 1.

Thirty-four marine species were reviewed including fish (16 bony fish and 5 elasmobranch species) and shellfish (4 crustaceans and 9 molluscs), based on a list of species of interest as initially identified by Marine Scotland Directorate, and integrated and agreed following discussion with the Project Steering Group. The species considered included Priority Marine Features in Scotland's Seas (PMF, NatureScot 2020) as well as species of commercial interest (e.g. gadoids, crustaceans) (Table 1).

The literature review allowed to identify the EFH type (e.g. nursery, spawning, refuge habitat) most relevant to each species as the habitat for which the available evidence indicated a clear preference for specific habitat characteristics to perform a given EFH function (Table 1). Depending on the EFH function, this evidence related to the habitat preferences of particular life stages of a species (e.g. juveniles for the nursery function; adult spawning individuals or eggs for the spawning function) or to the population as a whole (e.g. for the refuge function). For some species (benthic molluscs) it was not possible to discriminate between specific EFH due to the high overlap in habitat use by different life stages and for different functions. In these cases, the generic habitat for the species as a whole was assessed.

The EFH type thus selected for each species was subject to further assessment in this project (Table 1). Where sufficient data were available from fish surveys for the specific species/life stage, the data-based model approach was applied for the EFH assessment (see section 2.2 for details). Where the selected EFH type for a species was expected to occur mostly or exclusively inshore (as indicated by the literature review), and sufficient evidence from the literature was available to characterise it, but no suitable survey data were available for the modelling, the EFH assessment was undertaken by using the habitat proxy approach (see section 2.3 for details).

Only for four species, namely plaice, common sole, sprat and whiting, was it possible to apply both approaches. Sufficient data were available for juveniles of these species from the collated survey datasets to allow the EFH modelling approach to be applied. However, the nursery habitats of these species occur mostly inshore (see literature review in Annex 1), and therefore it is expected that the habitat proxy approach would provide a better assessment for these species.

The EFH could not be further assessed with either approach for common skate, sandy ray, queen and king scallops, and surf clam. The specific reasons for this are as follows:

- For the assessment of nursery habitat of common skate, occurrences of juvenile skates in the survey catches were too sparse to allow modelling, and the information about habitat preferences from the literature was mostly based on depth only[4] (see Annex 1 for details), hence there was insufficient habitat characterisation to allow an accurate assessment of habitat proxies.
- For the assessment of nursery habitat of sandy ray, no data for this species were available from the collated survey datasets, nor are specific habitat requirements known for juveniles or spawning (egg-laying grounds) according to the literature examined (Annex 1).
- For the assessment of the habitat of queen and king scallops, and of surf clam, survey data for these species could not be identified (for surf clam) or, where known (e.g. scallop dredge surveys), could not be obtained for the modelling in this project. Habitat characterisation for these species was available from the literature (Annex 1), but this mostly pertained to offshore habitats, where the species occur, and therefore it was not relevant to the habitat proxy assessment which was developed for inshore habitats only.

Table 1. List of fish and shellfish species considered in the study (literature review) and further analysed for the assessment of their EFH. Species highlighted in grey could not be further assessed for EFH due to insufficient evidence from the literature and lack of survey data.

Species reviewed			**EFH assessment**	
Common name	**Latin name**	**PMF (1)**	**Life stage (EFH) (2)**	**Approach**
Lesser sandeel	*Ammodytes marinus*	*	Any (R)	EFH model
Small sandeel	*Ammodytes tobianus*	*	Any (R)	Habitat proxy
Nephrops/Norway lobster	*Nephrops norvegicus*		Any (R)	EFH model
Herring	*Clupea harengus*	*	Adult (S)	Habitat proxy
Plaice	*Pleuronectes platessa*		Juvenile (N)	EFH model & Habitat proxy
Lemon sole	*Microstomus kitt*		Juvenile (N)	EFH model
Common sole	*Solea solea*		Juvenile (N)	EFH model & Habitat proxy

[4] Additional habitat characterisation was available only in Phillips et al. (2021), but this was mostly from anectodal evidence and was not supported by other literature, hence it was not considered sufficient to inform habitat proxy assessment.

Species reviewed			EFH assessment	
Common name	**Latin name**	**PMF (1)**	**Life stage (EFH) (2)**	**Approach**
Anglerfish	*Lophius piscatorius*	*	Juvenile (N)	EFH model
Whiting	*Merlangius merlangus*	*	Juvenile (N)	EFH model & Habitat proxy
			Adult (S)	EFH model
Cod	*Gadus morhua*	*	Juvenile (N)	Habitat proxy
			Adult (S)	EFH model
Haddock	*Melanogrammus aeglefinus*		Adult (S)	EFH model
Norway pout	*Trisopterus esmarkii*	*	Adult (S)	EFH model
Blue whiting	*Micromesistius poutassou*	*	Juvenile (N)	EFH model
Hake	*Merluccius merluccius*		Juvenile (N)	EFH model
Saithe	*Pollachius virens*	*	Juvenile (N)	Habitat proxy
Sprat	*Sprattus sprattus*		Juvenile (N)	EFH model & Habitat proxy
Mackerel	*Scomber scombrus*	*	Juvenile (N)	EFH model
			Egg (S)	EFH model
Common skate (complex, incl. flapper skate and blue skate)	*Dipturus batis* complex (incl. *D. intermedius* and *D. flossada/batis*)	*	Juvenile (N)	No assessment
Thornback ray	*Raja clavata*		Adult/Egg (S)	Habitat proxy
Spotted ray	*Raja montagui*		Juvenile (N)	Habitat proxy
Sandy ray	*Leucoraja circularis*	*	Juvenile (N)	No assessment
Spurdog	*Squalus acanthias*	*	Neonate (S)	Habitat proxy
Long finned squid	*Loligo forbesii*		Juvenile (N)	EFH model
European lobster	*Homarus gammarus*		Juvenile (N)	Habitat proxy
Brown crab / Edible crab	*Cancer pagurus*		Juvenile (N)	Habitat proxy
Velvet crab	*Necora puber*		Any (H)	Habitat proxy
Queen scallop	*Aequipecten opercularis*		Any (H)	No assessment
King scallop	*Pecten maximus*		Any (H)	No assessment

Species reviewed			EFH assessment	
Common name	**Latin name**	**PMF (1)**	**Life stage (EFH) (2)**	**Approach**
Common cockle	*Cerastoderma edule*		Any (H)	Habitat proxy
Dog cockle	*Glycymeris glycymeris*		Any (H)	Habitat proxy
Surf clam	*Spisula solida*		Any (H)	No assessment
Razor clam	*Ensis ensis*		Any (H)	Habitat proxy
Common whelk	*Buccinum undatum*		Any (H)	Habitat proxy
Dog whelk	*Nucella lapillus*		Any (H)	Habitat proxy

Table footnotes: (1) PMF, Priority Marine Features in Scotland's Seas (NatureScot 2020). (2) Life stages considered are indicated as relevant to the assessment of specific EFH function: R, refugia; N, nursery; S, spawning (incl. egg nursery for skates and rays, and parturition grounds for spurdog); H, generic species habitat (where same habitat is used for multiple functions).

2.2 Species Distribution Models

Aggregations of individuals were considered as an indicator of potentially suitable EFH for a fish/shellfish species. Specifically:

- aggregations of juveniles were considered to indicate potential nursery habitats;
- aggregations of adults in spawning condition or eggs were considered for the spawning function; and
- aggregations of individuals at any life stage were considered for burrowing species such as lesser sandeel and *Nephrops* as an indicator of habitats functioning as refugia for these species.

These operational definitions were applied to account for the added value associated with EFH (i.e. habitats with a higher contribution per unit area; habitat C in Figure 2) compared to the generic habitat where a species may occur (as a whole, or as a specific life stage or to perform a specific function; habitats A and B, respectively, in Figure 2), while also considering the type of data available from most marine fish surveys. Therefore, the habitats identified for the species/life stages via the modelling approach can be considered as potential EFH for the species.

The process undertaken to analyse the data with species distribution models and obtain the resulting EFH spatial outputs is summarised as diagrams in Appendix A, with further details on the various phases of the process being provided in the sections 2.2.1 to 2.2.5 below.

2.2.1 Fish survey data

Fish (and shellfish) survey data were collated and selected based on the following criteria:

- Even though the main interest of this study lies in Scottish waters, UK-wide surveys were selected, where possible, considering the mobile nature of the species investigated and to calibrate species distribution models of more general validity (given the wider range of environmental conditions explored). Therefore, broad scale scientific survey programmes were prioritised as they provide greater spatial coverage and standardisation of methods (hence allowing for better comparability).

- Data from surveys undertaken within the period 2010 - 2020 were selected.
- Original survey data available at the higher spatial resolution (e.g. at haul level) were considered, as opposed to data only available as cumulative or combined estimates (e.g. over a wider area/region).
- Minimum requirements for survey data were to include survey location and date (or at least year and month), species identity, and catch abundance (standardised as CPUE) by body length or development stage (e.g. for eggs). Supporting information on the survey methodology and design was also required to determine data comparability and allow confidence assessment.
- Fishery-dependent data were not used considering their bias towards commercial species and larger sizes, lack of standardisation (variable gear characteristics, fishing effort, taxonomic standards) and low spatial resolution at which data are often provided (e.g. by ICES rectangle)

Potentially suitable data sources were identified through exploration of known resources online (e.g. ICES databases) and direct contact with survey coordinators. The data search was also informed through consultation with external stakeholders (see section 2.4.2).

Raw data (species CPUE as number per hour per length class and hauling information) were obtained from DATRAS[5], the online Database of Trawl Surveys maintained by the International Council for the Exploration of the Seas (ICES). The selected surveys for the period 2010 - 2020 included the International Bottom Trawl Surveys (IBTS) and Beam Trawl Surveys (BTS) undertaken by different countries under ICES coordination. IBTS included the North Sea International Bottom Survey (NS-IBTS), Scottish West Coast Groundfish Survey (SCOWCGFS), Scottish Rockall Survey (SCOROC), Irish Ground Fish Survey (IE-IGFS), and Evaluation Halieutique Ouest Europeen (EVHOE). IBTS data were considered more suitable to model demersal and pelagic species (with variable confidence), while BTS data were used to model flatfish.

Even though the lesser sandeel, *Ammodytes marinus* was caught in IBTS and BTS, these survey methods are not considered to provide reliable estimates of sandeel abundance (Ellis et al. 2012, Wright et al. 2019). Therefore, alternative survey data were explored. Data on haul locations and CPUE (catch per hour, and also per age class) were obtained for the annual dredge survey undertaken by Marine Scotland Science in December at sandeel fishing grounds off the Firth of Forth and Turbot Bank (in Sandeel Area 4, east coast of Scotland, where the largest of the sandeel stocks in Scottish waters is and there is an active

[5] https://datras.ices.dk/Data_products/Download/Download_Data_public.aspx

fishery for it). The dataset also contained data from surveys on the west coast of Scotland in 2021 that were used for map validation (see section 2.4.1). Data in this dataset are reported for generic "sandeel", without distinction by species. However, most of the catches consist of the lesser sandeel *Ammodytes marinus* (ICES 2010), this species being the most abundant species of sandeel found in Scottish waters, and therefore the data and resultant outputs were considered as representative of this species.

Data on haul characteristics and anglerfish (*Lophius piscatorius*) CPUE by length class were obtained from Marine Scotland Science for the Scottish-Irish anglerfish and megrim industry-science survey (SIAMISS) undertaken to monitor the Northern shelf anglerfish stock in subareas 4 and 6, and division 3.a (North Sea, Rockall and West of Scotland, Skagerrak and Kattegat). Data from this survey were prioritised for the modelling of anglerfish, as SIAMISS survey is considered more effective than other IBTS surveys (e.g. NS-IBTS) at catching anglerfish of the size considered in this study (Danby et al. 2021).

Data on haul characteristics and egg CPUE were obtained for mackerel, *Scomber scombrus* from the ICES Eggs and Larvae database[6] for the Mackerel and Horse Mackerel Egg Survey (MEGS) in the Northeast Atlantic. The spatial and temporal distribution of sampling in this survey programme is designed to ensure an adequate coverage of the species spawning areas, with sampling effort being targeted at producing estimates of stage 1 (early development stage) egg production.

A summary of the data availability and methods for the above-mentioned surveys is given in Table 2, with the survey locations mapped in Figure 4 and Figure 5. Further details (metadata to MEDIN standard) of the selected datasets for the project are given as attached Excel worksheets including metadata for both collated raw survey datasets (worksheet 'EFH-SG2022_Raw survey datasets_Metadata_MEDIN format') and processed data for input into EFH modelling ('EFH-SG2022_Processed survey data for modelling_Metadata_MEDIN format').

Table 2. Fish surveys used to collate data for the EFH modelling.

Survey	Year (1)	Quarter	Gear (2)	Country	Reference
International Bottom Trawl Survey (IBTS):	as detailed below:		GOV		ICES 2017, 2020
NS-IBTS	1965-2021	Q1, Q3		Various (3)	
SCOWCGFS	2011-2021	Q1, Q4		Scotland	
SCOROC	2011-2021	Q3		Scotland	
IE-IGFS	2003-2021	Q4		Ireland	
EVHOE	1997-2021	Q4		France	

[6] https://eggsandlarvae.ices.dk/Download.aspx

Survey	Year [1]	Quarter	Gear [2]	Country	Reference
Beam Trawl Survey (BTS)	1985-2021	Q1, Q3	BT (4/7/8m)	Various [3]	ICES 2019a
Sandeel dredge survey	2008-2021	Q4 (Dec, +Nov in 2020)	Modified scallop dredge	Scotland	ICES 2010
Northern Shelf Anglerfish Survey (SIAMISS)	2013-2021	Q2, Q4	Bottom trawl	Scotland	Fernandes et al. 2007, ICES 2018
Mackerel Egg survey (MEGS)	2010, 2013-2019, 2021	All quarters	Bongo or 'Gulf type high-speed' samplers (national variants [4])	Various [4]	ICES 2019b

Table footnotes: [1] Data within the decade 2010 - 2020 were selected for the analysis in this study. [2] GOV, *Grande Ouverture Verticale* bottom trawl; BT, Beam trawl (4m BT used by England and Belgium, 7m BT by Germany and 8m BT by the Netherlands). [3] NS-IBTS: Denmark, Germany, France, England, Scotland, Netherlands, Norway, Sweden; BTS: Belgium, Germany, England, Netherlands. [4] Bongo used by Faroes and Iceland; Gulf VII by Faroes, Iceland, Scotland, Ireland, Netherlands, Norway; Nacktai (modified Gulf VII) by Germany.

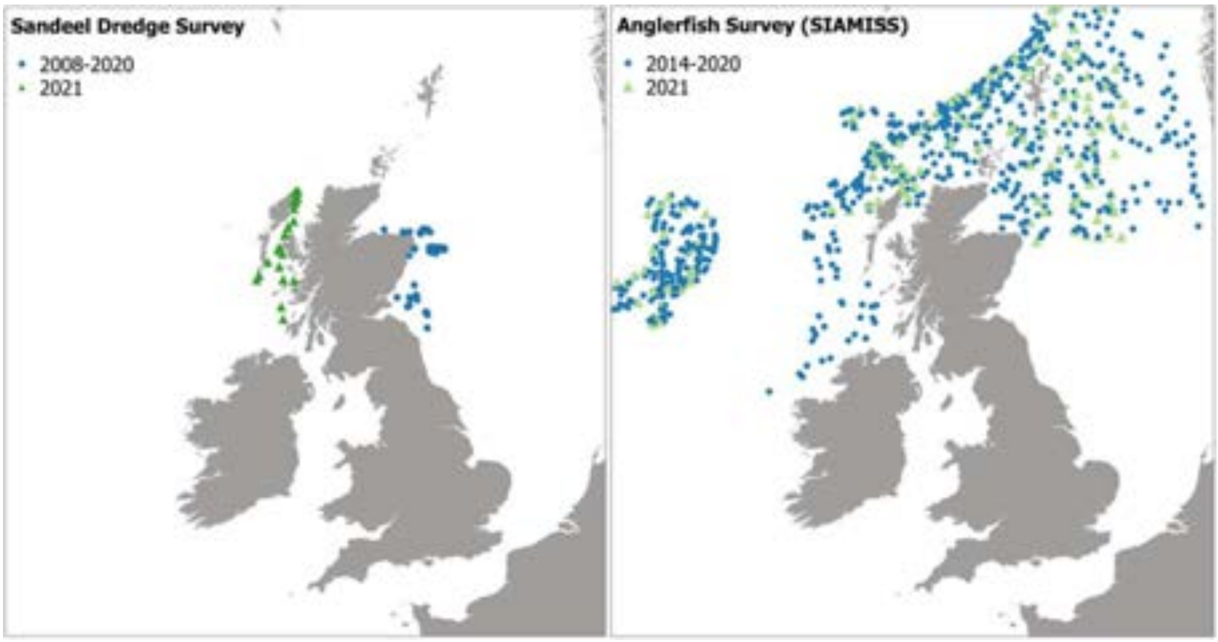


Figure 4. Survey locations for Sandeel dredge survey and Northern Shelf Anglerfish Survey (SIAMISS) data used in the study. 2021 surveys (not used for modelling, but used for qualitative validation of maps) are also shown.

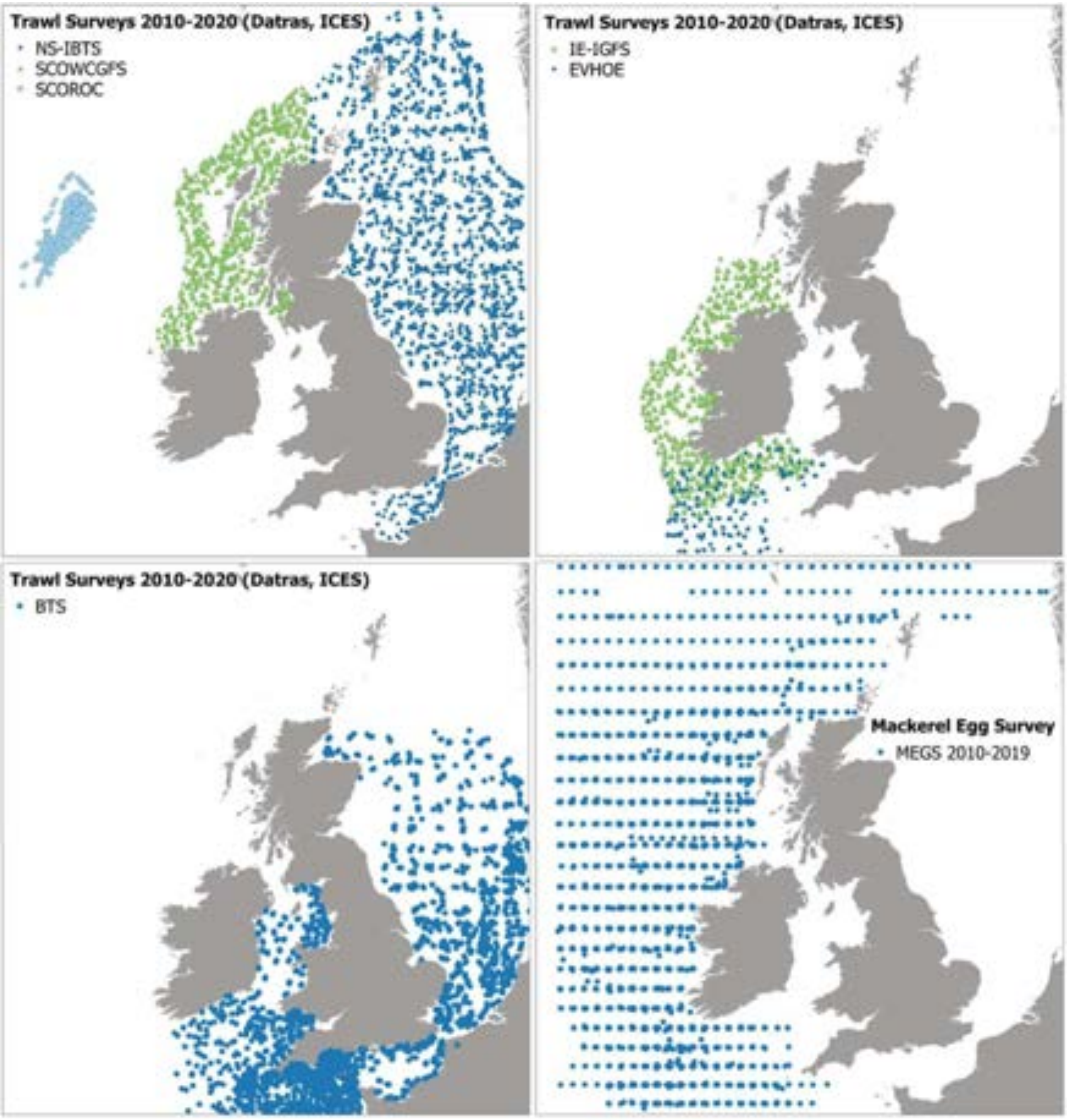


Figure 5. Survey locations for international surveys coordinated by ICES: International Bottom Trawl Surveys (NS-IBTS, SCOWCGFS, SCOROC, IE-IGFS, EVHOE), Beam Trawl Survey (BTS) and Mackerel Egg Survey (MEGS) as used in the study (see Table 2 for survey names).

Form the collated surveys, data were selected for inclusion in the models if they were within the 2010 - 2020 period at the desired geographical location (Longitude <5 deg. E and Latitude ≥49 deg. N).

Data for life stages relevant to the modelling of individual species and their EFH were identified based on the criteria summarised in Table 3. The relevant seasonality for the occurrence of the different life stages and the cut-off size (body length) for juveniles were identified based on size-frequency analysis of the survey data and validated through the literature review (see Annex 1). Juveniles were preferably identified as 0-group individuals (i.e. individuals in their first year of life), where possible. However, in some instances, 1-

group individuals (i.e. individuals in their second year of life) were included with the choice of the cut-off size in order to increase the dataset size and allow modelling. Despite this, data available were insufficient for some species which could not be modelled (Table 3).

For gadoids in the IBTS surveys, Spawning Maturity Age-Length Keys (SMALK) were available[7] and were used to discriminate catches of spawning adults ('running' adults in Table 3). The size frequency distribution of individuals by maturity stage was analysed for the different surveys. The relevant season (quarter) for which spawning catch data were analysed was selected based on the following conditions for data in SMALK: >1000 observations available, >15% of individuals being mature (in spawning, spent or resting condition) and mostly in spawning/spent condition (with the presence of individuals in spawning condition as a minimum). The relative size frequency of individuals in spawning or spent conditions (maturity stages III/63 or IV/64, respectively) as derived from SMALK data was applied to the survey dataset to distinguish catches of adults at 'running' stage based on size class.

For burrowing species such as lesser sandeel *A. marinus* and *Nephrops*, individuals of any size or life stage were considered, with the seasonality reflecting predominant emergence patterns of the species from their burrows (e.g. during winter for sandeel) and/or the period of the year when catches in the surveys were maximized.

Table 3. Criteria for the selection of data relevant to the life stage of interest from survey data.

Common name	Life stage	Season	Life stage selection criterion (1)	Data source	Modelled
Lesser sandeel	any size/stage	Q4	-	Sandeel dredge survey	Yes
Nephrops	any size/stage	Q1+Q3 +Q4	-	IBTS (NS-IBTS, SCOWCGFS, SCOROC, IE-IGFS, EVHOE)	Yes
Plaice	Juvenile, 0-group, recently metamorphosized	Q3	Body size (length): 4 cm to 12 cm	BTS	Yes
Lemon sole	Juvenile, 0-group	Q3	Body size (length): 3 cm to 15 cm	BTS	Yes

[7] SMALK data were also available for other species form IBTS and BTS surveys (e.g. herring), but the analysis of such data showed that mature individuals were almost exclusively in spent condition and therefore were not considered suitable for assessing spawning grounds.

Common name	Life stage	Season	Life stage selection criterion (1)	Data source	Modelled
Common sole	Juvenile, 0- and 1-groups	Q3	Body size (length): 3 cm to 25 cm	BTS	Yes
Anglerfish	Juvenile, 0- and 1-groups	Q2	Body size (length): 12 cm to 28 cm	SIAMISS	Yes
Whiting	Juvenile, 0-group	Q3+Q4	Body size (length): 12 cm to 16 cm(Q3) / 20 cm(Q4)	IBTS (NS-IBTS, SCOWCGFS, SCOROC, IE-IGFS, EVHOE)	Yes
	'Running' adult	Q1	Adults at spawning or spent stage (2)	IBTS (NS-IBTS, SCOWCGFS)	Yes
Cod	Juvenile, 0-group	Q3+Q4	Body size (length): 8 cm to 19 cm(Q3) / 25 cm(Q4)	IBTS (NS-IBTS, SCOWCGFS, SCOROC, IE-IGFS, EVHOE)	No (3)
	'Running' adult	Q1	Adults at spawning or spent stage (2)	IBTS (NS-IBTS, SCOWCGFS)	Yes
Haddock	'Running' adult	Q1		IBTS (NS-IBTS, SCOWCGFS)	Yes
Norway pout	'Running' adult	Q1		IBTS (NS-IBTS, SCOWCGFS)	Yes
Blue whiting	Juvenile, 0-group	Q3+Q4	Body size (length): 5 cm to 19 cm	IBTS (NS-IBTS, SCOWCGFS, SCOROC, IE-IGFS, EVHOE)	Yes
Hake	Juvenile, 0-group	Q3+Q4	Body size (length): 4 cm to 19 cm	IBTS (NS-IBTS, SCOWCGFS, SCOROC, IE-IGFS, EVHOE)	Yes
Saithe	Juvenile, 1-group	Q3+Q4	Body size (length): 18 cm to 33 cm	IBTS (NS-IBTS, SCOWCGFS, SCOROC, IE-IGFS, EVHOE)	No (3)
Sprat	Juvenile, 0-group	Q3+Q4	Body size (length): 2.5 cm to 9 cm(Q3) / 9.5 cm(Q4)	IBTS (NS-IBTS, SCOWCGFS, SCOROC, IE-IGFS, EVHOE)	Yes

Common name	Life stage	Season	Life stage selection criterion [1]	Data source	Modelled
Mackerel	Juvenile, 0-group	Q1+Q4	Body size (length): 12 cm to 22 cm(Q4) / 24 cm(Q1)	IBTS (NS-IBTS, SCOWCGFS, IE-IGFS, EVHOE)	Yes
	Eggs, early stage	Q2+Q3	Eggs at early development stage (EG1)	Mackerel Eggs survey (MEGS)	Yes
Long finned squid	Juvenile, immature/recruits	Q3+Q4	Body size (length): 1 cm to 15 cm	IBTS (NS-IBTS, SCOWCGFS, SCOROC, IE-IGFS, EVHOE)	Yes
Common skate	Juvenile, 0- and 1-groups	Q4+Q1	Body size (length): 13 cm to 40 cm	IBTS (NS-IBTS, SCOWCGFS, IE-IGFS, EVHOE)	No [3]
Thornback ray	Juvenile, 0-group including some 1-group individuals	Q1	Body size (length): 12 cm to 25 cm	IBTS (NS-IBTS, SCOWCGFS)	No [3]
Spotted ray	Juvenile [4]	Q4+Q1	Body size (length): 8 cm to 33 cm	IBTS (NS-IBTS, SCOWCGFS, IE-IGFS, EVHOE)	No [3]
Spurdog	Juvenile, newborn	Q1	Body size (length): 12 cm to 32 cm	IBTS (NS-IBTS, SCOWCGFS)	No [3]

Table footnotes: [1] For juveniles: minimum body size in the catch data and maximum (cut-off) size for juveniles based on literature review and size frequency analysis of the survey data. [2] Maturity stages III/63 + IV/64 as based on SMALK (Spawning Maturity Age-Length Keys) available for IBTS data. [3] Too few occurrences of the species life stage in the surveys (<250 hauls in total, with aggregations in <100 hauls). [4] No information on juvenile size or seasonality was available from the literature. This was derived from the size frequency analysis of the survey data based on the smaller size cohort represented in the catches for the species.

Aggregations of the species/ life stages of interest were identified based on the density (CPUE) of the catches in hauls where the species/life stage occurred, similarly to the approach used in Aires et al. (2014). A threshold value was identified as the minimum CPUE in the top quartile of the CPUE distribution of all hauls where the species/life stage was present for each survey type (Figure 6). Catches (for the selected species/life stage) with CPUE above the threshold value were identified as presence of aggregations, whereas absence of aggregations was determined where the species/life stage was present in the catch with CPUE below the threshold value. The use of presence/absence of aggregations allowed to reduce the variability in the data due to differences in sampling methodology between surveys (including gear and vessel performances) before modelling.

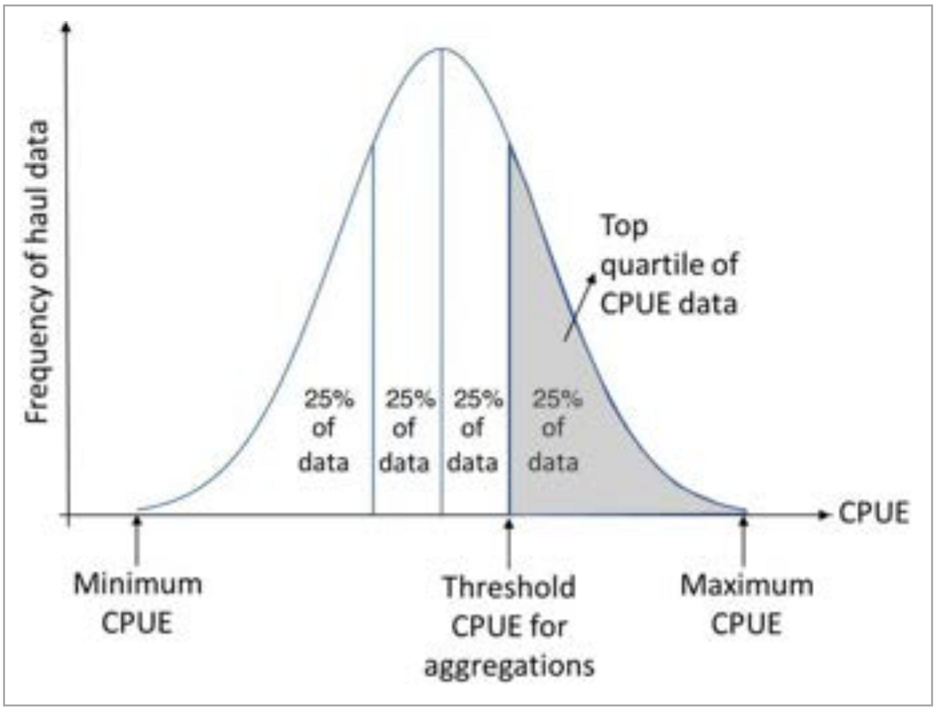


Figure 6. Criterion for identification of presence of aggregations based on the distribution of CPUE survey data. Quartiles (including 25% of the data each) in the data distribution are indicated. Aggregations were identified at CPUE above threshold (i.e. within top quartile).

For most of the benthic/demersal species considered, survey types were distinguished based on the combination of Survey and Country as per Table 2 (for BTS, this also allowed to distinguish catches from different sized BT), whereas data across all years were considered given the lower interannual variability in these catches.

For pelagic species (sprat and mackerel juveniles from IBTS and mackerel eggs from MEGS), a higher interannual variability of the catch data was observed, and therefore the aggregation calculations were undertaken on a year-by-year basis for the different survey types (for MEGS data, the latter were distinguished based on gear type and country as per Table 2). In addition, the following criteria were also applied when identifying aggregations of pelagic species from IBTS: (i) a CPUE <10 individuals per haul per hour was never considered as an aggregation, even if within the top quartile; (ii) a CPUE >500 individuals per haul per hour was always considered as an aggregation, even if out of the top quartile.

2.2.2 Environmental data

As guided by the literature review and findings of previous projects (e.g. MMO 2013), a range of environmental data layers were collated to characterise the physical, chemical, and biological parameters for the UK marine environment which may be important in determining important habitats of the target fish species at their various life stages. Datasets were chosen using criteria including geographical extent, relevance to target species (both benthic and pelagic), temporal representation, spatial resolution and confidence. Full details (metadata to MEDIN standard) of the selected data layers for the project are given in the attached Excel worksheet 'EFH-SG2022_Input+Output data layers_Metadata_MEDIN format', but are summarised in Table 4.

Environmental data layers were sourced which covered UK waters and, as far as possible the geographical extent of the fish survey data used for the project. In some cases, it was necessary to combine compatible or overlapping data products to increase geographical coverage or to include the presence of habitats which may not be specifically listed for protection (e.g. Annex 1, Habitats Directive) or as threatened or declining (e.g. OSPAR). For example, the presence of particular habitats that may influence the occurrence of a fish species in an area was measured by compiling composite datasets to represent the best geographical coverage of Sandbanks, Structured habitats (including reefs (various types), mussel/oyster beds, *Sabellaria*[8], *Lophelia*, corals, rocky walls, coral gardens etc.) and Vegetated habitats (including kelp and seaweed, maerl beds, seagrass beds). For simplicity, specific habitats within each data layer were reduced to describe only presence or absence of the umbrella habitat type.

Data for temporally variable parameters (including temperature, salinity, net primary production and mixed layer thickness) were sourced as monthly averages to match the timing of fishing events. These data layers were available for the whole ten-year period considered in this study (2010 – 2020) with extensive UK-wide marine coverage, which allowed a matching between the environmental data and the fishing events for >98% of the data. Monthly environmental data were then processed further to represent seasonal averages appropriate for important life stages of certain species.

Fish survey location data were reduced to single points using the haul centre location, or either shoot location or haul location where both coordinates were not available. In most cases, environmental data were extracted directly for each survey point location for the model calibration. However, as the hauls in the survey datasets integrated over a trawling distance of up to 5 km, for some environmental parameters which had potential to give variable and potentially misleading values over a 5 km distance, either an average value or a predominant feature category within a 5 km buffer of the haul central point was extracted (Table 4).

[8] Available data layers including *Sabellaria* reef features in Scottish and UK waters were used (see Table 4). It is acknowledged that recent work carried out by Marine Scotland Directorate indicates that *Sabellaria reef* is different in Scottish waters compared to English waters (Marine Scotland 2020).

Table 4. Environmental variables used in the models and their source data layer, with indication of their calculation for model calibration (based on survey data points) and prediction (based on grid, see section 2.2.4).

	Environmental Variable *(Variable name and unit)*	**Source Layer**	**Model** calibration (survey locations)	**Model** prediction (5 x 5 km grid)
Geo-morphology	**Distance from coast (high water level)** *(Dist, m)*	EMODnet	at survey point	at grid cell centre
Geo-morphology	**Depth** *(Depth, m)*	EMODnet Bathymetry 2020	at survey point	mean within grid cell
Geo-morphology	**Slope** *(Slope, degrees)*	(Derived from bathymetry data)	mean slope across 5 km buffer containing survey point	mean slope within grid cell
Habitat	**Substratum type** *(Substr, see* Table 5 *for classes)*	EMODnet Seabed Habitats 2019	predominant class within 5 km of survey point	predominant class within grid cell
Habitat	**Presence of Sandbank Habitat** *(SandbH01, class 0/1)*	Combination of: OSPAR 2020, EMODnet Seabed Habitats 2019, GEMS 2019	presence within 5 km of survey point	presence within grid cell
Habitat	**Presence of Structured Habitats** *(StructH01, class 0/1)*			
Habitat	**Presence of Vegetated Habitats** *(VegH01, class 0/1)*			
Energy	**Currents, kinetic energy at seabed** *(CUR, N m^2/s)*	EMODnet 2017	at survey point	mean within grid cell
Energy	**Waves, kinetic energy at seabed** *(WAV, N m^2/s)*	EMODnet 2019		
Water quality	**Sea Surface Temperature** *(SST, °C)*	E.U. Copernicus Marine Service	at survey point and mean for relevant month and year of survey	mean within grid cell and for relevant season within 2010 - 2020 period (or for individual years, where relevant)
Water quality	**Sea Bottom Temperature** *(SBT, °C)*			
Water quality	**Sea Surface Salinity** *(SSS, PSU)*			
Water quality	**Net Primary Production** *(NPPV, Carbon per unit volume of seawater, mg C m^{-3} day^{-1})*			
Water quality	**Mixed layer thickness** *(MLT, m)*			

Table 5. Key to codes used to identify substrate classes derived from EMODnet Seabed Habitats data layer for modelling (variable "Substr"). Only substrate classes relevant to the calibration datasets are shown.

EMODnet substrate classes	Substr (codes)
Coarse substrate/sediment	Coarse
Sand	Sand
Sandy mud	sMud
Sandy mud or Muddy sand	sMud_mSand
Muddy sand	mSand
Fine mud or Sandy mud or Muddy sand	f-sMud_mSand
Fine mud	fMud
Mixed sediment	Mixed
Sediment	Sed
Rock or other hard substrata	RockHard
[Sabellaria spinulosa] reefs	ssReef
Worm reefs	wReef

2.2.3 Species Distribution Models

Decision tree models, specifically Classification trees, were calibrated to predict the presence/absence of aggregations of a species/life stage based on the associated environmental conditions. All analyses were conducted using R version 3.3.3 (R Core Team 2017) and the R-package "rpart" (Therneau et al. 2019).

Classification trees are a type of supervised learning algorithm that organises explanatory variables in a hierarchical way, based on their effect on the response variable. The resulting model is visually represented as a decision tree that starts from a "Root node" (the full population of observations), and, after a series of splits into pairs according to alternative specific environmental conditions (e.g. depth < or ≥ of a certain value), a final prediction of presence/absence ("Terminal node" or "Leaf") is given at the end of a "Branch". Following the splits along a branch allows to identify unique combinations of variables associated with the resulting leaf prediction, and to highlight and describe the major influencing variables as a series of branches.

Compared to other classification approaches, decision trees closely mirror human decision-making and have several advantages (De'ath and Fabricius 2000, Zuur et al., 2007). The hierarchical nature of the trees allows researchers to identify the relative importance of different explanatory variables, and to accommodate the non-linearity and interaction between explanatory variables and with missing values (which may often be present for environmental variables in the datasets). A major advantage of decision trees is also that they are intuitively very easy to understand, and the resulting algorithm (i.e., the combination of environmental ranges that can be used to predict the occurrence of aggregations of a certain life stage) can be easily applied to a new environmental scenario to obtain predictions. As a result, they can be more easily communicated to a non-expert audience and used even without any statistical preparation or package needed.

Separate datasets for individual species/life stage were prepared, including the presence/absence of aggregations in the survey hauls (response variable) and the associated environmental conditions (explanatory variables or predictors, as extracted from the environmental data layers for the survey haul locations, month and year). Each dataset was randomly divided into a train subset, including 80% of the data used for calibrating the model, and a test subset including the remaining data (20%) for model statistical validation (see assessment of model performance in section 2.2.5)

On model calibration, a preliminary analysis of collinearity was undertaken to exclude highly correlated environmental variables (with Variance Inflation Factor >10 and/or Pearson's correlation coefficient ≥0.8) from the analysis. All the remaining variables were included in the analysis, with sea bottom temperature (SBT) specifically used for modelling of benthic flatfish and anglerfish, demersal gadoids and squid, while sea surface temperature (SST) was used for modelling sprat and mackerel life stages. Full tree models obtained were pruned, where needed, through cross-validation and following the "one standard deviation (1-SE) rule" (Faraway 2006, Zuur et al. 2007).

For a more detailed description of the modelling protocol used to select the best performing model, please see Annex 2.

2.2.4 Mapping

In order to predict the models over the wider marine area around the UK, a 5 x 5 km vector grid of the study area was created. The spatial resolution of the grid was defined based on the minimum resolution of the fish survey data used to calibrate the models (i.e. considering the length of the haul along which the catch data were integrated). The spatial coverage of the grid included, as a minimum, the UK territorial waters (Figure 7).

Environmental values associated with the predictors identified by the models were extracted from the relevant data layers at the resolution of the selected spatial grid (Table 4; see also diagram (c) in Appendix A). For persistent environmental variables (spatially structured but with no temporal variability), the gridded values were extracted by averaging the data from the environmental layer within the grid cells (Depth, CUR, WAV), considering the predominant substrate category in the grid cell (by area covered) (Substr) or calculating the variable at the grid cell centre (Dist) or across the whole grid cell (Slope). For non-persistent environmental variables (spatially structured and with temporal variability), data layers available for the years within the 2010 - 2020 timeframe were obtained (considering the appropriate months for the seasons relevant to the modelled species/life stages) and the gridded values were extracted by averaging the data within the grid cells and across the selected season and years (SST, SBT, SSS, NPPV, MLT).

As a result, the temporal reference for the environmental scenario and the associated predictions represented in the maps corresponds to the mean seasonal conditions for the decade 2010 - 2020.

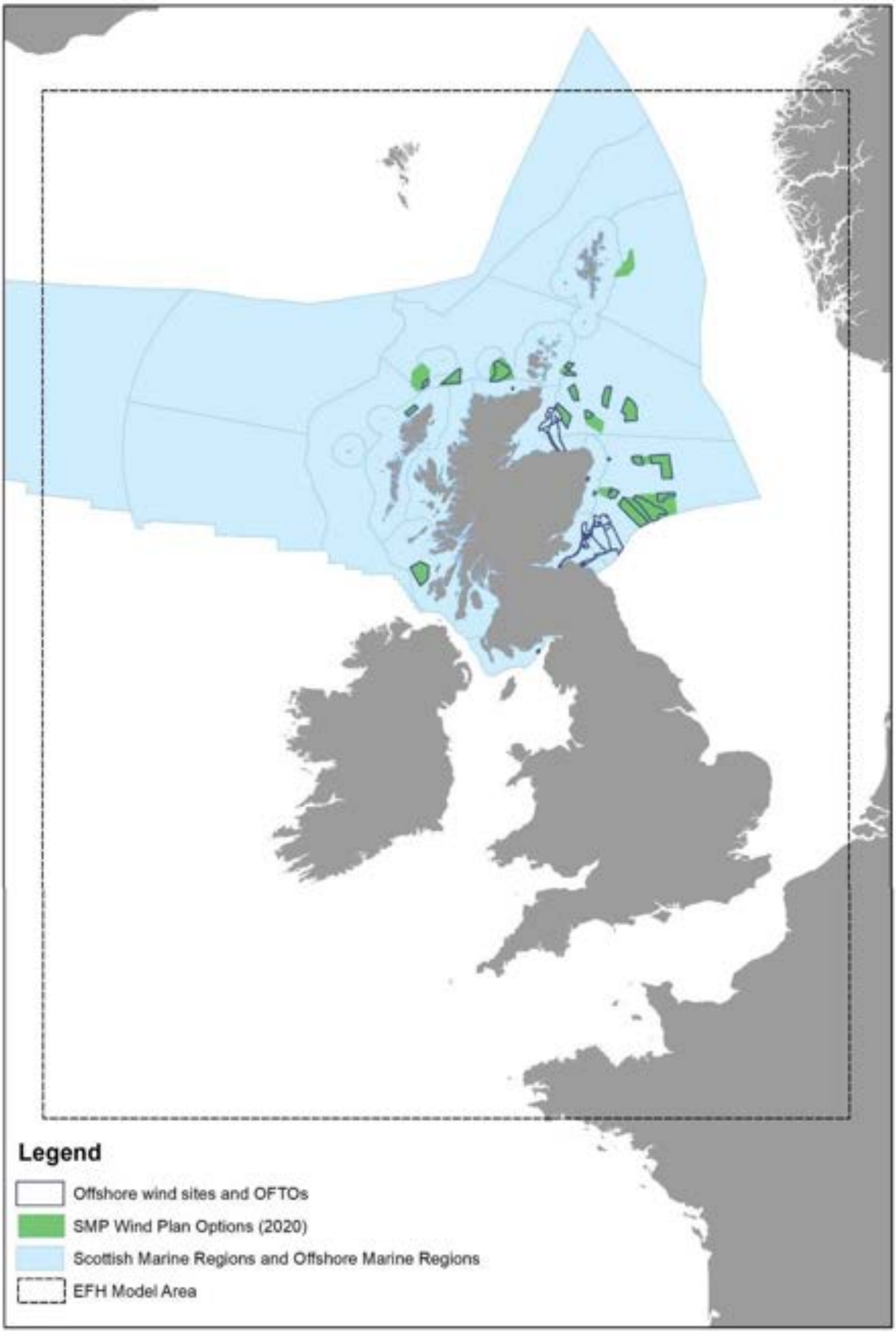


Figure 7. EFH Model Area where habitat mapping was undertaken using data-based models. Scottish waters and offshore wind developments are also shown for context.

Where a mean environmental estimate was used to represent the environmental conditions within a grid cell, the associated standard deviation was also estimated for confidence assessment purposes (see Annex 3).

The environmental criteria defined by the decision tree models were applied to the gridded environmental data to obtain maps of the associated predictions. Model predictions were mapped as both probability of presence of aggregations and as predicted presence or absence class (presence is identified by the model with a probability of presence >0.5).

The model predictions were only considered valid where the environmental variables were defined (excluding areas with missing data from the environmental layers) and were within the ranges at which the species/life stage occurred in the calibration dataset. Areas that did not satisfy these criteria were masked out in the maps (shown as grey areas). It is noted that spatial coverage by the environmental data layers was often poor in areas closer to shore (especially for data layers derived from oceanographic modelling, such as SST, SBT, SSS, NPPV, MLT), hence a better assessment of these areas is provided by the habitat proxy approach, which was developed specifically for inshore areas (see section 2.3).

For some species of higher interest (e.g. lesser sandeel, *Nephrops*, anglerfish) additional model predictions were mapped for individual years (2010, 2015 and 2020) to assess the influence of using more accurate environmental scenarios, compared to the average scenario for the period 2010 - 2020, as a basis for the prediction mapping. Resulting maps for the 2015 scenario for these species were used as baseline for the climate sensitivity assessment exploring changes in the mapped habitats under changes in the environmental conditions consistent with climate change predictions (see section 2.5).

The spatial implementation of the models was carried out in ArcGIS v10.8.1, with Excel (Microsoft Office Professional Plus 2016) used for part of the data processing.

2.2.5 Confidence assessment

Confidence is a key element associated with models and their predictions, as it provides guidance about how much the results can be trusted. In this study the confidence associated with the predicting model as a whole (overall confidence) was estimated along with the relative confidence associated with the spatial predictions within the resulting map (spatial distribution of confidence, associated to model predictions across cells of the spatial grid).

Both overall and spatial confidence assessments were based on the results of the statistical model used to derive the spatial prediction. For the overall confidence, a metric (the F1 score; Lewis and Gale 1994) was estimated from the statistical validation of the model by applying the model to the test dataset (see section 2.2.3) and comparing the resulting predictions against the true observations in the data. The F1 score (ranging between 0 and

19) measures how well the model predicts each observation into the correct class (presence or absence of aggregations), thus providing an estimate of the overall model performance. For the spatial confidence, the probability with which a class (presence or absence) is predicted in a grid cell was estimated based on the classification success as indicated for each 'leaf' of the calibrated decision tree (i.e. associated with the particular set of environmental criteria that are satisfied within the grid cell).

The above-mentioned statistical confidence was weighted by the confidence associated with the input data used to calibrate the model (to obtain overall confidence) and to obtain the mapped spatial predictions (for the spatial confidence).

For the overall confidence, this included:

- The confidence in the fish survey data used to calibrate the specific model, accounting for the ability of the survey to reliably represent the distribution of the species / life stage of interest; and
- The confidence in the environmental data used to calibrate the model, as extracted from the relevant data layers.

These two additional elements of confidence were scored according to a set of criteria reflecting sampling or mapping methodology and quality standards, timeliness and spatial coverage of the data. Where confidence maps were available for the environmental data layers, these were used to derive the scoring.

All scorings were combined into a total confidence value (standardised on a 0-1 range) associated with each model output, also taking into consideration the different weight (importance) of the different environmental variables as predictors in the individual model for the specific species/life stage.

For the spatial confidence, a similar approach was used to derive confidence rating for the individual cells of the mapped spatial grid. The statistical confidence was weighted by the confidence associated with the environmental data layers used to predict the map. In addition to spatial confidence estimates provided with the source environmental data layers, the variability of some environmental data around the mean estimate used to characterise the grid cell was also considered, along with the different importance of the variables as model predictors, as before.

The protocol for the confidence assessments is outlined in Appendix A (diagrams (c) and (d)), and further details including the scoring criteria (through expert assessment) and methods for combining all the confidence components into total confidence values for the model overall and its spatial predictions are given in Annex 3.

[9] An F1 score of 1 represents a model that perfectly classifies each observation into the correct class (hence identifying the perfect model) and a score of 0 represents a model that is unable to classify any observation into the correct class. Therefore, higher scores (closer to 1) are indicative of better model performance. See Annex 3 for details on how the F1 score is calculated.

With particular regard to *Nephrops*, it is acknowledged that using the abundance of individuals occurring on the seabed (from bottom trawl catches; see section 2.2.1) to identify burrow areas (refugia) may have some limitations, due to the highly irregular patterns in burrow emergence in this species. The direct assessment of burrows occurrence (and their density) would be a more accurate indicator for the refuge habitat of the species. As this type of data (from *Nephrops* TV surveys) was only made available at later stage in the project, they could not be used for the model calibration for *Nephrops*, but they were used for validating the resulting model map (see section 2.4.1). The limitation in using *Nephrops* catches to indicate refugia (burrow distribution) was taken accounted for when allocating confidence to the fish survey data used in the model.

2.3 Habitat proxies

The data collated for EFH modelling (see sections 2.2.1 and 2.2.2) had poor coverage of inshore coastal areas (especially internal waters), and therefore the EFH models were limited in their ability to assess those species which may preferably use habitats in these areas as EFH. To address this gap and complement the EFH model assessment, habitat proxies were identified for species using inshore waters.

This assessment relied on the availability of sufficiently detailed information from the literature review to allow the identification of habitat types with which the species associates for specific functions (refugia, nursery, spawning). In most cases, the evidence of this association was based on the species/life stage having been found in the habitat (or associated environmental conditions), but it was rarely based on abundance (e.g. considering aggregations) or other estimates (e.g. growth and survival rates) that may contribute to define the added value of an EFH (see section 1.2). Therefore, the habitat proxies in this assessment identify more generally the functional habitat of a species (habitat B in Figure 2), but they do not necessarily correspond to EFH, although it is likely that parts of the identified habitat function as EFH for the species (habitat C as a subset of habitat B in Figure 2).The process undertaken in the habitat proxy assessment and to obtain the resulting spatial outputs is summarised as diagrams in Appendix A, with further details on the various phases of the process being provided in the sections 2.3.1 to 2.3.2 below.

2.3.1 Habitat proxy assessment

In order to ensure standardisation through the habitat proxy assessment, the EUNIS habitat classification system was used to identify habitat types. The EUNIS habitat classification is widely used, with broad scale maps being available, covering most of the UK waters, thus allowing the results of the habitat proxy assessment to be widely implemented.

Marine EUNIS habitat types defined at Level 3 and 4 were used as potential proxies, including habitat types within the EUNIS marine habitat (code A) and marine habitat complexes (code X) classes. The assessment focused on inshore waters around the UK and, therefore, EUNIS habitats classed as offshore (deeper) circalittoral habitats (usually at a depth >60 - 80 m) were excluded *a priori* from the assessment, along with habitat types that are characteristics of other regions (e.g. habitats exclusive to the Baltic, Mediterranean, Black Sea and Pontic regions, and ice-associated habitats). A full list of the marine EUNIS habitat types considered for the habitat proxy assessment (including habitat code and description) is given in Appendix B.

In order to undertake the assessment, a spreadsheet (species-habitat matrix) was created in Microsoft Excel (Figure 8) where EUNIS Level 3 and Level 4 habitat types were scored according to their association with a species life stage or the species as a whole, thus potentially functioning as nursery habitats (considering juveniles), spawning grounds (considering adult spawners or spawned eggs) or refugia (e.g. for sandeel). For benthic shellfish species where the different functions may be provided by the same habitat, the assessment was undertaken for the generic species' habitat. EUNIS habitat types were rows in the matrix, and the species life stage were columns (Figure 8).

Overarching category (Eunis Level 2)	Eunis Habitat Level 3	Eunis Habitat Level 4 *(a brief description is given in cell notes but see web link in Column D for full*	Habitat Code (incl. Web link to full description)	Cod (juvenile) Nursery function (overall confidence Moderate)	
				Score	Confidence
Littoral sediment	**Littoral coarse sediment**		A2.1	**2**	**M**
		Shingle (pebble) and gravel shores	A2.11	2	M
		Estuarine coarse sediment shores	A2.12	2	M
	Littoral sand and muddy sand		A2.2	**1**	**L**
		Strandline	A2.21		
		Barren or amphipod-dominated mobile sand shores	A2.22		
		Polychaete/amphipod-dominated fine sand shores	A2.23		
		Polychaete/bivalve-dominated muddy sand shores	A2.24		
	Littoral mud		A2.3	**1**	**L**
		Polychaete/bivalve-dominated mid estuarine mud shores	A2.31		
		Polychaete/oligochaete-dominated upper estuarine mud shores	A2.32		
		Marine mud shores	A2.33		
	Littoral mixed sediments		A2.4	**2**	**M**
		Hediste diversicolor dominated gravelly sandy mud shores	A2.41		
		Species-rich mixed sediment shores	A2.42		
		Species-poor mixed sediment shores	A2.43		
	Coastal Saltmarshes and saline reedbeds		A2.5		
		Saltmarsh driftlines	A2.51		
		Upper saltmarshes	A2.52		
		Mid-upper saltmarshes and saline and brackish reed, rush and se	A2.53		
		Low-mid saltmarshes	A2.54		
		Pioneer saltmarshes	A2.55		
l sediment	**Littoral sediments dominated by aquatic angiosperms**		A2.6	**3**	**M**
		Seagrass beds on littoral sediments	A2.61	3	M

Figure 8. Excerpt from the scored matrix created to undertake the habitat proxy assessment (the excerpt only shows data for some of the littoral sediment habitats for juvenile cod).

An expert assessment was applied to the information obtained from the literature review, and a score between 1 and 3 was allocated to the habitats in the matrix for each species/life stage considered. Scores were only allocated where sufficient supporting evidence of an association of that habitat with the specific life stage existed. A higher score was assigned to habitats which were identified in the literature as important/primary habitats with which the species/life stage associated (e.g. where the species/life stage was most frequently found, or with higher abundance (if this was assessed) in a study). A lower score was assigned to habitats for which there was evidence of use, but not with the same intensity (e.g. frequency or abundance) as other habitats. In a limited number of occasions, a score of 0 could be attributed to habitats for which there was definitive evidence/knowledge that they are not suitable to support a specific life stage.

A measure of confidence (Low to High) was attributed to all scores assigned to individual habitats, based on expert assessment. This reflected the frequency of evidence available across the reviewed literature which supported the assigned score for the species-habitat association (e.g. where many papers reported a strong association of a species with a habitat, a higher confidence was assigned compared to the case where only fewer papers reported a similar level of association). The ability to match environmental conditions identified in the literature as suitable for use by the species/life stage with specific habitat types (as defined at the selected EUNIS Levels 3 and 4) also contributed to the confidence assessment (e.g. a lower confidence was assigned where the habitat/environmental conditions for a species/life stage were identified in generic terms in the literature, making the correspondence with a particular EUNIS habitat type more uncertain compared to evidence on more detailed habitat/environmental preferences). An overall confidence (Low to High) was also assigned based on expert assessment, taking into consideration the amount and detail of information supporting the species assessment as a whole (across all habitats).

Scoring was prioritised at the highest habitat resolution in the matrix (EUNIS Level 4 habitats), where possible, and the score for the parent EUNIS Level 3 habitat was derived as the highest score (and associated confidence) available across the assessed EUNIS Level 4 habitats within. Where the assessment was not possible at the finer habitat resolution (e.g. insufficiently detailed information on the species-habitat association), the EUNIS Level 3 habitat was directly scored, where possible.

The scoring (and associated confidence) was initially undertaken based on expert judgement of the project team as informed by the literature review. The assessment was subsequently reviewed and validated through stakeholder consultation with fish and shellfisheries experts (see section 2.4.2 for a list of the stakeholders consulted). Stakeholders were only asked to assess the generic provision of EFH functions for a species by a habitat typology occurring in inshore areas around the entire British Isles (irrespectively of their geographic distribution).

The final species-habitat matrix resulting from this assessment was produced into an Excel tool (see attached worksheet "EFH_HabitatProxies_MATRIX)" that allows to explore the scoring and filter the matrix based on species, life stage etc.

It is of note that a study developing EFH indicators has been undertaken concurrently to this one by Natural England[10] (Wells et al. 2022). Although the two studies have been undertaken independently, coordination in the tools used between projects was considered important for UK-wide consistency of the approach. Therefore, common structured tools for the literature review (tables) and the habitat proxy assessment (matrix based on EUNIS Level 3 and Level 4 habitats) were used. The Natural England study focused on species distributed along the freshwater-marine gradient, up to the 12 nm limit in English waters, hence had limited overlap with the species considered in this study. However, where an overlap occurred, the habitat proxy assessment undertaken for the Natural England project was also considered for the review and validation of the assessment in this study.

2.3.2 Mapping

Maps of habitat proxies for fish and shellfish species in inshore waters were produced as a spatial application of the habitat proxy assessment. The scoring system (and associated confidence) for individual species/ life stages was applied to EUNIS biotope data layers as per the assessment tool (Matrix).

EUNIS habitat datasets obtained from EMODnet were selected based on coverage of the study area and availability of habitat classification at EUNIS Level 3 and Level 4. These included broadscale data (from the EUSeaMap model) and a series of fine/medium scale layers from individual EUNIS habitat surveys. These data were processed so that habitats at the different levels of interest (i.e. Levels 3 and 4) could be layered independently. Where survey data obtained for the same area in different years were available, these were layered by EUNIS level and ordered by survey year so that the habitat classification from the most recent surveys was prioritised.

In order to fully represent the scoring (and associated confidence) from the assessment matrix, the habitat proxy maps were drawn as follows:

- Precedence was given to biotopes identified at the finer level (Level 4), which were coloured according to the combination of score and confidence received in the matrix.
- Where the Level 4 habitat was not scored in the matrix (e.g. due to lack of evidence), the score for the parent habitat at Level 3 was attributed, if assigned in the matrix.
- Any habitat in the map that was considered in the matrix, but that did not receive a score 1-3 was coloured grey in the map. This includes both habitats scored as 0 (unsuitable) or not scored (suitability unknown).
- Where the habitats in the map were identified at a coarser level than Level 3, or where habitats were classed as Level 3 or Level 4 but not assessed in the matrix (e.g.

[10] Anita Franco, the project lead for this present study was also involved as an expert in that project.

offshore (deeper) circalittoral habitats, mixed habitat classification), these were masked out in the map.

The drawing rule applied for mapping is summarised graphically in Figure 9.

The habitat proxy assessment was applied to the EUNIS habitat data layers clipped to the wider EFH model area (Figure 7). However, due to the fine scale of the inshore habitat data, a smaller case study area was selected for mapping purposes as a demonstration of the application of the approach and to ensure the detail of biotopes at EUNIS Level 4 could be viewed. The case study covers the inshore areas on the west coast of Scotland (Figure 10). It was selected because additional data from inshore fish surveys could be obtained for this area during the project, which allowed to undertake validation of the maps thus produced (see section 2.4). Only for one species (herring spawning grounds) habitat proxy maps were produced covering all Scottish inshore waters as an example of the full extent of the results.

The integrated base layer showing the coverage and distribution of EUNIS habitats (Level 3 and Level 4, as considered in the assessment Matrix) in the case study area is shown Figure 10.

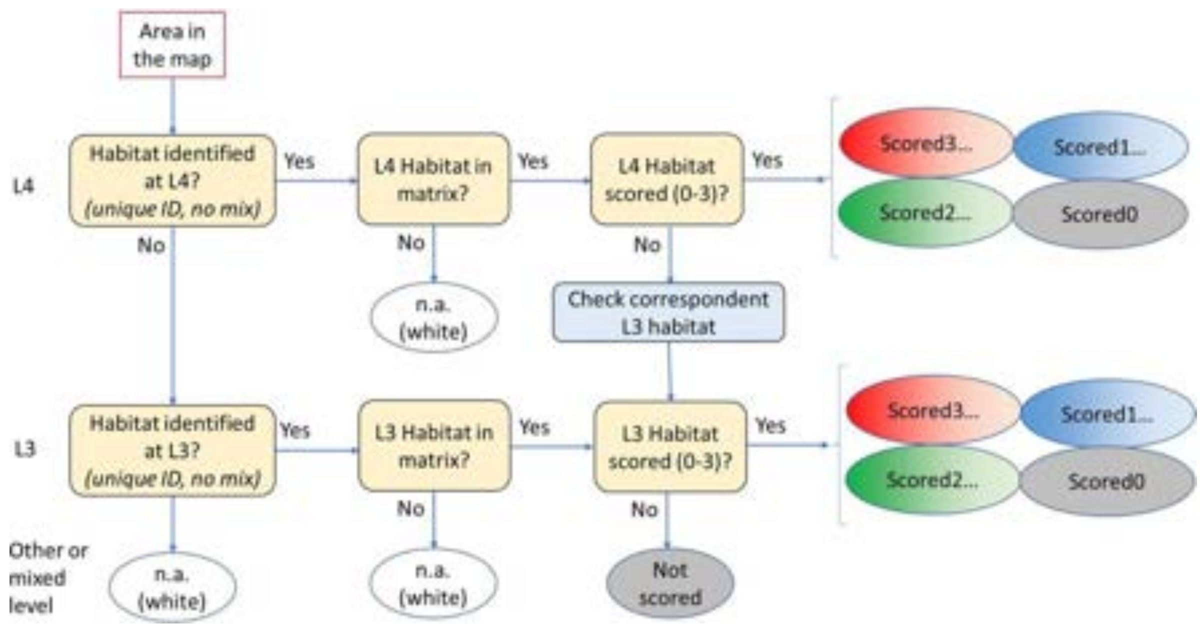


Figure 9. Summary of drawing rule applied to the mapping of habitat proxies based on EUNIS habitat data layers (L3, Level 3 habitat type; L4, Level 4 habitat type). Resulting gradient colours indicated reflect the colour shading in the maps as based on the combination of score and confidence level.

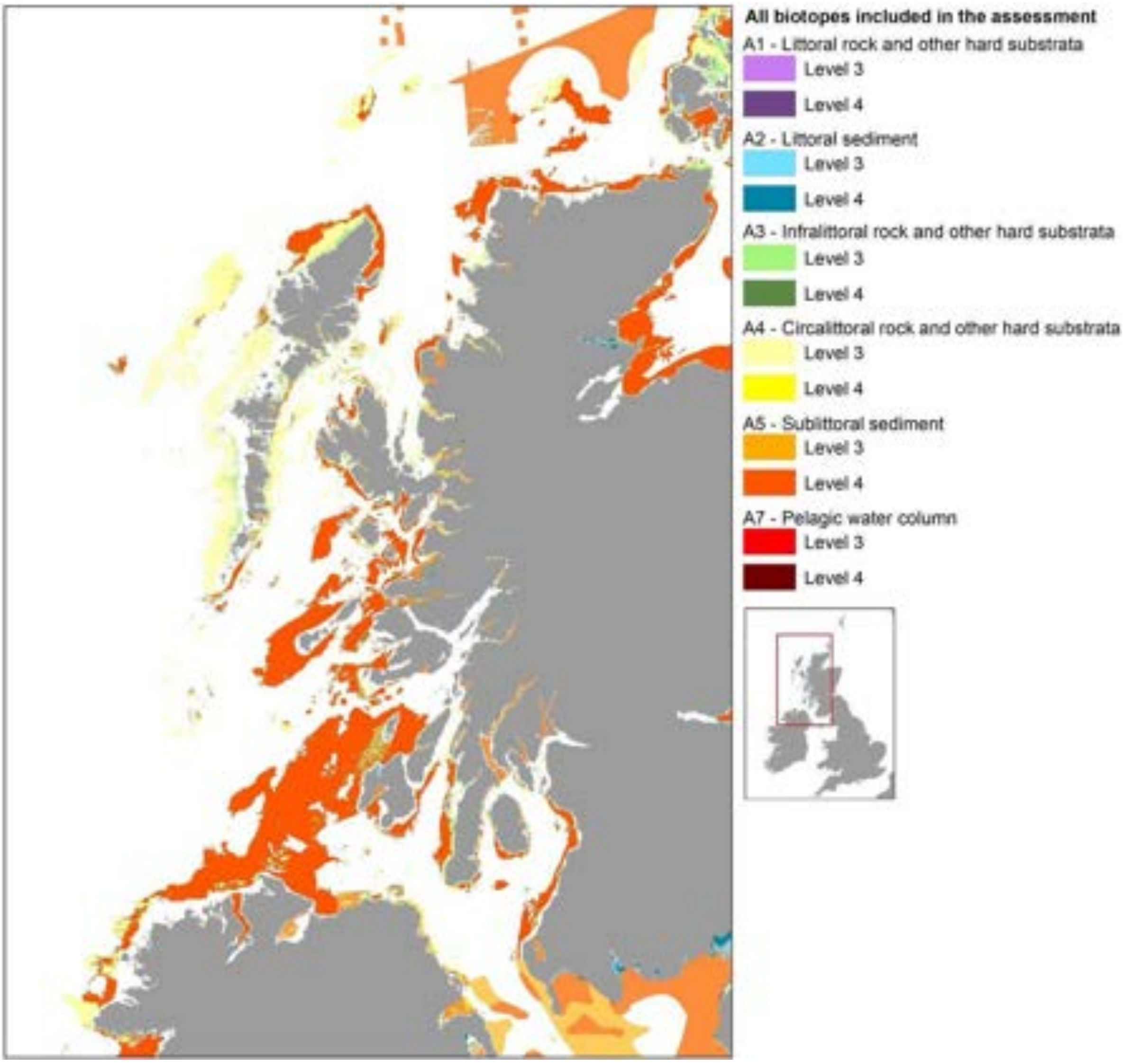


Figure 10. Coverage of the assessed EUNIS habitats in the case study area (west coast of Scotland). Only habitats included in the assessment (Matrix) are shown (coloured) at the highest level available (between Level 3 and Level 4; see Appendix B for details on the individual habitats considered). White marine area in the map includes areas covered by habitat types that were not considered in the matrix assessment (e.g. A5.27 deep circalittoral sand) or areas for which there is no habitat classification available at either Level 4 or Level 3.

2.4 Maps validation

2.4.1 Additional survey data and evidence

Additional survey data were collated to validate the maps obtained for fish and shellfish species from both data-based models and habitat proxy approach (Table 6).

For sandeel and anglerfish, additional data were obtained from the 2021 survey undertaken within the same survey programmes that were used for the model calibration (Sandeel dredge surveys and SIAMISS, respectively). This year of data could not be included in the model calibration as some of the environmental data layers for 2021 were not available at the time of the analysis. The survey locations for these data are shown in Figure 4.

For *Nephrops*, additional data were obtained from the *Nephrops* TV surveys undertaken by Marine Scotland Science in Scottish waters (Figure 11). These video surveys are restricted to suitable *Nephrops* habitat (identified based on sediment characteristics or fishery VMS data), and they measure *Nephrops* burrow density rather than individuals, thus providing a direct assessment of the refugia resource.

Survey data from the West Coast of Scotland Demersal Fish Project (WCDF; Ramiro Sánchez et al. 2015) were also obtained for the map validation. This was a joint industry/science project (managed by Marine Scotland Science and the Scottish Fishermen's Federation Services Limited) to better understand the distribution and abundance of demersal fish on the west coast of Scotland. Offshore and inshore quarterly trawl surveys were undertaken between December 2013 and November 2014 (Figure 11). These data were used to validate both model and habitat proxy maps for different fish species (Table 6).

To ensure comparability of these additional survey data with the model prediction maps, the life stages of interest (selected by body size and season; Table 3) and their aggregations (as top quartile CPUE catches in the survey) were identified using the same method applied to the modelled data (see section 2.2.1 for details). Similarly, the top quartile of density of burrows in the *Nephrops* TV survey was used to identify aggregations. The distribution of aggregations identified from these additional survey data were mapped for comparison with the maps obtained from the modelling approach.

For comparison with the habitat proxy maps, the additional data from all the seasons available for the WCDF survey were considered to identify the actual occurrence of the mapped species in the case study area. The smallest cut-off body size as in Table 3 was used to identify juveniles in the WCDF survey dataset for the mapped species. The distribution of the catches from these additional survey data were mapped for comparison with the maps obtained for the west coast of Scotland from the habitat proxy approach.

Table 6. List of fish and shellfish species for which data from additional surveys were available for map validation. Seasonality and life stage for the data selection are indicated.

Common name	Life stage	Additional survey data sources
Lesser sandeel	any size/stage	Sandeel Dredge Survey 2021 (December)
Nephrops	any size/stage	*Nephrops* TV survey (burrows) 2007-2016 (any season)
Plaice	Juvenile	WCDF 2013/14 (Q3 / all seasons)
Lemon sole	Juvenile, 0-group	WCDF 2013/14 (Q4)
Common sole	Juvenile, 0- and 1-groups	[1]
Anglerfish	Juvenile, 0- and 1-groups	SIAMISS 2021 (Q2) and WCDF 2013/14 (Q2)
Whiting	Juvenile, 0-group	WCDF 2013/14 (Q3+Q4/ all seasons)
	'Running' adult	[2]
Cod	Juvenile, 0-group	WCDF 2013/14 (all seasons)
	'Running' adult	[2]
Haddock	'Running' adult	[2]
Norway pout	'Running' adult	[2]
Blue whiting	Juvenile, 0-group	WCDF 2013/14 (Q3+Q4)
Hake	Juvenile, 0-group	WCDF 2013/14 (Q3+Q4)
Saithe	Juvenile, 1-group	WCDF 2013/14 (all seasons)
Sprat	Juvenile, 0-group	WCDF 2013/14 (Q3+Q4/ all seasons)
Mackerel	Juvenile, 0-group	WCDF 2013/14 (Q3+Q4)
	Eggs, early stage	WCDF 2013/14 (Q3+Q4)
Long finned squid	Juvenile, immature/recruits	WCDF 2013/14 (Q3+Q4)
Thornback ray	Juvenile, 0-group	WCDF 2013/14 (all seasons)
Spotted ray	Juvenile	WCDF 2013/14 (all seasons)
Spurdog	Juvenile, newborn	WCDF 2013/14 (all seasons)

Table footnotes: [1] There were doubts on the species identification for common sole in the WCDF survey and therefore data for this species were not considered. [2] Data available from the WCDF survey did not allow the identification of 'running' individuals in the catches.

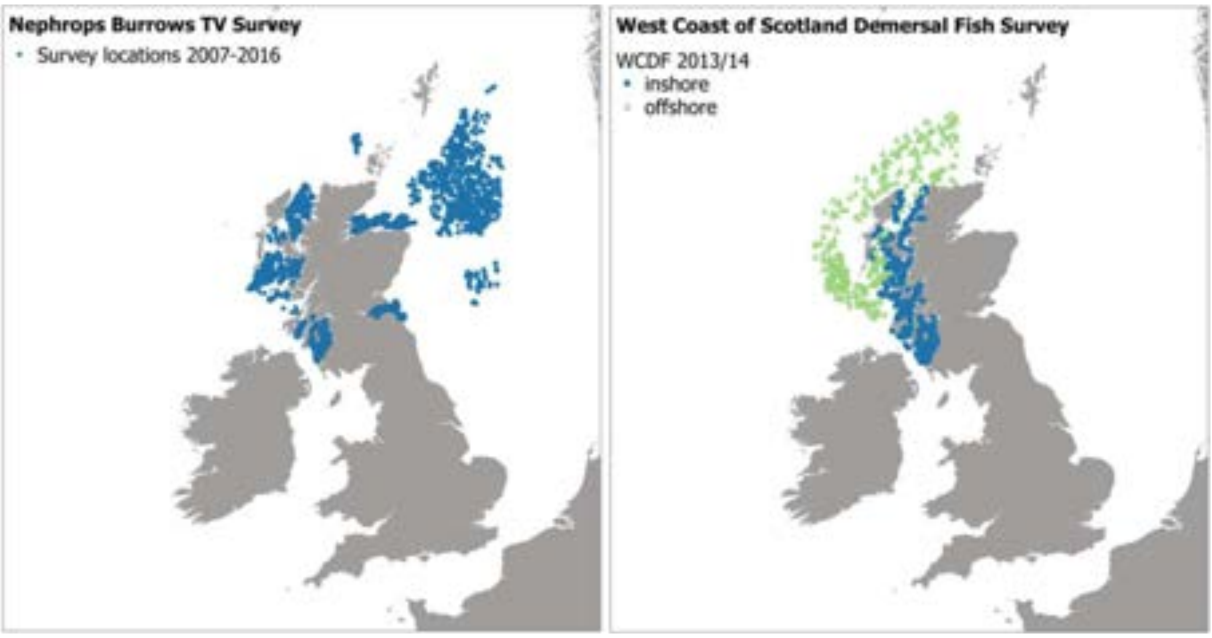


Figure 11. Survey locations for the *Nephrops* burrows TV survey 2007-2016 (left) and the West Coast of Scotland Demersal Fish (WCDF) 2013/14 survey (right) as used for map validation.

For herring, joint industry/science herring surveys have been undertaken in the western British Isles (ICES Divisions 6a, 7bc) since 2016 with the aim of improving the knowledge base for the herring spawning stock components in these areas and support ICES herring stock assessments (Mackinson et al. 2017, 2018, 2019, 2020, 2021). This includes acoustic surveys on known active spawning grounds, with targeted trawling to collect biological information (species confirmation, length/age, maturation state) and ground truth the acoustic data. As the information about the spawning component is given at an aggregate level by Area/Strata and cannot be disaggregated at sampling unit level, data obtained from these surveys were not directly suitable for modelling or mapping aggregations of spawning herring at the higher spatial resolution as used in the present study. Consultation with the coordinator of the surveys was undertaken instead for map validation (see section 2.4.2). Summary information on spatial distribution of herring spawning in Scottish waters, as recently mapped by Frost and Diele (2022), combining evidence from various current and historic surveys, was also used for the map validation.

Similarly, additional evidence including, for example, known areas specifically designated or managed to protect a species (or its life stages) was obtained from the literature (also including policy documents/reports) and used to inform the map validation (Appendix C).

2.4.2 Stakeholder engagement

A component of the map validation process was based on expert knowledge through stakeholder consultation as also done (MMO 2013, 2016) or called for (Aires et al. 2014) in previous projects.

Stakeholders were selected at the beginning of the project as representatives of Government agencies involved in marine conservation and management, the fishery industry, as well as academics with experience in research on fish and shellfish habitats. Stakeholders with knowledge of the species distribution and data within Scottish waters were prioritised, but the stakeholder selection was also extended to expertise available UK-wide. The list of affiliations of the stakeholders engaged in the project is given in Table 7.

Table 7. Affiliations of the stakeholders involved in the project, with number of consultees shown.

Government agencies and their scientific advisors
Marine Scotland Directorate (Marine Scotland Science and Marine Planning and Policy divisions, incl. Marine Licensing and Operations Team (1), Fisheries Policy Team (1), MARLAB Stock Assessment and Modelling Group, Pelagic Fisheries Group), 4
NatureScot, 1 (1)
Joint Nature Conservation Committee (JNCC), 1 (1)
Marine Management Organisation (MMO), 1 (1)
Natural England (NE), 1 (1,2)
Centre for Environment, Fisheries and Aquaculture Science (Cefas; Offshore Wind Evidence and Change Programme project), 1 (1)
Industry
Scottish White Fish Producers Association (SWFPA), 1
Scottish Pelagic Fishermen’s Association (SPFA; Industry Herring Survey West British Isles), 1
Scottish Fishermen's Federation (SFF), 1 (1)
National Federation of Fisherman's Organisations (NFFO), 2 (1)
Regional Inshore Fisheries Groups (RIFG), 1 (1)
Communities Inshore Fisheries Alliance (CIFA), 1 (1)
Squid Fisher (Moray Firth), 1
Academia / Consultancies
Edinburgh Napier University (WOSHH project, West of Scotland Herring Hunt), 2
University of Plymouth, 1 (2)
APEM Ltd, 1 (2)
University of Hull / International Estuarine & Coastal Specialists Ltd (IECS.ltd), 1 (2)

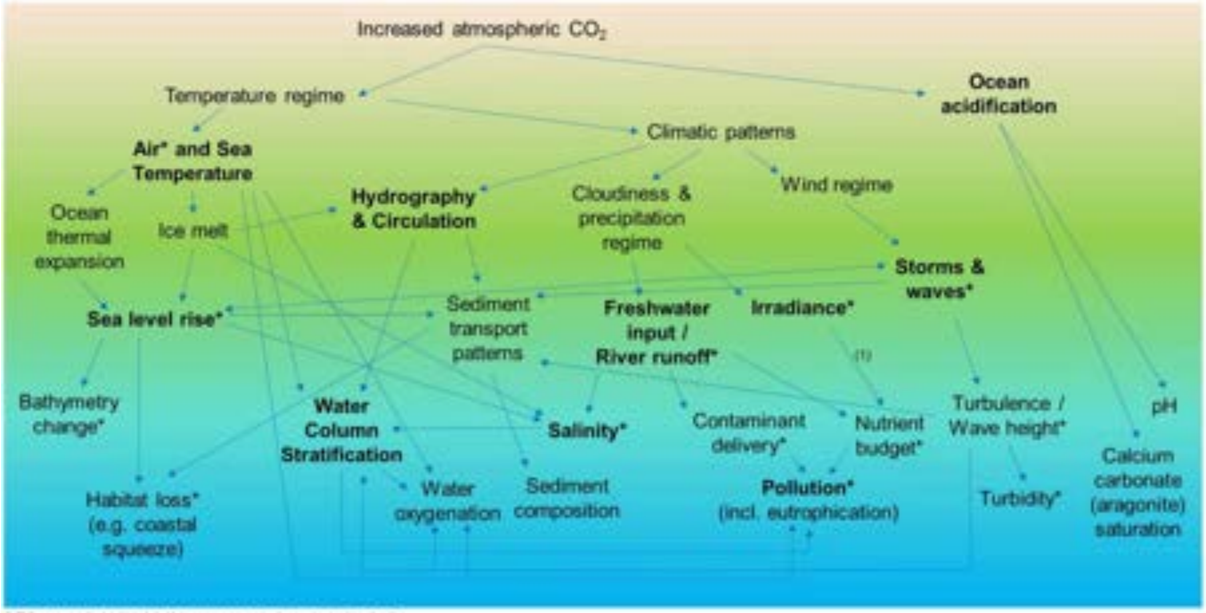
Table footnotes: (1) Member of the Project Steering Group (PSG). (2) Consultees also involved as leads (Natural England and APEM Ltd) and experts (academics) in the project on EFH indicators being developed for Natural England in parallel to this project. It is of note that the Natural England project lead was also formerly Estuarine & Coastal Fish specialist on the Environment Agency's Estuarine & Coastal Monitoring & Assessment Service, hence bringing that experience to the table as well.

Stakeholders were engaged since the start of the project to also inform data sourcing (section 2.2.1). For map validation, the maps resulting from the modelling and habitat proxy approaches were shared with the stakeholders with the request for feedback on how the maps matched their expert knowledge on the species distribution (often also arising from direct experience of surveys and observations). This feedback was transferred into the final (validated) maps by highlighting the areas where discrepancies occurred. The model/habitat proxy results were examined in more detailed in those areas to identify the reason for the mismatch, where possible (e.g. whether it was due to a limitation of the modelling tool, or of its mapping using particular environmental conditions).

2.5 Implications of climate change

This section of the report explores the possible implications of climate change for the distribution of essential fish habitats (EFH) in Scottish waters. Recent literature reviews about how climate change is expected to affect the marine environment, and Scottish waters in particular, and how these affect marine species distribution informed the assessment. In addition, the EFH models developed in the project were applied to scenarios of environmental change, to better understand their sensitivity to changes in environmental conditions that are comparable with expected climate variability over the next 100 years, and therefore the implications for the spatial distribution of EFH.

Climate change has its primary cause in greenhouse gas (primarily CO_2) accumulation in the atmosphere, which has been largely increased by anthropogenic inputs since the industrial era (IPCC 2014). This has caused the warming of air and water masses, with cascading effects on the ecosystem. Strong et al. (2017) summarised the effects of climate change on the marine environment, as shown in Figure 12. These include alterations of the physical, chemical, hydrological and ecological processes and properties of the marine ecosystem, and of their temporal regime (e.g. change in the frequency or clustering of rare or extreme storm events). Some of these changes affect the marine environment as a whole (e.g. temperature regime), others are more likely to affect inshore waters due to the proximity to land (e.g. river run-off inputs affecting salinity variability and contaminant and nutrient delivery to the sea), or to depth (e.g. wave action, sea level rise).



* Effect mediated by biotic processes (primary production)

Figure 12. Effects of climate change on the physico-chemical properties of the marine environment. Key climate change pressures are indicated in bold. Asterisks identify pressures and associated effects on the physico-chemical processes and variables that are relevant only to marine seabed in coastal areas (including intertidal and shallow subtidal habitats in estuarine and marine environments), as opposed to the other elements that are relevant to both coastal and marine (Continental Shelf) areas. From: Strong et al. (2017).

The influence of climate change on the ecology of the marine environment (also including inshore waters, such as estuaries and coastal areas) is complex and varied (Birchenough et al. 2013, Elliott et al. 2015). Fish (and shellfish) experience climate through temperature, winds, currents and precipitations, with the addition, in inshore areas, of changes in the hydrological regime, saline variability, water quality and habitat loss (Ducrotoy et al. 2019). These abiotic changes may solicit physiological and behavioural responses in the biota, altering the performance of individuals at different life stages or from different populations, influencing dispersal and recruitment and affecting species interactions within communities (see review by Ducrotoy et al. 2019 for details). Ecological effects may occur at individual, population and community levels, possibly affecting the productivity and functioning of aquatic ecosystems.

Changes in the marine environmental characteristics (e.g. water temperature, salinity, depth due to sea level rise) may alter the suitability of the habitat available to fish and shellfish in an area. The effects can vary between species or even between different life stages or populations of an individual species, for example due to the variability in their thermal tolerance range (Figure 13; Rijnsdorp et al. 2009, Freitas et al. 2010, Pörtner and Peck 2010). This may result in shifts in the geographical distribution of these species and their preferred habitats. It has been assumed that global warming, combined with local-scale processes, have led to the northward migration of marine fish along the northeast Atlantic seaboard over the last 30 years, hence affecting the distribution of their estuarine nursery grounds in this region (Nicolas et al. 2011). In the North Atlantic, the increased rate of immigration of southern species of marine fish has also been related to the warming of the water over the last 40 years (Stebbing et al. 2002). However, the effect recorded in an area may vary depending on the species, and their interaction with the local environment and physiography, and may results in variable shifts in the distribution range of different marine species in the same area (e.g. northwards or southwards, but also longitudinally or into deeper water; Perry et al. 2005, Rijnsdorp et al. 2009, Damalas et al. 2018).

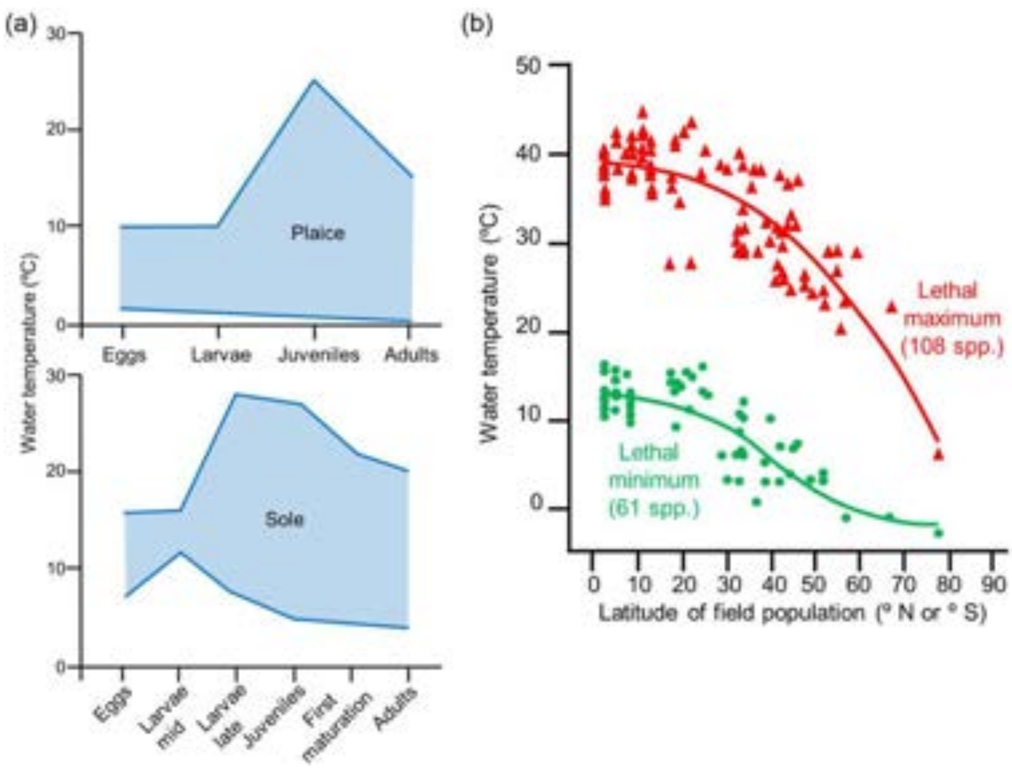


Figure 13. Change of temperature tolerance range in marine fish species (a) by life stage (modified from Rijnsdorp et al. 2009 and Freitas et al. 2010) and (b) latitude of the species and/or population (modified from Pörtner and Peck 2010).

2.5.1 Climate change in UK and Scottish waters

The effects of climate change on the marine environment are not geographically homogeneous, and therefore they may differently affect the distribution its biota and habitats in different areas.

Strong et al. (2017) reviewed the observed trends and future projection of climate change variables in the UK marine environment, and highlighted their spatial variability due to the local variability of physiographic and hydrographic conditions, and water masses characteristics. The variability in climate projections has also been highlighted within Scottish waters (Marine Scotland 2017a, b).

UK Climate Projections 2009 (UKCP09, for the period between 1970-80s and 2080s-90s, based on medium emissions scenario IPCC SRES A1B[11]) indicated a higher temperature increase (by 2.5°C to 4°C at both the sea surface and sea bottom) in the southern North Sea and coastal margins of Celtic and Irish Sea, compared to the increase in the northern North Sea (by 1.5-2.5°C at the sea surface and by 0- 1.5°C at the sea bottom). According to these projections, there is marked variation both at the regional and seasonal scale within Scottish waters, for example with sea surface temperature expected to be 1°C warmer in summer north and west of Scotland compared to 2-2.5°C warmer in the remaining seasons (particularly autumn) and areas. In the deep waters surrounding Scotland, off the shelf, temperatures are projected to change very little (Marine Scotland 2017a).

While UK Climate Projections 2009 (UKCP09) indicated +12 to +76 cm absolute sea level rise (SLR) between 1990-2095 around the UK (depending on emission scenario and including land ice melt), a lower magnitude of predicted sea level rise relative to the land level was predicted in parts of Scotland compared to southern UK due to differences in isostatic adjustment (i.e. vertical land movement). Differences could be also observed within Scottish waters (Marine Scotland 2017b), the smallest sea level rise (about 30 cm by 2095, based on central estimate UKCP09 projections for 2080-90 using the medium emission scenario) was predicted in the Clyde to Skye coastal waters, as well as the inner Firth of Forth and Moray Firth, whereas increasing rise predictions over the same period were obtained for the remainder of the mainland (approximately 35 cm rise), the Hebrides and Orkney (40 cm rise), and Shetland (about 50 cm rise).

A lower incidence of thermal stratification was also predicted for waters on the continental shelf compared to the deep sea, whereas other variables showed a lower spatial variability (e.g. salinity was projected to decrease by about 0.2 salinity units across the entire northeast Atlantic and the North Sea) (Marine Scotland 2017a, Strong et al. 2017).

2.5.2 Model predictions under environmental change

To better understand how spatial predictions of potential EFH developed in the study may respond to environmental variability, decision tree models were applied to scenarios of environmental change. This exercise was undertaken for selected species of interest, including lesser sandeel *Ammodytes marinus*, Norway lobster *Nephrops norvegicus*, anglerfish *Lophius piscatorius* (model for 0- and 1-group juveniles) and plaice *Pleuronectes platessa* (model for 0-group juveniles). The models predicted aggregations of these species (at a specific stage of their life cycle in some cases) as indicators of the potential distribution

[11] The A1B (business-as-usual medium emission scenario) describes a world that has rapid economic growth, quick spreading of new and efficient technologies, and a global population that reaches 9 billion mid-century and then gradually declines. It also relies on a balance between different energy sources. In this scenario the global mean surface temperature is expected to rise by around 1.7-4.4 ºC during the 21st century as atmospheric carbon dioxide concentrations rise to around 700 ppm. The equivalent carbon dioxide concentration (with greenhouse gas forcing from other gases also included) is estimated to rise to in excess of 850 ppm by 2100.

of habitats functioning as refugia for the sandeel and *Nephrops* species, and as nursery for juveniles of anglerfish and plaice (see main report for further details on these models).

Environmental conditions in the year 2015 were used to characterise the baseline scenario for the model application, in order to obtain more accurate predictions compared to environmental conditions averaged across multiple years. The temporal reference (seasonality) to characterise the baseline environmental scenario was selected as appropriate for each specific model (Table 8).

Table 8. Environmental scenarios used to predict potential distribution of essential fish habitat for selected models (n.a., environmental change not applied as the variable was not a predictor in the specific model).

Model	**Baseline scenario**	**Environmental change scenario**	
		Near Bottom Temperature (NBT) (1)	**Sea Level Rise (SLR) (2)**
Lesser sandeel	Dec-15	UKCP09 (winter)	n.a.
Nephrops	Q3+Q4+Q1 2015	UKCP09 (mean of summer, autumn and winter)	UKCP09
Anglerfish (juvenile)	Apr-15	UKCP09 (spring)	n.a.
Plaice (juvenile)	Q3 2015	n.a.	UKCP09

Table footnotes: Source of the mapped UKCP09 projections for Scottish waters: (1) Marine Scotland 2017a; (2) Marine Scotland 2017b.

The scenarios of environmental change were obtained from a subset of the UKCP09 marine and coastal projections over a 100 years span, based on a medium emission scenario and, where appropriate, medium probability, as available for Scottish waters from spatial layers in Marine Scotland Maps NMPi (National Marine Plan Interactive[12]). Specifically, the data layers for the following projections were sourced from NMPi:

- UKCP09 Projections - Change in near bed temperature (°C) by 2085, compared to 1975, medium emissions scenario for 1) winter; 2) spring; 3) summer; and 4) autumn.
- UKCP09 Projections - Rise in Relative Sea Level (cm), 2095 compared to 1985, medium emissions scenario and with medium probability.

Data were extracted for these maps into the model grid and the change (Figure 14) applied to relevant environmental variable (sea bottom temperature (SBT) or Depth) under the baseline scenario (year 2015), considering the relevant seasonality for the species considered (Table 8). As the relative sea level rise (SLR) predictions were only given for the

[12] https://marine.gov.scot/themes/climate-change

Scottish coastal waters, the depth change was only applied to coastal grid cells where this was assessed, whares water depth was left unchanged (from baseline conditions) in the other grid cells.

The models for the selected species were applied to both the baseline scenario and the one accounting for environmental change, in relation to the change relevant to the specific model predictors (Table 8).

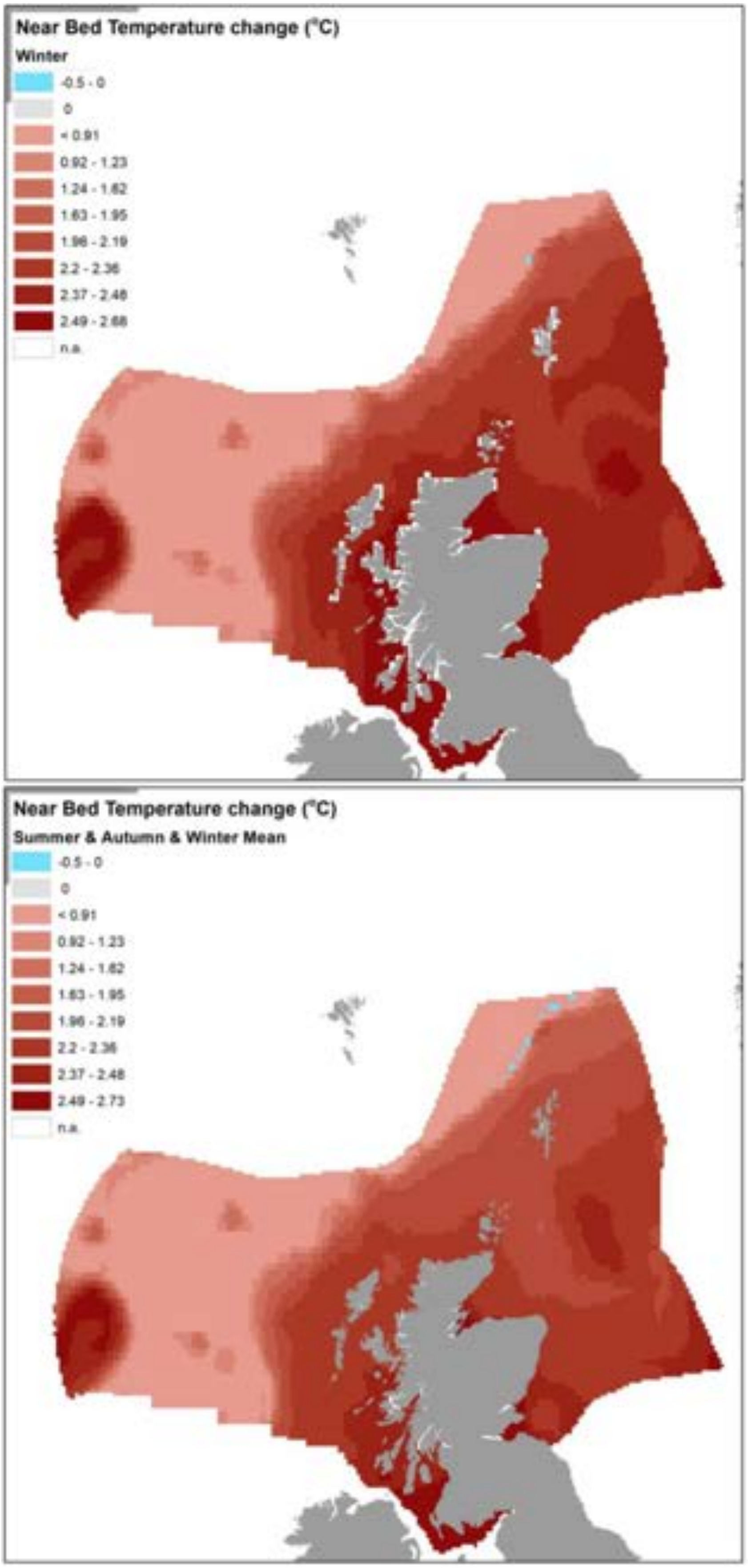


Figure 14. Environmental changes applied the spatial grid to test effects on the model predictions. Data sourced from UKCP09 projections available for Scottish waters in NMPi.

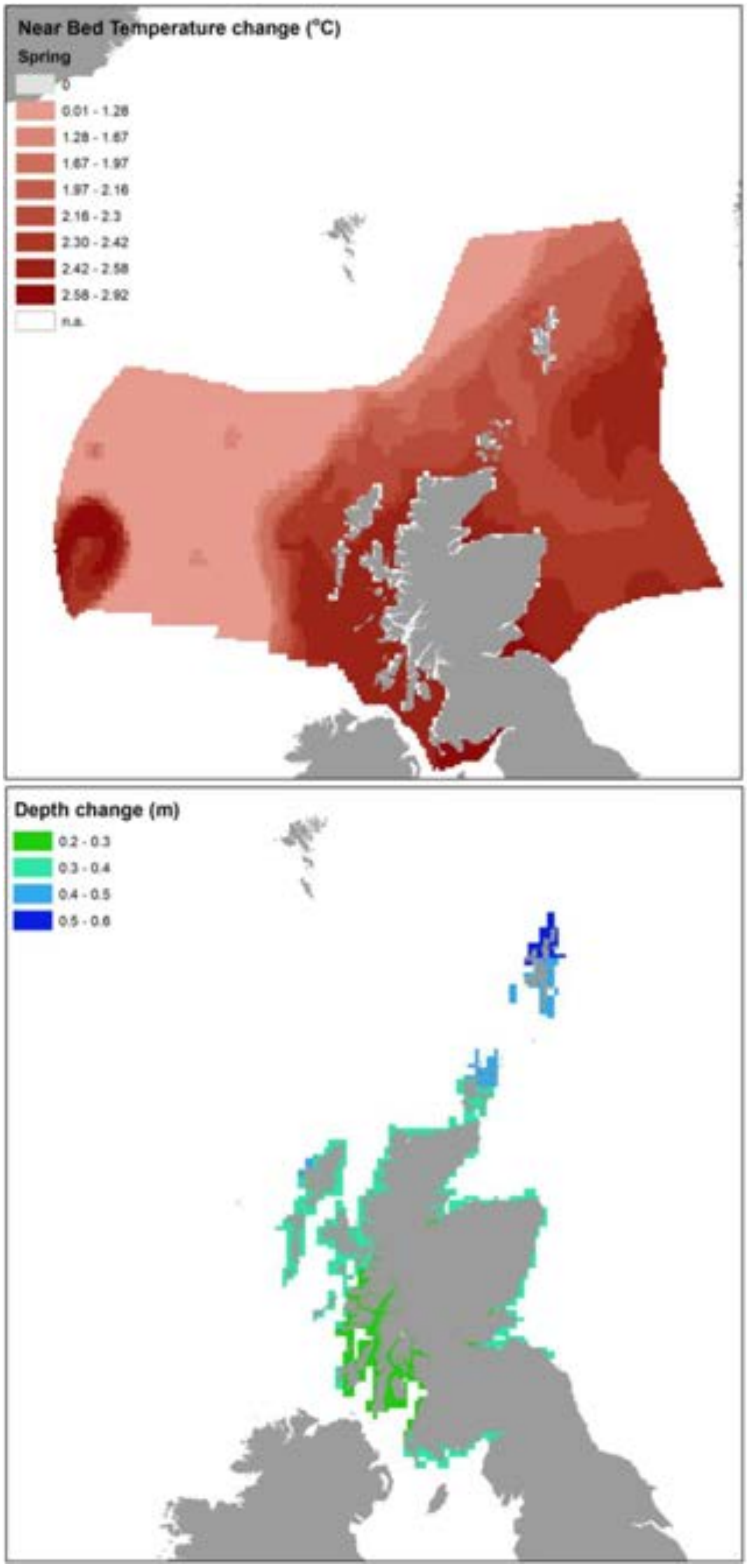


Figure 14. Continued

3. Results

3.1 EFH assessments by species

The results of the development of EFH maps for fish and shellfish species are presented by species, including the tool (model or habitat proxies) obtained from the relevant assessment(s) applied, and the associated map(s).

Assessment tools:

Where data-based models were applied, the decision tree resulting from the model is shown. This shows how the model predicted the presence (1) or absence (0) of aggregations of the selected species/life stage based on selected combinations of environmental conditions (see Annex 2 for details on how to read the decision trees). The environmental variables selected by the model as predictors of aggregations are indicated in the diagrams by using their variable short name. A full description of each variable and their measurement unit are given in Table 4. As the model predictions were considered valid only within the range of environmental conditions and substratum types represented in the survey datasets used to calibrate the models, these ranges are also given for reference. Variables in bold indicate variables that were selected as predictors by the model.

Where the habitat proxy approach was used, the habitat types identified for the species and its key life stage(s) are listed. Only the most important habitats (i.e. habitats that received a higher score in the assessment) are shown. The reader should refer to Appendix B and to the Habitat Proxy Matrix (Excel spreadsheet "EFH_HabitatProxies_MATRIX") for the full list of habitats identified as relevant to the species.

Maps:

The map(s) presented in this report for each species combine the results from different components of the study, thus providing an integrated view of the distribution of the species and their potential essential habitats in Scottish/UK waters. See Appendix A (diagrams (f), (g) and (i)) for an outline of the process applied to combine the multiple lines of evidence into the spatial outputs presented here.

Where data-based models were applied, the map combines different evidence layers (Appendix A, diagrams (e), (f) and (g)):

- The actual distribution of the species/life stage aggregations in the 2010 – 2020 surveys (data used to calibrate the model).
  The survey data are shown in the maps as relative frequency of aggregations, i.e. the proportion of hauls in each 5 x 5 km grid cell containing aggregations. Values range between 0 and 1, indicating respectively that none or all of the hauls undertaken between 2010 and 2020 within a grid cell contained aggregations of the species/life stage of interest. These data are displayed as points in the map at the centre of each grid cell (no point is shown where there were no surveys undertaken in a grid cell). This

shows not only the spatial distribution of aggregations from the surveys, but also informs on the recurrence of such aggregations over the years. Standalone maps for this layer on calibration survey data are given in Appendix C. A breakdown of the list of survey data used to calibrate the models is given by species in Table 3 (including information on data sources and relevant seasonality for the species/life stage considered).

- The distribution of aggregations predicted by the model.
  This layer identifies the location of areas where the environmental conditions (as considered in the mapped scenario, i.e. the mean seasonal conditions over the period 2010 - 2020) are suitable for aggregations of the species/life stage, thus indicating potential EFH. Additional results from the confidence assessment have been integrated in this layer by showing both the overall confidence associated with the predicting model (in the legend) and the spatial confidence associated with the spatial predictions of presence or absence of aggregations. The detailed results on the confidence for the different components combined into the overall confidence assessment are provided in Appendix D. Grey areas in the map ("n.a." in the legend) are areas where the environmental conditions (for the mapped scenario, i.e. seasonal mean of 2010 - 2020) fall outside the ranges identified on model calibration (as shown with decision trees) and, therefore, where model predictions are not considered to be valid. The list of species/life stages for which EFH modelling was undertaken (hence associated predictions are provided in the results) is given in Table 1.

- Map validation.
  This layer shows indicative areas where a notable mismatch between the model prediction and existing knowledge of the distribution of the species was identified. This was derived from both (i) comparison with additional data/evidence (see section 2.4.1) and (ii) stakeholder consultation. As often these areas were identified through descriptions given by stakeholders, rectangles/polygons were drawn on the maps to identify these areas of mismatch of information, hence denoting areas where the confidence associated with the underlying predictions is lowered. The nature of the mismatch (where present) is summarised in reference notes shown at the bottom of the map, with further explanation given in the text of the report. Maps of the specific additional evidence used for the comparison (e.g. additional survey data) are shown in Appendix C).

Where the habitat proxy approach was applied, the maps were drawn for the case study area of the west of Scotland only. The evidence layers combined on a map include:

- The distribution of habitats (EUNIS Level 3 and 4) assessed as proxies for the habitat of the species/life stage. The results of the assessment are shown by colour-coding the habitat types according to a combination of the score reflecting the importance of the habitat and the associated confidence as allocated in the Habitat Proxy Matrix. Grey areas in the maps indicate both habitats that were scored as 0 (unsuitable for the species/life sage) or not scored (suitability unknown) in the matrix. Areas shown as white in the map cover habitat types that were not included by the matrix assessment (e.g. offshore (deeper) habitats, habitats identified at levels other than Level 3 and 4) or where no information on the EUNIS habitat was available.

- The actual distribution of the species/life stage as directly derived from survey data, including both data used to calibrate the data-based models and additional survey data, where relevant and available for the case study area. The former (calibration survey data) are displayed as described above for the model maps. The latter (additional survey data) show survey data points categorised according to the abundance (CPUE) of the life stage of interest in the catches. Standalone maps of this specific survey evidence are shown in Appendix C.

A total of 29 species (20 fish including 3 elasmobranchs, plus 9 shellfish) were assessed in the study using the data-based model and/or the habitat proxy approach. The main results are shown in detail, species by species, in sections 3.1.1 to 3.1.29, and summary tables are presented in section 3.1.30.

3.1.1 Lesser sandeel, *Ammodytes marinus*

Lesser sandeel (*Ammodytes marinus* Raitt 1934) is a small shoaling benthopelagic species which is especially important as food for top predators with a reported decrease in sandeel stocks due to the fishery off the Scottish east coast being linked with declines in the breeding success of some seabirds at adjacent colonies (Rindorf et al. 2000). Sandeels are also commercially fished in the North Sea and are designated as Priority Marine Features in Scotland's seas. *A. marinus* occurs both inshore and offshore and has a close association with the seabed due to its burrowing behaviour which provides some protection from predators. The species spends most of the time buried in the sediment, particularly during low light intensity (at night and in the winter), and only emerges into the water column during the day for feeding (and for longer time in the summer), and for spawning in winter. *Ammodytes marinus* prefers burrowing into medium to coarse sand substrata, and therefore it is often found residing at the centre of sandbanks or feeding in the water column at sandbank edges (Annex 1).

A. marinus was assessed by using the model approach, with the distribution of aggregations of the species in winter being used as indicator of potential important habitats used as refugia. The model was based on data from winter dredge surveys targeting sandeel sedimentary habitats in Scottish waters. The range of environmental conditions characterising the surveyed locations where sandeel was found is shown in the table within Figure 15, along with the decision tree resulting from the analysis. Due to the high correlation (Pearson's correlation coefficient 0.8) between depth and water column mixing (MLT) in the sandeel dataset, the latter variable only was retained in the analysis[13].

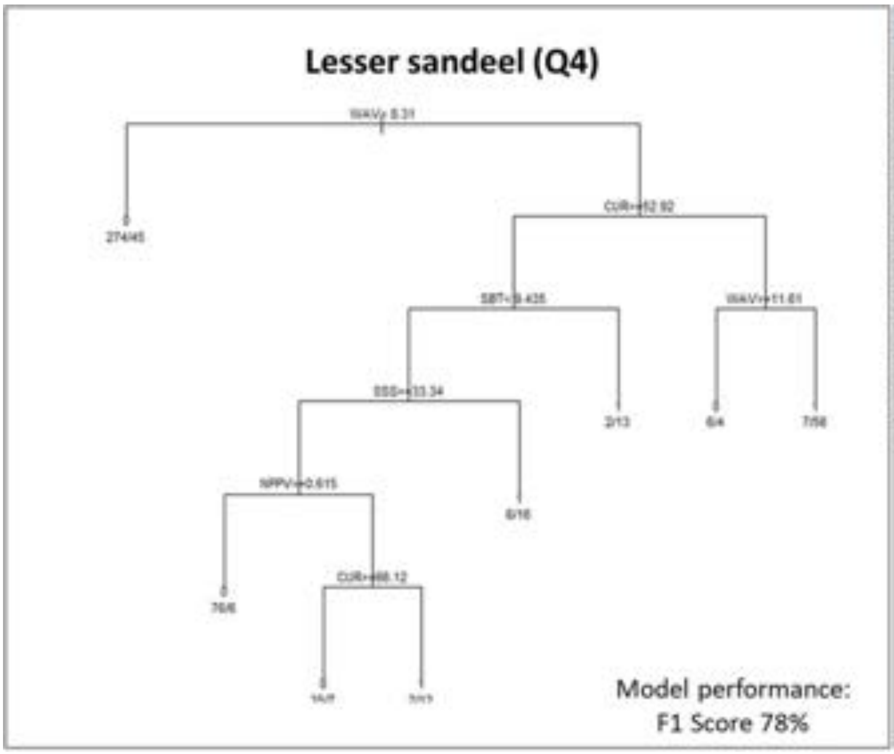
Current and wave energy at the seabed (CUR and WAV) were the most important predictors of aggregations of *A. marinus*. Low-moderate energy levels[14] generally characterised the surveyed sandeel grounds, with aggregations predicted with higher probability (0.89) in lower energy environments (wave energy between 8.3 and 11.6 N m^2/s and current energy ≤52.9 N m^2/s). Where current energy was higher than 52.92 N m^2/s, seabed temperature (SBT), salinity (SSS) and primary production (NPPV) also contributed to predicting sandeel aggregations, generally associated with higher mean winter monthly seabed temperature (≥9.4°C) or, at lower temperature, with lower salinity (<33.3) or lower primary production (<0.61 mg C m^{-3} day^{-1}) (Figure 15).

It is of note that the type of seabed (Substr) did not result as an important predictor in the model due to the fact that the surveys targeted only sandy and coarse sediment grounds.

[13] Depth was still considered in the analysis, albeit implicitly, by way of its correlate MLT. If MLT resulted as important model predictor (which it did not), this would have included the effect of Depth. The alternative approach of retaining Depth and excluding MLT from the analysis was explored, but it led to a model with lower predictive ability.

[14] Classification of current and wave energy as low, moderate or high is based on criteria defined for the EMODnet substrate layer as follows: tidal current energy is Low if <130 N m^2/s, High if >1160 N m^2/s and Moderate in between; tidal current energy is Low if <210 N m^2/s, High if >1200 N m^2/s and Moderate in between.

This relative homogeneity in the sampled substrata already representing preferred sandeel grounds led to the absence of further discrimination between sediment types by the model.



Variable	min	max
Dist	2719	65808
Depth	26.6	103.6
Slope	0.009	0.596
SBT	6.58	11.15
NPPV	0.1	6.6
SSS	32.88	35.03
MLT	10.51	99.45
CUR	6.98	306.2
WAV	0	95.31
SandbH01	0	1
StructH01	0	1
VegH01	0	0
Substr	a = "Coarse" b = "Sand"	

Figure 15. Decision tree for aggregations of lesser sandeel, *A. marinus* (Q4; full tree) and associated environmental ranges at which the species occurred in the surveys.

The model prediction applied to the mean winter environmental conditions of the period 2010 - 2020 allowed to map the potential winter distribution of aggregations of *A. marinus* and therefore of their refugia (Figure 16). The spatial coverage of the prediction was limited by the environmental ranges of the targeted sandeel grounds for which survey data were used to calibrate the model, which, for example, only included areas at a distance from the shore between 3 and 66 km. Therefore, the model predictions had poor coverage of areas closer to the shore or further offshore, and of the west coast of Scotland and the south and west coast of the UK.

Comparison with available survey data (both used for the model calibration and additional survey data for map validation; Appendix C, Figure C1 and Figure C2) as well with known sandeel grounds (Appendix C, Figure C3), as also highlighted during the consultation with stakeholders, has highlighted some inaccuracies in the map (Figure 16). These were mainly due to the failure of the map in identifying potential suitable areas for aggregation on protected sandeel grounds within the north east UK sandeel closure (where the sandeel fishery has been closed since 2000 to protect the stock; EU Regulation 227/2013) and within nature conservation Marine Protected Areas (NC MPAs) designated in Scottish waters with sandeels as the key feature. These include the North-west Orkney NC MPA, Turbot Bank NC

MPA, Mousa to Boddam NC MPA (not covered by the mapped predictions) and North-east Lewis NC MPA. The presence of aggregations of *A. marinus* in some of these areas was confirmed by survey data, with additional 2021 survey identifying further aggregation areas on the west coast of Scotland (Figure 16).

Further exploration of the model predictions showed that the inaccuracies highlighted in the map in Figure 16 were mainly due to limitations in the environmental scenario used to draw that map (environmental conditions averaged for the winter season over the period 2010 - 2020), rather than to limitation in the model predictive ability. In fact, the model predictive performance for lesser sandeel was good (78%), with the overall confidence lowered to 61% mainly due to the restricted geographical coverage of the fish survey data used to calibrate the model and the generally low confidence associated with the layer on wave energy, an important predictor in the model (Annex 3). As a result, the model for lesser sandeel aggregations was one of the models with higher confidence amongst those calibrated for the species in this study.

In turn, it appears that using the mean of winter environmental conditions over the study period 2010 - 2020 (particularly for the model predictors SBT, SSS and NPPV) provides an inaccurate representation of the actual conditions experienced by *A. marinus* over the years, thus leading to the observed inaccuracies in the map prediction in Figure 16. In fact, when predictions were applied to more accurate environmental scenarios , model predictions matched survey data more closely and known locations of sandeel grounds were observed.

An example of this higher accuracy in the model predictions is shown in Figure 17, Figure 18 and Figure 19, where the EFH model for *A. marinus* was applied to environmental conditions in December of individual years, namely 2010, 2015 and 2020. As a result, the model was able to also predict the presence of aggregations within areas that are known to include sandeel grounds, as for example off the Firth of Forth in the north east UK sandeel closure or Northwest of Orkney. The comparison between the maps in these figures also allow to appreciate the inter-annual variability in the species distribution as predicted by the model. In particular, an increase in the extent of the areas where aggregations of *A. marinus* were predicted to occur is observed between 2010, 2015 and 2020. In Scottish waters, this is observed for example along the north coast of Scotland, Northwest of Orkney, off the Firth of Forth on the east coast, and northwest of Islay on the west coast. This change is mostly due to the increase in seabed temperature (Table 9). In 2010, the seabed temperature in these areas was on average between 7.8°C and 9.0°C, and this combined with other environmental conditions such as wave energy (WAV) always >8.35 N m^2/s, mean current energy (CUR) always >70 N m^2/s, mean salinity (SSS) always >34, primary production (NPPV) mostly >0.61 mg C m^{-3} day^{-1}, or, when <0.61 mg C m^{-3} day^{-1}, often associated with current energy <66.1 N m^2/s. Under this set of environmental conditions, the model for *A. marinus* predicted absence of aggregations in most of these areas (Figure 17). In 2015 and 2020, the seabed temperature increased to values on average between 9.0°C and 9.9°C, with the mean values above 9.4°C in the north coast of Scotland and northwest of Islay in 2015, and in all areas in 2020 (Table 9). These thermal conditions, combined with wave energy (WAV) always >8.35 N m^2/s and mean current energy (CUR) always >70 N m^2/s, led to the observed increase in the prediction of presence of aggregations in these areas (Figure 18 and Figure 19).

Table 9. Mean seabed temperature (SBT) in 2010, 2015, 2020 in selected areas within Scottish waters where the predicted presence of sandeel aggregations increased over time.

Area	**Mean SBT (°C, December)**		
	2010	**2015**	**2020**
North coast of Scotland	8.75	9.52	9.54
Northwest of Orkney	8.67	9.36	9.51
Off the Firth of Forth	7.76	9.05	9.44
Northwest of Islay	9.02	9.87	9.90
Total mean	8.49	9.42	9.55

Langton et al. (2021) have also recently mapped the habitats of *A. marinus* in the Greater North Sea and Celtic Seas regions. These were based on species distribution models calibrated on Day grab surveys off the Firth of Forth, and using geomorphological variables only as predictors (depth, slope, percentage of silt and sand in the sediment). As these distributions are also based on model predictions and extrapolation, rather than on actual observations, they were not considered for the map validation in Figure 16, but a comparison was undertaken nevertheless (considering the better predictions for individual years in this study). Despite the difference in source data and in the variables selected as environmental predictors, the spatial results of both studies seem to converge in identifying areas of higher sandeel density off the Firth of Forth and the Moray Firth, north and west of Islay, along the northeast coast of Donegal and east of Dublin. However, both maps appear to fail in identifying the sandeel grounds on and east of the Turbot Bank NC MPA. The maps by Langton et al. (2021) also identified inshore areas of high sandeel density north of Lewis, which are only marginally identified in this study (Figure 16). In turn, the maps in Langton et al. (2021) seem to fail to identify sandeel habitats in the North-west Orkney NC MPA, while these are picked up by the predictions in Figure 16. Predictions for individual years in this study also identified potentially highly suitable areas for aggregations of *A. marinus* along the north coast of Scotland, which was only partially covered by the predictions in Langton et al. (2021). Finally, the maps in Langton et al. (2021) identified sandeel habitats with the widest extent and fish density on the Dogger Bank and the North Norfolk sandbanks, in the southern North Sea. As the environmental conditions in these areas were outside the range over which *A. marinus* were found in the dredge surveys used to calibrate our model (the most notable being distance from shore >66 km), our map does not cover those areas.

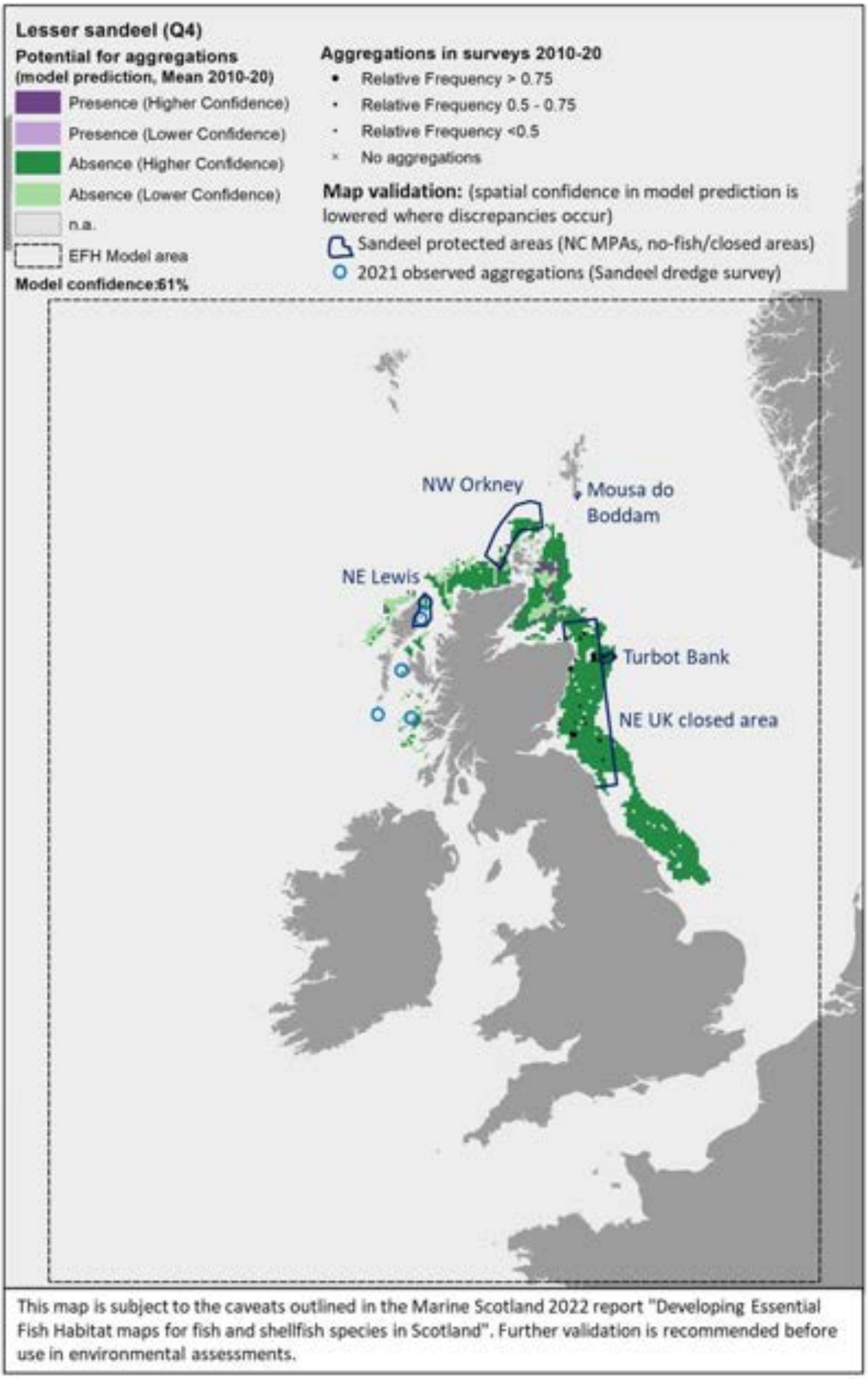


Figure 16. Aggregations of lesser sandeel, *Ammodytes marinus* (Q4): frequency of occurrence in the 2010 - 2020 surveys and model prediction (incl. confidence) based on mean environmental conditions across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons/circles.

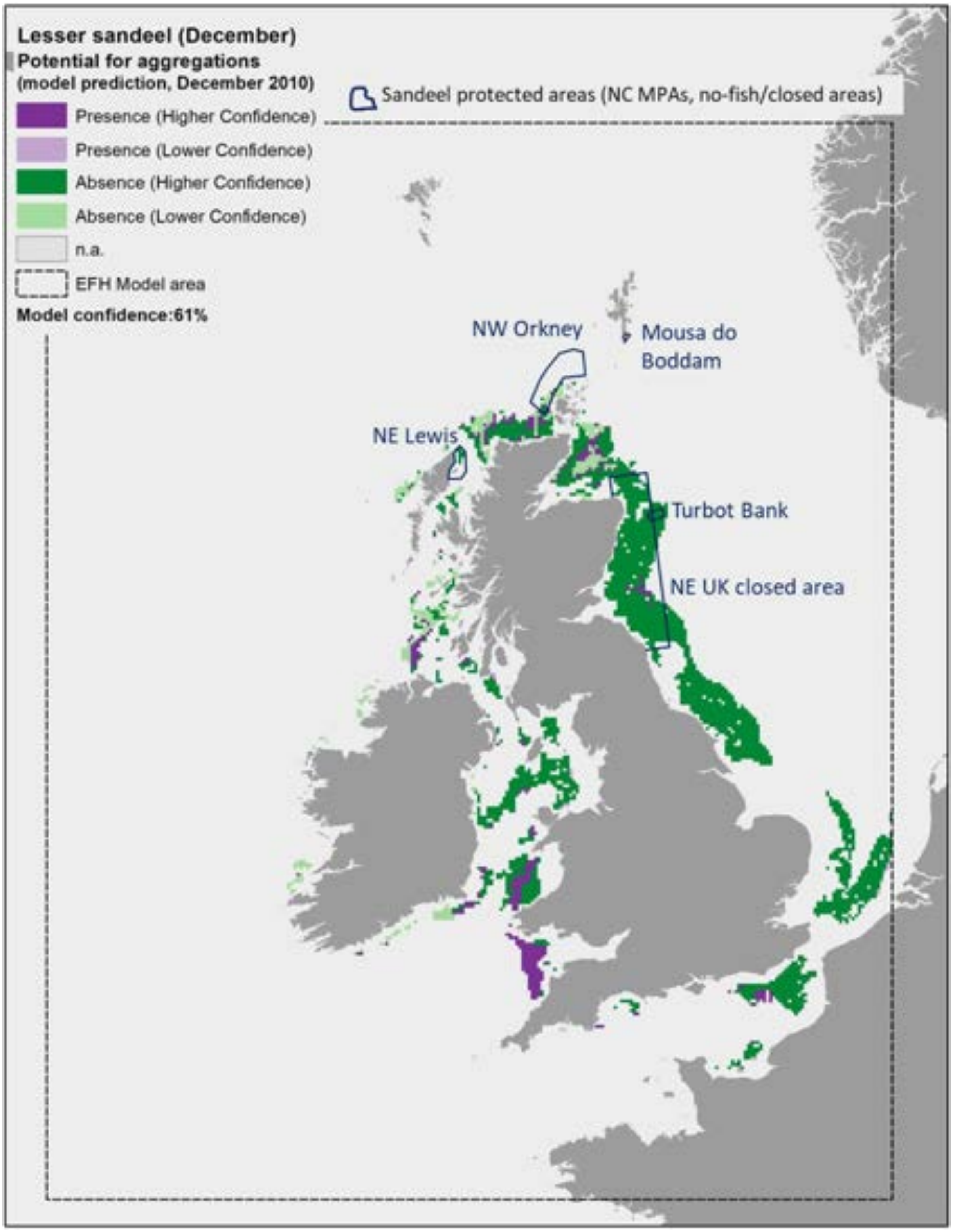


Figure 17. Aggregations of lesser sandeel, *Ammodytes marinus* (Q4): Model predictions based on environmental conditions in December 2010.

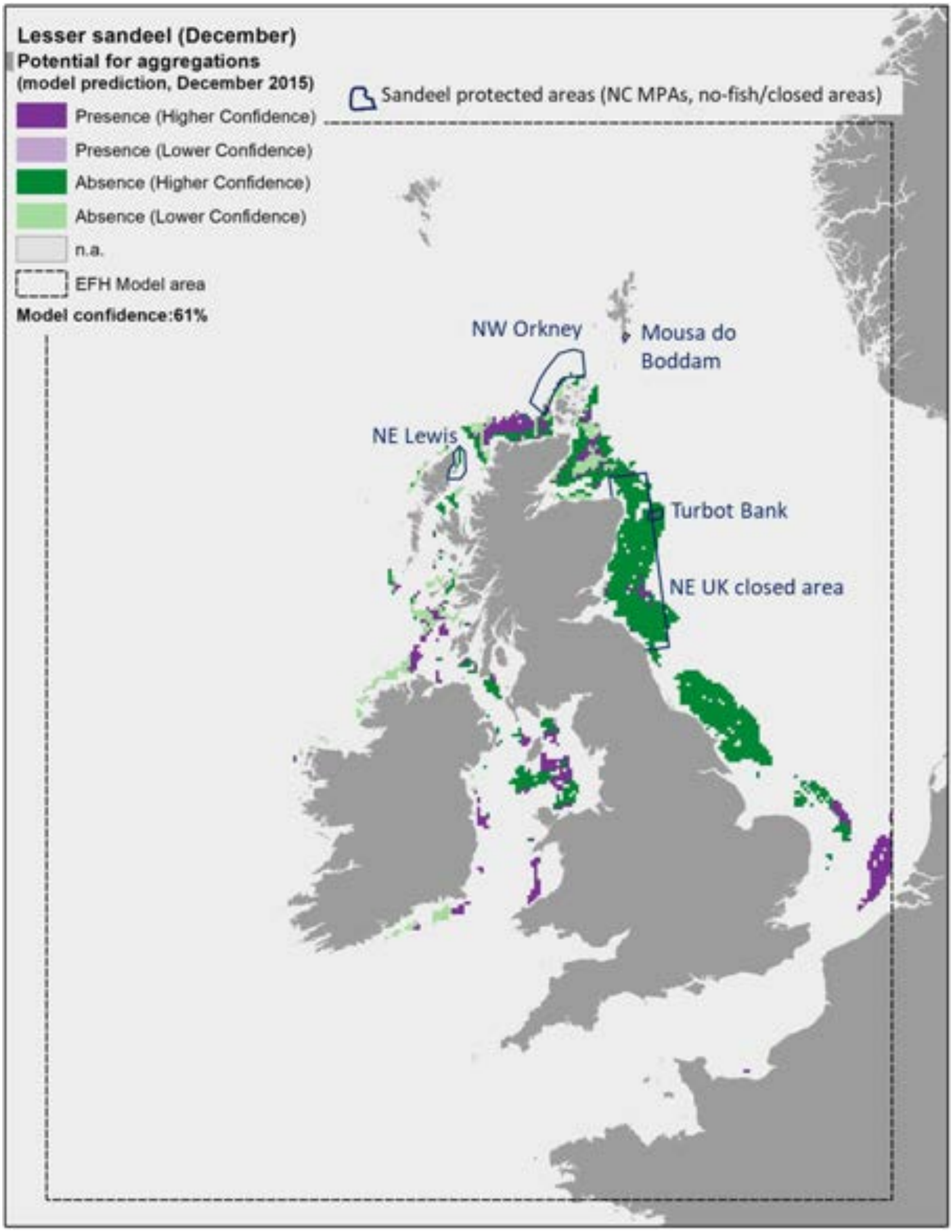


Figure 18. Aggregations of lesser sandeel, *Ammodytes marinus* (Q4): Model predictions based on environmental conditions in December 2015.

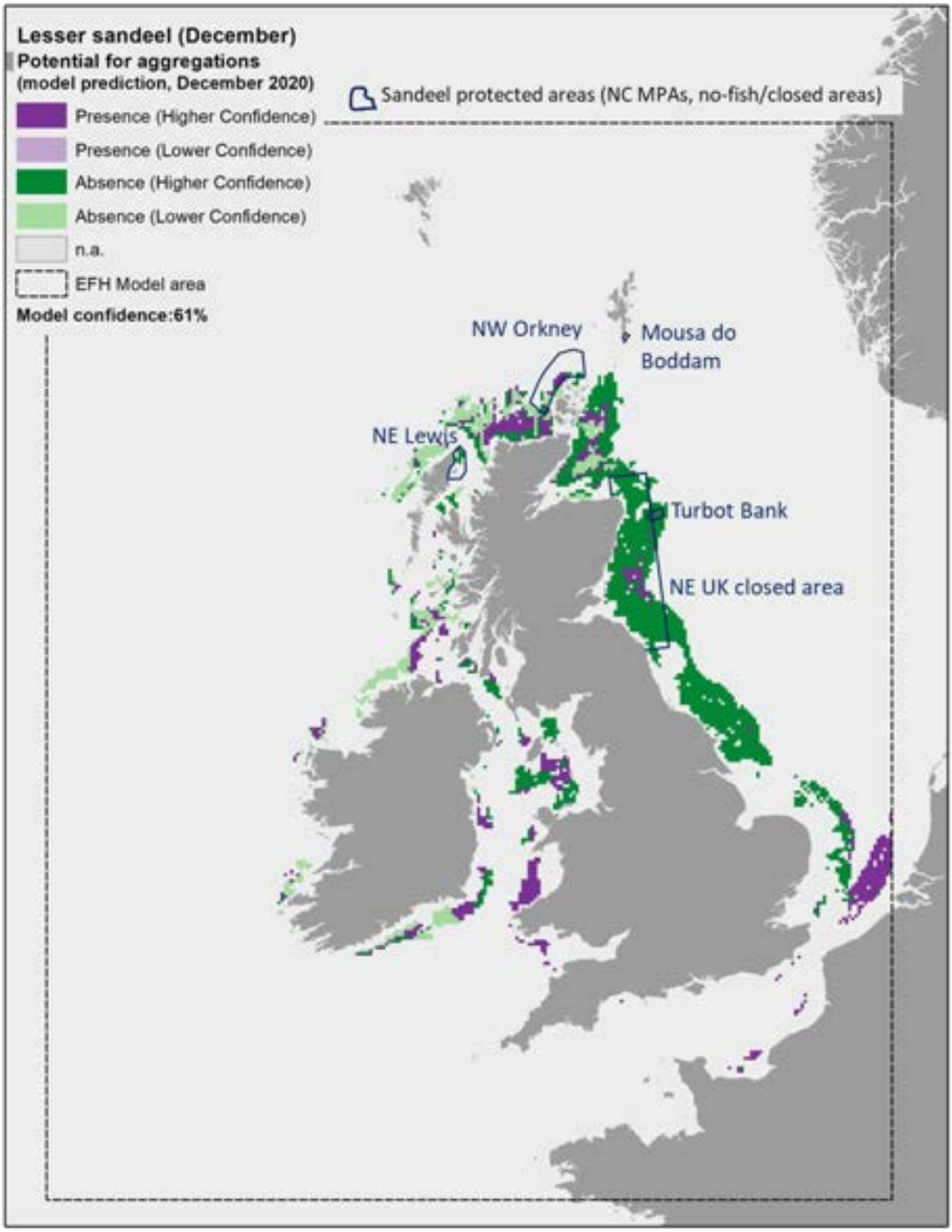


Figure 19. Aggregations of lesser sandeel, *Ammodytes marinus* (Q4): Model predictions based on environmental conditions in December 2020.

3.1.2 Small sandeel, *Ammodytes tobianus*

Small sandeel (*Ammodytes tobianus* Linnaeus 1758) has similar ecology and importance as food for top predators as the closely related lesser sandeel (*Ammodytes marinus*), except for the fact that small sandeel occurs mostly inshore (Annex 1). As such *A. tobianus* was assessed by using the habitat proxy approach to identify habitats that may potentially be used by the species as refugia.

Nineteen publications were reviewed (these often included both sandeel species *A. tobianus* and *A. marinus*, given the similarity in their ecology) and provided detailed characterisation of the species' habitat requirements (see Annex 1). This, along with expert input obtained with the stakeholder validation, led to a high confidence in the overall assessment of habitat proxies for *A. tobianus*. The most suitable inshore habitats functioning as refugia for the species were coarse sediments from the sublittoral and circalittoral zones, including where salinity is variable in estuaries (Table 10). These habitats had high scores for both suitability and confidence in the assessment (3/H). A less suitable but still high scoring habitat was infralittoral coarse sediments (2/H). Further possible habitats, scored with medium to low suitability and medium to low confidence (not shown in Table 10), included sublittoral sands and infralittoral, circalittoral and sublittoral mixed sediments.

The distribution of the inshore habitat proxies for *A. tobianus* in the case study area is mapped in Figure 20, compared with the distribution of sandeel aggregations from the 2021 Sandeel dredge survey in the area. The mapped habitat proxies seem to accurately match the occurrence of sandeel in the survey where this was undertaken, although the habitat proxies indicate wider areas than where sandeels were found in the survey. It should be noted that data from Sandeel Dredge surveys report catches for generic "sandeel". This likely includes *A. tobianus*, although *A. marinus* is considered to be predominant (ICES 2010). As the habitat requirements between the two sandeel species are very similar (see literature review, Annex 1), the map in Figure 20 can be considered to include potentially generic sandeel (multiple species) habitat occurring inshore. No stakeholder feedback was received on this map following consultation.

Table 10. Main (highest scoring) habitats potentially associated with refugia function for small sandeel, *A. tobianus*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Small sandeel – Habitat proxies for function as refugia (High confidence overall)
EUNIS Habitat type (score /confidence)
A5.1 Sublittoral coarse sediment (3/H)
A5.12 Sublittoral coarse sediment in variable salinity (estuaries) (3/H)
A5.13 Infralittoral coarse sediment (2/H)
A5.15 Circalittoral coarse sediment (3/H)

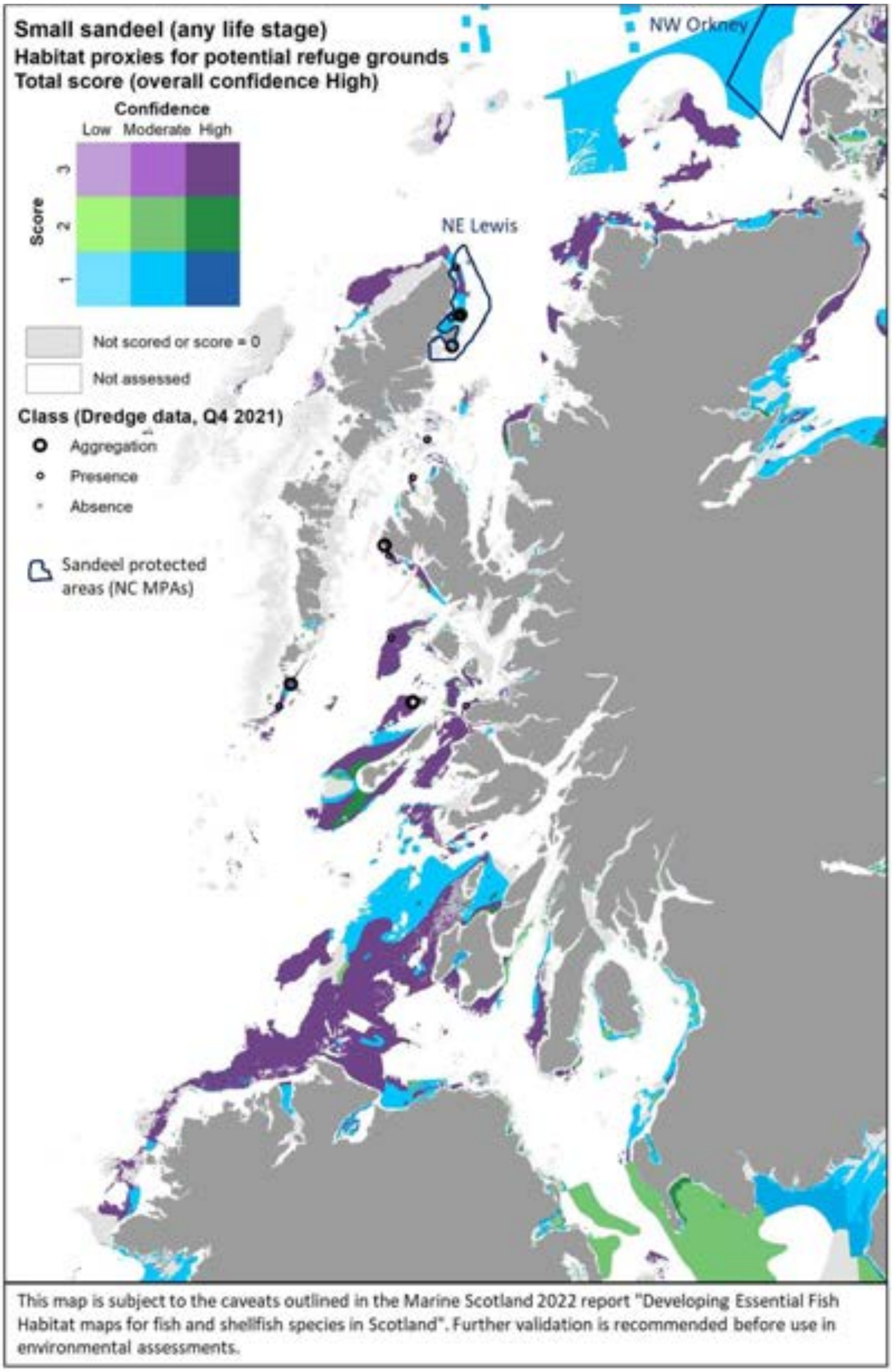


Figure 20. Habitat proxies for small sandeel, *Ammodytes tobianus* (refugia function) in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Occurrence of aggregations of the species from the 2021 Sandeel dredge survey data and sandeel protected areas (NC MPAs) in the study area are also shown.

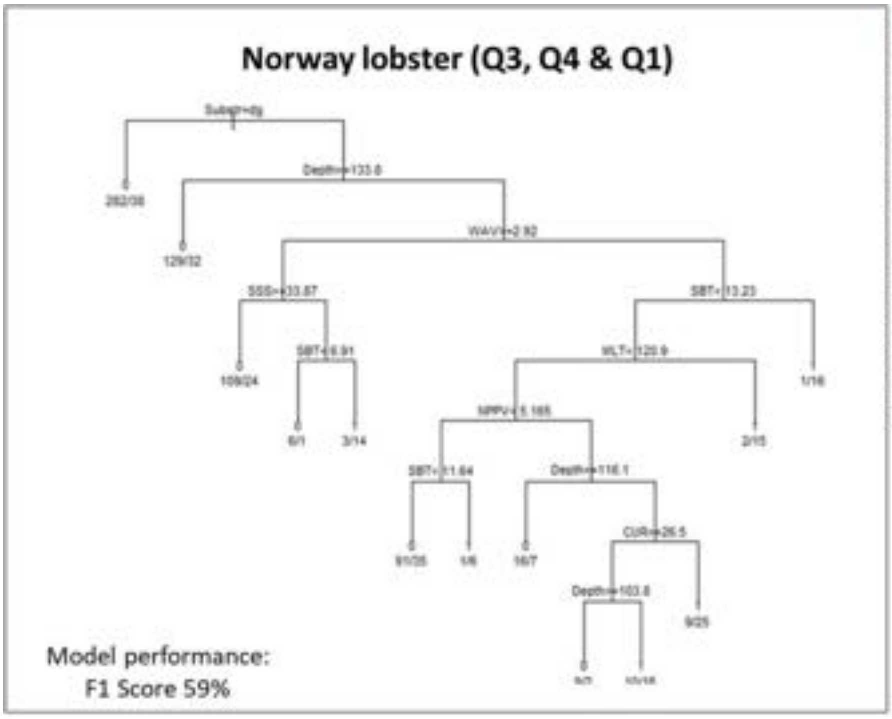
3.1.3 Norway lobster, *Nephrops norvegicus*

Norway lobster (*Nephrops norvegicus,* Linnaeus 1758), hereafter referred to as "*Nephrops*", is a benthic crustacean of high commercial importance, mostly found offshore at depths varying between 20 and 800 m (Annex 1). Its ecology is dominated by a territorial and burrowing behaviour, whereby *Nephrops* constructs and defends burrows in muddy substrata, which provide important refuge from predators. The species spends much of its time in the burrows, emerging from them for feeding or mating (Annex 1).

Nephrops was assessed using the model approach, with the distribution of aggregations of the species in summer to winter bottom trawl surveys being used as indicator of potential important habitats with higher value as refugia. It is acknowledged that bottom trawl surveys are not ideal to identify *Nephrops* burrow areas, particularly given the highly irregular patterns in burrow emergence. As such, bottom trawl survey data might underestimate the distribution of the *Nephrops* habitat, as a zero catch might also be obtained where burrows are present but *Nephrops* has not emerged from them. Underwater TV surveys are commonly used in estimating the abundance of *Nephrops,* as this type of survey is directed at burrow counting henceforth not affected by varying emergency patters. However, underwater TV survey data became available too late in the project and could not be used to calibrate the model, so that bottom trawl survey data were used instead. The limitation of this latter type of data was taken into account in the assessment of confidence associated with the modelling.

As expected, substratum type was the most important predictor of *Nephrops* aggregations. Aggregations were predicted to be absent from areas with sandy and mixed sediments, and to occur in all the other sedimentary substrata covered by the surveys (Figure 21). The latter mostly included sediments with a discernible mud component, as expected, although it is of note that coarse substrata were also included. The latter (coarse substrata) does not agree with the known substratum preferences for *Nephrops* (muddy sediment), and might have resulted from bottom trawl catches obtained from hauls that covered muddy habitat patches (with high *Nephrops* density) interspersed within a wider area of predominantly coarser sediment hence leading to the overall trawled area being classed as coarse sediment. The inclusion of coarse sediment as a potentially suitable substratum for *Nephrops* in the model likely contributed to lowering the model predictive performance (as per statistical validation; Figure 21) and the overall confidence associated with the model prediction as a whole (Figure 22).

Depth (Depth), temperature (SBT) and wave energy (WAV) at the seabed were also important predictors. Aggregations of *Nephrops* were generally predicted to occur in shallower conditions (<134 m depth) and, with the highest probability (0.94), at very low wave energy (<2.9 N m^2/s), consistent with conditions for mud deposition, and higher seabed temperature (monthly mean across the summer, autumn and winter seasons ≥13.2°C). Salinity (SSS), the mixing of the water column (MLT), primary production (NPPV) and current energy at the seabed (CUR) also contributed to predict aggregations of *Nephrops* with different combinations as shown in the decision tree (Figure 21).



Variable	min	max
Dist	1161	414214
Depth	26.1	452.9
Slope	0	1.806
SBT	4.53	18.89
NPPV	0	59.19
SSS	31.54	35.53
MLT	6.4	358.65
CUR	0.3	692.68
WAV	0	98.85
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" c = "fMud" d = "Mixed" e = "mSand" f = "sMud" g = "Sand" h = "sMud_mSand"	

Figure 21. Decision tree for aggregations of *Nephrops* (Q3, Q4 & Q1; pruned tree at cp=0.014) and associated environmental ranges at which the species occurred in the surveys.

The model prediction applied to the mean environmental conditions of the period 2010 - 2020 (summer to winter) allowed to map the potential distribution of *Nephrops* aggregations as an indication of potential location of higher value refugia (burrows) habitats (Figure 22).

Comparison with available survey data (both bottom trawl surveys considered for the model calibration and additional *Nephrops* TV burrow surveys in Scottish waters; Appendix C, Figure C4 and Figure C5) with well known *Nephrops* grounds (as identified by the survey data; Appendix C, Figure C6), highlighted during the consultation by stakeholders, has highlighted some inaccuracies in the map (Figure 22).

The predicted map appeared to capture well *Nephrops* aggregations on known grounds in inshore Scottish waters (e.g. Firth of Forth, Clyde, Moray, Inner Hebrides, the North Minch, and the eastern region of the South Minch) and in the Irish Sea (off the coast of Cumbria and in the north west Irish Sea). As confirmed by TV surveys in Scottish waters, these are *Nephrops* grounds characterised by higher burrow densities, hence confirming the ability of the map to identify *Nephrops* grounds of higher value (per unit area) in shallower waters (<130 m depth).

In turn, the map prediction failed to identify aggregations on deeper areas such as those at Fladen and in the western regions of the South Minch, where TV surveys confirmed the extensive distribution of *Nephrops* burrows (Appendix C, Figure C5). However, burrow density in these areas is lower compared to the other Scottish areas mentioned above, and this also corresponded to lower abundance of *Nephrops* individuals in the trawl catches, leading to the absence of aggregations as predicted by the EFH model.

Stakeholder feedback highlighted that there are different stocks of *Nephrops* with different abundance and variable connectivity, and suggested the model could be improved by analysing the data on a stock-by-stock basis rather than on a species basis. The analysis undertaken in this project partly accounted for stock variability between wider regions (by identifying aggregations separately for data collected from different surveys in different geographical areas, e.g. North Sea and Scottish West Coast). However, in some cases, this may not have been sufficient to discriminate between stocks occurring in the same region (e.g. *Nephrops* populations in Fladen grounds and Firth of Forth), with the resulting model better capturing the EFH distribution for higher-density stocks compared to the lower-density ones.

As mentioned before, the model for *Nephrops* aggregations also identified coarse sediments amongst suitable substrata, which does not match with the known requirements of the species. This has likely contributed to the lower statistical predictive performance (59%) and the resulting moderate overall confidence (49%) associated with this model. The inclusion of coarse sediment amongst potentially suitable conditions has led to predictions of the distribution of potential habitats of higher value as refugia (burrows) for *Nephrops* in certain areas that are not knows to support such resource. These areas have been indicated in the map and a lower confidence is attached to these areas.

Model predictions were further explored through the use of more accurate environmental scenarios for the summer to winter period in individual years (examples for 2010, 2015 and 2020 are shown in Figure 23, Figure 24 and Figure 25, respectively). The resulting maps were generally consistent with the average map in Figure 22, with only a minor improvement of the prediction of presence on the south west margins of the Fladen grounds in 2020 (Figure 25). The highest importance of substratum type as a model predictor for *Nephrops* aggregations is likely to account for this result, as this is a persistent environmental variable that does not change with time in the maps. This result confirms that the inaccuracies identified on the predicted map (Figure 22) are associated with limitations of the model and the data used to calibrate it (as reflected by the model overall confidence) rather than with inaccuracies in the environmental scenario used to obtain the average map.

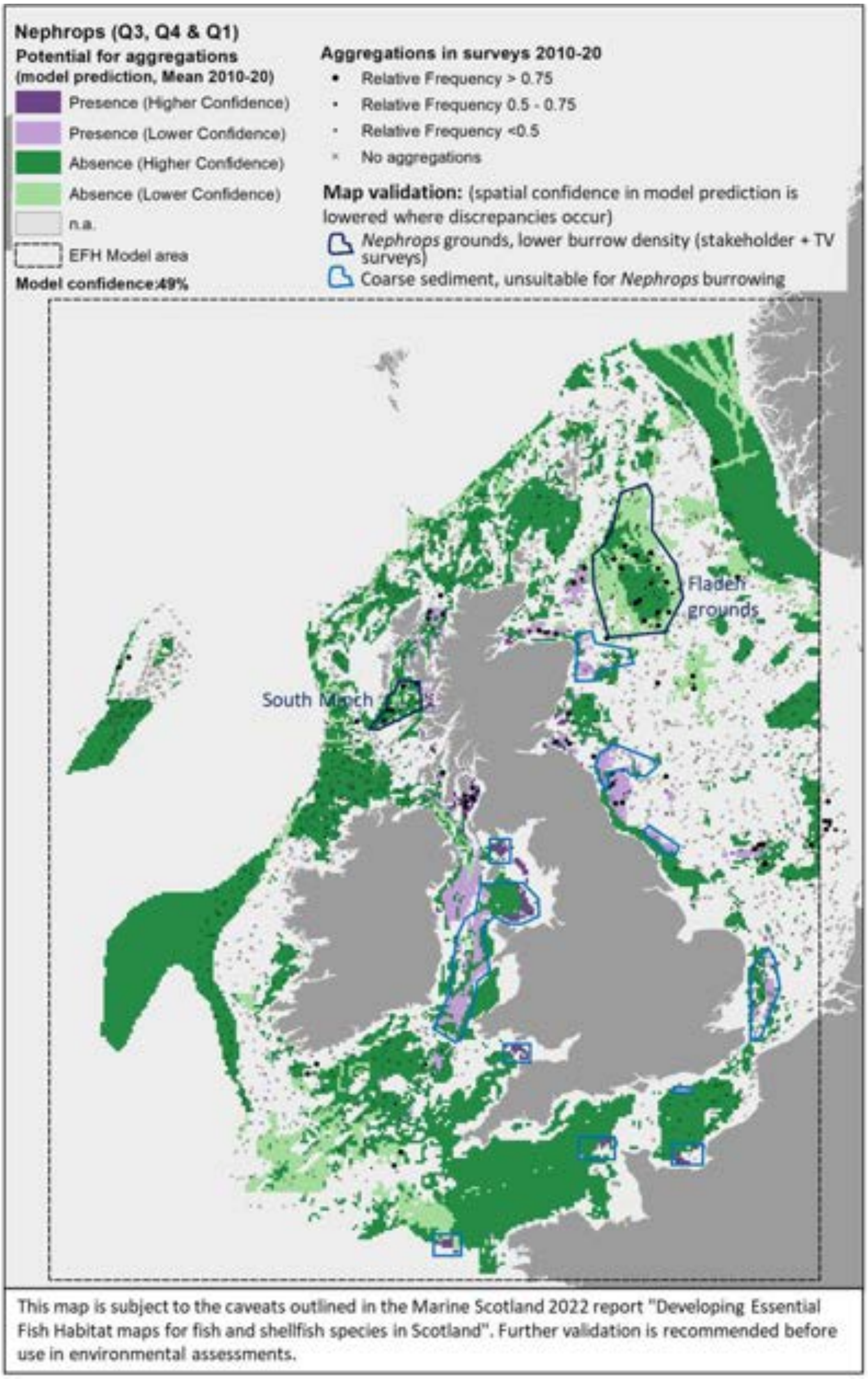


Figure 22. Aggregations of Norway lobster, *Nephrops norvegicus* (Q3, Q4 & Q1): frequency of occurrence in the 2010 - 2020 surveys and model prediction (incl. confidence) based on mean environmental conditions across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons.

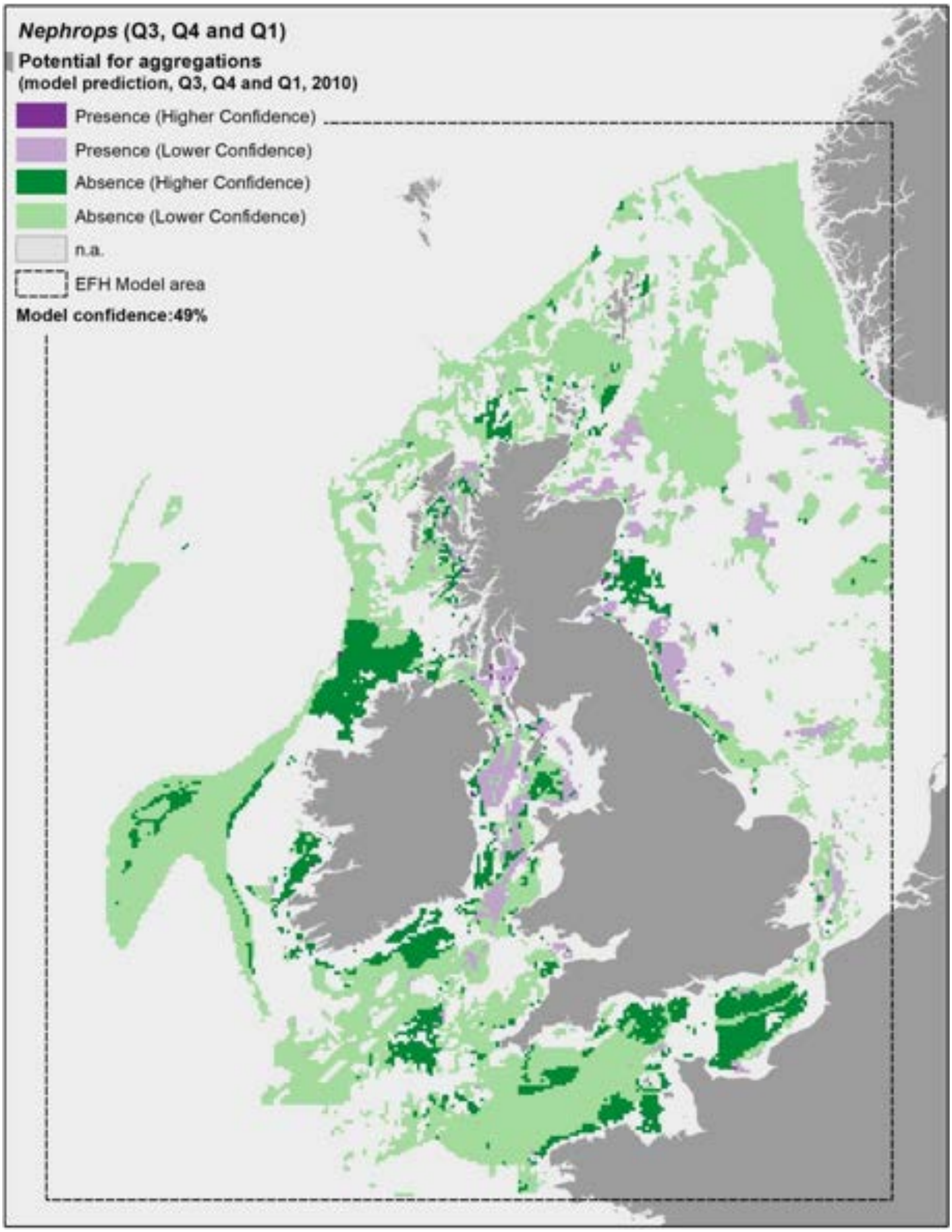


Figure 23. Aggregations of Norway lobster, *Nephrops norvegicus* (Q3, Q4 & Q1): Model predictions based on environmental conditions in Q3-Q1 2010.

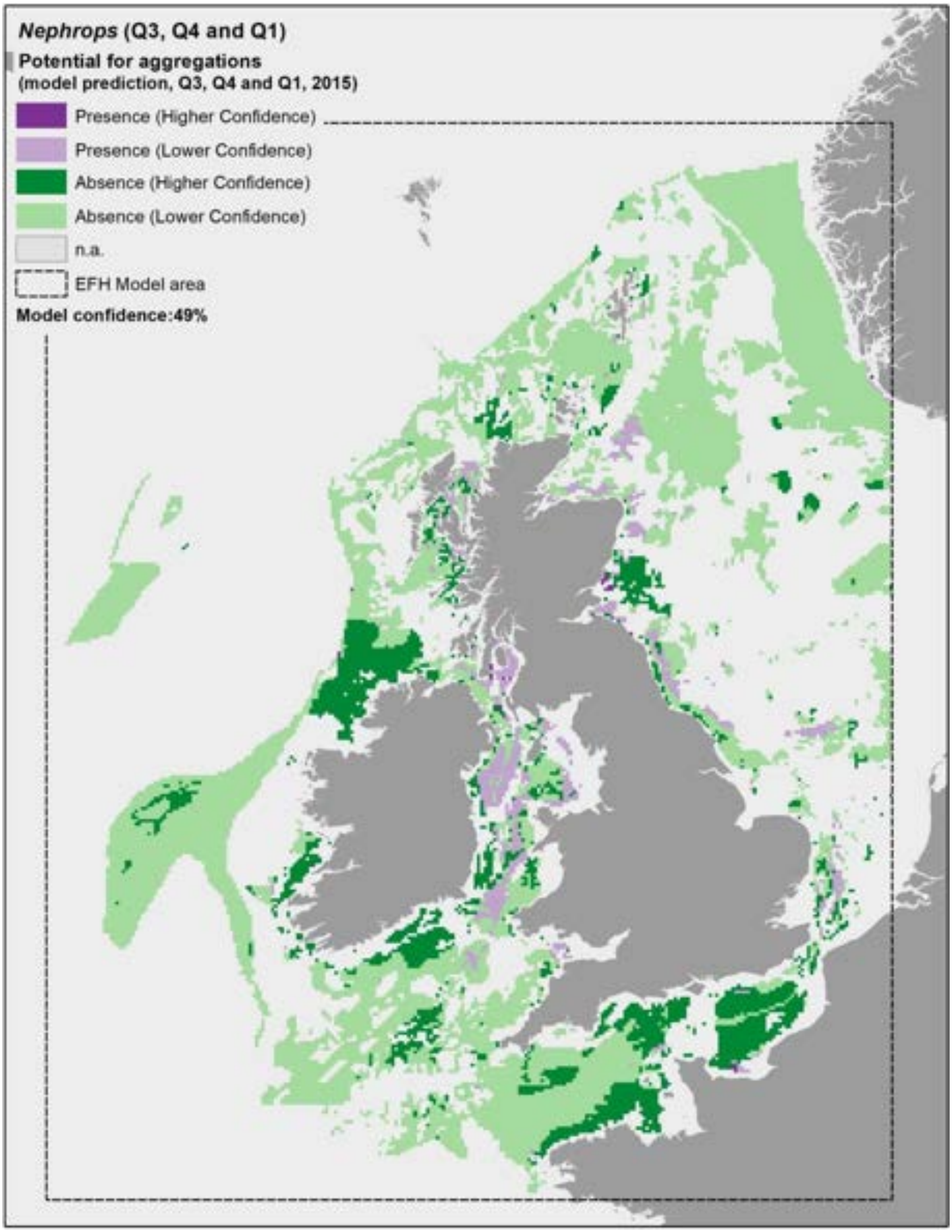


Figure 24. Aggregations of Norway lobster, *Nephrops norvegicus* (Q3, Q4 & Q1): Model predictions based on environmental conditions in Q3-Q1 2015.

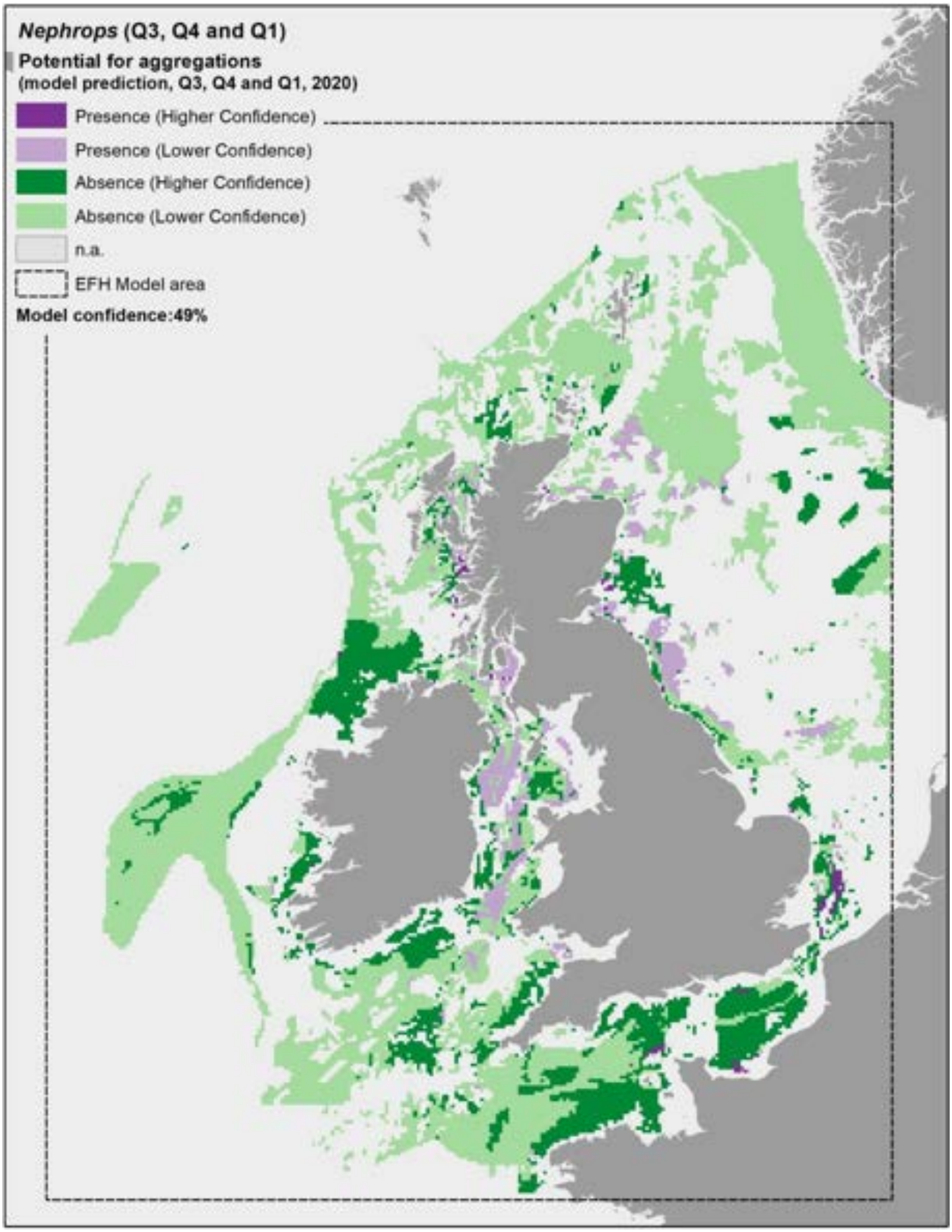


Figure 25. Aggregations of Norway lobster, *Nephrops norvegicus* (Q3, Q4 & Q1): Model predictions based on environmental conditions in Q3-Q1 2020.

3.1.4 Herring, *Clupea harengus*

Atlantic herring (*Clupea harengus* Linnaeus 1758), hereafter referred to as “herring", is a small fish of high commercial importance but also key in supporting marine ecosystems, being a key food resource for top predators (seabirds, marine mammals, predatory fish). As such, it is designated as a Priority Marine Feature in Scotland’s seas. Despite being pelagic for most of its life cycle, spawning is undertaken in strict association with the seabed, where dense mats of sticky eggs are laid (Haegele and Schweigert 1985). Spawning grounds are located both inshore and offshore, on a variety of substrata, albeit there is a requirement for these to be free from fine sediment which could prevent egg oxygenation and thus affect embryonic development (Annex 1). Herring shows site fidelity with regards to spawning areas, and its occupation of spawning grounds may contract or expand depending on the status of the stock (Frost and Diele 2022).

In the absence of suitable data to allow the modelling of these spawning habitats offshore[15], herring was assessed by using the habitat proxy approach to identify habitats that may potentially be used by the species for spawning in inshore areas.

Eleven publications were reviewed and provided detailed characterisation of the species' habitat requirements (see Annex 1). This, along with expert input obtained with the stakeholder validation, led to a high confidence in the overall assessment of habitat proxies for herring spawning grounds. There were a variety of habitats identified as potentially highly suitable for herring spawning with high confidence (Table 11). These included coarse sediments and shingles in the infralittoral and circalittoral zones, macrophyte and kelp dominated sediments in the sublittoral, maerl beds, seagrass beds, and areas with a full salinity water column. Further possible habitats, scored with medium to low suitability and medium to low confidence (not shown in Table 11), included other submerged substrata such as mussel beds, biogenic reefs, polychaete worm reefs and sublittoral sands.

The distribution of the inshore habitat proxies for herring spawning in Scottish inshore waters is mapped in Figure 26 (west coast), Figure 27 (east coast) and Figure 28 (north coast and northern isles). Known current and historical herring spawning grounds in these areas are also shown in the maps as identified by Frost and Diele (2022; Appendix C, Figure C7). The latter have been included as polygons indicating broad areas identified as recent spawning grounds (i.e. in use between 1980s and 2000s) as well as blue circles marking historical spawning locations (only locations outside the polygons are shown). The recent record of the spring-spawning event observed at Wester Ross in 2018/2019 is also shown in Figure 26.

[15] Data were available from ICES International Herring Larvae Surveys, but a decision was made not to use these data for modelling as larval aggregations were deemed unsuitable to accurately identify spawning areas with the models used in this study, due to larval drifting away from spawning grounds during the time elapsed between hatching and being surveyed.

The habitat proxy maps show that many of the habitat proxies identified for herring spawning are included in broad areas known as spawning grounds, although information on specific spawning locations within these areas is lacking (Frost and Diele 2022). For example, the habitat proxy maps seem to correctly identify known herring spawning grounds located inshore along the north coast of Ireland and around the isles of Tiree and Coll (Figure 26), around Cape Wrath on the north coast (Figure 26, Figure 28), in inshore areas to the east and north of the Moray Firth, south of the Firth of Forth (this latter area is known as Banks spawning grounds) (Figure 27), around Orkney and to the east of Shetland (Figure 28).

However, several areas and locations known for herring spawning appear not to be captured by the habitat proxy map, including, for example, the well-known spawning grounds occurring in the Firth of Clyde (Figure 26) or the Buchan spawning grounds off the Aberdeen coast (Figure 27). The location of the recent spring-spawning event observed in 2018/2019 in the Wester Ross area also seems not to be identified by the habitat proxies, although the habitat proxy map correctly identifies the presence of spawning grounds in the Wester Ross coastal area north of this location, where herring spawning has been identified both recently and historically (Figure 26; Appendix C, Figure C7).

It is clear that the mapped habitat proxies provide a limited view of the herring spawning grounds as they lack full coverage of inshore and offshore areas where such EFH may occur. As the habitat proxy assessment in this study was focused on inshore waters, EUNIS habitats classed as offshore (deeper) circalittoral habitats were excluded *a priori* from the assessment (see section 2.3.1), leading to the gaps of coverage in offshore waters (white areas identified as 'Not assessed' in the maps). In Scottish waters, these deeper habitats also occur inshore, thus accounting for the gaps of coverage of some of the coastal areas and locations where herring spawning is known to occur. Accordingly, this demonstrates the importance of taking into consideration all the lines of evidence shown in Figure 26, Figure 27 and Figure 28 when considering the (actual and potential) distribution of the herring spawning resource.

In turn, there are additional areas in the map where potentially suitable habitats for herring spawning have been identified, but their actual use appears not to be supported by recent and historic data. It is possible that these additional areas identified in the habitat proxy map present conditions (other than the factors accounted for by the EUNIS habitat classification, i.e. depth zone, type of substratum, energy) that have prevented the use of these areas so far. However, these areas may provide potential for expansion of the spawning grounds, should the conditions and availability of the existing spawning grounds change in the future (e.g. due to natural or anthropogenic processes affecting the seabed and environmental conditions). The expansion or contraction of the spawning grounds occupied by the species is also known to depend on the status of the stock (Frost and Diele 2022).

While the present study was being undertaken, Marine Scotland Science has been developing an alternative method accounting for larval transport and connectivity to map herring spawning areas in a separate project undertaken in collaboration with NatureScot[16]. This project has combined 46 years (1972-2017) of herring larvae catch data held by ICES with herring age model (to relate larval size to age) and particle tracking simulations of larvae to identify potential herring spawning grounds across Scottish Shelf Seas. The final outputs of the aforementioned study were not available when this report was being written, but consultation with the project leads was undertaken to identify possible similarities and differences between our respective results. Their results are also based on model predictions and extrapolation rather than on actual observations of spawning grounds, and may be influenced by larval sampling limitations (e.g. sampling locations and seasonality; O'Hara Murray, pers. comm.). Therefore, although a comparison was undertaken, they were not included in the validation of the habitat proxy maps. Despite the difference in source data and in the modelling approach, the spatial results of both studies seem to converge in identifying potential spawning grounds along the northwest coast of Lewis, west of Lewis, Harris and Uists, on the southern tip of the Outer Hebrides (Bara), along the northwest coast of mainland Scotland and the Minch (down as far as Skye) and the northern mainland Scotland coast, around Orkney (especially to the west), the coastal area to the east of the Moray Firth, and the Banks spawning grounds, south of the Firth of Forth. Larval modelling also showed some overlap of predicted spawning grounds in the marine area located approximately 30 nautical miles offshore to the west of Islay and north of Donegal (Ireland). The larval model also identified potential spawning grounds off the Hebrides of Mull, Coll, Tiree and the small isles, as identified by the habitat proxies in this study, but only as occasional features in certain years (e.g. 1981 and 1993) and not as a permanent feature across all the 46 years modelled. In contrast with the habitat proxy maps, the larval modelling did not identify herring spawning grounds in inshore areas around Islay and Mull of Kintyre, or to the east of Shetland, whereas it successfully identified the Buchan spawning grounds. These results from the larval model seem to agree with the locations of recent spawning grounds as identified in Frost and Diele (2022), which were considered for the validation of the habitat proxy maps.

[16] Herring Larval Modelling project, by Rory O'Hara Murray, Morven Carruthers, Alejandro Gallego and Ben James.

Table 11. Main (highest scoring) habitats potentially associated with spawning function for herring, *Clupea harengus*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Herring – Habitat proxies for spawning function (High confidence overall)
EUNIS Habitat type (score /confidence)
A2.1 Littoral coarse sediment (3/H)
A2.11 Shingle (pebble) and gravel shores (3/H)
A5.1 Sublittoral coarse sediment (3/H)
A5.13 Infralittoral coarse sediment (3/H)
A5.14 Circalittoral coarse sediment (3/H)
A5.5 Sublittoral macrophyte-dominated sediment (3/H)
A5.51 Maerl beds (3/H)
A5.52 Kelp and seaweed communities on sublittoral sediment (3/H)
A5.53 Sublittoral seagrass beds (3/H)
A7.3 Completely mixed water column with full salinity (3/H)
A7.33 Completely mixed water column with full salinity & long residence time (3/H)

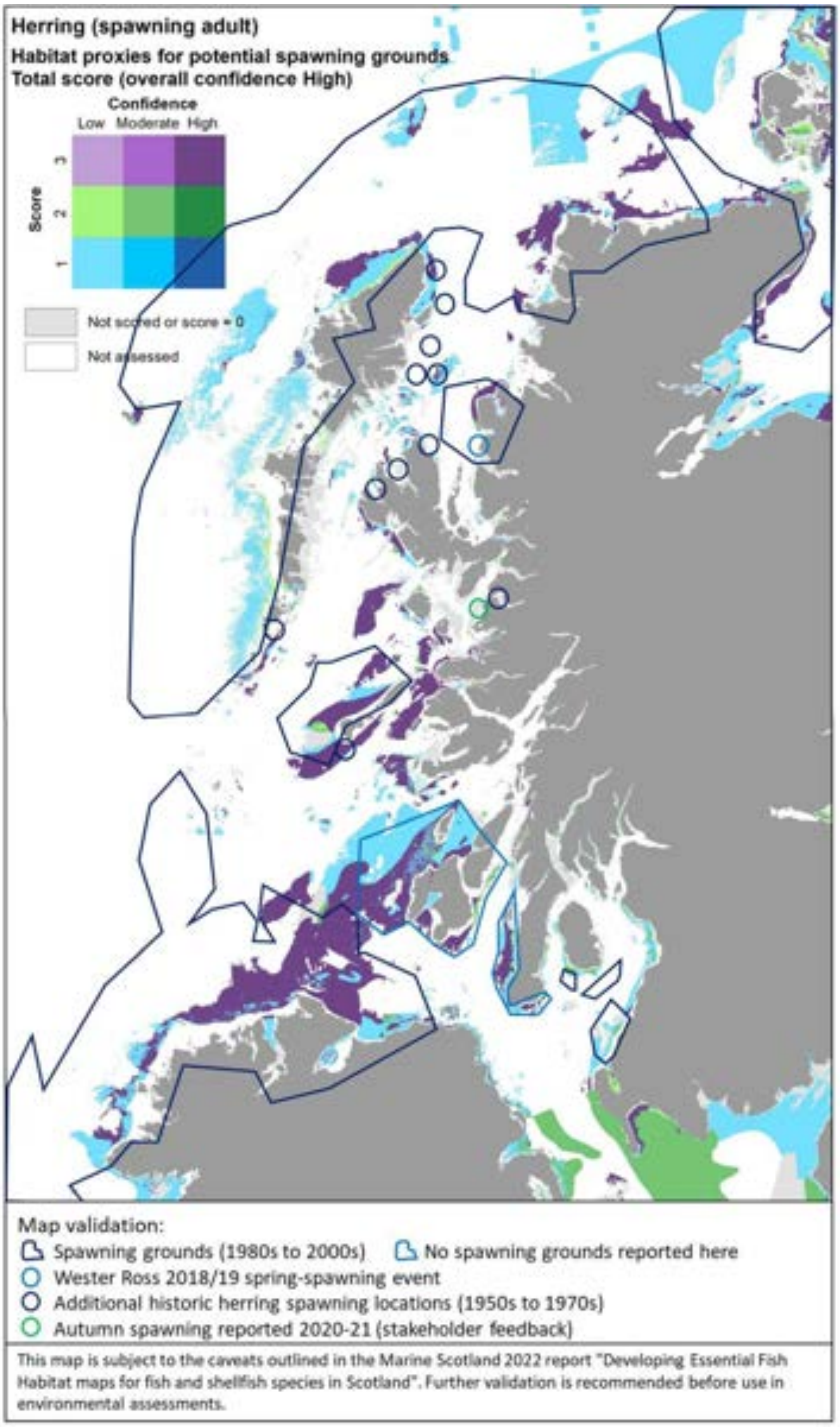


Figure 26. Habitat proxies for herring spawning on the west coast of Scotland. The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Additional areas of current and historic spawning grounds are identified in the map (polygons and circles) summarising evidence from Frost and Diele (2022; Appendix C, Figure C7) and stakeholder feedback. Only historic spawning locations not included in spawning grounds polygons are shown (blue circles).

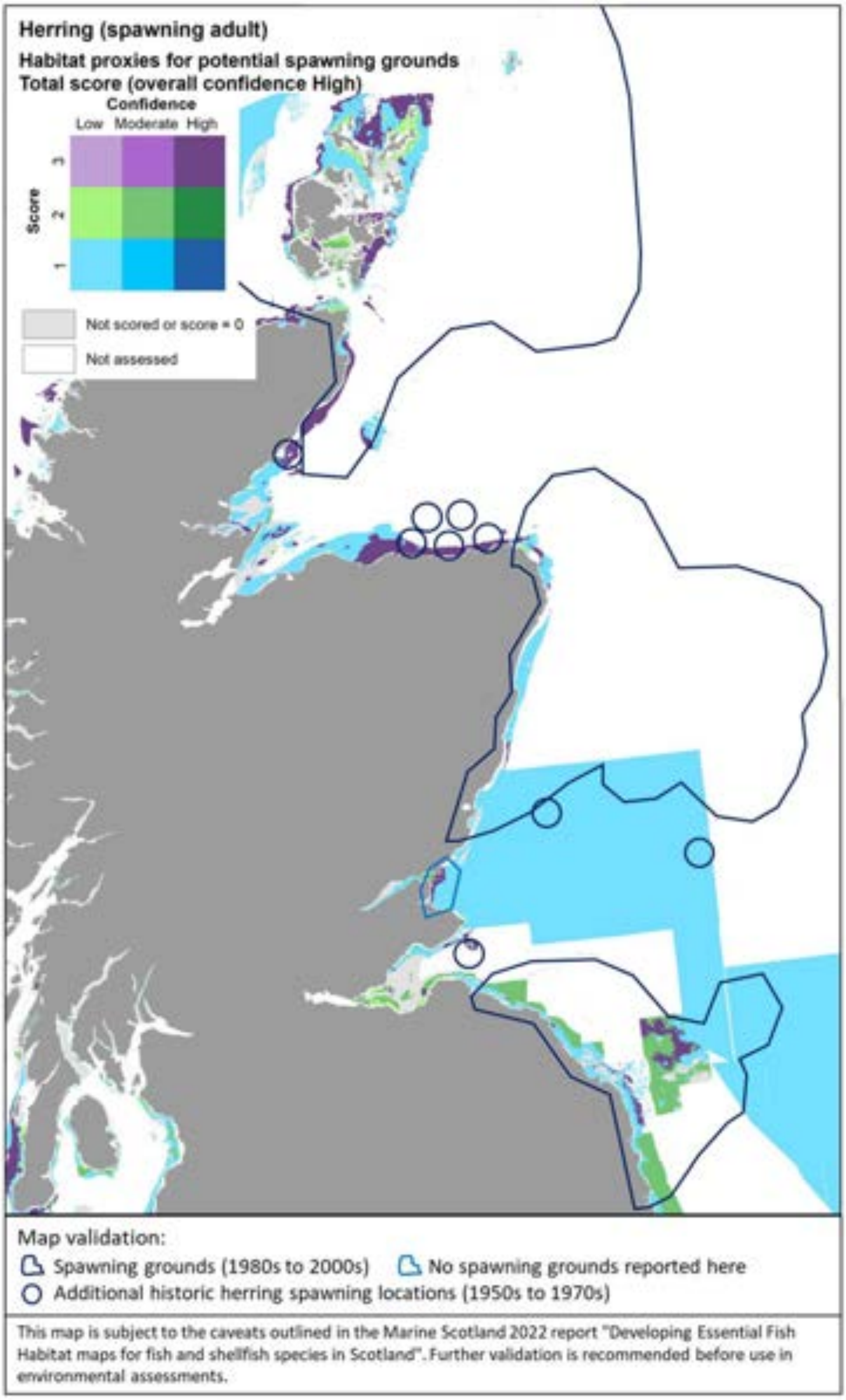


Figure 27. Habitat proxies for herring spawning on the east coast of Scotland. The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Additional areas of current and historic spawning grounds are identified in the map (polygons and circles) summarising evidence from Frost and Diele (2022; Appendix C, Figure C7). Only historic spawning locations not included in spawning grounds polygons are shown (blue circles).

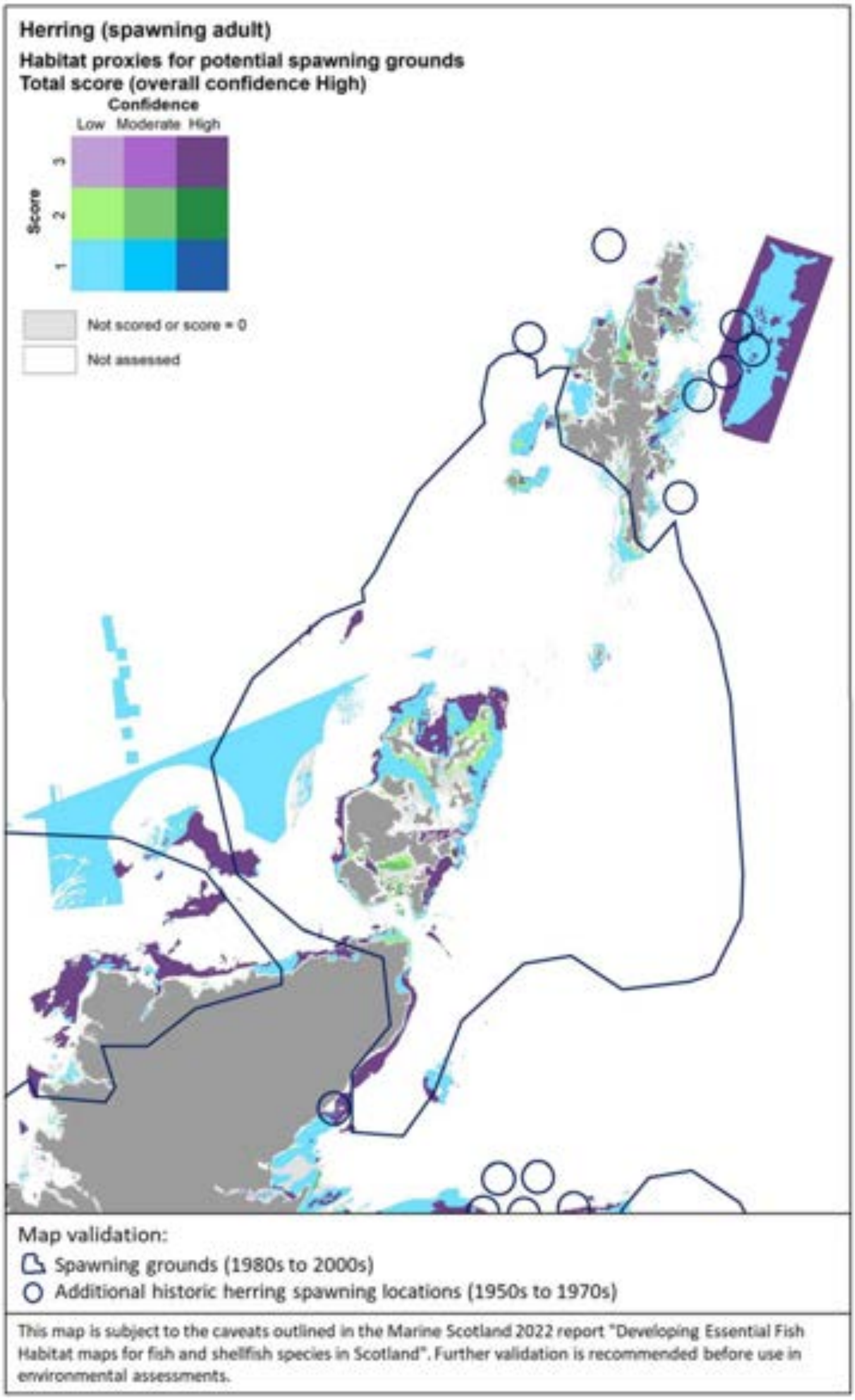


Figure 28. Habitat proxies for herring spawning on the north coast of Scotland and northern isles (Orkney and Shetland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Additional areas of current and historic spawning grounds are identified in the map (polygons and circles) summarising evidence from Frost and Diele (2022; Appendix C, Figure C7). Only historic spawning locations not included in spawning grounds polygons are shown (blue circles).

3.1.5 Plaice, *Pleuronectes platessa*

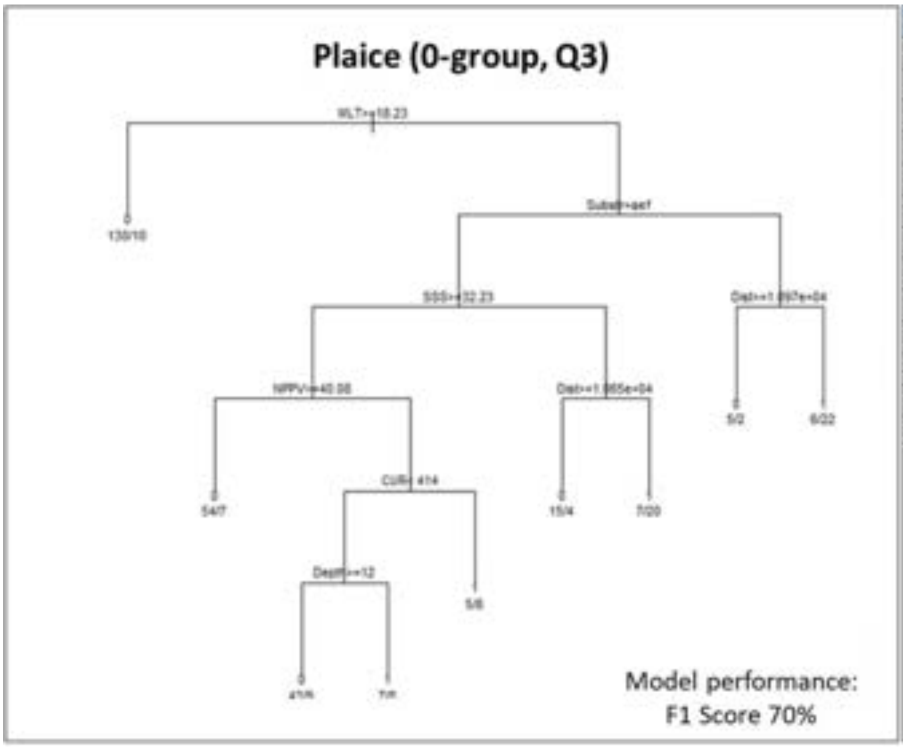
Plaice (*Pleuronectes platessa* Linnaeus 1758), also known as European plaice, is a benthic flatfish of high commercial importance, found both inshore and offshore (Annex 1). Dependence on intertidal and shallow subtidal sedimentary substrata in inshore areas has been reported particularly for juveniles of the species, which use these areas as nursery grounds between the spring and autumn (Annex 1).

Plaice was assessed by using both the data-based model and the habitat proxy approach. The former allowed modelling of the distribution of aggregations of juveniles of the species in summer as indicator of potential higher value habitats used as nurseries. Individuals <12 cm in length were considered to identify 0-group, recently metamorphosized plaice in summer catches from beam trawl surveys. The habitat proxy approach also allowed identification of habitats potentially used by the juveniles of the species, with better coverage of inshore habitats.

Water column mixing (MLT), distance from the shore (Dist) and depth were the most important predictors of juvenile plaice aggregations, followed by primary production (NPPV) and substratum type (Substr), and salinity (SSS) and current energy at the seabed (CUR) (Figure 29). Juvenile aggregations were generally predicted to occur in habitats with lower mixing of the water column (MLT <18.2 m), and, with the highest probability (0.78), on mixed sediment and muddy sand substrata within 11 km distance from the shore. On other sedimentary substrata (including coarse sediment, sand and sandy mud), juvenile aggregations were predicted to occur in different combinations of environmental conditions, including for example lower/mixed salinity (<32.2, down to 23.4) within 10 km distance from the shore, or in moderate current energy conditions or shallower depth (<12 m depth) in areas with lower primary production (NPPV <40.1 mg C m^{-3} day^{-1}) (Figure 29).

The model prediction applied to the mean summer environmental conditions of the period 2010 - 2020 allowed mapping of the potential distribution of juvenile aggregations as an indication of potential location of higher value juvenile habitats functioning as nursery for plaice (Figure 30).

Comparison with available survey data (both beam trawl surveys considered for the model calibration and additional inshore and offshore demersal surveys on the west coast of Scotland; Appendix C, Figure C8 and Figure C9) and feedback from the stakeholders have highlighted some limitations of the predicted map (Figure 30).



Variable	min	max
Dist	744	128576
Depth	3.71	77.59
Slope	0	0.283
SBT	10.97	21.37
NPPV	8.65	152.26
SSS	23.38	35.09
MLT	4.28	44.68
CUR	1.48	739.68
WAV	0.05	474.48
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" c = "Mixed" d = "mSand" e = "Sand" f = "sMud"	

Figure 29. Decision tree for juvenile aggregations of plaice, *Pleuronectes platessa* (Q3; full model) and associated environmental ranges at which the life stage occurred in the surveys.

There was a generally good agreement between the model prediction and the bottom trawl survey data, leading to a relatively good confidence associated with the model prediction overall (one of the highest amongst the models calibrated for the species in this study). The predicted map appears to capture well the distribution of settlement habitats of 0-group plaice (individuals <12 cm in length) in shallower areas along the coast (e.g. Moray Firth, Firth of Forth, Firth of Clyde) although the coverage of the most inshore areas (expected to be most important as nursery grounds) is limited due to the distribution of the data on which the model was based (see results of the habitat proxy approach below for a better assessment of more inshore habitats).

Additional survey data available for the west coast of Scotland (2013/14 WCDF survey) only had few occurrences of plaice 0-group juveniles in the summer catches, but areas where aggregations were identified have been added to the map in Figure 30 to account for these records of actual presence. Only areas where a mismatch between observed and predicted aggregations have been highlighted, whereas other aggregations were correctly predicted in the map.

Model predictions based on a more accurate environmental scenario (summer 2015) resulted in a spatial output (Figure 31) that was generally consistent with the average map in Figure 30.

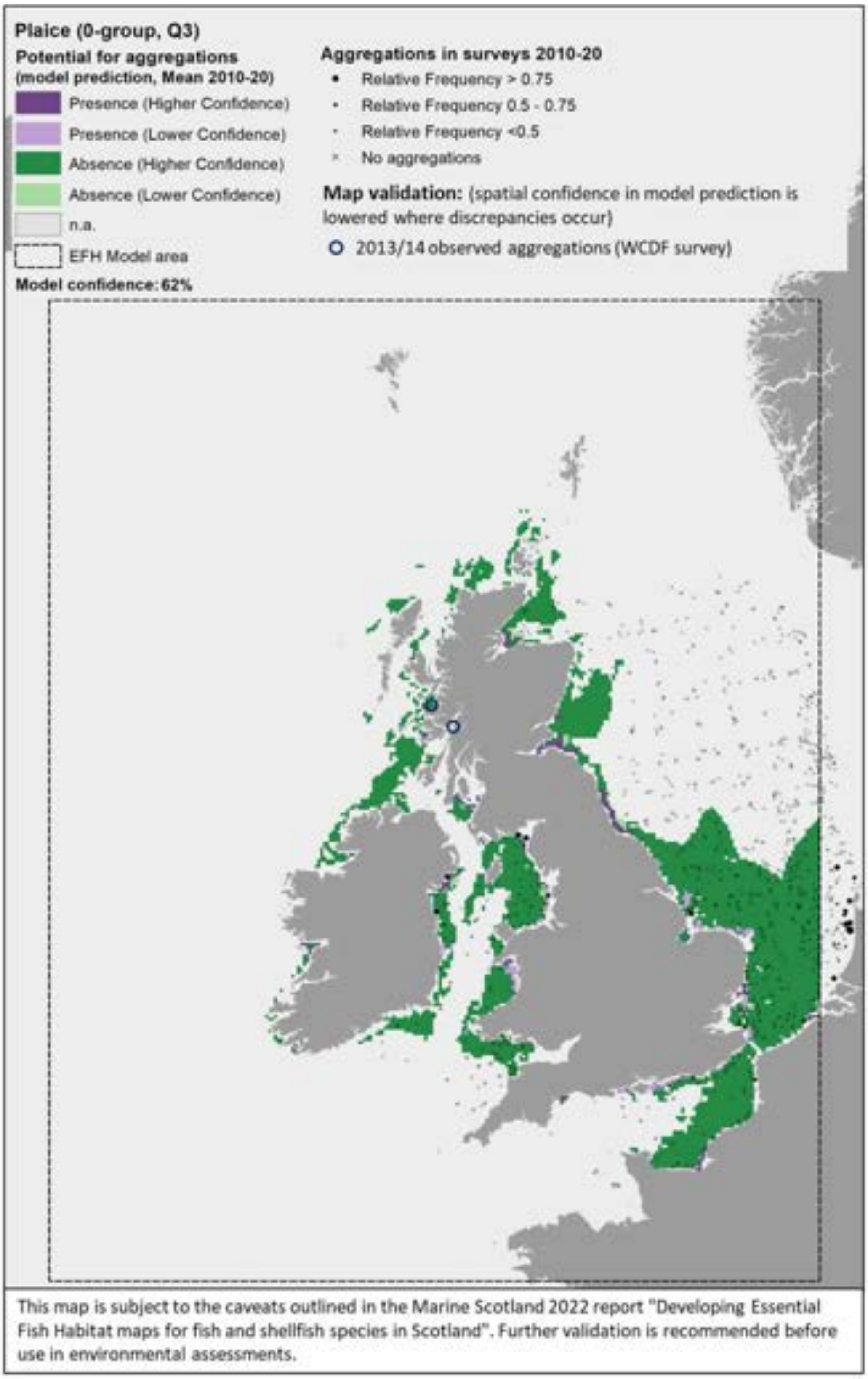


Figure 30. Aggregations of plaice juveniles (*Pleuronectes platessa* 0-group, Q3): Frequency of occurrence in the 2010 - 2020 Q3 surveys and model prediction (incl. confidence) based on mean environmental conditions for Q3 across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons and circles.

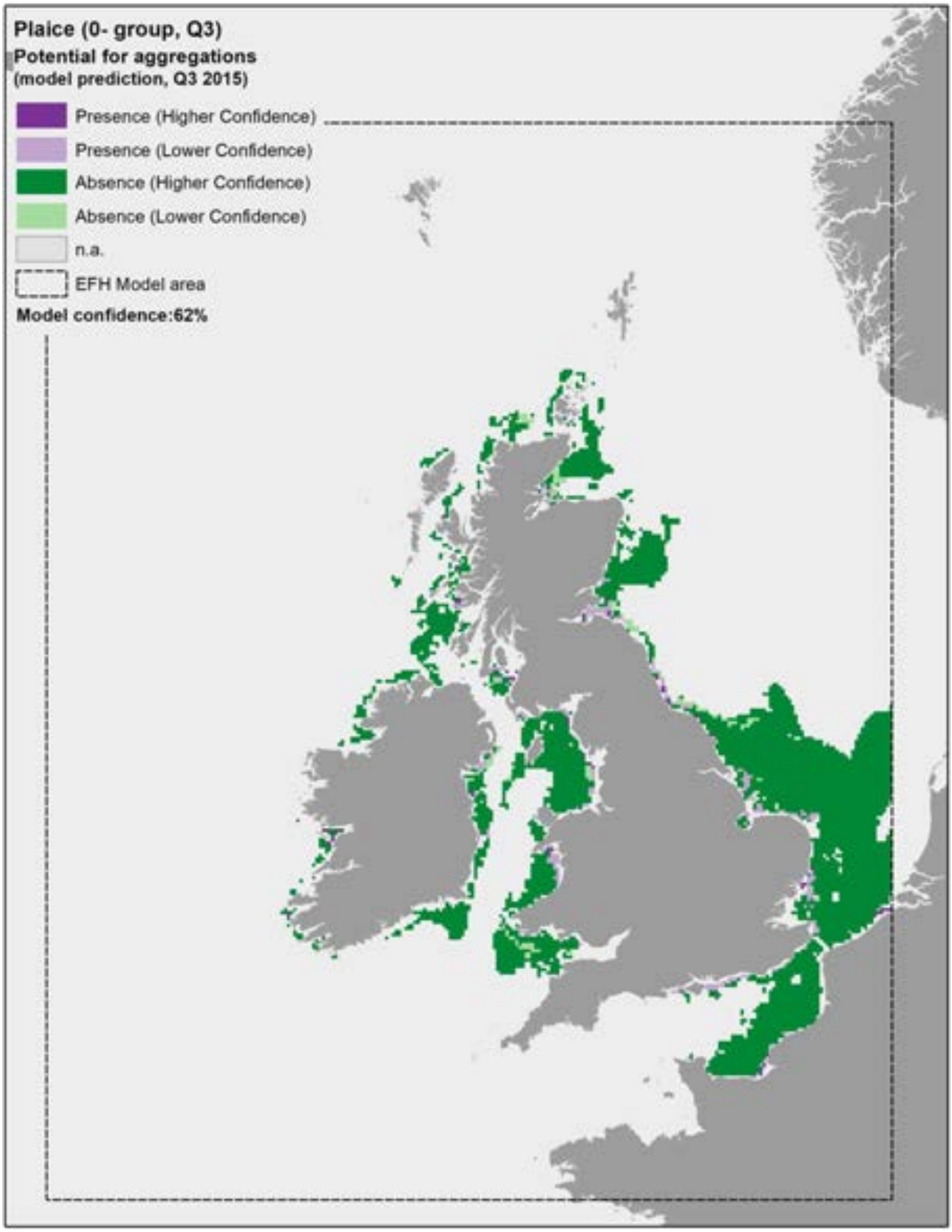


Figure 31. Aggregations of plaice juveniles (*Pleuronectes platessa* 0-group, Q3): Model predictions based on environmental conditions in Q3 2015.

For the assessment of habitat proxies for plaice juveniles inshore, seventeen publications were reviewed and provided detailed characterisation of the species' habitat requirements (see Annex 1). This, along with expert input obtained with the stakeholder validation, led to a high confidence in the overall assessment. Sandy habitats in the infralittoral and sublittoral zones were identified as the most suitable habitats potentially functioning as nursery for plaice, with a high confidence associated (Table 12). Other possible habitats were sublittoral sandy habitats in reduced salinity or estuarine areas (all scoring 2/H). Further possible habitats, though scored with medium to low suitability and medium to low confidence (not shown in Table 12) included sublittoral biogenic reefs, infralittoral, circalittoral and sublittoral coarse sediments, and mobile sandy shores dominated by amphipods, polychaetes and bivalves.

The distribution of the inshore habitat proxies for plaice juveniles in the case study area is mapped in Figure 32, compared with the distribution of juveniles (0-group) from the West Coast of Scotland Demersal Fish Survey (WCDF, 2013/14) in the area. The habitat proxy map appears to accurately identify areas where plaice juveniles were found with higher abundance along the eastern margin of the Firth of Clyde, with the survey data also showing juveniles entering the Firth into Loch Long, where there was no coverage for the EUNIS map. High juvenile abundances west of the Kintyre peninsula and off Jura also match with highly suitable juvenile habitats identified in the map. Relatively high abundances of plaice juveniles were also observed in the survey catches from east and west of the Small Isles. These locations do not directly match with suitable habitats in the map, although patches of suitable habitats are present nearby that are likely to be used by these juveniles. No stakeholder feedback was received on this map following consultation.

Table 12. Main (highest scoring) habitats potentially associated with nursery function for plaice juveniles (*Pleuronectes platessa)*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Plaice (juvenile) – Habitat proxies for nursery function (High confidence overall)
EUNIS Habitat type (score /confidence)
A5.2 Sublittoral sand (3/H)
A5.21 Sublittoral sand in low or reduced salinity (2/H)
A5.22 Sublittoral sand in variable salinity (estuaries) (2/H)
A5.23 Infralittoral fine sand (3/H)
A5.24 Infralittoral muddy sand (3/H)

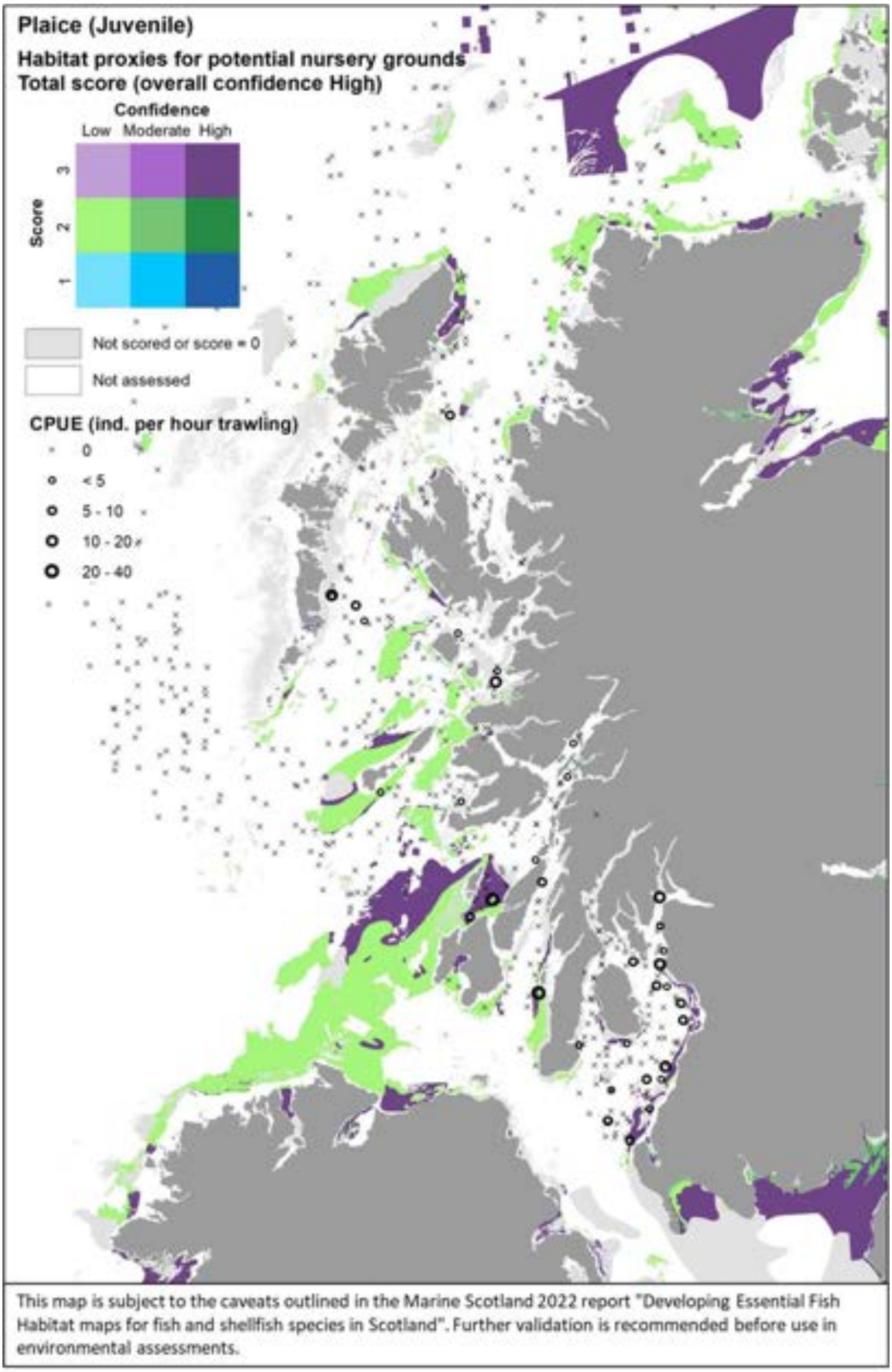


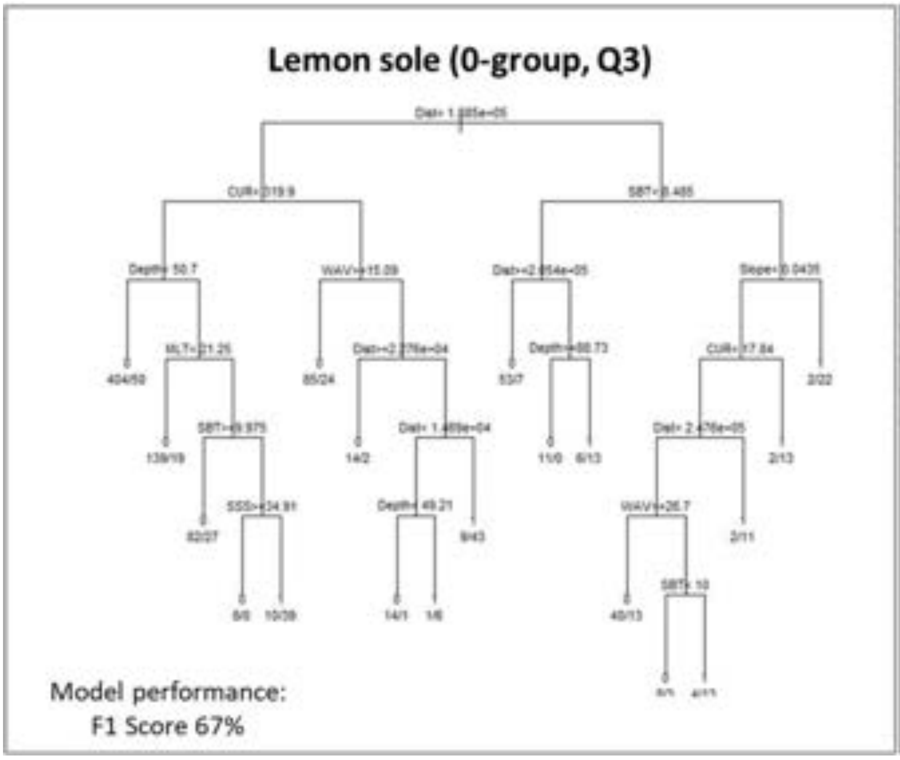
Figure 32. Habitat proxies for plaice juveniles in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Occurrence of aggregations of plaice juveniles from WCDF 2013/14 survey data in the study area are also shown.

3.1.6 Lemon sole, *Microstomus kitt*

Lemon sole (*Microstomus kitt*, Walbaum 1792) is a benthic flatfish of high commercial importance, found mostly offshore (Annex 1). Juveniles of this species are believed to settle in early nursery areas located in deeper, offshore areas, on rougher terrain compared to other flatfish, possibly overlapping with the species spawning areas, although the literature on this species and its environmental requirements is much sparser compared to other flatfish (Annex 1).

Lemon sole was assessed through modelling, based on summer catches from beam trawl surveys. Individuals <15 cm in length were considered to identify 0-group juveniles and their aggregations were used as indicator of potential higher value habitats used as nurseries.

Almost all variables accounting for geomorphological, energy and water quality characteristics (except for NPPV) were selected by the model as predictors. Distance from the shore (Dist), current energy at the seabed (CUR), depth and seabed temperature (SBT) being the most important. Juvenile aggregations were predicted to occur at various combinations of these variables (Figure 33). Predictions of occurrence were identified with the highest probability (0.92) in offshore areas (Dist ≥188 km) where the mean monthly temperature at the seabed in the summer is ≥8.5°C and on gently sloping seabed (Slope ≥0.04 degrees). The type of seabed (Substr) did not appear to affect the distribution of juvenile aggregations within the range of habitats where this life stage was sampled (Figure 33).



Variable	min	max
Dist	1768	294957
Depth	11.5	143.7
Slope	0	0.312
SBT	5.15	20.93
NPPV	3.34	150.86
SSS	28.48	35.42
MLT	5.07	83.14
CUR	5.23	768.09
WAV	0.03	465.81
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" b = "fMud" c = "Mixed" d = "mSand" e = "Sand" f = "sMud" g = "sMud_mSand"	

Figure 33. Decision tree for juvenile aggregations of lemon sole, *Microstomus kitt* (Q3; full model) and associated environmental ranges at which the life stage occurred in the surveys.

The model prediction applied to the mean summer environmental conditions of the period 2010 - 2020 allowed mapping of the potential distribution of juvenile aggregations as an indication of potential location of higher value juvenile habitats functioning as nursery for lemon sole (Figure 34).

Comparison with available survey data (both beam trawl surveys considered for the model calibration and additional inshore and offshore demersal surveys on the west coast of Scotland; Appendix C, Figure C11 and Figure C12) and feedback from the stakeholders have highlighted some limitations of the map (Figure 34).

Although the map correctly identifies potential nursery on the Dogger Bank, the observed presence of aggregations of lemon sole juveniles in the central North Sea and in more inshore areas to the south appear to be poorly predicted, a result that is likely accounted for by the model predictive performance (67%) and resulting moderate overall confidence (58%). Furthermore, larval surveys undertaken by Cefas identified abundant larvae close to settlement to the south and west of the Dogger Bank suggesting that also those areas may be potential nursery for the species.

The map has limited coverage of the most inshore areas that may also locally host aggregations of lemon sole juveniles, due to the distribution of the data on which the model was based. Stakeholder feedback also indicated the potential presence of small lemon sole in the Shetland waters, although the exact locations within this wider area were unknown (it was suggested that bottom trawl surveys and discard observer trips might account for these).

Additional survey data available for the west coast of Scotland (2013/14 WCDF survey; Appendix C, Figure C12) only had few occurrences of lemon sole 0-group juveniles (individuals <15 cm in length) in the catches, but areas where aggregations were identified have been added to the map in Figure 34 to account for these records of actual presence. Only areas where a mismatch between observed and predicted aggregations have been highlighted, whereas other aggregations were correctly predicted in the map.

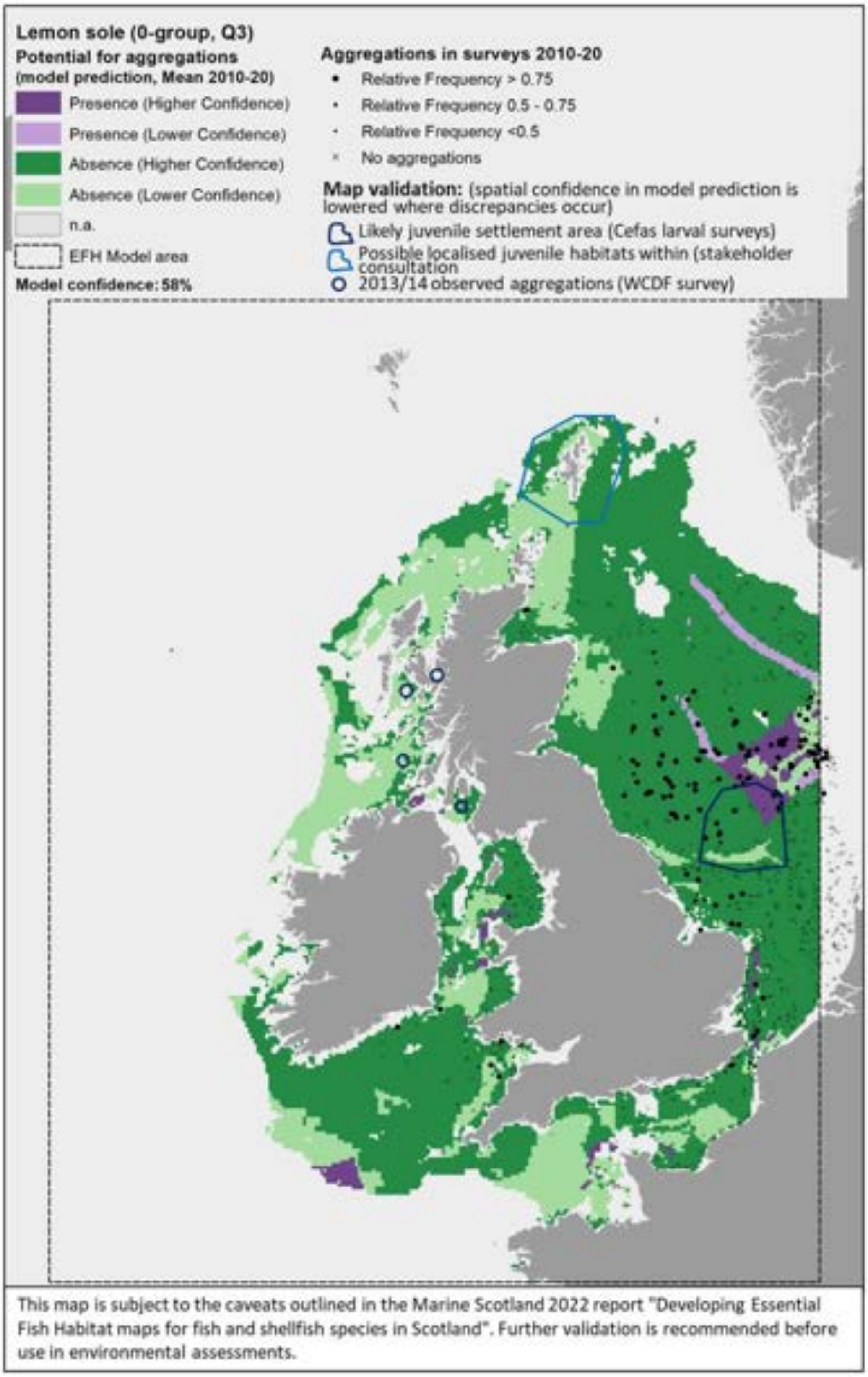


Figure 34. Aggregations of lemon sole juveniles (*Microstomus kitt* 0-group, Q3): Frequency of occurrence in the 2010 - 2020 Q3 surveys and model prediction (incl. confidence) based on mean environmental conditions for Q3 across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons and circles.

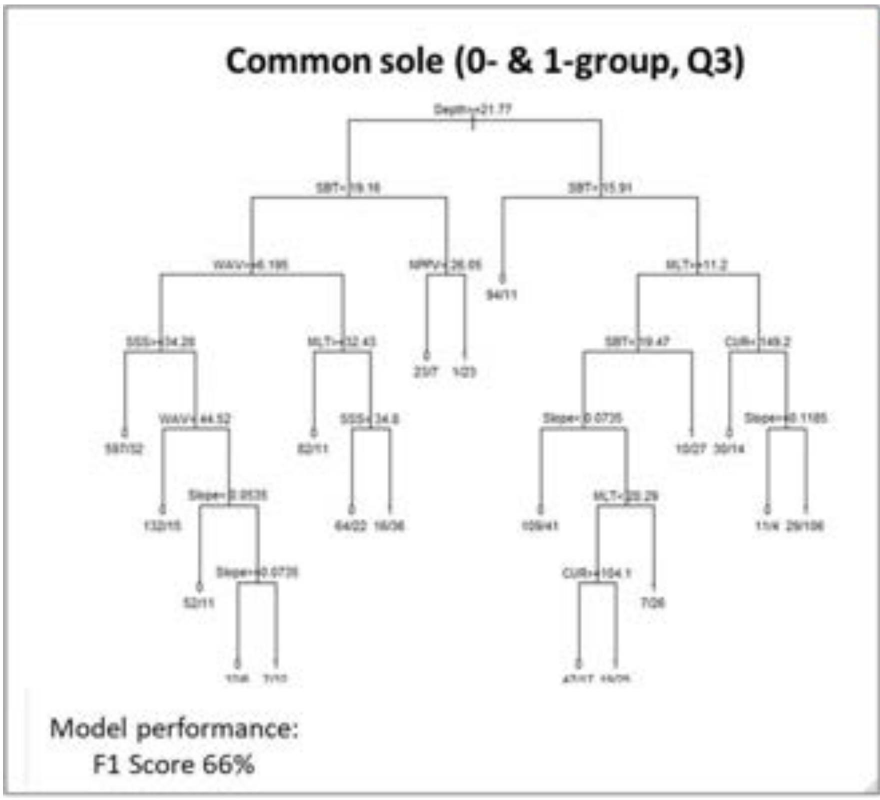
3.1.7 Common sole, *Solea solea*

Common sole (*Solea solea*, Linnaeus 1758), also known as Dover sole, is a benthic flatfish of high commercial importance, found both inshore and offshore (Annex 1). It is a predominantly southern species that reaches its northern limit in the Irish Sea, southern North Sea, Skagerrak and Kattegat, although it may sometimes be caught in low numbers around Scotland. Dependence on intertidal and shallow subtidal sandy and finer grained substrata in inshore areas (including estuaries) has been reported particularly for juveniles of the species, which use these areas as nursery grounds during the first 2 - 3 years of life before migrating into deeper offshore waters (Annex 1).

Common sole was assessed by using both the data-based model and the habitat proxy approach. The former predicted the distribution of aggregations of juveniles of the species in summer as an indicator of potential higher value habitats used as nurseries. 0-group individuals alone (<12 cm in length) were infrequent in the survey catch data, and therefore 1-group individuals (<25 cm) were also considered. As common sole is reported to spend 2 - 3 years in inshore nursery grounds (Annex 1), including 1-group individuals in the assessment was considered suitable to identify potential nursery aggregations. The habitat proxy approach also allowed identification of habitats that may potentially be used by the juveniles of the species, with better coverage of inshore habitats.

Almost all variables accounting for geomorphological (except for distance from the shore), energy and water quality characteristics were selected by the model as predictors. Depth (Depth) and water column mixing (MLT), followed by temperature (SBT) and wave energy at the seabed (WAV), and primary production (NPPV) were the most important predictors. Juvenile aggregations were predicted to occur at various combinations of these variables (Figure 35). Predictions of occurrence were identified with the highest probability (0.96) in deeper habitats (≥21.8 m depth) with warmer waters at the seabed (SBT ≥19.2°C) and higher primary production (NPPV ≥26.1 mg C m^{-3} day^{-1}). The type of seabed (Substr) did not appear to affect the distribution of juvenile aggregations within the range of sedimentary habitats where this life stage was sampled (Figure 35).

The model prediction applied to the mean summer environmental conditions of the period 2010 - 2020 allowed mapping of the potential distribution of juvenile aggregations as an indication of potential location of higher value juvenile habitats functioning as nursery for common sole (Figure 36).



Variable	min	max
Dist	744	237597
Depth	3.71	82.3
Slope	0	0.283
SBT	7.85	21.37
NPPV	4.59	157.18
SSS	23.38	35.44
MLT	4.03	76.33
CUR	1.48	745.33
WAV	0.03	474.48
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" b = "fMud" c = "Mixed" d = "mSand" e = "Sand" f = "sMud"	

Figure 35. Decision tree for juvenile aggregations of common sole, *Solea solea* (Q3; full model) and associated environmental ranges at which the life stage occurred in the surveys.

Comparison with available survey data (beam trawl surveys considered for the model calibration[17]; Appendix C, Figure C13) and feedback from the stakeholders have highlighted some limitations of the map (Figure 36).

The map correctly identifies potential inshore nurseries along the southeast, south and southwest coast of the UK, although the prediction along the west coast seems to fail to identify potentially suitable habitat patches in Liverpool Bay where juvenile aggregations were frequently observed in survey data. This is due to the fact that the mean summer environmental conditions for 2010 - 2020 used to predict the model in this area showed values that the model considered to be unsuitable for the presence of juvenile aggregations (namely, depth <21.8 m and SBT >15.9°C, with also CUR <149 N m^2/s where MLT was <11.2 m, or SBT <19.5°C and slope <0.07 degrees where MLT was >11.2 m; Figure 35). The coverage of more inshore areas (expected to be most important as nursery grounds) is also limited in the map, due to the distribution of the data on which the model was based (see results of the habitat proxy approach below for a better assessment of more inshore habitats).

[17] Survey data from additional inshore and offshore demersal surveys on the west coast of Scotland were not considered due to doubts raised during stakeholder consultation about the correct identification of common sole in the catches.

The model also appears to identify habitats that may be suitable for juvenile aggregations in northern waters (e.g. east and west of Scotland), despite common sole having a more southern distribution in UK waters, as confirmed by the absence of aggregations in the beam trawl survey catches that extended further north. This is likely accounted for by the model predictive performance (66%) and resulting moderate overall confidence (57%).

Stakeholder feedback confirmed the absence of common sole from commercial catches in the north and west of Scotland. This suggests that, although some of those areas may have environmental conditions that might be suitable to host juvenile aggregations (at least as far as regards the set of variables identified by the model; Figure 35), they are not currently used by common sole. This is likely due to the unsuitability of other environmental conditions that are not accounted for by the model.

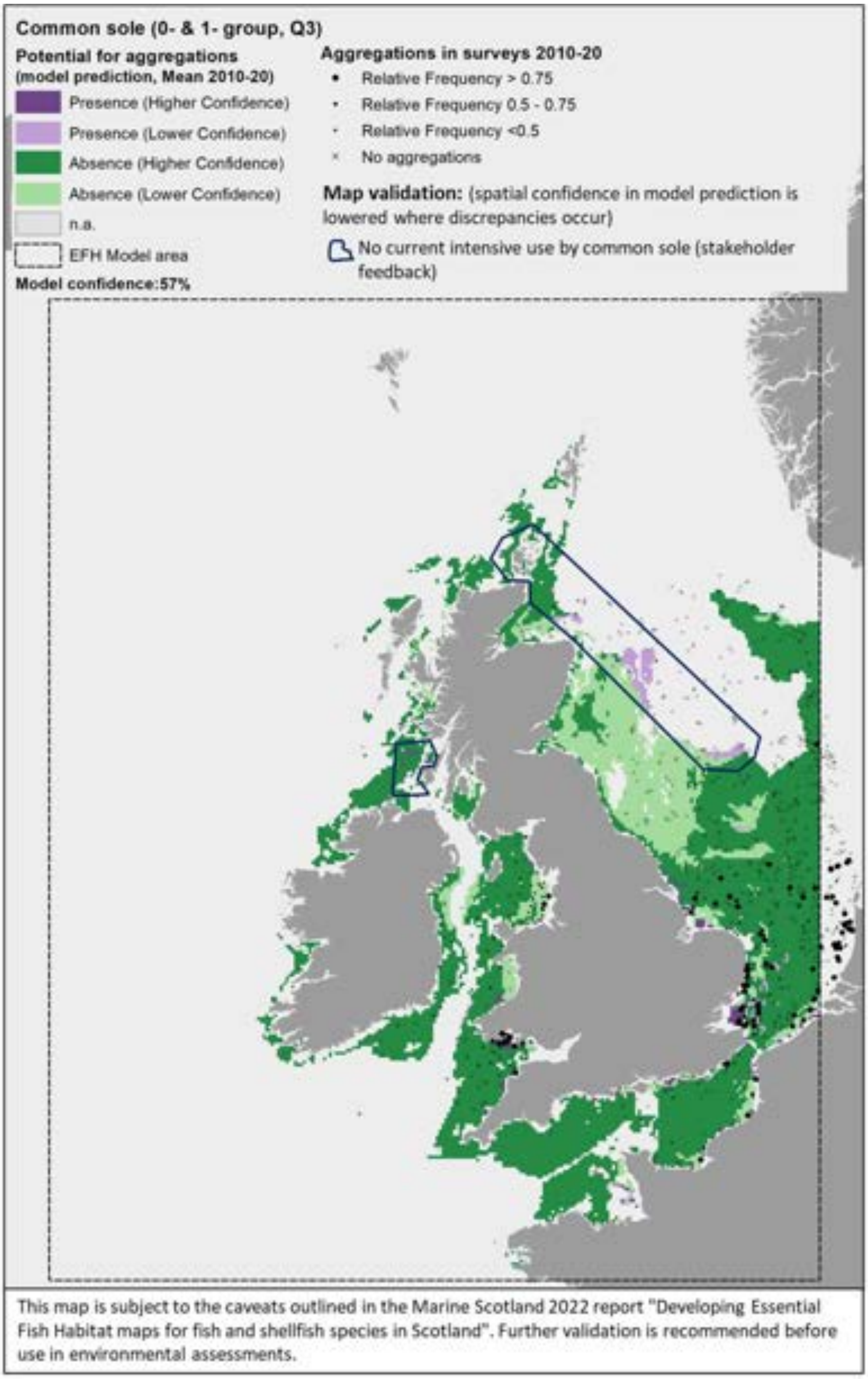


Figure 36. Aggregations of common sole juveniles (*Solea solea* 0- & 1-group, Q3): Frequency of occurrence in the 2010 - 2020 Q3 surveys and model prediction (incl. confidence) based on mean environmental conditions for Q3 across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons.

For the assessment of habitat proxies for juveniles of common sole inshore, thirteen publications were reviewed (see Annex 1). The specific information on juvenile habitat associations and environmental preferences was scarce (most of the information was about generic habitat preferences of the species) and often it was not detailed enough to discriminate suitable habitats at the higher resolution. This, along with expert input obtained with the stakeholder validation, led to a moderate confidence in the overall assessment of habitat proxies for juvenile common sole.

Sandy and muddy habitats in the infralittoral and sublittoral zones were identified as the most suitable habitats potentially functioning as nursery for common sole, with a high confidence associated (Table 13). Other possible habitats were fine sand shores or muddy shores, all with polychaete, oligochaete or bivalve dominance (all scoring 3/M). Further possible habitats, scored with medium to low suitability and medium to low confidence (not shown in Table 13), included circalittoral sands (habitat codes A5.25, A5.25, A5.35, A5.36) and sublittoral biogenic reefs (habitat code A5.6).

The distribution of the inshore habitat proxies for common sole juveniles in the case study area is mapped in Figure 37. It is of note that, currently, common sole has a predominant southern distribution in UK waters, occurring mainly along the west, south and east coast of England (the Humber Estuary represents its northern range limit in the North Sea). Therefore, the habitats in Figure 37 are not currently used by the species (as confirmed by stakeholder feedback), and are to be read as habitats that are potentially suitable and may become available for juvenile colonisation should the species extends its range northwards in the future.

Table 13. Main (highest scoring) habitats potentially associated with nursery function for common sole juveniles (Solea solea). Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Common sole (juvenile) – Habitat proxies for nursery function (Moderate confidence overall)
EUNIS Habitat type (score /confidence)
A2.2 Littoral sand and muddy sand (3/M)
A2.22 Barren or amphipod-dominated mobile sand shores (3/M)
A2.23 Polychaete/amphipod-dominated fine sand shores (3/M)
A2.24 Polychaete/bivalve-dominated muddy sand shores (3/M)
A2.3 Littoral mud (3/M)
A2.31 Polychaete/bivalve-dominated mid estuarine mud shores (3/M)
A2.32 Polychaete/oligochaete-dominated upper estuarine mud shores (3/M)
A2.33 Marine mud shores (3/M)
A5.2 Sublittoral sand (3/H)
A5.22 Sublittoral sand in variable salinity (estuaries) (3/H)
A5.23 Infralittoral fine sand (3/H)
A5.24 Infralittoral muddy sand (3/H)
A5.3 Sublittoral mud (3/H)
A5.32 Sublittoral mud in variable salinity (estuaries) (3/H)
A5.33 Infralittoral sandy mud (3/H)
A5.34 Infralittoral fine mud (3/H)

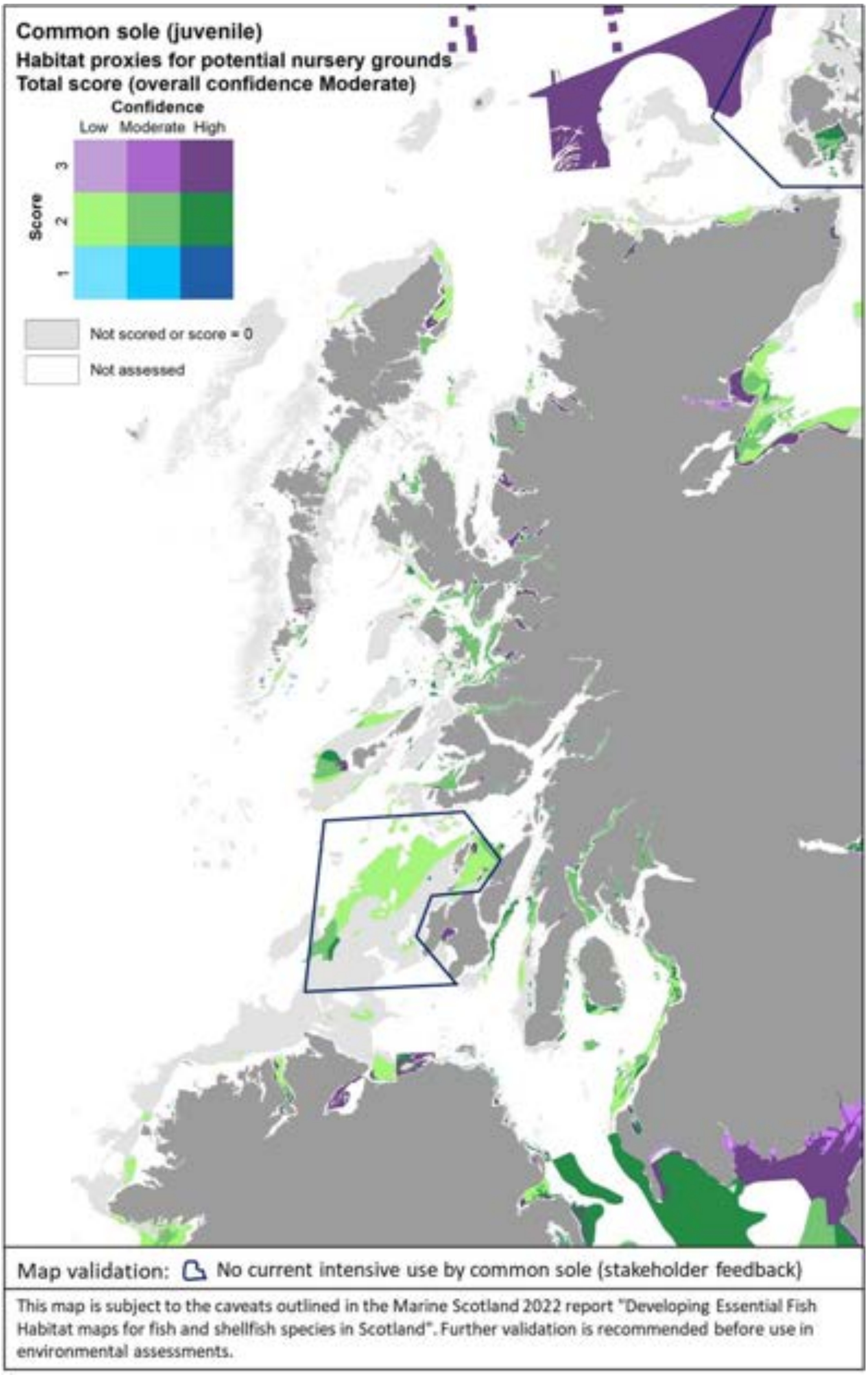


Figure 37. Habitat proxies for common sole juveniles in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Areas for which additional knowledge was obtained for map validation are indicated by polygons.

3.1.8 Anglerfish, *Lophius piscatorius*

Anglerfish (*Lophius piscatorius* Linnaeus 1758), also known as sea monkfish, are a slow moving, bottom dwelling marine fish which is designated as a Priority Marine Feature in Scotland seas. It is mostly widespread in deeper waters of the continental shelf and slope (Annex 1). Small numbers may also occur in shallow coastal waters, although these are largely juveniles which drift from the deeper spawning areas and settled into the inshore nursery grounds (Annex 1).

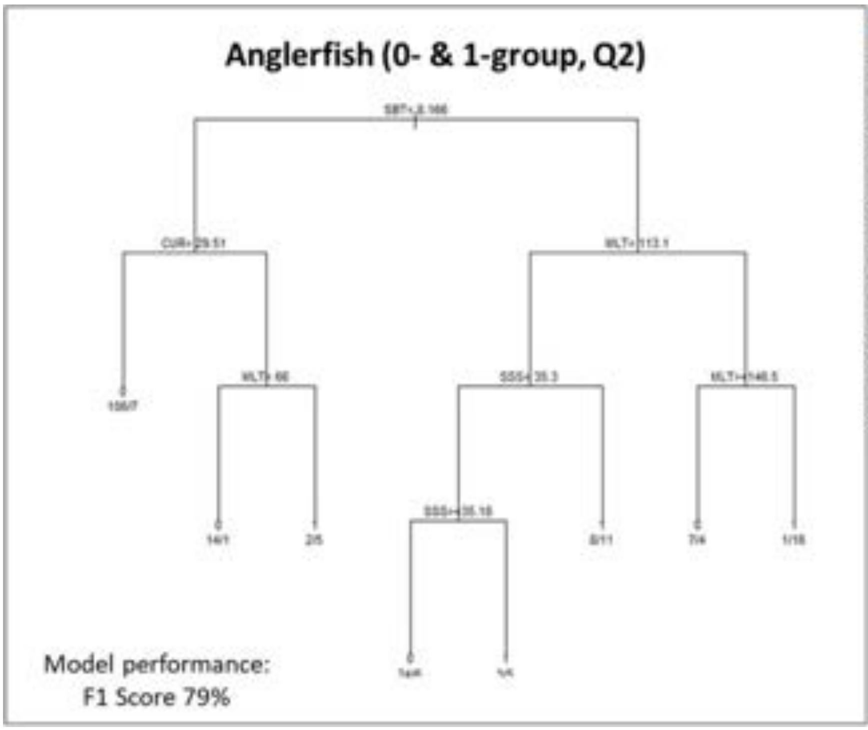
Anglerfish was assessed through modelling based on spring catches from trawl surveys targeting this species in Scottish waters. 0-group individuals alone (<18 cm in length) were infrequent in the survey catch data, likely due to the gear characteristics (e.g. large mesh size) as the surveys did not target specifically juveniles[18] (this was taken into account in the confidence assessment). Therefore, 1-group individuals (<28 cm) were also considered. These are still immature individuals (Annex 1) and including them in the assessment was considered suitable to identify potential higher value habitats used as nurseries.

Substratum type was excluded from the analysis due to its high collinearity with the other variables (VIF 12.1). Seabed temperature (SBT), water column mixing (MLT), salinity (SSS) and current energy at the seabed (CUR) were the environmental predictors selected by the model for juvenile aggregations. SBT and MLT were the most important predictors. Juvenile aggregations were identified with the highest probability (0.94) in warmer waters (mean monthly temperature at the seabed in the spring ≥8.2°C) characterised by an intermediate-low degree of vertical mixing (MLT between 113.1 and 146.5 m) within the range where juveniles were found (Figure 38). These conditions were mostly correspondent to substrata dominated by fine and sandy mud and muddy sand.

The model prediction applied to the mean spring environmental conditions of the period 2010 - 2020 allowed to map the potential distribution of juvenile aggregations as an indication of potential location of higher value juvenile habitats functioning as nursery for anglerfish (Figure 39).

Comparison with available survey data (both used for the model calibration and additional ones; Appendix C, Figure C14 and Figure C15) and feedback from stakeholders have highlighted some inaccuracies in the map (Figure 39).

[18] Data from scallop dredge surveys were indicated during stakeholder consultation as possibly better suited in sampling juvenile anglerfish. These data were not available at the time of the project.



Variable	min	max
Dist	4832	410943
Depth	52.1	836.1
Slope	0.006	5.854
SBT	5.16	9.46
NPPV	2.37	41.63
SSS	33.95	35.43
MLT	14.02	487.16
CUR	0.42	236.08
WAV	0	91.13
SandbH01	0	1
StructH01	0	1
VegH01	0	0
Substr	a = "Coarse" b = "f-sMud_mSand" c = "fMud" d = "Mixed" e = "mSand" f = "Sand" g = "sMud" h = "sMud_mSand"	

Figure 38. Decision tree for juvenile aggregations of anglerfish, *Lophius piscatorius* (Q2; full model) and associated environmental ranges at which the life stage occurred in the surveys.

Stakeholder feedback identified important anglerfish juvenile grounds that were not predicted by the model in the western English Channel and in most of the Celtic Seas. In turn, the model appeared to predict the presence of aggregations in west Rockall, an area where anglerfish has never been found according to both survey data and stakeholder personal observations, whereas the actual aggregation areas on east Rockall are wider than predicted in the map. Additional survey data also indicated further occurrence of aggregations on the west coast of Scotland and in the northern North Sea, where the model predicted absences or did not provide valid predictions (Figure 39). The latter was in inshore areas that are generally poorly covered by the model due to the distribution of the data on which the model was calibrated.

Further exploration of the model predictions showed that the inaccuracies highlighted in the map in Figure 39 (particularly those regarding Rockall and Celtic Seas) were mainly due to limitations in the environmental scenario used to draw that map (environmental conditions averaged for the spring season over the period 2010 - 2020), rather than to limitations in the model predictive ability. In fact, the model predictive performance for anglerfish was good (79%), with the overall confidence lowered to 65% mainly due to the restricted geographical coverage of the fish survey data (northern Scottish waters) used to calibrate the model and the lower confidence in the ability of the fishing gear used in SIAMISS surveys to effectively sample juveniles of the species (Annex 3), as also highlighted during stakeholder consultation. As a result, the model for anglerfish juvenile aggregations was the model with the highest confidence amongst those calibrated for the species in this study.

In turn, it appears that using the mean of spring environmental conditions over the study period 2010 - 2020 (particularly for the model predictors SBT, MLT and SSS) provides an inaccurate representation of the actual conditions experienced by anglerfish over the years, thus leading to the observed inaccuracies in the map prediction in Figure 22. In fact, when the model was applied to a more accurate environmental scenario (April 2015; Figure 40), a better matching with survey data and stakeholder feedback was observed.

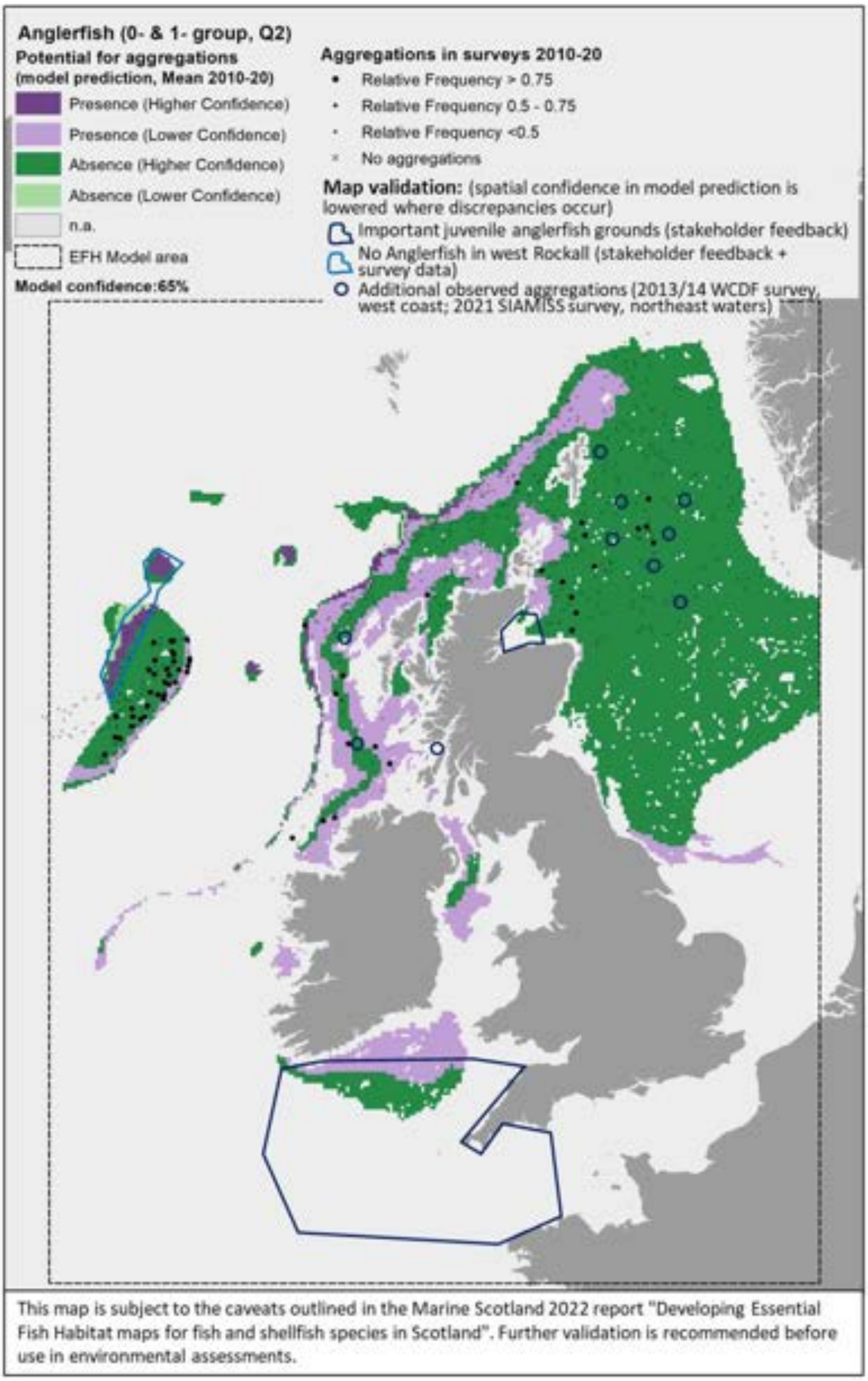


Figure 39. Aggregations of anglerfish juveniles (*Lophius piscatorius* 0- & 1-group, Q2): Frequency of occurrence in the 2010 - 2020 Q3 surveys and model prediction (incl. confidence) based on mean environmental conditions for Q3 across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons and circles.

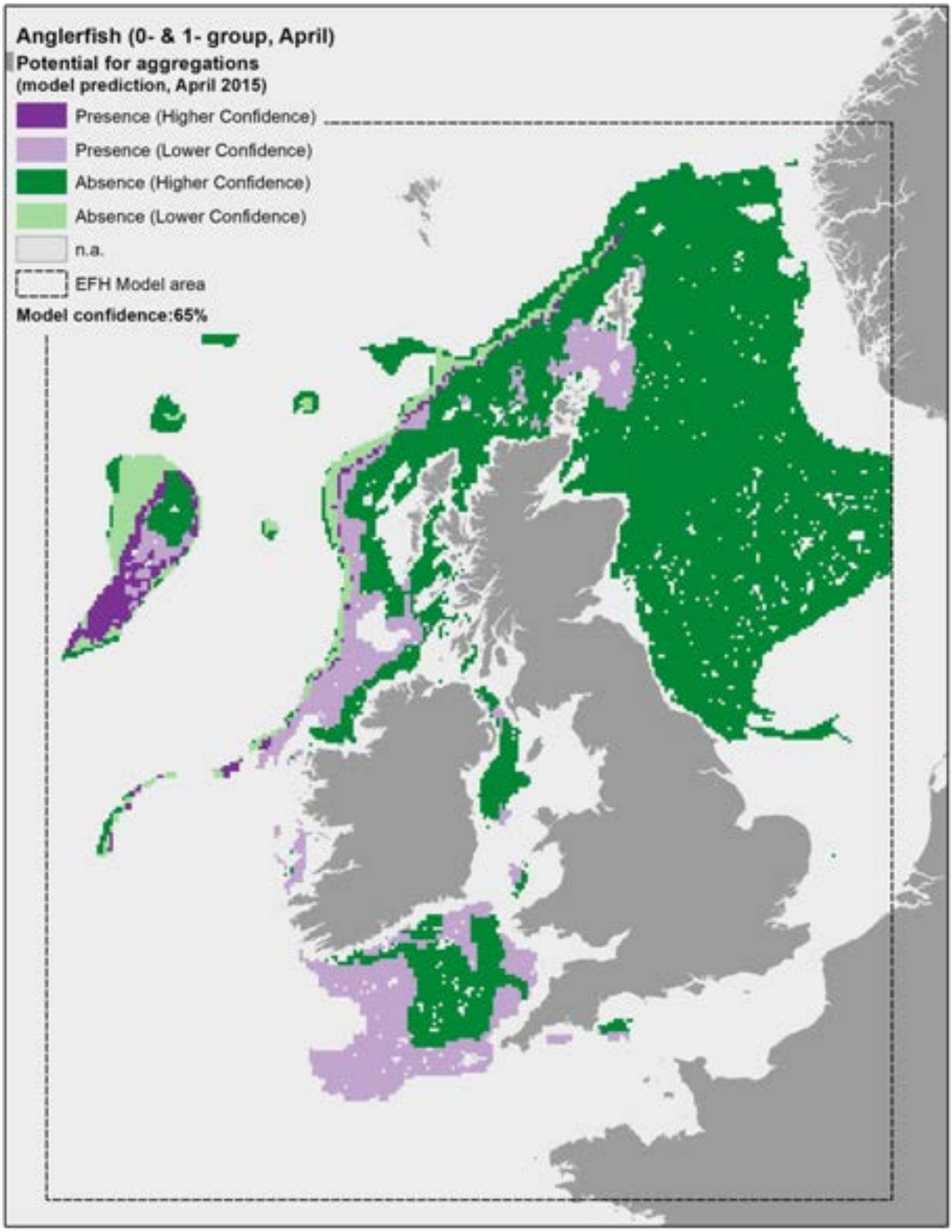


Figure 40. Aggregations of anglerfish juveniles (*Lophius piscatorius* 0- & 1-group, Q2): Model predictions based on environmental conditions in April 2015.

3.1.9 Whiting, *Merlangius merlangus*

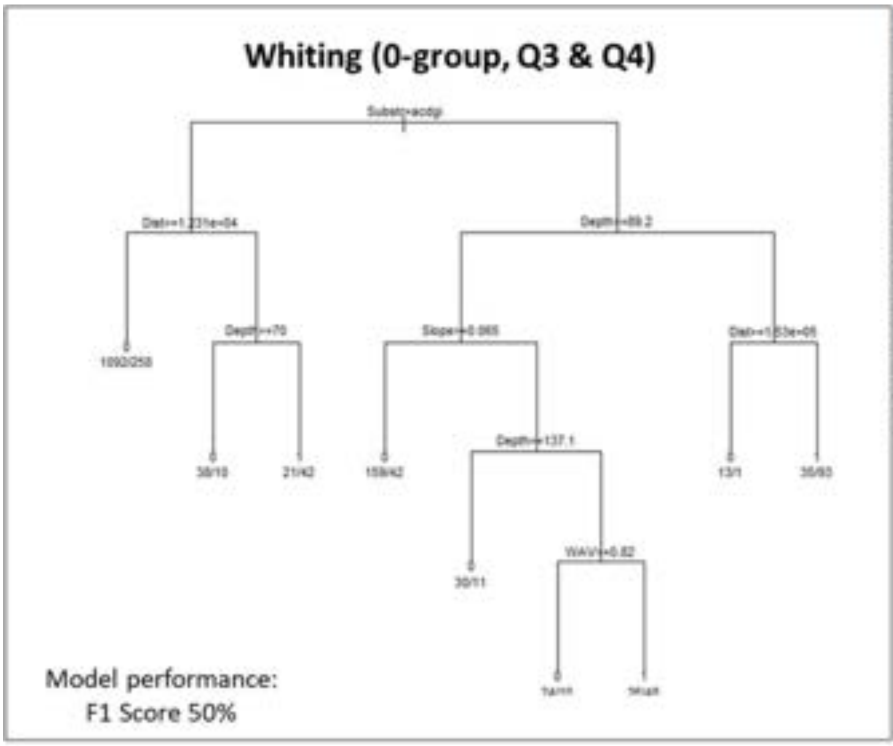
Whiting (*Merlangius merlangus*, Linnaeus 1758) is a demersal gadoid (cod-like) fish of commercial value, which is very common around much of the UK. It is designated as a Priority Marine Feature in Scotland seas. Whiting are pelagic spawners (in winter - spring) that demonstrate a high spatial fidelity to spawning sites, mostly located offshore, due to either geographical attachment or year-to-year persistence of the spatial distribution of the population (Annex 1). Nursery habitats for juveniles of the species are mostly inshore, with higher abundances often found in estuaries and sea lochs throughout the UK (Annex 1).

Whiting was assessed by using both the data-based model and the habitat proxy approach. The former allowed the authors to model the distribution of aggregations of both juveniles in summer-autumn and "running" individuals in winter as indicators of potential important habitats used as nursery or for spawning, respectively. Individuals of body length <16 cm and <20 cm were considered to identify 0-group whiting in summer and autumn catches from bottom trawl surveys, respectively. "Running" individuals were identified in the winter catches as mature individuals with gonads in spawning or spent condition as based on SMALK data available for the bottom trawl surveys analysed. The habitat proxy approach also allowed to identify habitats that may potentially be used by the juveniles of the species, with better coverage of inshore coastal areas.

<u>Juveniles</u>

Depth and distance from the shore (Dist) were the most important predictors of juvenile whiting aggregations selected by the model, followed by substratum type (Substr) and wave energy at the seabed (WAV), and, lastly, slope. Juvenile aggregations were predicted to occur at various combinations of these variables (Figure 41). Predictions of occurrence were identified with the highest probability (0.73) on habitats with predominant sandy mud, muddy sand, or rock or other hard substrata, at shallower depth (<89.2 m) and within 153 km from the shore.

The model prediction applied to the mean environmental conditions of the period 2010 - 2020 (summer-autumn) allowed mapping of the potential distribution of juvenile aggregations as an indication of potential location of higher value juvenile habitats functioning as nursery for whiting (Figure 42). This was the only model that did not include non-persistent environmental variables (SBT, SSS, NPPV or MLT) as predictors and therefore the mapped prediction is not sensitive to the temporal variability (between and within years) of water quality conditions as for the other species/life stages mapped.



Variable	min	max
Dist	1096	395926
Depth	15.1	314.4
Slope	0.001	1.191
SBT	5.32	20.68
NPPV	0.08	102.52
SSS	29.63	35.5
MLT	6.4	165.14
CUR	0.62	698.03
WAV	0	503.3
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" b = "f-sMud_mSand" c = "fMud" d = "Mixed" e = "mSand" f = "RockHard" g = "Sand" h = "sMud" i = "sMud_mSand"	

Figure 41. Decision tree for juvenile aggregations of whiting, *Merlangius merlangus* (Q3 and Q4; full model) and associated environmental ranges at which the life stage occurred in the surveys.

Based on the comparison with available survey data (both used for the model calibration and additional ones; Appendix C, Figure C17 and Figure C18) and the feedback from stakeholders, the mapped predictions appear to match well with the known distribution of juvenile whiting along the UK coast and in the northern North Sea, whereas the model appears to fail in predicting juvenile aggregations as observed in more offshore areas, e.g. at Rockall, off the southwest coast of Scotland, off Aberdeen and Forth estuary (Figure 42). This likely contributed to the moderate-low confidence (41%) associated with the model on the whole, although it is noted that, in some of these areas, survey catches are mostly infrequent. For example, stakeholder feedback highlighted that survey catch rates at Rockall are generally low, as also confirmed by fishery catches, so that it has been hypothesised that whiting in that area are vagrants from elsewhere rather than being part of a self-supporting stock from that area.

Additional survey data from demersal fish surveys on the west coast of Scotland have highlighted a wider distribution of juveniles in most inshore areas (Appendix C, Figure C18), which are poorly covered by the model predictions due to the distribution of the data on which the model was based (Figure 42). These areas are expected to be most important as nursery grounds, and are better assessed through the habitat proxy approach below.

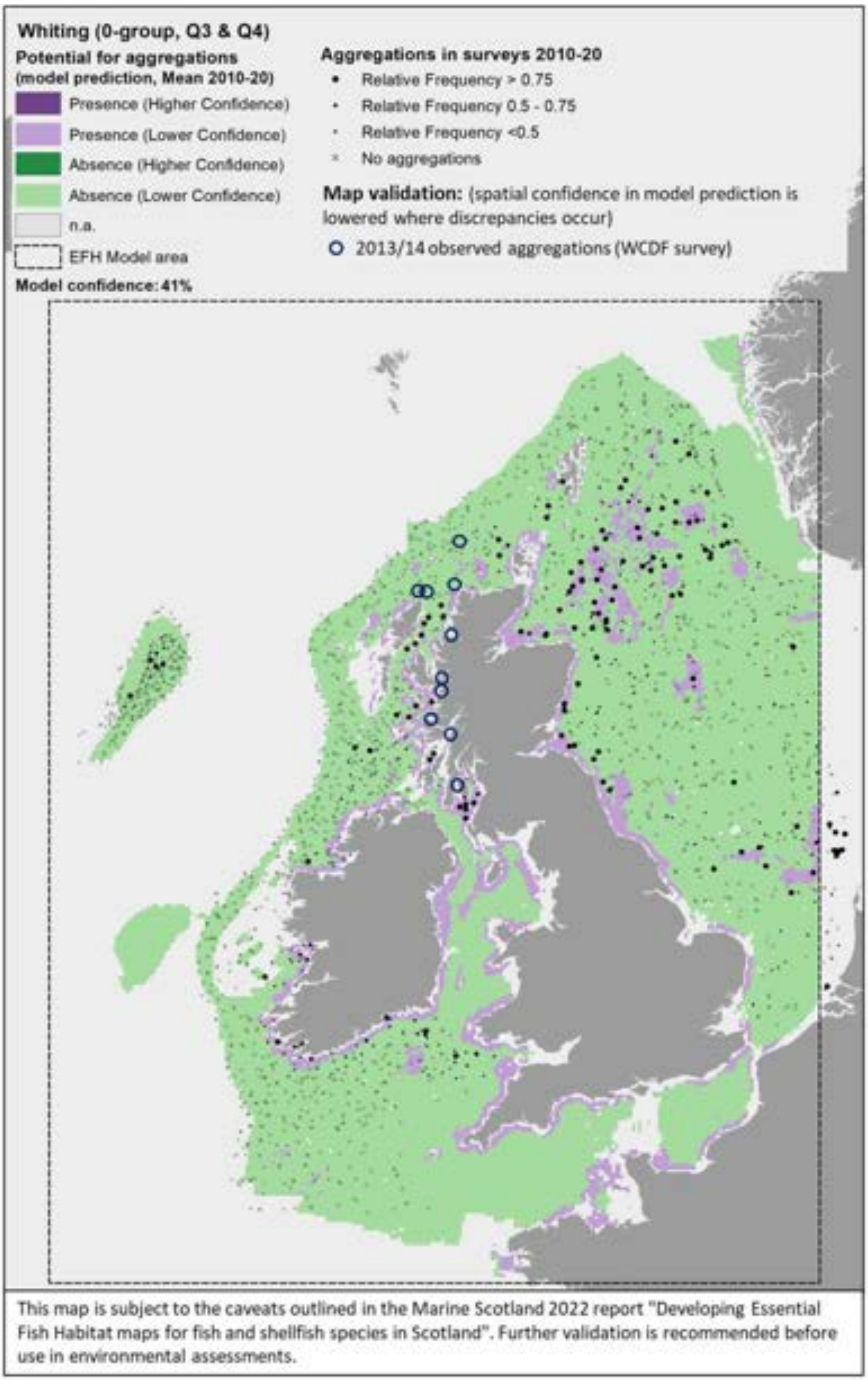


Figure 42. Aggregations of whiting juveniles (*Merlangius merlangus* 0-group, Q3 & Q4): Frequency of occurrence in the 2010 - 2020 surveys and model prediction (incl. confidence) based on mean environmental conditions across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons and circles.

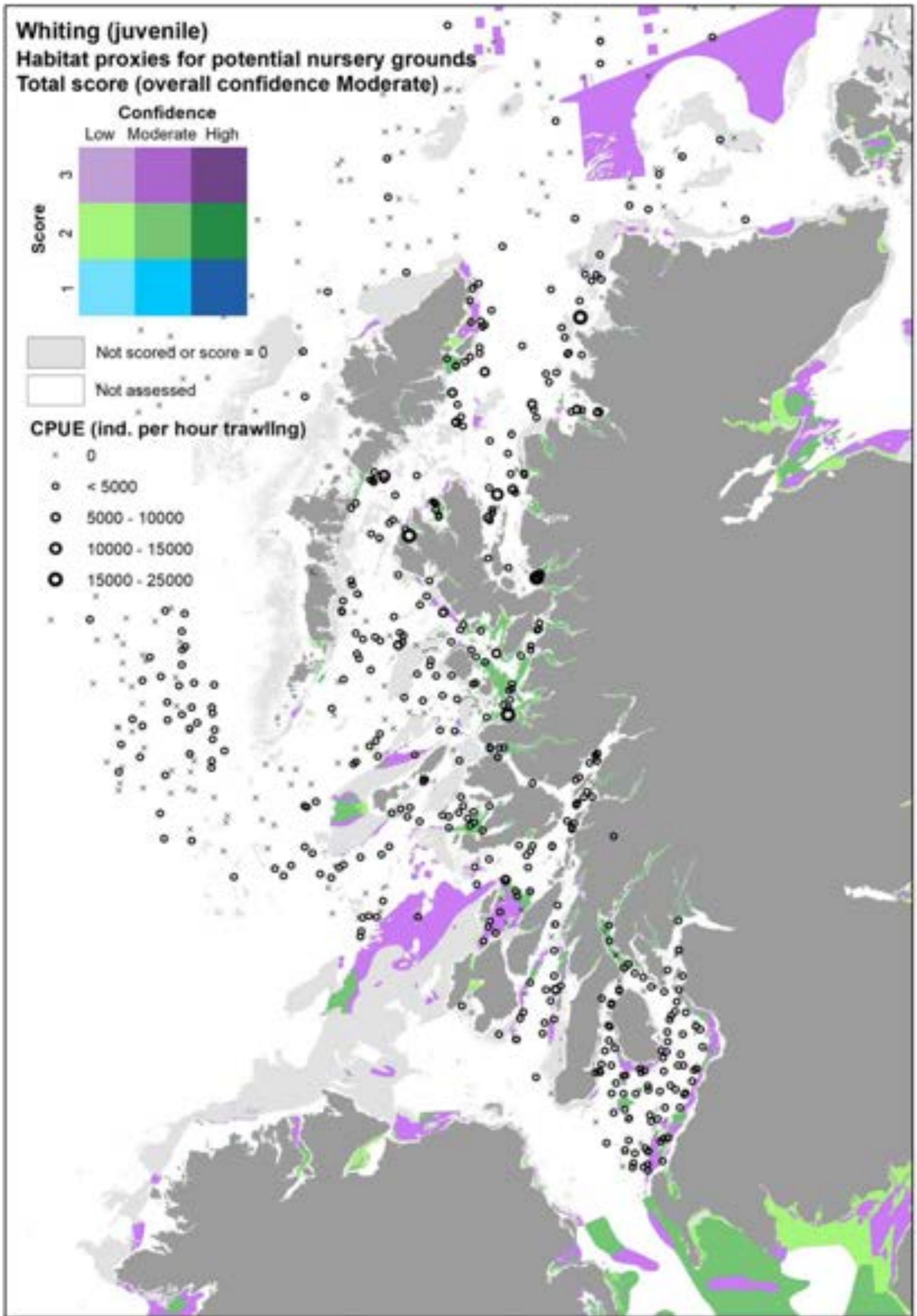
For the assessment of habitat proxies for whiting juveniles inshore, sixteen publications were reviewed and provided characterisation of the species' habitat requirements, although in some cases this was not detailed enough to discriminate suitable habitats at the higher resolution (see Annex 1). This, along with expert input obtained with the stakeholder validation, led to a moderate confidence in the overall assessment of habitat proxies for juvenile whiting.

Sublittoral vegetated habitats (macrophyte-dominated sediments or seagrass beds) were identified as the most suitable habitats potentially functioning as nursery for whiting, with a high confidence associated (Table 14). Other structured habitats in the intertidal or subtidal zones were also identified as highly suitable, albeit with lower (moderate) confidence. These included seagrass beds on littoral sediments, littoral sediments dominated by aquatic angiosperms, maerl beds and kelp and seaweed communities on sublittoral sediments, as well as circalittoral sediments. Further possible habitats, scored with medium to low suitability and medium to low confidence (not shown in Table 14), included littoral sediments, infralittoral sediments, mussel beds and biogenic reefs.

The distribution of the inshore habitat proxies for whiting juveniles in the case study area is mapped in Figure 43, compared with the overall distribution of juveniles from the West Coast of Scotland Demersal Fish Survey (WCDF, 2013/14) in the area. Both the map and the survey data show that whiting juveniles are widely distributed in the area, including in deeper areas not covered by the habitat proxy map. Although juveniles have been found at some distance from the shore, they occur with higher abundance in coastal habitat closer to shore, in agreement with the distribution of habitat proxies, often covering bays and sea lochs (e.g. Loch Dunvegan, west of Skye, and Loch Carron, to the east). Suitable habitats have also been identified into the Moray Firth, matching the data-base model prediction and survey data in Figure 42. No stakeholder feedback was received on this map following consultation.

Table 14. Main (highest scoring) habitats potentially associated with nursery function for whiting juveniles (*Merlangius merlangus*). Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Whiting (juvenile) – Habitat proxies for nursery function (Moderate confidence overall)
EUNIS Habitat type (score /confidence)
A2.6 Littoral sediments dominated by aquatic angiosperms (3/M)
A2.61 Seagrass beds on littoral sediments (3/M)
A5.2 Sublittoral sand (3/M)
A5.25 Circalittoral fine sand (3/M)
A5.26 Circalittoral muddy sand (3/M)
A5.4 Circalittoral mixed sediments (3/M)
A5.5 Sublittoral macrophyte-dominated sediment (3/H)
A5.51 Maerl beds (3/M)
A5.52 Kelp & seaweed communities on sublittoral sediment (3/M)
A5.53 Sublittoral seagrass beds (3/H)



This map is subject to the caveats outlined in the Marine Scotland 2022 report "Developing Essential Fish Habitat maps for fish and shellfish species in Scotland". Further validation is recommended before use in environmental assessments.

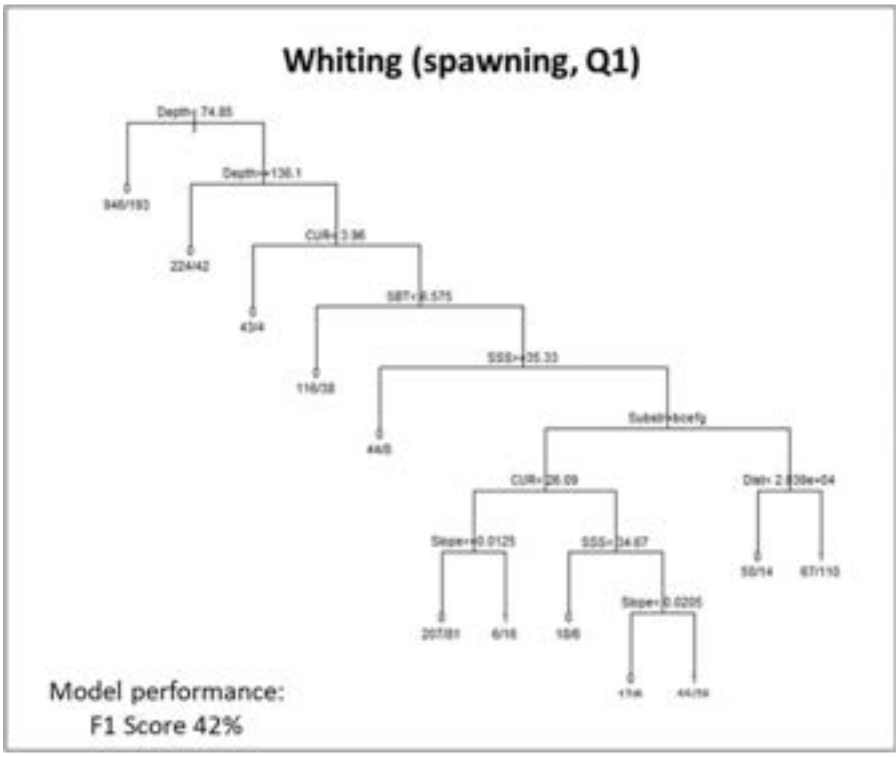
Figure 43. Habitat proxies for whiting juveniles in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Occurrence of aggregations of whiting juveniles from the WCDF 2013/14 survey data in the study area are also shown.

Spawning

As for whiting spawning aggregations, the model was calibrated on all environmental variables excluding the water column mixing (MLT), and its correlate, depth (Pearson's correlation coefficient 0.9) was used instead.

Depth was the most important predictor selected by the model, followed by current energy at the seabed (CUR) and salinity (SSS), by slope, distance from the shore (Dist) and seabed temperature (SBT), and, lastly, by substratum type (Substr). Prediction of spawning aggregations was always excluded from habitats shallower than 74.8 m or deeper than 136 m, with very low current energy (≤3.96 N m^2/s), in colder (mean monthly winter SBT <6.6°C) and more saline waters (SSS≥ 35.3) (Figure 44). Where present, spawning aggregations were predicted to occur with the highest probability (0.72) on habitats that were also characterised by predominant substrata such as sand, sandy mud, fine mud, mixed sediment, or rock or other hard substrata, low current energy at the seabed (<26.1 N m^2/s), and with almost no slope (<0.01 degrees)

The model prediction applied to the mean winter environmental conditions of the period 2010 - 2020 allowed mapping of the potential distribution of whiting spawning aggregations as an indication of potential location of higher value spawning habitats (Figure 45).



Variable	min	max
Dist	706	297289
Depth	11.1	229.9
Slope	0	3.01
SBT	2.91	10.57
NPPV	0	59.19
SSS	24.63	35.44
MLT	5.34	254.17
CUR	0.3	929.15
WAV	0	426.73
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" b = "fMud" c = "Mixed" d = "mSand" e = "RockHard" f = "Sand" g = "sMud"	

Figure 44. Decision tree for spawning aggregations of whiting, *Merlangius merlangus* (Q1; full model) and associated environmental ranges at which the life stage occurred in the surveys.

Comparison with available survey data (used for the model calibration; Appendix C, Figure C20) and the feedback from stakeholders showed a relatively good matching with the mapped predictions of spawning aggregations in the central and northern North Sea, north coast of Scotland and offshore areas to the west of Scotland. In turn, the model appeared to fail in predicting spawning aggregations observed in wide areas of the southern North Sea and eastern English Channel, likely contributing to the low confidence (36%) associated with this model. Stakeholder feedback also indicated the presence of spawning grounds for whiting in the English Channel and on the Trevose ground, where spawning aggregations were suitable conditions for spawning aggregations were not identified by the model (Figure 45). Therefore, a lower confidence should be associated with these predictions in the map and this is highlighted in the blue boxes.

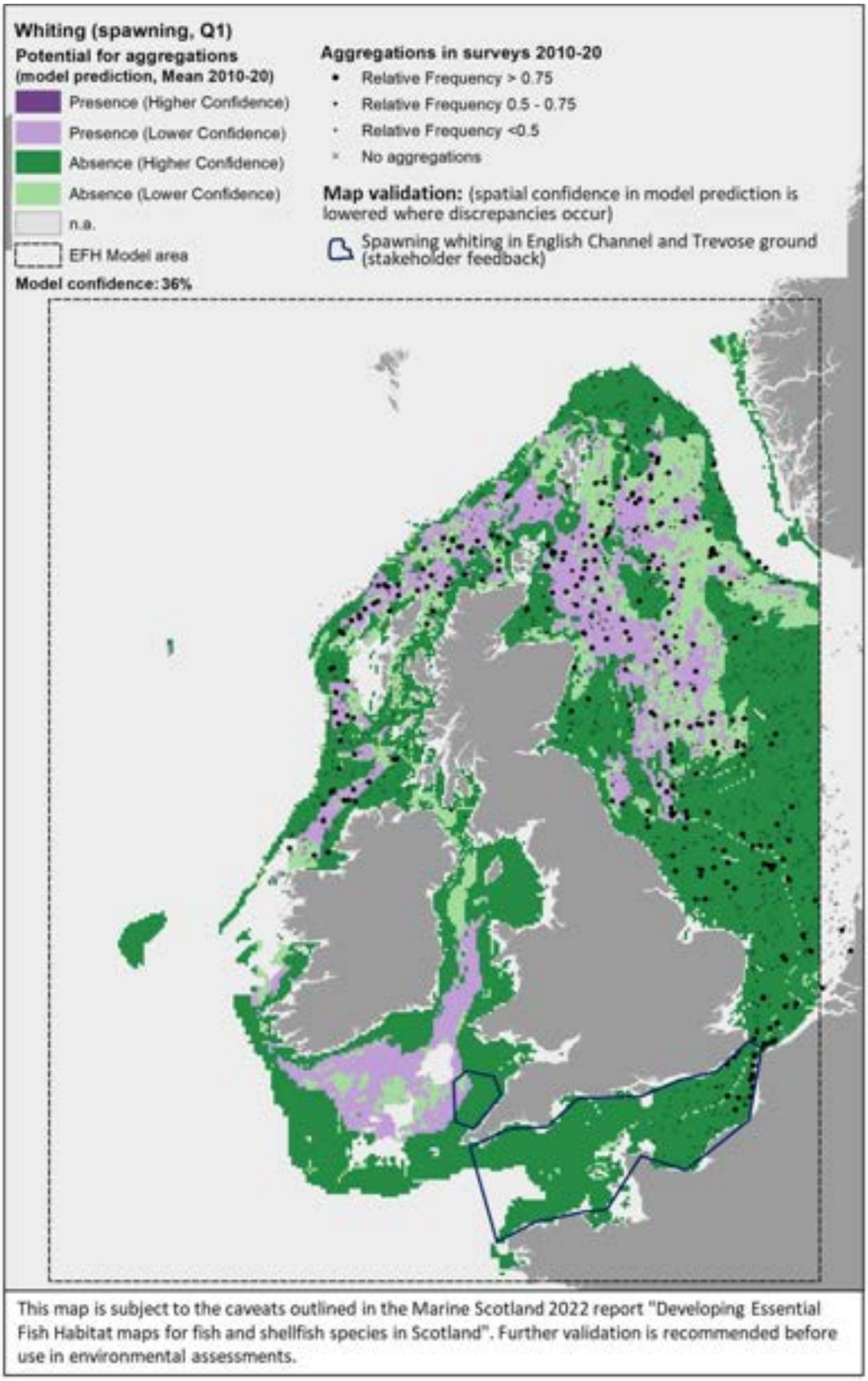


Figure 45. Spawning aggregations of whiting (*Merlangius merlangus* 'running' adults, Q1): Frequency of occurrence in the 2010 - 2020 surveys and model prediction (incl. confidence) based on mean environmental conditions across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons.

3.1.10 Cod, *Gadus morhua*

Atlantic cod (*Gadus morhua* Linnaeus 1758), hereafter referred to as “cod”, is a demersal gadoid fish of high commercial value, which is common around much of the UK (although less common than it used to be 30 years ago due to stock decline). It is designated as a Priority Marine Feature in Scotland seas. It is a pelagic winter spawner, which aggregates over specific grounds to spawn, mostly located offshore, and shows a high seasonal fidelity to spawning sites (Annex 1). Juveniles are demersal, with nursery habitats for 0-group Cod being almost exclusively inshore, in shallow waters and often associated with ‘complex’ habitats (e.g. associated with vegetation, maerl, biogenic structures on gravelly seabed). As juveniles grow, larger individuals gradually migrate to deeper waters to join adult stocks (Annex 1).

Cod was assessed by using both the data-based model and the habitat proxy approach. The former allowed to model the distribution of aggregations “running” individuals in winter as indicator of potential important habitats used for spawning. These were identified as winter aggregations of mature individuals with gonads in spawning or spent condition as based on SMALK data available for the bottom trawl surveys analysed. The habitat proxy approach, in turn, was used to identify inshore habitats that may potentially be used by the juveniles of the species.

Juveniles

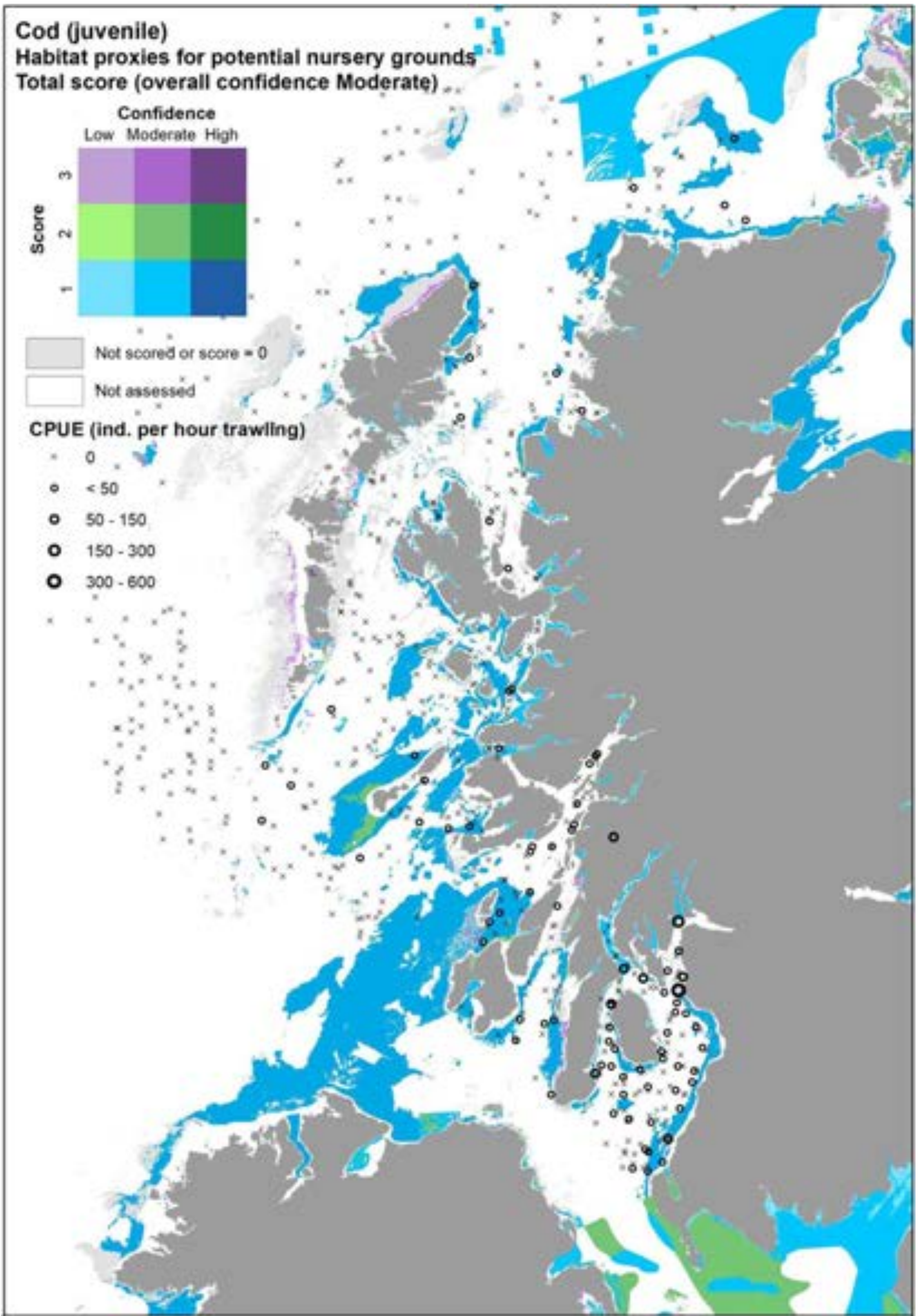
For the assessment of habitat proxies for cod juveniles inshore, fourteen publications were reviewed. These provided characterisation of the species' habitat requirements, although in some cases this was not detailed enough to discriminate suitable habitats at the higher resolution (see Annex 1). This, along with expert input obtained with the stakeholder validation, led to a moderate confidence in the overall assessment of habitat proxies for juvenile cod..

Juvenile cod had a range of potentially suitable habitats inshore. In terms of depth there was not a specific preference, with habitats from the littoral, infralittoral and sublittoral zones all scoring with high suitability and high or medium confidence (Table 15). The most suitable (scoring 3/H) were determined to be those habitats with prevalence of aquatic angiosperms, macrophytes and seagrasses. Other likely habitats included maerl beds, biogenic reefs and mussel beds. Further possible habitats, scored with medium to low suitability and medium to low confidence (not shown in Table 15), included sandy and mixed sediments in the infralittoral, circalittoral and sublittoral zones.

The distribution of the inshore habitat proxies for cod juveniles in the case study area is mapped in Figure 46, compared with the overall distribution of juveniles from the West Coast of Scotland Demersal Fish Survey (WCDF, 2013/14) in the area. Although potentially suitable habitats appear to be widely distributed in the case study area (albeit their suitability was identified as low in the assessment, based on literature review and stakeholder feedback), survey data seem to confirm the occurrence of cod juveniles mostly to the south of the study area, in the Firth of Clyde. Higher abundances were particularly found in the survey catches from the inner reaches (e.g. Loch Long, Loch Fyne), where suitable habitat proxies were also identified. However, gaps in the habitat map (due to lack of coverage by the EUNIS habitat data layers) restricted the ability to identify habitat proxies for juvenile cod in these inner areas. No stakeholder feedback was received on this map following consultation.

Table 15. Main (highest scoring) habitats potentially associated with nursery function for Cod juveniles. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Cod (juvenile) – Habitat proxies for nursery function (Moderate confidence overall)
EUNIS Habitat type (score /confidence)
A2.6 Littoral sediments dominated by aquatic angiosperms (3/H)
A2.61 Seagrass beds on littoral sediments (3/M)
A3.1 Atlantic and Mediterranean high energy infralittoral rock (3/M)
A3.11 Kelp with cushion fauna and/or foliose red seaweeds (3/M)
A3.15 Frondose algal communities (other than kelp) (3/M)
A5.5 Sublittoral macrophyte-dominated sediment (3/H)
A5.51 Maerl beds (3/M)
A5.52 Kelp and seaweed communities on sublittoral sediment (3/M)
A5.53 Sublittoral seagrass beds (3/H)
A5.6 Sublittoral biogenic reefs (3/M)
A5.62 Sublittoral mussel beds on sediment (3/M)



This map is subject to the caveats outlined in the Marine Scotland 2022 report "Developing Essential Fish Habitat maps for fish and shellfish species in Scotland". Further validation is recommended before use in environmental assessments.

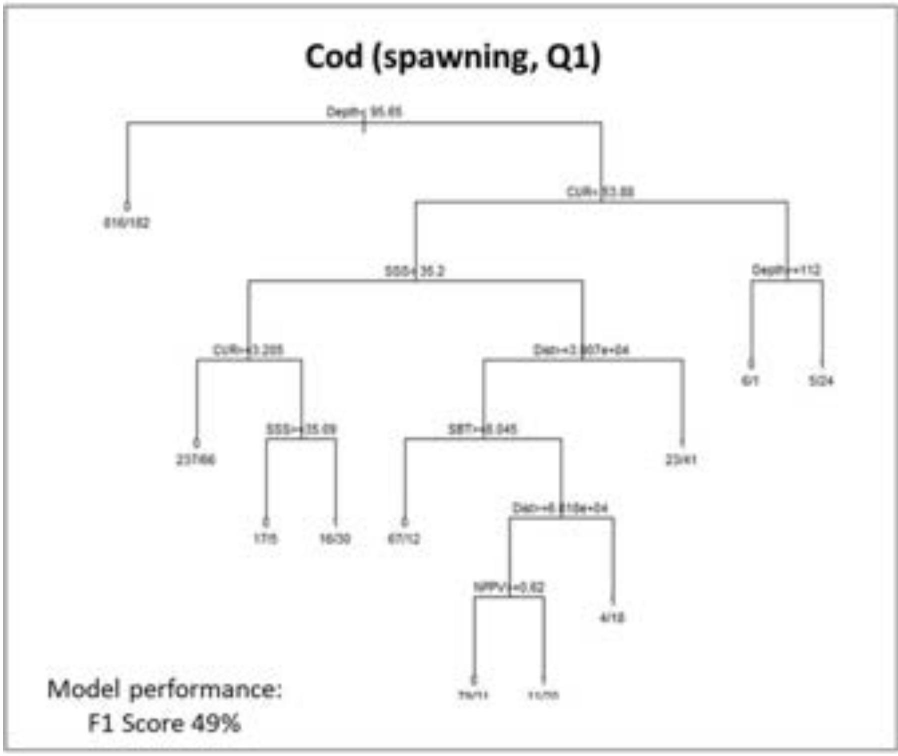
Figure 46. Habitat proxies for Cod juveniles in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Occurrence of aggregations of Cod juveniles from WCDF 2013/14 survey data in the study area are also shown.

Spawning

Water column mixing (MLT) was excluded from the analysis due to its collinearity with depth (Pearson's correlation coefficient 0.9), which was used instead. Depth and current energy at the seabed (CUR) were identified as the most important predictors of cod spawning aggregations, followed by distance from the shore (Dist) and salinity (SSS), and seabed temperature (SBT) and primary production (NPPV).

Cod spawning aggregations were generally predicted as absent from areas shallower than 95.6 m (Figure 47). They were predicted to occur with the highest probability (0.83) in areas with wide ranging current energy at the seabed (≥53.9 N m^2/s) to a maximum depth of 112 m. In lower current energy conditions, spawning aggregations were also predicted as highly probable (0.82) in areas with higher salinity (≥35.2), lower seasonal temperature at the seabed (<8°C) and at a distance between 39 and 60 km from the shore.

The model prediction applied to the mean winter environmental conditions of the period 2010 - 2020 allowed mapping of the potential distribution of cod spawning aggregations as an indication of potential location of higher value spawning habitats (Figure 48).



Variable	min	max
Dist	706	297289
Depth	11	324.2
Slope	0	4.472
SBT	2.71	10.18
NPPV	0	26.18
SSS	26.12	35.46
MLT	5.34	278.69
CUR	1.32	913.26
WAV	0	426.73
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" b = "fMud" c = "Mixed" d = "mSand" e = "RockHard" f = "Sand" g = "sMud"	

Figure 47. Decision tree for spawning aggregations of cod (Q1; full model) and associated environmental ranges at which the life stage occurred in the surveys.

Based on the comparison with available survey data (used for the model calibration; Appendix C, Figure C21) and the feedback from stakeholders, the mapped predictions appear to better predict the distribution of spawning cod in the northern North Sea and off the north coast of Scotland. However, the map appears to fail in predicting the aggregations observed in other areas of the North Sea, and particularly to the south (Figure 48). Such discrepancies have likely contributed to the moderate-low confidence (41%) associated with this model on the whole. Stakeholders also highlighted the presence of spawning grounds for cod in the English Channel and on the Trevose ground, off the north coast of Cornwall, and therefore the absence predicted by the model, particularly in these southern areas, is to be taken with lower confidence (Figure 48).

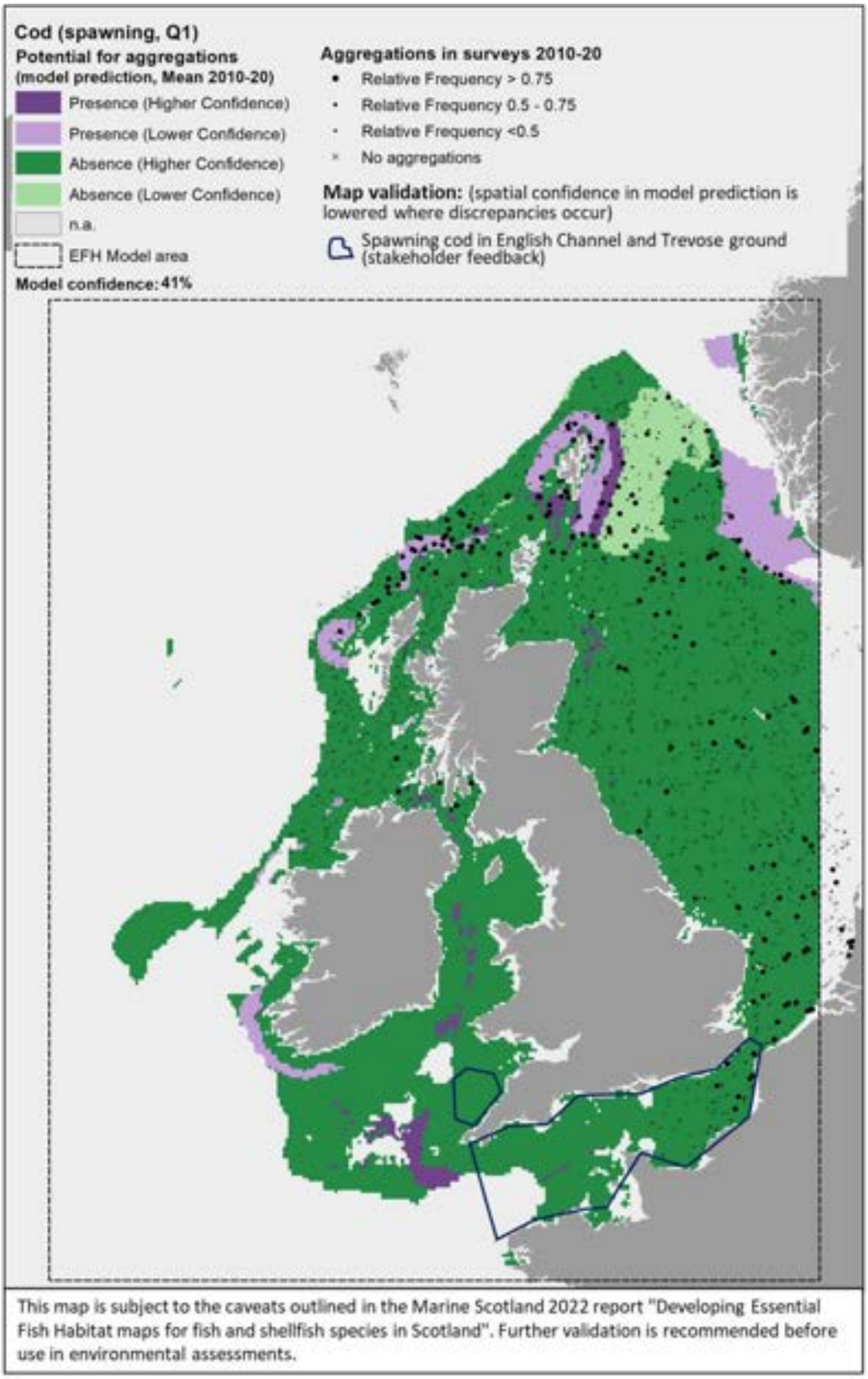


Figure 48. Spawning aggregations of cod ('running' adults, Q1): Frequency of occurrence in the 2010 - 2020 surveys and model prediction (incl. confidence) based on mean environmental conditions across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons.

3.1.11 Haddock, *Melanogrammus aeglefinus*

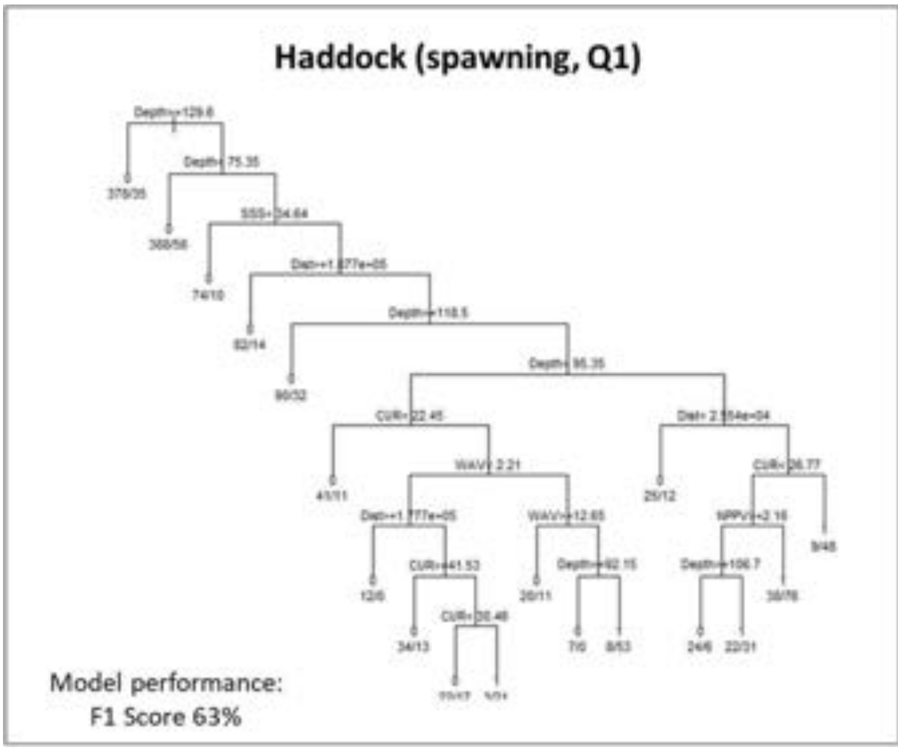
Haddock (*Melanogrammus aeglefinus*, Linnaeus 1758) is a demersal gadoid (cod-like) fish of commercial value, which is found throughout British and Irish waters, although it is more common in northern waters (e.g. off north-eastern Scotland, northeast England, Irish sea). The species mostly occurs offshore. It is a pelagic spawner (in winter - spring) known to aggregate over specific spawning grounds offshore. Juveniles are also pelagic, and they appear to disperse soon after settling, without occupying distinct areas of habitat repeatedly selected over time, therefore suggesting no particular use of nursery areas (Annex 1).

Haddock was assessed through modelling of spawning aggregations based on winter bottom trawl data as indicator of potential important habitats used for spawning. Mature individuals with gonads in spawning or spent condition were identified as based on SMALK data available for the bottom trawl surveys analysed.

Water column mixing (MLT) was excluded from the analysis due to its collinearity with depth (Pearson's correlation coefficient 0.9), which was used instead. Depth was by far the most important predictor of haddock spawning aggregations, this variable recurring at different levels of the decision tree model (Figure 49). Distance from the shore (Dist), current and wave energy at the seabed (CUR, WAV), salinity (SSS) and primary production (NPPV) were also selected as predictors by the model. Prediction of spawning aggregations was always excluded from habitats shallower than 75.3 m or deeper than 118 m, farther than 188 km from the shore and with salinity lower than 34.6 (Figure 49). Where present, spawning aggregations were generally predicted to occur with higher probability (0.87) in habitats at depths down to a maximum of 95.3 m and current energy at the seabed ≥22.5 N m^2/s. Under these conditions, presence of aggregations was predicted specifically in habitats with very low energy (CUR between 30.5 and 41.5 N m^2/s and WAV <2.21 N m^2/s) and within 178 km from the shore, or where wave energy is slightly higher (but still generally low, between 2.21 and 12.6 N m^2/s) and at depth <92.1 m.

The model prediction applied to the mean winter environmental conditions of the period 2010 - 2020 allowed mapping of the potential distribution of haddock spawning aggregations as an indication of potential location of higher value spawning habitats (Figure 50).

Based on the comparison with available survey data (used for the model calibration; Appendix C, Figure C23), the mapped predictions appear to predict well the distribution of spawning haddock in the central and northern North Sea and off the north coast of Scotland, with suitable habitats for spawning aggregations also being identified over most of the Celtic Seas (Figure 50). In turn, the distribution of survey data suggests that aggregations also occur along the Atlantic coast west of Scotland, despite the model predicting absence in some of these areas. No particular discrepancies with stakeholder knowledge were highlighted during consultation.



Variable	min	max
Dist	706	297289
Depth	17.9	328.6
Slope	0	4.472
SBT	4.37	10.13
NPPV	0	59.19
SSS	31.54	35.47
MLT	7.09	328.46
CUR	0.3	882.25
WAV	0	257.36
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" b = "fMud" c = "Mixed" d = "mSand" e = "RockHard" f = "Sand" g = "sMud"	

Figure 49. Decision tree for spawning aggregations of haddock (Q1; full model) and associated environmental ranges at which the life stage occurred in the surveys.

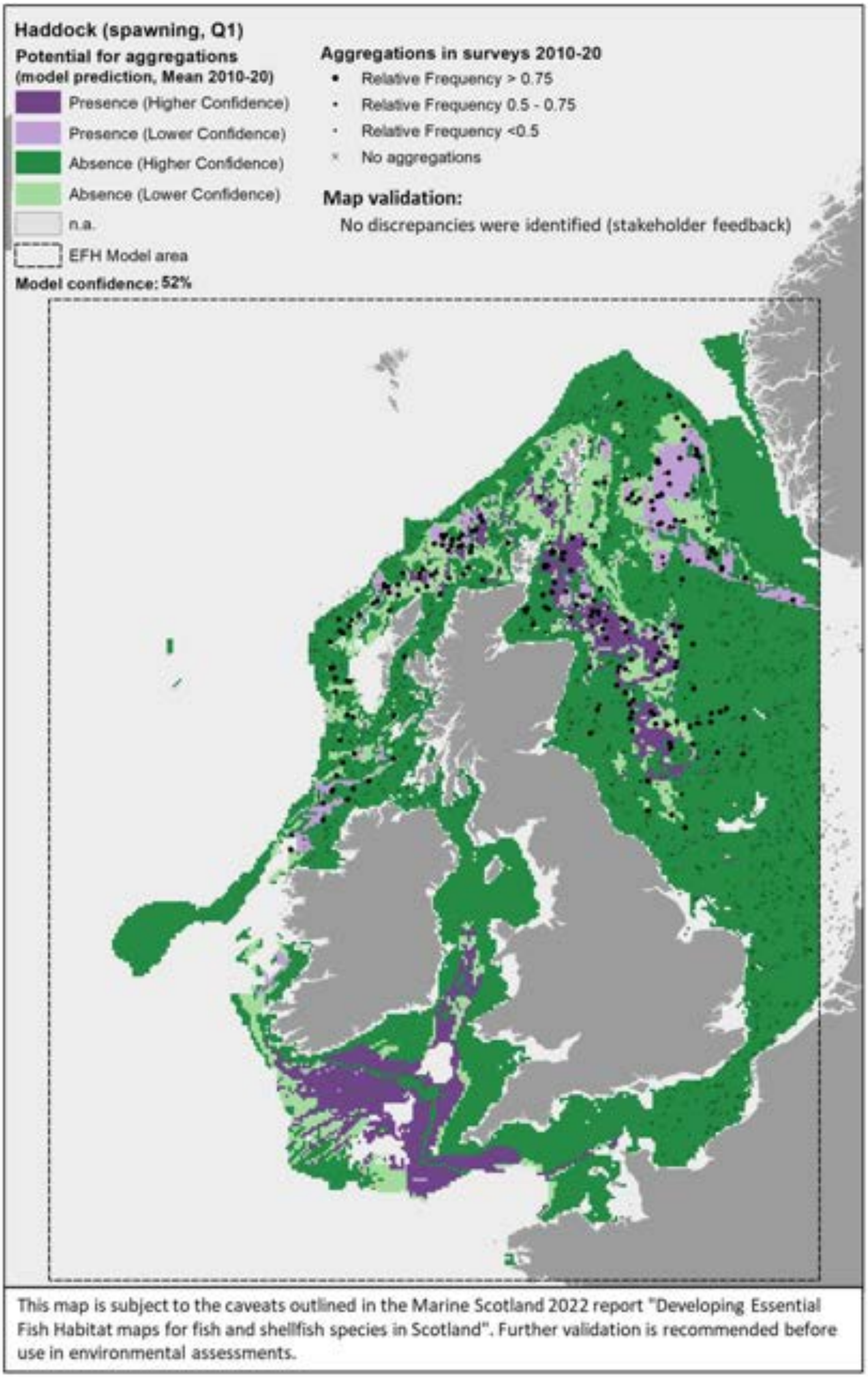


Figure 50. Spawning aggregations of haddock ('running' adults, Q1): Frequency of occurrence in the 2010 - 2020 surveys and model prediction (incl. confidence) based on mean environmental conditions across 2010 - 2020.

3.1.12 Norway pout, *Trisopterus esmarkii*

Norway pout (*Trisopterus esmarkii*, Nilsson 1855) is a benthopelagic gadoid (cod-like) fish of limited commercial value in the UK. It is found throughout British and Irish waters, although it is more common on the west coast. Norway pout is an important food item in the diet of other gadoid predators (e.g. hake, cod, whiting and pollack) and is designated as a Priority Marine Feature in Scotland's seas. The species occurs both inshore and offshore, although its spawning grounds are mostly located offshore, with spawning occurring mainly in winter over the coastal shelf and in spring in deeper areas. This species is not considered to have specific nursery grounds (Annex 1).

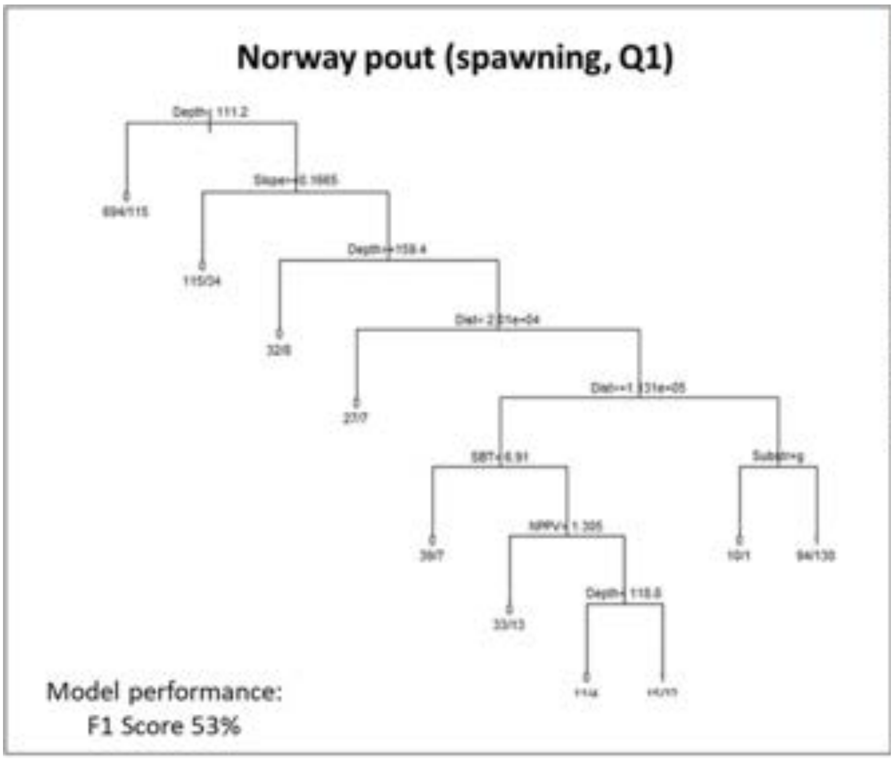
Norway pout was assessed through modelling of spawning aggregations based on winter bottom trawl data as indicator of potential important habitats used for spawning. Mature individuals with gonads in spawning or spent condition were identified as based on SMALK data available for the bottom trawl surveys analysed.

Water column mixing (MLT) was excluded from the analysis due to its collinearity with depth (Pearson's correlation coefficient 0.9), which was used instead. Depth was by far the most important predictor of Norway pout spawning aggregations, this variable recurring at different levels of the decision tree model (Figure 51). Seabed temperature (SBT) and substratum type (Substr) were also moderately important predictors, followed by distance from the shore (Dist), slope and primary production (NPPV). Prediction of spawning aggregations was always excluded from habitats shallower than 111 m or deeper than 159 m, within 20 km of the shore and with slope ≥0.17 degrees (Figure 51). In turn, spawning aggregations were predicted to occur either in habitats within 113 km of the shore where the dominant substratum is muddy sand, sand, coarse or mixed sediment (0.58 probability), or in deeper (≥119 m) habitats further offshore (Dist ≥113 km), with warmer waters (mean winter seabed temperature ≥6.9°C) and excluding areas with very low productivity (NPPV ≥1.3 mg C m^{-3} day^{-1}) (0.68 probability).

The model prediction applied to the mean winter environmental conditions of the period 2010 - 2020 allowed mapping of the potential distribution of Norway pout spawning aggregations as an indication of potential location of higher value spawning habitats (Figure 52).

Based on the comparison with available survey data (used for the model calibration; Appendix C, Figure C24), the mapped predictions appear to predict well the distribution of spawning Norway pout in the northern North Sea and off the north and west coast of Scotland, although a low probability of presence and associated low spatial confidence is associated with these predictions (Figure 52).

The potential presence of spawning aggregations is also predicted in some areas of the Celtic Seas, although stakeholder feedback suggested that spawning areas of Norway pout in this region are more widespread. The distribution of survey data suggests that aggregations also frequently occur in the central North Sea, despite the model predicting absence in some of these areas.



Variable	min	max
Dist	706	290431
Depth	27.6	324.2
Slope	0.001	4.472
SBT	4.37	9.6
NPPV	0	25.53
SSS	31.54	35.44
MLT	13.6	278.57
CUR	0.3	789.39
WAV	0	134.62
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" c = "Mixed" d = "mSand" f = "Sand" g = "sMud"	

Figure 51. Decision tree for spawning aggregations of Norway pout (Q1; full model) and associated environmental ranges at which the life stage occurred in the surveys.

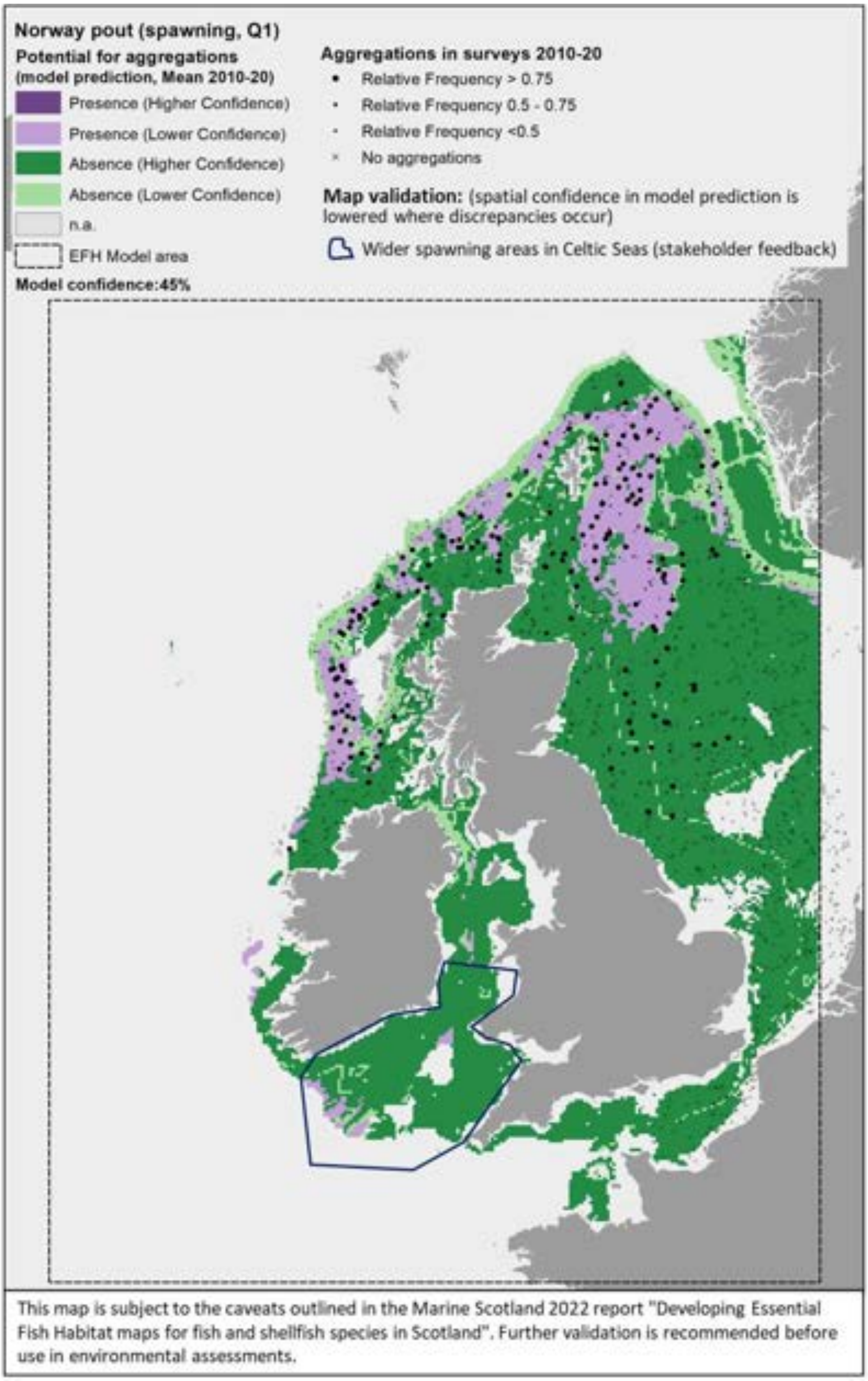


Figure 52. Spawning aggregations of Norway pout ('running' adults, Q1): Frequency of occurrence in the 2010 - 2020 surveys and model prediction (incl. confidence) based on mean environmental conditions across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons.

3.1.13 Blue whiting, *Micromesistius poutassou*

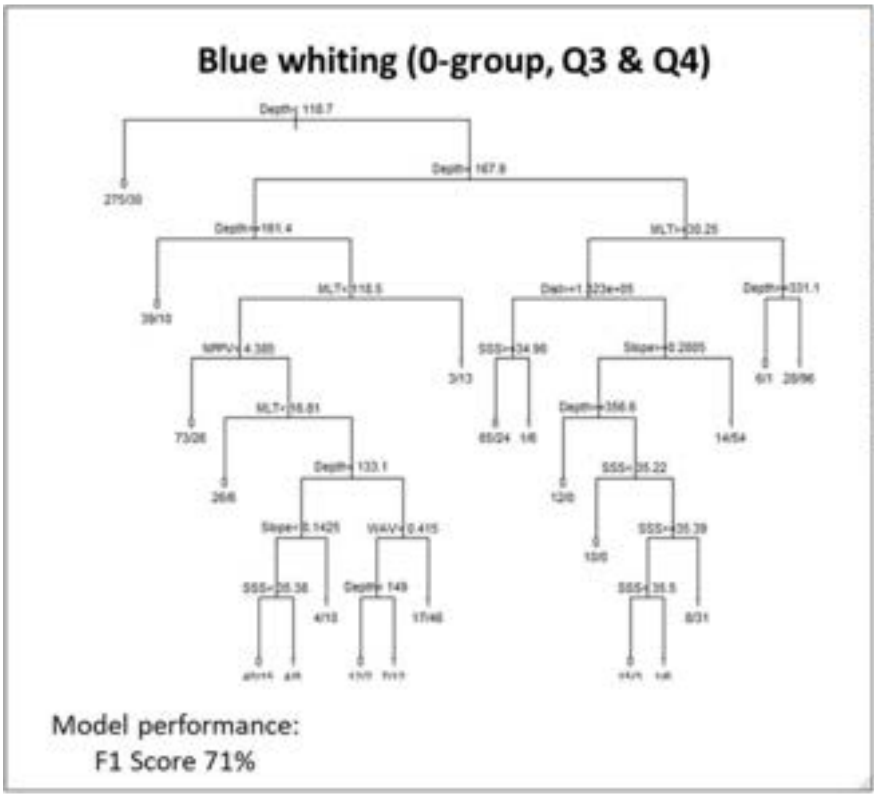
Blue whiting (*Micromesistius poutassou*, Risso 1827) is a benthopelagic gadoid (cod-like) fish of commercial value (mostly marketed outside the UK as fishmeal and oil), which inhabits the continental slope and shelf in deeper offshore areas, mostly off western and northern Scotland, in the North Sea and off the southern and western coasts of Ireland and the British Isles. It is designated as a Priority Marine Feature in Scotland seas (offshore only). Pelagic spawning is reported to occur in spring mostly along the edge of the continental shelf in areas west of the British Isles and on the Rockall Bank plateau, whereas there is no knowledge of specific habitat requirements for juveniles (Annex 1).

Blue whiting was assessed through modelling based on summer and autumn catches from bottom trawl surveys. Individuals <19 cm in length were considered to identify 0-group juveniles and their aggregations were used as indicator of potential higher value habitats used as nurseries.

As for the other gadoids, depth was the most important predictor of blue whiting juvenile aggregations, this variable recurring at different levels of the decision tree model (Figure 53). Wave and current energy at the seabed (WAV, CUR) were also moderately important predictors, followed by slope, salinity (SSS), water column mixing (MLT), distance from the shore (Dist) and primary production (NPPV). Prediction of juvenile aggregations was always excluded from habitats shallower than 119 m or at depths between 161 and 168 m (Figure 53).

In turn, juvenile aggregations were predicted to always occur with higher probability (>0.8) in deeper habitats (≥168 m) with variable degree of mixing (MLT ≥30.2 m). In these conditions, higher probability of occurrence was predicted either in offshore habitats (Dist ≥132 km) where mean salinity in the summer-autumn is <35, or in habitats within 132 km distance from the shore but with either negligible slope (<0.28 degrees) or, where slope is ≥0.28 degrees, at depth <357 m and with more saline waters (≥35.5).

The model prediction applied to the mean environmental conditions of the period 2010 - 2020 (summer-autumn) allowed mapping of the potential distribution of juvenile aggregations as an indication of potential location of higher value juvenile habitats functioning as nursery for blue whiting (Figure 54).



Variable	min	max
Dist	2411	414214
Depth	49	532.6
Slope	0.002	4.12
SBT	6.57	14.63
NPPV	0.04	49.12
SSS	32.03	35.6
MLT	9.39	293.55
CUR	0.94	698.03
WAV	0	131.54
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" b = "f-sMud_mSand" c = "fMud" d = "Mixed" e = "mSand" f = "RockHard" g = "Sand" h = "sMud" i = "sMud_mSand"	

Figure 53. Decision tree for juvenile aggregations of blue whiting, *Micromesistius poutassou* (Q3 and Q4; full model) and associated environmental ranges at which the life stage occurred in the surveys.

The comparison with the distribution of aggregations in the survey data (Figure 54, and Appendix C, Figure C25) showed a good agreement of the mapped predictions in locating juvenile aggregations mostly along the continental shelf edge west and north of the British Isles, these also overlapping with the known spawning migration routes for blue whiting in the northern Atlantic (Worsøe Clausen et al. 2005). A lower agreement was observed over Rockall (this also being reported as a spawning ground for the species), where aggregations were frequently found over a wider area than the one predicted by the model. Additional survey data from demersal fish surveys along the west coast of Scotland showed juvenile aggregations of blue whiting also occurring in areas further inshore (Appendix C, Figure C26), which instead are poorly covered by the predicted map due to the distribution of the data that were used to calibrate the model (Figure 54).

Stakeholder feedback highlighted that the status of the blue whiting stock in the North Sea (ICES area VI) is such that fishery catches in the area northeast of Shetland are negligible (ICES 2019c). This evidence does not directly pertain to juvenile stages, and survey data showed the presence of juvenile aggregations in this area, albeit sparsely. However, it might indirectly suggest that juvenile aggregations may also be less widely distributed in this area compared to what predicted by the map, and therefore the confidence associated with this spatial prediction could possibly be lower (Figure 54).

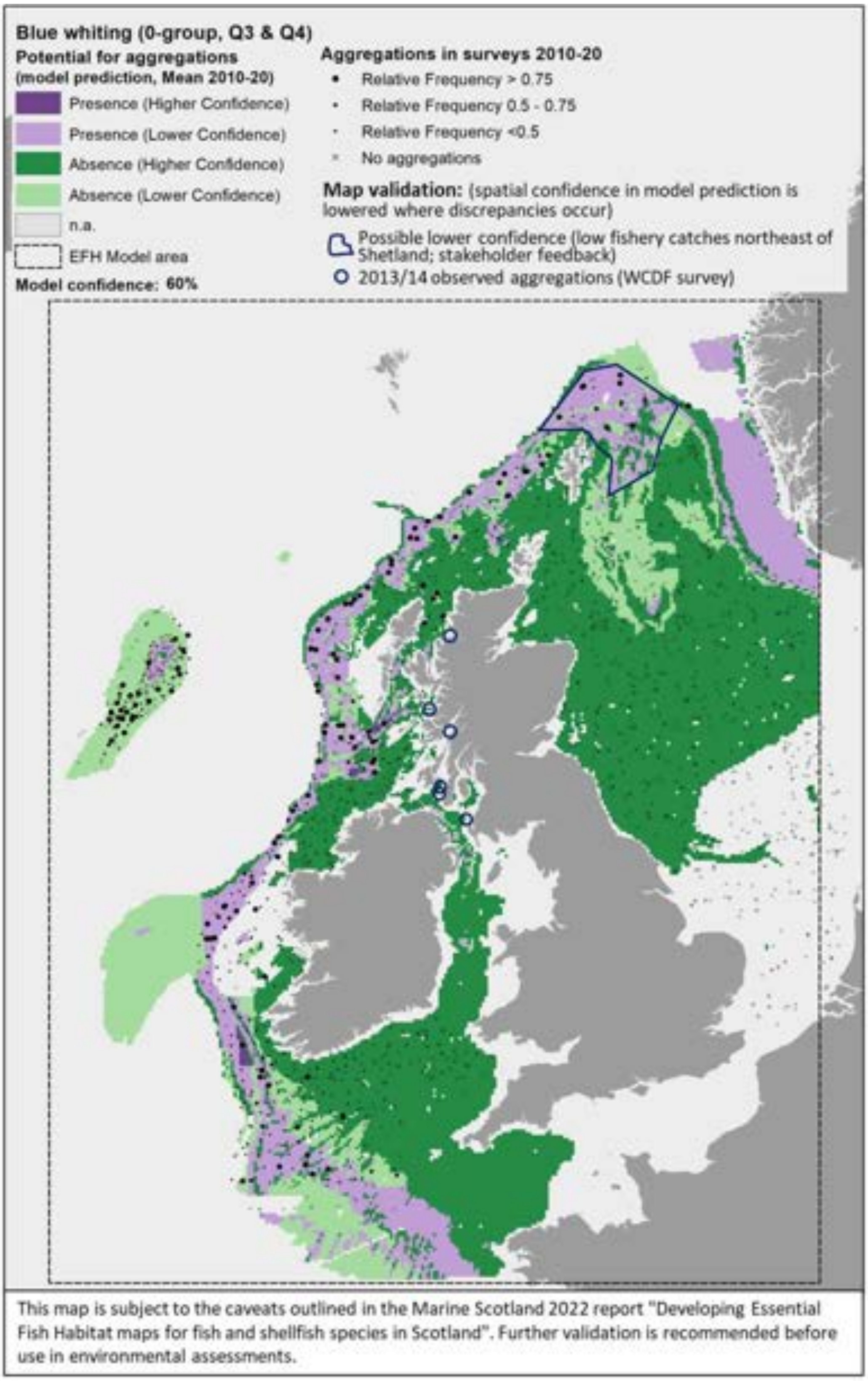


Figure 54. Aggregations of blue whiting juveniles (*Micromesistius poutassou* 0-group, Q3 & Q4): Frequency of occurrence in the 2010 - 2020 surveys and model prediction (incl. confidence) based on mean environmental conditions across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons and circles.

3.1.14 Hake, *Merluccius merluccius*

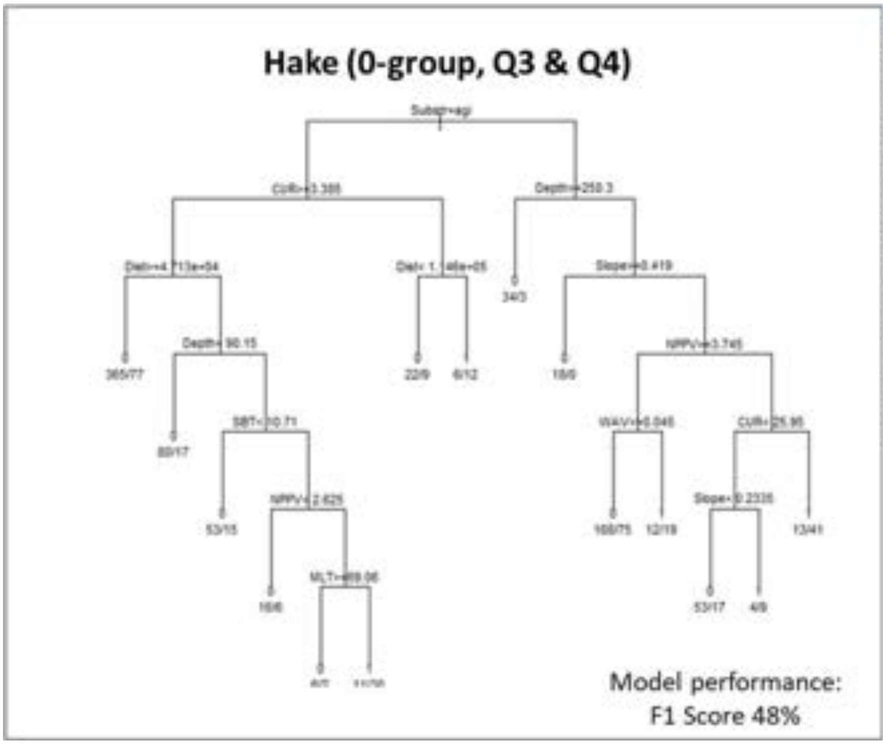
European hake (*Merluccius merluccius*, Linnaeus 1758), hereafter referred to as “hake”, is a demersal and benthopelagic gadoid (cod-like) fish of commercial value. It is a top predator in the demersal marine community (e.g. feeding on other gadoid fish, clupeids, squids). It inhabits offshore deeper areas in the western English Channel, the southern Irish Sea and off southern Ireland although it has been also recorded off western Scotland and in the North Sea. Hake spawns (winter - spring) in deeper waters along the continental shelf edge, with demersal juveniles usually found on muddy substrata on the continental shelf (Annex 1).

Hake was assessed through modelling based on summer and autumn catches from bottom trawl surveys. Individuals <19 cm in length were considered to identify 0-group juveniles and their aggregations were used as indicator of potential higher value habitats used as nurseries.

Current energy at the seabed (CUR) and depth were the most important predictors identified by the model for hake juvenile aggregations, followed by wave energy at the seabed (WAV), slope and substratum type (Substr), and distance from the shore (Dist), primary production (NPPV), seabed temperature (SBT) and water column mixing (MLT). Juvenile aggregations were predicted to occur at various combinations of these variables Figure 55). Predictions of occurrence were identified with the highest probability either in habitats with predominant muddy sand, sandy mud, fine mud, mixed sediment, or rock or other hard substrata, at depth <250 m, with slope <0.4 degrees, lower primary production (NPPV <3.7 mg C m^{-3} day^{-1}) and current energy at the seabed ≥26 N m^2/s (0.76 probability), or in habitats where the substratum is dominated by a combination of sandy mud-muddy sand, or sand or coarse sediment, at depth >90 m, within 47 km distance from the shore, and where current energy at the seabed is ≥3.4 N m^2/s, waters in the summer-autumn are warmer (SBT ≥10.7°C), with lower mixing of the water column (MLT <69 m) and variable primary production (NPPV ≥2.6 mg C m^{-3} day^{-1}) (0.73 probability).

The model prediction applied to the mean environmental conditions of the period 2010 - 2020 (summer-autumn) allowed mapping of the potential distribution of juvenile aggregations as an indication of potential location of higher value juvenile habitats functioning as nursery for hake (Figure 56).

Comparison with available survey data (both bottom trawl surveys considered for the model calibration and additional inshore and offshore demersal surveys on the west coast of Scotland; Appendix C, Figure C27 and Figure C28) and feedback from the stakeholders have highlighted some limitations of the map (Figure 56).



Variable	min	max
Dist	1216	233120
Depth	30.2	437.2
Slope	0.002	2.819
SBT	5.84	14.43
NPPV	0.06	28.13
SSS	31	35.6
MLT	6.4	248.63
CUR	0.94	215.75
WAV	0	260.8
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" c = "fMud" d = "Mixed" e = "mSand" f = "RockHard" g = "Sand" h = "sMud" i = "sMud_mSand"	

Figure 55. Decision tree for juvenile aggregations of hake, *Merluccius merluccius* (Q3 and Q4; full model) and associated environmental ranges at which the life stage occurred in the surveys.

Aggregations in the surveys undertaken along the south coast of Ireland were not correctly predicted in the map. These are notably included in the Hake Box (Appendix C, Figure C29), an area defined as part of the EU's Hake Recovery Plan, where catches of small hake in fisheries are regulated to protect the hake nursery grounds in this area (Figure 56). Stakeholder feedback also highlighted that hake juveniles occur widely in the Celtic Seas. Although this information does not account for density (which differentiates between aggregations, considered in the model, and mere presence of juvenile), it is possible that juvenile aggregations are also more widespread in this area than what predicted by the model. A lower confidence should therefore be ascribed to the predictions of absence in these areas.

Hake juvenile aggregations found to be frequent in the northern North Sea and on the west coast of Scotland (mainly in the south Minch) also appear to be poorly predicted in the map. The additional survey data from demersal fish surveys (Appendix C, Figure C28) confirmed the presence of aggregations of hake juveniles in this latter area and also in the inner Clyde (these have not been marked in Figure 56).

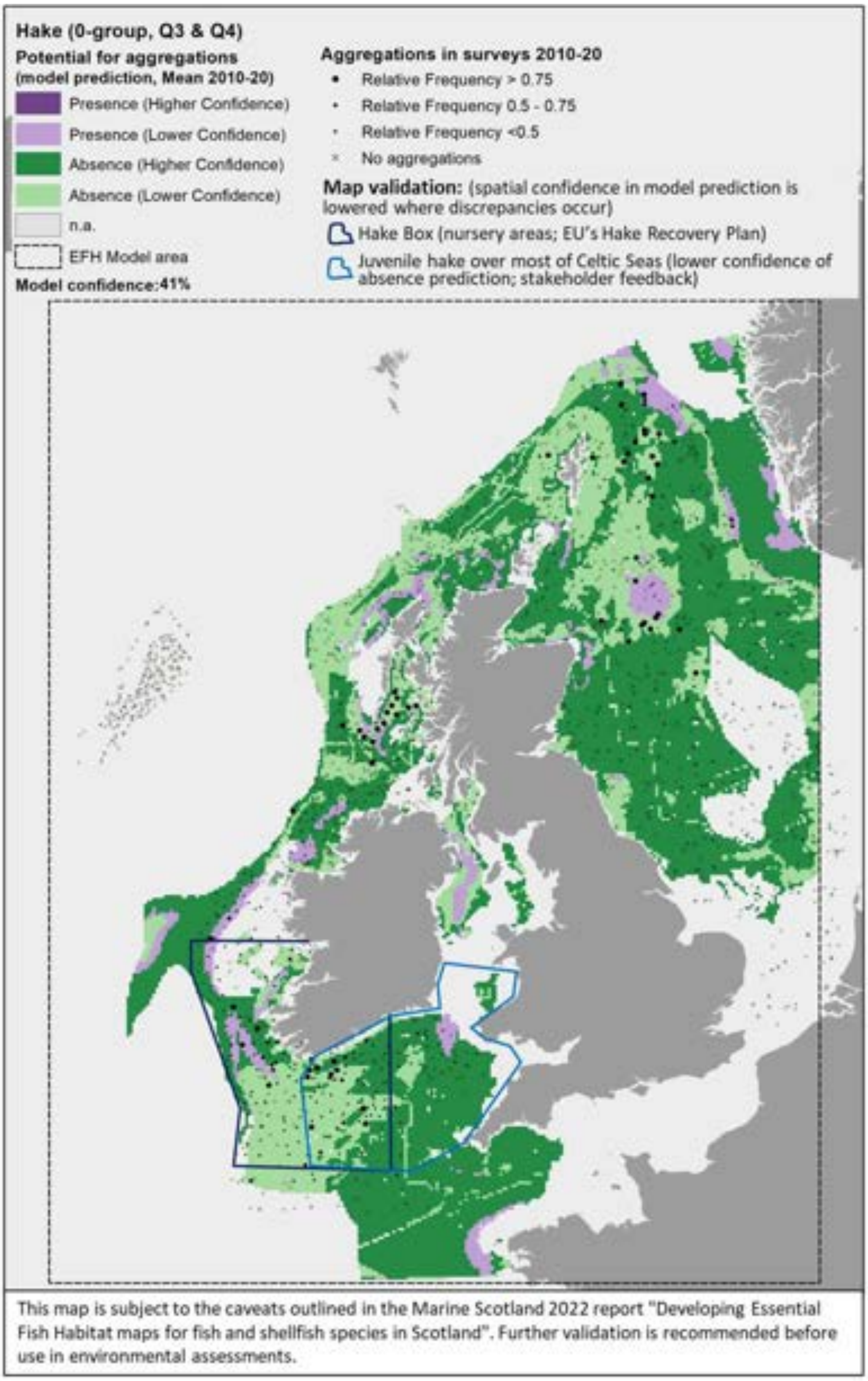


Figure 56. Aggregations of hake juveniles (*Merluccius merluccius* 0-group, Q3 & Q4): Frequency of occurrence in the 2010 - 2020 surveys and model prediction (incl. confidence) based on mean environmental conditions across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons.

3.1.15 Saithe, *Pollachius virens*

Saithe (*Pollachius virens*, Linnaeus 1758) is a benthopelagic gadoid (cod-like) fish of high commercial value, which is found throughout British and Irish waters, although it is more common off the north-west coasts of Scotland and Ireland. The species occurs both inshore and offshore. It is designated as a Priority Marine Feature in Scotland's seas. Pelagic winter spawning mostly occurs offshore, although there is limited information on the characteristics of these area in British waters. In turn, nursery areas are mostly located inshore, where saithe juveniles enter in spring and may spend 2 - 3 years before returning to deeper waters offshore (Annex 1).

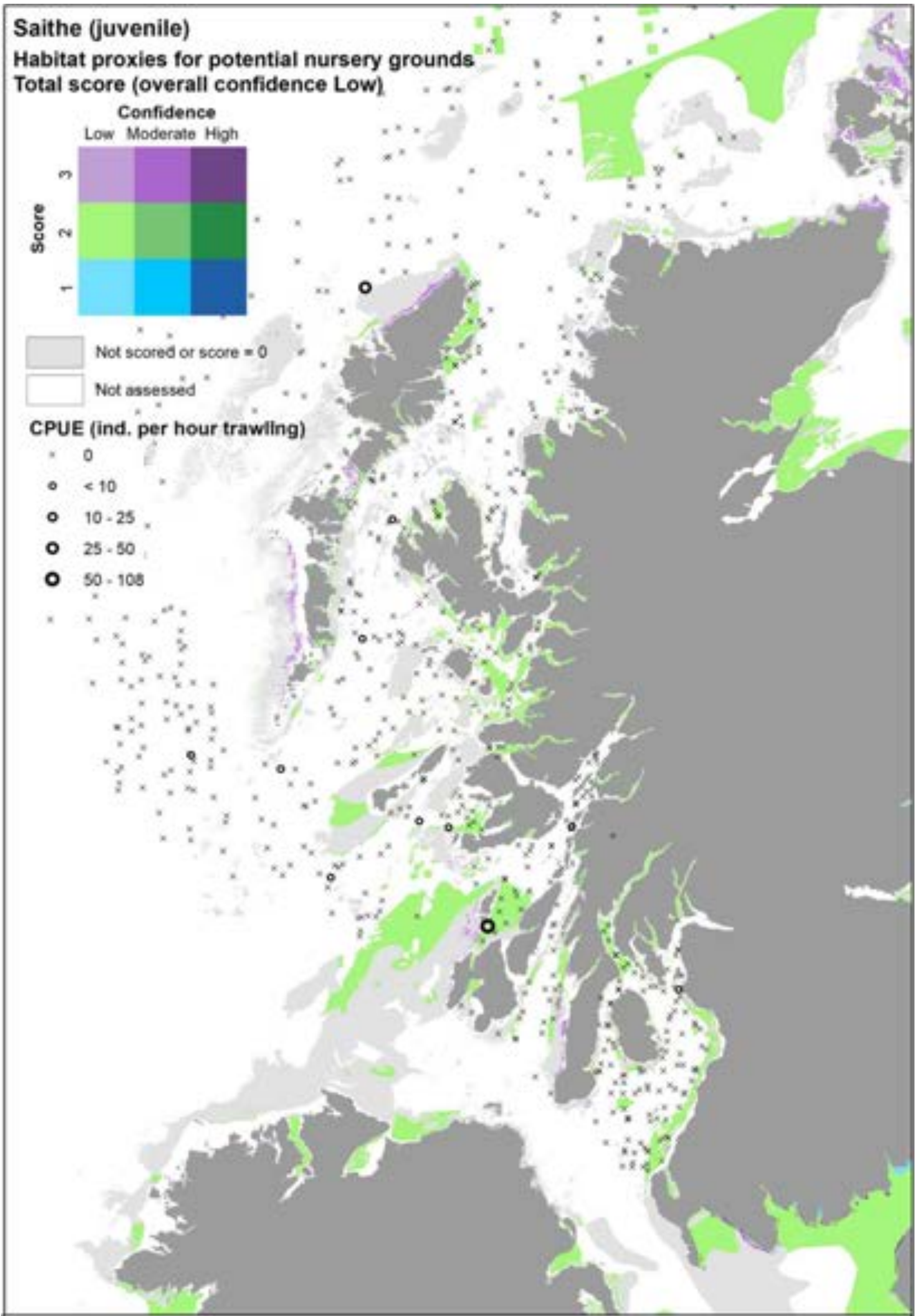
Saithe were assessed by using the habitat proxy approach to identify inshore habitats that may potentially be used by the juveniles of the species. Twelve publications were reviewed, but the specific information on juvenile habitat associations and environmental preferences was not detailed enough to discriminate suitable habitats at the higher resolution (see Annex 1). Furthermore, no stakeholder feedback was received for this species. As a result, a moderate confidence was associated with the overall assessment of habitat proxies for juvenile saithe.

There were a wide variety of highly suitable habitats identified for saithe juveniles with high confidence. These included rocky environments in the littoral zone often with the presence of fucoids, barnacles and mussels (Table 16). Other high scoring habitats, albeit identified with a lower (moderate) confidence, were rocky habitats in the infralittoral zone, largely those with the presence of kelps and seaweeds. Further possible habitats, scored with medium to low suitability and medium to low confidence (not shown in Table 16), included sandy and muddy substrate in the infra- circa- and sublittoral zones, as well as maerl beds and water column habitats.

The distribution of the inshore habitat proxies for saithe juveniles in the case study area is mapped in Figure 57, compared with the overall distribution of juveniles from the West Coast of Scotland Demersal Fish Survey (WCDF, 2013/14) in the area. Habitats with the highest potential suitability for saithe juveniles were identified mainly to the south of the case study area (littoral rocky fringes along the Scottish coastline in the northern Irish Sea), where no survey data were available for validation. Where survey data overlapped with the habitat proxy map, a general match could be observed between potentially suitable areas in the map and locations where saithe juveniles were found with higher abundance closer to the shore (e.g. in the Clyde, north of Islay, west of Mull). Aggregations of juveniles were also occasionally found in deeper habitats farther from the shore. Although these habitats were not assessed in the map, potentially suitable habitats were identified nearby, which are likely to be used by these juvenile fish, considering their mobility. No stakeholder feedback was received on this map following consultation.

Table 16. Main (highest scoring) habitats potentially associated with nursery function for saithe juveniles (*Pollachius virens*). Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Saithe (juvenile) – Habitat proxies for nursery function (Low confidence overall)
EUNIS Habitat type (score /confidence)
A1.1 High energy littoral rock (3/H)
A1.12 Robust fucoid and/or red seaweed communities (3/H)
A1.15 Fucoids in tide-swept conditions (3/H)
A1.2 Moderate energy littoral rock (3/H)
A1.21 Barnacles & fucoids on moderately exposed shores (3/H)
A1.22 Mussels & fucoids on moderately exposed shores (3/H)
A1.3 Low energy littoral rock (3/H)
A1.31 Fucoids on sheltered marine shores (3/H)
A3.1 Atlantic and Mediterranean high energy infralittoral rock (3/M)
A3.11 Kelp with cushion fauna and/or foliose red seaweeds (3/M)
A3.14 Encrusting algal communities (3/M)
A3.2 Atlantic and Mediterranean moderate energy infralittoral rock (3/M)
A3.21 Kelp & red seaweeds (moderate energy infralittoral rock) (3/M)
A3.22 Kelp & seaweed communities in tide-swept sheltered conditions (3/M)



This map is subject to the caveats outlined in the Marine Scotland 2022 report "Developing Essential Fish Habitat maps for fish and shellfish species in Scotland". Further validation is recommended before use in environmental assessments.

Figure 57. Habitat proxies for saithe juveniles in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Occurrence of aggregations of saithe juveniles from WCDF 2013/14 survey data in the study area are also shown.

3.1.16 Sprat, *Sprattus sprattus*

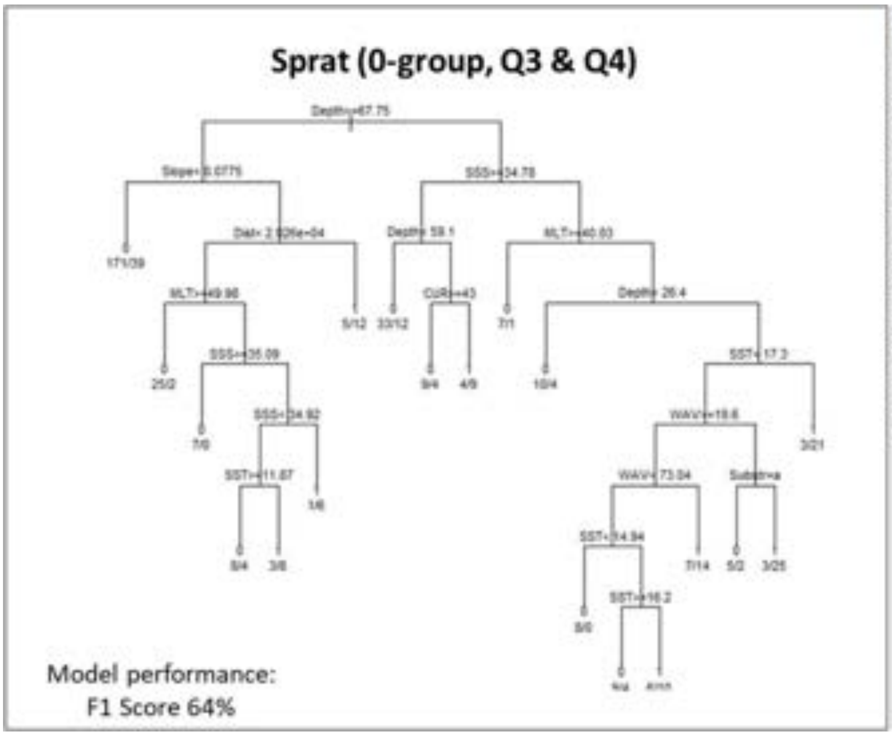
Sprat (*Sprattus sprattus*, Linnaeus 1758) are a small pelagic schooling fish found all around the coasts of Britain and Ireland and is exploited commercially. It is usually found in inshore waters, also entering estuaries to areas of low salinity. Spawning generally occur farther from the shore, with hydrography playing a key role in eggs and larval distribution and survival. Nursery grounds are known to occur in shallow inshore waters (e.g. Severn Estuary) (Annex 1).

Sprat was assessed by using both the data-based model and the habitat proxy approach. The farther allowed to model the distribution of aggregations of juveniles in summer-autumn as indicators of potential important habitats used as nursery. Individuals of body length < 9 cm and 9.5 cm were considered to identify 0-group sprat in summer and autumn catches from bottom trawl surveys, respectively. The habitat proxy approach also allowed identification of habitats that may potentially be used by the juveniles of the species, with better coverage of inshore coastal areas.

Almost all variables accounting for geomorphological, energy and water quality characteristics (except for NPPV) were selected by the model as predictors (Figure 58). Water depth, salinity (SSS), water column mixing (MLT), temperature (SST) and wave energy at the seabed were the most important predictors of sprat juvenile aggregations. Despite sprat being a pelagic species, substratum type was also identified as model predictor, although this had lower importance compared to the variables mentioned above. This does not necessarily imply a cause-effect relationship with aggregation distribution. The inclusion of substratum type as predictor could be ascribed to its correlation to another variable (not accounted for by the model) which has a more direct causative effect on the distribution of sprat juvenile aggregations.

Juvenile aggregations were predicted to occur at various combinations of these variables (Figure 58). Aggregations were predicted with higher probability (>0.85) in shallower habitats (Depth <26.4 m) with moderate-low mixing of the water column (MLT <40.8 m) and salinity <34.8, either in warmer waters (SST ≥17.3°C) (0.87 probability), or, in cooler conditions (<17.3°C), on fine mud, sandy mud, muddy sand or sand seabed with low wave energy (<19.6 N m^2/s) (0.89 probability).

The model prediction applied to the mean environmental conditions of the period 2010 - 2020 (summer - autumn) allowed mapping of the potential distribution of juvenile aggregations as an indication of potential location of higher value juvenile habitats functioning as nursery for sprat (Figure 59).



Variable	min	max
Dist	1069	278928
Depth	15.2	172.1
Slope	0.002	0.418
SST	7.79	20.73
NPPV	0.1	102.52
SSS	29.63	35.48
MLT	4.88	126.3
CUR	1.29	698.03
WAV	0	487.57
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" b = "fMud" c = "mSand" d = "Sand" e = "sMud"	

Figure 58. Decision tree for juvenile aggregations of sprat, *Sprattus sprattus* (Q3 and Q4; full model) and associated environmental ranges at which the life stage occurred in the surveys.

The predicted map confirms the predominant presence of aggregations of juvenile sprat in inshore coastal areas around the UK, with particularly higher confidence in the Clyde and Forth, confirming survey data, as well in the Moray Firth area (Figure 59). The importance of the latter two areas (Firth of Forth and Moray Firth) for sprat is also confirmed by seasonal management measures (fishery closure) that are in place there to protect juvenile sprat and herring (European Council Regulation No 850/98 of 30 March 1998). Habitats potentially suitable for juvenile aggregations of sprat are also predicted in more offshore waters in the northern North Sea, north and west of Scotland, despite not being supported by survey observations, although a low confidence is associated with these predictions of presence. This mismatch has likely contributed to the moderate confidence (51%) associated with the model predictions overall, in addition to the lower efficiency of bottom trawl surveys in sampling pelagic juvenile sprat.

The model seems to fail to correctly predict the occurrence of juvenile aggregations particularly in southern inshore areas, as indicated by survey data (south-west coast of Ireland) and by stakeholder feedback (e.g. Thames, English Channel, Bristol Channel, Severn estuary) (Figure 59). This is also influenced by the poor coverage of most inshore areas by the predicted map, which reflects the distribution of the data that have been used to calibrate the model (see results of the habitat proxy approach below for a better assessment of more inshore habitats). Such limitation is also apparent when comparing the model prediction with additional survey data from demersal fish surveys on the west coast of Scotland (Appendix C, Figure C32). Although several of the locations of juvenile aggregations found during this survey are confirmed by the model predictions of presence (albeit at lower confidence), additional aggregations were found in some areas located further inshore waters, where there is poor coverage by the model (Figure 59).

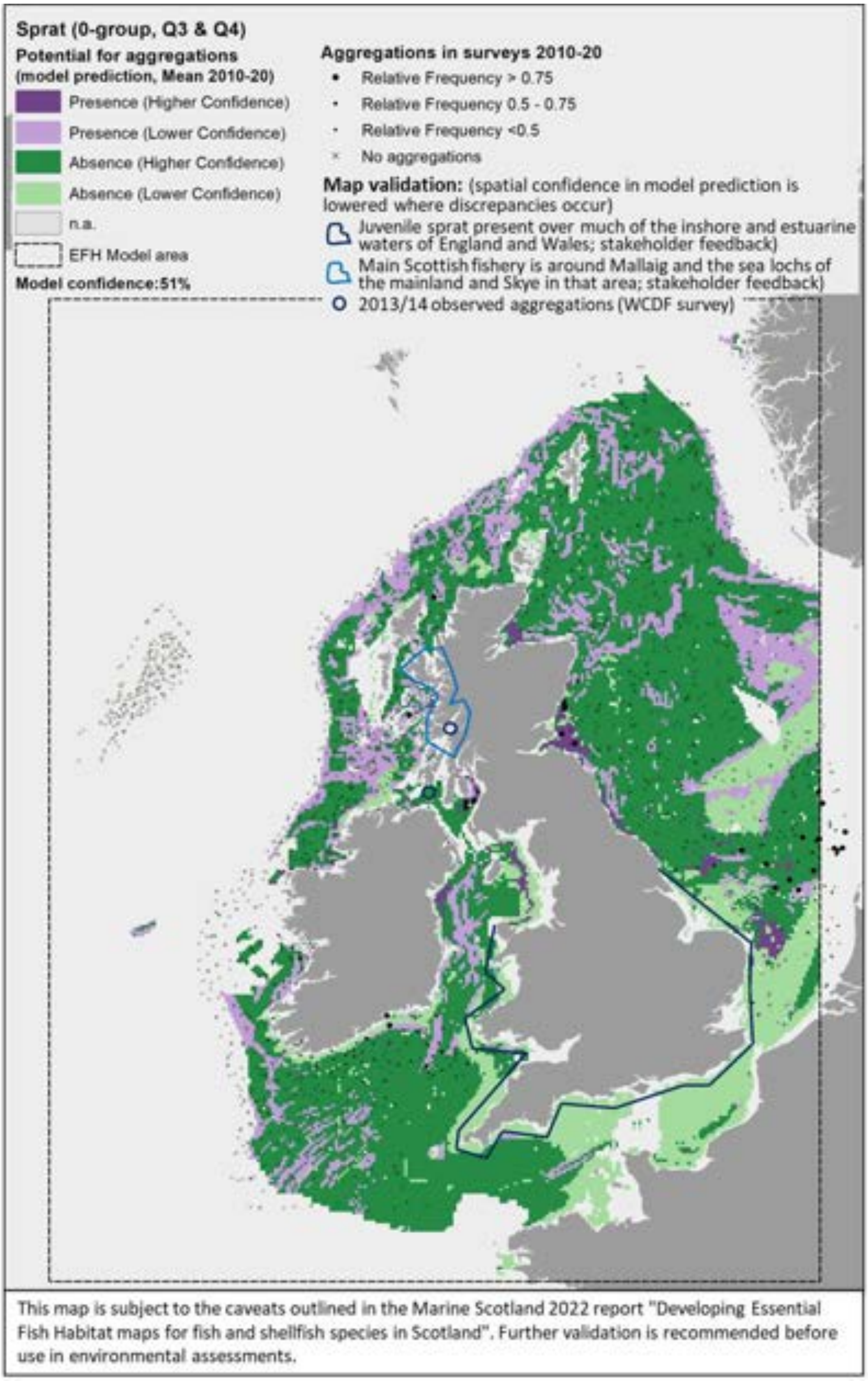


Figure 59. Aggregations of sprat juveniles (*Sprattus sprattus* 0-group, Q3 & Q4): Frequency of occurrence in the 2010 - 2020 surveys and model prediction (incl. confidence) based on mean environmental conditions across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons/circles.

For the assessment of habitat proxies for sprat juveniles inshore, nine publications were reviewed. The specific information on juvenile habitat associations and environmental preferences was scarce and not detailed enough to discriminate suitable habitats at the higher resolution (see Annex 1). This, along with expert input obtained with the stakeholder validation, led to a moderate confidence in the overall assessment of habitat proxies for juvenile sprat.

The habitat proxy assessment indicated full salinity water column habitats as the most suitable habitats potentially functioning as nursery for this small pelagic fish, with a high confidence associated (Table 17). Other possible habitats, though scored with medium to low suitability and medium to low confidence (not shown in Table 17) were relatively wide-ranging benthic habitats, including saltmarshes, seagrass beds, sublittoral sediments and littoral sediments.

The distribution of the inshore habitat proxies for sprat juveniles in the case study area is mapped in Figure 60, compared with the overall distribution of juveniles from bottom trawl surveys in the area (including IBTS undertaken between 2010 and 2020, and the WCDF 2013/14 survey). Both the habitat map and the survey data confirm that sprat juveniles aggregate in the Firth of Clyde, suggesting this site as nursery area for the species. Juvenile aggregations are also found on suitable habitats close to the shore along the west coast (Inner Hebrides), with more frequent observations northwest of Coll and northeast of Lewis, where potentially suitable habitats were identified. No stakeholder feedback was received on this map following consultation.

Table 17. Main (highest scoring) habitats potentially associated with nursery function for sprat juveniles (*Sprattus sprattus)*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Sprat (juvenile) – Habitat proxies for nursery function (Moderate confidence overall)
EUNIS Habitat type (score /confidence)
A7.3 Completely mixed water column with full salinity (3/H) **A7.33 Completely mixed water column with full salinity & long residence time (3/H)** **A7.8 Unstratified water column with full salinity (3/H)** **A7.81 Euphotic (epipelagic) zone in unstratified full salinity water (3/H)**

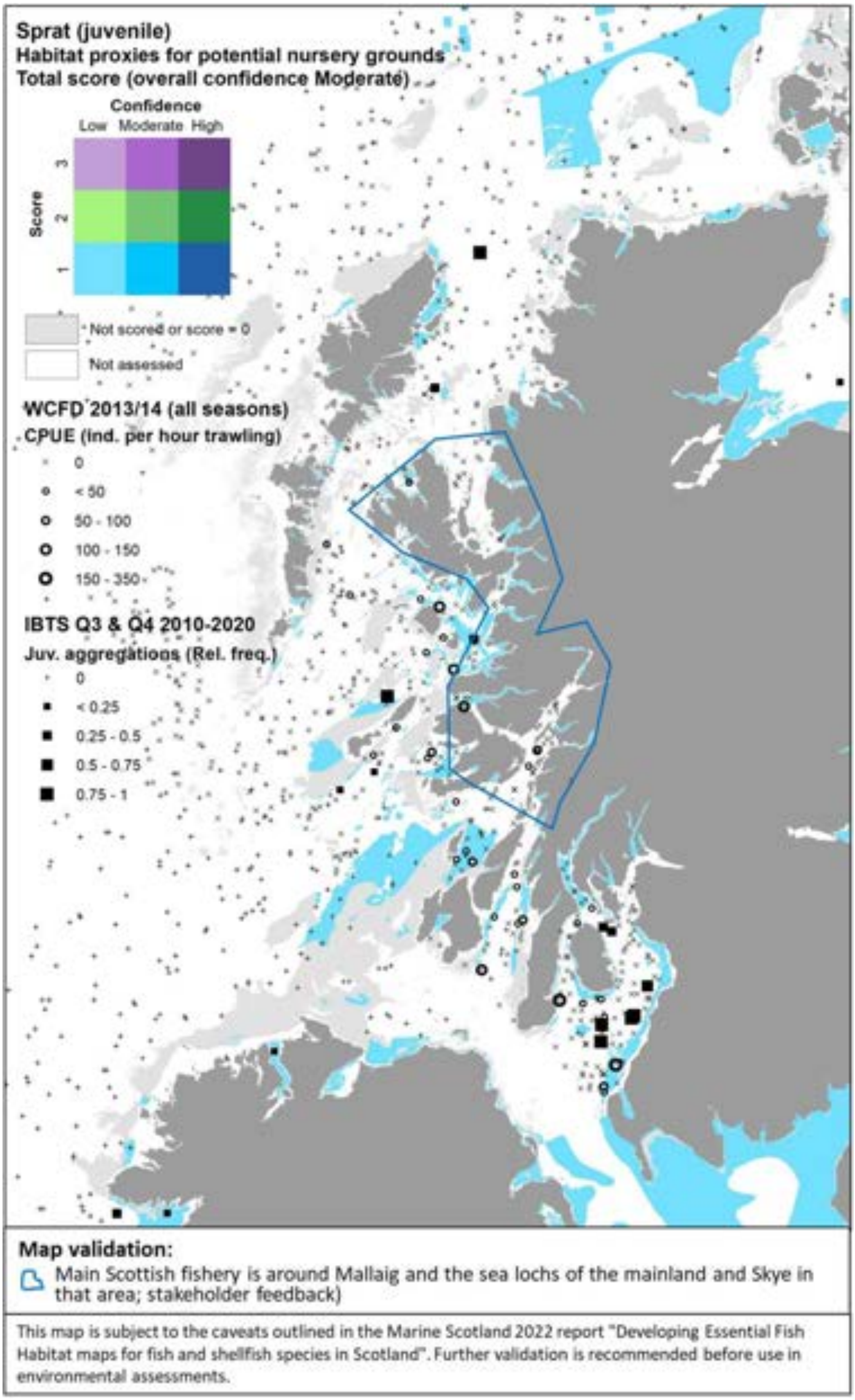


Figure 60. Habitat proxies for sprat juveniles in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Occurrence of aggregations of sprat juveniles from survey data in the study area are also shown.

3.1.17 Mackerel, *Scomber scombrus*

Atlantic mackerel (*Scomber scombrus* Linnaeus 1758), hereafter referred to as "mackerel",) is a pelagic shoaling species widely distributed in the continental shelf seas around the British Isles and Ireland. It is notably the highest value species landed in Scotland. Mackerel is a highly mobile top predator that makes extensive migrations, its distribution being mainly affected by a variety of hydrographical features and prey distribution. Pelagic spawning occurs mainly in the spring-summer (North Sea) and in the spring (west coast, Atlantic) offshore, while juveniles also occupying shallower inshore areas (Annex 1).

Mackerel was assessed by using the data-based model approach. Autumn-winter bottom trawl survey data were used to model aggregations of juveniles as an indicator of potential higher value habitats used as nurseries. Individuals of body length <22 and 24 cm were considered to identify 0-group mackerel in autumn and winter, respectively. Spring-summer catches from mackerel egg surveys were also used to model aggregations of early-stage eggs as an indicator of potential spawning areas.

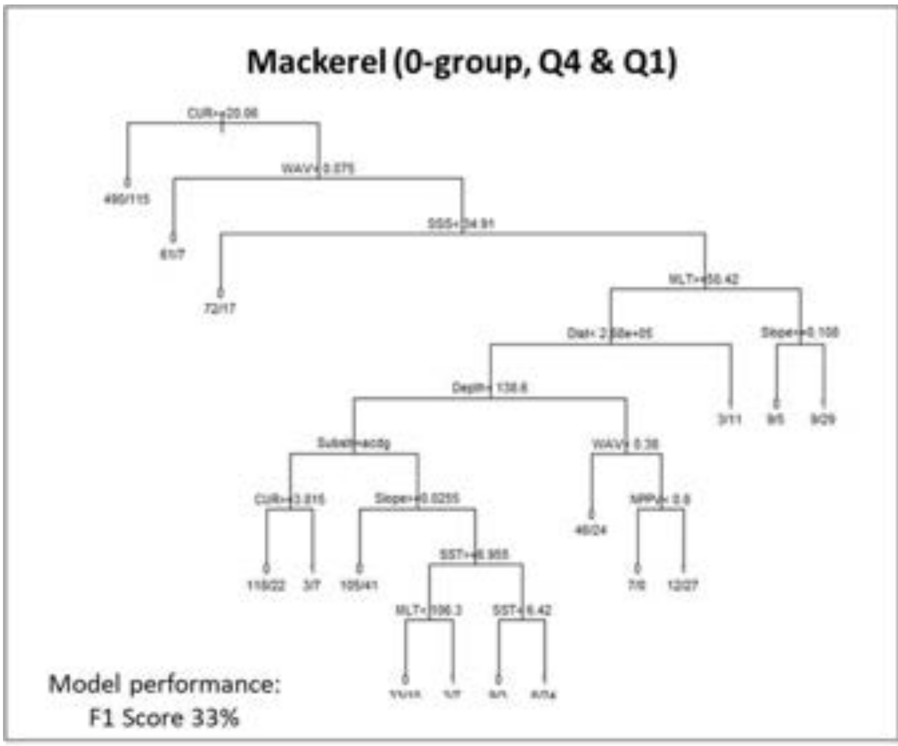
<u>Juveniles</u>

All variables accounting for geomorphological, energy and water quality characteristics were selected as predictors by the model for mackerel juvenile aggregations (Figure 61). Water column mixing (MLT), current and wave energy at the seabed (CUR, WAV), depth, distance from the shore (Dist) and water temperature (SST) were the most important predictors. Substratum type was also identified as a model predictor of this pelagic species, albeit with the lowest importance. As observed for sprat, substratum type could have been included as predictor due to its correlation to another variable (not accounted for by the model) which has a more direct causative effect on the distribution of mackerel juvenile aggregations.

Areas where mackerel juvenile aggregations were predicted to occur had generally very low current energy (<20.1 N m^2/s) and some degree of wave energy at the seabed (≥0.07 N m^2/s), as well as higher mean salinity (≥34.9). Under these conditions, juvenile aggregations were predicted to occur with the highest probability (0.79-0.8) in areas with some mixing of the water column (MLT ≥50.4 m) either located farther offshore (Dist ≥268 km), or, if within 268 km from the shore, on fine mud or sand substrata shallower than 139 m, with negligible slope (<0.02 degrees) and mean autumn-winter water temperature between 6.4 and 7°C.

The model prediction applied to the mean environmental conditions of the period 2010 - 2020 (autumn - winter) allowed mapping of the potential distribution of juvenile aggregations as an indication of potential location of higher value juvenile habitats functioning as nursery for mackerel (Figure 62).

Comparison with available survey data (both bottom trawl surveys considered for the model calibration and additional inshore and offshore demersal surveys on the west coast of Scotland; Appendix C, Figure C34 and Figure C35) and feedback from the stakeholders have highlighted some limitations of the map (Figure 62).



Variable	min	max
Dist	1069	290431
Depth	14.2	399.2
Slope	0.002	3.01
SST	4.81	15.35
NPPV	0	22.92
SSS	28.67	35.55
MLT	6.47	286.14
CUR	1.29	789.39
WAV	0	505.87
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" b = "fMud" c = "Mixed" d = "mSand" f = "Sand" g = "sMud"	

Figure 61. Decision tree for juvenile aggregations of mackerel, *Scomber scombrus* (Q4 and Q1; full model) and associated environmental ranges at which the life stage occurred in the surveys.

While the model predictions confirmed observed juvenile aggregations occurring off the west coast of Scotland and along the continental shelf edge north of Scotland, predictions were less accurate in the norther North Sea and in the Celtic Seas. The latter notably include the South West Mackerel Box (Appendix C, Figure C29), a fishery management area that was introduced in 1986 by Council Regulation (EEC) No. 3094/86 in order to protect juvenile mackerel in this area, thus suggesting that juvenile aggregations are possibly more widespread in this area than what predicted by the model. A lower confidence should therefore be ascribed to the predictions of absence in these areas (see orange boxed area in Figure 62).

The additional survey data from demersal fish surveys confirmed the presence of aggregations of mackerel juveniles in areas off the west of Scotland as predicted by the map and/or already indicated by the survey data shown in the map (Figure 62).

It should be noted that the overall confidence associated with the model predictions is low (26%), due to a poor model performance (Figure 61) combined with the lower efficiency of bottom trawl surveys in sampling pelagic juvenile mackerel.

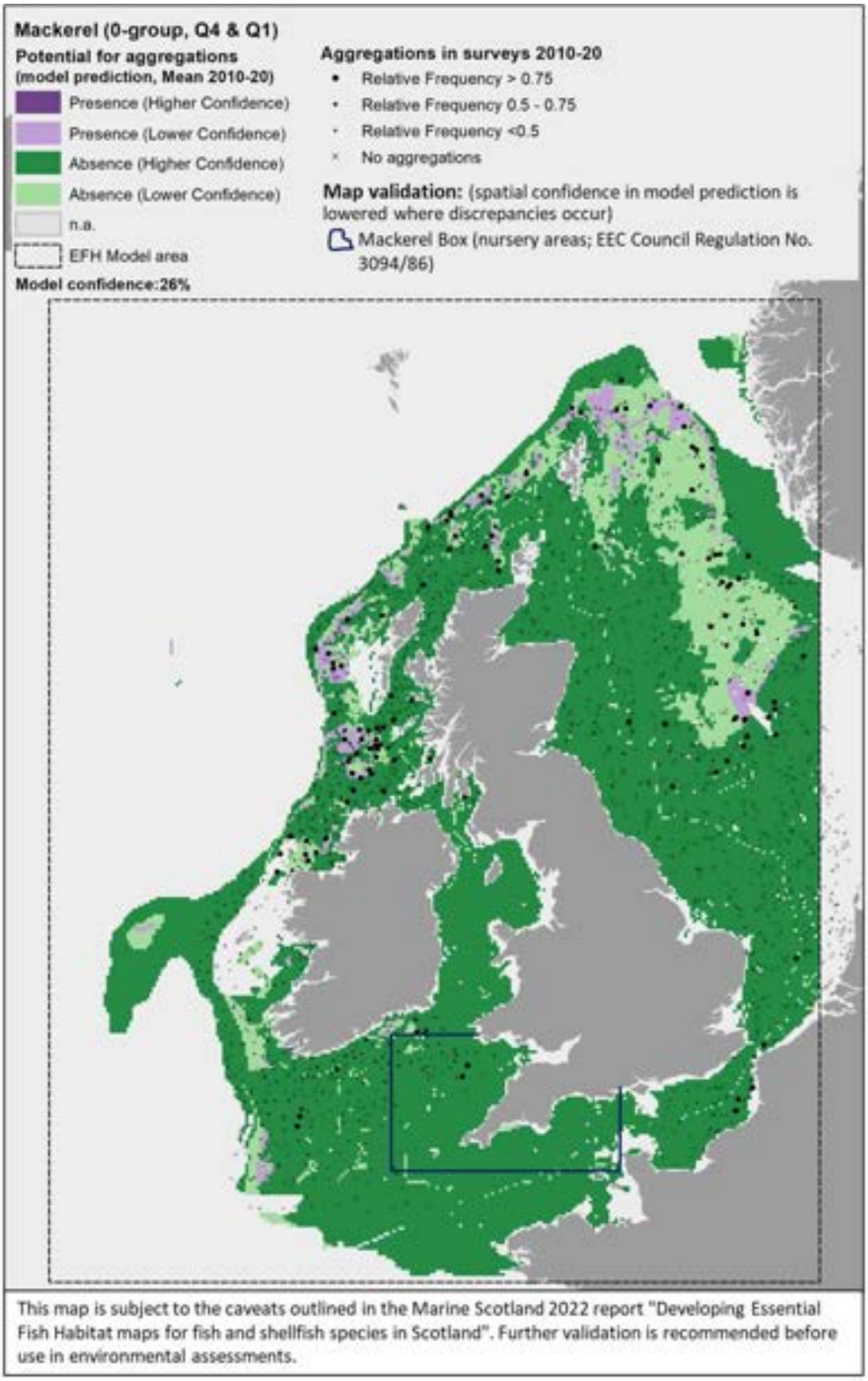


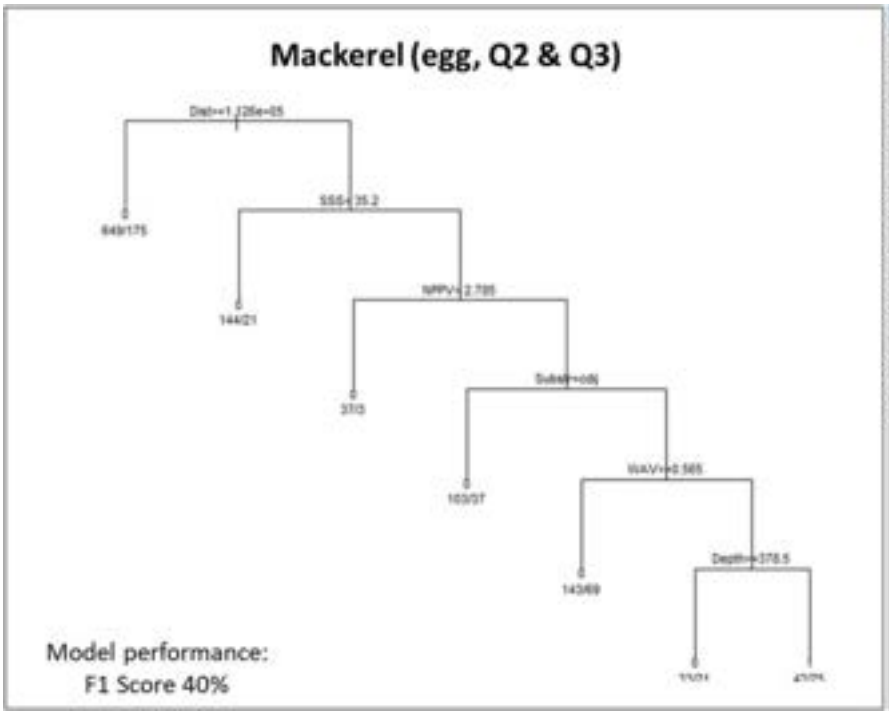
Figure 62. Aggregations of mackerel juveniles (*Scomber scombrus* 0-group, Q4 & Q1): Frequency of occurrence in the 2010 - 2020 surveys and model prediction (incl. confidence) based on mean environmental conditions across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons.

Eggs

As for mackerel egg aggregations, depth and wave energy at the seabed (WAV) were the most important predictors identified in the model, followed by distance from the shore (Dist), salinity (SSS), substratum type (Substr) and primary production (NPPV). Egg aggregations were only predicted (with 0.64 probability) in areas at depth <378 m, within 113 km distance from the shore, with negligible wave energy (<0.6 N m^2/s) on muddy sand, sand, coarse sediment, or rock or other hard substrata, higher salinity (≥35.2) and primary production (≥2.8 mg C m^{-3} day^{-1}) (Figure 63).

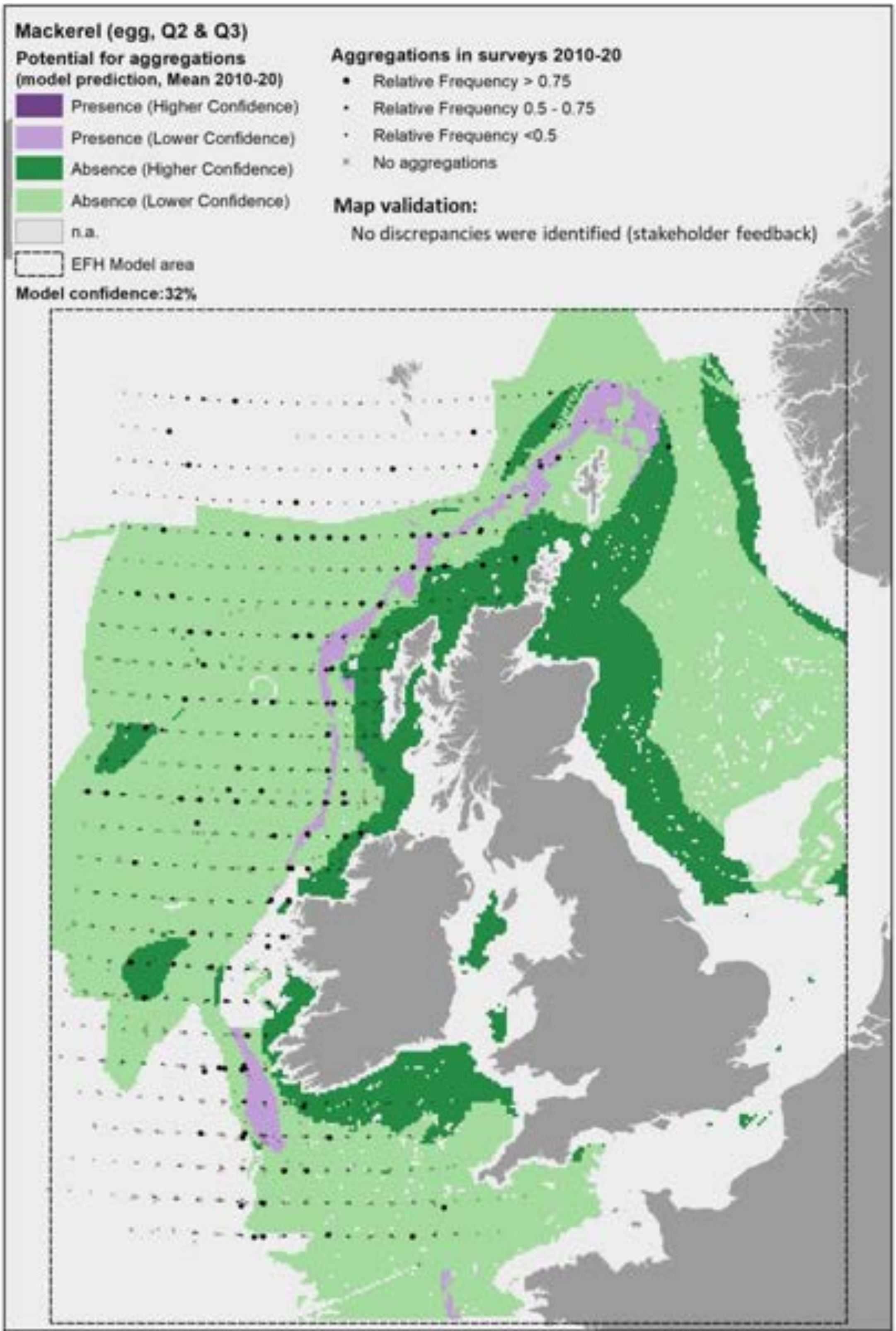
The model prediction applied to the mean environmental conditions of the period 2010 - 2020 (spring-summer) allowed mapping of the potential distribution of mackerel egg aggregations as an indication of potential location of higher value spawning habitats (Figure 64).

Despite the survey data on which the model was calibrated did not show clear spatial patterns in the egg distributions (Figure 64, and Appendix C, Figure C36), the model predicted suitable environmental conditions for the occurrence of egg aggregations mostly along continental shelf edge to the west and north of the British Isles. This mismatch contributed to the overall low confidence (32%) associated with the model and the low confidence of the spatial predictions of presence of mackerel egg aggregations (Figure 64). Despite this, the mapped prediction of egg aggregations (and potential associated spawning grounds) appeared to be in line with the knowledge available to stakeholders.



Variable	min	max
Dist	4953	445929
Depth	39	3199
Slope	0.006	6.661
SST	7.06	18.07
NPPV	0.02	89.13
SSS	34.29	35.6
MLT	8.44	681.51
CUR	0.13	232.6
WAV	0	551.62
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" c = "fMud" d = "Mixed" e = "mSand" f = "RockHard" g = "Sand" i = "sMud" j = "sMud_mSand"	

Figure 63. Decision tree for aggregations of mackerel eggs (*Scomber scombrus* Q2 and Q3; full model) and associated environmental ranges at which the life stage occurred in the surveys.



This map is subject to the caveats outlined in the Marine Scotland 2022 report "Developing Essential Fish Habitat maps for fish and shellfish species in Scotland". Further validation is recommended before use in environmental assessments.

Figure 64. Aggregations of mackerel eggs (*Scomber scombrus* early-stage eggs, Q2 & Q3): Frequency of occurrence in the 2010 - 2020 surveys and model prediction (incl. confidence) based on mean environmental conditions across 2010 - 2020.

3.1.18 Thornback ray, *Raja clavata*

Thornback ray (*Raja clavata* Linnaeus 1758) is an elasmobranch fish (skate) widespread around the British Isles. It inhabits shelf and upper slope waters (down to 190 m depth), and is most common in inshore coastal waters, also occasionally occurring in estuaries. An oviparous fish with internal fertilisation, it anchors demersal egg capsules on shallow sediments inshore, and juvenile nursery grounds are thought to overlap with these spawning/egg-laying grounds (also referred to as 'egg nursery'), although little evidence is available about specific locations of these habitats (Annex 1).

Thornback ray were assessed by using the habitat proxy approach to identify inshore habitats that may potentially be used by the species for the laying of eggs (egg-nurseries, potentially overlapping with juvenile nursery grounds). Fourteen publications were reviewed but these showed that there is little knowledge of specific environmental preferences associated with egg-nurseries (see Annex 1). Furthermore, no feedback was received from stakeholders. As such, a low confidence was associated with the overall assessment of habitat proxies for egg-nursery grounds of thornback ray.

Habitats high scoring for suitability could not be identified and, at best, habitats with moderate suitability (score 2) were identified, but with low confidence. These were sublittoral and infralittoral coarse sediments, sublittoral sand, infralittoral fine sand and infralittoral muddy sand (Table 18).

The distribution of the inshore habitat proxies for thornback ray egg-nursery in the case study area is mapped in Figure 65. It has been reported in the literature (Annex 1) that egg-nurseries potentially overlap with juvenile nursery grounds. Therefore, the habitat proxy distribution was compared with the overall distribution of juveniles of thornback ray from the West Coast of Scotland Demersal Fish Survey (WCDF, 2013/14) in the study area (no data on egg distribution were available).

The occurrence of juveniles in the survey was sparse, possibly due to limitations in the survey ability to catch these fish. Therefore, the survey data offer limited validation of the habitat map. Where observed, thornback ray juveniles appeared to overlap with suitable habitat patches identified in the northern Minch and in the Clyde. The survey data also suggested that thornback ray juvenile distribution into Loch Linnhe, an area for which there was no EUNIS habitat data coverage and therefore not assessed for habitat proxies. The habitat proxy map also identified a broad extent of potentially suitable habitat to the west of Islay and along the coast of Northern Ireland, west of Tiree and in the North Atlantic west of Orkney, although no survey data were available for most of these areas to confirm habitat use. No stakeholder feedback was received on this map following consultation.

Table 18. Main (highest scoring) habitats potentially associated with egg-nursery function for thornback ray, *Raja clavata*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Thornback ray (eggs) – Habitat proxies for egg-nursery function (Low confidence overall)
EUNIS Habitat type (score /confidence)
A5.1 Sublittoral coarse sediment (2/L)
A5.13 Infralittoral coarse sediment (2/L)
A5.2 Sublittoral sand (2/L)
A5.23 Infralittoral fine sand (2/L)
A5.24 Infralittoral muddy sand (2/L)

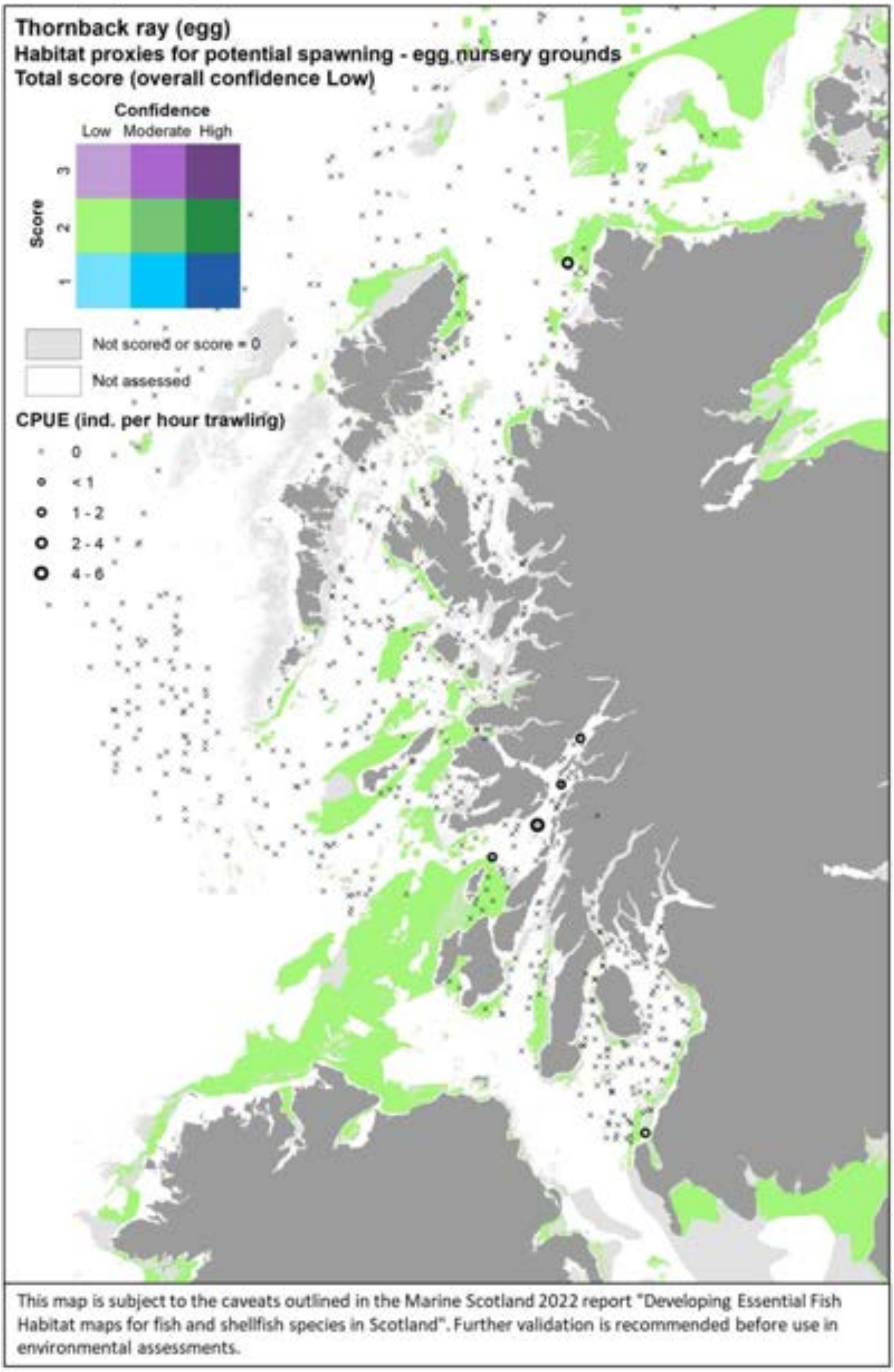


Figure 65. Habitat proxies for thornback ray egg-nursery in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Occurrence of aggregations of thornback ray juveniles from WCDF 2013/14 survey data in the study area are also shown.

3.1.19 Spotted ray, *Raja montagui*

Spotted ray (*Raja montagui* Fowler 1910) is an elasmobranch fish (skate) widespread around the British Isles. Its distribution normally overlaps with that of thornback ray, inhabiting offshore shelf and upper slope waters (down to 280 m depth), and being also common (mostly as juveniles) in inshore coastal waters. It may also occasionally occur in estuaries. This species also anchors demersal egg capsules on shallow substrata inshore, although little is known about habitat preferences and site locations for these spawning grounds (also referred to as 'egg nursery'). Coastal areas with rocks and sand seabed are considered potential nursery areas, possibly overlapping with these spawning/egg-laying grounds (Annex 1).

Spotted ray was assessed by using the habitat proxy approach to identify habitats that may potentially be used by the juveniles of the species. Nine publications were reviewed but the information on juvenile habitat preferences was limited and not detailed enough to discriminate suitable habitats at the higher resolution (see Annex 1). Furthermore, no feedback was received from stakeholders. As such, a low confidence was associated with the overall assessment of habitat proxies for juvenile spotted ray.

Habitats high scoring for suitability could not be identified and, at best, habitats with moderate suitability (score 2) were identified, but with low confidence. These were sublittoral sands and infralittoral fine sands (Table 19).

The distribution of the inshore habitat proxies for spotted ray juveniles in the case study area is mapped in Figure 66, compared with the overall juvenile distribution from the West Coast of Scotland Demersal Fish Survey (WCDF, 2013/14) data in the study area. Juveniles were most frequently found in the southern surveyed areas, locally overlapping with suitable habitat identified (sometimes as small patches) in the map, e.g. north and west of Islay, west of Coll, south of Tiree, in the northern Minch. Juveniles were also found at the entrance of the Clyde (albeit in lower numbers) near areas where potentially suitable habitat was identified. No stakeholder feedback was received on this map following consultation.

Table 19. Main (highest scoring) habitats potentially associated with nursery function for spotted ray, *Raja montagui*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Spotted ray (juvenile) – Habitat proxies for nursery function (Low confidence overall)
EUNIS Habitat type (score /confidence)
A5.2 Sublittoral sand (2/L) A5.23 Infralittoral fine sand (2/L)

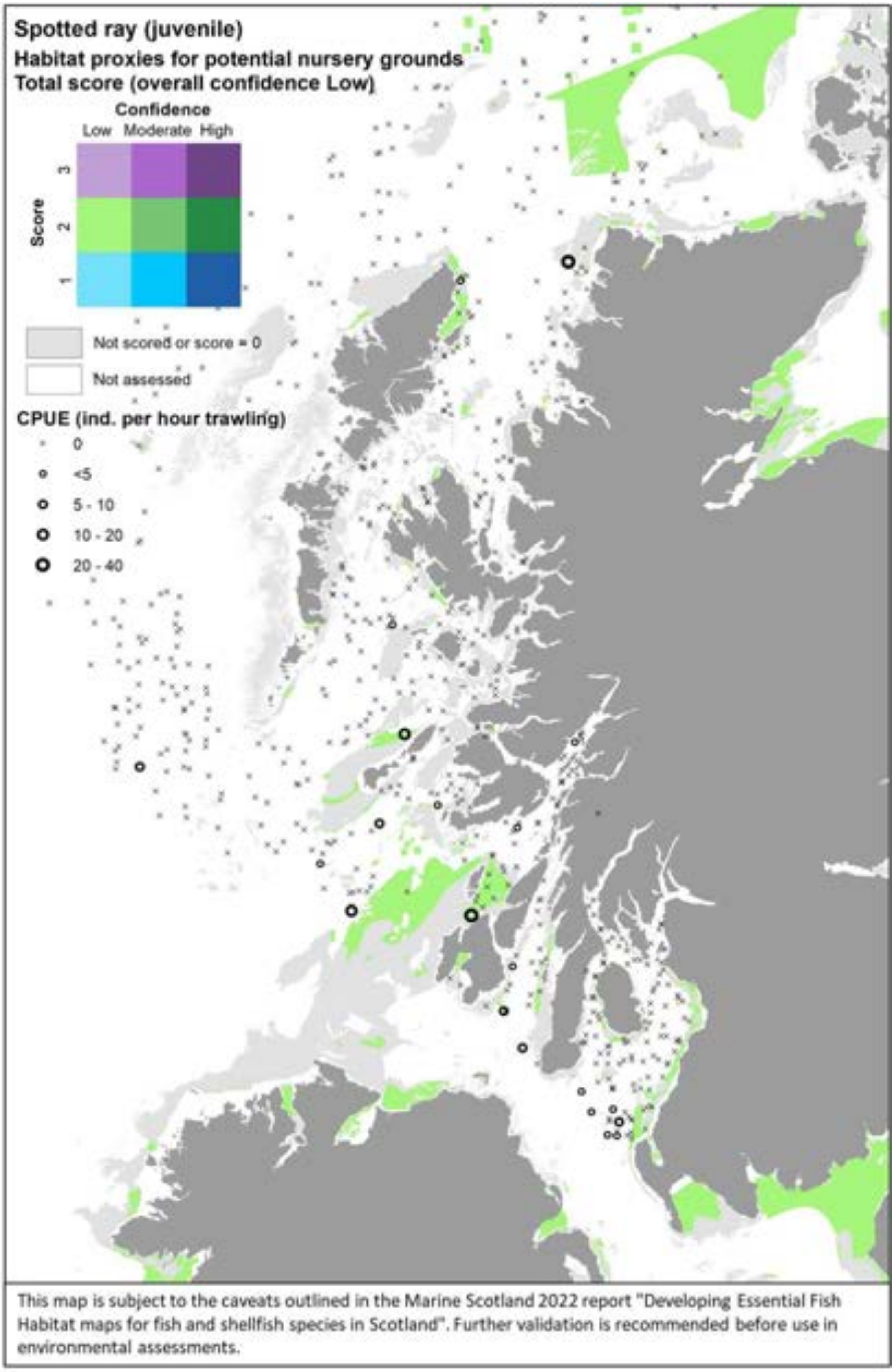


Figure 66. Habitat proxies for spotted ray juveniles in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Occurrence of juvenile aggregations from WCDF 2013/14 survey data in the study area are also shown.

3.1.20 Spurdog, *Squalus acanthias*

Spurdog (*Squalus acanthias* Linnaeus 1758) is an elasmobranch fish (dogfish) widespread around the British Isles. It is a marine species commonly inhabiting the continental shelf (at depth between 15 and 528 m), although it also tolerates brackish water conditions and is often found in enclosed bays and estuaries (including sea lochs). It is designated as a Priority Marine Feature in Scotland seas. It is an ovoviviparous species, with gravid females carrying pups for almost two years before parturition. It is not known whether or not there are discrete parturition and nursery areas, although, historically, large numbers of new-born and pregnant spurdog have been found in relatively shallow waters and it has been hypothesised that young moved away from shallow waters after parturition (Annex 1).

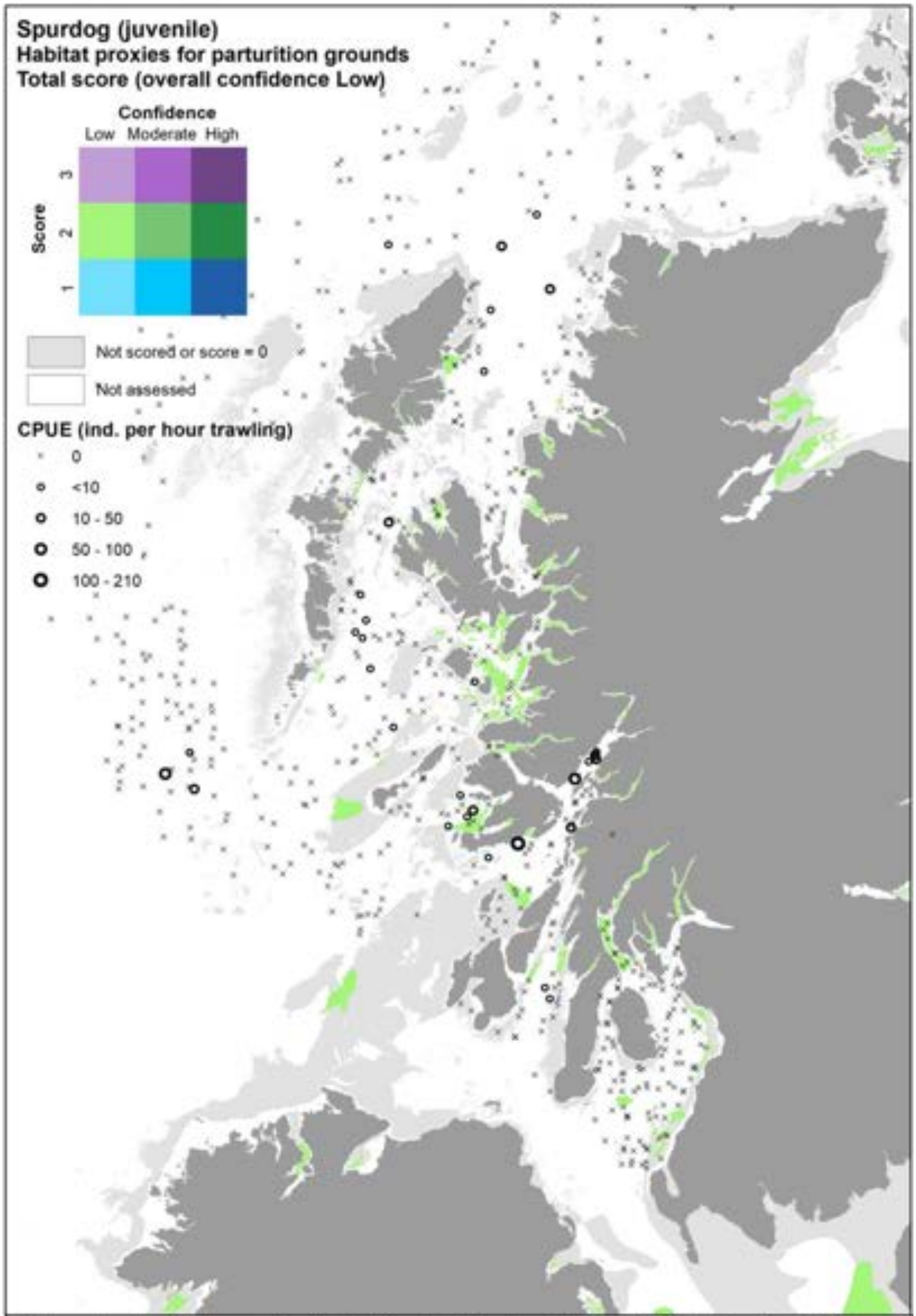
Spurdog was assessed by using the habitat proxy approach to identify habitats that may potentially be used by neonates of the species, hence indicating possible parturition and nursery areas. Ten publications were reviewed but the information on juvenile/parturition habitat preferences was limited and not detailed enough to discriminate suitable habitats at the higher resolution (see Annex 1). Furthermore, no feedback was received from stakeholders. As such, a low confidence was associated with the overall assessment of habitat proxies for juvenile spurdog.

Habitats high scoring for suitability could not be identified and, at best, habitats with moderate suitability (score 2) were identified, but with low confidence. These were sublittoral sands and infralittoral fine sands (Table 20).

The distribution of the inshore habitat proxies for spurdog juveniles in the case study area is mapped in Figure 67, compared with the distribution of juveniles from the West Coast of Scotland Demersal Fish Survey (WCDF, 2013/14) data in the study area. The catches of spurdog juveniles in the survey highlight in particular the use of Loch Linnhe and the approaching areas (south of Mull). The coverage of the EUNIS habitat layer is limited in this area, but, where habitat proxies could be assessed, the location of suitable habitats in the area (south of Coull and upstream of Loch Linnhe, into Loch Eil) seems to support the survey observations. No stakeholder feedback was received on this map following consultation.

Table 20. Main (highest scoring) habitats potentially associated with nursery function for spurdog, *Squalus acanthias*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Spurdog (juvenile) – Habitat proxies for nursery function (Low confidence overall)
EUNIS Habitat type (score /confidence)
A5.3 Sublittoral mud (2/L) A5.36 Circalittoral fine mud (2/L)



This map is subject to the caveats outlined in the Marine Scotland 2022 report "Developing Essential Fish Habitat maps for fish and shellfish species in Scotland". Further validation is recommended before use in environmental assessments.

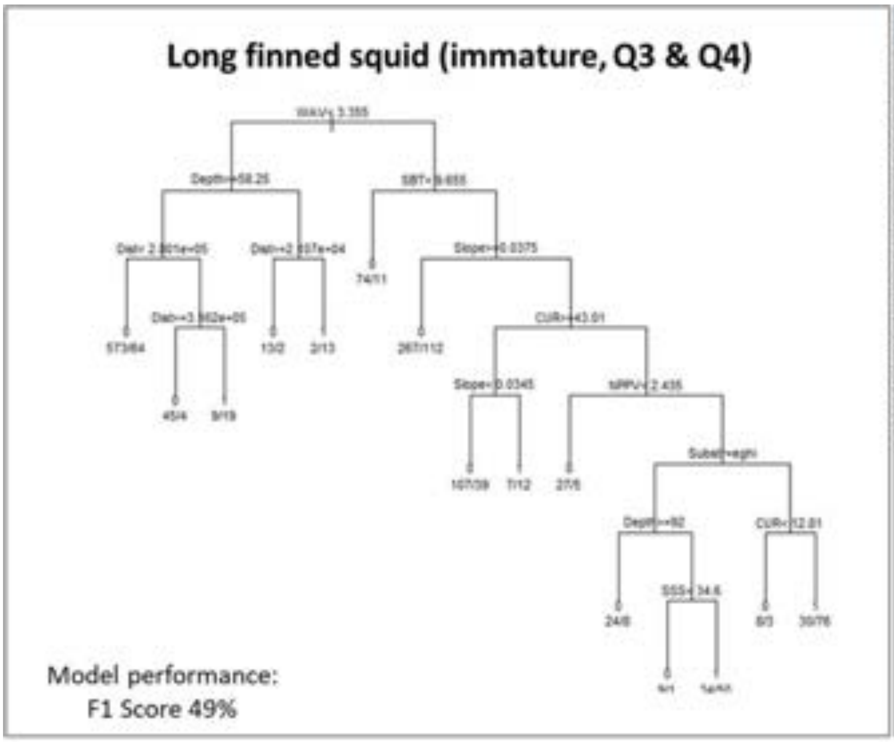
Figure 67. Habitat proxies for spurdog juveniles in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Occurrence of juvenile aggregations from WCDF 2013/14 survey data in the study area are also shown.

3.1.21 Long finned squid, *Loligo forbesii*

Long finned squid (*Loligo forbesii* Steenstrup 1856) is a cephalopod mollusc widely distributed around all British and Irish coasts. It is a short-lived species (1 year), characterised by rapid early growth being followed by maturation, spawning (mainly in winter in Scottish waters) and death after spawning. There is little knowledge about environmental requirements for spawning and nursery grounds, these being mainly in shallow inshore waters, with gradual migration to offshore feeding grounds as juvenile grow (Annex 1).

Long finned squid was assessed through modelling based on summer and autumn catches from bottom trawl surveys. Individuals <15 cm in mantel length were considered to identify immature recruits and their aggregations were used as indicator of potential higher value habitats used as nurseries.

Almost all variables accounting for geomorphological, energy and water quality characteristics (except for MLT) were selected by the model as predictors, as well as substratum type (Figure 68). Depth, wave energy at the seabed (WAV) and distance from the shore (Dist) were the most important predictors. Juvenile aggregations were predicted to occur at various combinations of these variables, but their highest probability of occurrence (0.87) was identified for shallower habitats (<58.2 m depth) within 21 km distance from the shore and with very low wave energy at the seabed (<3.3 N m^2/s) (Figure 68).



Variable	min	max
Dist	1070	411187
Depth	17	409.4
Slope	0.002	3.216
SBT	5.32	20.68
NPPV	0.04	102.52
SSS	29.63	35.57
MLT	6.4	293.55
CUR	1.29	698.03
WAV	0	355.37
SandbH01	0	1
StructH01	0	1
VegH01	0	1
Substr	a = "Coarse" c = "fMud" e = "mSand" g = "Sand" h = "sMud" i = "sMud_mSand"	

Figure 68. Decision tree for juvenile aggregations of long finned squid, *Loligo forbesii* (Q3 and Q4; full model) and associated environmental ranges at which the life stage occurred in the surveys.

The model prediction applied to the mean environmental conditions of the period 2010 - 2020 (summer-autumn) allowed mapping of the potential distribution of juvenile aggregations as an indication of potential location of higher value juvenile habitats functioning as nursery for long finned squid (Figure 69).

The model predicted juvenile squid aggregations with moderate-low confidence (41%), and appeared to better capture the actual occurrence of juvenile aggregations offshore in the Rockall area, southern North Sea and off the south Irish coast, and in front of the Firth of Forth. In turn, comparison with the survey data showed that it failed to identify juvenile aggregations occurring off the Moray Firth, north of Scotland and Ireland (Figure 69).

Consultation with stakeholders highlighted that spawning and early nursery grounds occur further inshore than what is predicted by the model. This limitation of the model is due to the survey data used to calibrate it, both in terms of their distribution (poor coverage inshore) and seasonality. For example, in the Moray Firth fishers observe the laying of eggs in shallow areas very close to the shore in December-January, and their hatching in late May- early June, with abundant catches of smaller squids (around 4 cm in length) close to the shore, at depth <10 m. As they grow in size, juveniles gradually move farther from the shore, and by October-December they are found further offshore. This is a common pattern also observed by squid fishers elsewhere. Therefore, it is likely that the model (based on summer-autumn catch data further from the shore) only identifies secondary nursery grounds, i.e. aggregations of larger juveniles when they have already moved farther from the shore. Based on this information, additional areas were added on the map to identify primary nursery (and spawning) inshore grounds earlier in the year (Figure 69). These inshore areas were located in particular in correspondence of juvenile aggregations observed and/or predicted to occur further offshore later in the year. Occasional occurrences of juvenile aggregations recorded from the additional inshore demersal fish survey on the west coast of Scotland (Appendix C, Figure C41) locally confirmed the use of inshore habitats as nursery grounds (Figure 69).

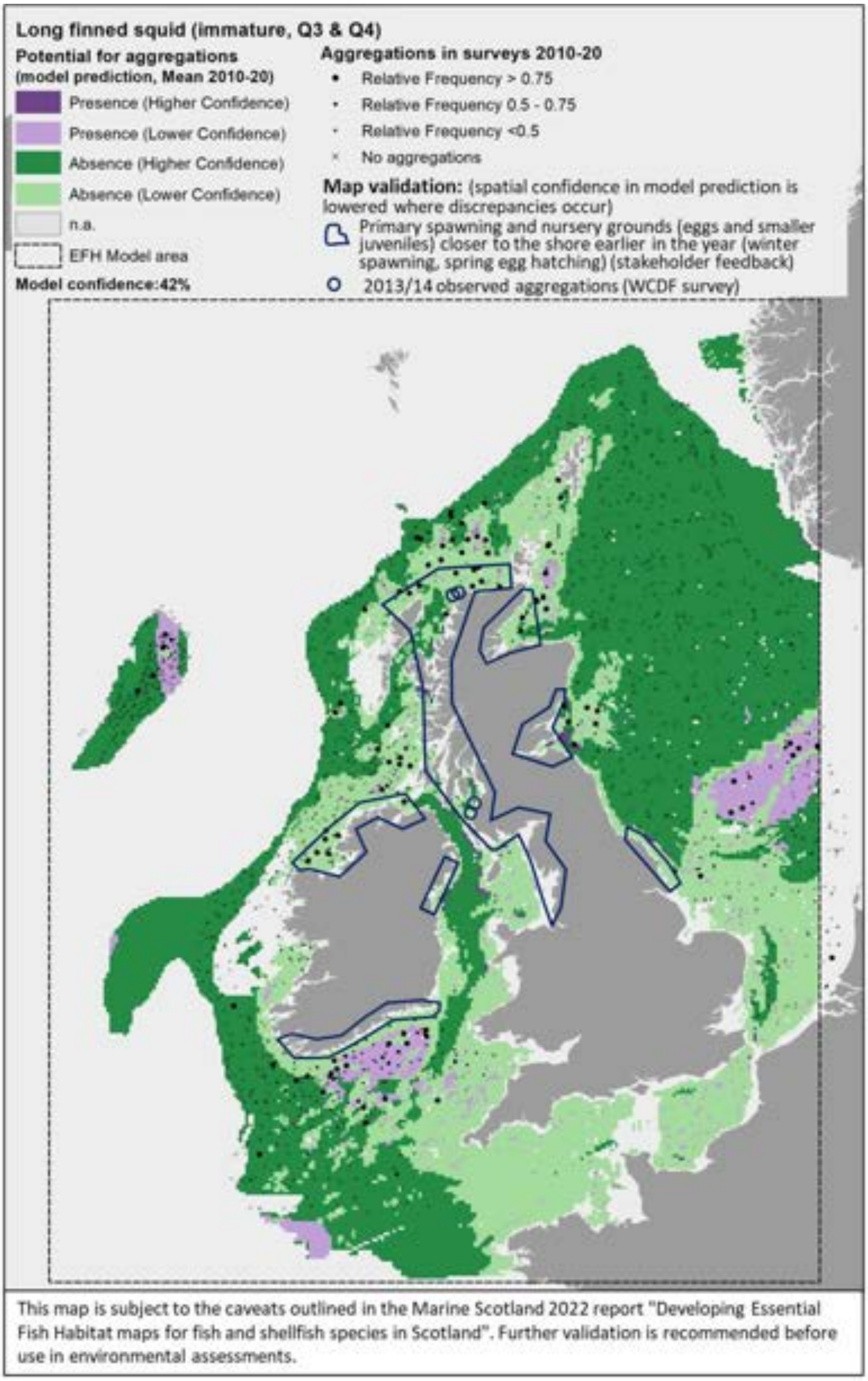


Figure 69. Aggregations of long finned squid juveniles (*Loligo forbesii* immature, Q3 & Q4): Frequency of occurrence in the 2010 - 2020 surveys and model prediction (incl. confidence) based on mean environmental conditions across 2010 - 2020. Areas highlighting discrepancies with additional evidence and knowledge from map validation are indicated by polygons and circles.

3.1.22 European lobster, *Homarus gammarus*

European lobster (*Homarus gammarus*, Linnaeus 1758) is a common benthic crustacean of high commercial importance which occurs around all British and Irish coasts. It is mostly found on rocky substrata, living in holes and excavated tunnels from the lower shore to about 60 m depth. Juveniles are thought to inhabit different habitats than adults and to have wide habitat tolerances enabling them to inhabit a variety of habitats, although most of the evidence comes from laboratory studies than from studies in the wild (Annex 1).

European lobster was assessed by using the habitat proxy approach to identify habitats that may potentially be used by the juveniles of the species. Nineteen publications were reviewed, but in most cases the information on specific habitat preferences of juveniles was not detailed enough to discriminate suitable habitats at the higher resolution (see Annex 1). In addition, no feedback was received from stakeholders. Therefore, a low confidence was associated with the overall assessment of habitat proxies for juvenile European lobster.

Habitats scoring high for suitability could not be identified and, at best, habitats with moderate suitability (score 2) were identified, but with low confidence. These were infralittoral rock, kelp and algal communities, infralittoral and circalittoral coarse sediments and fine muds (Table 21). Further possible habitats, scored with low suitability and low confidence (not shown in Table 21), included high and moderate energy littoral rock, exposed and tide swept shores, muddy sands and the neuston layer[19].

The distribution of the inshore habitat proxies for juveniles of European lobster in the case study area is mapped in Figure 70. No survey data were available for the map validation, nor stakeholder feedback was received on this map following consultation.

[19] Neuston layer is the pelagic (water column) habitat at the interface between air and sea waters.

Table 21. Main (highest scoring) habitats potentially associated with nursery function for juveniles of European lobster, *Homarus gammarus*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

European lobster (juvenile) – Habitat proxies for nursery function (Low confidence overall)
EUNIS Habitat type (score /confidence)
A3.1 Atlantic and Mediterranean high energy infralittoral rock (2/L)
A3.11 Kelp with cushion fauna and/or foliose red seaweeds (2/L)
A3.15 Frondose algal communities (other than kelp) (2/L)
A3.2 Atlantic and Mediterranean moderate energy infralittoral rock(2/L)
A3.21 Kelp and red seaweeds (moderate energy infralittoral rock) (2/L)
A3.3 Atlantic and Mediterranean low energy infralittoral rock (2/L)
A5.1 Sublittoral coarse sediment (2/L)
A5.13 Infralittoral coarse sediment (2/L)
A5.14 Circalittoral coarse sediment (2/L)
A5.3 Sublittoral mud (2/L)
A5.34 Infralittoral fine mud (2/L)
A5.36 Circalittoral fine mud (2/L)

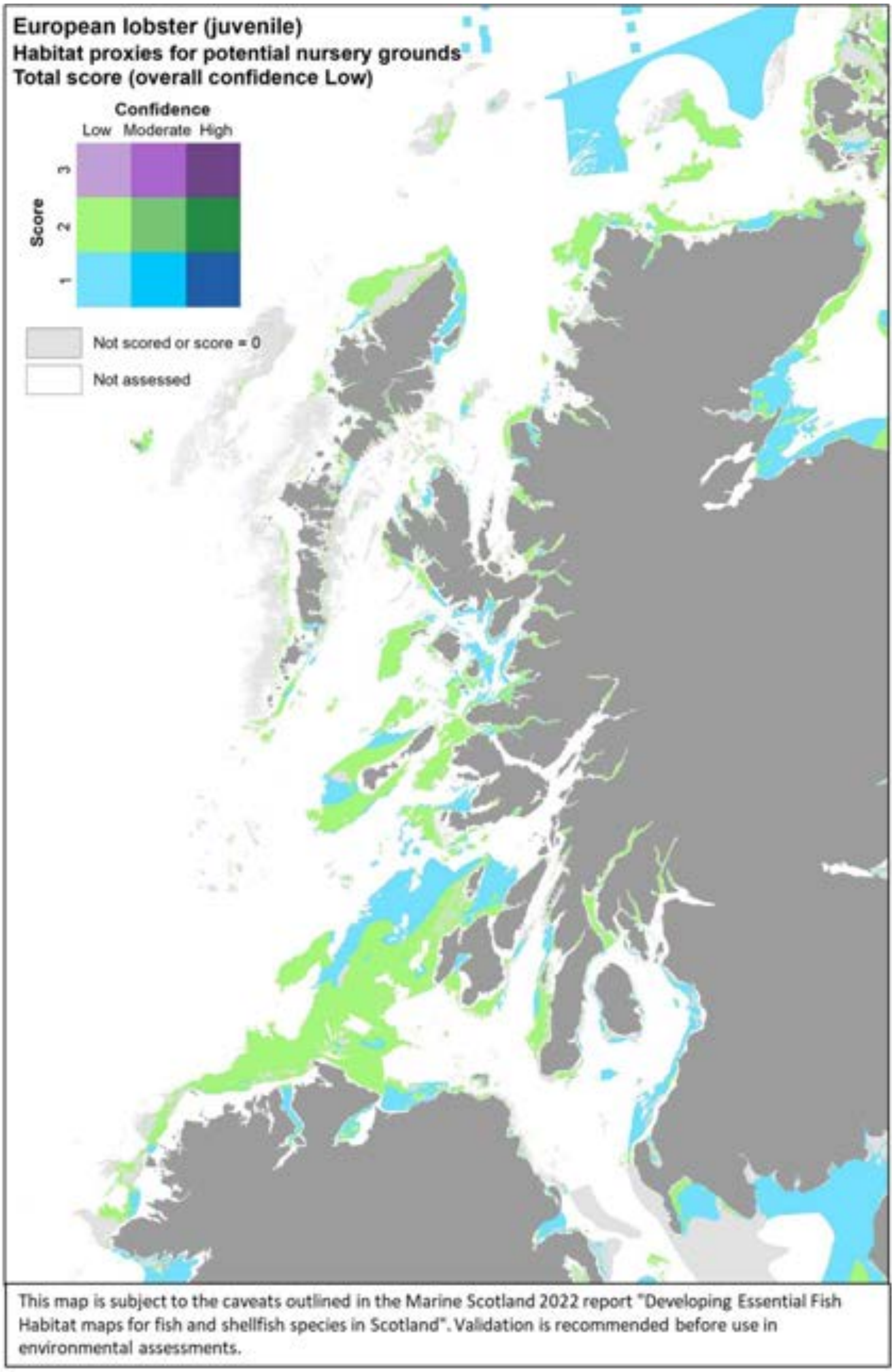


Figure 70. Habitat proxies for juveniles of European lobster in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated.

3.1.23 Brown crab, *Cancer pagurus*

Brown crab (*Cancer pagurus* Linnaeus 1758), also known as edible crab, is a common benthic crustacean of high commercial importance which occurs around all British and Irish coasts, with its distribution extending both further north and south. It is mostly found on bedrock including under boulders, mixed coarse grounds, and offshore in muddy sand, down to about 100 m depth. Ovigerous females find shelter in pits dug in sandy, gravelly sediment or under rocks, while juvenile habitat preference is for structurally complex biotopes (e.g. maerl beds, boulders, seagrass and rock formations, kelp forests or macroalgae), which provide shelter from predation (Annex 1).

Brown crab was assessed by using the habitat proxy approach to identify habitats that may potentially be used by the juveniles of the species. Fourteen publications were reviewed, but often the available evidence for juvenile habitat preferences was not detailed enough (e.g. mostly accounting for depth) to discriminate suitable habitats at the higher resolution (see Annex 1). In addition, no feedback was received from stakeholders. Therefore, a low-moderate confidence was assigned to the overall assessment of habitat proxies for juvenile brown crab.

The most suitable habitats for juveniles of brown crab were rocky habitats in the littoral and circalittoral zones, with higher scores allocated with high confidence to the littoral zones (A1.4, A1.41, A1.44) (Table 22). Other possible habitats, scored with medium to low suitability and medium to low confidence (not shown in Table 22) included kelp and seaweed habitats, maerl beds and seagrass beds.

The distribution of the inshore habitat proxies for juveniles of brown crab in the case study area is mapped in Figure 71. No survey data were available for the map validation, nor stakeholder feedback was received on this map following consultation.

Table 22. Main (highest scoring) habitats potentially associated with nursery function for juveniles of brown crab, *Cancer pagurus*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Brown crab (juvenile) – Habitat proxies for nursery function (Low-Moderate confidence overall)
EUNIS Habitat type (score /confidence)
A1.4 Features of littoral rock (3/H)
A1.41 Communities of littoral rockpools (3/H)
A1.44 Communities of littoral caves and overhangs (3/H)
A4.2 Atlantic & Mediterranean moderate energy circalittoral rock (2/M)
A4.23 Communities on soft circalittoral rock (2/M)

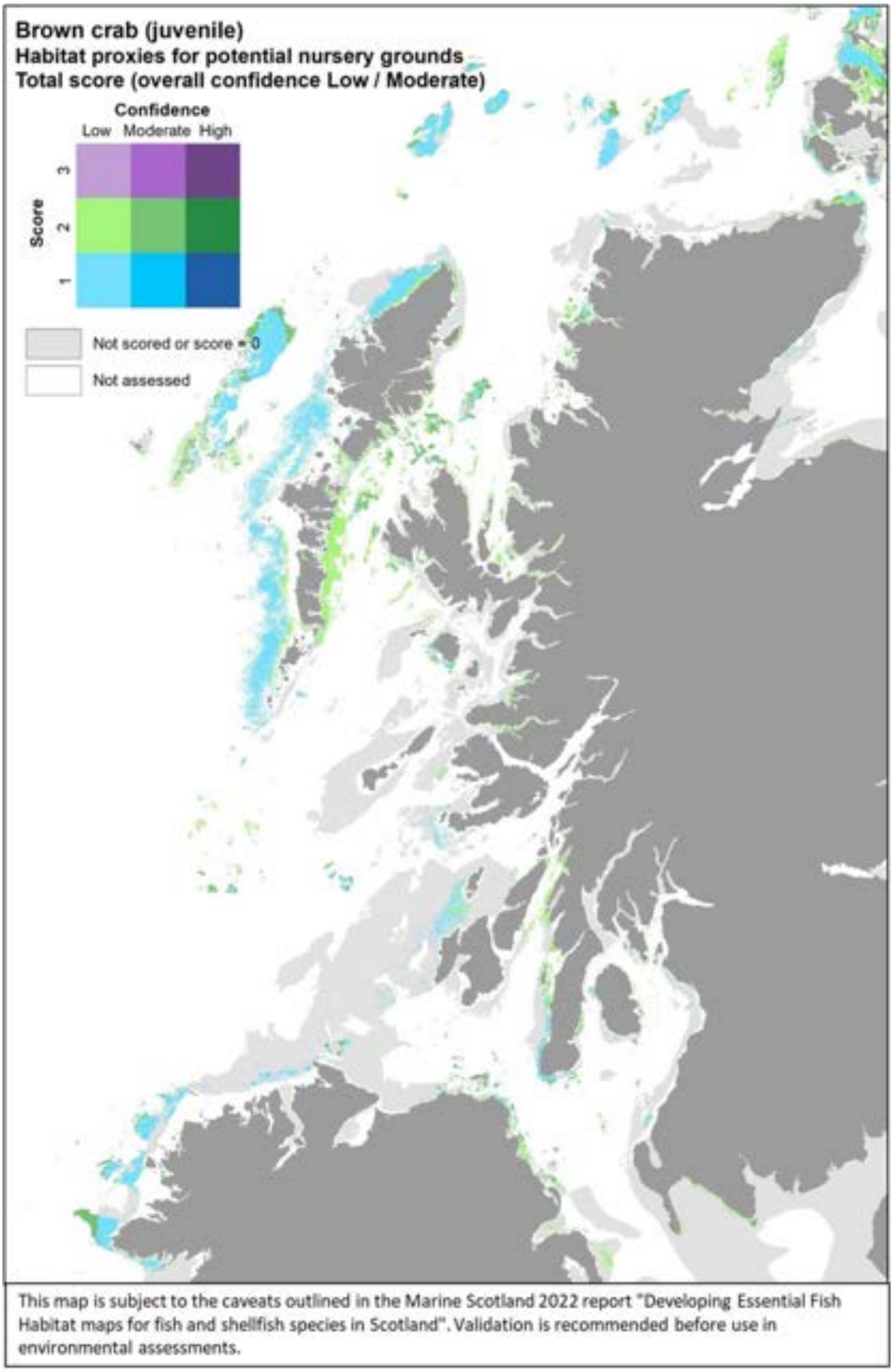


Figure 71. Habitat proxies for juveniles of brown crab in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated.

3.1.24 Velvet crab, *Necora puber*

Velvet crab (*Necora puber*, Linnaeus 1767), also known as swimming crab, is a benthic crustacean of commercial interest which occurs around all British and Irish coasts. It is mostly found in inshore waters, on stony and rock substrata intertidally and in shallow water, most abundant on moderately sheltered shores. There is no evidence in the literature of a specific spawning or nursery habitat that is distinguished from where the species normally lives (Annex 1).

Velvet crab was assessed by using the habitat proxy approach to identify habitats that may potentially be used by the species (for different functions). Seven publications were reviewed, but the available evidence was not always detailed enough to discriminate suitable habitats at the higher resolution (see Annex 1). In addition, no feedback was received from stakeholders. Therefore, a moderate confidence was assigned to the overall assessment of habitat proxies for velvet crab.

Atlantic and Mediterranean moderate energy infralittoral rock was identified as a highly suitable habitat for velvet crab, albeit with moderate confidence, whereas moderate energy littoral rock had moderate suitability (also with associated moderate confidence) (Table 23). Further possible habitats, though scored with low suitability and low confidence included the neuston[20], rockpools and circalittoral rocks (not shown in Table 23).

The distribution of the inshore habitat proxies for velvet crab in the case study area is mapped in Figure 72. No survey data were available for the map validation, nor stakeholder feedback was received on this map following consultation.

Table 23. Main (highest scoring) habitats potentially associated with velvet crab, *Necora puber*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Velvet crab – Habitat proxies for the species' habitat (Moderate confidence overall)	
EUNIS Habitat type (score /confidence)	
A1.2	Moderate energy littoral rock (2/M)
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock (3/M)

[20] The pelagic (water column) habitat at the interface between air and sea waters.

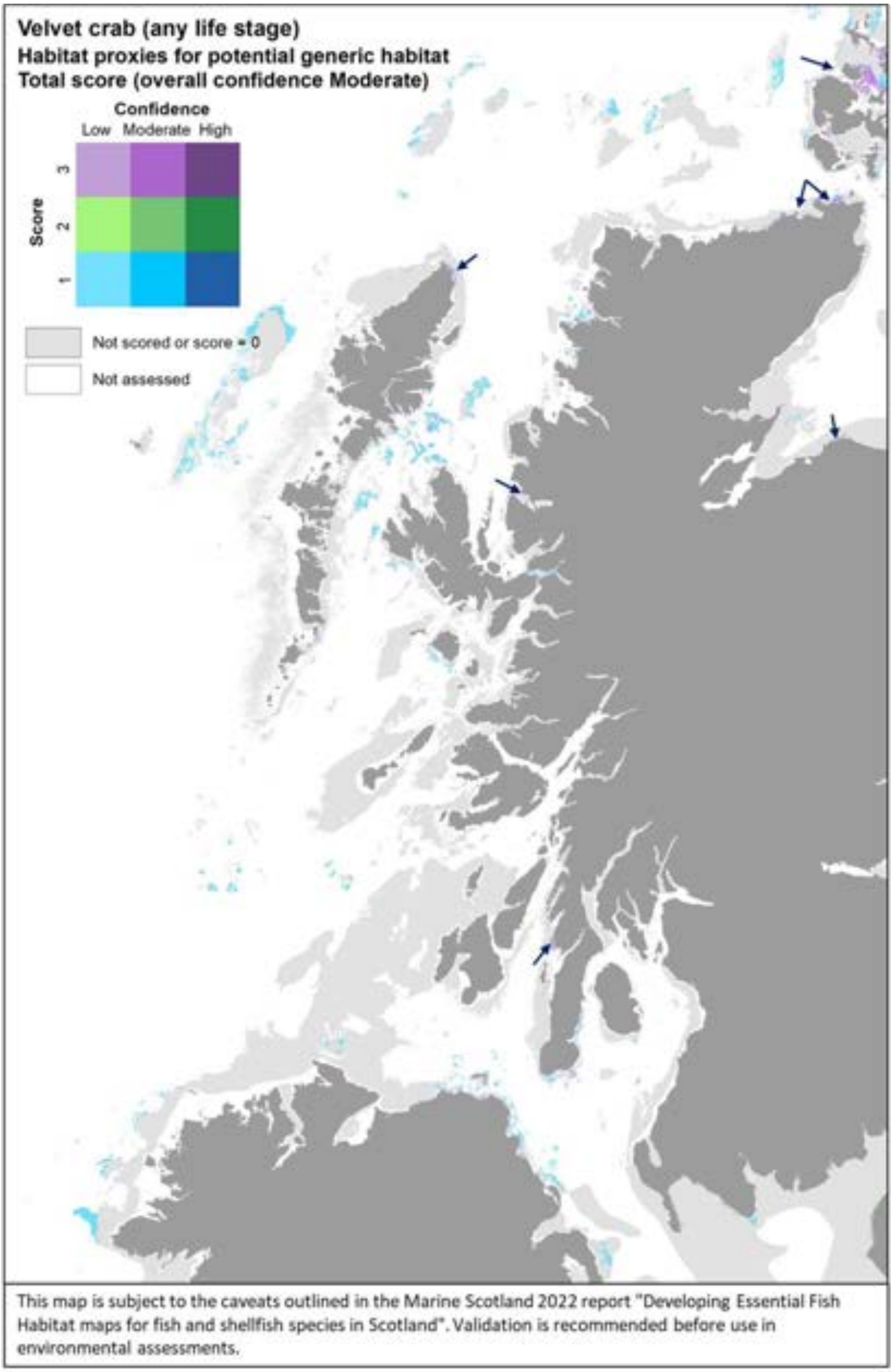


Figure 72. Habitat proxies for velvet crab in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Arrows indicate examples of small habitat patches with higher score (3) in the map.

3.1.25 Common cockle, *Cerastoderma edule*

Common cockle (*Cerastoderma edule*, Linnaeus 1758) is a predominantly intertidal bivalve widely distributed in estuaries and sandy bays around the coasts of Britain and Ireland, where it inhabits the surface of sediments, burrowing to a maximum depth of 5 cm. Gametes are released in the water column and larvae are free drifting until settlement. A sessile species, adults distribute where the juveniles settle, hence the same habitat performs multiple functions (feeding, spawning, nursery) (Annex 1).

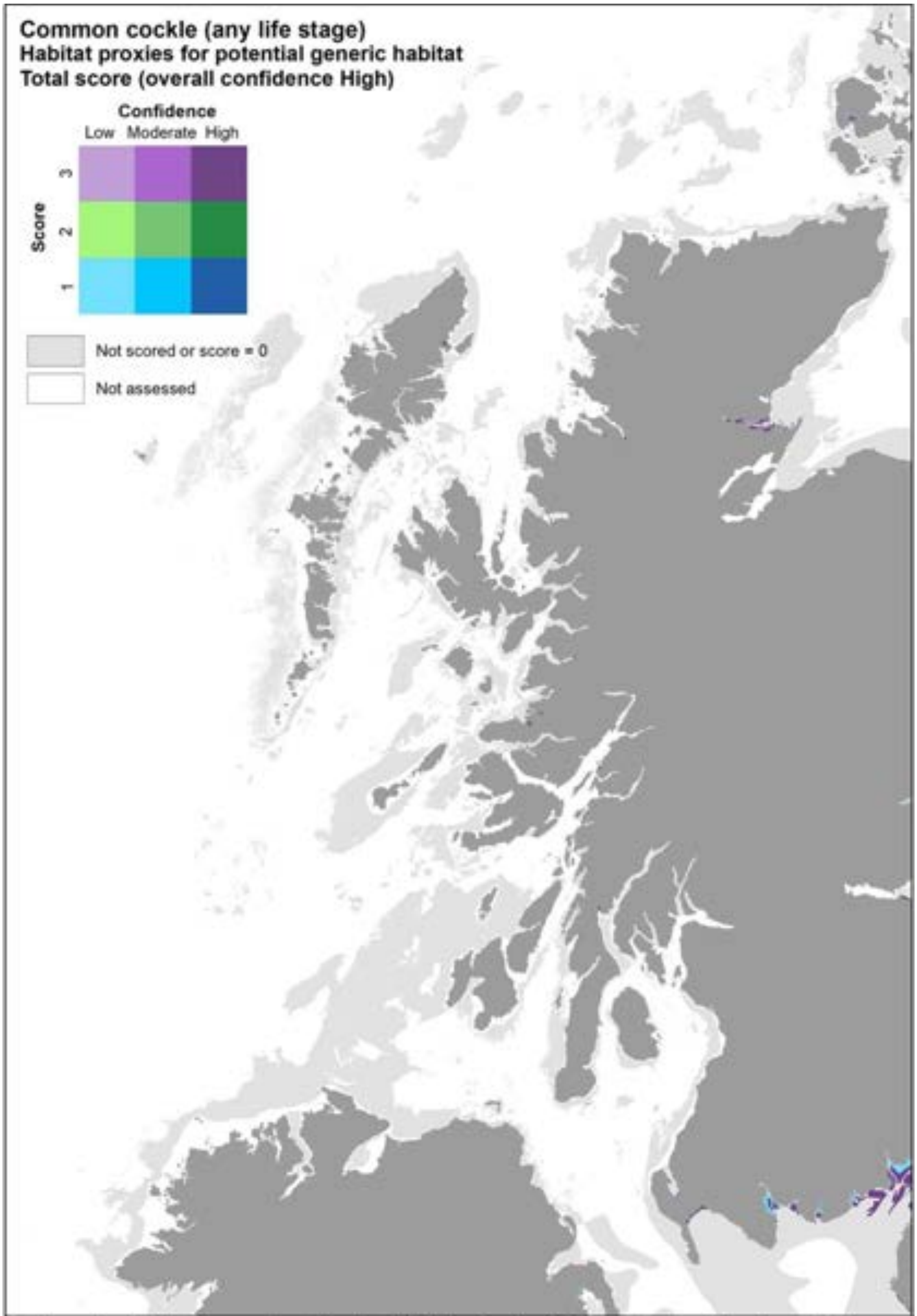
Common cockle was assessed by using the habitat proxy approach to identify habitats that may potentially be used by the species (for different functions). Six publications were reviewed and provided extensive and detailed characterisation of the species' habitat requirements (see Annex 1). This, along with expert input obtained with the stakeholder validation, led to a high confidence in the overall assessment of habitat proxies for common cockle.

Sandy and mixed habitats in the littoral zone were identified as highly suitable habitats for common cockle, and with high confidence (Table 24). Other possible habitats (not shown in Table 24) were areas with ephemeral green or red algae with a freshwater influence and littoral sediments dominated by aquatic angiosperms, specifically seagrass, all scoring 2/M. Further possible habitats, scored with medium to low suitability and medium to low confidence, included littoral mud and strandline habitats.

The distribution of the inshore habitat proxies for common cockle in the case study area is mapped in Figure 73. No survey data were available for the map validation, nor stakeholder feedback was received on this map following consultation.

Table 24. Main (highest scoring) habitats potentially associated with common cockle, *Cerastoderma edule*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Common cockle – Habitat proxies for the species' habitat (High confidence overall)
EUNIS Habitat type (score /confidence)
A2.2 Littoral sand and muddy sand (3/H)
A2.23 Polychaete/amphipod-dominated fine sand shores (3/H)
A2.24 Polychaete/bivalve-dominated muddy sand shores (3/H)
A2.4 Littoral mixed sediments (3/H)
A2.42 Species-rich mixed sediment shores (3/H)



This map is subject to the caveats outlined in the Marine Scotland 2022 report "Developing Essential Fish Habitat maps for fish and shellfish species in Scotland". Validation is recommended before use in environmental assessments.

Figure 73. Habitat proxies for common cockle in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated.

3.1.26 Dog cockle, *Glycymeris glycymeris*

Dog cockle (*Glycymeris glycymeris*, Linnaeus 1758) is a bivalve of the endofauna (i.e. living below the surface of the sediment), found in Scottish waters (around the Shetland Islands and the Orkneys), along the south and west coasts of Britain, Northern Ireland and Ireland. It is generally found in both inshore and offshore waters (to a depth of 100 m), on fine shell gravel or sandy/muddy gravel substrata. There is no information about spawning and juvenile habitat preferences, but, being a sessile species, it is expected that the same habitat performs multiple functions for different life stages (feeding, spawning, nursery) (Annex 1).

Dog cockle was assessed by using the habitat proxy approach to identify habitats that may potentially be used by the species (for different functions). Four publications were reviewed and provided information in sufficient detail to identify clearly and uniquely the habitat preference for the species (see Annex 1). No feedback was received from stakeholders for this species. A moderate-high confidence was assigned to the overall assessment of habitat proxies for dog cockle.

Subtidal coarse or mixed sediments in variable depth zones (sublittoral, infralittoral, circalittoral) were identified as a highly suitable habitats for dog cockle, and with high confidence (Table 25). This species has clear habitat preferences and no other habitat types were identified as suitable.

The distribution of the inshore habitat proxies for dog cockle in the case study area is mapped in Figure 74. No survey data were available for the map validation, nor stakeholder feedback was received on this map following consultation.

Table 25. Main (highest scoring) habitats potentially associated with dog cockle, *Glycymeris glycymeris*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Dog cockle – Habitat proxies for the species' habitat (Moderate-High confidence overall)
EUNIS Habitat type (score /confidence)
A5.1 Sublittoral coarse sediment (3/H)
A5.13 Infralittoral coarse sediment (3/H)
A5.14 Circalittoral coarse sediment (3/H)
A5.4 Sublittoral mixed sediments (3/H)
A5.43 Infralittoral mixed sediments (3/H)
A5.44 Circalittoral mixed sediments (3/H)

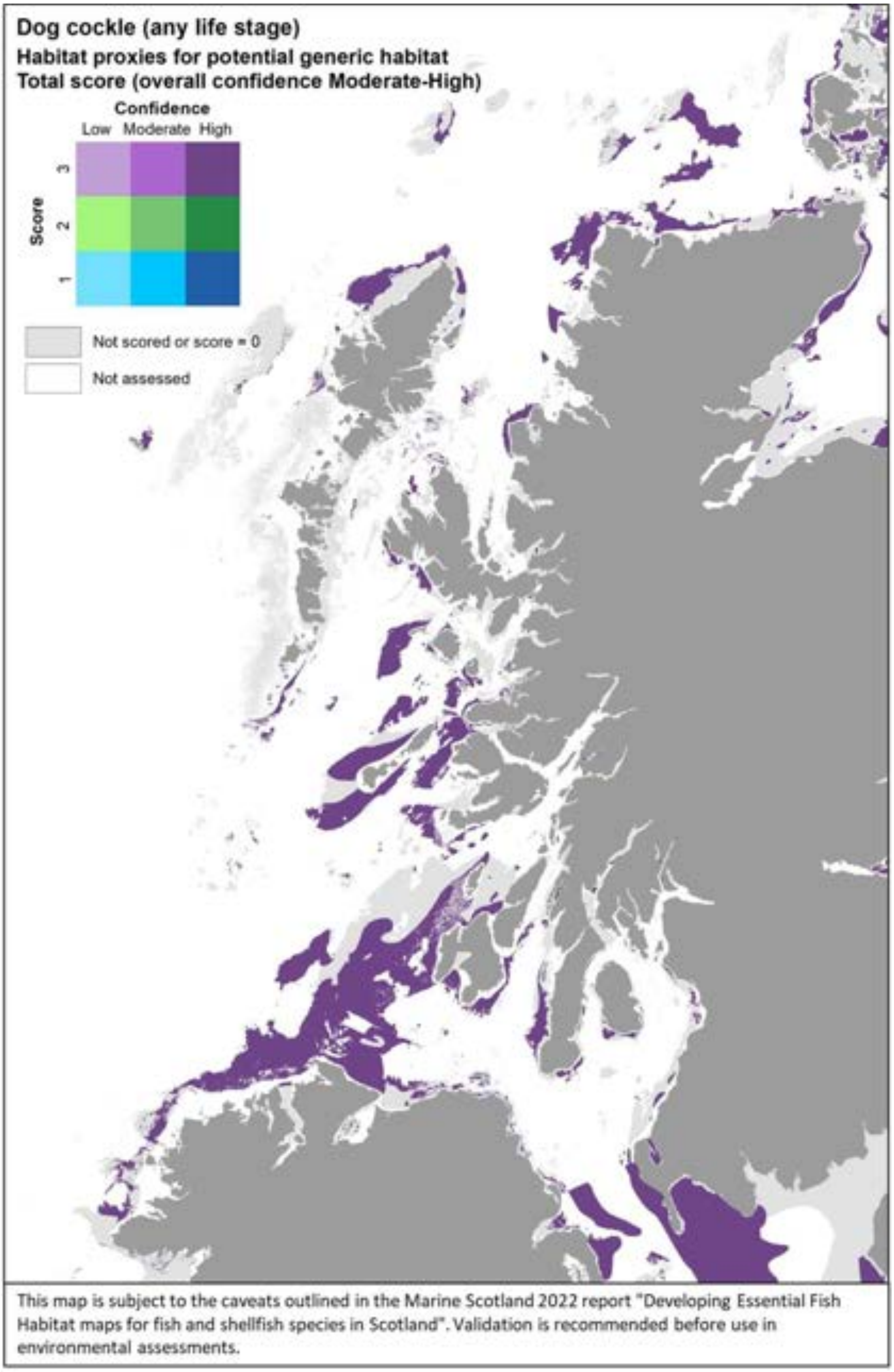


Figure 74. Habitat proxies for dog cockle in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated.

3.1.27 Razor clam, *Ensis ensis*

Razor clam (*Ensis ensis*, Linnaeus 1758) is an elongated bivalve of the endofauna which lives in deep, vertical, permanent burrows. It is commonly found in inshore shallow habitats along all British coasts, on fine sand (sometimes muddy sand). There is no information about spawning and juvenile habitat preferences, but, being a sessile species, it is expected that the same habitat performs multiple functions for different life stages (feeding, spawning, nursery) (Annex 1).

Razor clam was assessed by using the habitat proxy approach to identify habitats that may potentially be used by the species (for different functions). Four publications were reviewed and provided extensive and detailed characterisation of the species' habitat requirements (see Annex 1). Despite no feedback being received from stakeholders on the scoring of this species, the available evidence was judged enough to assign a high confidence to the overall assessment of habitat proxies for razor clam.

Fine and muddy sands from the infralittoral and sublittoral zones were identified as a highly suitable habitats for razor clam, and with high confidence (Table 26). These represent optimal substrata for the species to make their burrows. Similar habitats, but at greater depth (circalittoral zone) were identified as moderately suitable, also with high confidence. Further possible habitats, though scored with medium to low suitability and medium to low confidence (not shown in Table 26), included sandy muds and mixed sediments in the sublittoral (infralittoral and circalittoral) zone.

The distribution of the inshore habitat proxies for razor clam in the case study area is mapped in Figure 75. No survey data were available for the map validation, nor stakeholder feedback was received on this map following consultation.

Table 26. Main (highest scoring) habitats potentially associated with razor clam, *Ensis ensis*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Razor clam – Habitat proxies for the species’ habitat (High confidence overall)
EUNIS Habitat type (score /confidence)
A5.2 Sublittoral sand (3/H)
A5.2 Infralittoral fine sand (3/H)
A5.24 Infralittoral muddy sand (3/H)
A5.25 Circalittoral fine sand (2/H)
A5.26 Circalittoral muddy sand (2/H)

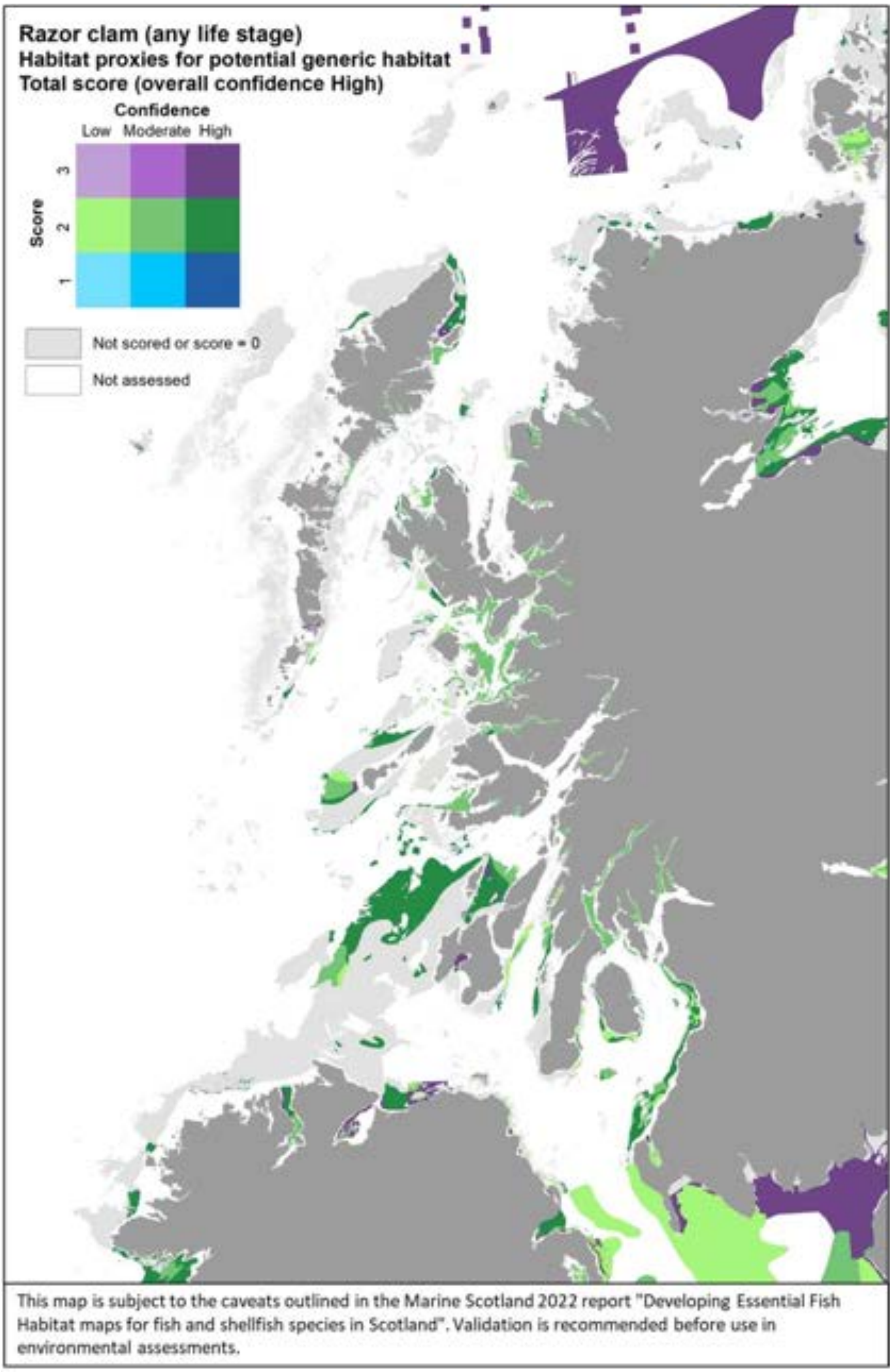


Figure 75. Habitat proxies for razor clam in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated.

3.1.28 Common whelk, *Buccinum undatum*

Common whelk (*Buccinum undatum* Linnaeus 1758) is a gastropod mollusc of the endofauna, which lives buried in the sediment. It is commonly found subtidally (down to 1200 m depth) off all British coasts. Unlike other molluscs, all its life stages are benthic, with eggs being laid on the seabed (attached to rocks, stones, shells) and the larva developing inside the egg, from which it hatches as a fully formed benthic juvenile. It is expected that the same habitat performs multiple functions for different life stages (feeding, spawning, nursery) (Annex 1).

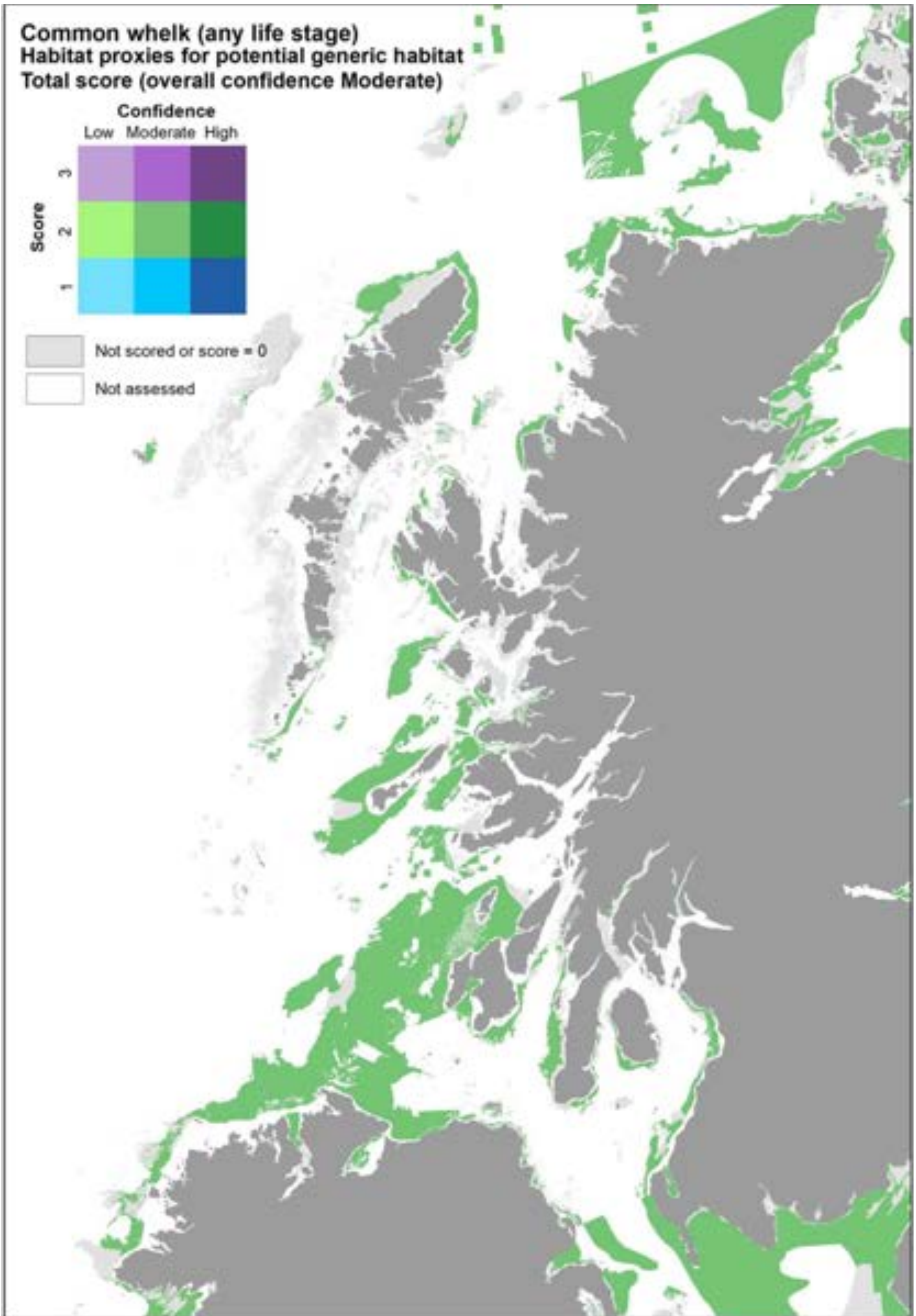
Common whelk was assessed by using the habitat proxy approach to identify habitats that may potentially be used by the species (for different functions). Nine publications were reviewed and provided detailed characterisation of the species' habitat requirements (see Annex 1). No feedback was received from stakeholders on the scoring of this species. A moderate confidence was assigned to the overall assessment of habitat proxies for common whelk.

Habitats scoring highly for suitability could not be identified and, at best, habitats with moderate suitability (score 2) were identified, generally with moderate confidence. These were sedimentary habitats in the sublittoral (infralittoral and circalittoral) zone, including a variety of grain sizes (mud, sand, coarse and mixed sediments) (Table 27). Further possible habitats, scored with low suitability and medium confidence (not shown in Table 27), were estuarine subtidal habitats, characterised by variable salinity and sublittoral coarse, sandy and mixed sediment substrata.

The distribution of the inshore habitat proxies for common whelk in the case study area is mapped in Figure 76. No survey data were available for the map validation, nor stakeholder feedback was received on this map following consultation.

Table 27. Main (highest scoring) habitats potentially associated with common whelk, *Buccinum undatum*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Common whelk – Habitat proxies for the species' habitat (Moderate confidence overall)
EUNIS Habitat type (score /confidence)
A5.1 Sublittoral coarse sediment (2/M)
A5.13 Infralittoral coarse sediment (2/M)
A5.14 Circalittoral coarse sediment (2/M)
A5.2 Sublittoral sand (2/M)
A5.23 Infralittoral fine sand (2/M)
A5.24 Infralittoral muddy sand (2/M)
A5.25 Circalittoral fine sand (2/M)
A5.26 Circalittoral muddy sand (2/M)
A5.4 Sublittoral mixed sediments (2/M)
A5.43 Infralittoral mixed sediments (2/M)
A5.44 Circalittoral mixed sediments (2/M)



This map is subject to the caveats outlined in the Marine Scotland 2022 report "Developing Essential Fish Habitat maps for fish and shellfish species in Scotland". Validation is recommended before use in environmental assessments.

Figure 76. Habitat proxies for common whelk in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated.

3.1.29 Dog whelk, *Nucella lapillus*

Dog whelk (*Nucella lapillus*, Linnaeus 1758) is a predominantly intertidal gastropod mollusc, common on all rocky coasts of Britain and Ireland. It is a mobile but sedentary species, with adults thought to move less than 30 m in their lifetime. As for common whelk, all its life stages are benthic, with eggs being laid on the seabed (attached to rocks) and the larva developing inside the egg, from which it hatches as a fully formed benthic juvenile. Although spawning aggregations have been observed, these are on the same rocky shores where the species lives, this habitat performing multiple functions for different life stages (feeding, spawning, nursery) (Annex 1).

Dog whelk were assessed by using the habitat proxy approach to identify habitats that may potentially be used by the species (for different functions). Four publications were reviewed and provided sufficiently detailed information to identify clearly and uniquely the habitat preference for the species (in terms of depth, substratum, salinity tolerance etc), likely aided by the highly specific habitat requirements of this species (see Annex 1). Despite no feedback being received from stakeholders on the scoring of this species, the available evidence was judged enough to assign a high confidence to the overall assessment of habitat proxies for dog whelk.

Rocky habitats in the intertidal zone, namely Fucoids in tide-swept conditions, Moderate energy littoral rock, and Barnacles and fucoids on moderately exposed shores, were identified as a highly suitable habitats for dog whelk, and with high confidence (Table 28). A variety of other rocky habitats in the littoral zone were identified as moderately or highly suitable (the latter being mussel and barnacle communities), albeit with a lower (moderate) confidence. Further possible habitats, scored with medium to low suitability and medium to low confidence (not shown in Table 28), included circalittoral rock (most likely restricted to the upper circalittoral zone, as dog whelk is primarily an intertidal species).

The distribution of the inshore habitat proxies for common whelk in the case study area is mapped in Figure 77. No survey data were available for the map validation, nor stakeholder feedback was received on this map following consultation.

Table 28. Main (highest scoring) habitats potentially associated with dog whelk, *Nucella lapillus*. Habitat suitability score varies from 1 (Low) to 3 (High), with confidence in the scoring assessed as Low (L), Medium (M) or High (H). Habitat codes and names are as per EUNIS Habitat classification.

Dog whelk – Habitat proxies for the species' habitat (High confidence overall)
EUNIS Habitat type (score /confidence)
A1.1 High energy littoral rock (3/H)
A1.11 Mussel and/or barnacle communities (3/M)
A1.12 Robust fucoid and/or red seaweed communities (2/H)
A1.15 Fucoids in tide-swept conditions (3/H)
A1.2 Moderate energy littoral rock (3/H)
A1.21 Barnacles and fucoids on moderately exposed shores (3/H)
A1.22 Mussels and fucoids on moderately exposed shores (2/H)
A1.3 Low energy littoral rock (2/H)
A1.31 Fucoids on sheltered marine shores (2/H)
A1.4 Features of littoral rock (2/H)
A1.44 Communities of littoral caves and overhangs (2/H)

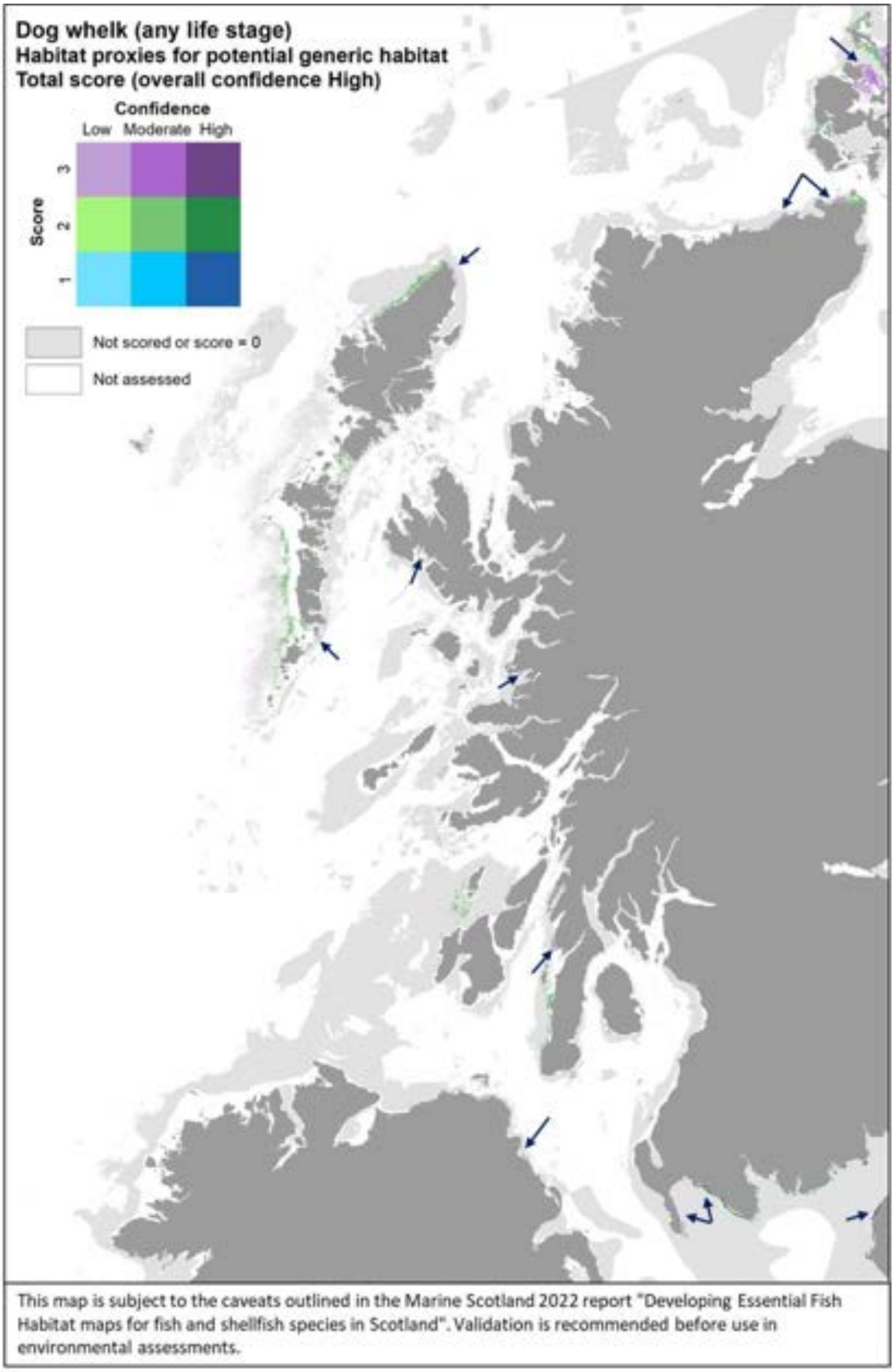


Figure 77. Habitat proxies for dog whelk in the case study area (west coast of Scotland). The score reflects the potential suitability of the assessed inshore habitats in the area (1/Low to 3/High), with Low to High confidence associated. Arrows indicate examples of small habitat patches with higher score (3) in the map.

3.1.30 Summary tables

A summary of the main results of the assessments undertaken and mapped for the fish and shellfish species in this study is given in Table 29.

Table 29. Summary results of the data-based EFH modelling (offshore) and habitat proxy assessment (inshore) of fish and shellfish species/life stages and the associated spatial outputs (UK-wide for the EFH models; west coast of Scotland only for the habitat proxy assessment).

Species (life stage, EFH function)	Assessment results
Lesser sandeel, *Ammodytes marinus* (Any life stage, Refugia)	EFH model (individuals of any size, Quarter 4 (December)): Overall confidence 61% (spatial coverage of valid predictions was restricted by limited geographical coverage hence environmental ranges of survey data used for calibrations (e.g. no surveys at >66 km from shore); this contributed to lower overall confidence). EFH predictors (decreasing importance): CUR, WAV, SSS, NPPV, SBT. Map validation via additional data & stakeholder feedback, with discrepancies highlighted in integrated spatial output (e.g. predicted absence on protected sandeel grounds in north east UK sandeel closure area, North-west Orkney NC MPA, Turbot Bank NC MPA, Mousa to Boddam NC MPA and North-east Lewis NC MPA). Discrepancies partly eliminated when model was predicted for individual years rather than for mean environmental scenario over 2010 - 2020 study period.
Small sandeel, *Ammodytes tobianus* (Any life stage, Refugia)	Habitat proxy assessment (overall confidence high): Most important EUNIS habitat types (Level 3) identified with score 3 and high confidence: A5.1 (sublittoral coarse sediment). Map validation via survey data only (no stakeholder feedback received), generally agreeing with habitat proxies where identified.
Norway lobster, *Nephrops norvegicus* (Any life stage, Refugia)	EFH model (individuals of any size, Quarters 1, 3 and 4): Overall confidence 49% (use of trawl catch data, rather than direct observations of burrow density from TV surveys, contributed to lower the overall confidence). EFH predictors (decreasing importance): Substr, Depth, SBT, WAV, SSS, MLT, NPPV, CUR. Map validation via additional data & stakeholder feedback, with discrepancies highlighted in integrated spatial output. Discrepancies likely due to density differences between stocks, accounted only in part during data modelling (model predictions confirmed in areas where burrows occur with high-density; discrepancies mainly in areas with lower-density of burrows, e.g. Fladen and western regions of the South Minch), and, in other areas, to inclusion of coarse sediment as suitable substrata by the model.

Species (life stage, EFH function)	Assessment results
Herring, *Clupea harengus* (Spawning adult, Spawning) [Habitat proxy map]	Habitat proxy assessment (overall confidence high): Most important EUNIS habitat types (Level 3) identified with score 3 and high confidence: A2.1 (littoral coarse sediment), A5.1 (sublittoral coarse sediment), A5.5 (sublittoral macrophyte-dominated sediment), and A7.3 (completely mixed water column with full salinity). Map validation via stakeholder feedback only (based on known current and historic herring spawning grounds identified in Frost and Diele 2022), with discrepancies highlighted in integrated spatial output (e.g. observed spawning in the Firth of Clyde and Wester Ross area not captured in the habitat proxy map).
Plaice, *Pleuronectes platessa* (Juvenile, Nursery)	EFH model (0-group, 4 - 12 cm length, Quarter 3): Overall confidence 69%. EFH predictors (decreasing importance): MLT, Dist, Depth, NPPV, Substr, SSS, CUR. Map validation via additional data & stakeholder feedback, with discrepancies highlighted in integrated spatial output (model predictions of settlement habitats of juvenile plaice confirmed in Moray Firth, Firth of Forth, Firth of Clyde, but gaps in the spatial coverage of the most inshore areas (expected to be most important as nursery grounds) due to data limitations).
	Habitat proxy assessment (overall confidence high): Most important EUNIS habitat types (Level 3) identified with score 3 and high confidence: A5.2 (sublittoral sand). Map validation via survey data only (no stakeholder feedback received), generally agreeing with habitat proxies where identified (e.g. eastern margin of the Firth of Clyde, areas west of the Kintyre peninsula and off Jura, east and west of the Small Isles).
Lemon sole, *Microstomus kitt* (Juvenile, Nursery)	EFH model (0-group, 3 - 15 cm length, Quarter 3): Overall confidence 58%. EFH predictors (decreasing importance): Dist, CUR, Depth, SBT, MLT, WAV, Slope, SSS. Map validation via additional data & stakeholder feedback, with discrepancies highlighted in integrated spatial output (model predictions confirmed on Dogger Bank, but absence predicted where juvenile aggregations were observed southwest of the Dogger Bank, in central North Sea and more inshore areas to the south, where there are also spatial gaps in the model maps due to data limitations).

Species (life stage, EFH function)	Assessment results
Common sole, *Solea solea* (Juvenile, Nursery)	EFH model (0- and 1-groups, 3 - 25 cm length, Quarter 3): Overall confidence 57%. EFH predictors (decreasing importance): Depth, MLT, SBT, WAV, NPPV, SSS, Slope, CUR. Map validation via stakeholder feedback only, with discrepancies highlighted in integrated spatial output (model predictions confirmed on inshore nurseries along the southeast, south and southwest coast of the UK, but absence predicted in areas of juvenile aggregation within Liverpool Bay; there are also spatial gaps in model maps in most inshore areas due to data limitations, while possible nurseries are identified in Scottish coastal waters, despite they are not currently used by the species, which has a more southern distribution in UK waters).
	Habitat proxy assessment (overall confidence moderate): Most important EUNIS habitat types (Level 3) identified with score 3 and high confidence: A5.2 (sublittoral sand), A5.3 (sublittoral mud) (also A2.2 and A2.3 (littoral sand and muddy sand, and littoral mud, respectively), but moderate confidence). Map validation via stakeholder feedback only, with discrepancies highlighted in integrated spatial output (habitat proxies identified along the west coast of Scotland are not currently used by the species).
Anglerfish, *Lophius piscatorius* (Juvenile, Nursery)	EFH model (0- and 1-groups, 12 - 28 cm length, Quarter 2): Overall confidence 65% (the highest across species assessed, despite confidence being lowered by the fact that trawl surveys considered did not target specifically juveniles, and other data (e.g. from scallop dredge surveys) could be better suited). EFH predictors (decreasing importance): SBT, MLT, SSS, CUR. Map validation via additional data & stakeholder feedback, with discrepancies highlighted in integrated spatial output (important anglerfish juvenile grounds in the western English Channel and in most of the Celtic Seas not identified by the model; poor predictions in Rockall area; spatial gaps in most inshore areas due to data limitations). Discrepancies partly eliminated when model was predicted for individual years rather than for mean environmental scenario over 2010 - 2020 study period.
Whiting, *Merlangius merlangus* ('Running' adult, Spawning)	EFH model (adults at spawning or spent stages, Quarter 1): Overall confidence 36%. EFH predictors (decreasing importance): Depth, CUR, SSS, Slope, Dist, SBT, Substr. Map validation via stakeholder feedback only, with discrepancies highlighted in integrated spatial output (model predictions confirmed in the central and northern North Sea, north coast of Scotland and offshore areas to the west of Scotland, but spawning aggregations in southern North Sea and spawning grounds in the English Channel and on the Trevose ground poorly predicted by the model).

Species (life stage, EFH function)	Assessment results
Whiting, *Merlangius merlangus* (Juvenile, Nursery)	EFH model (0-group, 12 - 16 cm length in Quarter 3, up to 20 cm length in Quarter 4): Overall confidence 41%. EFH predictors (decreasing importance): Depth, Dist, WAV, Substr, Slope. Map validation via additional data & stakeholder feedback, with discrepancies highlighted in integrated spatial output (model predictions confirmed by juvenile whiting distribution along the UK coast and in the northern North Sea, but with spatial gaps in most inshore areas (due to data limitations) which are expected to be most important as nursery grounds for the species).
	Habitat proxy assessment (overall confidence moderate): Most important EUNIS habitat types (Level 3) identified with score 3 and high confidence: A5.5 (Sublittoral macrophyte-dominated sediment) (also A2.6 (littoral sediments dominated by aquatic angiosperms), A5.2 (sublittoral sand) and A5.4 (circalittoral mixed sediments), but moderate confidence). Map validation via survey data only (no stakeholder feedback received), generally agreeing with habitat proxies where identified (whiting juvenile habitat widely distributed in inshore waters, with higher importance of coastal habitat closer to shore, bays and sea lochs, e.g. Loch Dunvegan, west of Skye, and Loch Carron, to the east).
Cod, *Gadus morhua* ('Running' adult, Spawning)	EFH model (adults at spawning or spent stages, Quarter 1): Overall confidence 41%. EFH predictors (decreasing importance): Depth, CUR, SSS, Dist, SBT, NPPV. Map validation via stakeholder feedback only, with discrepancies highlighted in integrated spatial output (model predictions confirmed in the northern North Sea and off the north coast of Scotland, but spawning aggregations observed in other areas of the North Sea, and particularly to the south, and cod spawning grounds in the English Channel and on the Trevose ground, off the north coast of Cornwall, poorly predicted by the model).
Cod, *Gadus morhua* (Juvenile, Nursery)	Habitat proxy assessment (overall confidence moderate): Most important EUNIS habitat types (Level 3) identified with score 3 and high confidence: A2.6 (littoral sediments dominated by aquatic angiosperms) and A5.5 (sublittoral macrophyte-dominated sediment) (also A5.6 (sublittoral biogenic reefs) and 3.1 (Atlantic and Mediterranean high energy infralittoral rock), but moderate confidence). Map validation via survey data only (no stakeholder feedback received), generally agreeing with habitat proxies where identified (habitat proxies confirmed in the south of the study area, in the Firth of Clyde, and in inner reaches (e.g. Loch Long, Loch Fyne), albeit with some spatial gaps in these inner areas due to lack of coverage by the EUNIS habitat data layers).

Species (life stage, EFH function)	Assessment results
Haddock, *Melanogrammus aeglefinus* ('Running' adult, Spawning)	EFH model (adults at spawning or spent stages, Quarter 1): Overall confidence 52%. EFH predictors (decreasing importance): Depth, Dist, WAV, CUR, SSS, NPPV. Map validation via stakeholder feedback only, generally agreeing with model predictions (spawning EFH in the central and northern North Sea and off the north coast of Scotland, and over most of the Celtic Seas).
Norway pout, *Trisopterus esmarkii* ('Running' adult, Spawning)	EFH model (adults at spawning or spent stages, Quarter 1): Overall confidence 45%. EFH predictors (decreasing importance): Depth, SBT, Substr, Dist, Slope, NPPV. Map validation via stakeholder feedback only, with discrepancies highlighted in integrated spatial output (model predictions confirmed in northern North Sea and off the north and west coast of Scotland, but aggregations in central North Sea are poorly predicted and spawning areas in the Celtic Seas are more widespread than predicted).
Blue whiting, *Micromesistius poutassou* (Juvenile, Nursery)	EFH model (0-group, 5 - 19 cm length, Quarters 3 and 4): Overall confidence 60%. EFH predictors (decreasing importance): Depth, WAV, CUR, Slope, SSS, MLT, Dist, NPPV. Map validation via additional data & stakeholder feedback, with discrepancies highlighted in integrated spatial output (model predictions of aggregations confirmed along the continental shelf edge west and north of the British Isles, with overlapping with known spawning migration routes in the northern Atlantic, but aggregations observed in areas further inshore along the west coast of Scotland poorly predicted, also because of spatial gaps inshore due to data limitations; distribution of juveniles in the area northeast of Shetland also possibly less wide than predicted).
Hake, *Merluccius merluccius* (Juvenile, Nursery)	EFH model (0-group, 4 - 19 cm length, Quarters 3 and 4): Overall confidence 41%. EFH predictors (decreasing importance): CUR, Depth, WAV, Slope, Substr, NPPV, Dist, SBT, MLT. Map validation via additional data & stakeholder feedback, with discrepancies highlighted in integrated spatial output (juvenile aggregations within the Hake Box and Celtic Seas likely more widespread than what predicted; the same applies to aggregations predicted in the northern North Sea and South Minch).

Species (life stage, EFH function)	Assessment results
Saithe, *Pollachius virens* (Juvenile, Nursery)	Habitat proxy assessment (overall confidence low): Most important EUNIS habitat types (Level 3) identified with score 3 and high confidence: A1.1 , A1.2 and A1.3 (high, moderate and low energy littoral rock, respectively) (also A3.1 and 3.2 (Atlantic and Mediterranean high and moderate energy infralittoral rock, respectively), but moderate confidence). Map validation via survey data only (no stakeholder feedback received), generally agreeing with habitat proxies where identified (e.g. in the Clyde, north of Islay, west of Mull, with habitat proxies also identified on the littoral rocky fringes along the Scottish coastline in the northern Irish Sea).
Sprat, *Sprattus sprattus* (Juvenile, Nursery)	EFH model (0-group, 2.5 - 9 cm length in Quarter 3, up to 9.5 cm in Quarter 4): Overall confidence 51%. EFH predictors (decreasing importance): Depth, SSS, MLT, SST, WAV, Dist, CUR, Substr, Slope. Map validation via additional data & stakeholder feedback, with discrepancies highlighted in integrated spatial output (model predictions confirm the predominant distribution of sprat nursery EFH in inshore coastal areas around the UK, and also in known specific nursery areas protected by seasonal management measures (Firth of Forth and Moray Firth); juvenile aggregations in inshore areas along the south-west coast of Ireland, in the Thames, English Channel, Bristol Channel, and Severn estuary poorly predicted, also because of spatial gaps in more inshore areas due to data limitations).
	Habitat proxy assessment (overall confidence moderate): Most important EUNIS habitat types (Level 3) identified with score 3 and high confidence: A7.3 and A7.8 (completely mixed and unstratified water column with full salinity, respectively). Map validation via survey data only (no stakeholder feedback received), generally agreeing with habitat proxies where identified (e.g. in the Firth of Clyde, in areas close to the shore along the west coast (Inner Hebrides), northwest of Coll and northeast of Lewis).

Species (life stage, EFH function)	Assessment results
Mackerel, *Scomber scombrus* (Juvenile, Nursery)	EFH model (0-group, 12 - 22 cm length in Quarter 4, up to 24 cm in Quarter 1): Overall confidence 29% (the lowest across species assessed, mainly due to poor model performance combined with the lower efficiency of bottom trawl surveys in sampling pelagic juvenile mackerel). EFH predictors (decreasing importance): MLT, CUR, WAV, Depth, Dist, SST, Slope, NPPV, SSS, Substr. Map validation via additional data & stakeholder feedback, with discrepancies highlighted in integrated spatial output (model predictions of aggregations confirmed off the west coast of Scotland and along the continental shelf edge north of Scotland; less accurate predictions in the norther North Sea and in the Celtic Seas, e.g. in the South West Mackerel Box).
Mackerel, *Scomber scombrus* (Egg, Spawning)	EFH model (eggs at early development stage (EG1), Quarters 2 and 3): Overall confidence 32% (mainly due to poor model performance). EFH predictors (decreasing importance): Depth, WAV, Dist, SSS, Substr, NPPV. Map validation via stakeholder feedback only, generally agreeing with model predictions (potential spawning EFH mostly along continental shelf edge to the west and north of the British Isles).
Thornback ray, *Raja clavata* (Spawning adult/Egg, Spawning)	Habitat proxy assessment (overall confidence low): Most important EUNIS habitat types (Level 3) identified with score 2 and low confidence: A5.1 and A5.2 (sublittoral coarse sediment and sand, respectively) . Map validation via survey data only (no stakeholder feedback received), generally agreeing with habitat proxies where identified (e.g. suitable habitat patches in the northern Minch and in the Clyde), although sparse occurrence of the species in the survey catches and limited spatial coverage of the surveys did not allow validation of all areas predicted by habitat proxies (e.g. west of Islay and along the coast of Northern Ireland, west of Tiree and in the North Atlantic west of Orkney).
Spotted ray, *Raja montagui* (Spawning adult/Egg, Spawning)	Habitat proxy assessment (overall confidence low): Most important EUNIS habitat types (Level 3) identified with score 2 and low confidence: A5.2 (sublittoral sand). Map validation via survey data only (no stakeholder feedback received), generally agreeing with habitat proxies where identified (e.g. north and west of Islay, west of Coll, south of Tiree, in the northern Minch, and at the entrance of the Clyde).

Species (life stage, EFH function)	Assessment results
Spurdog, *Squalus acanthias* (Neonate juvenile, Spawning)	Habitat proxy assessment (overall confidence low): Most important EUNIS habitat types (Level 3) identified with score 2 and low confidence: A5.3 (sublittoral mud). Map validation via survey data only (no stakeholder feedback received), generally agreeing with habitat proxies where identified (e.g. Loch Linnhe and the approaching areas south of Mull, south of Coull and upstream of Loch Linnhe, into Loch Eil).
Long finned squid, *Loligo forbesii* (Juvenile, Nursery)	EFH model (immature/recruits, 1 - 15 cm length, Quarters 3 and 4): Overall confidence 42%. EFH predictors (decreasing importance): Depth, WAV, Dist, SBT, SBT, CUR, Substr, SSS, Slope, NPPV. Map validation via additional data & stakeholder feedback, with discrepancies highlighted in integrated spatial output (model prediction of aggregations confirmed in Rockall area, southern North Sea and off the south Irish coast, and in front of the Firth of Forth, but aggregations off the Moray Firth, north of Scotland and Ireland, and generally in areas closer to the shore were poorly predicted, also because of spatial gaps in most inshore areas due to data limitations).
European lobster, *Homarus gammarus* (Juvenile, Nursery)	Habitat proxy assessment (overall confidence low): Most important EUNIS habitat types (Level 3) identified with score 2 and low confidence: A3.1, A3.2 and A3.3 (Atlantic and Mediterranean high, moderate and low energy infralittoral rock, respectively), and A5.1 and A5.3 (sublittoral coarse sediment and mud, respectively). No map validation (no survey data, nor stakeholder feedback received).
Brown crab, *Cancer pagurus* (Juvenile, Nursery)	Habitat proxy assessment (overall confidence low-moderate): Most important EUNIS habitat types (Level 3) identified with score 3 and high confidence: A1.4 (features of littoral rock, including rockpools, caves and overhangs) (also A4.2 (Atlantic & Mediterranean moderate energy circalittoral rock), but score 2 and moderate confidence). No map validation (no survey data, nor stakeholder feedback received).
Velvet crab, *Necora puber* (Any life stage, generic species' habitat)	Habitat proxy assessment (overall confidence moderate): Most important EUNIS habitat types (Level 3) identified with score 3 and moderate confidence: A3.2 (Atlantic and Mediterranean moderate energy infralittoral rock) (also A1.2 (Moderate energy littoral rock), but score 2 and moderate confidence). No map validation (no survey data, nor stakeholder feedback received). Most important habitat proxies occurred as small habitat patches along the coastal fringe.

Species (life stage, EFH function)	**Assessment results**
Common cockle, *Cerastoderma edule* (Any life stage, generic species' habitat)	Habitat proxy assessment (overall confidence high): Most important EUNIS habitat types (Level 3) identified with score 3 and high confidence: A2.2 and A2.4 (littoral sand and muddy sand, and littoral mixed sediments, respectively). No map validation (no survey data, nor stakeholder feedback received). Most important habitat proxies occurred as small habitat patches, mainly in the intertidal zone in more internal areas.
Dog cockle, *Glycymeris glycymeris* (Any life stage, generic species' habitat)	Habitat proxy assessment (overall confidence moderate-high): Most important EUNIS habitat types (Level 3) identified with score 3 and high confidence: A5.1 and A5.4 (sublittoral coarse sediment and sublittoral mixed sediments, respectively). No map validation (no survey data, nor stakeholder feedback received).
Razor clam, *Ensis ensis* (Any life stage, generic species' habitat)	Habitat proxy assessment (overall confidence high): Most important EUNIS habitat types (Level 3) identified with score 3 and high confidence: A5.2 (sublittoral sand). No map validation (no survey data, nor stakeholder feedback received).
Common whelk, *Buccinum undatum* (Any life stage, generic species' habitat)	Habitat proxy assessment (overall confidence moderate): Most important EUNIS habitat types (Level 3) identified with score 2 and moderate confidence: A5.1, A5.2 and A5.4 (sublittoral coarse sediment, sand, and mixed sediments, respectively). No map validation (no survey data, nor stakeholder feedback received).
Dog whelk, *Nucella lapillus* (Any life stage, generic species' habitat)	Habitat proxy assessment (overall confidence high): Most important EUNIS habitat types (Level 3) identified with score 3 and high confidence: A1.1 and A1.2 (high and moderate energy littoral rock) (and A1.3 (low energy littoral rock) and A1.4 (features of littoral rock), but with score 2 and high confidence). No map validation (no survey data, nor stakeholder feedback received). Most important habitat proxies occurred as small habitat patches along the coastal fringe.

Table footnotes: Codes in the table for the EFH model environmental predictors are: Depth, water depth; SBT, sea bottom temperature; SST, sea surface temperature; NPPV, net primary production; SSS, sea surface salinity; MLT, mixing layer thickness; Dist, distance from coast; CUR, current energy at the seabed; WAV, wave energy at the seabed; Slope; seabed slope; Substr, substratum type.

3.2 Implications of climate change

The predictions for the baseline environmental scenario (year 2015) and the scenario accounting for environmental change (based on changes, compared to the baseline, in seasonal SBT and/or Depth of magnitude consistent with climate change predictions) are shown for the selected models in Figure 78 to Figure 81.

The comparison between the baseline map and the one accounting for environmental change shows that major changes occur in the distribution of habitats where lesser sandeel and juvenile anglerfish are expected to aggregate (potentially indicative of their refuge and nursery grounds, respectively), whereas the spatial changes for *Nephrops* and juvenile plaice appear to be marginal.

The predicted change for lesser sandeel, following a change in winter sea bed temperature (SBT), shows a notable contraction of the areas where environmental conditions reflect those of sandeel grounds where the species was found in the surveys (2008-2020) used to calibrate the model (Figure 78). In fact, many of the areas where sandeel aggregations were predicted to occur with high probability under the baseline scenario around the coast of Scotland (including known sandeel grounds off the Firth of Forth, on Turbot Bank, or northwest of Orkney) appear to show environmental conditions that are no longer reflecting those of surveyed sandeel grounds under the SBT change scenario, and therefore are excluded from the model prediction (as grey areas). As a result, potentially suitable habitats for sandeel appear to be "squeezed" to small patches closer to the coast under the scenario of SBT change.

The predicted change for anglerfish, following a change in spring sea bed temperature, also indicates a contraction of the areas potentially suitable for aggregating juveniles of the species, with their disappearance from Rockall and along the coastal shelf margin to the west and north of Scotland (Figure 79). In turn, an expansion of areas potentially suitable as anglerfish nursery grounds is predicted in more inshore areas in the Minch and along the north coast of Scotland, and, to the east, in the northern North Sea and east of Shetland, albeit with lower (<0.75) probability of occurrence. Very small pockets of highly suitable habitats appear to remain only in few areas along the coastal shelf margin north and west of Shetland (Figure 79).

For *Nephrops*, the change in mean sea bed temperature across the summer, autumn and winter seasons, combined with the depth change inshore, only appear to lead to a marginal expansion of the areas potentially suitable for aggregations of the species, specifically resulting in additional small patches of habitat off the Moray Firth to become highly suitable under the changed conditions (Figure 80). A similar result is observed for juvenile plaice habitats in the same inshore area, as effected by depth change (Figure 81).

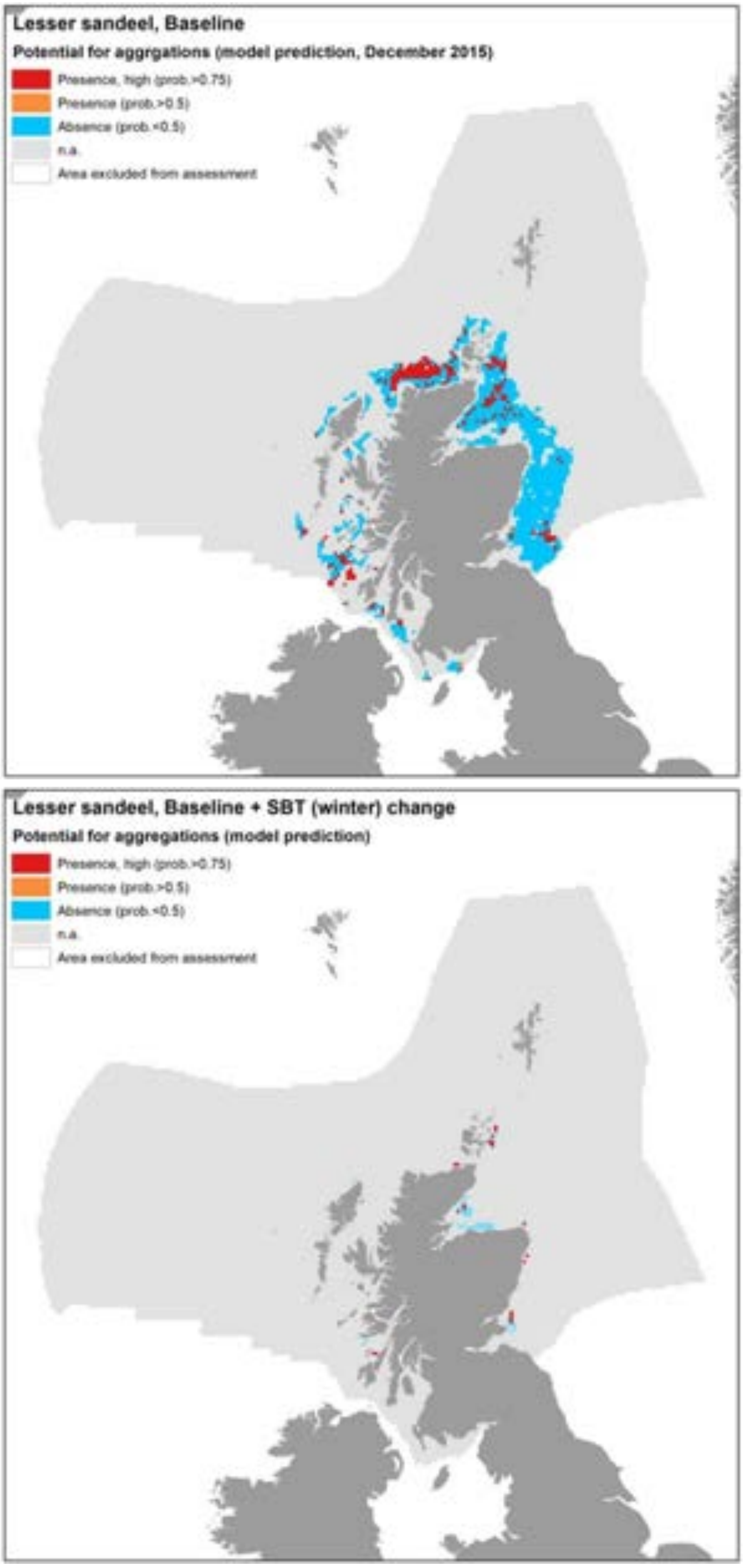


Figure 78. Aggregations of lesser sandeel, *Ammodytes marinus*: Model predictions based on environmental conditions in December 2015 (Baseline, top) and with applied sea bottom temperature (SBT) change as per UKCP09 projection for winter near bed temperature (bottom).

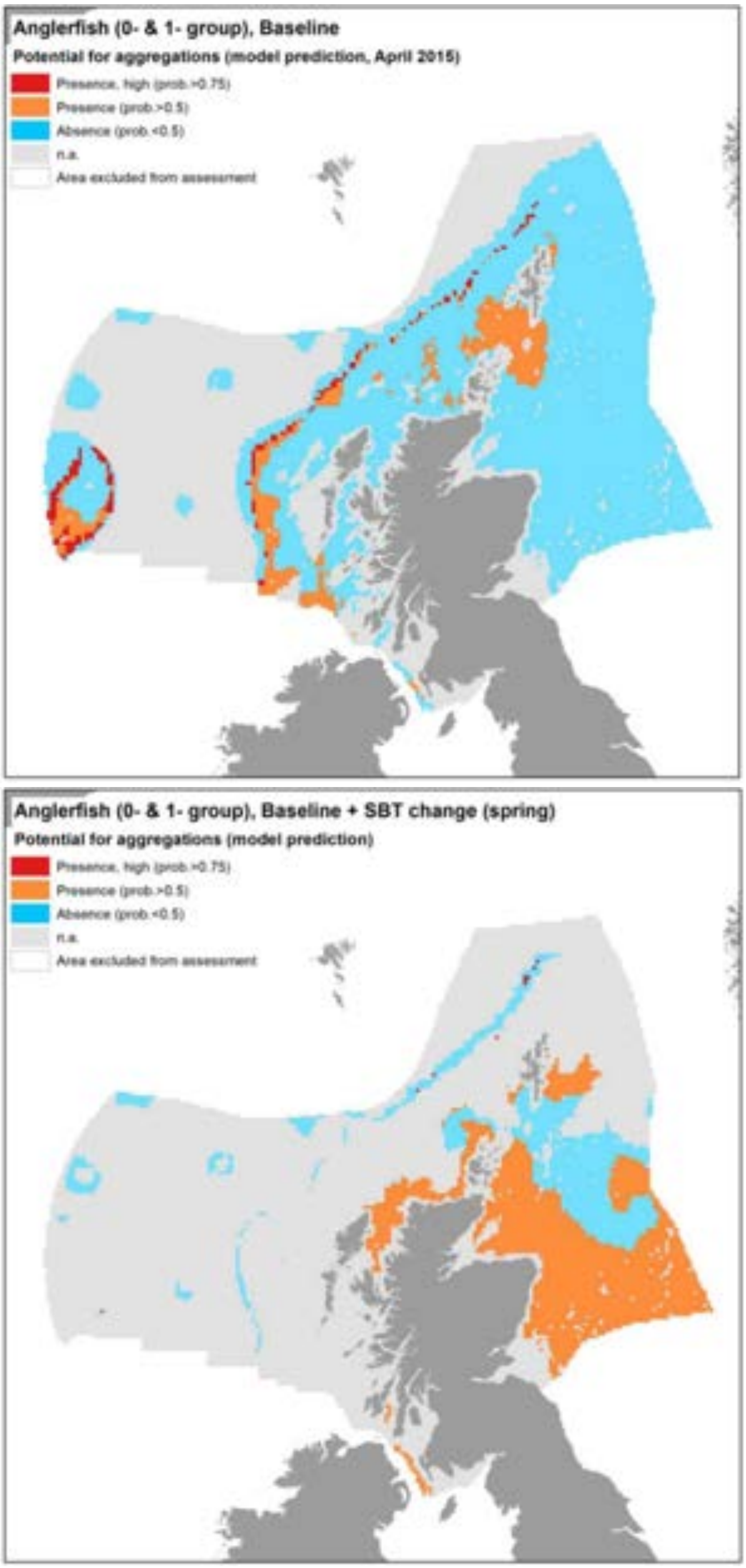


Figure 79. Aggregations of anglerfish juveniles (*Lophius piscatorius* 0- & 1-group): Model predictions based on environmental conditions in April 2015 (Baseline, top) and with applied sea bottom temperature (SBT) change as per UKCP09 projection for spring near bed temperature (bottom).

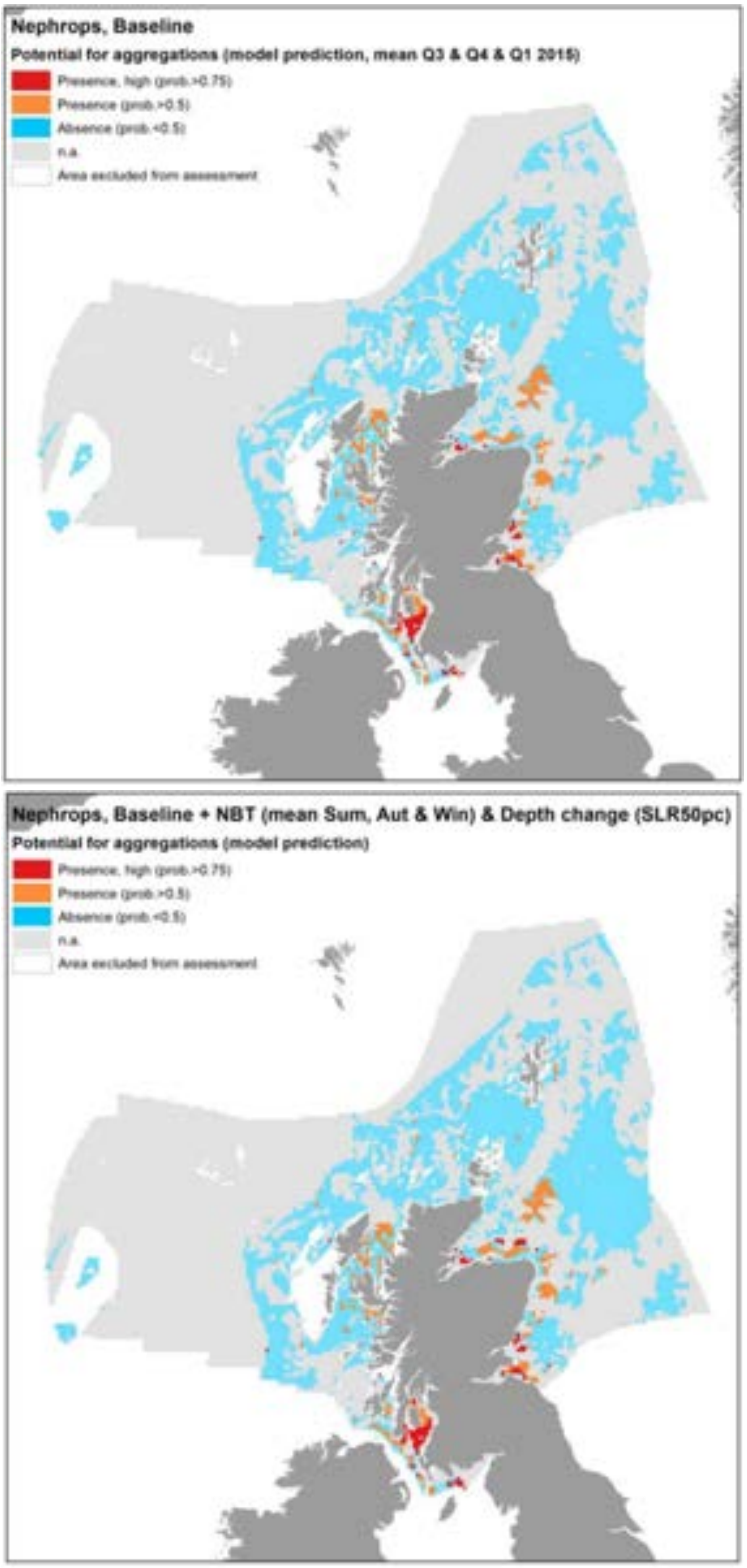


Figure 80. Aggregations of Norway lobster, *Nephrops norvegicus*: Model predictions based on environmental conditions in Q3, Q4 and Q1 2015 (Baseline, top) and with applied sea bottom temperature (SBT) and depth changes as per UKCP09 projection for near bed temperature (mean projection for summer, autumn and winter) and sea level rise (SLR50pc, medium probability) (bottom).

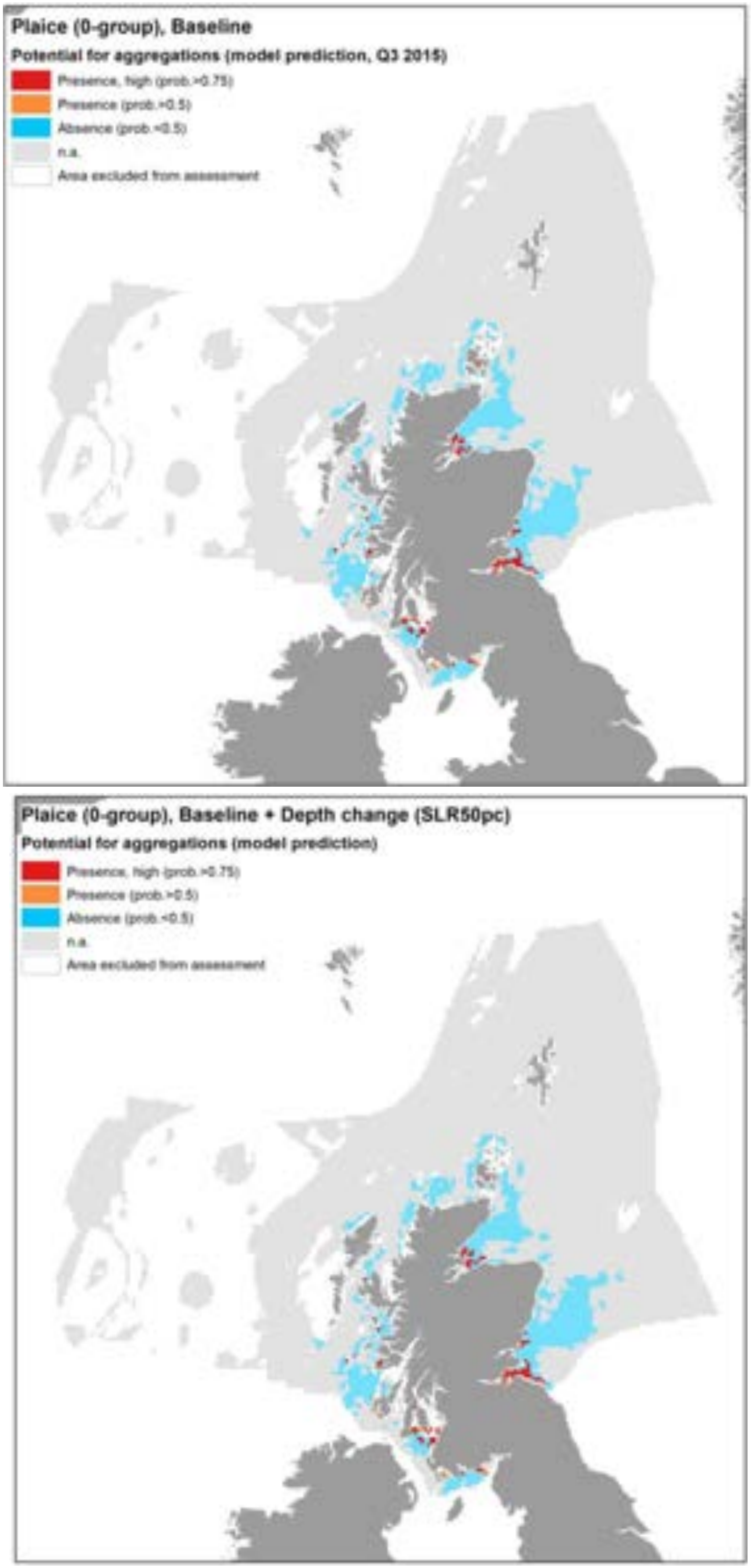


Figure 81. Aggregations of plaice juveniles (*Pleuronectes platessa* 0-group): Model predictions based on environmental conditions in Q3 2015 (Baseline, top) and with applied depth change as per UKCP09 projection for sea level rise (SLR50pc, medium probability) (bottom).

4. Discussion

This study developed the methodological framework and maps to identify potential essential fish habitats for 29 fish and shellfish species that are relevant to Scottish waters for their commercial or ecological importance (including 13 species that are designated as Priority Marine Features in Scotland's seas; NatureScot 2020). Where fish survey and environmental data were available, species distribution models were applied to map the potential EFH based on the distribution of aggregations of the species as a whole (for habitats used as refuge) or of their specific life stages (using juveniles to indicate nursery habitats, spawning adults or eggs for spawning grounds). For inshore areas, where suitable data were lacking, a habitat proxy approach was applied instead. This relied on literature review and expert input to quantify the importance of different inshore EUNIS habitat types in supporting the species during their life cycle, or at particular stages of it (e.g. juveniles, spawning adults, eggs).

Distribution mapping for several of the species considered in this study has been undertaken before, particularly for gadoids and flatfish of commercial interest and some elasmobranchs (e.g. Coull et al. 1998, Ellis et al. 2012, Aires et al. 2014, González-Irusta and Wright 2016a, 2016b, 2017, Franco et al. MMO 2013, 2016, AFBI 2021, Katara et al. 2021, Langton et al. 2021), and, recently, also for brown crab (Mesquita et al. 2021). The most recent of these studies adopted species distribution modelling to infer the spatial distribution of life stages of these species at a high spatial resolution and over decades based on environmental predictors. However, several of these applications did not cover Scottish waters (Franco et al. MMO 2013, 2016, AFBI 2021, Katara et al. 2021), or focused only on juveniles (Aires et al. 2014). In turn, less recent studies (Coull et al. 1998, Ellis et al. 2012) derived UK-wide maps directly plotting survey catch data, resulting in a snapshot of the observed distribution in a restricted period of time (e.g. in 2010 in Ellis et al. 2012) and at a low spatial resolution (ICES rectangle). The present study has expanded the high-resolution distribution mapping of these species into Scottish waters, and indeed with UK-wide coverage for several species. A high spatial resolution is a pre-requisite for such spatial products to be used as supporting tools for marine spatial planning hence to make decisions on siting of activities at sea (e.g. offshore wind farms). Furthermore, to our knowledge, this study is the first to provide habitat mapping for some shellfish species that were poorly covered in previous studies (e.g. long finned squid, European lobster, velvet crab, cockles, clams and whelks).

4.1 Weight of evidence assessment

Aires et al. (2014) suggested that the maps resulting from species distribution model predictions should be used as an additional tool to complement existing information, rather than replacing it. These authors also called for stakeholder input (particularly from the fishing industry) to complement the outputs. Both these aspects were addressed in the present study by applying a 'Weight of evidence assessment' approach and undertaking map validation through consultation of stakeholders, including the fishing industry.

The 'Weight of evidence assessment' approach (EFSA 2017) was used in this study to identify and locate habitats with particular functional roles (as refugia, nursery or spawning) for the studied species in the marine environment. This approach relies on integrating multiple lines of evidence from different sources to answer the question about the location of such habitats. Specifically, the maps developed and presented in this report integrated (i) evidence on the distribution of the species as directly observed in fish surveys, (ii) the potential distribution of their habitats as predicted through species distribution models (based on survey and environmental data) or habitat proxies (based on literature and expert knowledge), and (iii) expert assessment based on stakeholder validation.

Any individual line of evidence had its strengths and weaknesses:

i. Survey data alone provided an accurate representation of the actual distribution of a species at a certain point in time in most of the cases, but had limitations in their spatial and temporal coverage, or in their ability to represent certain species and/or life stages (depending on the survey method affecting catchability; e.g. *Nephrops*). For example, the International Bottom Trawl Survey data used in this study were widely distributed in UK waters, but with poor coverage of inshore waters, and poorer or no adequate representation of certain species (e.g. pelagic species, benthic shellfish). In turn, other surveys that extended further inshore were often restricted to smaller scale areas (Sandeel Dredge surveys, West Coast of Scotland Demersal Fish (WCDF) survey) and/or provided information on the species distribution for one year only (WCDF 2013/14).

ii. Predictions obtained from species distribution models or using habitat proxies allowed to extrapolate the distribution of the species even in areas where no direct observations are available, thus providing indication of areas that may be potentially used by a species or its life stages. This was based on suitability of the specific environmental or habitat characteristics considered in these assessments, but did not account for the species interactions with other factors that might also affect the actual use of the area, for example, natural biotic interactions such as competition or disease. These are seldom included in predictive models due to the difficulty in measuring these complex relationships, and may result in the overprediction of the species distribution (Velazco et al. 2020). Efforts to account for biotic factors were made in this study by including net primary productivity as a potential indirect predictor for food availability in the EFH models. However, other direct interactions with prey, predators or competitors which might also affect the distribution of a species could not be included, nor anthropogenic factors, which may also alter the natural environmental/habitat suitability of certain areas (e.g. through impacts on the seabed). Therefore, predictions obtained with these assessments were based on a simplified representation of the interactions of a species with the marine environment, with consequent limitations in the ability to accurately represent the species distribution. The confidence assessment undertaken for the EFH models and habitat proxies in this study provided an indication of the extent of such limitations, while also accounting for limitations in the evidence (data, literature, expert knowledge) supporting these predictions.

iii. Expert input from stakeholders provided a broader assessment of the species habitat distributions represented in the maps, but this line of evidence is also not exempt from potential biases, e.g. due to the specific expertise and experience of the individuals. Consultation with a high number of stakeholders with highly diverse expertise (e.g. on different species) would allow to reduce the effect of these biases, although this requires time (also depending on stakeholder availability), which was limited in a short-term study such as this one.

The spatial outputs provided in this report should be read considering the combination of all these lines of evidence to indicate the distribution of the species and their possible EFH. The confidence shown on the map is related to the model or habitat proxy assessment that led to the map predictions (line of evidence ii above). This confidence should be used as a baseline to guide consideration about the relative validity of the predicted results for different species (with more weight to be given to outputs with higher confidence, i.e. closer to 100%, as shown in Table 29 and Table 30). However, a higher overall confidence is associated with the final spatial product where the multiple lines of evidence were combined. In fact, the 'Weight of evidence assessment' approach allows for individual lines of evidence to partly compensate for each other's failings (e.g. the comparison with additional survey data and/or the expert input obtained from stakeholders during map validation allowed to identify areas where the EFH is known to occur but that were 'missed' by the EFH model prediction; see Table 31). This balances the biases of the individual lines of evidence considered, thus improving the overall confidence in the integrated output. The confidence is reinforced particularly where different lines of evidence converge towards the same result and no discrepancies were observed (EFSA 2017).

4.2 Operationalising the 'Essential fish habitat' concept

Essential fish habitats (EFH) are defined based on the function they perform for a species (spawning, nursery, etc.; U.S. Magnuson-Stevens Fishery Conservation and Management Act 1976). Such function is often associated with a specific life stage or phase of the life cycle of the species (e.g. juveniles for nursery), so that an EFH would be part of the area where that life stage occurs (as per conceptual representation in Figure 2). Whether a habitat for a given life stage can be identified as an EFH depends on whether the habitat is able to improve the condition of that life stage and thus giving an advantage (or added value) that other habitats are not able to provide (or provide to a lesser degree), with a resulting benefit for the population as a whole. For example, Beck et al. (2001) identified this advantage for nursery habitats as a greater contribution per unit area to the production of individuals that recruit into adult populations compared to other habitats where the juveniles were present (see difference between habitat B and C in Figure 2). This greater contribution can be realized through increased density of individuals in the habitat, improved or faster growth of the individuals and of the population (i.e. greater survival and lower mortality), increased biomass production, and increase of the rate of successful export of this biomass into the wider population.

The combination of all the factors mentioned above likely results in an 'added value' associated with an EFH compared to other habitats used by the species/life stage. However, data measuring some of these factors are not always easily obtained, and occurrence and abundance data available from wide-scaled, repeated monitoring programmes are used instead. This approach was adopted for the identification of habitats potentially providing key EFH functions through species distribution modelling in this study, whereby aggregations of juveniles, adults in spawning conditions or eggs were used as indicators of potential nursery or spawning grounds, respectively. For EFH functions that benefit multiple life stages of the population (e.g. refuge function or mixed functions provided by a habitat), aggregations of individuals irrespective of their life stage were considered. The assessment of aggregations (as opposed to considering the mere occurrence of a species or life stage) was assumed to provide an indication of habitat with potential added value for their ability to support higher densities, hence reflecting one of the elements characterizing EFH (*sensu* Beck et al. 2001).

Specific criteria (e.g. body size, seasonality, spawning condition) were applied to identify the life stages of interest, and therefore their aggregations for species distribution modelling, and the results (EFH models and maps) are therefore dependent on these choices. Standardisation of these criteria with previous assessments was undertaken, where possible, so that consistency and comparability was allowed. For example, 0-group individuals were identified as indicators of juvenile habitats potentially functioning as nursery for most species (e.g. as in Ellis et al. 2012, Aires et al. 2014), although in some cases 1-group fish were also included where the survey data for 0-group alone were insufficient. Aires et al. (2014) suggested this approach for saithe, for example, on the account that juveniles of this species use inshore nursery habitats until they are 2 - 3 years of age, thus allowing to expand the age group considered while still representing nursery areas. Similarly, common sole juveniles are known to spend 2 - 3 years in inshore nursery grounds before migrating offshore (Rijnsdorp et al. 1991, ICES 2012), and therefore 1-group individuals were also considered in this case. The size criterion used for anglerfish juveniles also led to the inclusion of some 1-group individuals in the analysis to compensate for the scarcity of catch data available for 0-group individuals only. This was done on the account that the species does not reach sexual maturity until 5 years of age at least (Laurenson et al. 2001).

Where the habitat proxy approach was applied for inshore waters, it would be incorrect to identify its results as EFH. In fact, this assessment only accounted for the association of the life stage (relevant to an EFH function) with the habitat as reported in the literature. The supporting evidence was often based on observations of occurrence, resulting in an indication of key habitat for the species (habitat B in Figure 2) rather than on abundance (hence aggregation) or other more detailed parameters (increased growth etc), which would have allowed an indication of EFH (habitat C in Figure 2), as it was done in the data-based EFH modelling approach. Therefore, the habitat proxies identified through this method may overestimate the distribution of a species (across the inshore habitats assessed at least), and its EFH is probably a subset of the mapped potential distribution (as outlined in Figure 2).

4.3 Important Data/Knowledge Gaps identified in the EFH Assessment

The collation of data and evidence in this study highlighted specific areas where gaps in the evidence available (data or knowledge) occurred and that need further work. A summary of the identified knowledge and data gaps is given in Table 30 and Table 31, respectively. It is highlighted that the relatively short time available to develop this project was a limiting factor to the extent of the literature review, data identification, collation and analysis that could be undertaken. This may have influenced the identification of knowledge/data gaps, and is taken into consideration in the discussion below, where additional evidence was known to exist but it could not be obtained within this project.

Table 30. Summary of knowledge gaps identified from literature review in this project and relevant to habitat proxy assessment for fish and shellfish species/life stages inshore.

Species	Knowledge gap
Sandy ray; common skate	No knowledge about habitat preferences of juvenile/spawning. Habitat proxy assessment could not be undertaken.
Thornback ray	Little knowledge of specific environmental preferences for egg-nurseries. Reduced confidence in habitat proxy assessment.
Sprat; common sole; spotted ray	Scarce knowledge and little detail about juvenile habitat preferences. Reduced confidence in habitat proxy assessment.
Spurdog	Scarce knowledge and little detail about parturition habitat preferences. Reduced confidence in habitat proxy assessment.
Saithe; cod; whiting; European lobster; brown crab; velvet crab	Little detail about juvenile habitat preferences (often limited to depth). Reduced confidence in habitat proxy assessment.

Table 31. Summary of data gaps identified in this project.

Feature	Data gap in project	Possible additional data sources
Shellfish, offshore: queen and king scallop; surf clam (+ possibly dog cockle, common whelk)	No offshore shellfish survey data obtained. EFH models could not be calibrated.	• MS scallop dredge surveys (Scotland)[(1)]. • Other additional data sources not known[(2)]. Possible need for further monitoring for species/geographic areas not represented by dredge survey data.
Shellfish, inshore: European lobster (juvenile); brown crab (juvenile); velvet crab; razor clam; common and dog cockle; common and dog whelk.	No inshore shellfish survey data obtained. Habitat proxy maps could not be validated. EFH models could not be calibrated inshore (see also data gaps for environmental layers inshore)	• UHI Shellfish Stock Assessment Programme (Shetland, since 2000; relevant to crabs and common whelk). • SAMS/MS razor clam surveys (electrofishing with towed video; Firth of Clyde). • Offshore wind industry crustacean monitoring for impact assessment (accessibility to be ascertained on a case-by-case basis). • Other additional data sources not known. Possible need for further monitoring for species/geographic areas not represented by the survey data above.
Fish, inshore: juvenile stages of common sole, plaice, cod, whiting, saithe, Norway pout, anglerfish, sprat, skates, rays, spurdog (parturition grounds) (also juvenile long finned squid)	No inshore survey data obtained. EFH models could not be calibrated inshore (see also data gaps for environmental layers inshore)	• WFD fish monitoring programme for transitional and coastal waters (since 2000, at least; EA data for England and Wales readily available from online database; accessibility of SEPA data for Scotland to be checked). • Other additional data sources not known, but possibly from multiple local research/ inshore monitoring studies. Possible need for further monitoring for species/geographic areas not represented by the survey data above.

Feature	Data gap in project	Possible additional data sources
Environmental and EUNIS habitat data layers, inshore	Reduced spatial coverage in more inshore areas (e.g. sea lochs, areas closer to shore) by environmental and habitat data layers. Resulting in spatial gaps in habitat proxy maps, and limiting ability of calibrating EFH models from inshore survey data.	• Additional data sources not known, but possibly from multiple local inshore environmental/habitat monitoring studies. Possible need for further environmental/habitat monitoring for geographic areas of interest where gaps persist.

Table footnotes: (1) Scallop dredge survey data may also provide suitable data on juvenile stages of anglerfish and thornback ray, to integrate/calibrate EFH models for these species/life stages. (2) The use of VMS data was suggested to identify boundaries of fishing grounds, but these data would not provide sufficient information (e.g. on species CPUE to identify aggregations) or at the required resolution (higher than the broad scale area) needed for the EFH modelling. However, these data could be used for map validation of EFH model map for shellfish, should these be developed in the future.

Lack of or poor ecological knowledge on specific habitat preferences existed in the literature for some species (Table 30). This gap was particularly relevant for skates and sandy ray as it did not allow the assessment of habitat proxies for their inshore habitats, whereas it led to a reduction of the overall confidence in the assessment of other species (Table 32). This is a notable knowledge gap, also considering that most of these species are of commercial relevance as food products (e.g. lobster, crabs, cod, whiting) or of conservation importance (e.g. endangered/critical state of ray and skates as per IUCN red list). As mentioned above, the literature review was by no means exhaustive, but sufficient evidence could be obtained for several other species, suggesting this reflects a real knowledge gap that should be addressed through further targeted research so that more can be learned about these species' habitats (with particular regard for the life stages mentioned in Table 32). Furthering knowledge on these species would make it easier to predict their key habitats with higher confidence and, if needed, this would then enhance efficacy of protection efforts and marine spatial planning.

There was also a clear gap in data availability for shellfish, with the exception of Norway lobster and the squid species considered in this study (Table 33). No survey data could be obtained for European lobster, brown crab, velvet crab, queen and king scallops, common and dog cockles, surf and razor clams, and common and dog whelks. This led to the inability to calibrate data-based EFH models for these shellfish species, or to validate the habitat proxy maps developed for inshore habitats used by some of these species (Table 33). It is of note that several of the shellfish species considered here have their main habitats inshore, in some cases restricted to the intertidal fringe (e.g. common cockle and dog whelk).

Therefore, existing surveys for these species are likely to be small scale (compared to the wider fish survey offshore) and/or short term.

Some data sources were identified in the project, but the data could not be obtained within the available timescale. For example, Marine Scotland Science regularly undertakes scallop dredge surveys that may provide suitable data for the calibration of EFH models for scallops and other shellfish occurring offshore (Table 33). Stakeholders have also indicated the potential use of these surveys to provide data on juvenile anglerfish and juvenile thornback ray. Surveys for razor clam have been recently undertaken along the Ayr coast, in the Firth of Clyde to test a new sampling method (Fox et al. 2019), and a Shellfish Stock Assessment Programme (Shetland UHI 2022) has been undertaken by the North Atlantic Fisheries College, University of the Highlands and Islands since 2000, involving inshore sampling in the Shetland targeting in particular velvet crab, brown crab and common whelk. The private sector is also a possible source for shellfish data. For example, crustacean monitoring is often undertaken by the offshore energy industry to assess impacts on lobster and crab stocks (e.g. Roach et al. 2018). If they can be accessed, these data (particularly from control/unimpacted areas) may be used to develop EFH models for lobster and crab species (particularly where the data include information on juvenile catches). In any case, individual local surveys alone would provide limited evidence on the wider distribution and general habitat preferences of the species, and the combination of evidence from multiple surveys (possibly with cumulative wide geographical distribution) would be needed to calibrate EFH models that have wider applicability. Such data gathering requires more time and effort to identify and source the data, where these can be made available.

Limited data from inshore fish surveys could be obtained for this project. Although they were used for the validation of some of the habitat proxy outputs, they could not enough to calibrate EFH models, due to the limited representativity of these data[21] (covering one year of survey on the west coast of Scotland only). The collation of additional inshore fish survey data could allow the EFH modelling of inshore habitats for fish species, and further validation of the habitat proxy mapping around the Scottish (and UK-wide) coastline. A potential useful source of data in this case would be from the fish monitoring of transitional and coastal waters that environment protection agencies around the UK have undertaken since 2000 to comply with the Water Framework Directive. While these data are publicly available from the online database held by the Environment Agency for English and Welsh estuaries (WFD TraC fish count data, Environment Agency 2021), the survey data for the Scottish TraC waters are currently unavailable due to a hacking event on SEPA IT in 2021. Therefore, these data could not be obtained in this study, and further efforts could be made once the problem is resolved.

Limitations in the spatial coverage of inshore areas by environmental data layers might still reduce the ability of calibrating species distribution models for fish and shellfish species

[21] The WCDF data also became available later in the project, and could not be included in the EFH modelling (e.g. to integrate the other data available for the EFH models calibrated in the project).

inshore. Maps for the water quality variables used in the models (e.g. sea temperature, salinity) are obtained from the application of broad scale, oceanographic models which do not provide reliable data for marine areas closer to shore and internal waters (e.g. sea lochs), where land influences occur with higher spatial and temporal variability. Spatial gaps were also observed in the EUNIS habitat data layers used for the habitat proxy assessment, particularly in internal areas (e.g. sea lochs) that may be used as EFH by some species (e.g. cod). Environmental/habitat surveys targeting these most inshore areas where data are lacking could help filling these gaps.

4.4 EFH model outputs

Where the data allowed it, species distribution models were applied for the UK-wide mapping of the potential important habitats for fish and shellfish species, as inferred from the environmental suitability for aggregations of relevant life stages. The nature and distribution of the fish survey data used to calibrate the EFH models affected the spatial coverage of the mapped predictions (as the EFH model predictions were considered to be valid only within the environmental ranges represented in the survey data that were used to calibrate the model) as well as the overall confidence in the resulting model.

Most of the predicted maps for fish and shellfish EFH models are based on bottom trawl and beam trawl data had poor coverage of most inshore areas, partly due also to the lack of coverage of these areas by environmental data layers (e.g. for variables obtained from oceanographic models). This was an issue in particular for the mapping of plaice, common sole, sprat, whiting and long finned squid, for which nursery habitats are known to occur closer to shore. The limited distribution of the collated survey data in inshore nursery areas, hence their limited ability to fully represent these primary nursery habitats, also likely contributed to the relatively low confidence of some of these EFH models (e.g. whiting and squid). For the same reason, a model for juvenile cod could not be calibrated due to insufficient data, and therefore the collation of additional survey data from inshore areas would also benefit the modelling of this species.

In turn, survey data for *Ammodytes marinus* were restricted to sandeel grounds located on sand and coarse sediments relatively inshore (<66 km from the shore, at depth <100 m) off the east coast of Scotland. The resulting map provided limited spatial coverage, as it did not allow predictions for offshore sandbanks that might function as sandeel EFH (e.g. Dogger Bank and North Norfolk sandbanks; Van der Kooij et al. 2008, Langton et al. 2021). Expanding the survey database for the sandeel EFH models (e.g. with data from sandeel habitats on the west coast of Scotland and in NC MPAs, on Dogger bank and Norfolk sandbanks) would allow the validity of these model predictions to be extended to wider environmental ranges (over space and, likely, time), thus improving the geographical coverage in the maps. This would also likely increase the overall confidence of the sandeel EFH model predictions, as the spatial (and temporal) coverage of the surveys was one of the elements considered to assess confidence in the survey data.

Including survey data from targeted surveys for individual species was also a way to improve the EFH model overall confidence, as this also accounted for the assessment of the survey data used in the model. In fact, a higher catch efficiency of the survey method is expected from surveys targeting individual species (e.g. sandeel dredge survey, anglerfish surveys), compared to other broader-target surveys (although a trade-off could occur with spatial coverage, as observed for the sandeel surveys), thus contributing to a higher confidence in the survey data. For *Nephrops*, broad scale bottom trawl surveys were used to predict aggregations of individuals as a proxy for areas with higher density of burrows, hence with an added value as refuge habitats. Although bottom trawling is a common fishing method for the species, the emergence of individuals from the burrows (to feed or mate) may be unpredictable and therefore bottom trawl catch data may not be optimal for an accurate assessment of *Nephrops*' burrow distribution. Direct observations of burrow density are available from TV video surveys undertaken by Marine Scotland Science (ongoing since 2007). Such data (for the period 2007-2016 only) were obtained for the present study, but could not be included in the EFH modelling (due to timing issues) and were only used for map validation. Inclusion of these surveys in the database for the EFH model (as aggregations of burrows), along with the assessment of aggregations at the stock level (as suggested in stakeholder feedback), would likely lead to better model predictions with higher associated confidence.

The environmental data used to calibrate the EFH models included both persistent and non-persistent (i.e. temporally variant) variables. The latter (obtained from data layers for water temperature, salinity, water column mixing and net primary production) were specifically included to allow the EFH model to capture temporal as well as spatial dynamics in the distribution of the species. The incorporation of non-persistent data is an essential element to allow predictions under temporally variable environmental scenarios, including for example climate change (see Annex 4). Almost all EFH models that were calibrated were dynamic tools that included at least one non-persistent environmental predictor (the only exception was the EFH model whiting juveniles which only included persistent variables as predictors of the aggregations of this species). However, mapped predictions are a static representation of the EFH model applied to a specific environmental scenario, and the choice of the latter may affect the resulting spatial outputs and their accuracy in representing the species distribution. This was evident for the EFH model maps developed in this study, for which the underpinning environmental scenario was based on the average conditions over the studied period 2010 - 2020 (for the season relevant to the specific life stage). As such, the maps were not able to fully represent the temporal variations (between years and even within a season) in species distribution or persistence at given sites.

Some of the inaccuracies highlighted by the stakeholder validation in the mapped EFH model predictions could be ascribed to the average environmental scenario used rather than to a failing of the model predictive ability. This was clear, for example, for maps for lesser sandeel and anglerfish, two of the top-ranking EFH models in terms of model statistical performance and overall model confidence. The comparison of these with maps predicted on more accurate temporal scenarios (for individual years) showed a better correspondence with the data and expert knowledge on map validation. Therefore, this possible limitation in the static map (but not in the dynamic model) should be taken into consideration when using the maps. As this does not affect the validity of the EFH model themselves, but rather of the mapped predictions, the EFH models can be applied to a specific scenario of interest (e.g. to ascertain potential distribution of the EFH in a certain year or under specific environmental conditions) to obtain a more accurate predicted map (see Annex 2 for guidance on how this can be easily done, without the need for specific statistical knowledge or tools other than the EFH model decision tree diagram). In turn, the more general maps shown in this report could be improved to better capture the temporal variability and site persistence in the species distribution by applying the EFH model to multiple temporal environmental scenarios (e.g. environmental conditions in different years) and then combining the resulting spatial predictions (e.g. by average, frequency of results). This was not possible within the short timescale of this study. A similar approach has been used for example by Katara et al. (2021).

4.5 Habitat proxies

The use of habitat proxies facilitated the development of indicative maps in inshore waters where data was lacking to develop EFH models. Habitat proxies were applied to species for which essential habitats occur mostly inshore. These habitat proxy assessments carried variable confidence, depending on the amount and detail of the supporting evidence and expert knowledge. Higher confidence was generally associated with the assessment of species that had clear and very specific habitat preferences (e.g. sandeel, herring, cockles), as opposed to species for which there was poor knowledge (e.g. elasmobranchs) or for which habitat characterisation was more generic. A more generic habitat characterisation could possibly reflect more generalist habitat preferences, or just the poor detail in the characterisation of the habitat for these species, which often did not allow to discriminate suitability at the higher habitat resolution (EUNIS habitats Level 4) (e.g. cod, whiting).

In the case study area mapped for habitat proxies (west coast of Scotland), available survey data showed that higher abundance of juveniles (mostly 0-group individuals, with 1-group also considered for some species as described for the EFH models) in the catches appeared to often correspond with areas on or in near proximity to areas predicted as potentially suitable for the species. Considering that fish juveniles are mobile, and therefore may also be detected in trawl surveys near their preferred habitat, these results were considered as a fair validation of the habitat maps. However, some species (elasmobranchs and saithe) were poorly represented in the fish survey catches, and, with these data being from surveys undertaken over one year only (2013/14), little information could be obtained about persistence of use of the observed areas. No survey data could be obtained for benthic shellfish (European lobster, brown crab, velvet crab, queen and king scallops, common and dog cockles, surf and razor clams, and common and dog whelks) for the map validation. Gathering further survey data from inshore surveys (for fish and shellfish) in the study area would improve validation of the habitat proxy maps produced here. Also, additional stakeholder consultation of these maps would be beneficial to further validate the habitat maps providing an additional line of evidence.

Similar to the EFH model maps, the use of habitat proxies provided an indication of areas that may be potentially suitable for functional use by the species/life stages, and which likely include EFH for the species (see sections 2.3.1 and 4.2). However, factors other than the habitat type may also influence the actual functional use of the habitat by a species, including for example other abiotic conditions not accounted for in the habitat type classification (e.g. water temperature), biotic interactions or anthropogenic impacts. As a result, it is possible that the suitable functional habitats in the maps may overestimate the extent of habitats used by the species (at least within the range of inshore habitats that were assessed in this study). Improving the map validation via comparison with additional survey data and expert knowledge would confirm if and where habitats of a species may be over predicted. In fact, habitat proxies identify suitable functional habitat areas that may be more extensive than the actual EFH, and this may be indicated by areas where the functional habitat is identified by habitat proxies but for which there is no evidence from survey data on the presence of aggregations of the species/life stage.

As observed for the EFH model maps, the choice of the mapped environmental layers (EUNIS habitat data in this case) to spatially predict the results of the assessment (as per habitat proxy matrix in this case) had also an influence on the spatial output. The assessment of habitat proxies for the fish and shellfish species was focused on inshore habitats, and this led to the *a priori* exclusion of deep circalittoral habitats (e.g. EUNIS sedimentary habitats A5.15, A5.27, A5.37), which were often identified as “offshore (deep) circalittoral habitats” of habitats “in the offshore circalittoral zone” in the EUNIS habitat descriptions[22]. On mapping the habitat proxies in the case study area, it became apparent that these EUNIS habitats may occur close to the shore. A choice was made to prioritise mapping at the higher resolution, both spatial and in terms of habitat classification (EUNIS Level 4), so to provide a more accurate spatial representation of the habitat proxy assessment as undertaken via the matrix tool. However, this resulted in spatial gaps in the maps for the non-assessed habitats (along with assessed habitats that could not be scored due to lack of supporting evidence of use). The habitat proxy maps could have been drawn by only considering Level 3 habitats (including all the possible sub-habitats within) and their respective scoring in the assessment matrix. However, this would have likely led to an overestimation of the spatial distribution and suitability of the habitats for a species. This could have resulted in the score allocated to the EUNIS Level 3 habitat also attributed to areas in the map where, at the finer resolution (Level 4), parent habitats that were scored lower, were not scored (due to lack of evidence) or were not included in the assessment

[22] https://eunis.eea.europa.eu/habitats.jsp

(deeper habitats) occurred. This was not considered suitable for the purpose of the maps in supporting marine spatial planning, and therefore, a higher accuracy and resolution of the spatial products was favoured, despite the gaps. These gaps could be filled by integrating the assessment with additional consideration of the excluded deeper habitats. Whether a score could be allocated to these additional habitats would depend on the re-examination of the available literature to determine whether there is evidence of their use or on expert input from stakeholders.

Within the time allowed in the project, mapping of habitat proxies was only undertaken for the case study area on the west coast of Scotland as an example of the spatial implementation of the assessment. However, the assessment undertaken in this study (as per habitat proxy matrix) has a wider validity and was spatially applied to EUNIS data layers available at the appropriate habitat level (Levels 3 and 4) in UK waters. Therefore, the spatial implementation of the assessment can be extended to the whole of inshore Scottish waters (or indeed to the whole of the UK coastline, if desired) for a more comprehensive mapping. However, considering the small scale of the suitable habitat areas for certain species, a combination of finer scale maps for different case study areas as opposed to a single map for the whole extent of Scottish inshore waters would be preferable to better represent the results of the habitat proxy assessment.

Whichever spatial implementation is applied, the confidence associated with the habitat proxy assessment (matrix) should be always considered as an integral part of the assessment to weight the results being considered for a species. However, for the spatial implementation of the habitat proxies, the variable confidence in the EUNIS habitat data used as base layers should also be considered. In fact, EUNIS habitat data layers are available at different spatial resolution, with a trade-off existing between this and the spatial coverage and confidence. More resolved EUNIS layers are available from habitat surveys (from different years and locations), thus providing a direct assessment of the habitat distribution with higher confidence, albeit often covering smaller areas. In turn, broadscale EUNIS layers are interpolated from models, hence carrying a lower confidence compared to direct observations, but allowing coverage of wider areas. Both types of data layers were used for habitat proxy mapping, although, where available, data from most recent surveys were prioritised over broadscale habitats predicted for the same locations. This was considered a good compromise between resolution, confidence and coverage of the resulting spatial implementation. Where a different selection of the base EUNIS habitat maps is made (e.g. use of broadscale data layers only to increase spatial coverage), the loss in spatial resolution and confidence should be considered.

4.6 Potential implications of climate change

Different species may respond differently to environmental change, depending on their environmental tolerance, preferences and optima. Changes in the abiotic conditions of the marine environment may also affect species indirectly, e.g. by influencing other biota with which the species interact (e.g. through prey-predator, competitor, host-parasites relationships) or biota which provide other benefits to the species (e.g. habitat structuring species such as aquatic vegetation or biogenic reef). The variability in the species response was confirmed by the predictions for their potential distribution under environmental change (namely sea bottom temperature and/or depth), where major changes were predicted for lesser sandeel and anglerfish, whereas the changes in the distribution of *Nephrops* and juvenile plaice were marginal. In addition, while the changes for juvenile anglerfish suggested a redistribution of areas potentially suitable as nursery grounds towards more inshore waters and the northern North Sea, a notable loss of potentially suitable areas for sandeel was predicted under the scenario of environmental change.

It is emphasised that the observed predictions tested in this document under the environmental change scenario should by no means be considered as accurate projections of the distribution of the species' suitable habitats in the next 100 years under climate change effects. Rather, they should be read as an indication of the potential sensitivity of the relative distribution of essential fish habitats to some environmental changes of similar magnitude and direction as those predicted with climate change conditions. There are different reasons for this. First, the changes applied to sea bottom temperature and water depth inshore (following sea level rise) were derived starting from a different temporal baseline (year 2015) than in the UKCP09 projections (years 1975 and 1985, respectively). In addition, the scenarios of environmental change applied here only account for change in either sea bottom temperature and/or water depth, while there are other environmental variables that might vary with climate change and that are important predictors in the EFH models considered.

Salinity, for example, is one factor that contributed in predicting the distribution of all the species/ life stages considered in this annex, as well as of several other species that were modelled in the study (e.g. juvenile sprat and common sole, spawning cod and whiting, mackerel eggs; see main report). In addition, the assessment of habitat proxies for the distribution of species /life stages inshore as applied in this study often identified a variety of habitat types at reduced or variable salinity as potentially highly suitable, for example for the small sandeel *A. tobianus*, spawning herring, and juvenile common sole, cod, whiting and sprat (see results for these species in section 3). While the marine projections for salinity under climate change suggest a minor decrease (by 0.2 salinity units) across the entire northeast Atlantic and the North Sea, it is acknowledged that they mainly reflect wide scale changes in the ocean rather than the local effect of rivers (Marine Scotland 2017a, Strong et al. 2017). At the local scale, inshore, the latter effect on salinity might become predominant (e.g. in estuaries and firths). Projected climate changes for the 21st century predict wetter winters, with a 25% increase in river flows, and drier summers, with a 40-80% decrease in the mean flow particularly in upland western regions of the UK (Strong et al. 2017). This has the potential to lead to alteration of the balance between marine and fresh waters in estuarine systems. Sea level rise may also contribute to affecting saline intrusion in estuaries: a SLR of 1 m has been predicted to increase saline intrusion length by >7 % in deep estuaries and >25 % in estuaries shallower than 10 m (Prandle and Lane 2015). Past climate-induced shifts in estuarine hydrological and salinity conditions were identified as the main factor responsible for changes in the abundance of fish species using some estuarine systems as nursery ground (Pasquaud et al. 2012, Chaalali et al. 2013). For marine species such as those mentioned above, able to use habitats at reduced or variable salinity, a climate-induced variability in the saline intrusion into the estuaries might lead to marked changes in the extent of estuarine habitats suitable for use by these species, also depending on the seasonality of the life stages using these habitats (e.g. juvenile fish use often peaking in the spring-summer). For example, an increased use of the Gironde Estuary (France) by sprat was observed during past events of increased intrusion of marine waters as a consequence of a decreased river discharge and river runoff, while opposite trends were observed for the estuarine flatfish flounder (*Platichthys flesus*) and catadromous species such as smelt (*Osmerus eperlanus*) (Pronier and Rochard 1998, Pasquaud et al. 2012, Chaalali et al. 2013).

Climate-induced changes may also lead to spatially variable alterations of the water column mixing, hydrographic circulation and wave height (likely to affect current and wave energy and their distribution) (Strong et al. 2017). These were often important predictors for the species/life stages considered here and for others of the species modelled in this study. The energy of the environment (as accounted by waves and currents) is also one of the factors determining the EUNIS habitat classification, and therefore changes in current and wave energy conditions might affect the habitat distribution in inshore areas, hence their use y fish and shellfish. For example, predicted decreasing trends in wave height (–0.3 cm yr^{-1}) north of Scotland (Strong et al. 2017) might reduce, in the long term, the energy of high-moderate energy habitats that have been identified as highly suitable for example for use by juvenile saithe, dog whelk (see results of habitat proxy assessment for these species in section 3), thus potentially altering their suitability for these species.

In turn, on the intertidal zone, sea level rise is likely to enhance wave and tidal energy (due to increased water depth), thus likely affecting sediment processes (erosion, deposition, transport) (Strong et al. 2017). Through sea level rise, climate change has the potential to modify the estuarine and coastal topography thus further altering the availability, configuration, and location of habitats (Taylor et al. 2004, Fujii and Raffaelli 2008, Masselink and Russell 2013). Effects are expected to be particularly marked where the habitat high water mark is residing against a hard defence structure such as a sea wall, which would prevent the shore to naturally retreat, leading, eventually, to the loss of the intertidal sediment through ‘coastal squeeze’ (Pontee 2013). Similarly, the area cover of intertidal rocky shores is likely to decline with sea level rise (Robins et al. 2016). While the EFH models in this study provide only partial coverage of inshore waters, the habitat proxy assessment identified the importance of shallow nearshore habitats for several fish and shellfish species, with intertidal (littoral) habitats being often indicated as highly or moderately suitable, for example, for juveniles of saithe, common sole, plaice, cod and whiting, and for common cockle and dog whelk (see results of habitat proxy assessment for these species in section 3). The loss of intertidal habitats (including tidal flats and saltmarshes) resulting from cumulative impacts of a range of anthropogenic pressures is already considered an extreme pressure in estuarine areas (Colclough et al. 2010), and has been suggested to reduce the attractiveness of these systems for fish use (Amorim et al. 2017). Climate-induced changes might locally exacerbate such loss of intertidal habitats, reducing their availability to fish and shellfish, with possible bottleneck effects on the size and productivity populations (e.g. where habitat loss reduces availability of estuarine nursery habitats, Pörtner and Peck 2010).

While the potential effects on the availability and distribution of important habitats for fish and shellfish has been discussed above considering some of the environmental factors of change individually, these may interact with each other and with other abiotic and biotic variability, as well as with local anthropogenic pressures, affecting the habitat use by fish and shellfish. For example, effects on wind intensity and patterns, and ocean circulations will have the potential to affect the connectivity between estuarine and marine habitats, through effects on the larval transport from spawning to nursery grounds. Also, increased residence times in transitional waters would likely reduce the dilution of dissolved nutrients and pollutants and increase the time to flush then from the system (Struyf et al. 2004), thus possibly affecting the habitat quality (e.g. through increased risk and frequency of algal blooms and consequent low oxygen conditions, greater exposure to pollutants; Graham and Harrod 2009), hence its suitability and use.

4.7 Conclusions and recommendations

The recommendations about using and improving the assessment tools and associated maps developed in this report are outlined in Table 32, with additional details and conclusions provided summarised in the text below

Table 32. Final recommendations.

Recommendations towards:	
A. Use of the overall (integrated) spatial outputs produced in this project:	
	• Spatial outputs to be read in their entirety, i.e. including all lines of evidence.
	• Spatial outputs to be used in combination with results from previous mapping studies (as additional line of evidence).
	• Ground truthing recommended where spatial outputs are used for project-level assessments.
B. Improvement of the overall (integrated) spatial outputs produced in this project:	
	• Further stakeholder validation (esp. for maps not validated, but also for the others as validation was limited by time available in the project).

	• Further collection of additional survey data for map validation, including more years and wider areas, and especially for species for which no survey data were available in the project.
	• Expand habitat proxy mapping to Scotland/UK-wide inshore areas (as multiple small scale maps, for better visibility of inshore habitat proxies).
C. Improvement of EFH models and their prediction maps:	
	• Expand survey database on which models are calibrated to
	(i) Improve predictive ability and overall confidence of EFH models:
	- Lesser sandeel (*A. marinus*): include survey data with wider spatial coverage (e.g. offshore, UK-wide).
	- *Nephrops*: include data from Nephrops TV surveys (burrow density).
	- Anglerfish (juveniles): explore MS scallop dredge surveys and IBTS surveys for additional data inclusion.
	- All models: expanding time series considered, hence increasing dataset size and environmental range covered can improve confidence.
	(ii) Extend geographical/species coverage of EFH models:
	- Offshore/Scallops, surf clam, and possibly thornback ray juveniles, dog cockle and common whelk: collate and explore MS scallop dredge surveys for additional EFH models.
	- Offshore/Lobster and crabs: explore accessibility of offshore wind industry data sources on crustacean monitoring.
	- Inshore/shellfish (lobster, crabs, razor clam, cockles, whelks) and fish (juvenile flatfish, gadoids, sprat, skates, rays, spurdog): assess accessibility, collate and explore inshore survey data (e.g. UHI Shellfish Stock Assessment Programme, SEPA WFD fish monitoring for transitional and coastal waters) to calibrate additional models for inshore EFH habitats.
	- Inshore/environmental data layers: fill gaps in spatial coverage of environmental data layers in more internal/inshore areas through mapping from local environmental monitoring, where available (to be assessed on a case-by-case basis).
	• Account for stock differences when defining aggregations to be modelled rather than doing it at species level (across different stocks) (e.g. *Nephrops*).
	• Apply EFH model to environmental data layers for individual years and then combine outputs
	• Revise EFH models periodically by including new survey data as they become available (e.g. from ongoing sandeel dredge surveys, bottom trawl surveys, *Nephrops* TV surveys, scallop dredge surveys).
	• Explore implications of climate change on EFH distribution more accurately (identify and collate climate change spatial projections for multiple environmental model predictors, where available, and apply to EFH models with appropriate baseline and with variable time-span).

D. Improvement of habitat proxy assessment and the resulting maps:	
	• Extend matrix assessment to scoring of deeper habitats that were excluded *a priori* (because described as offshore) but that occur in inshore areas to fill spatial gaps in the maps.
	• Further research on species/life stages for which information on habitat preferences was not sufficient for the assessment or for which detail was low.
	• Periodically revise habitat proxy assessment matrix and update scoring and confidence as new/more information becomes available on habitat preferences of the species/life stages considered.
	• Periodically update EUNIS habitat data layers used for habitat proxy mapping. • Explore availability of EUNIS habitat map predictions under climate change, as these could be used to assess implications of climate change on geographical distribution of habitat proxies for species/life stages.

Recommendations towards the correct use of the overall (integrated) spatial outputs produced in this project:

- The spatial outputs of this study should be used in their entirety, i.e. considering all the lines of evidence shown, from EFH model results (including confidence), to survey data, to stakeholder feedback.
- It is also recommended that, where available, additional results from previous mapping studies are also considered as further lines of evidence to be combined with those from the present study. This would further increase the confidence on the conclusions drawn cumulatively from all the available spatial products, particularly where different lines of evidence (often based on different approaches and/or data) converge in indicating certain areas as key habitats for a species.
- The EFH models and habitat proxy assessments can be used in project-level assessments to provide an indication of areas of possible concern, i.e. areas where key habitats potentially suitable for fish and shellfish species may occur and overlap with the proposed marine project development (and its impact areas). The habitat suitability for a species or its life stage(s) may be affected by multiple abiotic and biotic variables, but some of these (or their interactions) might not be included in the EFH models or the way EUNIS habitat types are defined and identified. This may affect the accuracy of the model or habitat proxy predictions and the way these reflect the actual use of an area. Therefore, it is recommended that, where the spatial outputs of this project are to be used for project-level assessments, ground truthing surveys for the specific area of interest are always undertaken to verify the actual use by fish or shellfish at the time of the project-level assessment. Such surveys should be undertaken using the most appropriate method and design (e.g. relevant seasonality) to represent the species or life stage of concern. They could be periodically repeated to confirm possible changes in habitat use with changing environmental conditions, particularly where predictions

under scenarios of environmental (or habitat) change have highlighted changes in potential suitability of the environment/habitat for the species/life stage.

Recommendations towards the improvement of the overall (integrated) spatial outputs produced in this project:

- Further map validation is recommended, especially for those maps that received no validation at all (either through survey data or stakeholder feedback), such as habitat proxy maps for European lobster (juvenile), brown crab (juvenile), velvet crab, common and dog cockles, common and dog whelk, and razor clam. However, even where map validation was possible, this was partial in some cases (based on either additional survey data or stakeholder feedback), and, in any case, it was limited by the time constraints of the project, and therefore all maps would benefit from further validation. This would entail:
  - Further stakeholder consultation on the EFH model and habitat proxy maps, with consequent inclusion of its results as one of the lines of evidence shown in the spatial products of this study. Maps for which no stakeholder feedback was received should be prioritised (inshore habitat proxy maps for small sandeel (*A. tobianus*), juveniles of cod, whiting, saithe, plaice, sprat and spurdog, and spawning adult/eggs of spotted and thornback ray, as well as habitats for the shellfish species mentioned above), but all maps would benefit from receiving more stakeholder feedback. A further stage of engagement with stakeholders and further validation of the maps based on the experience of the fishermen and of other fishery experts was highlighted by the Scottish Fishermen's Federation (SFF) as a key step to finalise the spatial outputs for use in environmental assessments.
  - Further data sourcing and collation to complement stakeholder input in map validation. Additional survey data could not be obtained for validation of maps for several species, including: all the shellfish species assessed in habitat proxy maps (as mentioned above); spawning habitats of cod, whiting, haddock, mackerel (eggs) (EFH model maps), and herring and Norway pout (habitat proxy maps); and juvenile common sole (both EFH model and habitat proxy maps). Data for some of these species may become available with time (e.g. current/forthcoming data from ongoing survey programmes such as IBTS for spawning gadoids, MEGS for mackerel eggs, BTS for juvenile sole), or with further exploration of existing data sources (e.g. for inshore fish and shellfish surveys; see Table 33). However, additional monitoring effort might be needed to complement map validation for species/life stages and/or areas where actual data gaps occur (to be identified based on a more comprehensive data exploration than was allowed in this project).
- The spatial implementation of the habitat proxy assessment should be extended to all areas of Scottish (and possibly UK) waters, as it was done for the mapping of herring spawning grounds, to better represent the potential distribution of essential habitats

for other species (e.g. areas surrounding Orkney for for shellfish). It is recommended that a combination of finer scale maps for different coastal areas is used, as opposed to a single map for the whole extent of Scottish inshore waters, for better visibility of smaller areas of the suitable functional habitat represented by habitat proxies. Further collection of inshore survey data from these additional areas (e.g. survey data from the Shellfish Stock Assessment Programme around Shetland) would allow the validation of these maps.

Recommendations towards the improvement of EFH models and their prediction maps:

- Data sourcing and collation may be a time-consuming task, and it was limited by the relatively short timescale of this project. The EFH model assessments undertaken in this study would benefit from extending the database used for both model calibration, particularly for those species that are of higher interest or that had poorer assessments (with lower confidence or which could not be fully assessed or validated). More specific recommendations include:
    - Catch data from sandeel surveys more widely distributed around the UK should be obtained and included in the modelling, with surveys also covering areas further offshore than those considered in the present study. This would allow a wider spatial applicability of the model (due to the wider range of environmental conditions for which the model provides valid predictions) and a likely increase in the overall confidence in the model (which was lowered for the model output developed in this project given the reduced spatial coverage of the sandeel dredge surveys used for model calibration).
    - Aggregations of *Nephrops* burrows from MS TV burrow density surveys available to date can be included to improve the EFH model for the species. These surveys, which directly target the refuge habitat resource (burrows), held a higher confidence compared to the bottom trawl survey data used in this project (targeting *Nephrops* individuals instead). As a result, an increase in the overall confidence in the model output is expected from their inclusion in the analysis.
    - Longer-term data bases could be obtained for species which had limited data in the selected study period 2010-20 to allow modelling of species/life stages that could not be covered in this study (e.g. cod juveniles) or improve the EFH model performance for species/life stages modelled with lower confidence (e.g. whiting life stages). For bottom trawl surveys (used for calibration of most EFH models), these data are available from the existing online ICES database (Datras).

More time and effort should be dedicated to identify and collate data from (i) shellfish monitoring surveys and (ii) fish monitoring inshore (e.g. fish count data obtained to comply with the Water Framework Directive), in Scottish waters as a minimum, but preferably UK-wide where possible. Potential data sources and the species that would benefit from the modelling of these additional data are as indicated in

  - Table 31, and include species with EFH both offshore (e.g. scallops, surf clam) and inshore (e.g. European lobster and crab nursery, cockles and whelks, nursery grounds for flatfish, gadoids, skates and rays). It is acknowledged that, this would likely require gathering many small-scale datasets from multiple sources, and accessibility for some of these data (e.g. from the offshore wind industry sector, or WFD fish monitoring from SEPA) needs to be ascertained. Furthermore, this would require considerable additional effort to combine and standardise the different datasets into a wider-scale database that could be used to complete the modelling for fish and shellfish species and/or inshore habitats (or at least to validate the habitat proxy maps obtained based on expert assessment and literature review).
  - The ability to calibrate EFH models for species in inshore areas would also depend on the availability of environmental data layers to be used as model predictors in those areas. Coverage of these data layers may not be complete inshore, particularly in most internal areas (e.g. sea lochs, estuaries), as broad-scale environmental layers are often the result of oceanographic models that have limited applicability closer to the water/land boundary (e.g. for sea temperature, water column mixing). Alternative local maps covering site-specific spatial gaps should be sourced (or data from existing local environmental monitoring should be mapped), where available, although temporal consistency with correspondent fish/shellfish survey data will need to be taken into consideration for them to be used for model calibration.

- Stakeholder feedback has highlighted that, as different stocks of a species can be characterised by different densities, the assessment on a stock-by-stock basis (i.e. identifying aggregations based on abundance within stocks rather than between stocks) is recommended to improve the model predictions (e.g. *Nephrops*).
- It is recommended that spatial outputs from EFH model predictions are generated for individual years (using the appropriate environmental data layers) and the results combined across years (as explained in section 4.4) to be able to account for temporal variability in the habitat distribution and persistence of use of certain areas.
- The EFH models could be periodically revised through inclusion of new survey data as they become available to strengthen the statistical tool and improve its confidence.
- A preliminary overview of the potential implications of climate change for mapped distributions of EFH was undertaken in this project (see section 3.2). However, further work should be undertaken to explore such implications more accurately. For the EFH model maps, this would mean to source (or produce, where not available) climate change spatial projections for as many of the environmental predictors used by the models (the analysis in this project was limited to sea bottom temperature and depth variability in inshore areas as a consequence of sea level rise), where possible, and with variable time span to assess possible variability on different timescales (e.g. also

relevant to the life span of a project that is being assessed, from construction to decommissioning). The models could then be applied to environmental scenarios accounting for these changes (using the appropriate baseline) to assess the spatial variation in the mapped habitat distributions.

Recommendations towards the improvement of the habitat proxy assessment and the resulting maps:

- A trade-off between spatial/habitat resolution and coverage was apparent for the habitat proxy maps. Considering that the main aim of the spatial products developed in this study is to support marine spatial planning, high spatial resolution is essential. Therefore, it is recommended, that this aspect is prioritised (hence mapping habitat proxies is undertaken at EUNIS Level 4 wherever possible, using EUNIS Level 3 classification only when Level 4 is not available), even if it leads to spatial gaps in the map (where EUNIS habitat is not identified at Level 3 or 4).
- In order to reduce the spatial gaps in the habitat proxy maps, it is further recommended that the habitat proxy assessment (matrix) is extended to include those deeper habitats that were excluded *a priori*, but that may also occur in inshore areas.
- Further targeted research on certain species may be required so that knowledge gaps species can be filled for these species, their habitat requirements and life cycle, which prevented further assessment in this study. This should focus in particular on ascertaining habitat characteristics for juvenile and spawning individuals of sandy ray and common skate, which could not be assessed in this study. Further research into the detailed habitat characterisation for spawning thornback ray and spurdog, and juveniles of sprat, common sole, spotted ray, saithe, cod, whiting, European lobster, brown and velvet crab would also allow to increase the confidence in the habitat proxy assessments for these species/life stages. It is acknowledged that the literature review undertaken in this study was not exhaustive, hence further literature search for these species should be undertaken beforehand, to ascertain whether knowledge gaps in this study correspond effectively to gaps in the wider knowledge of these species.
- The habitat proxy assessment matrix should be maintained as a live tool, with periodic revision undertaken through expert input to allow inclusion of new/updated knowledge on the species and life stages of interest and it becomes available. This could allow expanding the range of habitat types that can be scored for a species, improving the confidence associated with the habitats already scored, or extending the assessment to other species that could not be assessed due to lack of evidence/knowledge at the time of this study.
- The EUNIS habitat data used as base layers for the spatial application of the matrix assessment should also be periodically revised, by using the most recent, high resolution habitat survey data where possible. This would allow habitat proxy maps to take into account possible changes in the underlying habitat types and their spatial

distribution (e.g. due to local losses, or depth or energy changes that might alter the classification of an area into a specific habitat class).

- If predictions existed (or were developed) of possible changes in the spatial classification of areas into EUNIS habitat types (e.g. based on broadscale models accounting for future climate effects), these could be considered for the application of the habitat proxy assessment to assess resulting changes in the habitat distribution for specific species/life stages, in an analogous way as suggested for model maps (but using changes in habitat type layers in this case rather than in environmental data layers).

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Appendix A. Project methodological protocol (diagrams)

The methodological process undertaken in this project to develop the resulting EFH spatial outputs is summarised as a series of interrelated diagrams (flow charts).

The following diagrams are included (the relevant section of the report and technical annexes are indicated in parenthesis):

For the EFH spatial outputs from data-based modelling:

a) EFH models: Model calibration (report sections 2.2.1 to 2.2.3; Annex 2);

b) EFH models: Model application (report section 2.2.4; Annex 2);

c) EFH models: Confidence assessment (overall) (report section 2.2.5; Annex 3);

d) EFH models: Confidence assessment (spatial) (report section 2.2.5; Annex 3);

e) EFH models: Spatial output (survey data and model lines of evidence) (report section 3.1);

f) EFH models: Spatial output (map validation survey line of evidence) (report section 3.1);

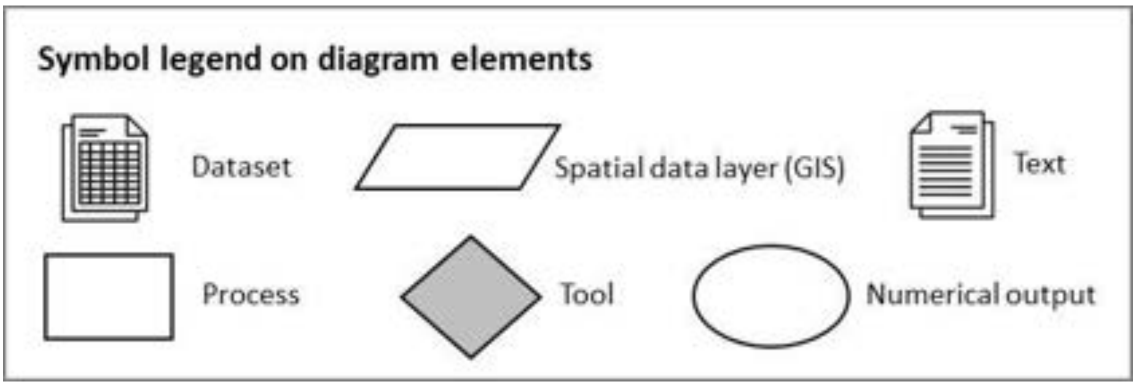
g) EFH models: Spatial output (lines of evidence combined) (report section 3.1).

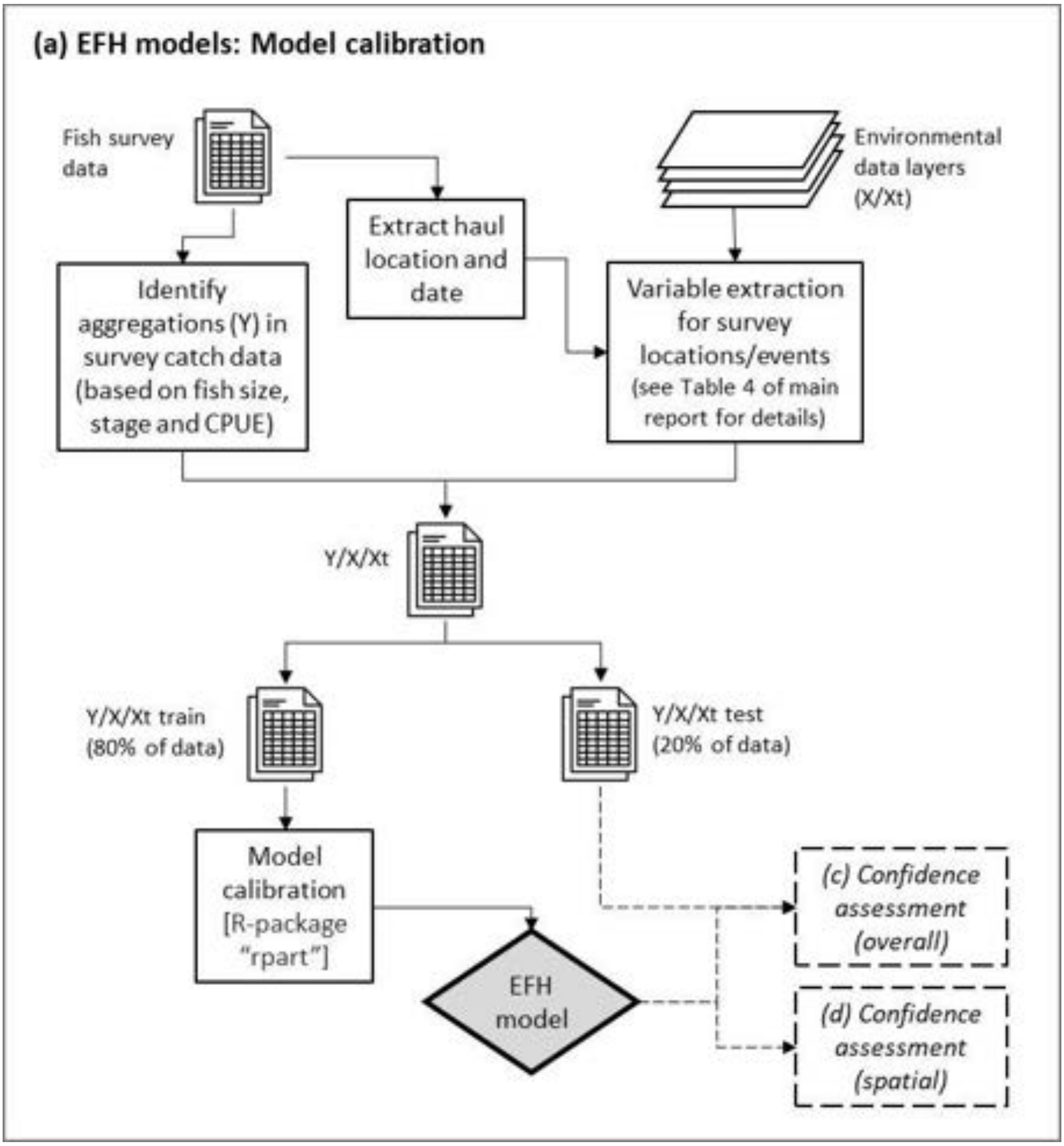
For the spatial outputs from the habitat proxy assessment:

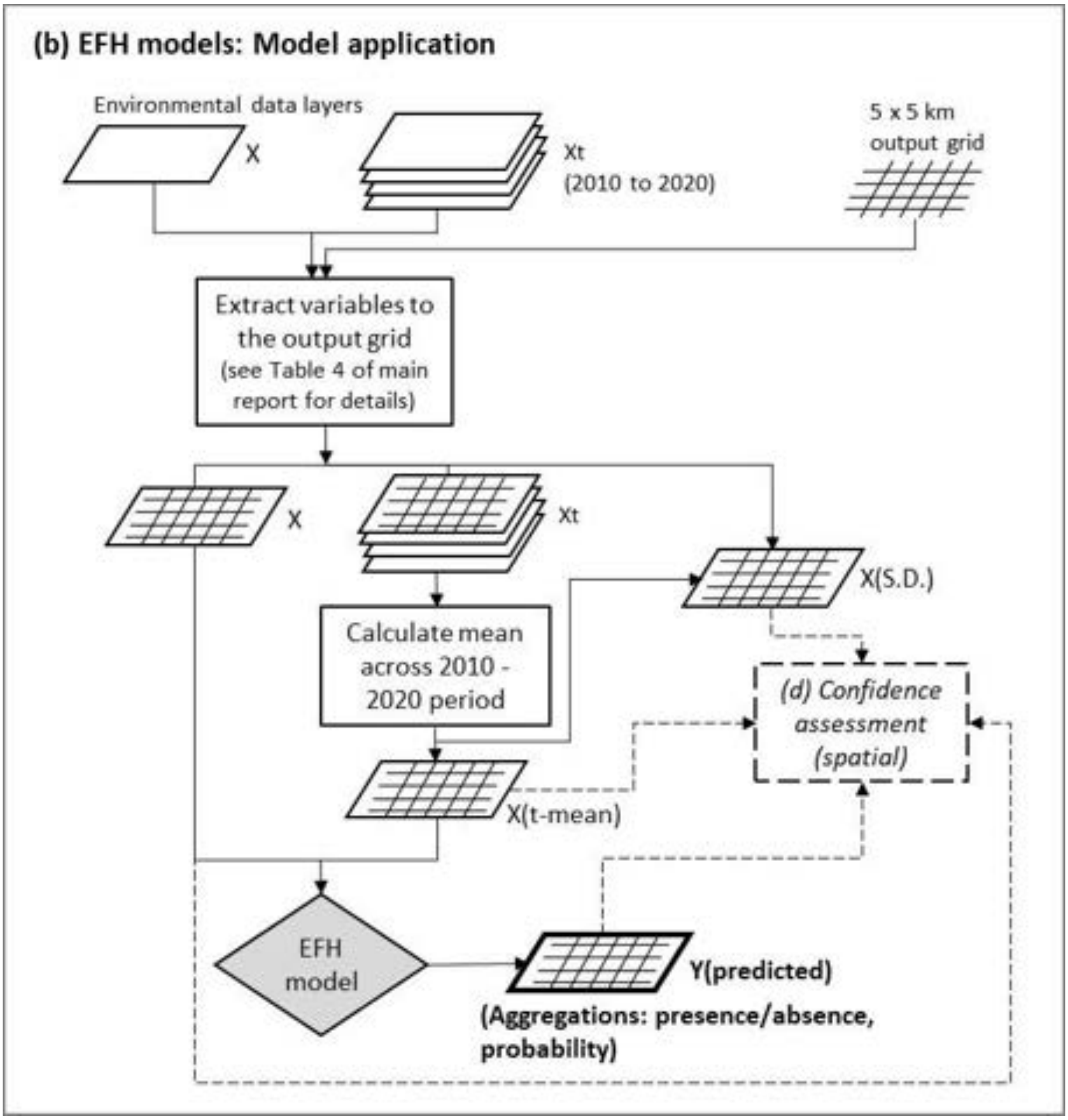
h) Habitat proxies: Assessment and mapping (report section 2.3);

i) Habitat proxies: Spatial output (report section 3.1).

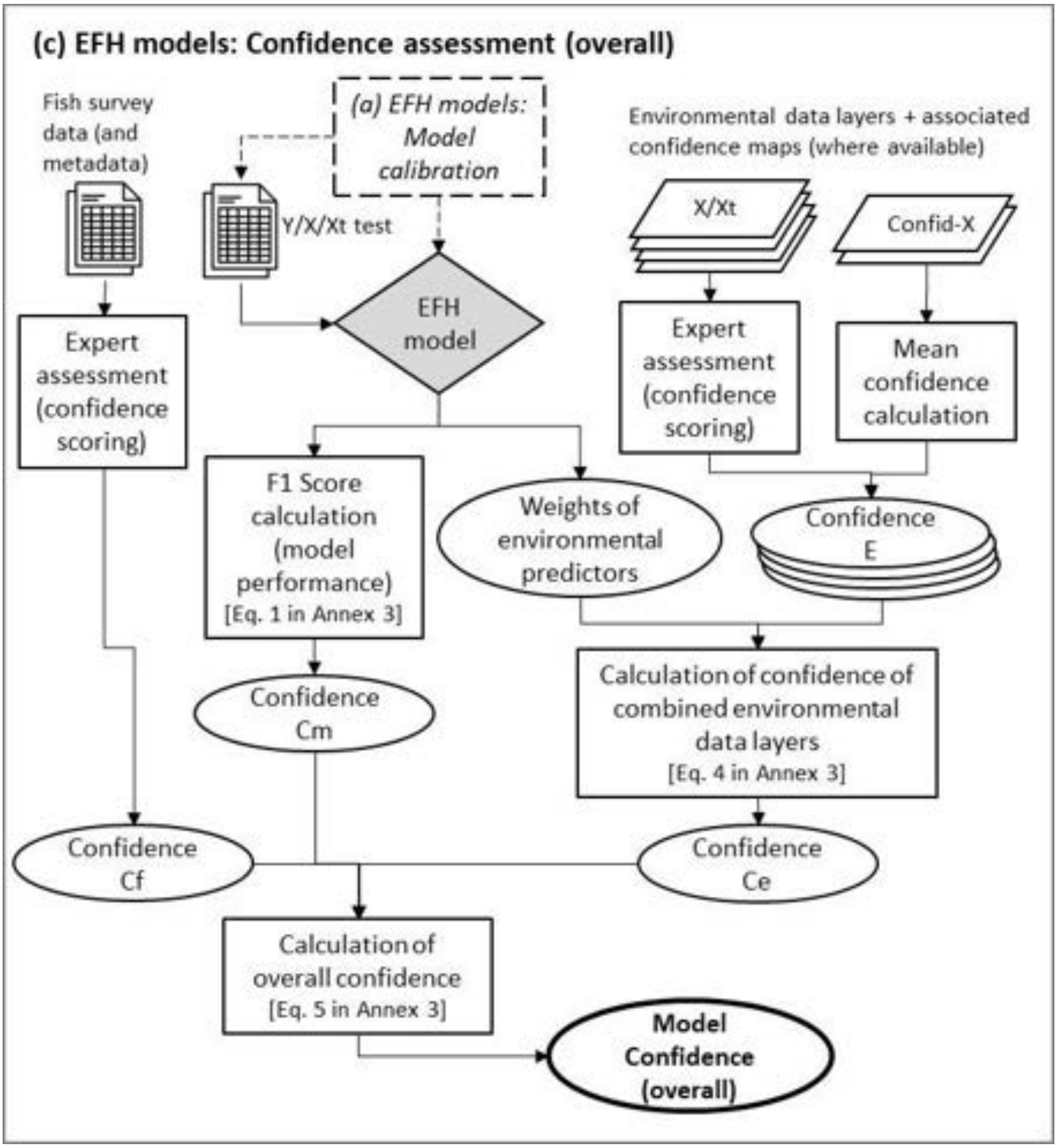
A legend of the symbols used in the diagrams is given below. In addition, dashed lines in a diagram indicate flows of data/information from/into another main process (represented in a separate diagram). Bold lines and text indicate the main output of the process represented in a diagram. Y indicates data on fish/shellfish aggregations. X indicates persistent environmental variables (e.g. Depth), whereas Xt indicates non-persistent environmental variables (e.g. SST).

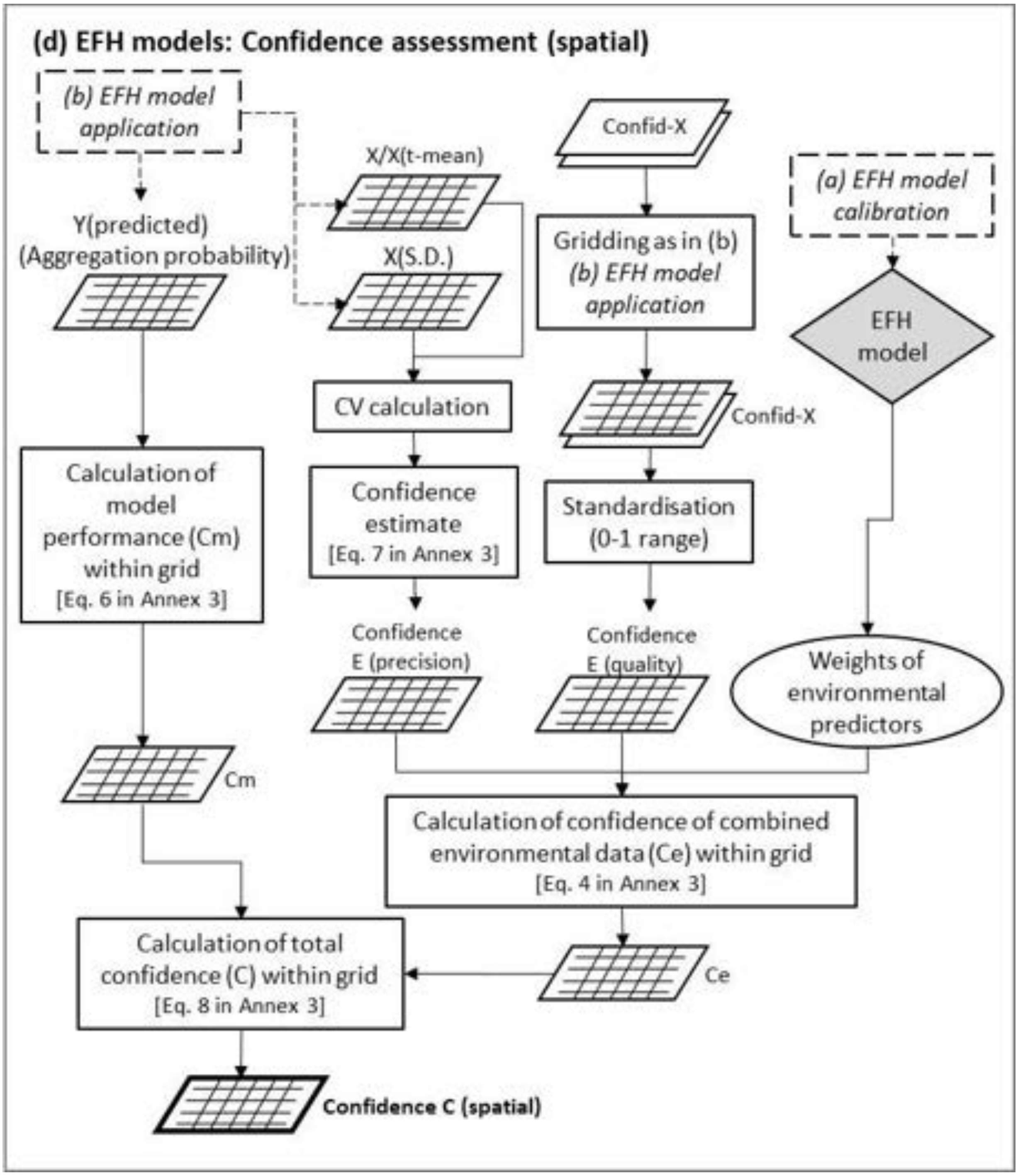


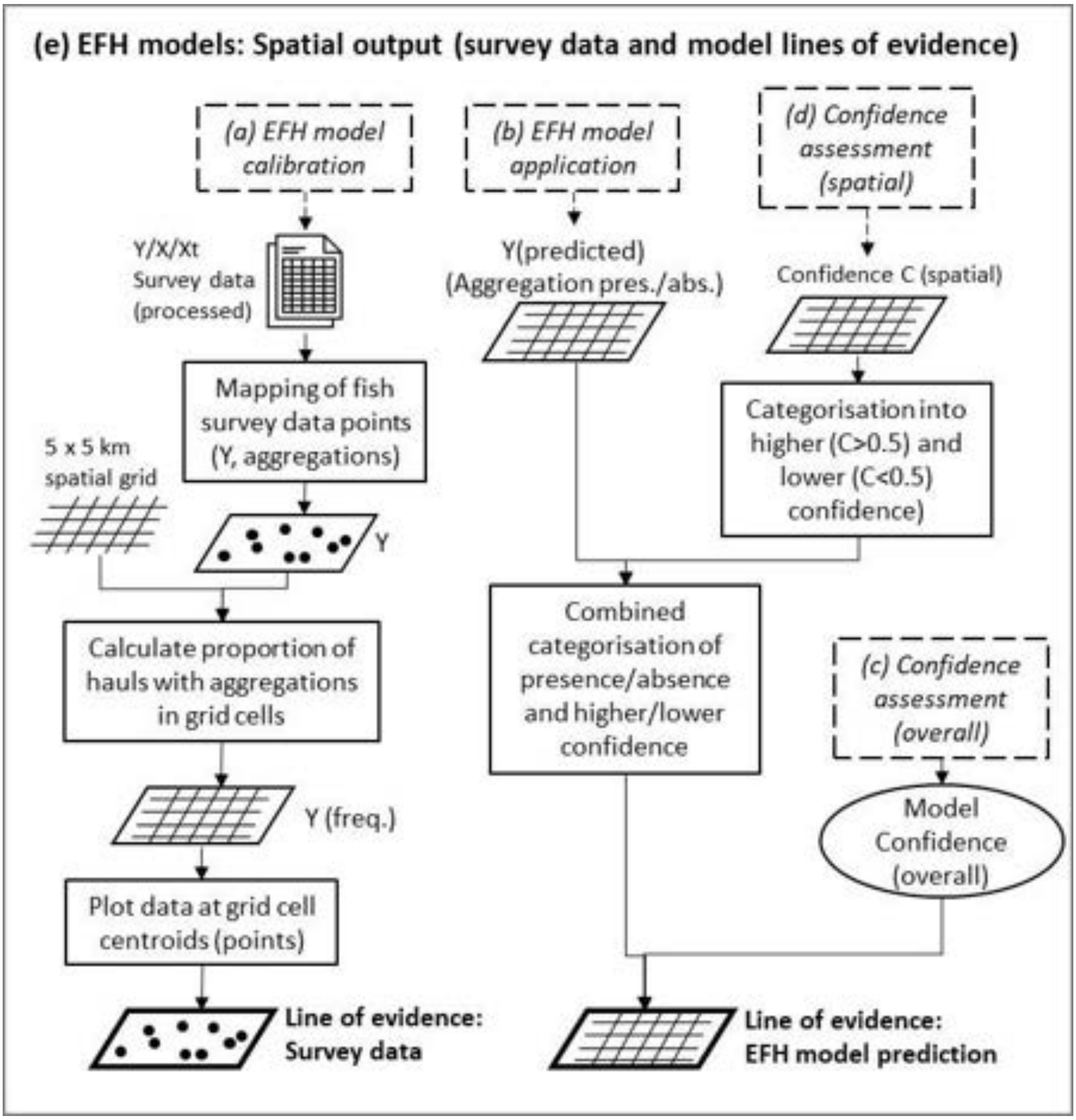

(a) EFH models: Model calibration
Fish survey data
Environmental data layers (X/Xt)
Extract haul location and date
Identify aggregations (Y) in survey catch data (based on fish size, stage and CPUE)
Variable extraction for survey locations/events (see Table 4 of main report for details)
Y/X/Xt
Y/X/Xt train (80% of data)
Y/X/Xt test (20% of data)
Model calibration [R-package "rpart"]
EFH model
(c) Confidence assessment (overall)
(d) Confidence assessment (spatial)

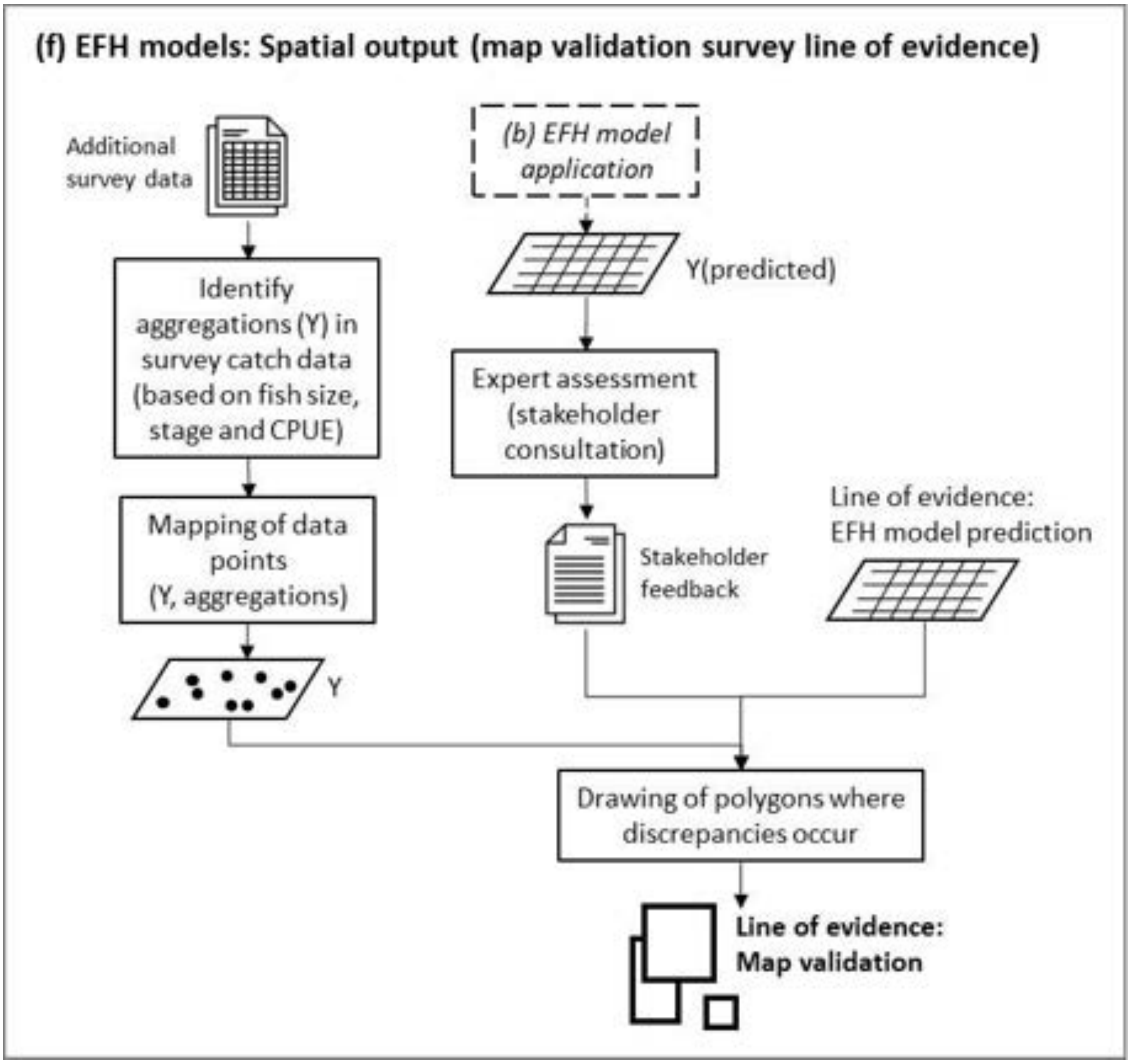


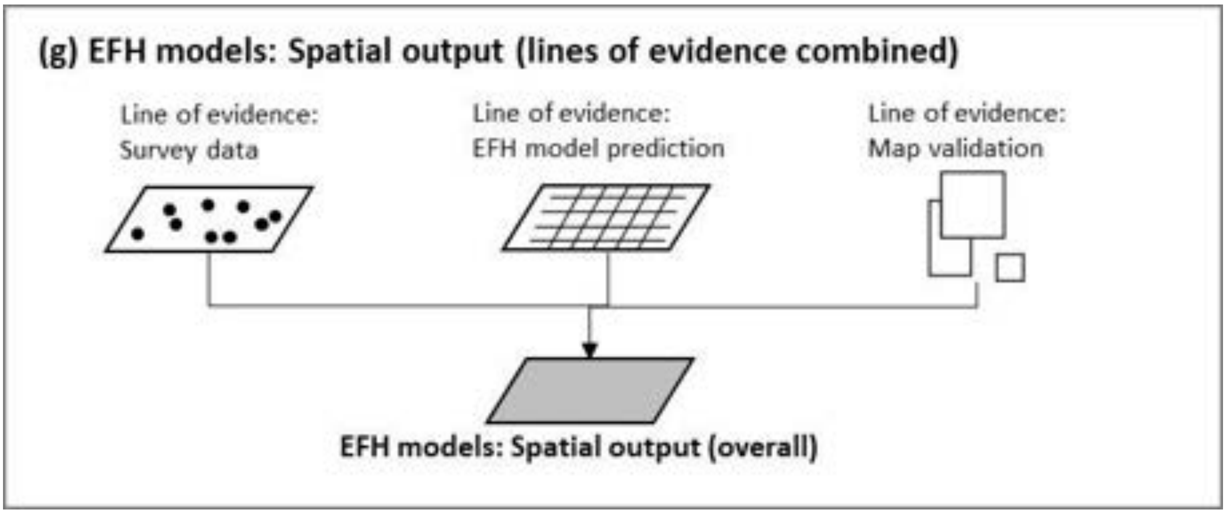
Footnote: Standard deviation (S.D.) is also derived from the gridding process to obtain the coefficient of variation (CV) that contributes to the spatial confidence assessment.

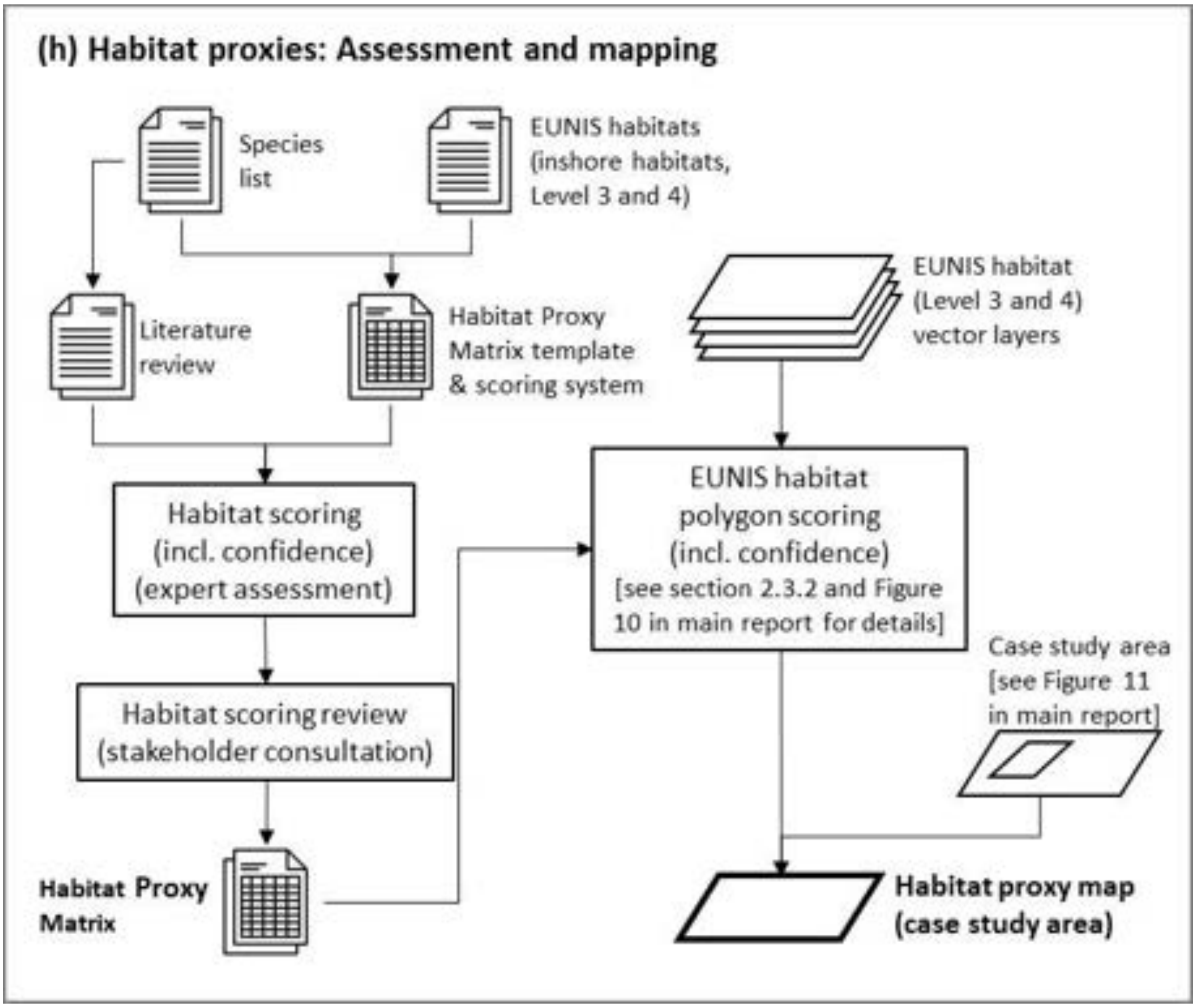

(c) EFH models: Confidence assessment (overall)
Fish survey data (and metadata)
(a) EFH models: Model calibration
Environmental data layers + associated confidence maps (where available)
Y/X/Xt test
X/Xt
Confid-X
EFH model
Expert assessment (confidence scoring)
Expert assessment (confidence scoring)
Mean confidence calculation
F1 Score calculation (model performance) [Eq. 1 in Annex 3]
Weights of environmental predictors
Confidence E
Calculation of confidence of combined environmental data layers [Eq. 4 in Annex 3]
Confidence Cm
Confidence Cf
Confidence Ce
Calculation of overall confidence [Eq. 5 in Annex 3]
Model Confidence (overall)

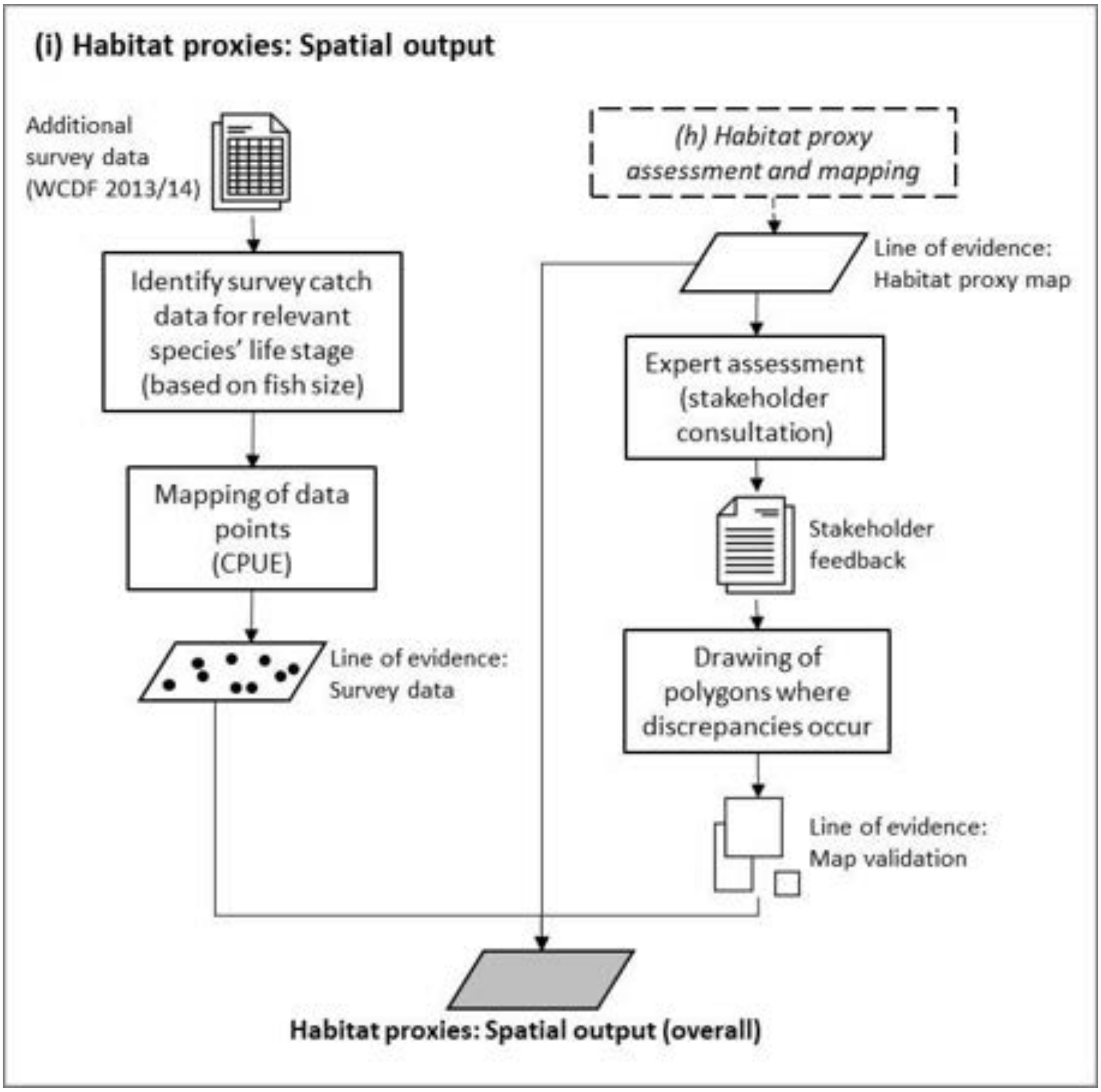

(d) EFH models: Confidence assessment (spatial)
(b) EFH model application
Y(predicted)
(Aggregation probability)
X/X(t-mean)
X(S.D.)
Confid-X
(a) EFH model calibration
Gridding as in (b)
(b) EFH model application
EFH model
CV calculation
Confid-X
Calculation of model performance (Cm) within grid
[Eq. 6 in Annex 3]
Confidence estimate
[Eq. 7 in Annex 3]
Standardisation (0-1 range)
Confidence E (precision)
Confidence E (quality)
Weights of environmental predictors
Cm
Calculation of confidence of combined environmental data (Ce) within grid
[Eq. 4 in Annex 3]
Calculation of total confidence (C) within grid
[Eq. 8 in Annex 3]
Ce
Confidence C (spatial)


(e) EFH models: Spatial output (survey data and model lines of evidence)
(a) EFH model calibration
(b) EFH model application
(d) Confidence assessment (spatial)
Y/X/Xt Survey data (processed)
Y(predicted) (Aggregation pres./abs.)
Confidence C (spatial)
Mapping of fish survey data points (Y, aggregations)
5 x 5 km spatial grid
Categorisation into higher (C>0.5) and lower (C<0.5) confidence)
Y
Calculate proportion of hauls with aggregations in grid cells
Combined categorisation of presence/absence and higher/lower confidence
(c) Confidence assessment (overall)
Y (freq.)
Model Confidence (overall)
Plot data at grid cell centroids (points)
Line of evidence: Survey data
Line of evidence: EFH model prediction


(f) EFH models: Spatial output (map validation survey line of evidence)
Additional survey data
(b) EFH model application
Y(predicted)
Identify aggregations (Y) in survey catch data (based on fish size, stage and CPUE)
Expert assessment (stakeholder consultation)
Mapping of data points (Y, aggregations)
Stakeholder feedback
Line of evidence: EFH model prediction
Y
Drawing of polygons where discrepancies occur
Line of evidence: Map validation


(g) EFH models: Spatial output (lines of evidence combined)
Line of evidence: Survey data
Line of evidence: EFH model prediction
Line of evidence: Map validation
EFH models: Spatial output (overall)


(h) Habitat proxies: Assessment and mapping
Species list
EUNIS habitats (inshore habitats, Level 3 and 4)
Literature review
Habitat Proxy Matrix template & scoring system
EUNIS habitat (Level 3 and 4) vector layers
Habitat scoring (incl. confidence) (expert assessment)
EUNIS habitat polygon scoring (incl. confidence) [see section 2.3.2 and Figure 10 in main report for details]
Habitat scoring review (stakeholder consultation)
Case study area [see Figure 11 in main report]
Habitat Proxy Matrix
Habitat proxy map (case study area)


(i) Habitat proxies: Spatial output
Additional survey data (WCDF 2013/14)
Identify survey catch data for relevant species' life stage (based on fish size)
Mapping of data points (CPUE)
Line of evidence: Survey data
(h) Habitat proxy assessment and mapping
Line of evidence: Habitat proxy map
Expert assessment (stakeholder consultation)
Stakeholder feedback
Drawing of polygons where discrepancies occur
Line of evidence: Map validation
Habitat proxies: Spatial output (overall)

Appendix B. List and names of EUNIS habitat types (Level 3 and 4)

Full list of marine EUNIS habitat types considered for the habitat proxy assessment. The list also includes habitats that were excluded *a priori* from the habitat proxy assessment (highlighted in grey) because considered not relevant to UK inshore areas due to geographical/environmental reasons: N(1), habitats typical of Baltic, Mediterranean, Black Sea or Pontic region; N(2), habitats described as deep offshore or deep sea habitat; N(3), ice-associated habitats.

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
A. Marine habitats (Level 1)							
A1. Littoral rock and other hard substrata (Level 2)							
	A1.1	High energy littoral rock	Level 3	Y	Y	Y	Y
	A1.11	Mussel and/or barnacle communities	Level 4	Y	Y	Y	Y
	A1.12	Robust fucoid and/or red seaweed communities	Level 4	Y	Y	Y	Y
	A1.13	Mediterranean and Black Sea communities of upper mediolittoral rock	Level 4	N(1)			
	A1.14	Mediterranean and Black Sea communities of lower mediolittoral rock very exposed to wave action	Level 4	N(1)			
	A1.15	Fucoids in tide-swept conditions	Level 4	Y	Y	Y	Y
	A1.16	Pontic communities of exposed mediolittoral rock	Level 4	N(1)			
	A1.2	Moderate energy littoral rock	Level 3	Y	Y	Y	Y
	A1.21	Barnacles and fucoids on moderately exposed shores	Level 4	Y	Y	Y	Y
	A1.22	Mussels and fucoids on moderately exposed shores	Level 4	Y	Y	Y	Y
	A1.23	Mediterranean communities of lower mediolittoral rock moderately exposed to wave action	Level 4	N(1)			

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
	A1.24	Pontic communities of lower mediolittoral rock moderately exposed to wave action	Level 4	N(1)			
	A1.3	Low energy littoral rock	Level 3	Y	Y	Y	Y
	A1.31	Fucoids on sheltered marine shores	Level 4	Y	Y	Y	Y
	A1.32	Fucoids in variable salinity	Level 4	Y	Y	Y	Y
	A1.33	Red algal turf in lower eulittoral, sheltered from wave action	Level 4	Y	Y		Y
	A1.34	Mediterranean communities of lower mediolittoral rock sheltered from wave action	Level 4	N(1)			
	A1.4	Features of littoral rock	Level 3	Y	Y	Y	Y
	A1.41	Communities of littoral rockpools	Level 4	Y	Y	Y	Y
	A1.42	Communities of rockpools in the supralittoral zone	Level 4	Y	Y		Y
	A1.43	Brackish permanent pools in the geolittoral zone	Level 4	Y	Y		Y
	A1.44	Communities of littoral caves and overhangs	Level 4	Y	Y	Y	Y
	A1.45	Ephemeral green or red seaweeds (freshwater or sand-influenced) on non-mobile substrata	Level 4	Y	Y		Y
	A1.46	Hydrolittoral soft rock	Level 4	Y	Y		Y
	A1.47	Hydrolittoral solid rock (bedrock)	Level 4	Y	Y		Y
	A1.48	Hydrolittoral hard clay	Level 4	Y	Y		Y
	A1.49	Hydrolittoral mussel beds	Level 4	Y	Y		Y

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
	A1.4A	Hydrolittoral peat	Level 4	Y	Y		Y
A2. Littoral sediment (Level 2)							
	A2.1	Littoral coarse sediment	Level 3	Y	Y	Y	Y
	A2.11	Shingle (pebble) and gravel shores	Level 4	Y	Y	Y	Y
	A2.12	Estuarine coarse sediment shores	Level 4	Y	Y	Y	Y
	A2.2	Littoral sand and muddy sand	Level 3	Y	Y	Y	Y
	A2.21	Strandline	Level 4	Y	Y	Y	Y
	A2.22	Barren or amphipod-dominated mobile sand shores	Level 4	Y	Y	Y	Y
	A2.23	Polychaete/amphipod-dominated fine sand shores	Level 4	Y	Y	Y	Y
	A2.24	Polychaete/bivalve-dominated muddy sand shores	Level 4	Y	Y	Y	Y
	A2.3	Littoral mud	Level 3	Y	Y	Y	Y
	A2.31	Polychaete/bivalve-dominated mid estuarine mud shores	Level 4	Y	Y	Y	Y
	A2.32	Polychaete/oligochaete-dominated upper estuarine mud shores	Level 4	Y	Y	Y	Y
	A2.33	Marine mud shores	Level 4	Y	Y	Y	Y
	A2.4	Littoral mixed sediments	Level 3	Y	Y	Y	Y
	A2.41	Hediste diversicolor dominated gravelly sandy mud shores	Level 4	Y	Y	Y	Y
	A2.42	Species-rich mixed sediment shores	Level 4	Y	Y	Y	Y
	A2.43	Species-poor mixed sediment shores	Level 4	Y	Y		Y

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
	A2.5	Coastal Saltmarshes and saline reedbeds	Level 3	Y	Y	Y	Y
	A2.51	Saltmarsh driftlines	Level 4	Y	Y		Y
	A2.52	Upper saltmarshes	Level 4	Y	Y		Y
	A2.53	Mid-upper saltmarshes and saline and brackish reed, rush and sedge beds	Level 4	Y	Y		Y
	A2.54	Low-mid saltmarshes	Level 4	Y	Y		Y
	A2.55	Pioneer saltmarshes	Level 4	Y	Y		Y
	A2.6	Littoral sediments dominated by aquatic angiosperms	Level 3	Y	Y	Y	Y
	A2.61	Seagrass beds on littoral sediments	Level 4	Y	Y	Y	Y
	A2.62	Marine *Cyperaceae* beds	Level 4	N(1)			
	A2.7	Littoral biogenic reefs	Level 3	Y	Y		Y
	A2.71	Littoral Sabellaria reefs	Level 4	Y	Y		Y
	A2.72	Littoral mussel beds on sediment	Level 4	Y	Y		Y
	A2.8	Features of littoral sediment	Level 3	Y	Y	Y	Y
	A2.81	Methane seeps in littoral sediments	Level 4	Y	Y		Y
	A2.82	Ephemeral green or red seaweeds (freshwater or sand-influenced) on mobile substrata	Level 4	Y	Y	Y	Y
	A2.83	Hydrolittoral stony substrata	Level 4	N(1)			
	A2.84	Hydrolittoral gravel substrata	Level 4	N(1)			
	A2.85	Hydrolittoral sandy substrata	Level 4	N(1)			

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
	A2.86	Hydrolittoral muddy substrata	Level 4	N(1)			
	A2.87	Hydrolittoral mixed sediment substrata	Level 4	N(1)			
A3. Infralittoral rock and other hard substrata (Level 2)							
	A3.1	Atlantic and Mediterranean high energy infralittoral rock	Level 3	Y	Y	Y	Y
	A3.11	Kelp with cushion fauna and/or foliose red seaweeds	Level 4	Y	Y	Y	Y
	A3.12	Sediment-affected or disturbed kelp and seaweed communities	Level 4	Y	Y		Y
	A3.14	Encrusting algal communities	Level 4	Y	Y	Y	Y
	A3.15	Frondose algal communities (other than kelp)	Level 4	Y	Y	Y	Y
	A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	Level 3	Y	Y	Y	Y
	A3.21	Kelp and red seaweeds (moderate energy infralittoral rock)	Level 4	Y	Y	Y	Y
	A3.22	Kelp and seaweed communities in tide-swept sheltered conditions	Level 4	Y	Y	Y	Y
	A3.23	Mediterranean and Pontic communities of infralittoral algae moderately exposed to wave action	Level 4	N(1)			
	A3.24	Faunal communities on moderate energy infralittoral rock	Level 4	Y	Y		Y
	A3.3	Atlantic and Mediterranean low energy infralittoral rock	Level 3	Y	Y	Y	Y

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
	A3.31	Silted kelp on low energy infralittoral rock with full salinity	Level 4	Y	Y	Y	Y
	A3.32	Kelp in variable salinity on low energy infralittoral rock	Level 4	Y	Y	Y	Y
	A3.33	Mediterranean submerged fucoids, green or red seaweeds on full salinity infralittoral rock	Level 4	N(1)			
	A3.34	Submerged fucoids, green or red seaweeds (low salinity infralittoral rock)	Level 4	Y	Y		Y
	A3.35	Faunal communities on low energy infralittoral rock	Level 4	Y	Y		Y
	A3.36	Faunal communities on variable or reduced salinity infralittoral rock	Level 4	Y	Y		Y
	A3.4	**Baltic exposed infralittoral rock**	Level 3	**N(1)**			
	A3.5	**Baltic moderately exposed infralittoral rock**	Level 3	**N(1)**			
	A3.6	**Baltic sheltered infralittoral rock**	Level 3	**N(1)**			
	A3.7	Features of infralittoral rock	Level 3	Y	Y		Y
	A3.71	Robust faunal cushions and crusts in surge gullies and caves	Level 4	Y	Y		Y
	A3.72	Infralittoral fouling seaweed communities	Level 4	Y	Y		Y
	A3.73	Vents and seeps in infralittoral rock	Level 4	Y	Y		Y
	A3.74	Caves and overhangs in infralittoral rock	Level 4	Y	Y		Y
A4. Circalittoral rock and other hard substrata (Level 2)							
	A4.1	Atlantic and Mediterranean high energy circalittoral rock	Level 3	Y	Y	Y	Y

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
	A4.11	Very tide-swept faunal communities on circalittoral rock	Level 4	Y	Y	Y	Y
	A4.12	Sponge communities on deep circalittoral rock	Level 4	Y	Y		Y
	A4.13	Mixed faunal turf communities on circalittoral rock	Level 4	Y	Y	Y	Y
	A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	Level 3	Y	Y	Y	Y
	A4.21	Echinoderms and crustose communities on circalittoral rock	Level 4	Y	Y	Y	Y
	A4.22	Sabellaria reefs on circalittoral rock	Level 4	Y	Y		Y
	A4.23	Communities on soft circalittoral rock	Level 4	Y	Y	Y	Y
	A4.24	Mussel beds on circalittoral rock	Level 4	Y	Y	Y	Y
	A4.25	Circalittoral faunal communities in variable salinity	Level 4	Y	Y		Y
	A4.26	Mediterranean coralligenous communities moderately exposed to hydrodynamic action	Level 4	N(1)			
	A4.27	Faunal communities on deep moderate energy circalittoral rock	Level 4	Y	Y		Y
	A4.3	Atlantic and Mediterranean low energy circalittoral rock	Level 3	Y	Y	Y	Y
	A4.31	Brachiopod and ascidian communities on circalittoral rock	Level 4	Y	Y		Y
	A4.32	Mediterranean coralligenous communities sheltered from hydrodynamic action	Level 4	N(1)			

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
	A4.33	Faunal communities on deep low energy circalittoral rock	Level 4	Y	Y		Y
	A4.4	**Baltic exposed circalittoral rock**	Level 3	**N(1)**			
	A4.5	**Baltic moderately exposed circalittoral rock**	Level 3	**N(1)**			
	A4.6	**Baltic sheltered circalittoral rock**	Level 3	**N(1)**			
	A4.7	Features of circalittoral rock	Level 3	Y	Y		Y
	A4.71	Communities of circalittoral caves and overhangs	Level 4	Y	Y		Y
	A4.72	Circalittoral fouling faunal communities	Level 4	Y	Y		Y
	A4.73	Vents and seeps in circalittoral rock	Level 4	Y	Y		Y
A5. Sublittoral sediment (Level 2)							
	A5.1	Sublittoral coarse sediment	Level 3	Y	Y	Y	Y
	A5.11	Infralittoral coarse sediment in low or reduced salinity	Level 4	N(1)			
	A5.12	Sublittoral coarse sediment in variable salinity (estuaries)	Level 4	Y	Y	Y	Y
	A5.13	Infralittoral coarse sediment	Level 4	Y	Y	Y	Y
	A5.14	Circalittoral coarse sediment	Level 4	Y	Y	Y	Y
	A5.15	Deep circalittoral coarse sediment	Level 4	N(2)			
	A5.2	Sublittoral sand	Level 3	Y	Y	Y	Y
	A5.21	Sublittoral sand in low or reduced salinity	Level 4	Y	Y	Y	Y
	A5.22	Sublittoral sand in variable salinity (estuaries)	Level 4	Y	Y	Y	Y
	A5.23	Infralittoral fine sand	Level 4	Y	Y	Y	Y

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
	A5.24	Infralittoral muddy sand	Level 4	Y	Y	Y	Y
	A5.25	Circalittoral fine sand	Level 4	Y	Y	Y	Y
	A5.26	Circalittoral muddy sand	Level 4	Y	Y	Y	Y
	A5.27	Deep circalittoral sand	Level 4	N(2)			
	A5.3	Sublittoral mud	Level 3	Y	Y	Y	Y
	A5.31	Sublittoral mud in low or reduced salinity	Level 4	Y	Y	Y	Y
	A5.32	Sublittoral mud in variable salinity (estuaries)	Level 4	Y	Y	Y	Y
	A5.33	Infralittoral sandy mud	Level 4	Y	Y	Y	Y
	A5.34	Infralittoral fine mud	Level 4	Y	Y	Y	Y
	A5.35	Circalittoral sandy mud	Level 4	Y	Y	Y	Y
	A5.36	Circalittoral fine mud	Level 4	Y	Y	Y	Y
	A5.37	Deep circalittoral mud	Level 4	N(2)			
	A5.4	Sublittoral mixed sediments	Level 3	Y	Y	Y	Y
	A5.41	Sublittoral mixed sediment in low or reduced salinity	Level 4	Y	Y		Y
	A5.42	Sublittoral mixed sediment in variable salinity (estuaries)	Level 4	Y	Y	Y	Y
	A5.43	Infralittoral mixed sediments	Level 4	Y	Y	Y	Y
	A5.44	Circalittoral mixed sediments	Level 4	Y	Y	Y	Y
	A5.45	Deep circalittoral mixed sediments	Level 4	N(2)			
	A5.5	Sublittoral macrophyte-dominated sediment	Level 3	Y	Y	Y	Y

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
	A5.51	Maerl beds	Level 4	Y	Y	Y	Y
	A5.52	Kelp and seaweed communities on sublittoral sediment	Level 4	Y	Y	Y	Y
	A5.53	Sublittoral seagrass beds	Level 4	Y	Y	Y	Y
	A5.54	Angiosperm communities in reduced salinity	Level 4	Y	Y	Y	Y
	A5.6	Sublittoral biogenic reefs	Level 3	Y	Y	Y	Y
	A5.61	Sublittoral polychaete worm reefs on sediment	Level 4	Y	Y	Y	Y
	A5.62	Sublittoral mussel beds on sediment	Level 4	Y	Y	Y	Y
	A5.63	Circalittoral coral reefs	Level 4	Y			Y
	A5.7	Features of sublittoral sediments	Level 3	Y			Y
	A5.71	Seeps and vents in sublittoral sediments	Level 4	Y			Y
	A5.72	Organically-enriched or anoxic sublittoral habitats	Level 4	Y			Y
A6. Deep sea bed (Level 2)							
	A6.1	Deep-sea rock and artificial hard substrata	Level 3	N(2)			
	A6.2	Deep-sea mixed substrata	Level 3	N(2)			
	A6.3	Deep-sea sand	Level 3	N(2)			
	A6.4	Deep-sea muddy sand	Level 3	N(2)			
	A6.5	Deep-sea mud	Level 3	N(2)			
	A6.6	Deep-sea bioherms	Level 3	N(2)			
	A6.7	Raised features of the deep-sea bed	Level 3	N(2)			
	A6.8	Deep-sea trenches and canyons, channels, slope	Level 3	N(2)			

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
		failures and slumps on the continental slope					
	A6.9	Vents, seeps, hypoxic and anoxic habitats of the deep sea	Level 3	N(2)			
A7. Pelagic water column (Level 2)							
	A7.1	Neuston	Level 3	Y	Y	Y	Y
	A7.11	Temporary neuston layer	Level 4	Y	Y		Y
	A7.12	Permanent neuston layer	Level 4	Y	Y	Y	Y
	A7.2	Completely mixed water column with reduced salinity	Level 3	Y	Y	Y	Y
	A7.21	Completely mixed water column with reduced salinity and short residence time	Level 4	Y	Y		Y
	A7.22	Completely mixed water column with reduced salinity and medium residence time	Level 4	Y	Y		Y
	A7.23	Completely mixed water column with reduced salinity and long residence time	Level 4	Y	Y		Y
	A7.3	Completely mixed water column with full salinity	Level 3	Y	Y	Y	Y
	A7.31	Completely mixed water column with full salinity and short residence time	Level 4	Y	Y		Y
	A7.32	Completely mixed water column with full salinity and medium residence time	Level 4	Y	Y		Y
	A7.33	Completely mixed water column with full salinity and long residence time	Level 4	Y	Y	Y	Y
	A7.4	Partially mixed water column with reduced	Level 3	Y	Y	Y	Y

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
		salinity and medium or long residence time					
	A7.41	Partially mixed water column with full salinity and medium residence time	Level 4	Y	Y		Y
	A7.42	Partially mixed water column with full salinity and long residence time	Level 4	Y	Y		Y
	A7.5	Unstratified water column with reduced salinity	Level 3	Y	Y	Y	Y
	A7.51	Euphotic (epipelagic) zone in unstratified reduced salinity water	Level 4	Y	Y		Y
	A7.52	Mesopelagic zone in unstratified reduced salinity water	Level 4	Y	Y		Y
	A7.53	Bathypelagic zone in unstratified reduced salinity water	Level 4	Y	Y		Y
	A7.6	Vertically stratified water column with reduced salinity	Level 3	Y	Y	Y	Y
	A7.61	Water column with ephemeral thermal stratification and reduced salinity	Level 4	Y	Y		Y
	A7.62	Water column with seasonal thermal stratification and reduced salinity	Level 4	Y	Y		Y
	A7.63	Water column with permanent thermal stratification and reduced salinity	Level 4	Y	Y		Y
	A7.64	Water column with ephemeral halocline and reduced salinity	Level 4	Y	Y		Y
	A7.65	Water column with seasonal halocline and reduced salinity	Level 4	Y	Y		Y

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
	A7.66	Water column with permanent halocline and reduced salinity	Level 4	Y	Y		Y
	A7.67	Water column with ephemeral oxygen stratification and reduced salinity	Level 4	Y	Y		Y
	A7.68	Water column with seasonal oxygen stratification and reduced salinity	Level 4	Y	Y		Y
	A7.69	Water column with permanent oxygen stratification and reduced salinity	Level 4	Y	Y		Y
	A7.7	Fronts in reduced salinity water column	Level 3	Y	Y	Y	Y
	A7.71	Ephemeral fronts in reduced salinity water column	Level 4	Y	Y		Y
	A7.72	Seasonal fronts in reduced salinity water column	Level 4	Y	Y		Y
	A7.73	Persistent fronts in reduced salinity water column	Level 4	Y	Y		Y
	A7.8	Unstratified water column with full salinity	Level 3	Y	Y	Y	Y
	A7.81	Euphotic (epipelagic) zone in unstratified full salinity water	Level 4	Y	Y	Y	Y
	A7.82	Mesopelagic zone in unstratified full salinity water	Level 4	Y	Y	Y	Y
	A7.83	Bathypelagic zone in unstratified full salinity water	Level 4	Y	Y		Y
	A7.9	Vertically stratified water column with full salinity	Level 3	Y	Y	Y	Y
	A7.91	Water column with ephemeral thermal stratification and full salinity	Level 4	Y	Y		Y

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
	A7.92	Water column with seasonal thermal stratification and full salinity	Level 4	Y	Y		Y
	A7.93	Water column with permanent thermal stratification and full salinity	Level 4	Y	Y		Y
	A7.94	Water column with ephemeral halocline and full salinity	Level 4	Y	Y		Y
	A7.95	Water column with seasonal halocline and full salinity	Level 4	Y	Y		Y
	A7.96	Water column with permanent halocline and full salinity	Level 4	Y	Y		Y
	A7.97	Water column with ephemeral oxygen stratification and full salinity	Level 4	Y	Y		Y
	A7.98	Water column with seasonal oxygen stratification and full salinity	Level 4	Y	Y		Y
	A7.99	Water column with permanent oxygen stratification and full salinity	Level 4	Y	Y		Y
	A7.A	Fronts in full salinity water column	Level 3	Y	Y	Y	Y
	A7.A1	Ephemeral fronts in full salinity water column	Level 4	Y	Y		Y
	A7.A2	Seasonal fronts in full salinity water column	Level 4	Y	Y		Y
	A7.A3	Persistent fronts in full salinity water column	Level 4	Y	Y		Y
A8. Ice-associated marine habitats (Level 2)							
	A8.1	Sea ice	Level 3	N(3)			

EUNIS Habitat type: Code, Name and Level			EUNIS Level 3/4	Included in the Habitat proxy assessment (Matrix)	Scored (incl. 0 score)	Scored (excl. 0 score)	Included in EUNIS habitat maps
	A8.2	Freshwater ice	Level 3	N(3)			
	A8.3	Brine channels	Level 3	N(3)			
	A8.4	Under ice habitat	Level 3	N(3)			
X. Habitat complexes (Level 1)							
	X01	Estuaries	Level 2	Y	Y	Y	
	X02	Saline coastal lagoons	Level 2	Y	Y	Y	
	X03	Brackish coastal lagoons	Level 2	Y	Y	Y	
	X30	Bentho-pelagic habitats	Level 2	Y	Y	Y	
	X31	Mosaics of mobile and non-mobile substrata in the littoral zone	Level 2	Y	Y	Y	
	X32	Mosaics of mobile and non-mobile substrata in the infralittoral zone	Level 2	Y	Y	Y	
	X33	Mosaics of mobile and non-mobile substrata in the circalittoral zone	Level 2	Y	Y	Y	
	X34	Anchihaline caves	Level 2	Y			

Appendix C. Evidence on actual species distribution

This appendix combines the evidence gathered on the actual distribution of each studied species, as used in this study.

This includes:

- Where data-based models were applied, map of the actual distribution of aggregations of the species/life stage as directly derived from the survey data used for the model calibration. The map shows the relative frequency of occurrence of aggregations across the surveys within the study period (2010 - 2020). Individual survey hauls were grouped within 5x5km grid cells for the calculation of the frequency of occurrence, with the grid cell centroid being shown as a point in the map. For details about these surveys, the identification of the life stages of interest and of aggregations of them, see section 2.2.1 of the main report.
- Map(s) derived from the analysis of additional survey data (not used for the modelling) showing survey data points categorised according to presence of aggregations, generic presence (not as aggregation) and absence of the species/life stage. For details about these surveys, see section 2.4.1 of the main report. To allow comparability with the predicted maps, the identification of the life stages of interest (by size, season etc) and of aggregations (as top quartile CPUE catches in the survey) followed the same method as used for the modelled survey data (see section 2.2.1 of the main report for details). These maps are zoomed to the extent of the survey data available.
- Maps providing evidence on the distribution of the species or areas identified as key for them, as obtained from the literature (articles, reports, policy documents, etc). These include for example maps of areas specifically identified for the protection of the species and its habitats (MPAs etc), or maps summarising evidence on te species distribution from different sources.

The maps are shown by species and relevant life stage.

C1. Lesser sandeel (*Ammodytes marinus*)

C1.1 Any life stage

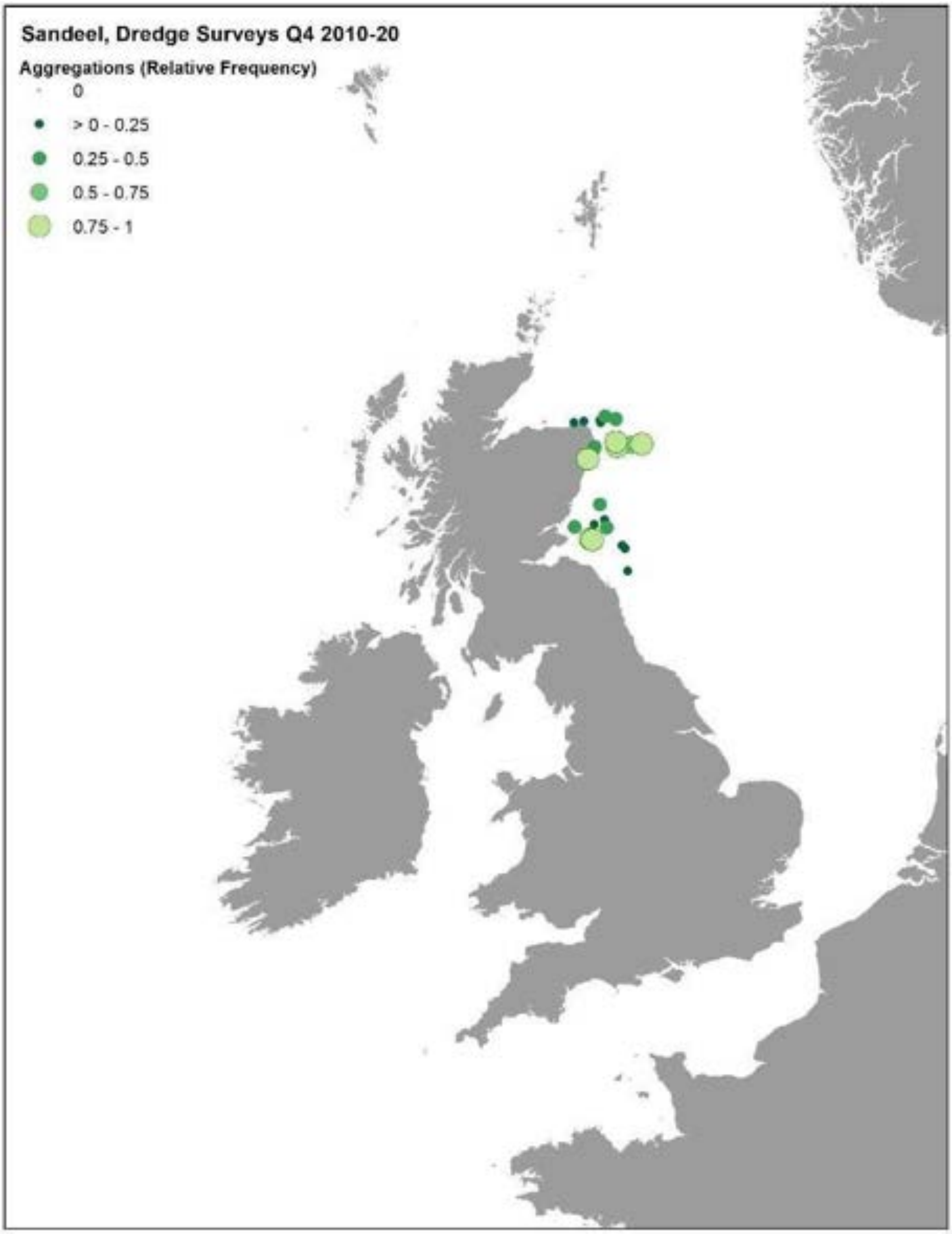


Figure C1. Lesser sandeel (*Ammodytes marinus*): relative frequency of presence of aggregations in Sandeel Dredge Surveys within 2010 - 2020 period (Q4, mostly December; data used to calibrate model).

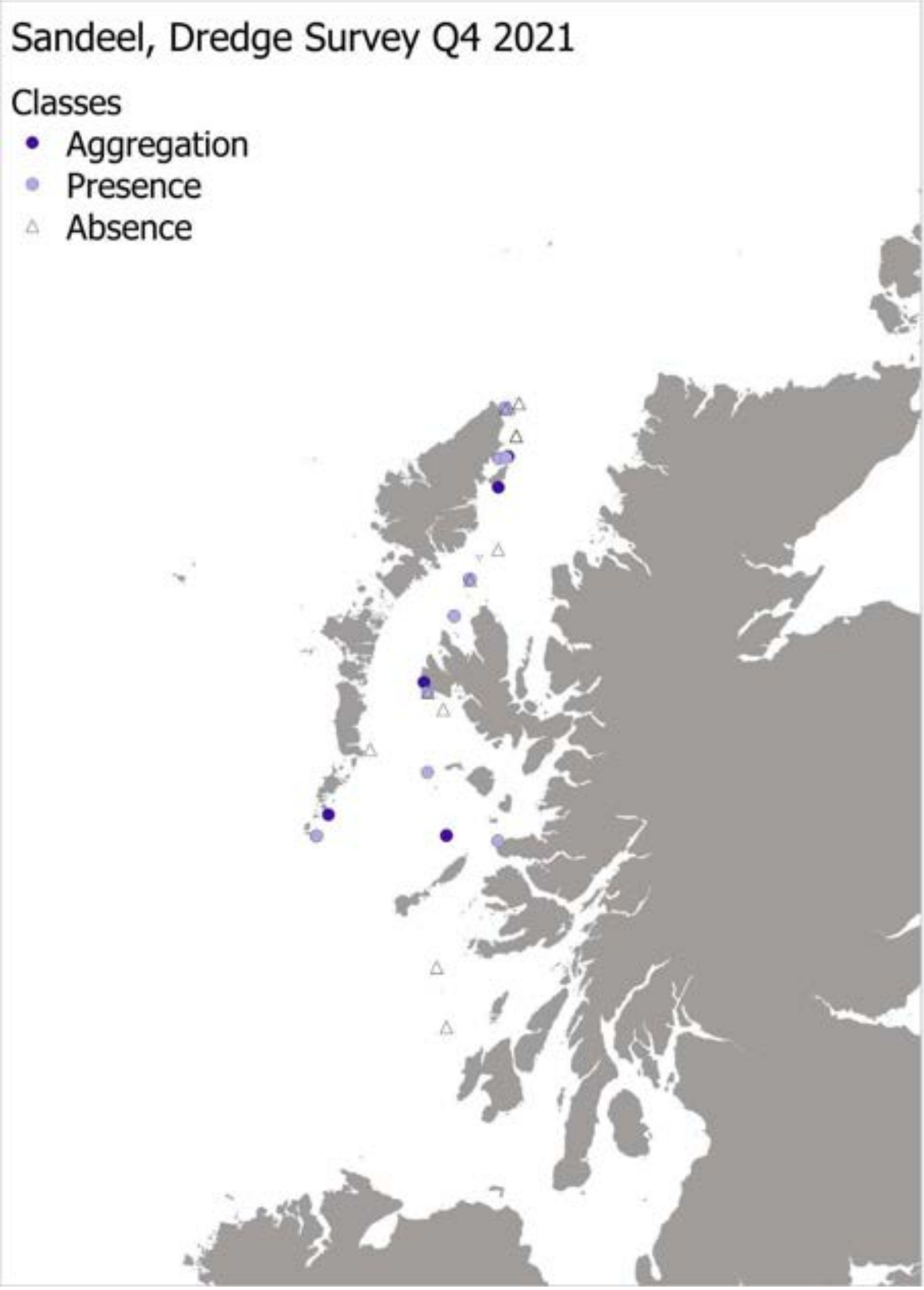


Figure C2. Lesser sandeel (*Ammodytes marinus*): Presence/Absence of the species and their aggregations in Sandeel Dredge Survey in December 2021 (data not used in the modelling).

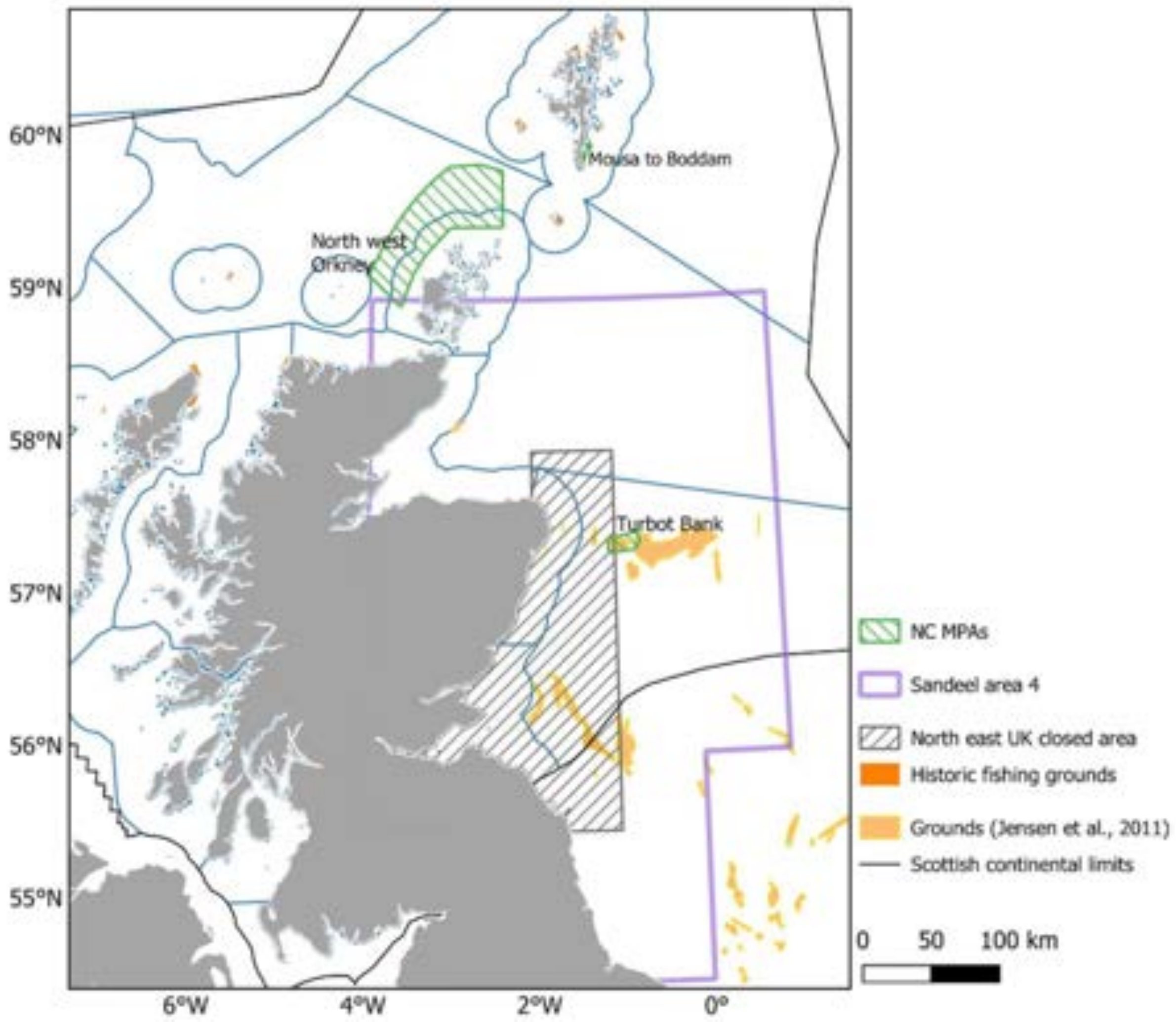


Figure C3. ICES assessment area 4 and various spatial measures for sandeels within Scottish waters. Blue lines show Scottish Marine and Offshore Regions for context. From: Marine Scotland (2022).

C2. Norway lobster (*Nephrops norvegicus*)

C2.1 Any life stage

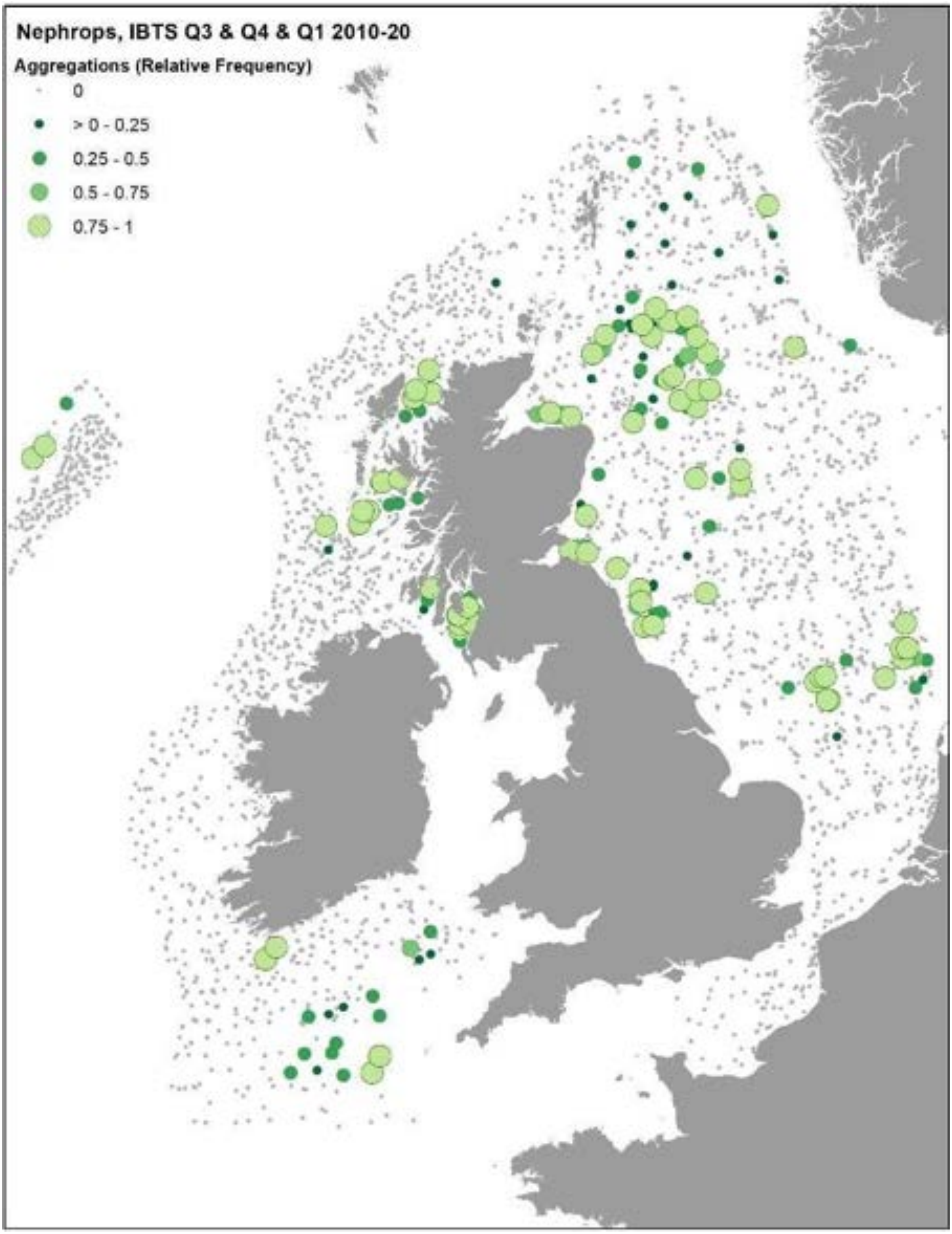


Figure C4. Norway lobster (*Nephrops norvegicus*): relative frequency of presence of aggregations in International Bottom Trawl Surveys (IBTS) within 2010 - 2020 period (Q3+Q4+Q1; data used to calibrate model).

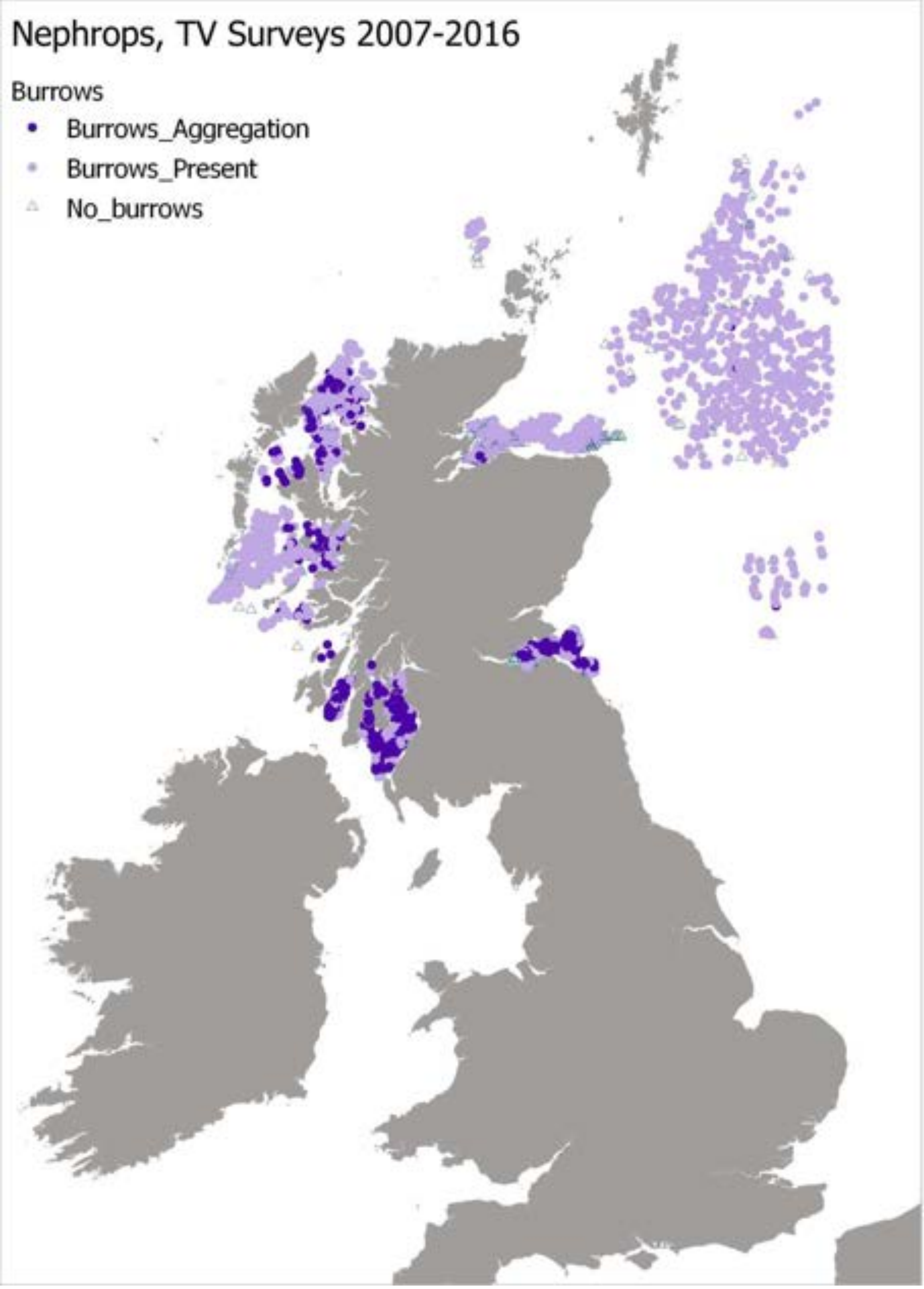


Figure C5. Norway lobster (*Nephrops norvegicus*): Presence/Absence of *Nephrops* burrows and their aggregations (top quartile burrow density) in *Nephrops* Burrows TV Surveys 2007-2016 (any Quarter).

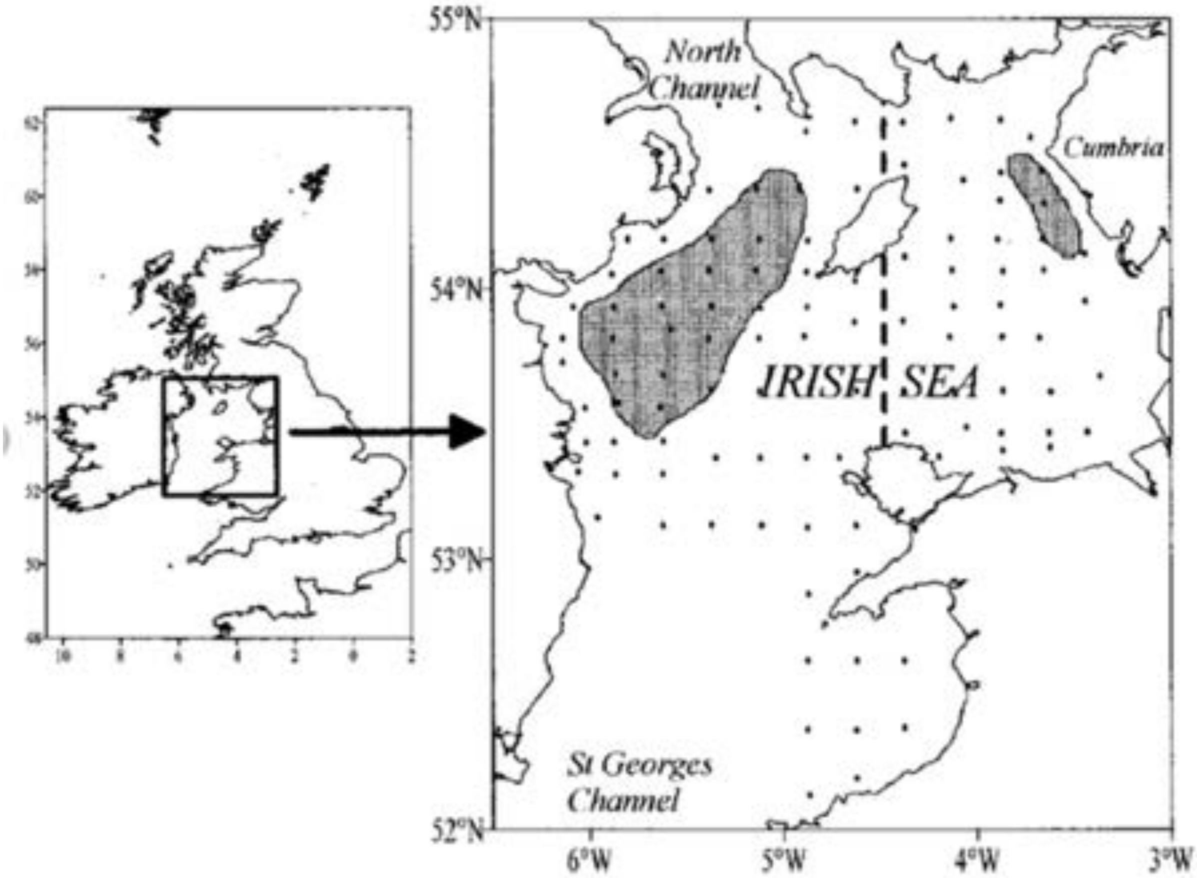


Figure C6. Location of *Nephrops* grounds in the Irish Sea (shaded areas). Source: Dickey-Collas et al. (2000).

C3. Herring (*Clupea harengus*)

C3.1 Spawning

Additional survey data were not available to identify herring spawning. The summary map of spatial data on herring spawning grounds in Scottish waters (below) as published in Frost and Diele (2022) was used instead for comparison.

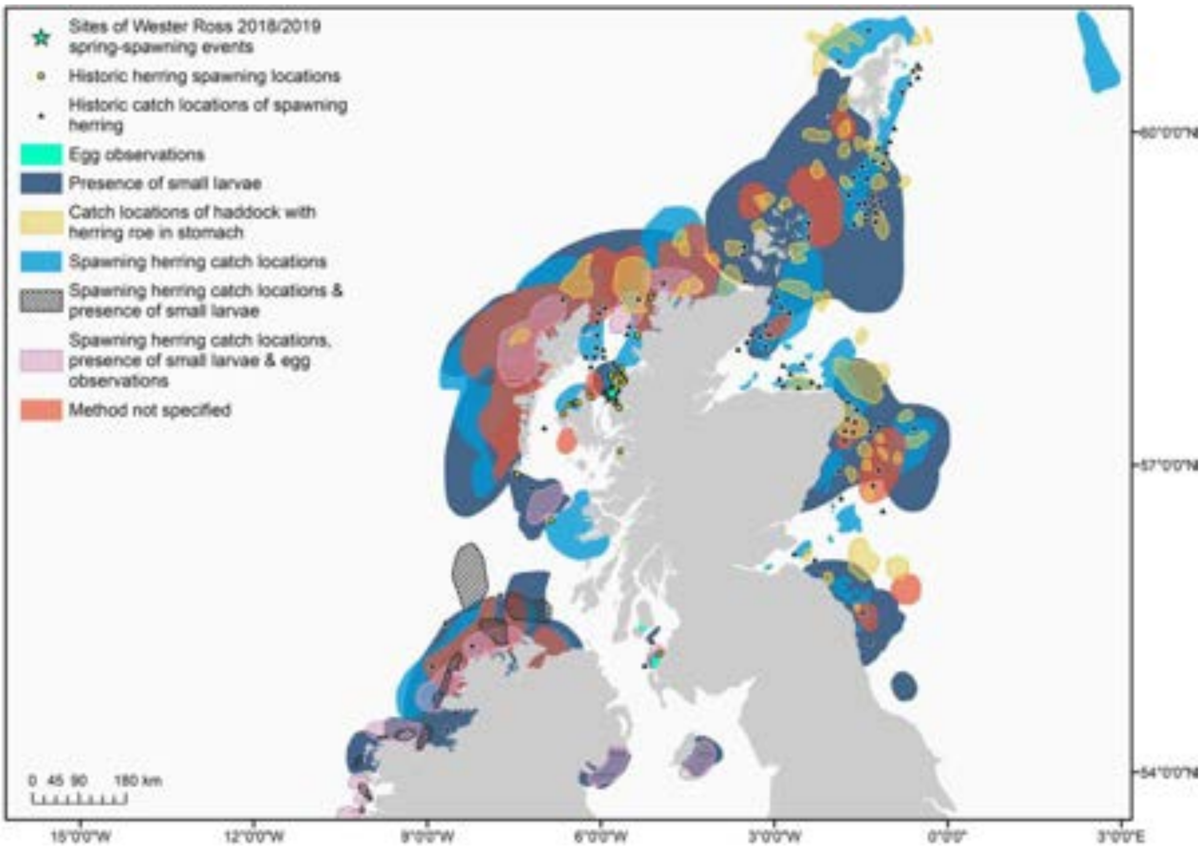


Figure C7. Spawning herring (*Clupea harengus*): Spatial-temporal data on herring reproduction, spawning grounds and larval occurrences in different seasons between 1990 and 2018 for ICES areas IV, VI and VII (including Isle of Man) (d). Polygons represent spawning areas identified based on different evidence (e.g. occurrence ripe or spawning herring, of herring eggs (on the seabed or in stomach of predator fish), of herring larvae). Point locations are also included for historic data on the catch locations of ripe or running herring, historic spawning grounds mentioned by fishers (a, b, c), and spawning grounds filmed off Wester Ross in 2018/2019. Source: Frost and Diele (2022).

C4. Plaice (*Pleuronectes platessa*)

C4.1 Juvenile

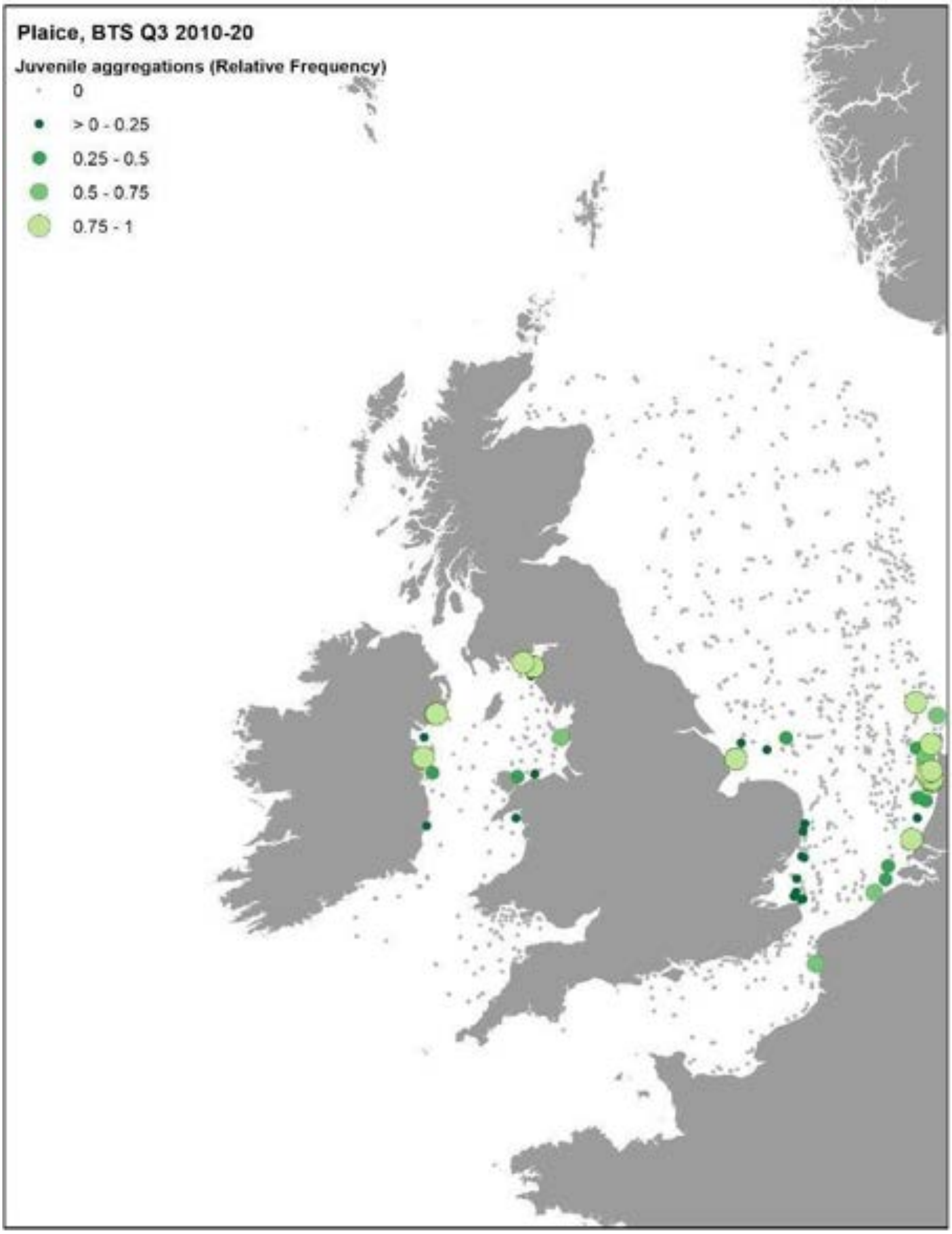


Figure C8. Juvenile plaice (*Pleuronectes platessa*, 0-group): relative frequency of presence of aggregations in Beam Trawl Surveys (BTS) within 2010 - 2020 period (Q3; data used to calibrate model).

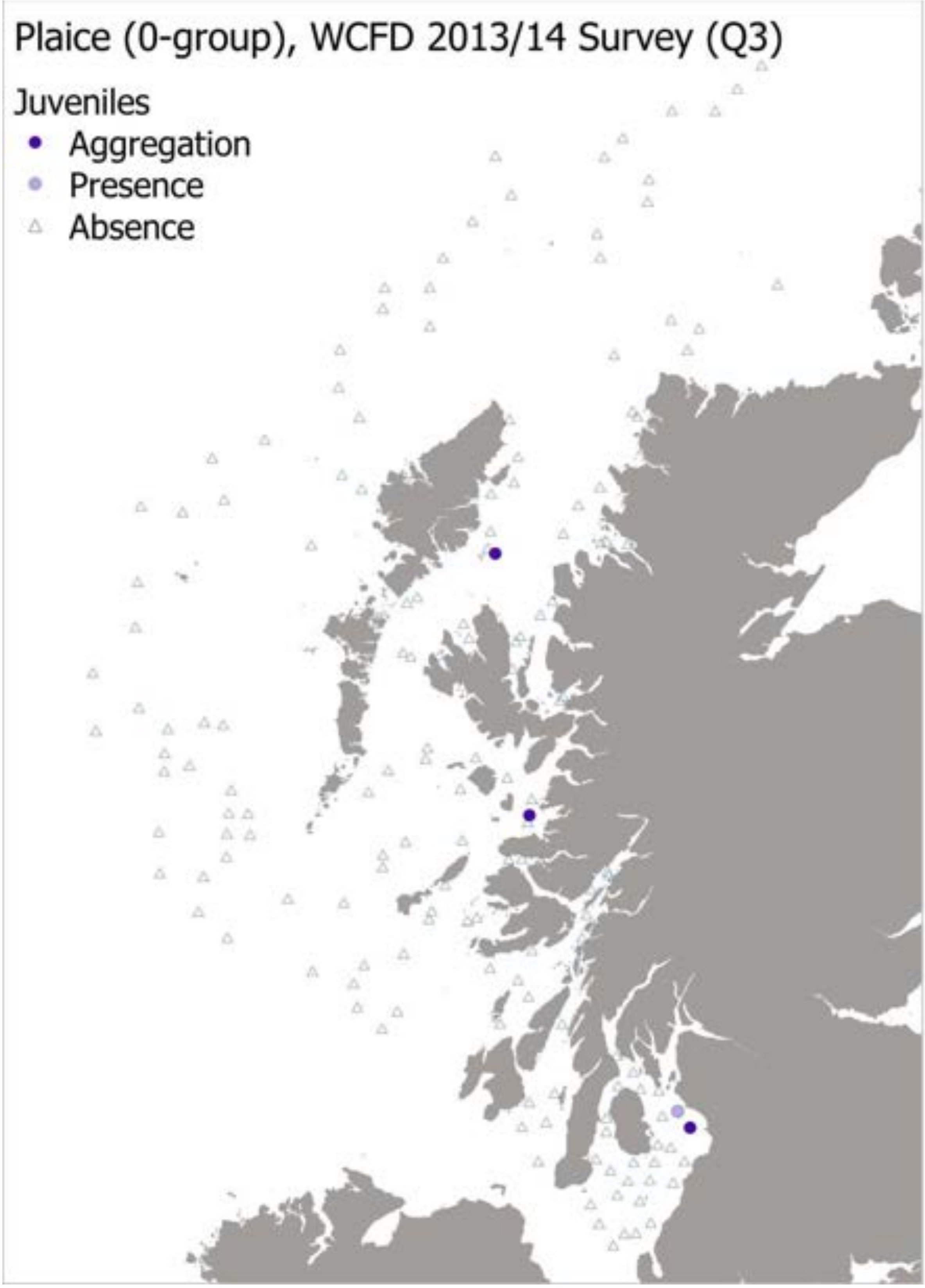


Figure C9. Juvenile plaice (*Pleuronectes platessa*, 0-group) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14: Presence/Absence of juveniles and their aggregations in Q3 catches.

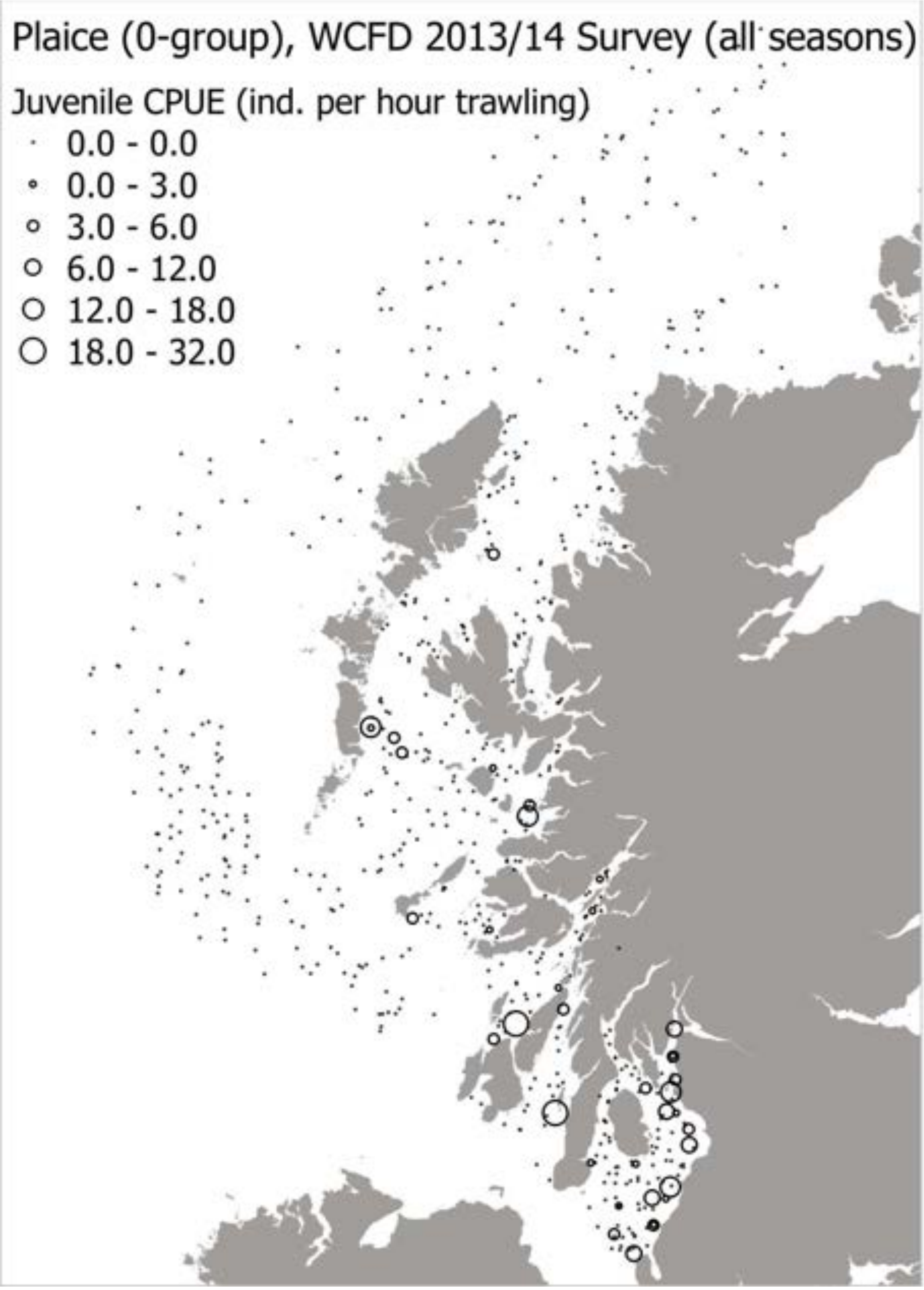


Figure C10. Juvenile plaice (*Pleuronectes platessa*, 0-group) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14:Mean CPUE (individuals per hour) in hauls from all seasons.

C5. Lemon sole (*Microstomus kitt*)

C5.1 Juvenile

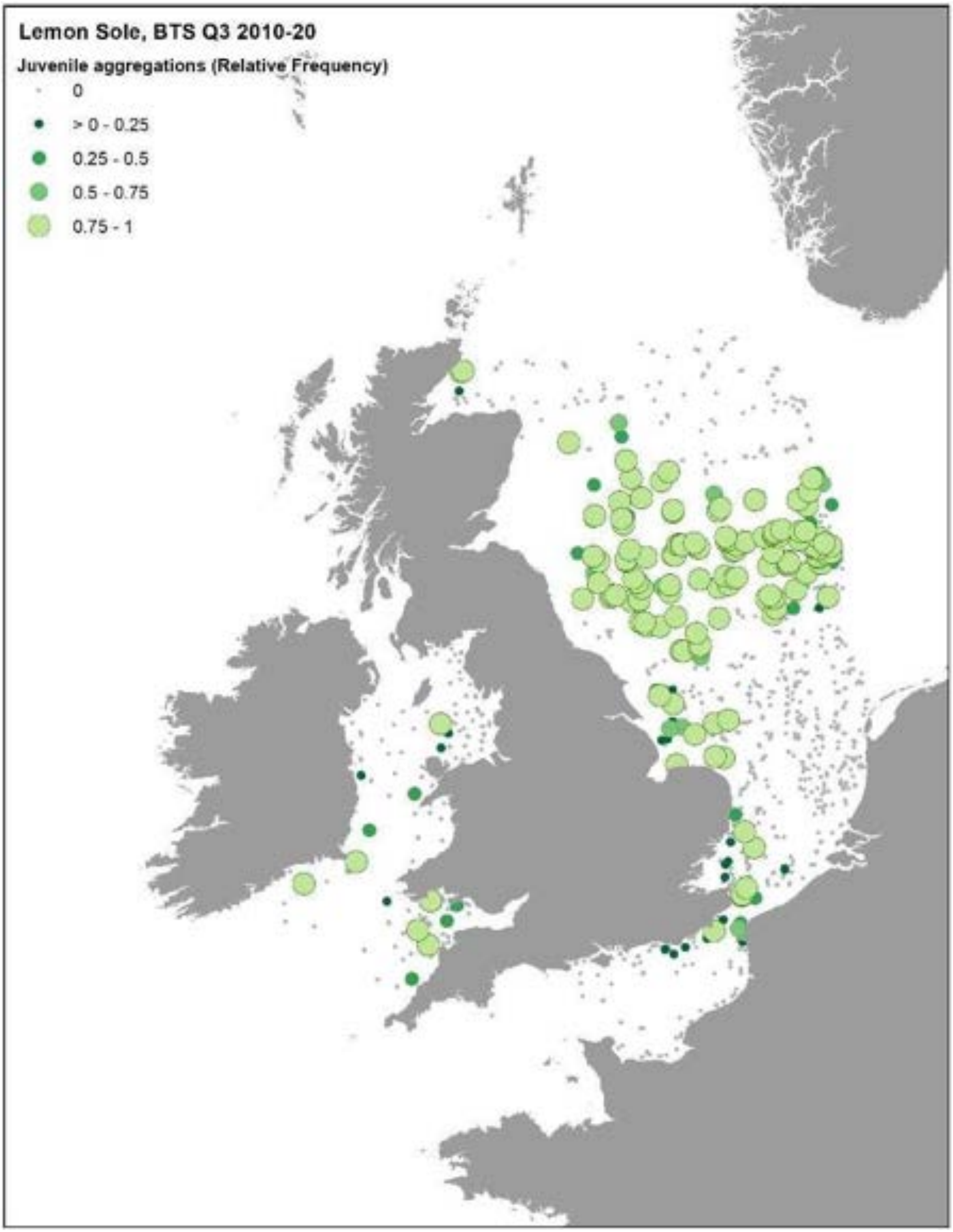


Figure C11. Juvenile lemon sole (*Microstomus kitt*, 0-group): relative frequency of presence of aggregations in Beam Trawl Surveys (BTS) within 2010 - 2020 period (Q3; data used to calibrate model).

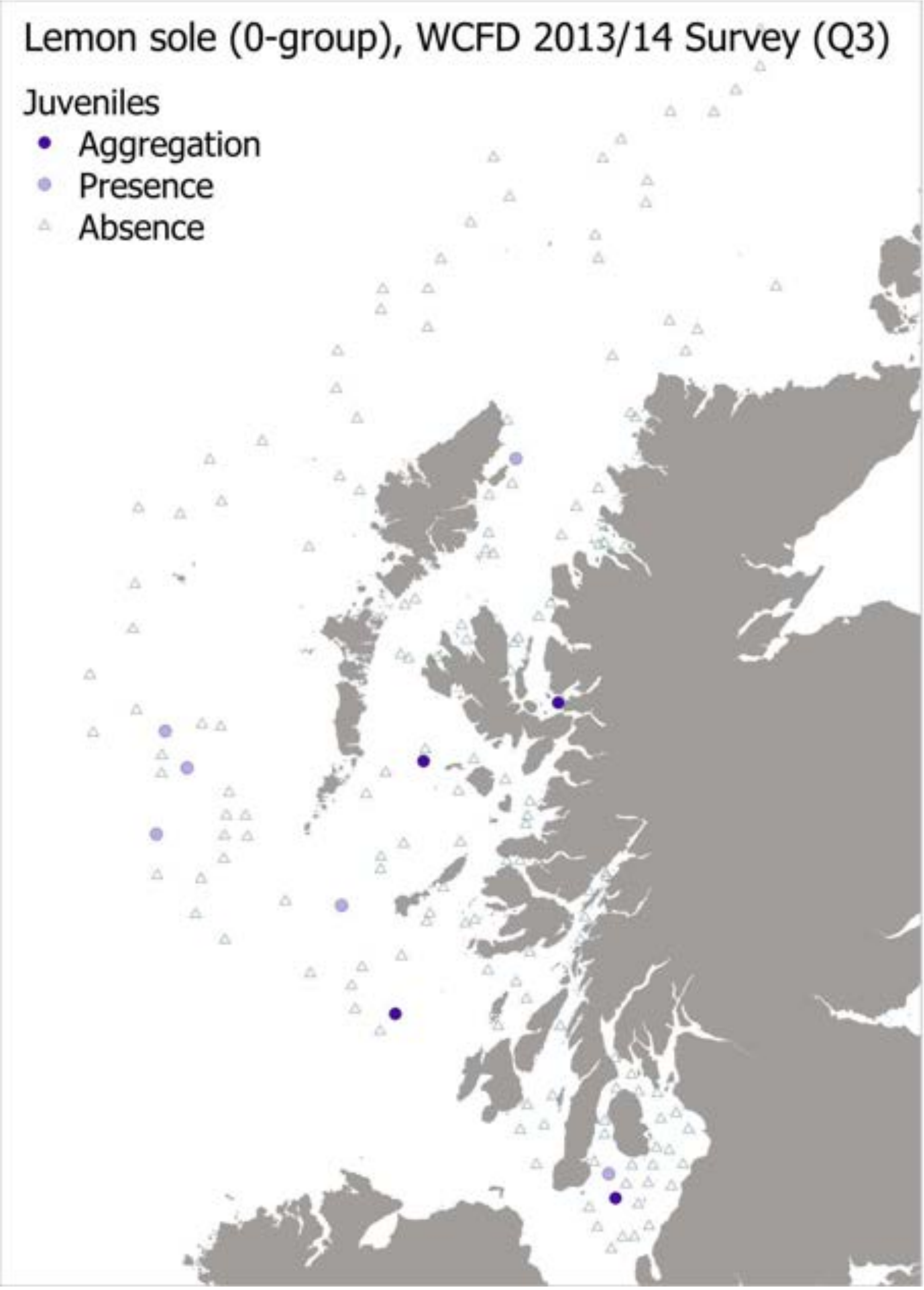


Figure C12. Juvenile lemon sole (*Microstomus kitt*, 0-group): Presence/Absence of juveniles and their aggregations in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14 (Q3).

C6. Common sole (*Solea solea*)

C6.1 Juvenile

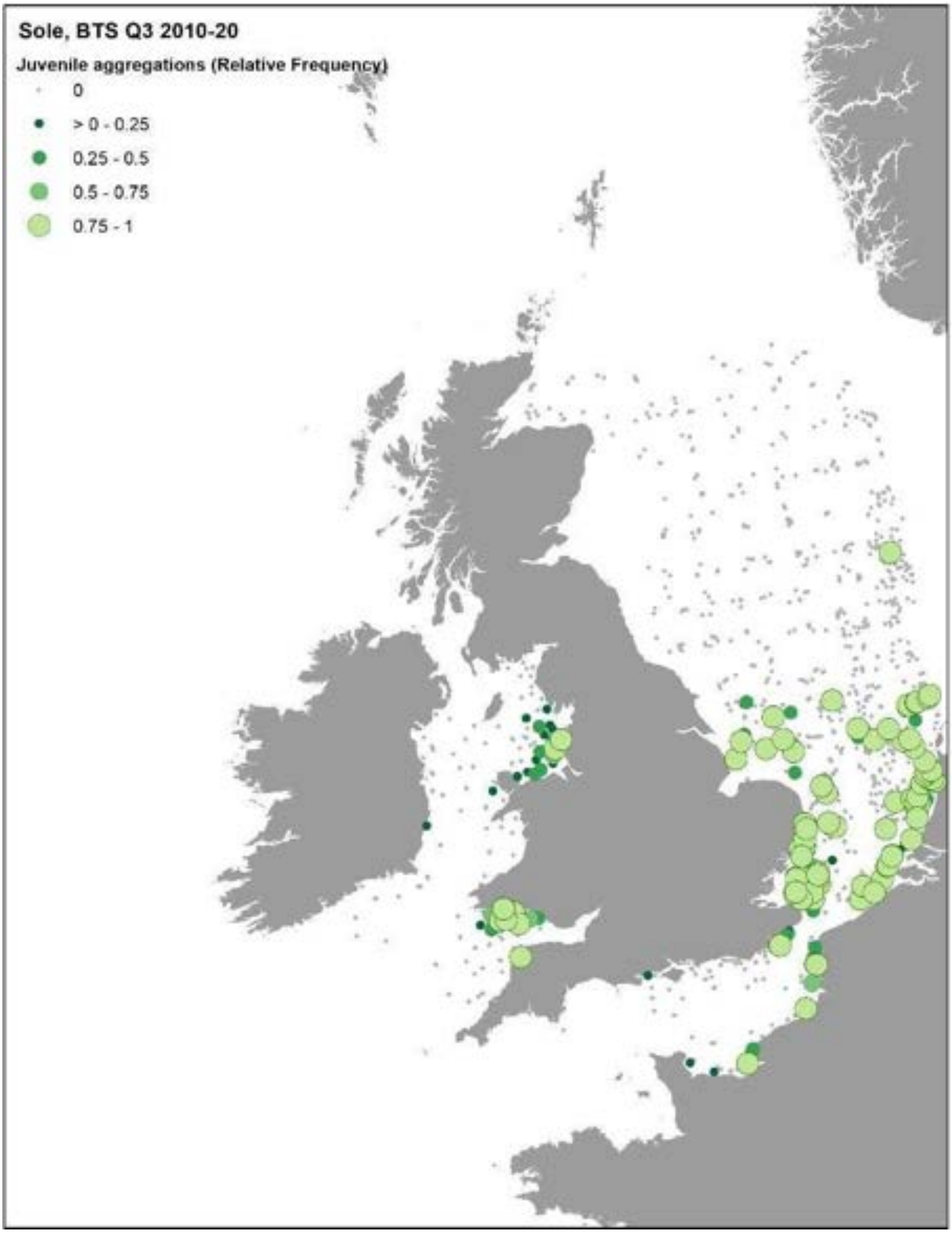


Figure C13. Juvenile common sole (*Solea solea*, 0- and 1-groups): relative frequency of presence of aggregations in Beam Trawl Surveys (BTS) within 2010 - 2020 period (Q3; data used to calibrate model).

C7. Anglerfish (*Lophius piscatorius*)

C7.1 Juvenile

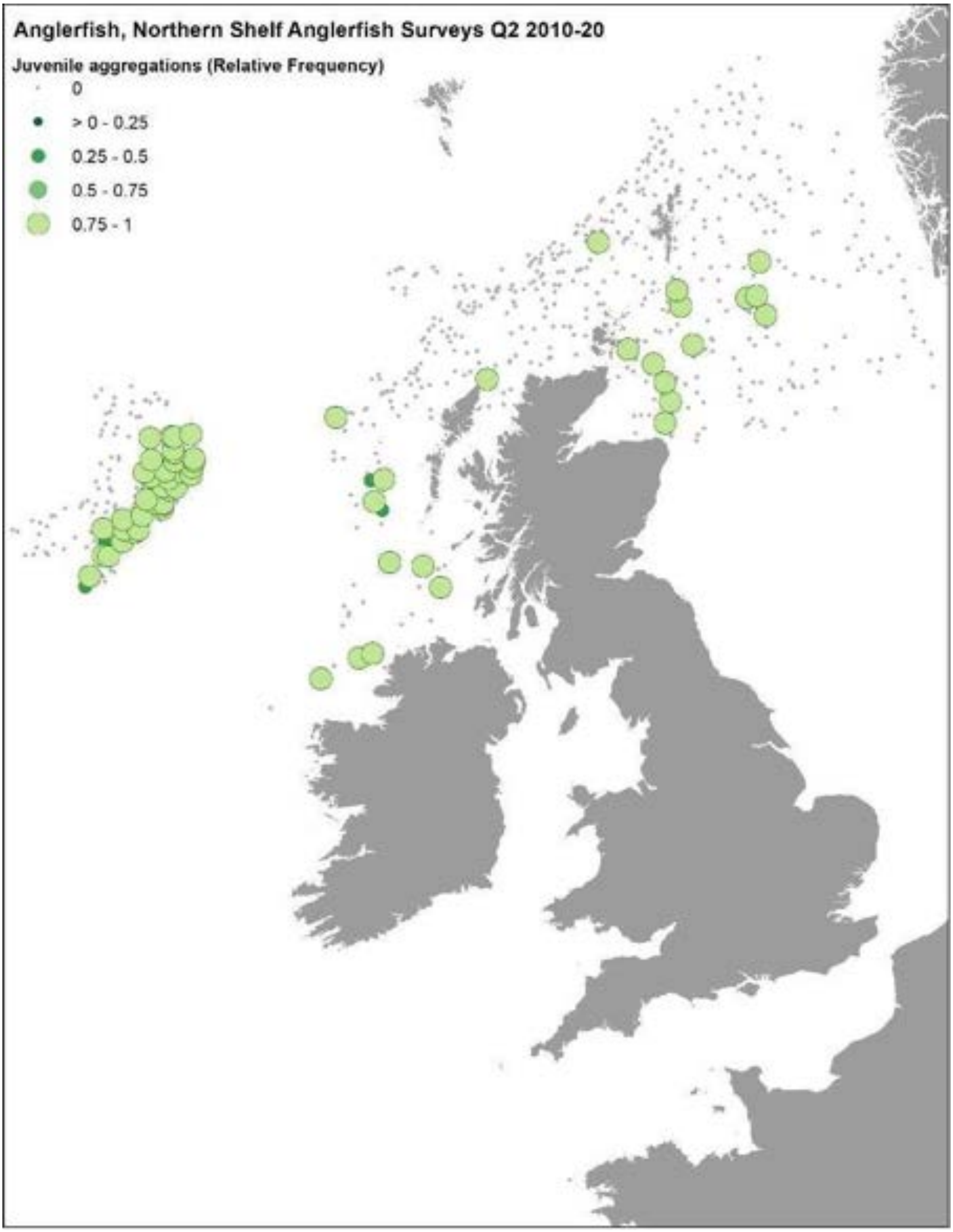


Figure C14. Juvenile anglerfish (*Lophius piscatorius*, 0- and 1-groups): relative frequency of presence of aggregations in Northern Shelf Anglerfish Surveys (SIAMISS) within 2010 - 2020 period (Q2; data used to calibrate model).

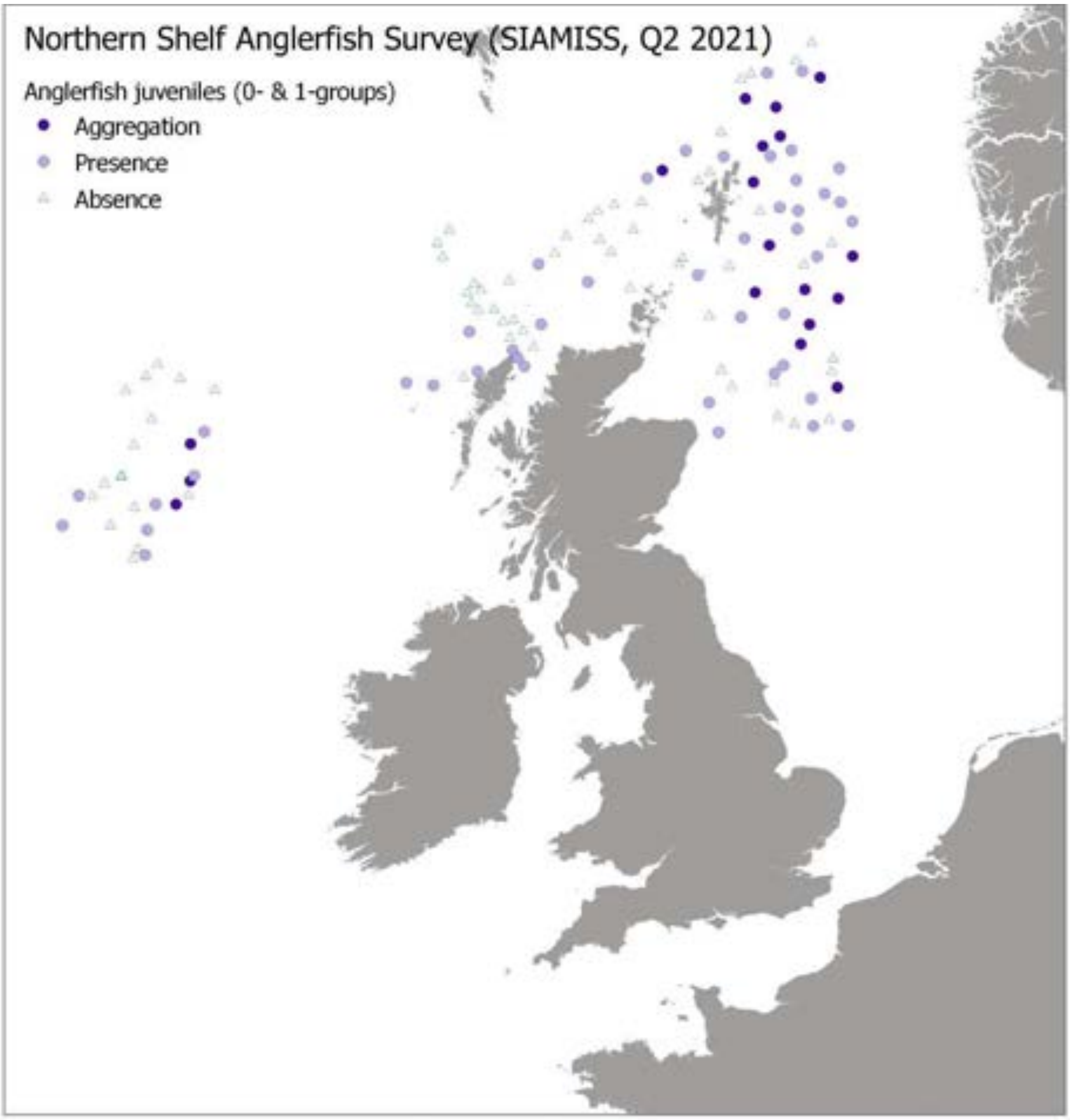


Figure C15. Juvenile anglerfish (*Lophius piscatorius*, 0- and 1-groups): Presence/Absence of juveniles and their aggregations in the 2021 Northern Shelf Anglerfish Survey (SIAMISS) (Q2).

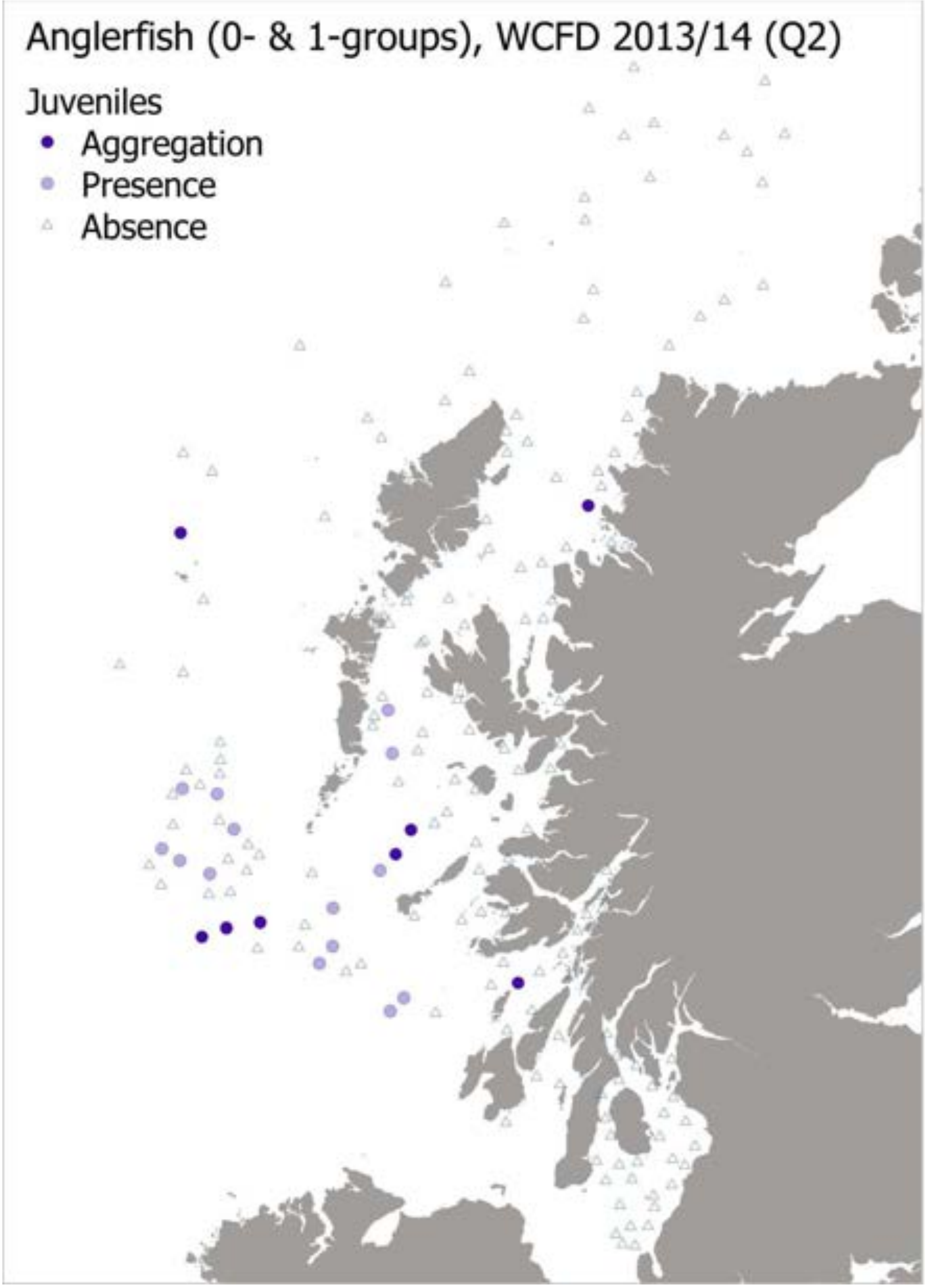


Figure C16. Juvenile anglerfish (*Lophius piscatorius*, 0- and 1-groups): Presence/Absence of juveniles and their aggregations in the West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14 (Q2).

C8. Whiting (*Merlangius merlangus*)

C8.1 Juvenile

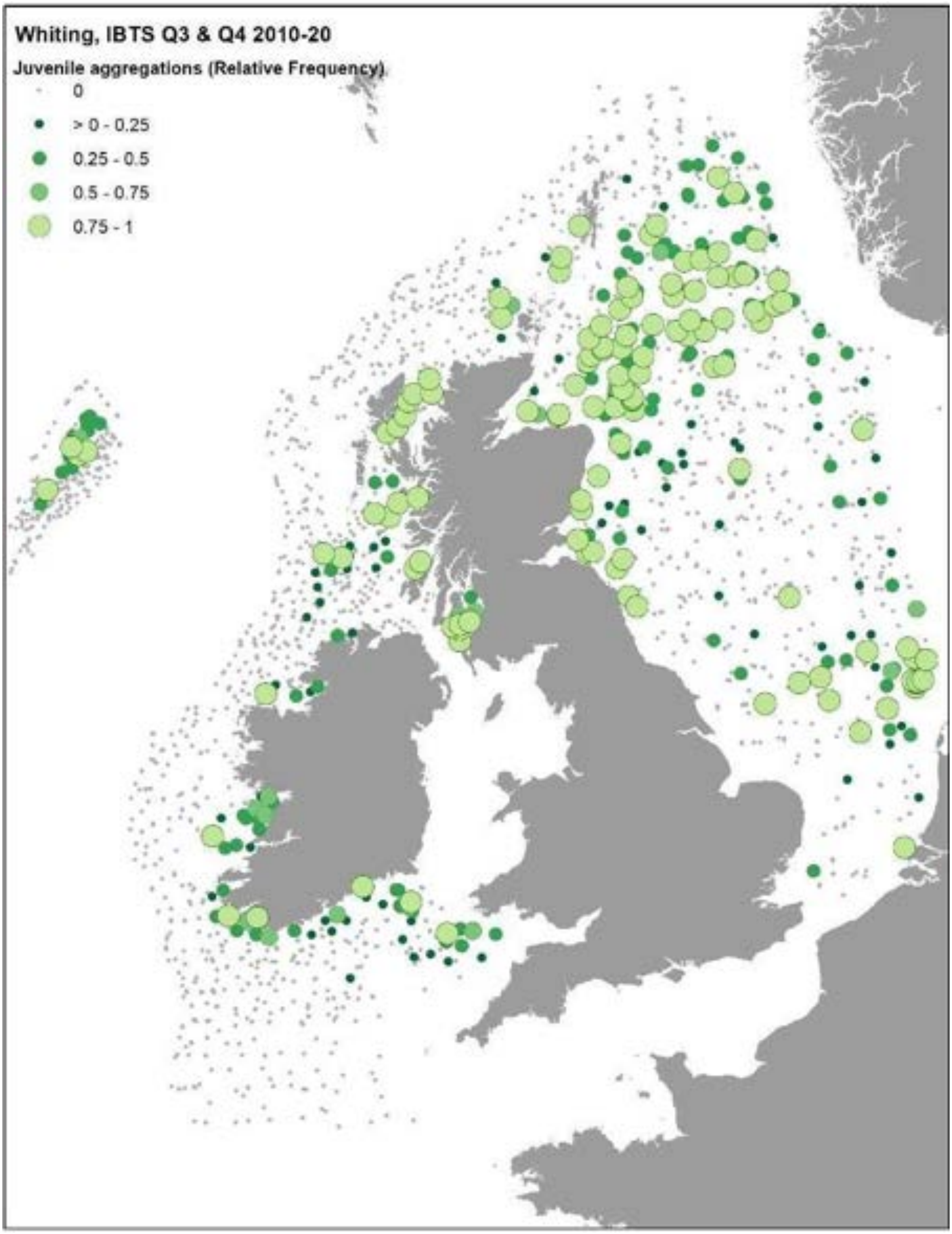


Figure C17. Juvenile whiting (*Merlangius merlangus*, 0-group): relative frequency of presence of aggregations in International Bottom Trawl Surveys (IBTS) within 2010 - 2020 period (Q3+Q4; data used to calibrate model).

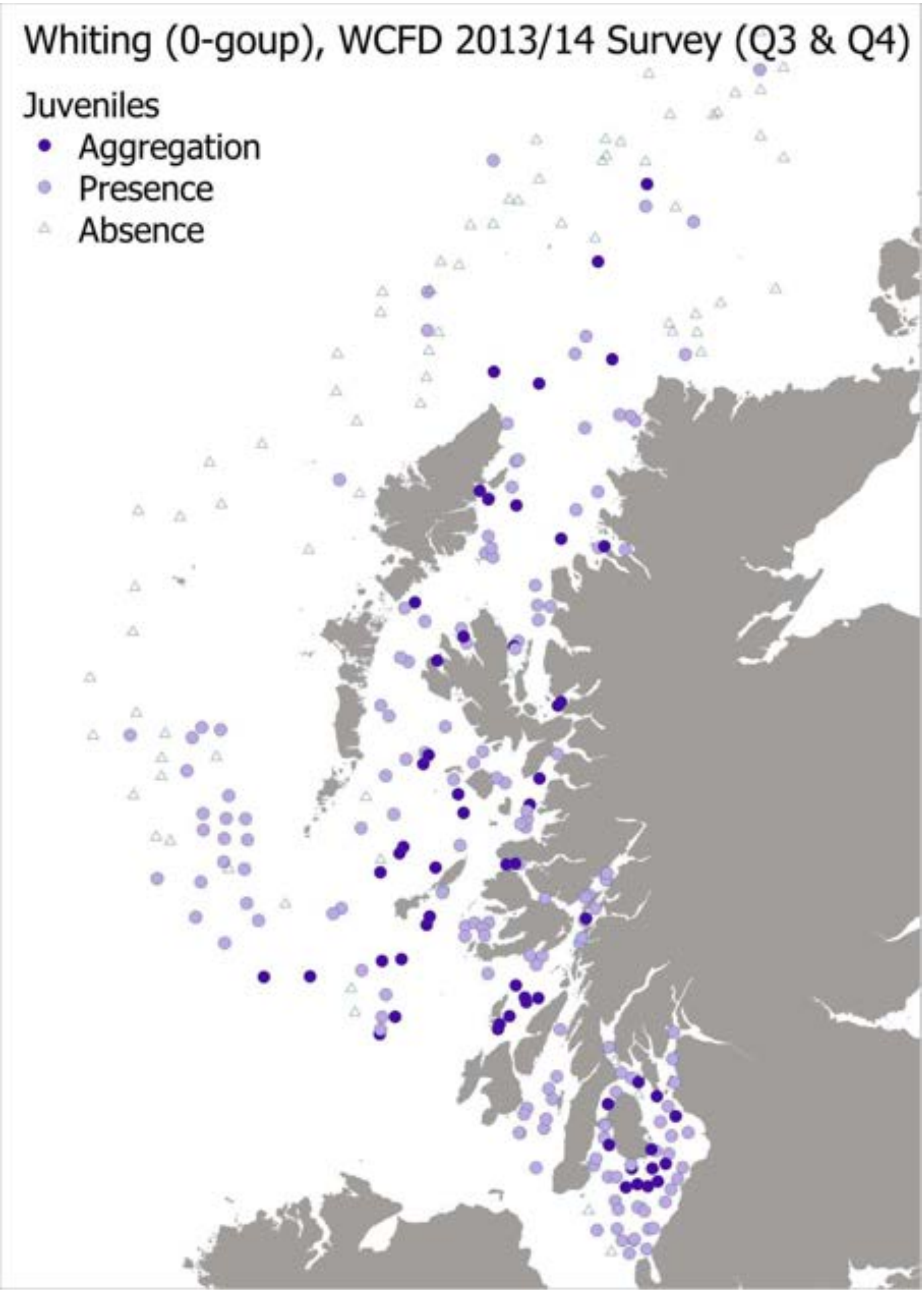


Figure C18. Juvenile whiting (*Merlangius merlangus*, 0-group) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14: Presence/Absence of juveniles and their aggregations in Q3 & Q4 catches.

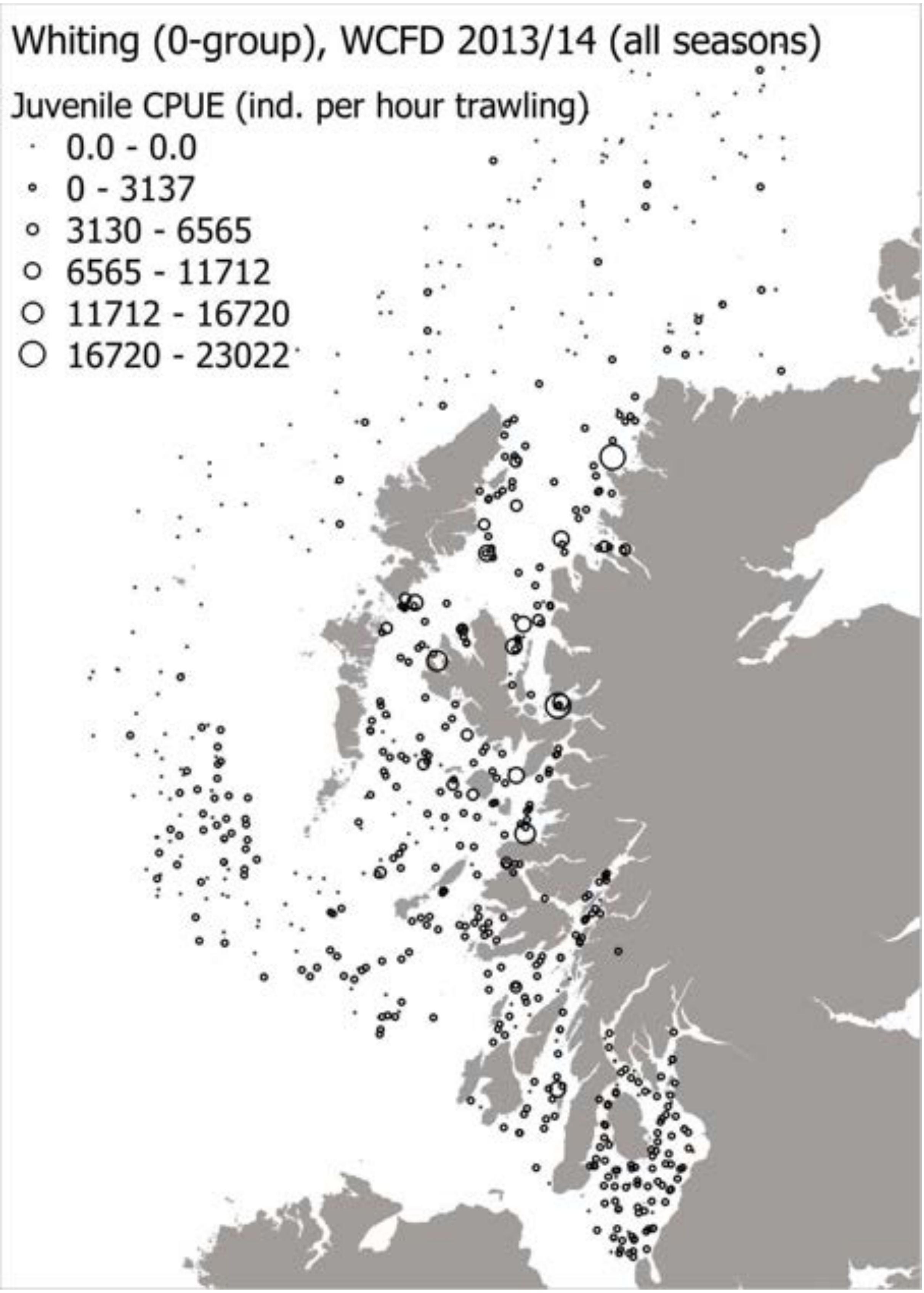


Figure C19. Juvenile whiting (*Merlangius merlangus*, 0-group) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14: Mean CPUE (individuals per hour) in hauls from all season.

C8.2 Spawning

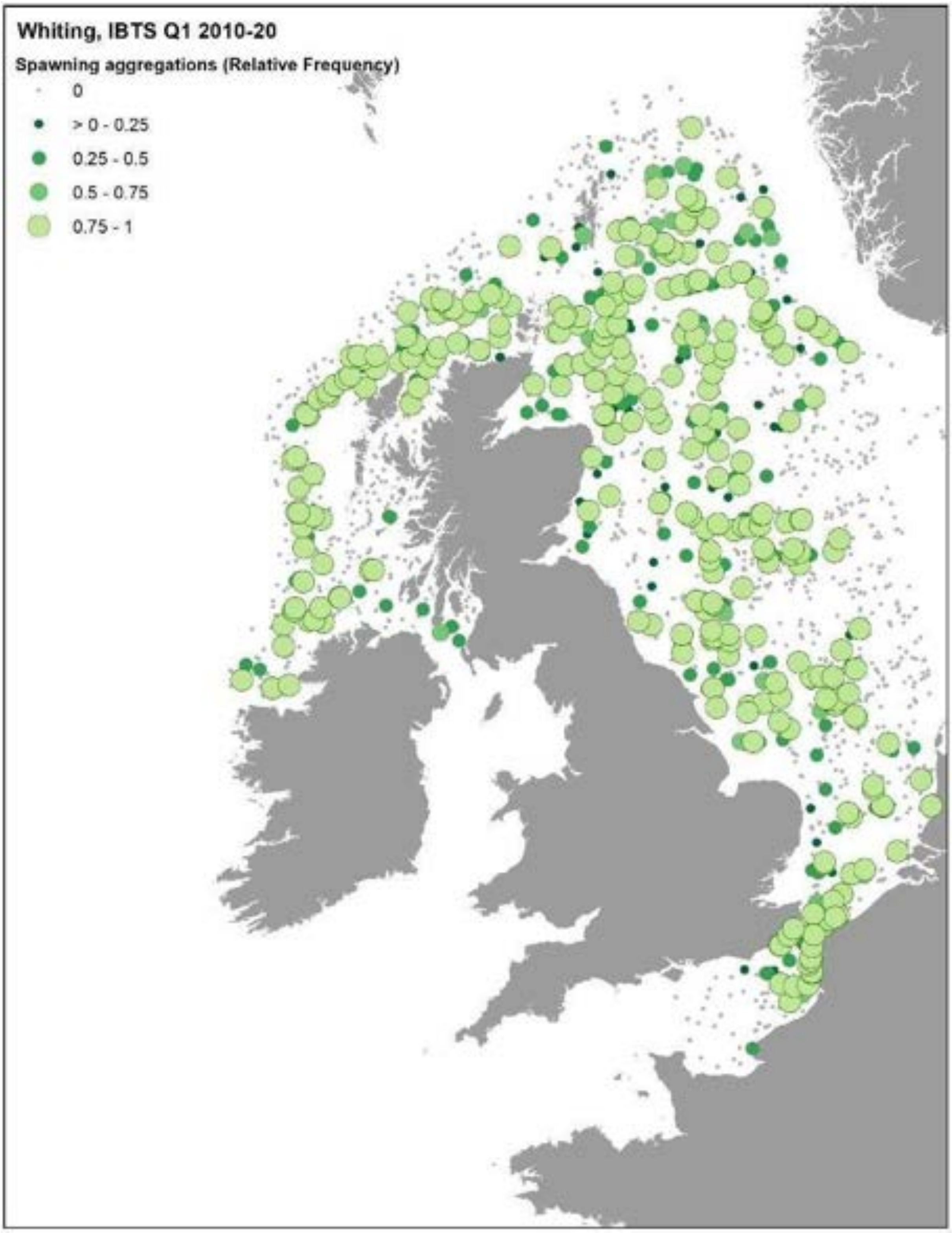


Figure C20. Spawning whiting (*Merlangius merlangus*, 'running' adults): relative frequency of presence of aggregations in International Bottom Trawl Surveys (IBTS) within 2010 - 2020 period (Q1; data used to calibrate model).

C9. Cod (*Gadus morhua*)

C9.1 Spawning

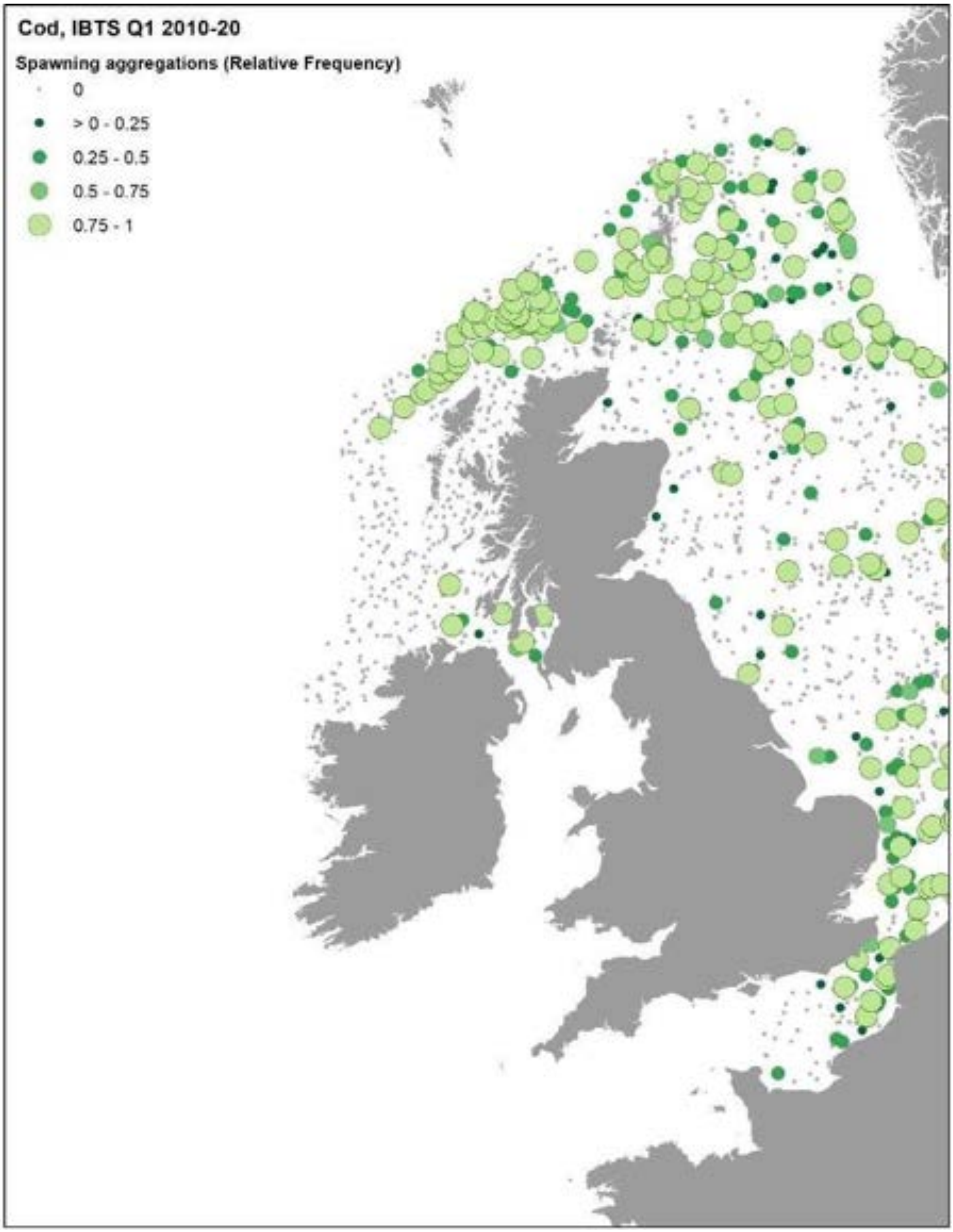


Figure C21. Spawning cod (*Gadus morhua*, 'running' adults): relative frequency of presence of aggregations in International Bottom Trawl Surveys (IBTS) within 2010 - 2020 period (Q1; data used to calibrate model).

C9.2 Juvenile

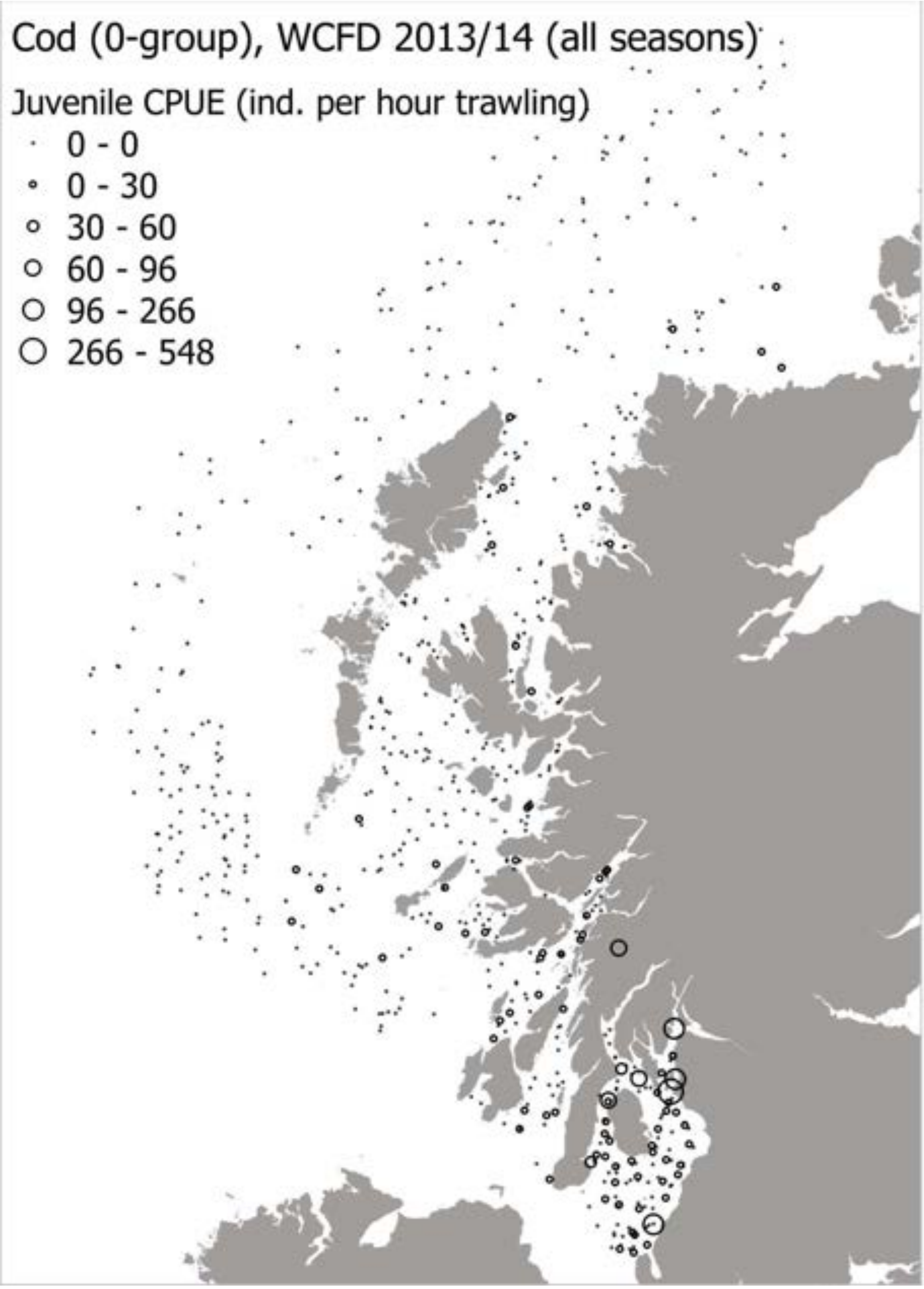


Figure C22. Juvenile cod (*Gadus morhua*, 0-group) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14: Mean CPUE (individuals per hour) in hauls from all seasons.

C10. Haddock (*Melanogrammus aeglefinus*)

C10.1 Spawning

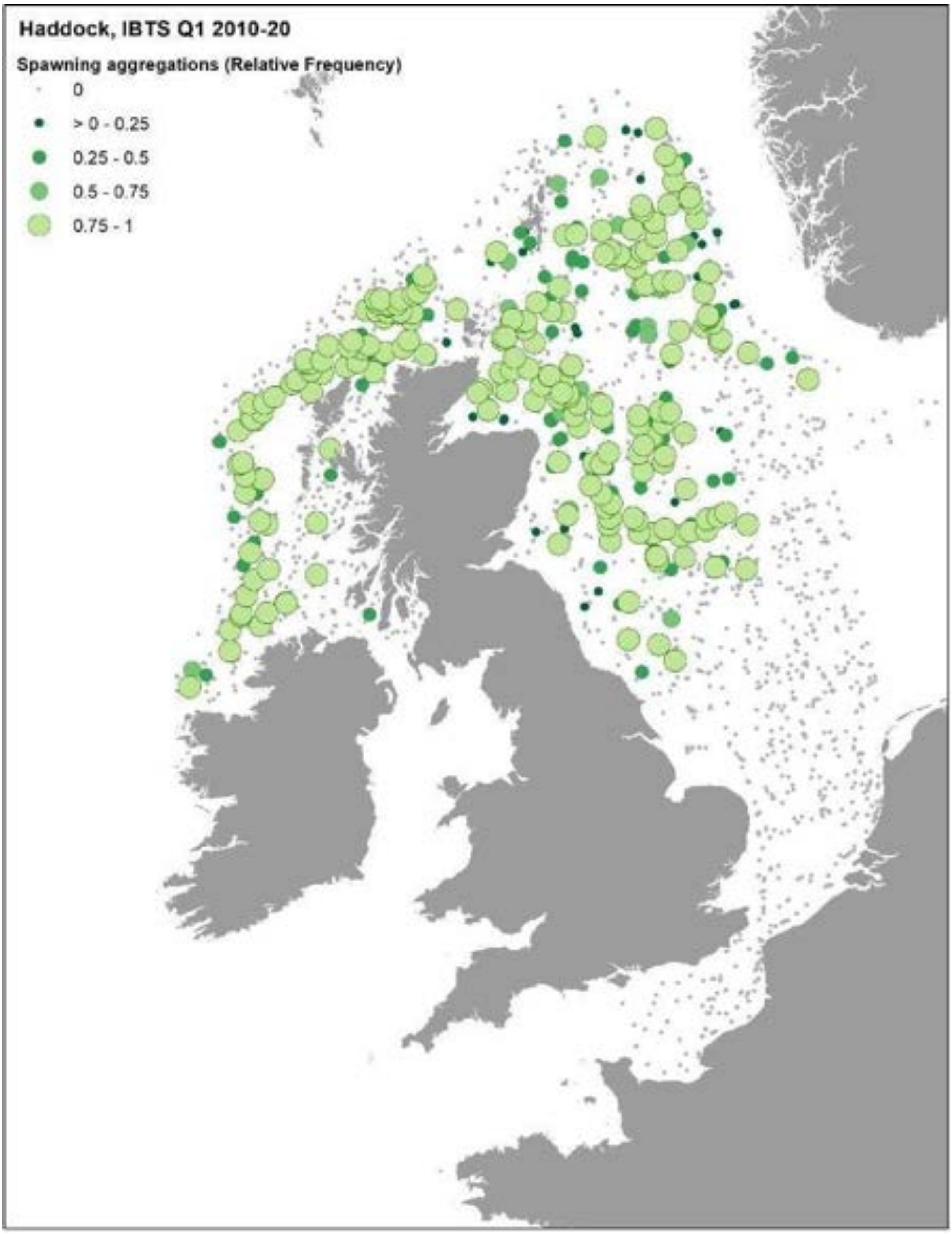


Figure C23. Spawning haddock (*Melanogrammus aeglefinus*, 'running' adults): relative frequency of presence of aggregations in International Bottom Trawl Surveys (IBTS) within 2010 - 2020 period (Q1; data used to calibrate model).

C11. Norway pout (*Trisopterus esmarkii*)

C11.1 Spawning

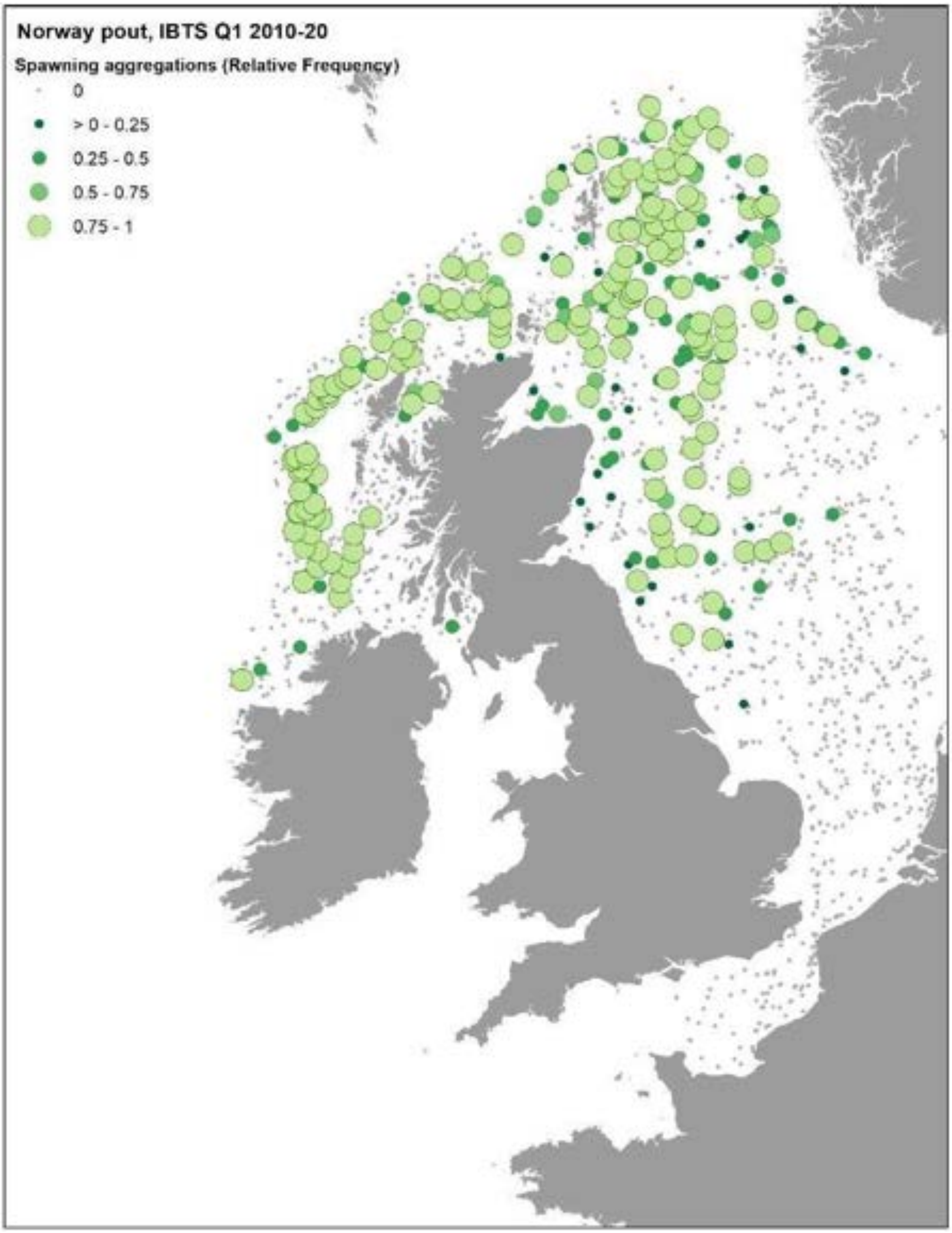


Figure C24. Spawning Norway pout (*Trisopterus esmarkii*, 'running' adults): relative frequency of presence of aggregations in International Bottom Trawl Surveys (IBTS) within 2010 - 2020 period (Q1; data used to calibrate model).

C12. Blue whiting (*Micromesistius poutassou*)

C12.1 Juvenile

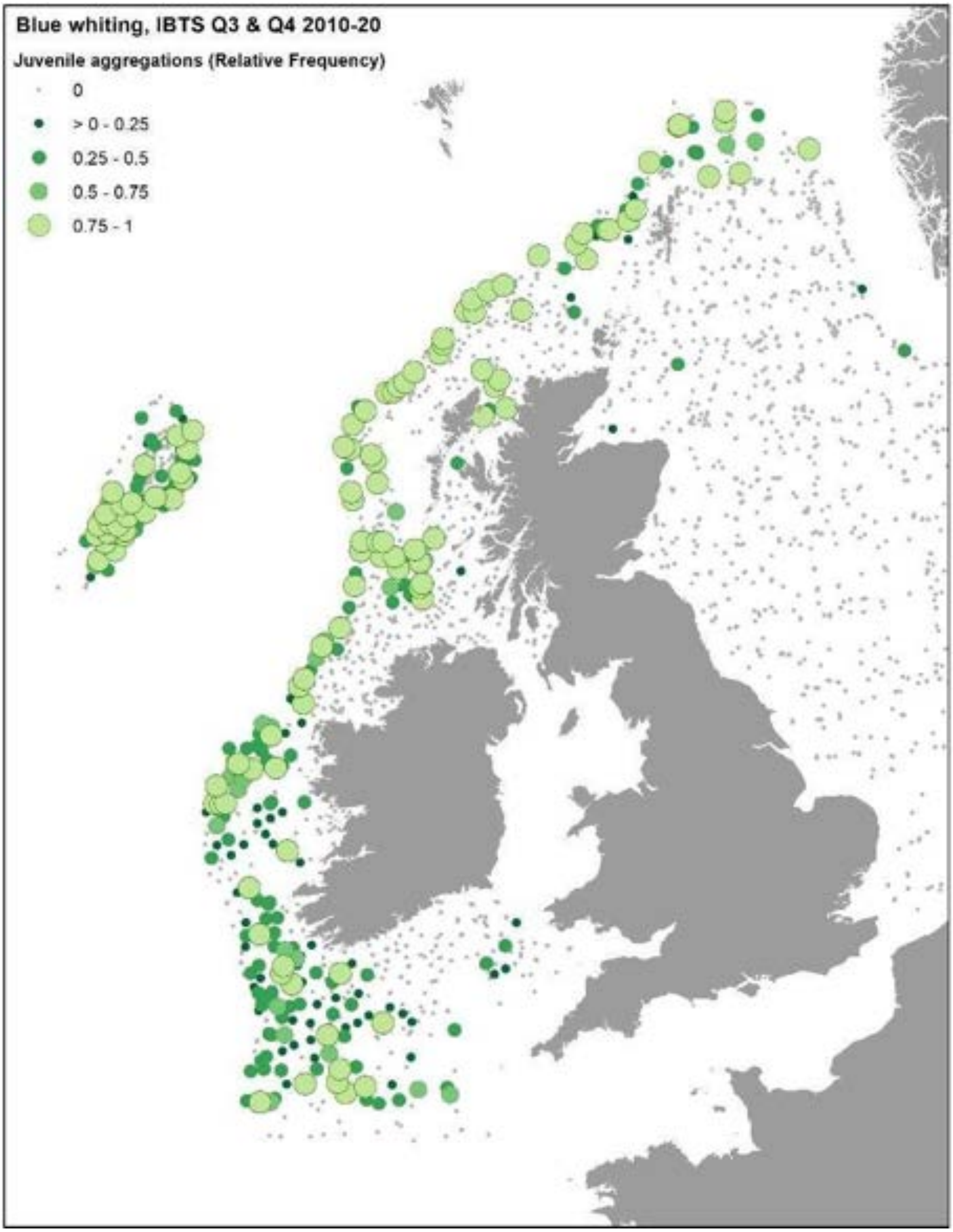


Figure C25. Juvenile blue whiting (*Micromesistius poutassou*, 0-group): relative frequency of presence of aggregations in International Bottom Trawl Surveys (IBTS) within 2010 - 2020 period (Q3+Q4; data used to calibrate model).

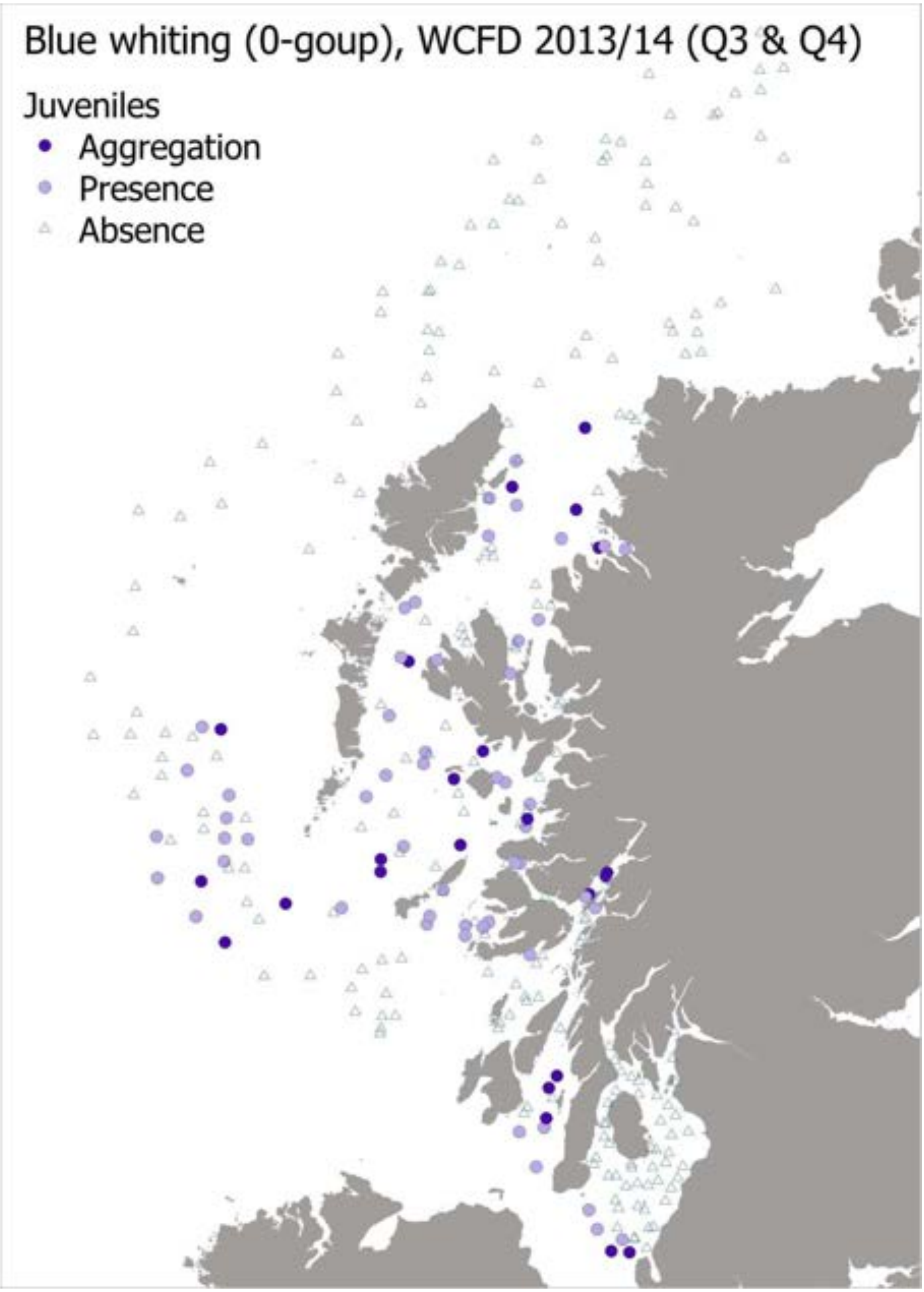


Figure C26. Juvenile blue whiting (*Micromesistius poutassou*, 0-group) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14: Presence/Absence of juveniles and their aggregations in Q3 & Q4 catches.

C13. Hake (*Merluccius merluccius*)

C13.1 Juvenile

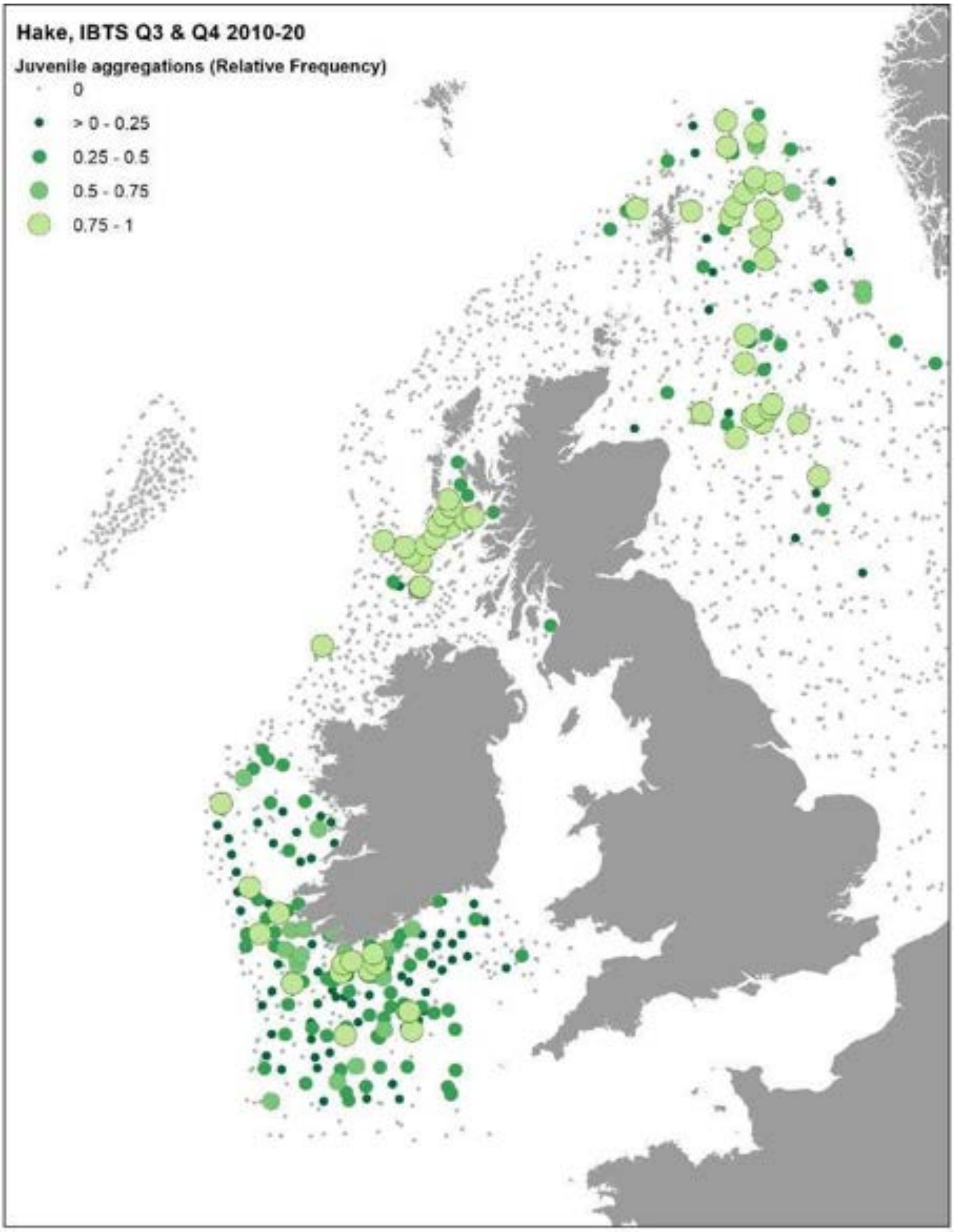


Figure C27. Juvenile hake (*Merluccius merluccius*, 0-group): relative frequency of presence of aggregations in International Bottom Trawl Surveys (IBTS) within 2010 - 2020 period (Q3+Q4; data used to calibrate model).

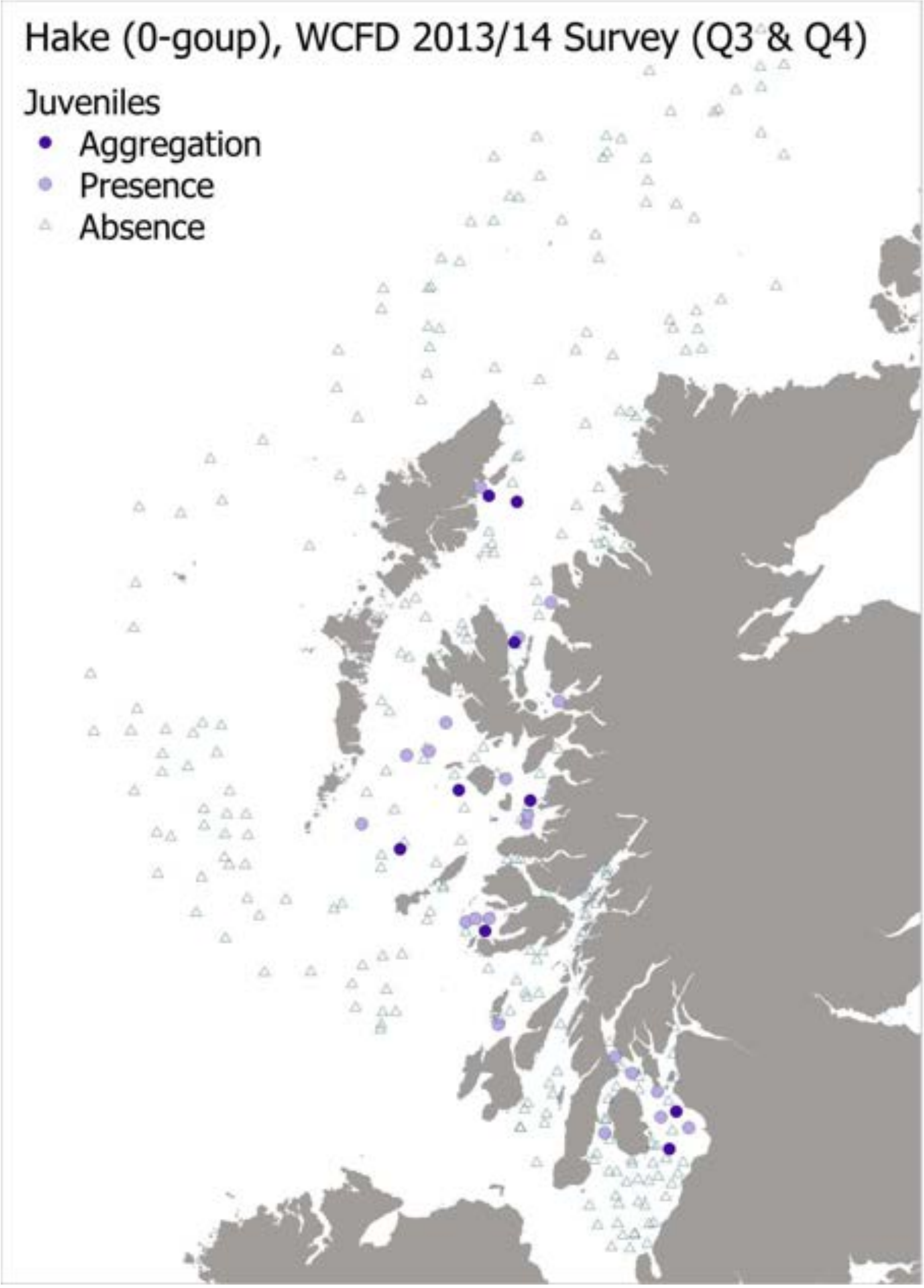


Figure C28. Juvenile hake (*Merluccius merluccius*, 0-group) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14: Presence/Absence of juveniles and their aggregations in Q3 & Q4 catches.

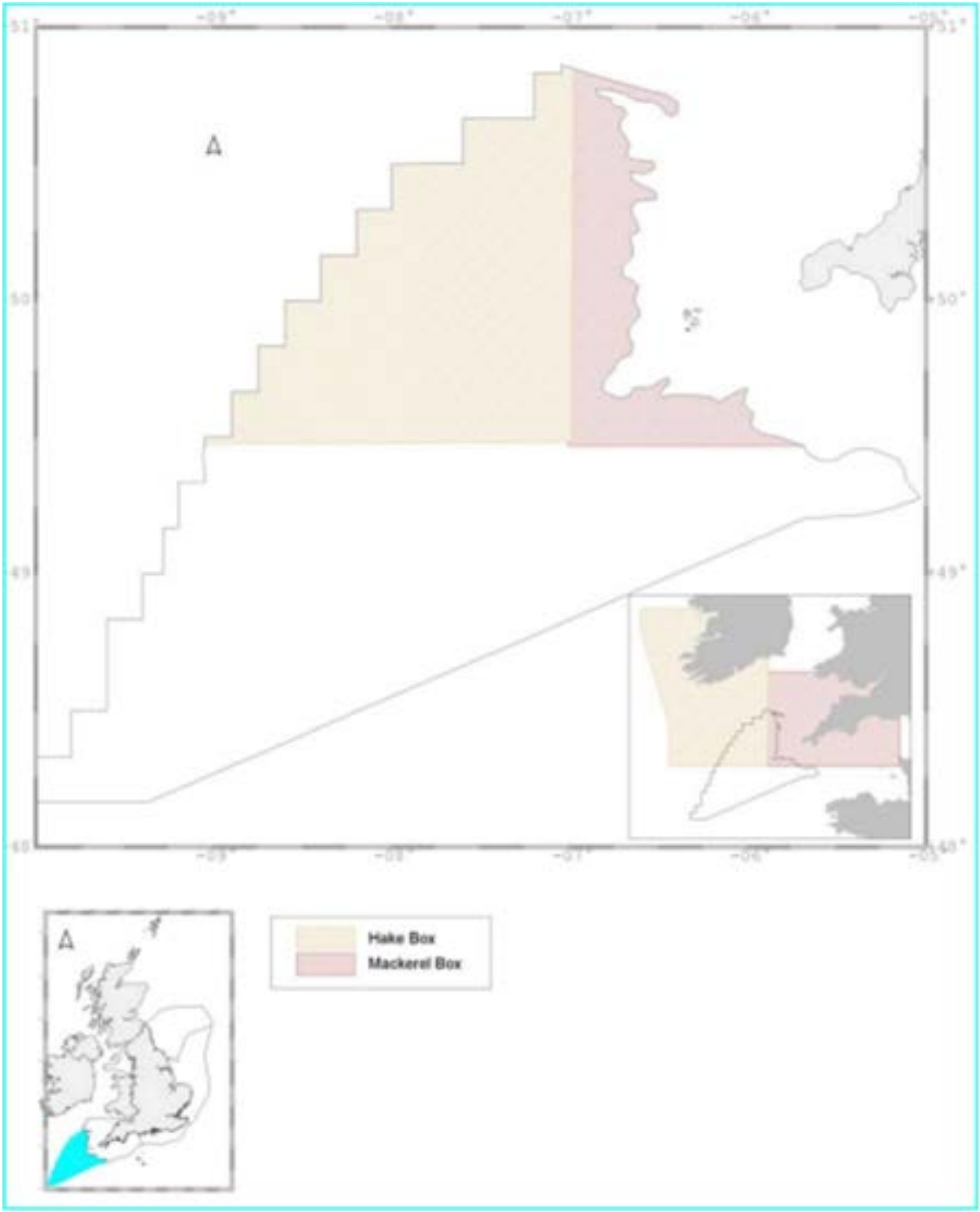


Figure C29. Location of Hake and Mackerel Boxes introduced to protect juveniles of the species within the Western Approaches Natural Area. Source: Jones et al. 2004.

C14. Saithe (*Pollachius virens*)

C14.1 Juvenile

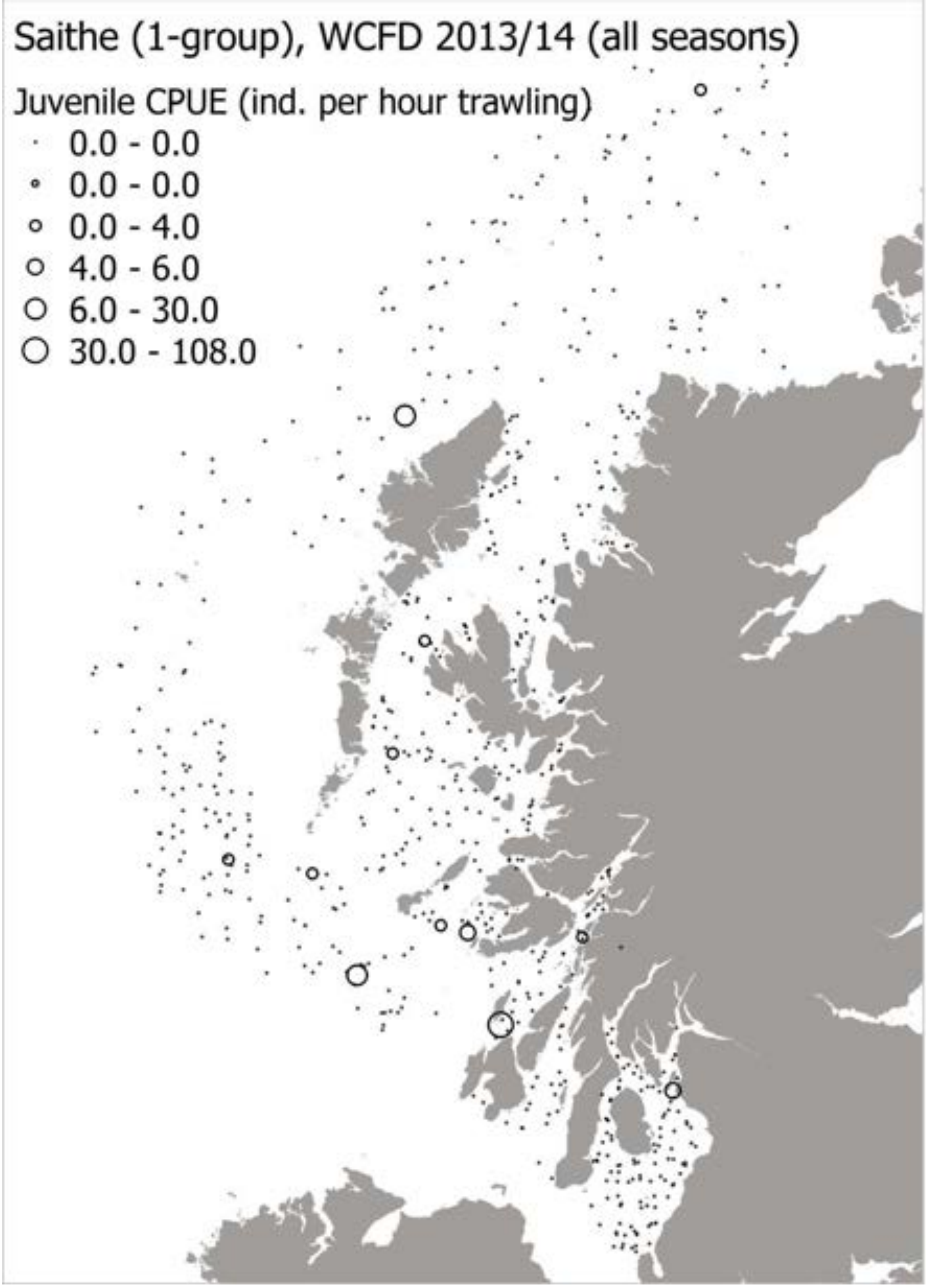


Figure C30. Juvenile saithe (*Pollachius virens*, 1-group) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14: Mean CPUE (individuals per hour) in hauls from all seasons.

C15. Sprat (*Sprattus sprattus*)

C15.1 Juvenile

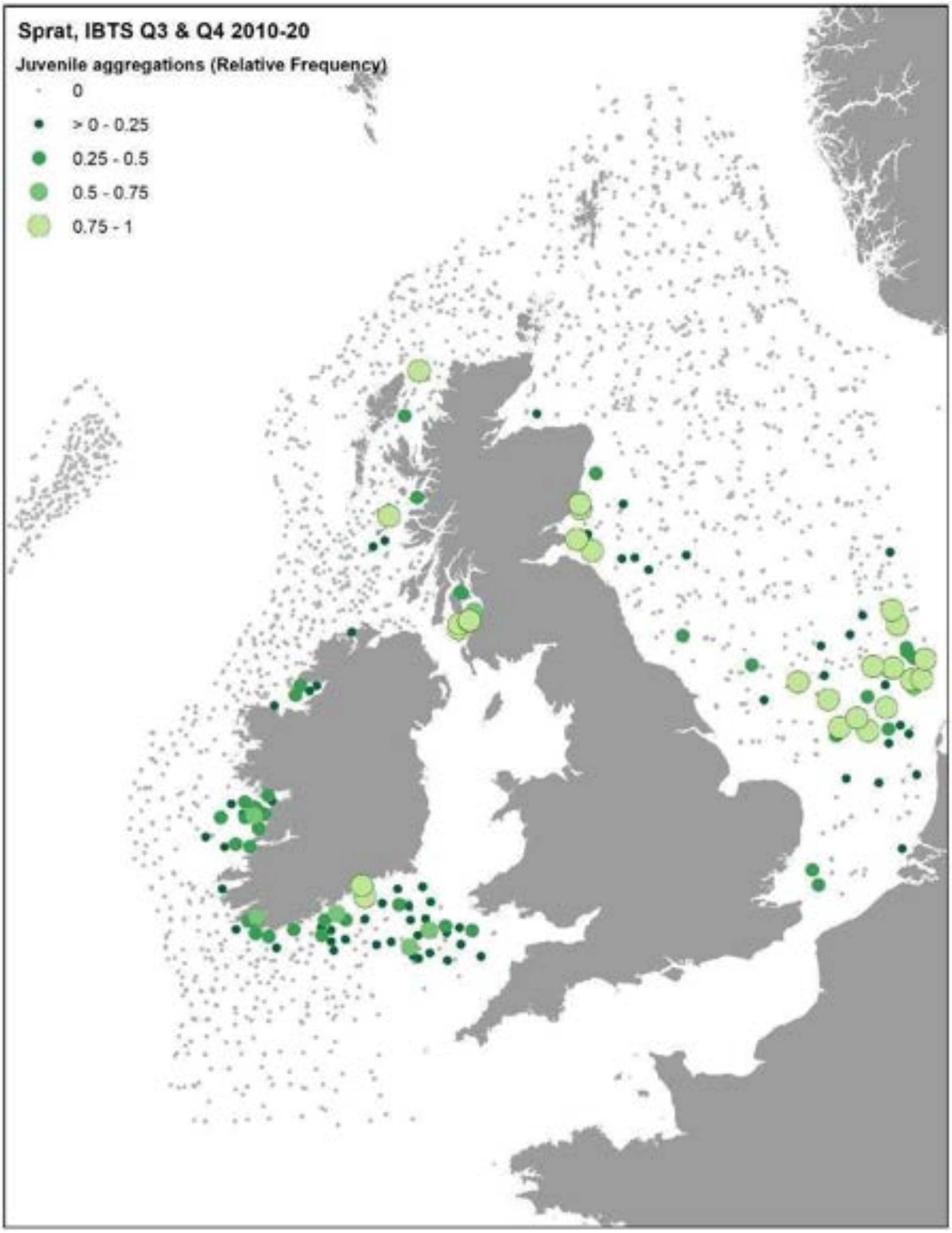


Figure C31. Juvenile sprat (*Sprattus sprattus*, 0-group): relative frequency of presence of aggregations in International Bottom Trawl Surveys (IBTS) within 2010 - 2020 period (Q3+Q4; data used to calibrate model).

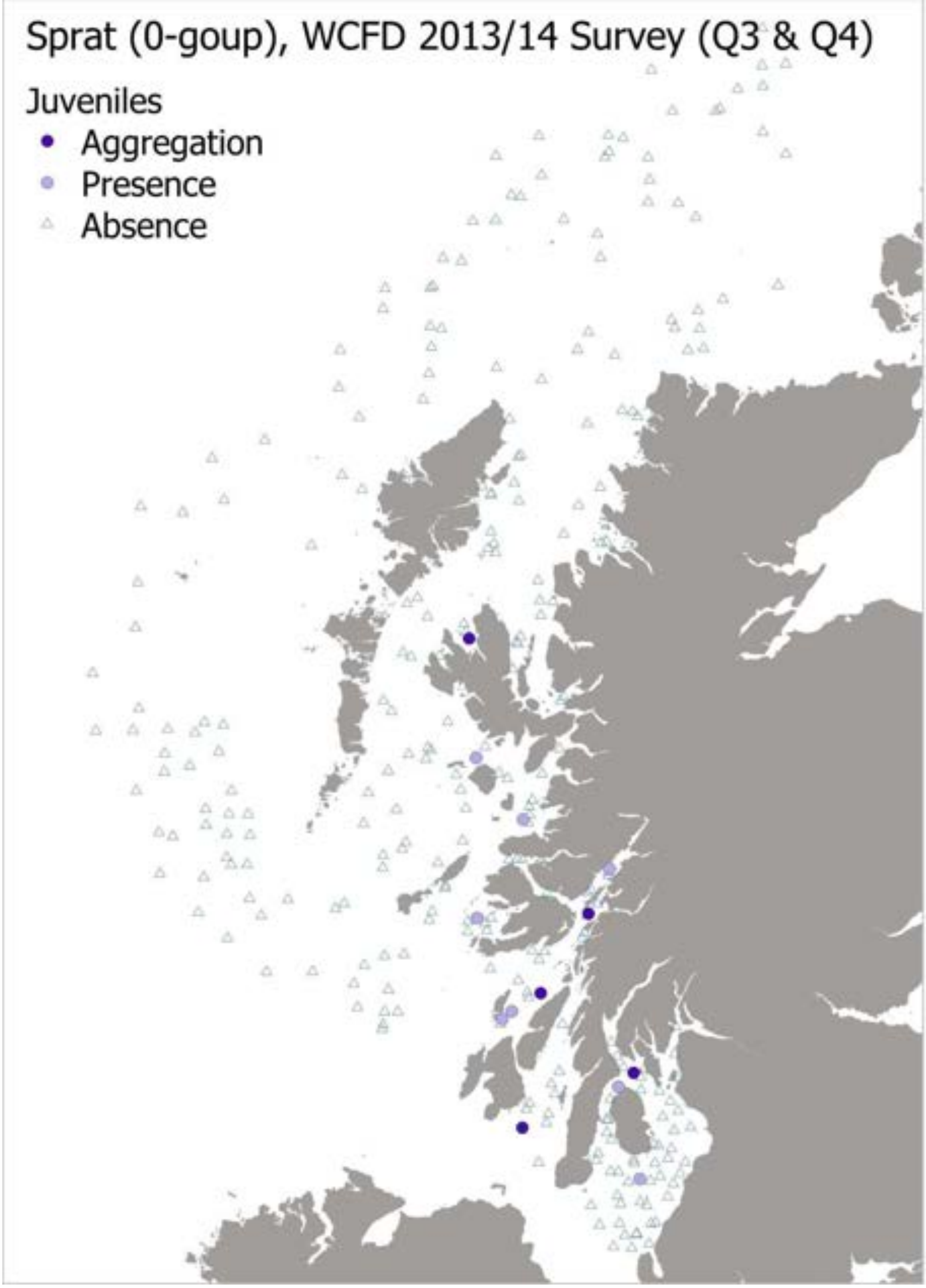


Figure C32. Juvenile sprat (*Sprattus sprattus*, 0-group) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14: Presence/Absence of juveniles and their aggregations in Q3 & Q4 catches.

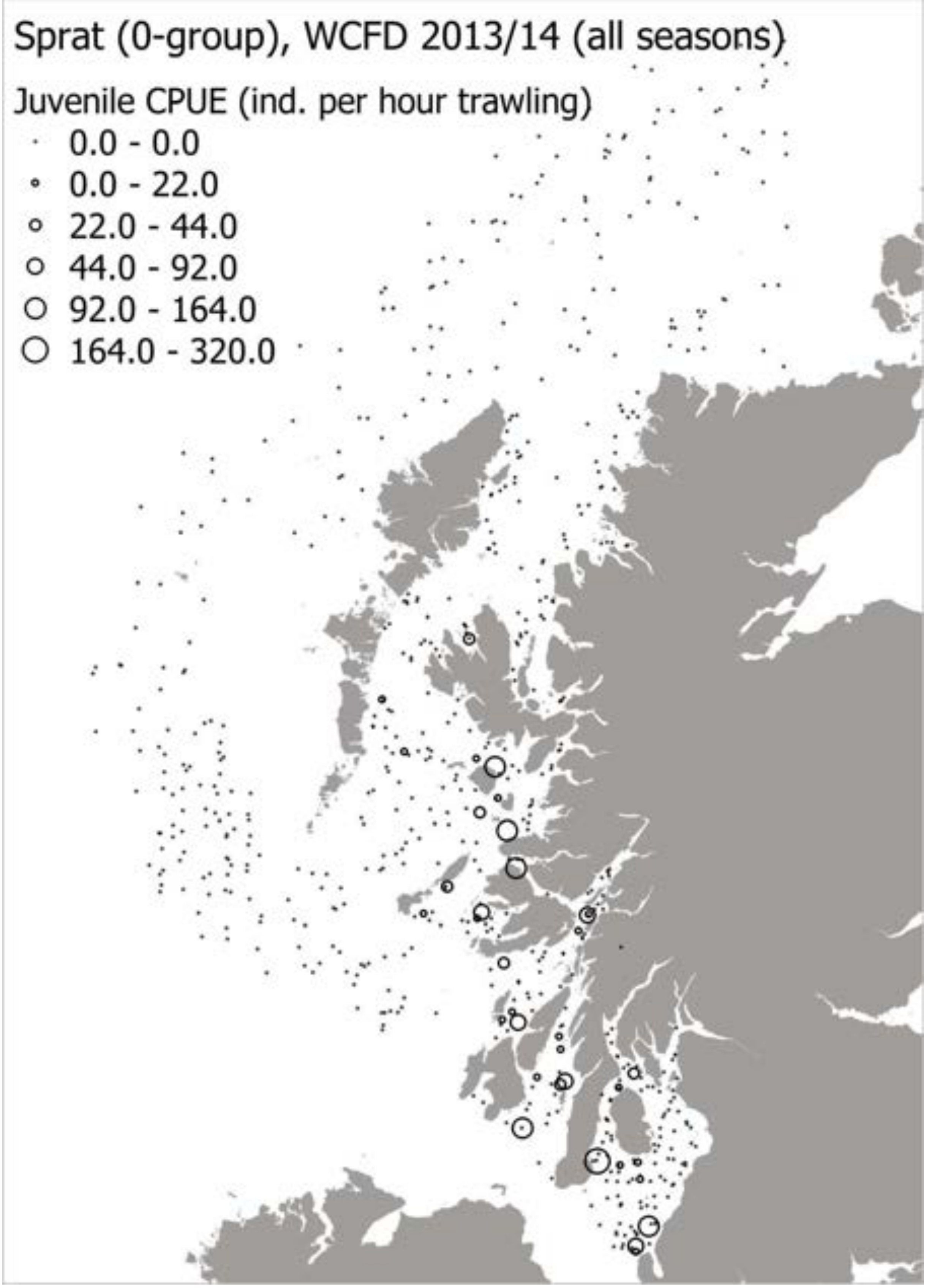


Figure C33. Juvenile sprat (*Sprattus sprattus*, 0-group) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14: Mean CPUE (individuals per hour) in hauls from all seasons.

D16. Mackerel (*Scomber scombrus*)

D16.1 Juvenile

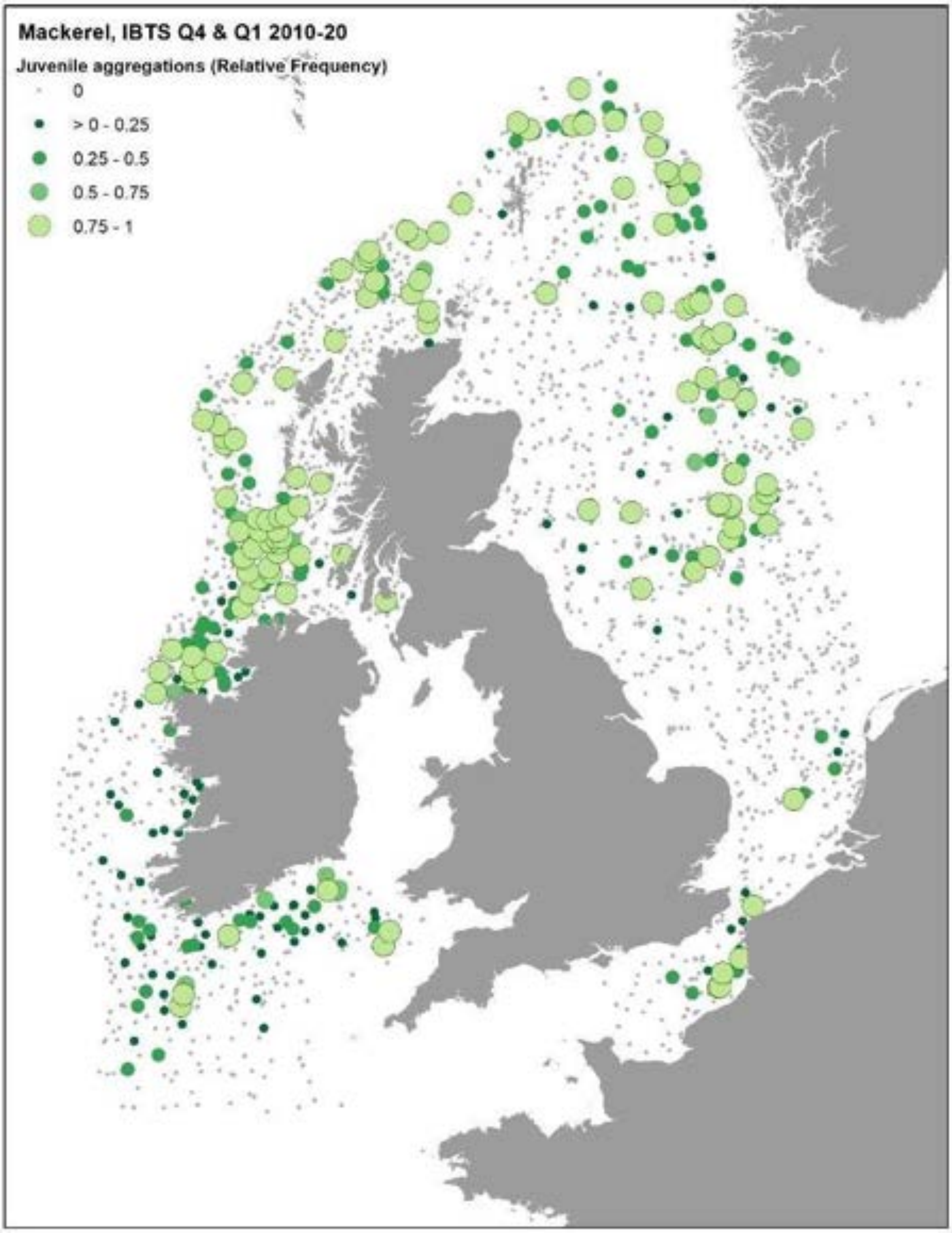


Figure C34. Juvenile mackerel (*Scomber scombrus*, 0-group): relative frequency of presence of aggregations in International Bottom Trawl Surveys (IBTS) within 2010 - 2020 period (Q4+Q1; data used to calibrate model).

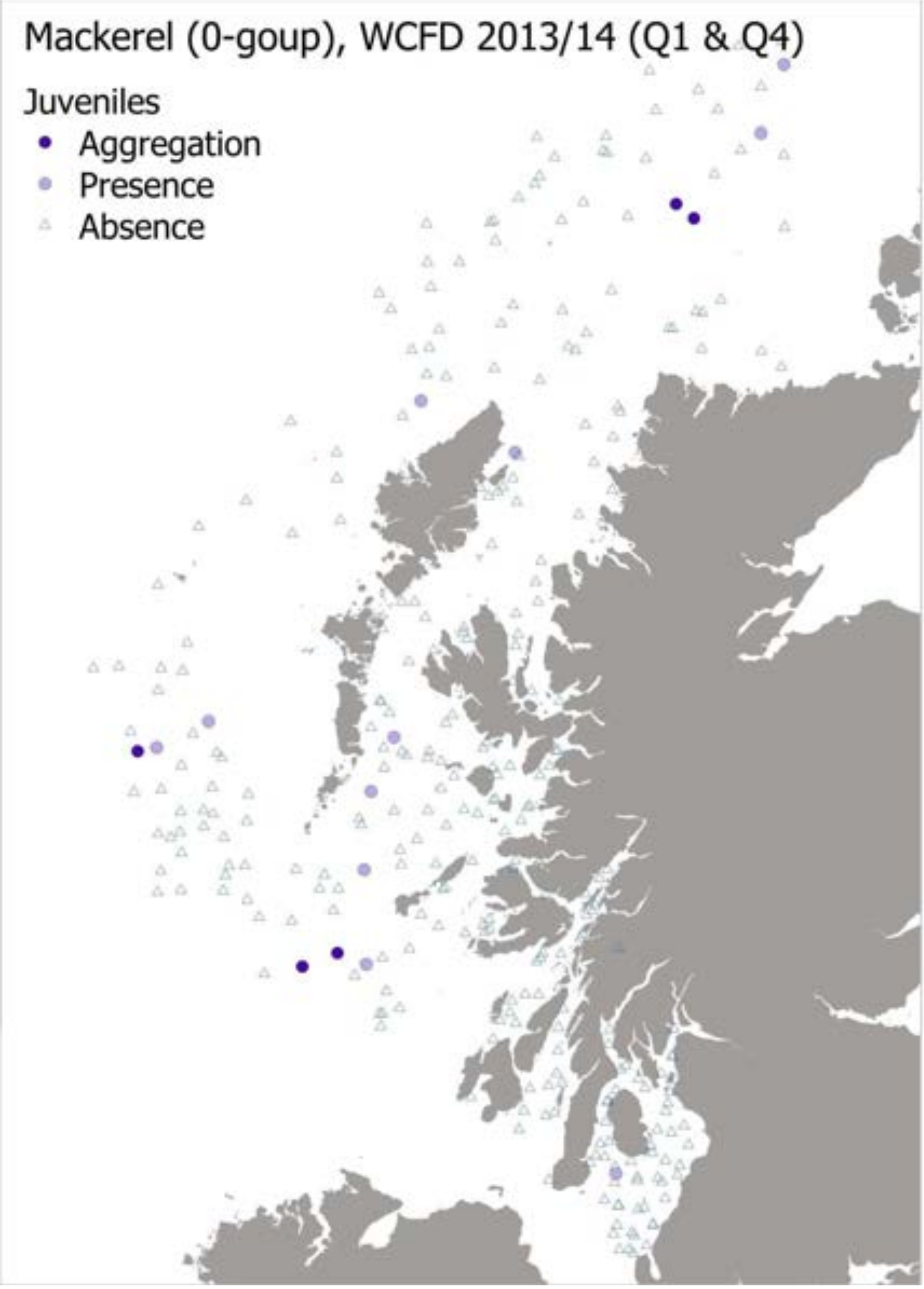


Figure C35. Juvenile mackerel (*Scomber scombrus*, 0-group): Presence/Absence of juveniles *and their aggregations in West Coast of Scotland Demersal Fish Survey 2013/14 (Q4+Q1).*

See also Figure C29 for location of Mackerel box introduced to protect juveniles of the species within the Western Approaches Natural Area (Source: Jones et al. 2004).

C16.2 Egg

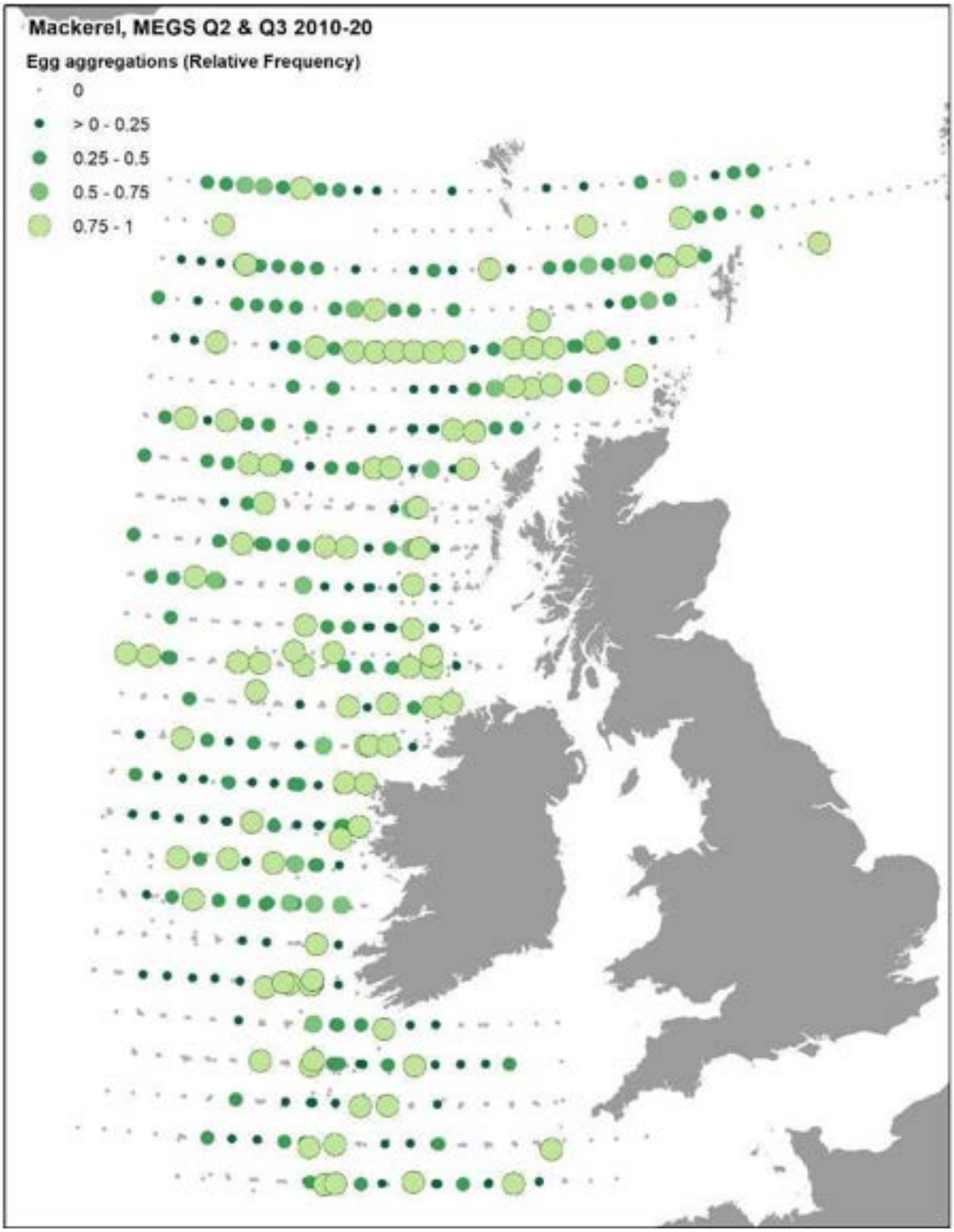


Figure C36. Mackerel eggs (*Scomber scombrus*, early-stage eggs): relative frequency of presence of aggregations in Mackerel Egg Surveys (MEGS) within 2010 - 2020 period (Q2+Q3; data used to calibrate model).

C17. Thornback ray (*Raja clavata*)

C17.1 Juvenile

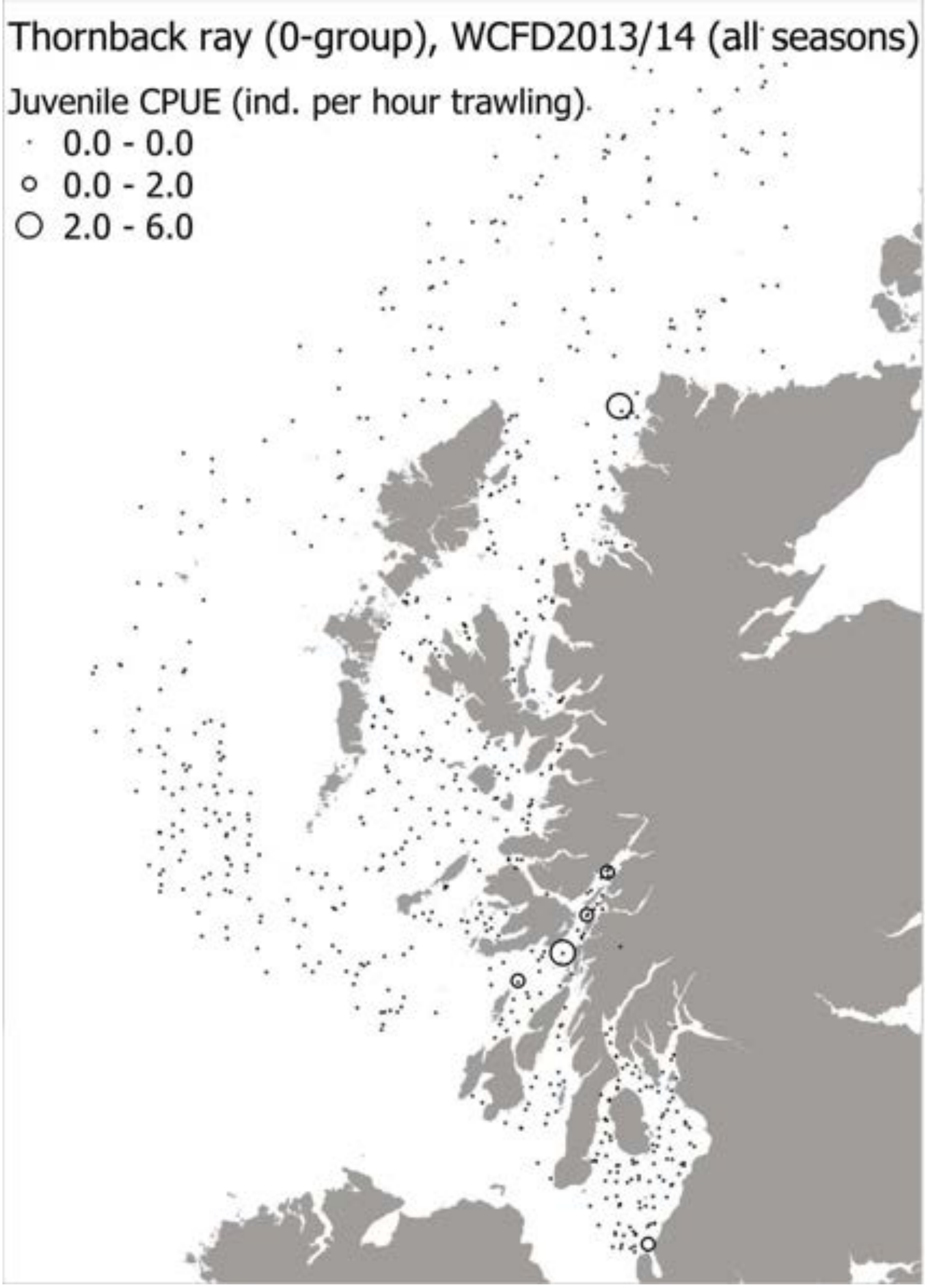


Figure C37. Juvenile thornback ray (*Raja clavata*, 0-group including some 1-group individuals) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14: Mean CPUE (individuals per hour) in hauls from all seasons.

C18. Spotted ray (*Raja montagui*)

C18.1 Juvenile

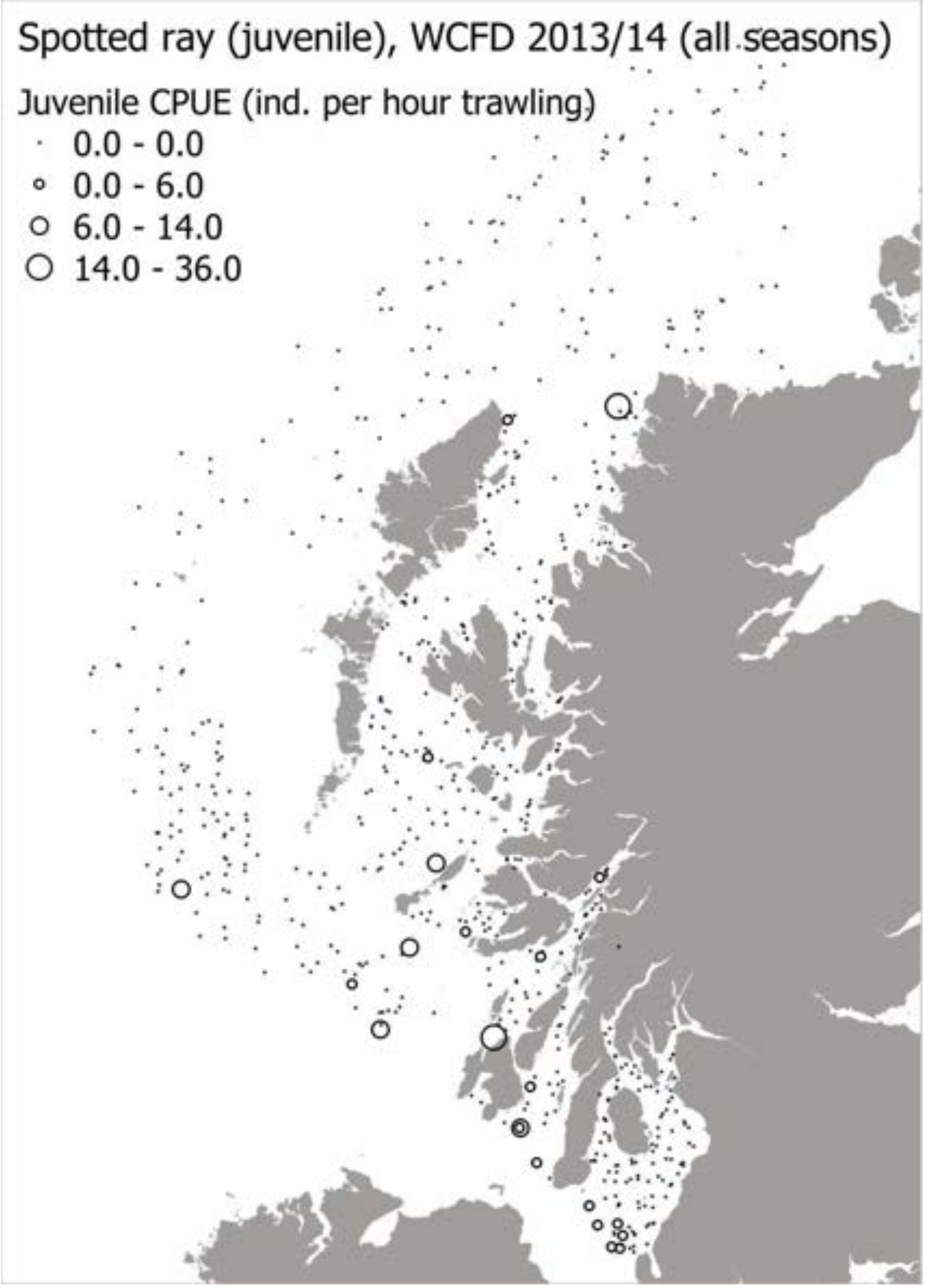


Figure C38. Juvenile spotted ray (*Raja montagui*, juvenile) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14: Mean CPUE (individuals per hour) in hauls from all seasons.

C19. Spurdog (*Squalus acanthias*)

C19.1 Juvenile

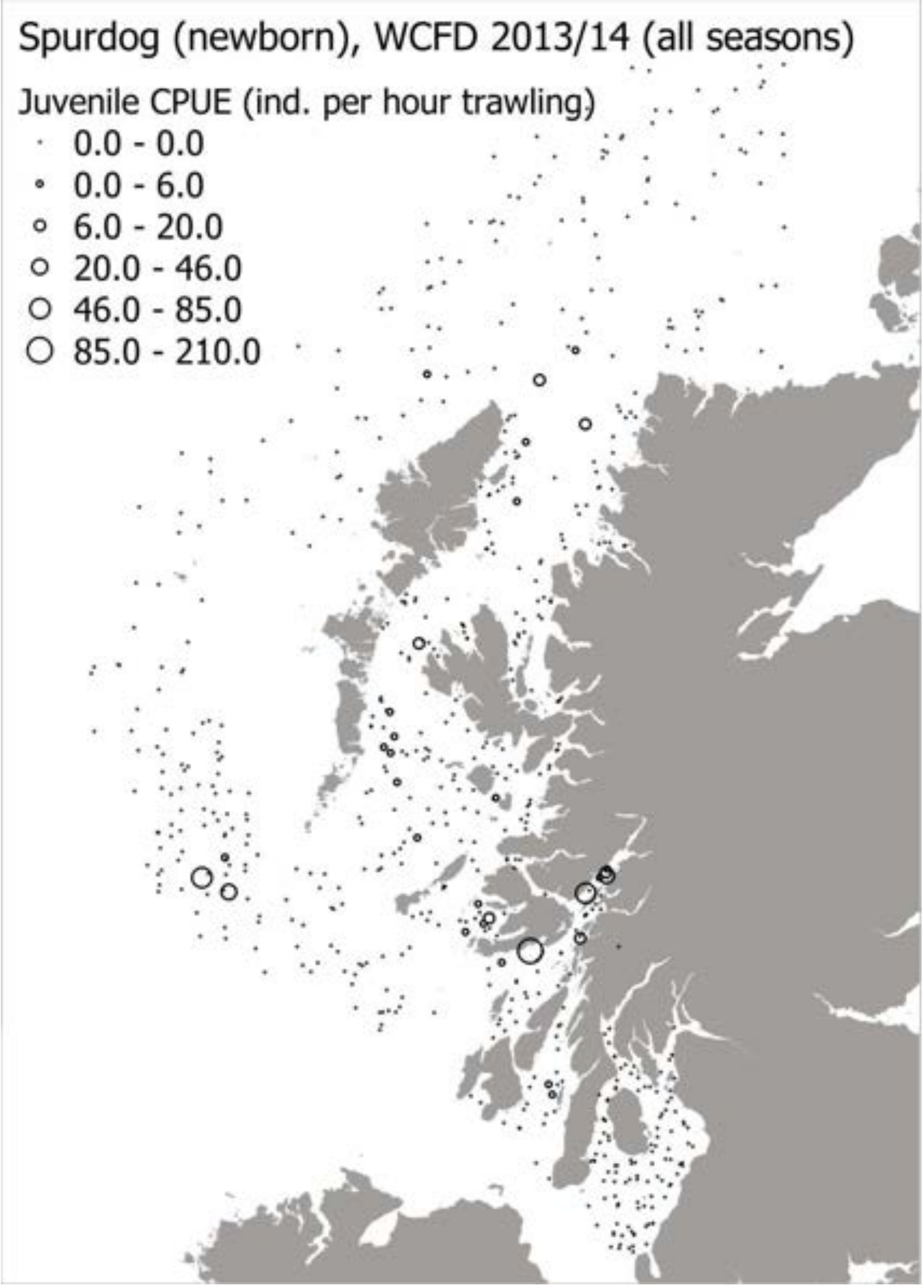


Figure C39. Juvenile spurdog (*Squalus acanthias*, newborn) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14: Mean CPUE (individuals per hour) in hauls from all seasons.

C20. Long finned squid (*Loligo forbesi*)

C20.1 Juvenile

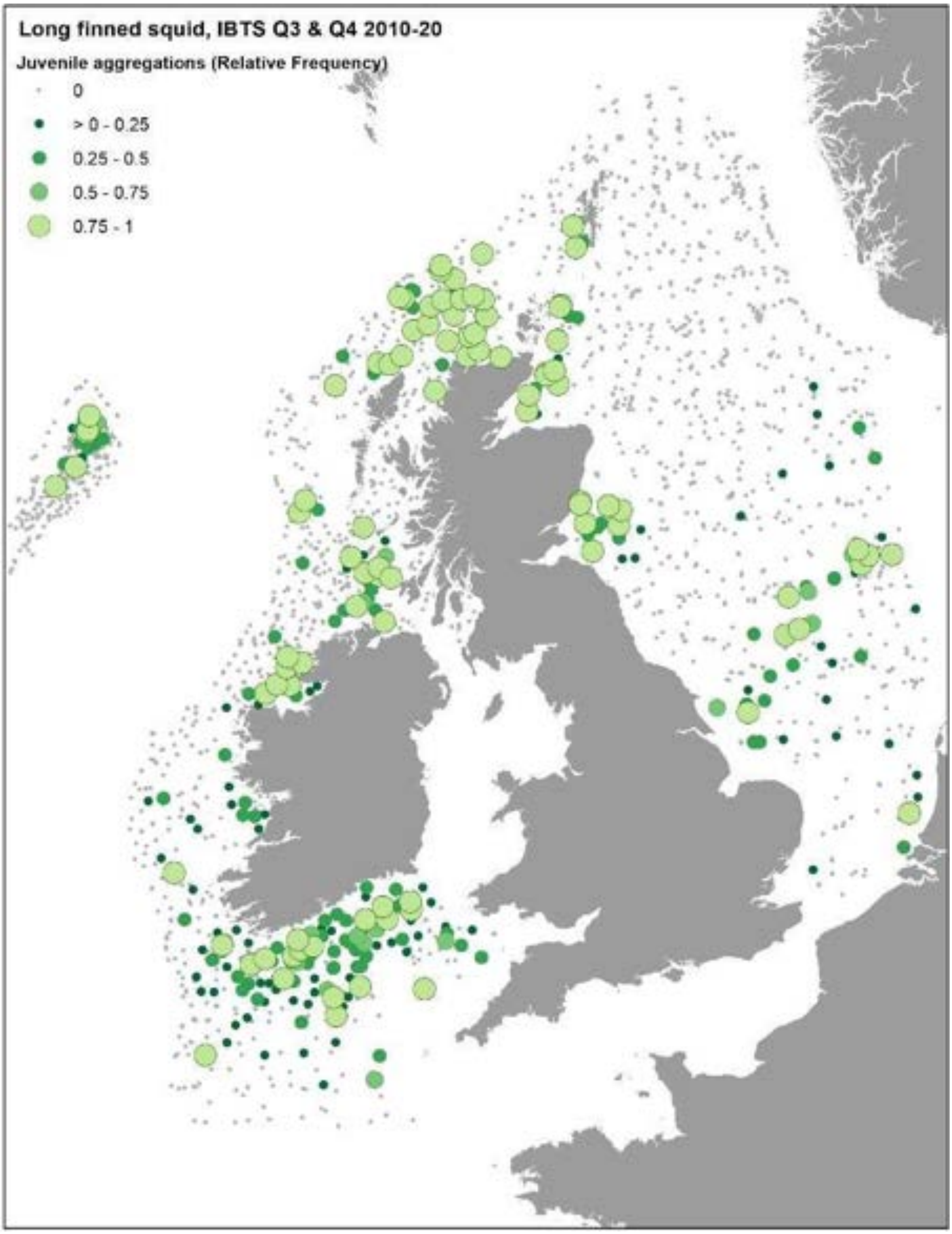


Figure C40. Juvenile long finned squid (*Loligo forbesi*, immature/recruits): relative frequency of presence of aggregations in International Bottom Trawl Surveys (IBTS) within 2010 - 2020 period (Q3+Q4; data used to calibrate model).

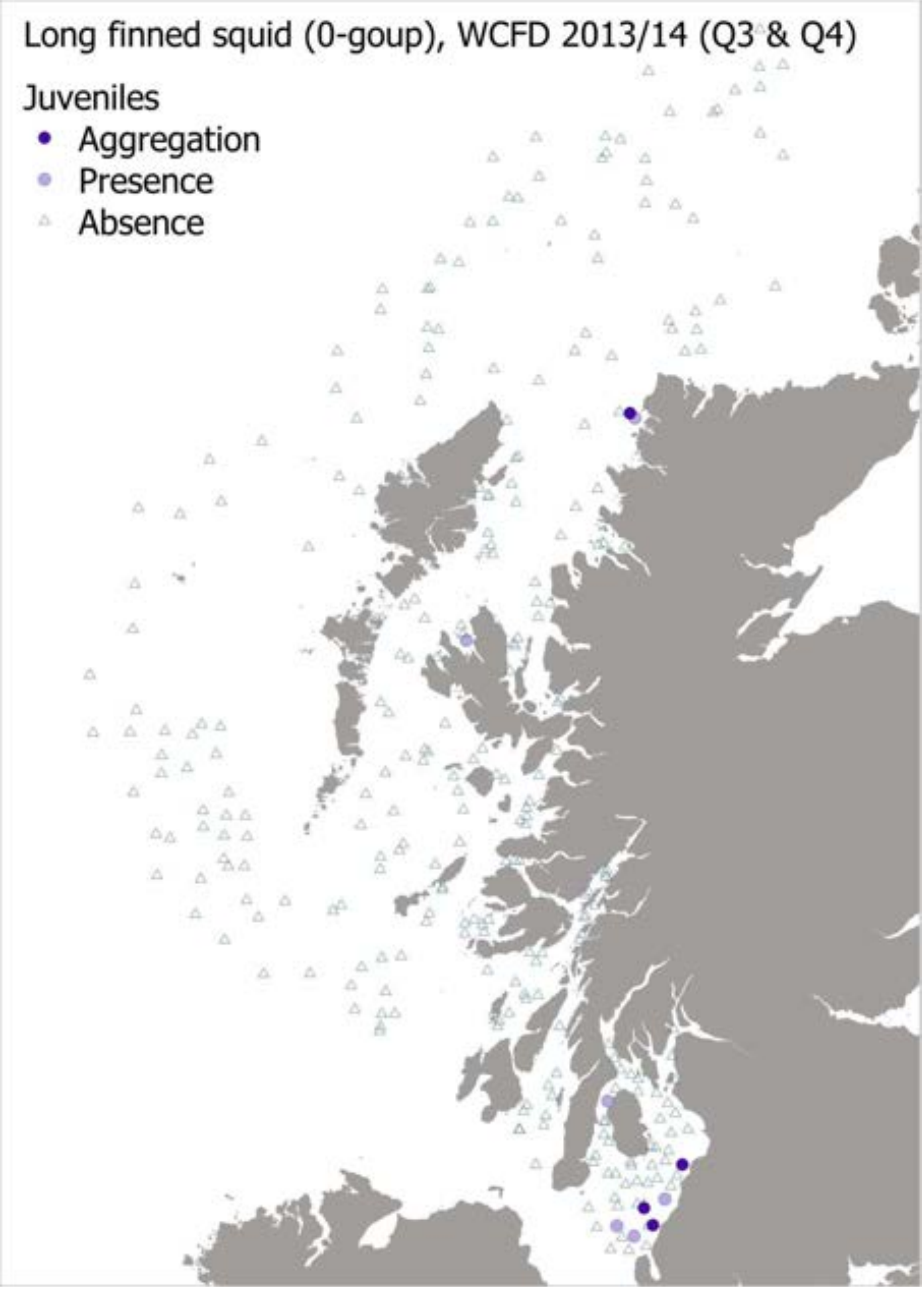


Figure C41. Juvenile long finned squid (*Loligo forbesi*, immature/recruits) in West Coast of Scotland Demersal Fish Survey (WCDF) 2013/14: Presence/Absence of juveniles and their aggregations in Q3 & Q4 catches.

Appendix D. Confidence results for the data-based EFH models

A summary of the confidence scores assigned to the different confidence elements of the overall confidence assessment are provided in Table D1. All scores are standardised over 0-1 range, with higher values indicating higher confidence.

Table D1. Summary scores for overall confidence assessment (all scores range 0-1). Cm, model statistical performance (F1 score); Cf, confidence associated with the fish survey data used to calibrate the model; Ce, confidence associated with the set of environmental layers used to predict the model.

Species, life stage	Cm	Cf	Ce	Confidence overall
Lesser sandeel, any	0.78	0.8	0.76	0.61
Nephrops, any	0.59	0.875	0.77	0.49
Plaice, juvenile	0.7	0.925	0.85	0.62
Lemon sole, juvenile	0.67	0.925	0.81	0.58
Common sole, juvenile	0.66	0.925	0.79	0.57
Anglerfish, juvenile	0.79	0.725	0.91	0.65
Whiting, juvenile	0.5	0.95	0.70	0.41
Whiting, spawning	0.42	0.9	0.83	0.36
Cod, spawning	0.49	0.8	0.86	0.41
Haddock, spawning	0.63	0.9	0.76	0.52
Norway pout, spawning	0.53	0.9	0.79	0.45
Blue whiting, juvenile	0.71	0.95	0.73	0.60
Hake, juvenile	0.48	0.95	0.76	0.41
Sprat, juvenile	0.64	0.8	0.79	0.51
Mackerel, juvenile	0.33	0.8	0.80	0.26
Mackerel, egg	0.4	0.85	0.73	0.32
Long finned squid, juvenile	0.49	0.95	0.76	0.42

Detailed tables for these scores (e.g. including intermediate scores for individual environmental data layers and reasons behind the score) are provided separately as an Excel worksheet “Confidence tables” as they are too big for visualisation in a Word document.

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