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Updating Fisheries Sensitivity Maps in British Waters

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UPDATING FISHERIES SENSITIVITY MAPS IN BRITISH WATERS

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This report presents the results of marine and freshwater scientific work carried out by Marine Scotland Science.

Contents

1. Introduction

The requirement to display sensitive areas relating to the life history of commercially important fish species in British waters is well recognized and has been used by the Oil and Gas and other offshore industries for over thirty years. An update of these maps will continue to contribute accurate spatial information which will aid sustainable ecosystem-based marine management.

Sensitive areas have previously been described as spawning and nursery grounds. Here we consider only areas where there is evidence of aggregations of 0 group fish and/or larvae of key commercial species. 0 group fish are defined as fish in the first year of their lives.

These fish sensitivity maps were originally generated to provide a spatial and temporal description of where physical damage could potentially occur to fish species at sensitive stages in essential habitats of their life cycle. Sources of damage in this context referred to seismic surveying conducted by the offshore Oil and Gas industry during their site investigations. In addition to the acoustic energy that the seismic survey activities generate, we should now add other percussive impact noises from pile-driving seabed foundation pins into the seabed, such as those required for offshore renewable energy sites. These noises can carry sufficient energy to rupture internal structures in the fragile developmental stages of young fish, particularly those with swim bladders (Oestman *et al*., 2009). It is also known they can damage the auditory system of fish and cephalopods (McCauley, 2003; André *et al*., 2011) or may even produce body malformations during larval development in marine invertebrates (de Soto, 2013). These maps can be used to ascertain the requirement for mitigation against these potential damages during industrial activities offshore.

The spatial location of these fish life history events and their potential interaction with offshore industries can heavily influence the planning, costs and delivery of these offshore developments. It is imperative that these maps reflect the current extent of these areas.

Ambitious targets have been set by European nations to reduce carbon emissions by 2020 and beyond, and using low carbon energy sources is one of the approaches to meet them. Activity offshore has thus increased in quantity and diversity with renewable projects and their infrastructure being planned and built in near-shore waters (ABPmer and Marine Scotland, 2013). This increase in offshore developments has been the catalyst for the current update to the fish sensitivity maps upgrade. This report follows on from the Coull *et al.* (1998) layers and the upgrade of that report as done by CEFAS in 2010 and subsequently in 2012 (Ellis *et al.*, 2010, 2012). The existing fish sensitivity maps have been used regularly in compiling Environmental Impact Assessment reports (EIA) for offshore developments and allow offshore operators to take into account these areas of environmental concern.

The specific locations of these sites of fish sensitivity are not static and may shrink, expand or move from one site to another over time. Anthropogenic activity may, with time, impinge upon previously un-impacted areas of sensitivity, for example areas of 0 group fish aggregations.

Mean sea water temperature increase associated with climate change and its effect on the distribution of these sensitive sites will also have to be considered as a potential reason for the regular requirements for updates of these maps; scientific trawl data dating back from early 20^{th} century reveals trends in species composition in UK waters that may lead to changes in the range of the species harvested commercially, see Beare *et al.* (2004, 2005) and Genner *et al.* (2004).

Data on the distribution of fish species in British waters are collected yearly through the regular stock monitoring surveys as conducted by European marine research institutes in their role as fisheries data suppliers to the International Council for the Exploration of the Sea (ICES). Data used for this update have again been taken from various of these available sources including the National and International Bottom Trawl Surveys (BTS, IBTS), Beam Trawl Surveys (BTS) and International Herring Larval Surveys (IHLS). In addition to these, commercial fishing observer trips and stand-alone surveys to investigate particular issues have provided further data on the distribution of 0 group fish of relevant species.

As well as new and additional data, different data analysis techniques have been used to generate alternative outputs from the existing survey datasets. The principal analysis technique used was Species Distribution Modelling (SDM), also known as Habitat Suitability Models or Ecological Niche Models. These models combine observations of species occurrence or abundance with environmental data. This allows us to predict the distribution of species in geographic space on the basis of a mathematical representation of their known distribution in environmental space – the ecological niche (Elith and Leathwick, 2009). This technique has been used extensively on land, as data are more plentiful and continuous, but progressively more work is being done on marine species: see Maxwell *et al.* (2009), Moore *et al.* (2010) and Reiss *et al.* (2011) as examples.

For this report this technique has been applied using data indicating aggregations of 0 group fish, or for some species, presence or absence of 0 group fish, used together with the most up-to-date and relevant environmental layers, to offer an evidence-based modelled estimate of the probability of presence over the entire study area. The outputs from this process can be used as a guide to the most likely locations for aggregations of fish during their first year.

It must be borne in mind that the quality and reliability of the model outputs will be dependent on the quality and resolution of the data used, the type of ecological niche of each species and the assumptions and biological threshold cut-off points made by the operator. However, with the correct controls, this is a very powerful technique. As such, prior to using these final outputs in a practical context it would be appropriate to complement the outputs by corroboration of physical presence through surveys in the predicted areas.

These processes will benefit from complementary stakeholder input; the fishing industry, in particular, will be able to add value to the final outputs by communicating their view of where and when, in their experience, the sensitive sites occur. It is envisaged that the fishing industry's views will be communicated through a small number of consultations after distributing the outputs to fishing representatives.

2 Method

2.1 Fisheries Survey Data

2.1.1 Areas of 0 group Aggregations

In Gibb *et al.* (2007) nursery areas were defined as areas of habitat which support significantly higher juvenile densities than other areas. In this study the same definition was used for 0 group aggregation areas. To determine these, hauls with aggregations of 0 group fish of selected species were identified from several national and international fisheries surveys, and their distribution modelled using species distribution models, as detailed in the sections below.

The raw data for the trawl surveys used were downloaded from DATRAS, the Database of Trawl Surveys maintained by the International Council for the Exploration of the Seas, (ICES) (http://www.ices.dk/marine-data/data-portals/Pages/DATRAS.aspx) in July 2012. Data from the commercial fishing observer trips to gather data on fish discarding carried out by Marine Scotland Science staff between the years of 2005 and 2011, and held in the Scottish Government Fisheries Management Database (FMD), were also used. Other data sources include the Inshore Surveys carried out from 2001 to 2004 summarised by Gibb *et al.* (2007).

Data were filtered by month, so that only Quarter 3 and Quarter 4 hauls were considered, as there were no available Age-Length-Keys (ALKs) for 0 group fish in Quarters 1 and 2 – this is because, to standardise age estimates when ageing fish, there is a convention to use 1st of January as the birthday for most Atlantic species (Holden & Raitt, 1974). The data sources used are summarized in Table 1 and Table 2, and their haul distribution can be seen in Figure 1, below.

As fish distribution is subject to change, only years >= 2000 were considered for cod and other gadoid species (haddock, whiting, saithe, ling and Norway pout).

Table 1

Summary list of fishery surveys used to collate 0 group fish data. GOV = *Grande Ouverture Verticale*, BT = Beam Trawl, (+) = See Table 2.

Survey	Years	Quarters	Gear	Country	Reference	Pelagic	Gadoid	Benthic
International Bottom Trawl Surveys (IBTS)								
North Sea IBTS NS-IBTS	1991-2012	3, 4	GOV(+)	Various	ICES (2012a)	✓	✓	✓
Scottish West Coast IBTS SWC-IBTS	1990-2011	4	GOV	Scotland		✓	✓	✓
Irish Ground Fish Survey IE-IGFS	2003-2008	3, 4	GOV	Ireland		✓	✓	✓
Evaluation Halieutique Ouest Européen EVHOE	1997-2012	4	GOV	France		✓	✓	✓
Beam Trawl Surveys (BTS)								
BTS	1987-2011	3, 4	BT(+)	Various	ICES (2009)	X	✓	✓
BTS-VIIa	1993-2008	3, 4	BT 4m	England		X	✓	✓
Inshore Surveys								
Various chartered fishing vessels	2001	3	Various	Scotland	Gibb *et al.* (2007)	X	✓	Plaice
Alba na Mara	2002-2004	4	BT158	Scotland		X		
Discard trips								
Various fishing vessels	2005-2011	3, 4	Various	Scotland	Fernandes *et al.* (2011)	✓	✓	✓

Table 2

Summary of participating countries in the North Sea IBTS and the BTS surveys used to collate 0 group fish data. GOV = *Grande Ouverture Verticale*, GRT = Granton trawl, DHT = Dutch Herring Trawl, ABD = Aberdeen 18 ft trawl, BT = Beam Trawl.

	Quarter 3			Quarter 4		
Survey	Country	Years	Gear	Country	Years	Gear
North Sea IBTS	Denmark	1998-2011	GOV	Denmark	1991-96	GOV
	England	1991-2011	GRT (1991) GOV	England	1991-96	GOV
	France	1992-96	GOV	France	1995	GOV
	Germany	1992, 96-2011	GOV	Netherlands	1991-96	GOV
	Netherlands	1991-97	GOV	Norway	1991-96 2003-04	GOV
	Norway	1999-2011	GOV			
	Scotland	1991-2011	DHT (1991) ABD (1992-97) GOV			
	Sweden	1991-2011	GOV			
BTS	England	1990-2011	BT 4m	England	2010	BT 4m
	Germany	2003-2011	BT 7m			
	Netherlands	1987-2011	BT 8m			

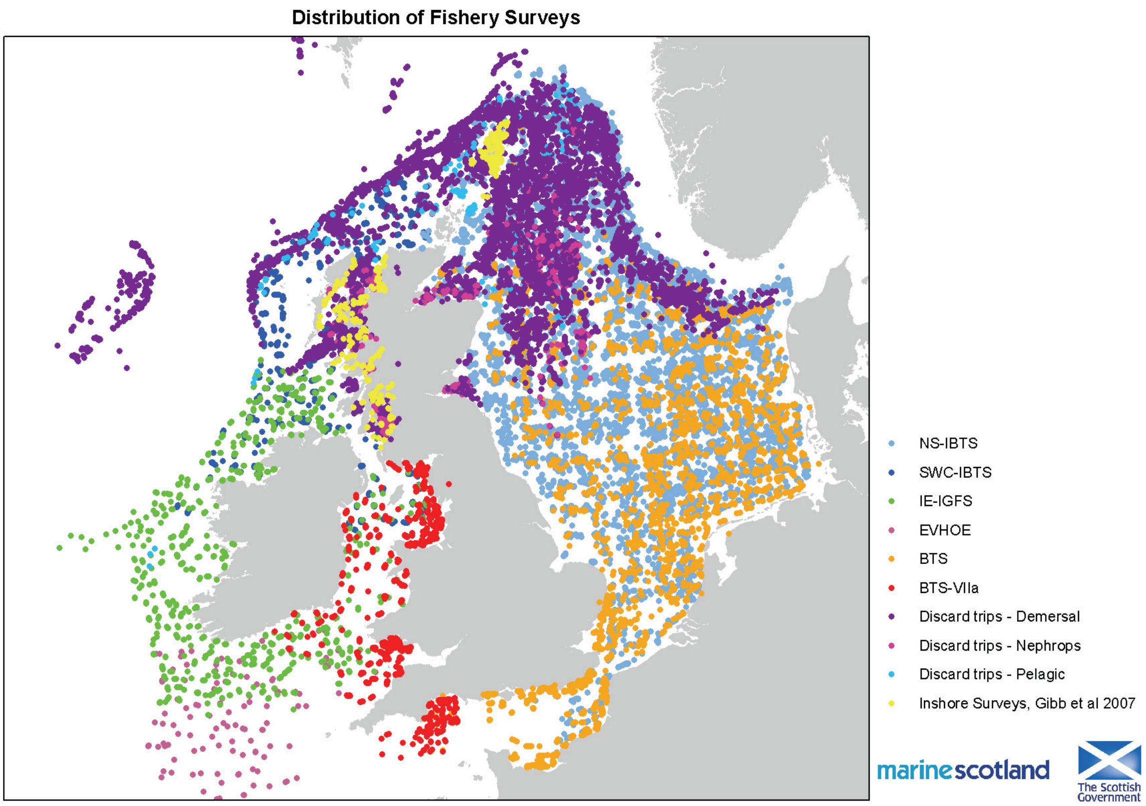

Figure 1: Distribution of fishery surveys used to collate juvenile fish data.

The cut-off lengths used to identify 0 group fish of the different species are summarised in Table 3. All lengths are "less than" the value shown. These lengths were determined based in the surveys' age-length keys (ALKs) available and chosen to represent more than 90% of 0 group fish and less than 6% of 1 group fish. The exception to this rule is sprat in Quarter 3 of North Sea IBTS, where length < 9.0 cm represents 88.1% of 0 group fish and 6.86% of 1 group fish.

ALKs were only available for some of the species, in some of the surveys. When no information from ALKs was available, information from the closest (in space) survey was used, if existent; if not, the preliminary age-length splits from the literature were used (ICES, 2012a).

Table 3

Cut-off lengths (cm) used to identify 0-group fish. All lengths are "less than".

Survey	NS-IBTS		SWC-IBTS	IE-IGFS		EVHOE	BTS/BTS-VIIa		Discards	
Age	0-group		0-group	0-group		0-group	0-group		0-group	
Quarter	3	4	4	3	4	4	3	4	3	4
Cod	20	23	33	20	33	30	20	33	20	23
Haddock	18	21	21	18	21	21	18	21	18	21
Whiting	17	20	20	17	20	22	17	20	17	20
Norway pout	12	13	14	12	14	14	12	14	12	13
Saithe	22	25	25	22	25	25	-	-	22	25
Herring	15.5	16.5	16.5	15.5	16.5	16.5	-	-	15.5	16.5
Mackerel	23	26	26	23	26	26	-	-	23	26
Horse mackerel	9	15	15	9	15	15	-	-	9	15
Sprat	9.0	9.5	9.5	9.0	9.5	9.5	-	-	9.0	9.5
Blue whiting	19	19	19	19	19	19	-	-	19	19
Plaice	14	16	17	15	17	17	15	17	14	16
Sole	12	13	13	12	13	13	12	13	12	13
Hake	19	19	19	19	19	19	19	19	19	19
Anglerfish	16	16	16	16	16	16	16	16	16	16
Ling	21	21	21	21	21	21	21	21	21	21

In this study areas of habitat which support significantly higher 0 group fish densities than other areas were identified. To achieve this the distribution of 0 group fish aggregations was modelled, instead of the distribution of all 0 group fish. This work uses density threshold to delimit what is considered a presence and what is not before applying the model. Similar approaches have been used in other SDM studies. For example, Howell *et al.* (2011) compared the distribution of *Lophelia pertusa* with the distribution of *L. pertusa* reefs (defined not only for its abundance, but clearly related to this feature) whereas other authors (Moritz *et al*., 2012; Martín-García *et al.*, 2013) modelled communities defined by differences in species biomass or using a density threshold implicit in their definition (e.g. brown garden eel).

Aggregations of 0 group fish were identified by sorting in ascending order all hauls where the selected species was present in each survey type, then ranking their abundance and selecting the top quartile of the distribution (≥ 75%). This way catch data was standardised by reducing each haul's catch to presence (≥ 75%) or absence (≤ 75%) of aggregations of 0 group fish for each species, thus reducing the variations introduced by differences in sampling methodology between different surveys, as well as gear and vessel performances and catch variation between and within years.

For gadoids and other demersal species this was done across the entire dataset, as their numbers remained consistent over the years, while for pelagic species the process was repeated on a year by year basis, as numbers by haul can vary by several orders of magnitude from one year to the next. Given the numbers involved and the extreme differences in numbers from year to year, two additional criteria were introduced when identifying aggregations for pelagic species:

a) Fewer than 10 fish per haul was never considered an aggregation, even if in the 75% quartile;
b) More than 500 fish per haul was always considered an aggregation, even if out of the 75% quartile.

For saithe and ling there were not enough hauls with 0 group fish present so that aggregations could be identified. As the juveniles of both these species stay in their inshore nursery habitats until they are 2-3 years of age (Heessen *et al.*, 2006; Rowley, 2008) nursery areas could in the future be modelled using data of age 1 fish.

2.1.2 Herring Small Larvae Aggregation Area

Herring spawning grounds have been defined using a number of data sources, including grab surveys on spawning grounds (e.g. Parrish *et al*., 1959; Bowers, 1969), the presence of recently hatched larvae (reviewed in Heath, 1993), the presence of herring eggs in haddock stomachs (e.g. Bowman, 1922) and the capture of mature adult fish from both commercial boats and surveys (ICES 2010a). At this stage of the work, data for recently hatched larvae were used and their distribution modelled by species distribution models, as detailed in the sections below.

The herring to the west of the British Isles are currently fished, managed and assessed separately as four stocks: 1) VIa North; 2) VIa South and VIIb,c; 3) Irish Sea (VIIaN) and 4) Celtic Sea and VIIj (ICES, 2010a). Similarly, The North Sea herring stock is also generally understood as representing a complex of multiple spawning components (Cushing, 1955; Harden Jones, 1968; Iles and Sinclair, 1982; Heath *et al*., 1997). Most authors distinguish four major components, highlighted in Figure 2, each defined by distinct spawning times and sites (Iles and Sinclair, 1982; Corten, 1986; Heath *et al*., 1997). The Orkney-Shetland component spawns in August/September; the Buchan component to the east of Scotland in September/October; the Banks component off the English coast around the same time; and the Downs component in the English Channel mainly during December. Although the different components mix outside the spawning season and are exploited together, each component is thought to have a high degree of population integrity (Iles and Sinclair, 1982) and, therefore, could be expected to have relatively unique population dynamics (Payne, 2010).

The ICES programme of International Herring Larval Surveys (IHLS) in the North Sea and adjacent areas has been in operation since 1967. It's main purpose is to provide quantitative estimates of herring larval abundance, which are used as a relative index of changes of the herring spawning stock biomass in the assessment (ICES 2008).

The larval surveys are carried out in specific time periods and areas, following the autumn and winter spawning activity of herring from north to south (ICES 2008) and are considered to have been consistent since 1972 (Payne, 2010). Survey data are reported to the ICES International Herring Larvae database annually. This database contains information about the surveys conducted since 1972 and is currently available through the ICES Eggs and Larvae Data Portal (http://www.ices.dk/marine-data/data-portals/Pages/Eggs-and-larvae.aspx).

The raw data for the IHLS used in this work were downloaded from this portal in March 2013 and are summarised below in Table 4 (west of Scotland and northwest Ireland) and Table 5 (North Sea). The IHLS haul distribution, highlighting the different sampling regions, can also be seen in Figure 2.

Surveys off northwest Ireland suffered from poor sampling coverage and were discontinued after 1988 (Heath *et. al*, 1993), as were those off the west of Scotland after 1994. Because of this difference in temporal coverage, and also because herring in the Atlantic and in the North Sea are different stocks (see references above), data east and west of the 4°W meridian were treated and modelled separately.

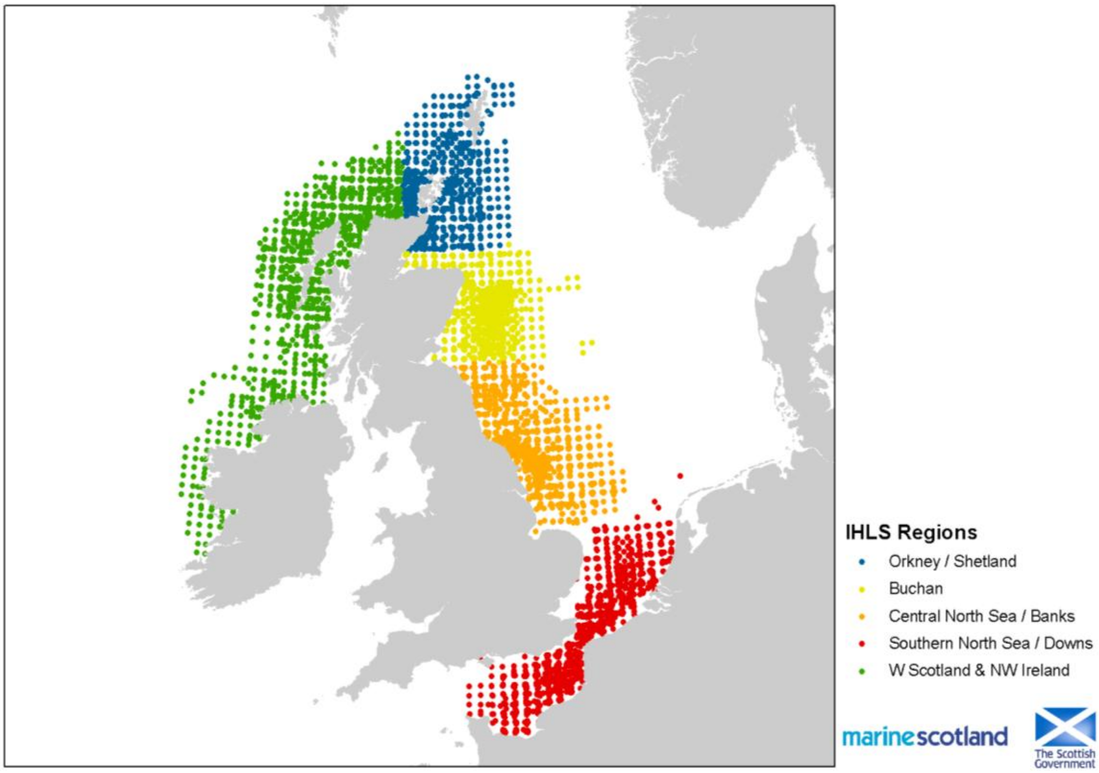

Figure 2: Distribution of International Herring Larvae Survey (IHLS) hauls, highlighting sampling regions, from 1972 to 2011.

Table 4

Summary of participating countries in the IHLS, west of Scotland and northwest Ireland, from 1972 to 1994.

Country	Years	Season	Month	Gear
Region: West of Scotland and Northwest Ireland				
Germany	1980-89	Autumn	Sep	GULF III
Ireland	1981-88	Autumn	Sep (86-87) Oct, Nov	GULF III
Netherlands	1974, 1980	Autumn	Sep (74), Oct (80)	GULF III
Norway	1980	Autumn	Oct	GULF III
Scotland	1972-94	Autumn	Aug (74, 78-79) Sep, Oct	DG III (82-89) GULF III (72-81, 90-94)
England	1972-75	Autumn	Sep	GULF III

Table 5

Summary of participating countries in the IHLS, North Sea, from 1972 to 2011.

Country	Years	Season	Month	Gear
Region: Orkney / Shetland				
Denmark	1972, 1975 1981-83, 88-89	Autumn	Sep	GULF III
Germany	1974-77 1979-2011	Autumn	Aug (79, 81-82, 85, 88-89) Sep, Oct	GULF III
Netherlands	1977-87 2004-06, 08-09	Autumn	Aug (77-78, 82, 84) Sep	TORPEDO (84) GULF III
Norway	2000	Autumn	Sep	GULF III
Scotland	1972-75 1977-89	Autumn	Aug (73) Sep, Oct (74, 77-78)	DG III (83-87, 89) GULF III (72-82, 88)
England	1972-75	Autumn	Sep	GULF III
Region: Buchan				
Denmark	1972, 1974 1981-89	Autumn	Sep	GULF III DG III (86)
Germany	1976, 93, 96-97 2000, 02, 07, 09	Autumn	Sep	GULF III
Netherlands	1978, 82, 88-92, 96, 98-2011	Autumn	Sep Oct (78, 89-90)	GULF III
Norway	1979, 81, 2000	Autumn	Sep (00), Oct (79, 81)	GULF III
Portugal	1977	Autumn	Sep, Oct	GULF III
Scotland	1972-1989 1993	Autumn	Aug (72-73), Sep Oct (72, 74-75, 93)	DG III (83-87, 89) GULF III (72-82, 88, 93)
England	1973	Autumn	Oct	GULF III
Region: Central North Sea / Banks				
Denmark	1974	Autumn	Aug, Sep	GULF III
Germany	1998-99 2003	Autumn	Sep (98) Oct (99, 03)	GULF III
Netherlands	1972-73 1975-96 1998-2011	Autumn	Aug (87), Sep, Oct (72-73, 75-76, 78, 80, 87-95, 02-03)	TORPEDO (84) GULF III (72-03) GULF VII (04-11)
Norway	1976-81	Autumn	Oct	GULF III
Portugal	1976	Autumn	Oct	GULF III
England	1972-89	Autumn	Aug (79, 84) Sep (72-73, 76-81, 84-85, 87) Oct	20 TTN (81-82) 50 TTN / HSTN (83-84) 53 TTN / HSTN (84-89) GULF III (72-80)
Region: Southern North Sea / Downs				
France	1981-82	Winter	Jan, Feb (82)	GULF III
Germany	1972-74 1979-2011	Winter	Jan	GULF III
Netherlands'	1972-2011	Winter	Dec Jan	GULF III (72-03) GULF VII (04-11)
England	1972-75, 77 1979-1989	Winter	Dec (82) Jan Feb (73, 80-81, 88)	20 TTN (81-82) 50 TTN / HSTN (83-84) 53 TTN / HSTN (84-89) GULF III (72-80, 87, 89)

The IHLS is centred upon the estimate of a Larval Abundance Index (LAI). An annual LAI is calculated on the basis of catches of only the most recently hatched larvae, and in particular larvae <11 mm in length in the Downs region and <10 mm in all the other regions (Heath, 1993; ICES 2008; Payne, 2010). The mean hatching length of larvae is approximately 6.5 mm, and growth rates estimated from field investigations have been approximately 0.2 to 0.3 mm per day. Hence, the LAI includes all larvae up to approximately 10 to 15 days old (Heath, 1993).

Similarly to what was described in Section 2.1.2. above for 0 group fish, IHLS catch data were also standardised by reducing each haul's catch to presence or absence of aggregations of small larvae. Rankine (1986) suggested that densities of >500 larvae per square metre should be used to indicate the main spawning grounds around the Scottish coastal areas. However, because in some of the years (1974 to 1980) the maximum density was well below this level at most of the sampling regions, a threshold of 85% of the distribution density curve was used, in Rankine's work, to represent the core spawning area per year, as proposed in ICES (2008). Therefore, aggregations of small larvae were identified for every year, by sorting in ascending order all hauls where small larvae were present, ranking their abundance and selecting the upper fifteenth percentile of the distribution (≥ 85%) as per Rankine (1986). In this report these larval aggregations are not used as a proxy for spawning areas of herring but simply as a predictive spatial representation of small herring larvae aggregations.

During the Quarter 1 IBTS an international herring larval survey takes place which uses a Methot-Isaacs-Kidd (MIK) net to survey over-wintering herring larvae. These data have not been used in the model for predicting small larvae aggregations, as given that four to five months may have passed since spawning these fish are mostly larger than 11 mm and are entering the post-larval stage.

Also, due to the available MIK data collation's large spatial resolution - the data points are averaged to a statistical rectangle - these data are incompatible with the environmental layers required for the model to work due to the difference in spatial resolution between these datasets.

This large resolution of the MIK data collation also precludes data from the MIK survey being used in the 0 group aggregation predictions for the same reason.

2.2 Environmental Data

All spatial operations and analysis used to prepare the environmental layers at this point of the work were developed using the ESRI® ArcGIS application for desktop ArcMap™, version 10.0.

Water depth, in meters, was obtained from the gridded bathymetry dataset GEBCO_08. The GEBCO_08 Grid is a global 30 arc-second grid largely generated by combining quality-controlled ship depth soundings with interpolation between sounding points guided by satellite-derived gravity data. It is developed by the General Bathymetric Chart of the Oceans (GEBCO) and made available through the British Oceanographic Data Centre (BODC) online at http://www.bodc.ac.uk/data/online_delivery/gebco/. The version used for this work, version 20100927, was released in September 2010 and downloaded in May 2013.

The GEBCO_08 grid was the spatial layer with the finest resolution available for the present work. Therefore, in order to preserve the best possible resolution in all layers, GEBCO_08 was used as the limiting factor for spatial resolution. At the latitudes of the present study area, a 30 arc-second grid has an average cell size of 780 x 780 m, and so all the other layers were created with, or resampled to, this grid resolution.

The layer slope was derived from the bathymetry grid GEBCO_08, by using the "Slope" tool of the Spatial Analyst package of ESRI® ArcMap™. Slope is the gradient, or rate of maximum change in z-value, of each cell of a raster surface.

Time series of the environmental layers temperature, salinity, eastward and northward water velocities and concentration of diatoms and flagellates were obtained from the biophysical model NORWECOM (Skogen *et al.*, 1995; Skogen and Søiland, 1998). This model was selected against the other models available – two biophysical, POLCOMS (Holt *et al.*, 2005) and ECOSMO (Schrum *et al.*, 2006) and one climatology, ICES / WODC (Berx and Hughes, 2008) – because it presented a more complete spatio-temporal coverage of the area and timeline analysed, and also offered the finest spatial resolution. Even so, this model does not have a complete cover of inshore areas and in particular it lacks coverage of the sea lochs and the intricate coastline on the west of Scotland. For this reason, it was not possible at this stage of the work to produce model outputs for these areas. For the set-up, validation and the latest information on the NORWECOM simulation refer to Hjøllo *et al.* (2009) and Skogen and Mathisen (2009).

NORWECOM offers monthly averages for each variable for the time period covering 1970-2012 (1970-2010 for temperature and salinity) and the datasets were extracted from the Institute of Marine Research NORWECOM hindcast download webpage in May 2013 (http://www.imr.no/~morten/wgoofe/). Several different extractions were carried out for temperature, salinity, eastward and northward water velocities and concentration of diatoms and flagellates intended for different models:

i) Near-bottom values for Quarter 3 and Quarter 4, for the period 2000-2012; this dataset was used to model 0 group aggregation areas of gadoid fish: cod, haddock, whiting, and Norway pout; saithe and ling were not modelled.
ii) Near-bottom values for Quarter 3 and Quarter 4, for the period 1970-2012; this dataset was used to model 0 group aggregation areas of benthic fish: plaice and sole. For hake and anglerfish presences of 0 group fish, not aggregations of 0 group fish were modelled.
iii) Mean-depth values for Quarter 3 and Quarter 4, for the period 1970-2012; this dataset was used to model 0 group aggregation areas of pelagic fish: herring, mackerel, horse mackerel, sprat and blue whiting;
iv) Near-bottom annual values, for the period 1970-2012; this dataset was used to model small larvae aggregation areas of herring.

The seabed sediments data was obtained from the European Marine Observation and Data Network (EMODNET) Seabed substrate map. The map was collated and harmonised from substrate information within the EMODNET-Geology project (http://www.emodnet-geology.eu/), with the contribution of more than 200 separate sea-bed substrate maps. In British waters the data was provided by the British Geographical Survey (BGS) and the existing substrate classifications have been translated to a scheme that is supported by EUNIS, the European Nature Information System. This EMODNET reclassification scheme consists of four substrate classes defined on the basis of the modified Folk triangle (mud to sandy mud; sand to muddy sand; coarse sediment; mixed sediment) and two additional substrate classes (diamicton and rock). In addition, the mixed sediment includes four subcategories: mixed sediment with bimodal grain-size distribution; Glacial clay, Hard bottom complex and Highly patchy seafloor areas. The final version (EMODNET, 2012) was produced in June 2012 and is available online at http://geomaps2.gtk.fi/ArcGIS/services/EMODnet/MapServer/WMSServer as a polygon feature class. To convert this into a raster layer of the same resolution as the other environmental layers, the Polygon to Raster tool from the Conversion toolbox of ESRI® ArcMap™ was used, with the MAXIMUM_COMBINED_AREA cell assignment method: if there was more than one feature in a cell with the same value of sediment type, this method combined the areas of these features, and the combined feature with the largest area within the cell determined the value to assign to that cell.

The distance to coast layer was produced by the Euclidean Distance tool of the Spatial Analyst package of ESRI® ArcMap™. This tool produces a raster output giving the distance from each cell in the raster to the closest source, which in this case was a combination of the layers pan50 for the coastline of Scotland (the 0 m contour from the OS PANORAMA dataset, http://www.ordnancesurvey.co.uk/business-and-government/products/land-form-panorama.html) and britisles for the remaining coastline of the British Isles.

Finally, the same Euclidean Distance tool was used to calculate the layer distance to gravel, this time using the categories Gravel (GV) and Sandy Gravel (SDGV) of the BGS's Marine SeaBed Sediment Map - UK Waters - 250k (DigSBS250) as source. This layer, being especially relevant for defining herring spawning grounds (Parrish *et al.*, 1959; Bowers, 1969; Holliday (1958) cited in Rankine, 1986), was only used to model small larvae aggregation areas of herring and left out of the other models.

Because the IHLS surveys are designed so that the hauls take place within a 10 x 10 nautical mile (NM) grid (ICES, 2008), there was a need to adapt the resolution of the environmental layers to accommodate this coarser resolution of the survey data for the models of herring spawning areas. The centre of these 10 x 10 NM cells is well-defined as the positions where the samples should be taken. Most hauls take place close to the cell centre, depending on weather conditions, wind stress, presence of oil platforms etc. So there is some kind of flexibility, most often in the order of magnitude of up to one mile deviation, seldom two (Norbert Rohlf, personal communication, 21/08/2013). Therefore a 2 x 2 NM grid was created, in order to allow for a 1 NM radius around the centre of each cell, and all the environmental layers were resampled to this resolution. The resampling was done with the Resample tool of the ArcMap Data Management toolbox, using the cubic convolution algorithm as the resampling technique. This algorithm uses the value of the sixteen nearest input cell centres to determine the value on the output raster. The new value for the output cell is a weighted average of these sixteen values, adjusted to account for their distance from the centre of the output cell.

A summary of all the environmental layers used in the present work can be found in Table 6.

Table 6

List of environmental layers used in the species distribution models.

Variable	Resolution	Reference
Bathymetry	30 arc-sec ≈ 780m	The GEBCO_08 Grid, version 20100927. http://www.gebco.net
Slope	30 arc-sec ≈ 780m	Derived from Bathymetry, GEBCO_08 Grid, version 20100927. http://www.gebco.net
Temperature	0.1° ≈ 7km	NORWECOM (Skogen *et al.*, 1995; Skogen & Søiland, 1998). http://www.imr.no/~morten/wgoofe/
Salinity	0.1° ≈ 7km	NORWECOM (Skogen *et al.*, 1995; Skogen & Søiland, 1998). http://www.imr.no/~morten/wgoofe/
Eastward sea water velocity	0.1° ≈ 7km	NORWECOM (Skogen *et al.*, 1995; Skogen & Søiland, 1998). http://www.imr.no/~morten/wgoofe/
Northward sea water velocity	0.1° ≈ 7km	NORWECOM (Skogen *et al.*, 1995; Skogen & Søiland, 1998). http://www.imr.no/~morten/wgoofe/
Diatoms concentration	0.1° ≈ 7km	NORWECOM (Skogen *et al.*, 1995; Skogen & Søiland, 1998). http://www.imr.no/~morten/wgoofe/
Flagellates concentration	0.1° ≈ 7km	NORWECOM (Skogen *et al.*, 1995; Skogen & Søiland, 1998). http://www.imr.no/~morten/wgoofe/
Seabed sediments	30 arc-sec ≈ 780m	EMODNET Seabed substrate map (1:1 million), EMODNET-Geology. http://geomaps2.gtk.fi/ArcGIS/services/EMODnet/MapServer/WMSServer
Distance to gravel	30 arc-sec ≈ 780m	Euclidean distance calculated from categories Gravel (GV) and Sandy Gravel (SDGV) Marine SeaBed Sediment Map - UK Waters - 250k (DigSBS250). http://www.bgs.ac.uk/discoverymetadata/13605549.html
Distance to coast	30 arc-sec ≈ 780m	Euclidean distance calculated from pan50 (Scotland) and britisles (rest of the coastline)

2.3 Species Distribution Models

All analyses were conducted using R 2.15. (R Development Core Team2009, URL: http://www.R-project.org). Two distinct modelling approaches were used, one based on presence-only data, MAXENT, and one based on presence-absence data, Random Forest.

For the presence only approach, the MAXimum ENTropy (MAXENT) algorithm (Phillips *et al.* 2006) was used. This model is based on the concept of the ecological niche defined by Hutchinson (1957). It uses different mathematical algorithms to calculate the ecological niche of the target species based on the environmental variable values at the presence point (Monk *et al.* 2010). The MAXENT method (Phillips *et al.*, 2006; Elith *et al.*, 2011) minimizes the relative entropy between two probability densities (one estimated from the presence data and the other from the landscape) defined in covariate space. After defining the niche, the model projects it into geographic space to produce a predictive map of suitable habitat. In this work the R implementation MAXENT in the R package 'dismo' was used.

The presence-absence based approach was conducted using the Random Forest model (Breiman, 2001). Random Forest is an advanced modification of the Classification and Regression Trees (CARTs, Breiman, 1984). As the name suggests, Random Forest fits many classification trees to a dataset, and then combines the predictions from all the trees. As described in Cutler *et al.*, (2007), the algorithm begins with the selection of many bootstrap samples from the data. A classification tree is then fit to each bootstrap sample, but at each node, only a small number of randomly selected variables are available for the binary partitioning. The trees are fully grown and each is used to predict the out-of-bag observations, which are those that are present in the original dataset, but do not occur in a bootstrap sample. The predicted class of an observation is calculated by majority vote of the out-of-bag predictions for that observation, with ties split randomly.

To assess the importance of a specific predictor variable, the values of that variable are randomly permuted for the out-of-bag observations, and then the modified data are passed down the tree to get new predictions. The difference between the misclassification rate for the modified and original out-of-bag data, divided by the standard error, is a measure of the importance of the variable.

The presence-absence data for each species was randomly divided into a training subsample (with 90% of the total points) and a test subsample (with the remaining 10%), following the methodology described by Hijmans and Elith (2013). The ability of the training subsample to predict the probability of presence was tested using the test subsample. Moreover, the data were also tested on a year-by-year basis: for each year analysis, the data were divided into a training subsample containing all the years, except the year being used as the test subsample.

The performance of the models was estimated using two different statistics: the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC, Fielding and Bell, 1997) and the kappa statistic (Cohen, 1960). The AUC varies between 0 and 1, with values higher than 0.9 considered as excellent performance, whereas values between 0.9 and 0.7 indicate good prediction and values lower than 0.7 indicate poor prediction (Hosmer and Lemeshow, 2000). The kappa statistic ranges from -1 to 1, with values higher than 0.75 indicating excellent prediction, values between 0.4 and 0.75 indicating good prediction and values lower than 0.4 indicating poor prediction (Landis and Koch, 1977). This evaluation process was repeated 10 times in each combination of species and model (and once per year in the case of the year-by-year evaluation), calculating the AUC and kappa values each time based in a different random selection of training and test subsamples. Both statistics were calculated using the implementation of evaluate in the R package ‘dismo’. The threshold used to compute the kappa value was calculated each time, using the implementation of threshold in the same package. The threshold which provided maximum kappa values was selected and used as the probability of presence above which to identify the most sensitive areas.

For a more technical description of how the model variables were used to predict the probability outputs shown in this report please refer to the Technical Annex at the end of this report.

READ BEFORE USING THESE SENSITIVITY MAPS

Caveats Regarding use of 0 Group Distribution Maps

a) Lack of Environmental Data for Coastal Areas

The GIS layers based on oceanographic models used for modelling 0 group fish distribution do not cover the inner coastal areas of some parts of Britain's coastline. This is most noticeable in the west coast.

For the model to run correctly and the statistical processes to make sense all the environmental layers have to be clipped (cover the same spatial extent) to the same spatial layer. In this case, the hydrographic layers are the ones that create the spatial gaps due to lack of data close to the coast.

These are shown as the white areas in the probability of presence of aggregations maps. It is important to highlight that these "white" areas are not included in the model prediction hence no outputs are available for these areas.

MSS is aware that this is an important issue and is already seeking methods to resolve it.

Hence these maps should be used in combination with alternative information that describes the species' nursery areas around the areas that are missing from these outputs. A source for this information for cod around the Scottish coast is:

Gibb, F., Gibb, I. & Wright, P. (2007). ***Isolation of Atlantic cod (Gadus morhua) nursery areas***. Marine Biology, 151(3): 1185-1194.

b) Using the Prediction Probability Maps

The sensitivity maps show the probability of finding 0 group aggregations in a huge area around the UK, larger than the extent of UK territorial waters. This has allowed the development of models to be more robust but also can be inconvenient for some species when high abundances of 0 group aggregations occur outside of UK waters. This can be compounded by the lack of local data within the area of interest.

In some species, for example whiting, the probability of presence of aggregations of 0 groups in UK waters can appear relatively less probable due to high probability of aggregations in waters outside of UK. It is advisable to use a local interpretation of the model outputs.

c) The Maps Represent Aggregations of Fish in their First Year of Life

They do not represent "nursery areas" as described in the precursor to this report, Coull *et al*. (1998). "Nursery areas" can comprise a larger spread of ages and sizes. These representations are of 0 group fish, fish that are in the first year of their life.

d) Herring Larvae Aggregations Model, Performance Evaluation

The timing between the act of spawning and the surveying of these herring larvae aggregations mean that the larvae have been drifting in the currents for an unknown period of time. This makes it difficult to find a connection between the explanatory variables used in the models and the probability of presence of aggregations. This problem has a direct effect on the herring larvae aggregation model's performance compared to the predictive strength of other species' models.

Also, the parameters that predominantly drove this model were counter-intuitive to what could be expected given the life history of this species. For example: distance to gravel, the preferred substrate for herring spawning, did not give a strong signal in these predictions.

For these reasons, the herring larvae maps are only presented here as a first approach to updating the spawning areas, and should not be published and used as spawning maps for herring.

These maps of herring larvae aggregations may benefit from further applications of this model once additional environmental layers that, for instance, better describe herring larvae dispersal or give a stronger predictive signal can be included in the modelling process.

e) Species-specific Issues

Insufficient data on 0 group fish were available to perform the species distribution modelling approach on saithe and ling, these two species have not been included in this report.

Hake and anglerfish outputs represent presences and absences of 0 group fish as insufficient data were available to apply the species distribution modelling approach to aggregations of 0 group fish of these two species.

3 Fisheries Sensitivity Maps

3.1 Areas of 0 Group Aggregations

There is a set of three maps for each of the selected species:

a) The first map shows the probability of presence of aggregations of 0 group fish; aggregations were determined as detailed in Section 2.1.1. For hake and anglerfish the maps presented here show the probability of presence of 0 group fish and not the probability of presence of aggregations.

   The first map also shows information about the performance of the Random Forest model, evaluated by the AUC and kappa statistics, as explained in Section 2.3 above. Random Forest always showed higher values than MAXENT and, therefore, this model was used to produce the final outputs. A summary of the performance of every model can be seen in Table 7 and Table 8.

b) The second map shows areas of 0 group aggregations in red, identified as the areas with a probability of presence above the value at which kappa is maximum – as detailed in Section 2.3 above

   This map also shows Presence and Absence source data.

c) The third map shows how the newly defined 0 group aggregation areas compare to the areas defined in Coull *et al.* (1998), for the species where these were available. Horse mackerel, hake and anglerfish were not included in the Coull (1998) report hence for these three species there are no maps of this kind.

Table 7

Evaluation of models performance: AUC (Area Under the Curve) and kappa statistics, using a random division of the data.

	AUC		Kappa	
	Value	**Performance**	**Value**	**Performance**
Cod	0.977 ± 0.018	Excellent	0.682 ± 0.053	Good
Haddock	0.987 ± 0.009	Excellent	0.859 ± 0.043	Excellent
Whiting	0.980 ± 0.005	Excellent	0.823 ± 0.021	Excellent
Norway pout	0.988 ± 0.005	Excellent	0.861 ± 0.023	Excellent
Herring	0.949 ± 0.012	Excellent	0.539 ± 0.033	Good
Mackerel	0.985 ± 0.010	Excellent	0.837 ± 0.057	Excellent
Horse mackerel	0.988 ± 0.004	Excellent	0.848 ± 0.033	Excellent
Sprat	0.988 ± 0.010	Excellent	0.857 ± 0.049	Excellent
Blue whiting	0.997 ± 0.002	Excellent	0.879 ± 0.038	Excellent
Plaice	0.997 ± 0.003	Excellent	0.893 ± 0.030	Excellent
Sole	0.995 ± 0.007	Excellent	0.750 ± 0.096	Excellent
Hake	0.977 ± 0.005	Excellent	0.657 ± 0.034	Good
Anglerfish	0.979 ± 0.013	Excellent	0.667 ± 0.036	Good

Table 8

Evaluation of models performance: AUC (Area Under the Curve) and kappa statistics, using a year-by-year division of the data.

Herring, mackerel and sole were not analysed using this division of data.

	AUC		Kappa	
	Value	**Performance**	**Value**	**Performance**
Cod	0.79 ± 0.08	Good	0.19 ± 0.08	Poor
Haddock	0.82 ± 0.08	Good	0.37 ± 0.07	Poor
Whiting	0.83 ± 0.05	Good	0.42 ± 0.08	Good
Norway pout	0.86 ± 0.04	Good	0.38 ± 0.1	Poor
Herring	-	-	-	-
Mackerel	-	-	-	-
Horse mackerel	0.91 ± 0.07	Excellent	0.51 ± 0.15	Good
Sprat	0.86 ± 0.08	Good	0.33 ± 0.11	Poor
Blue whiting	0.95 ± 0.03	Excellent	0.51 ± 0.18	Good
Plaice	0.96 ±0.03	Excellent	0.67 ± 0.16	Good
Sole	-	-	-	-
Hake	0.92 ± 0.05	Excellent	0.47 ± 0.17	Good
Anglerfish	0.97 ± 0.01	Excellent	0.67 ± 0.03	Good

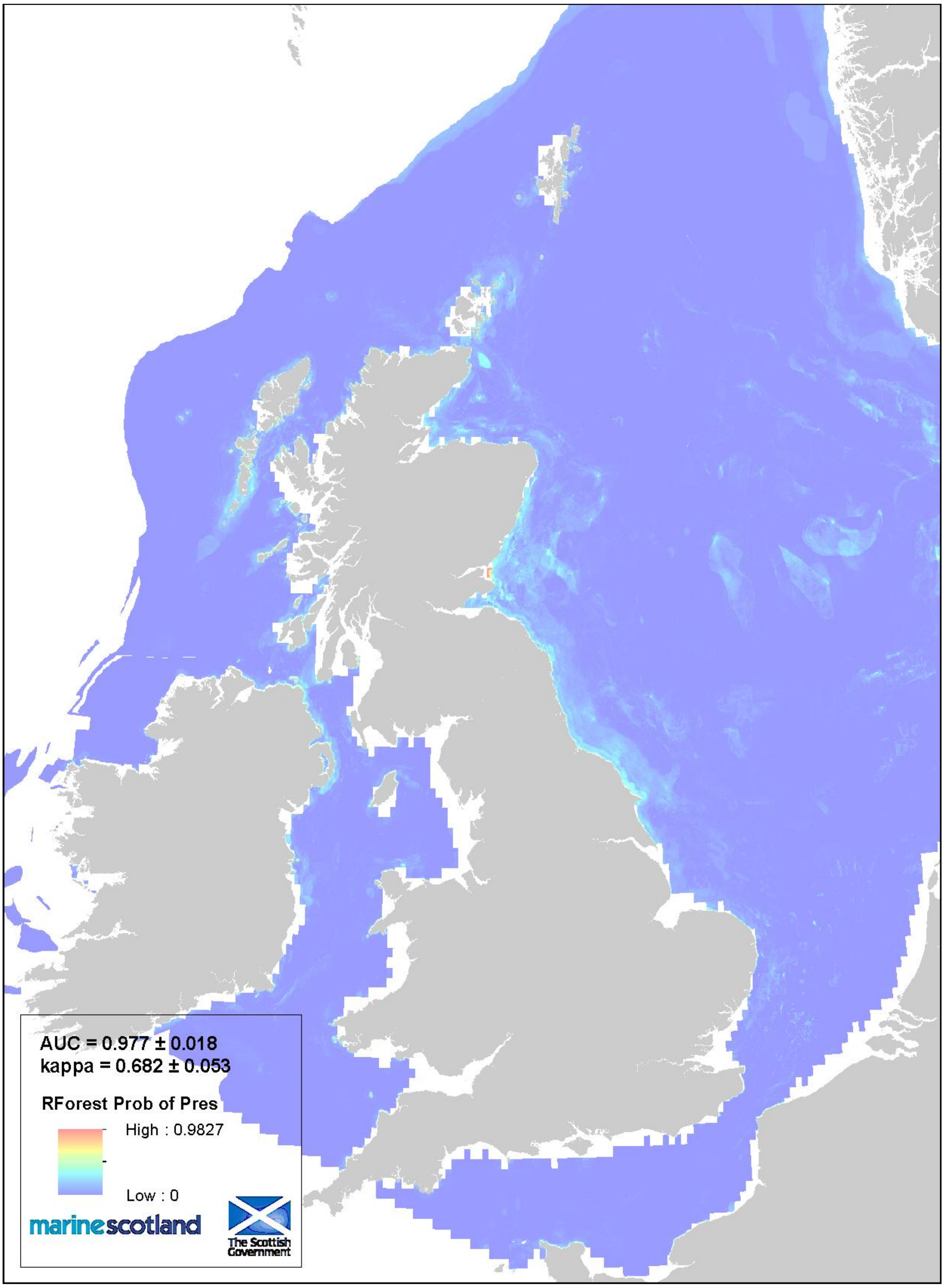

Figure 3: Probability of presence of 0 group aggregations. Cod.

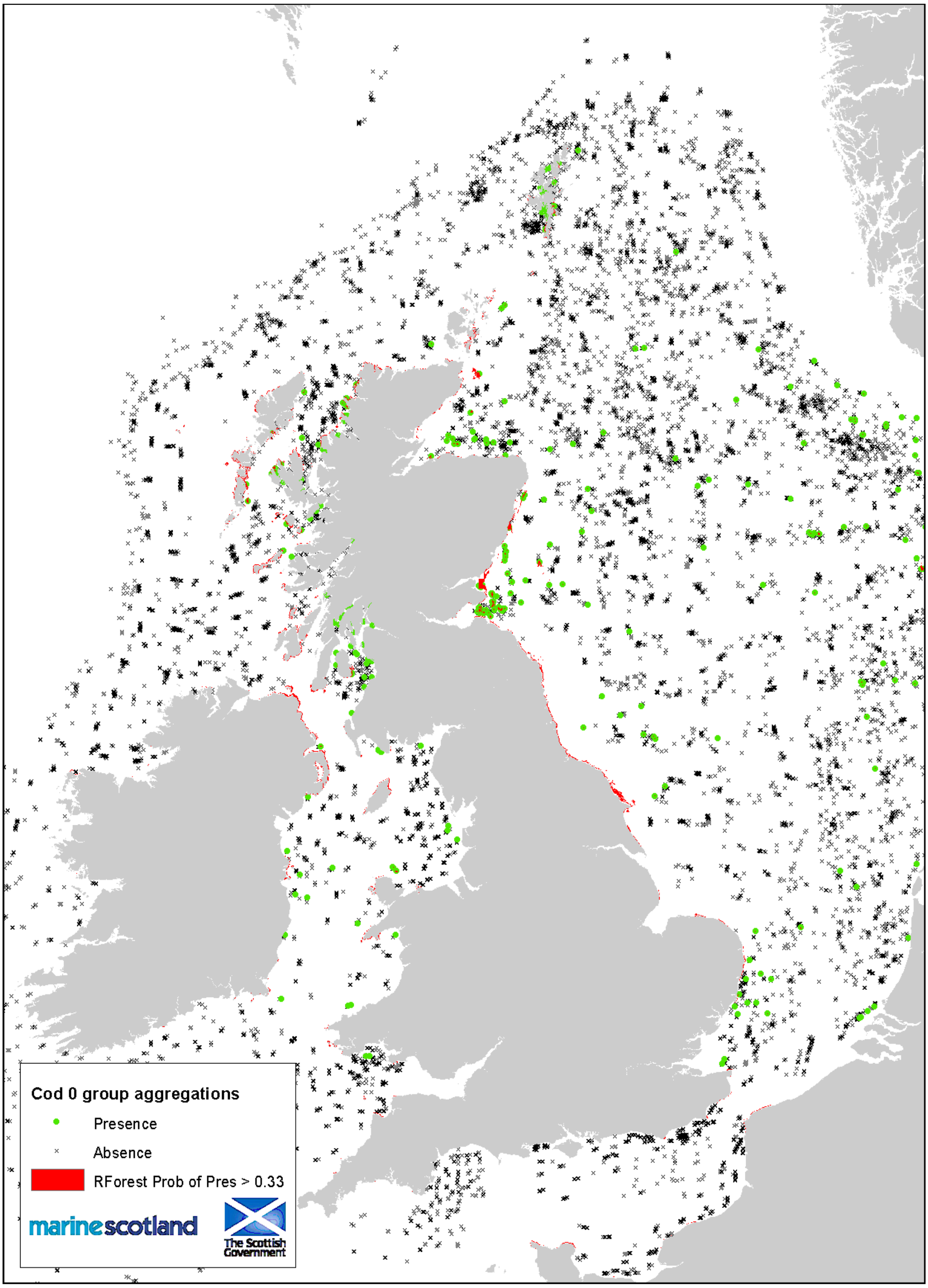

Figure 4: 0 group aggregations and areas of Presence/Absence source data. Cod.

Figure 5: 0 group aggregation areas and Coull (1998) nursery areas. Cod.

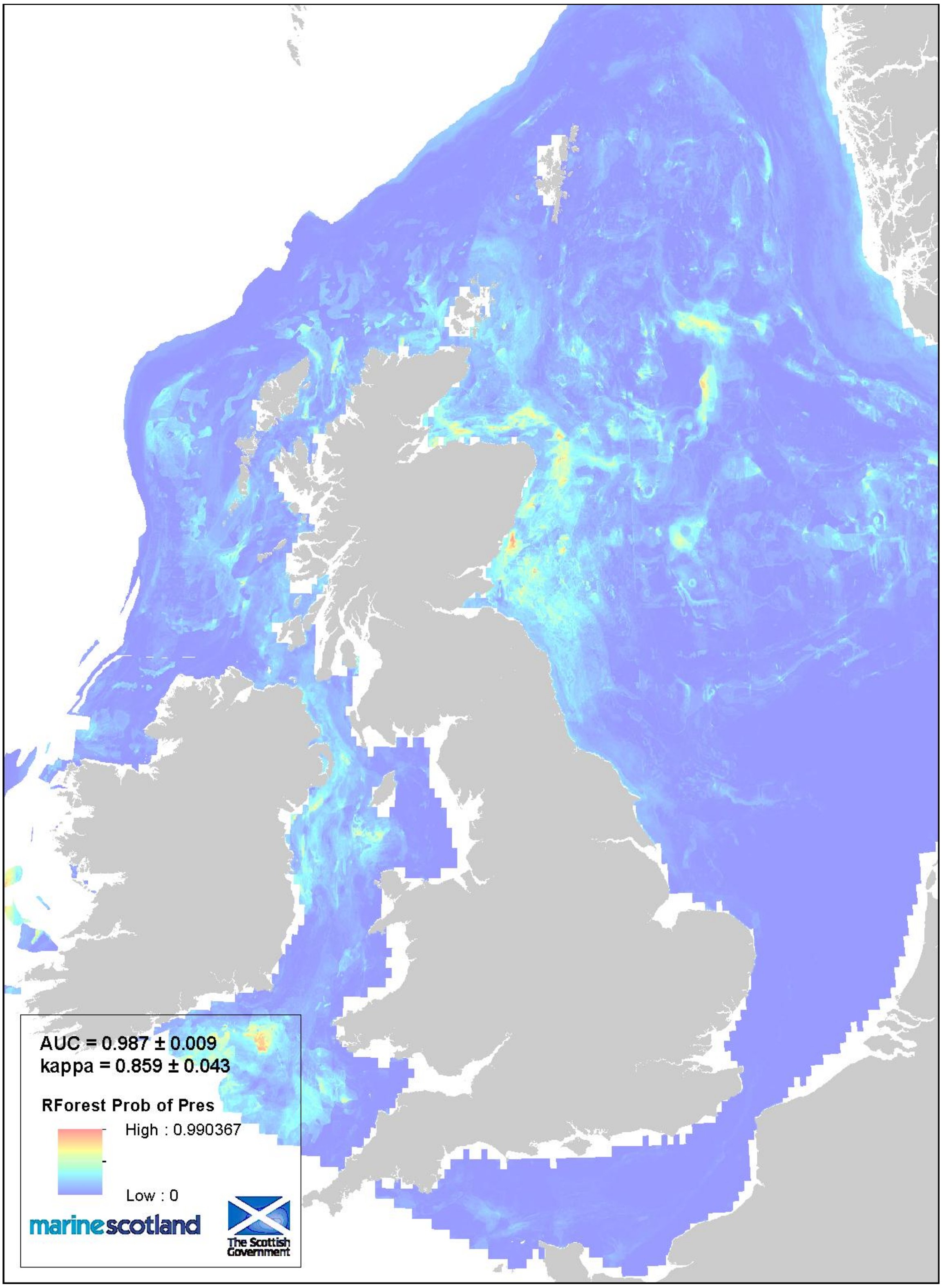

Figure 6: Probability of presence of 0 group aggregations. Haddock

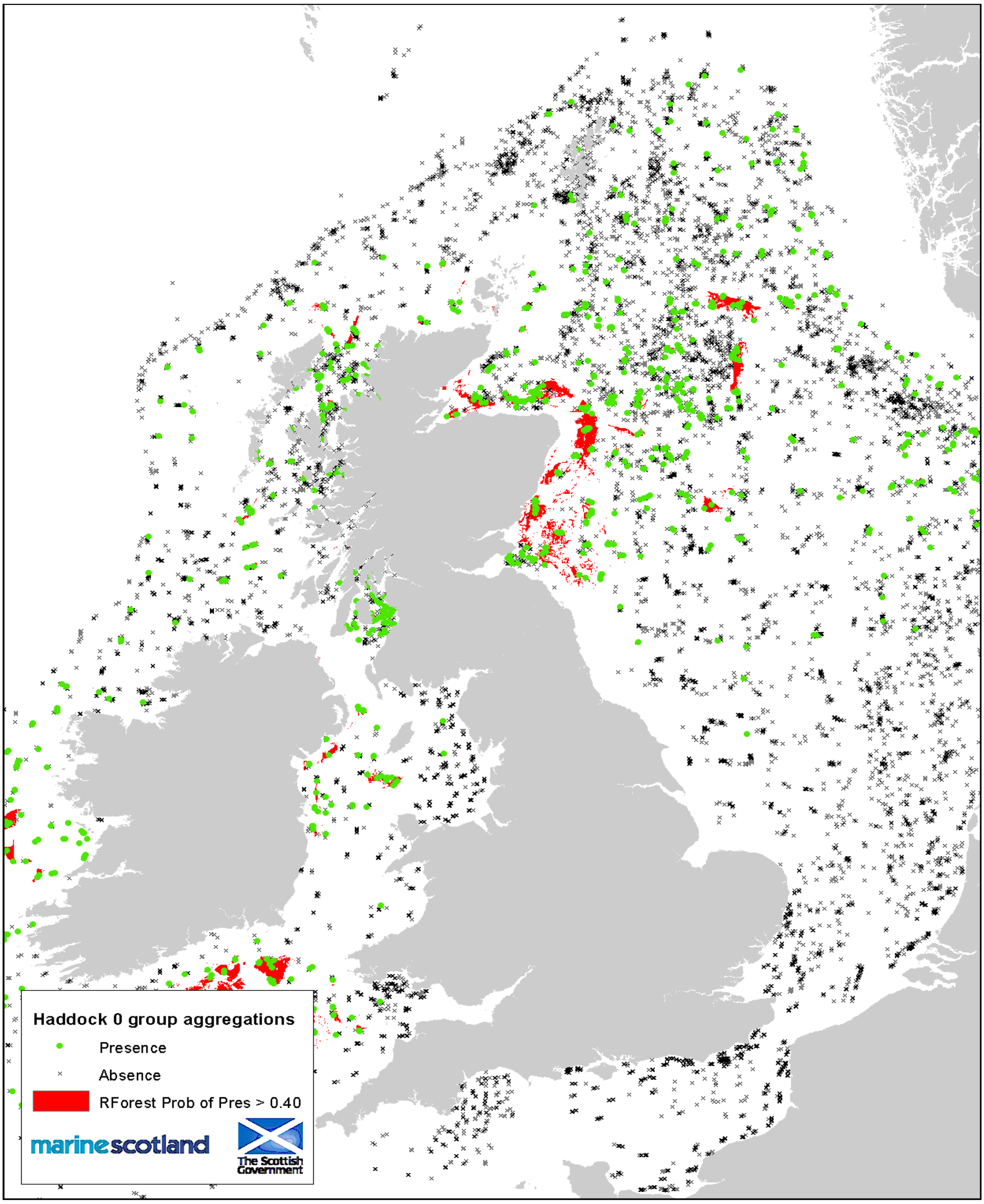

Figure 7: 0 group aggregations and areas of Presence/Absence source data. Haddock.

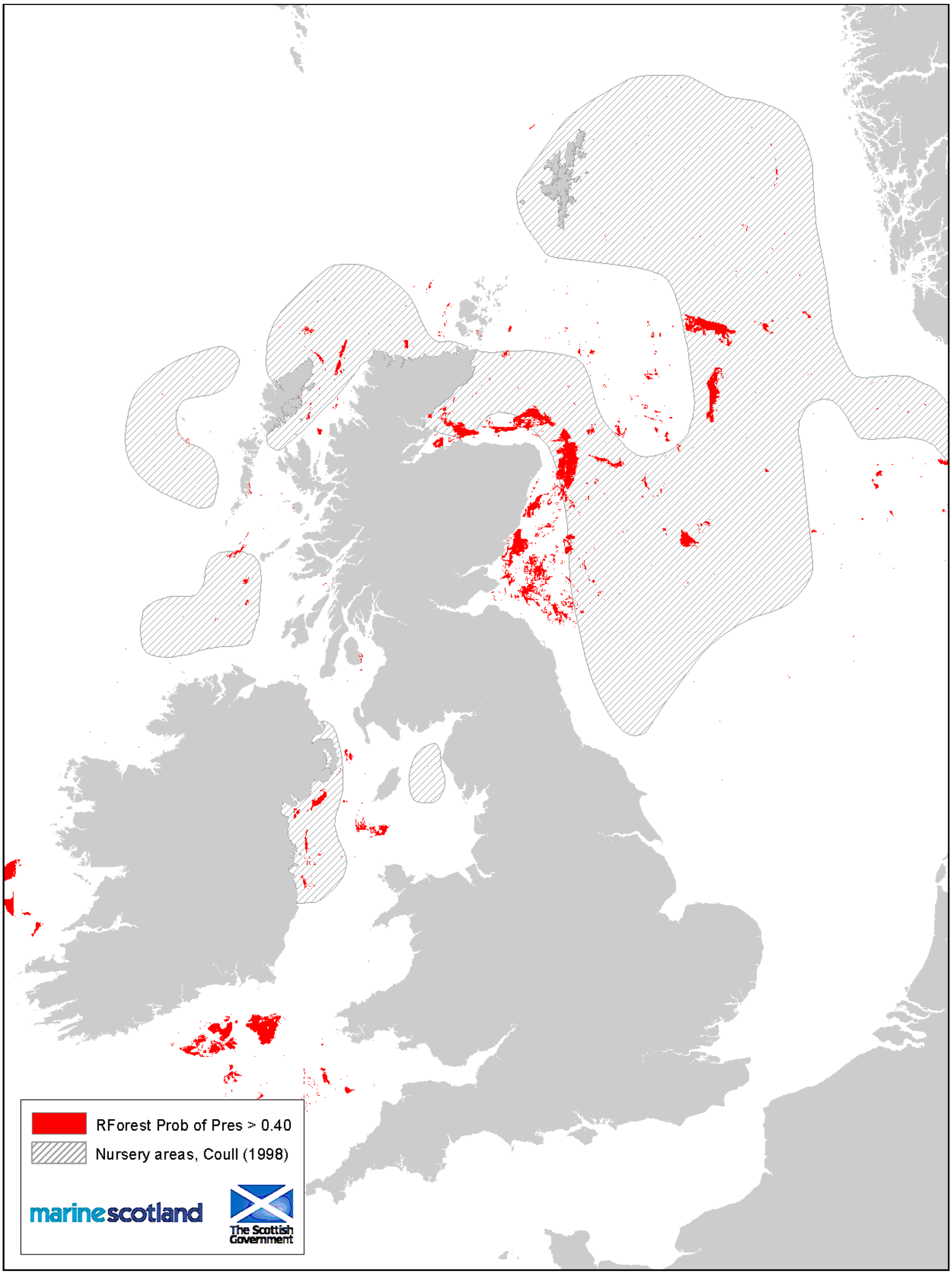

Figure 8: 0 group aggregation areas and Coull (1998) nursery areas. Haddock.

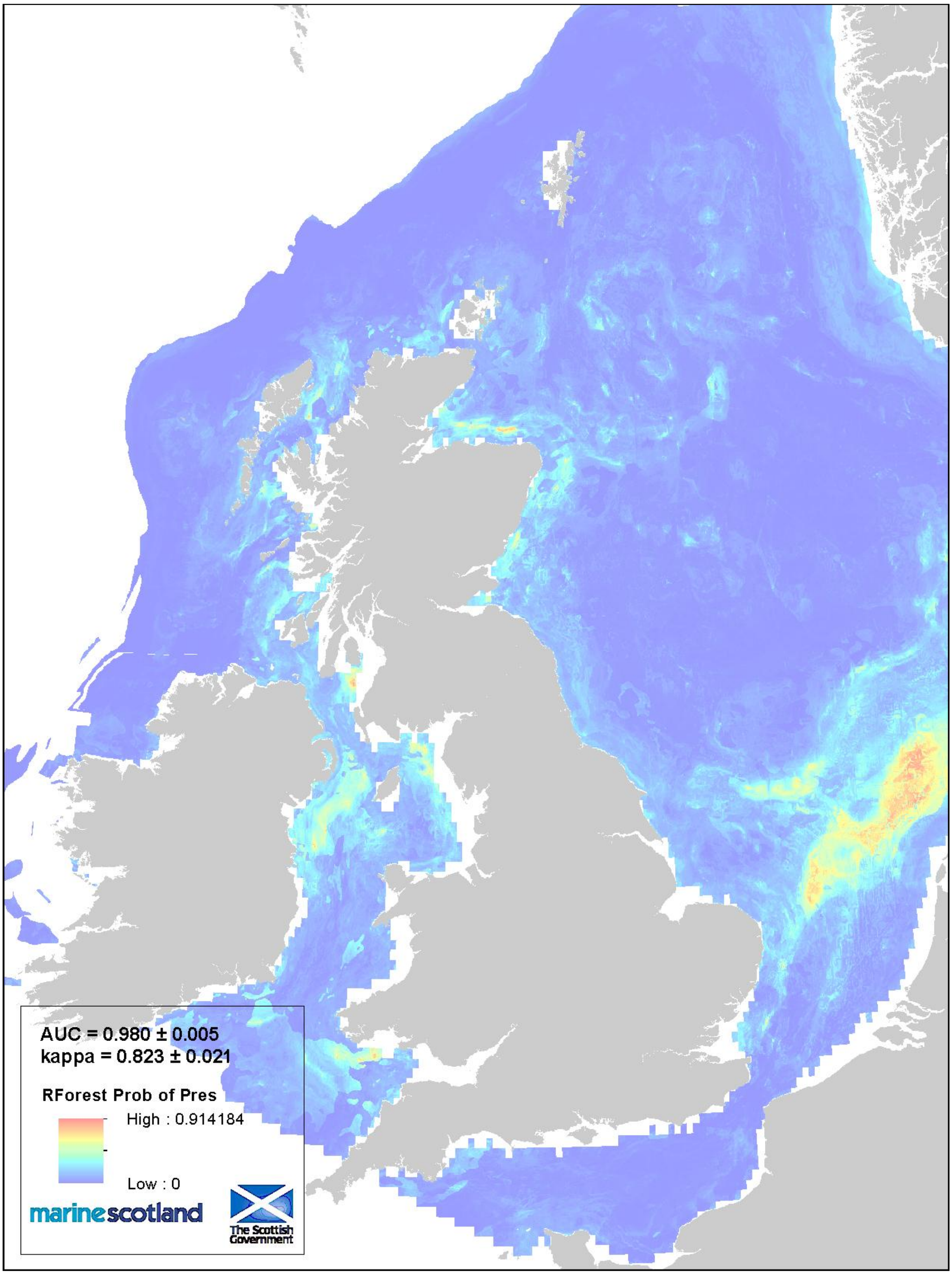

Figure 9: Probability of presence of 0 group aggregations. Whiting.

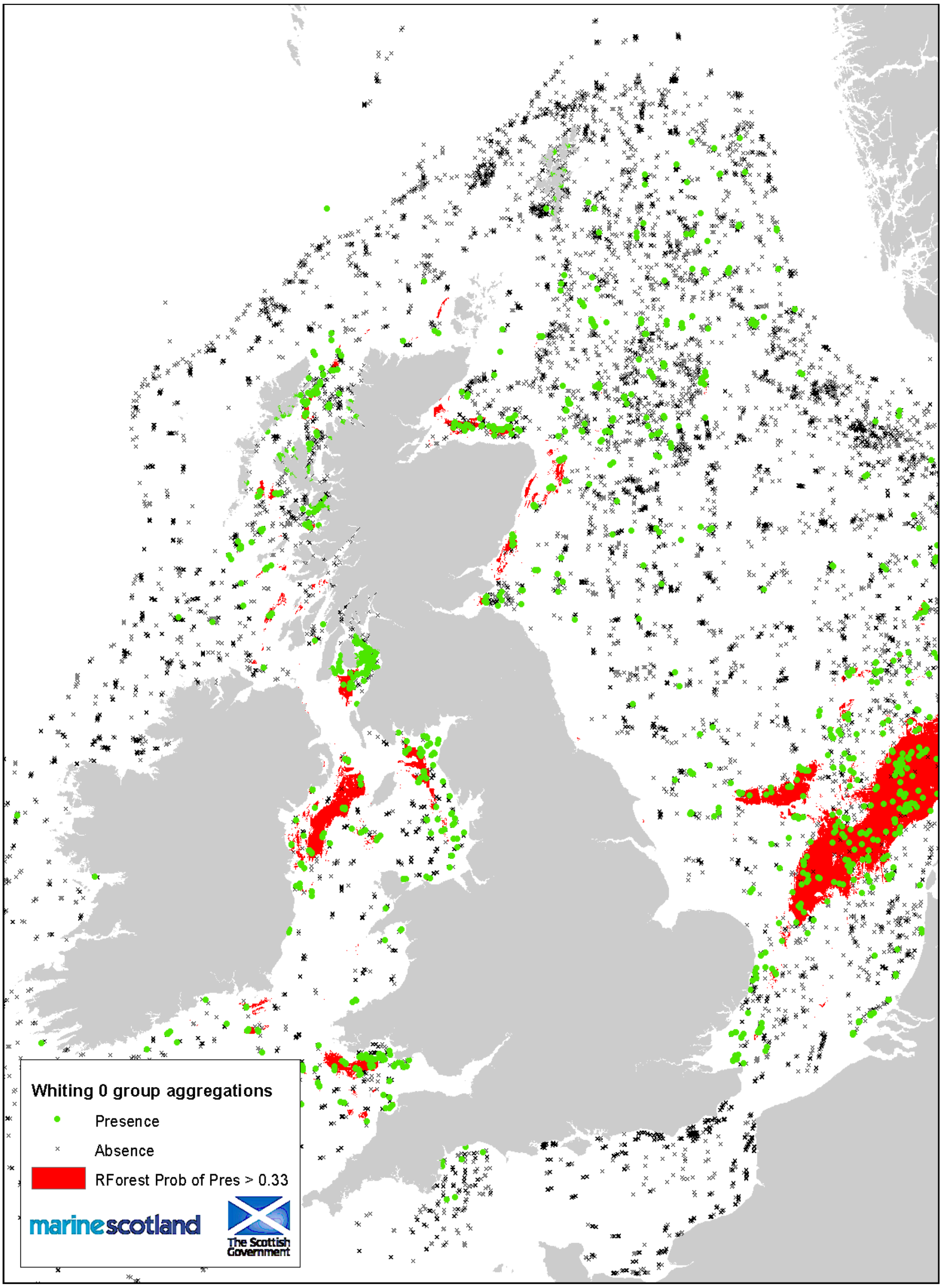

Figure 10: 0 group aggregations and areas of Presence/Absence source data. Whiting.

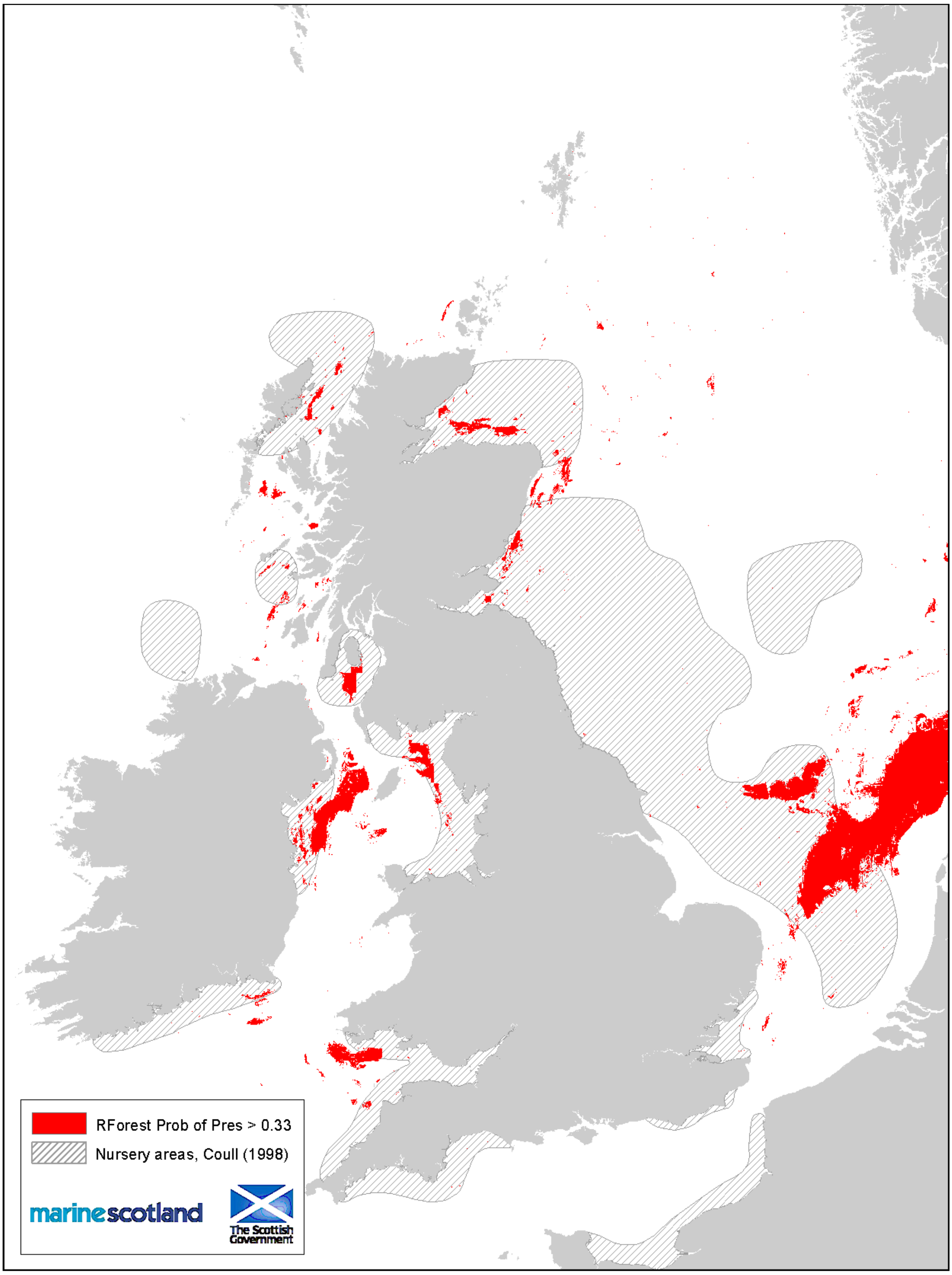

Figure 11: 0 group aggregation areas and Coull (1998) nursery areas. Whiting.

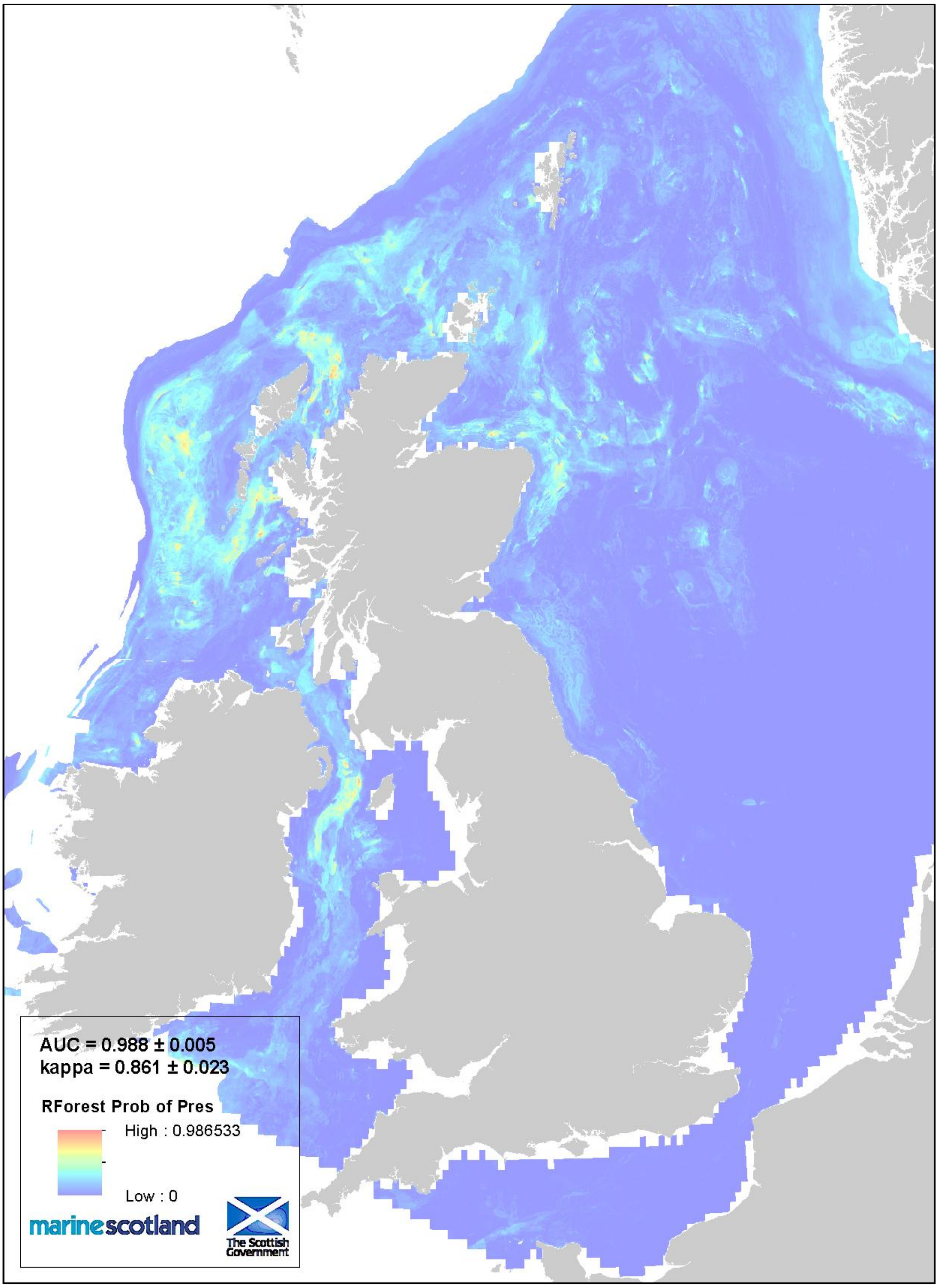

Figure 12: Probability of presence of 0 group aggregations. Norway pout.

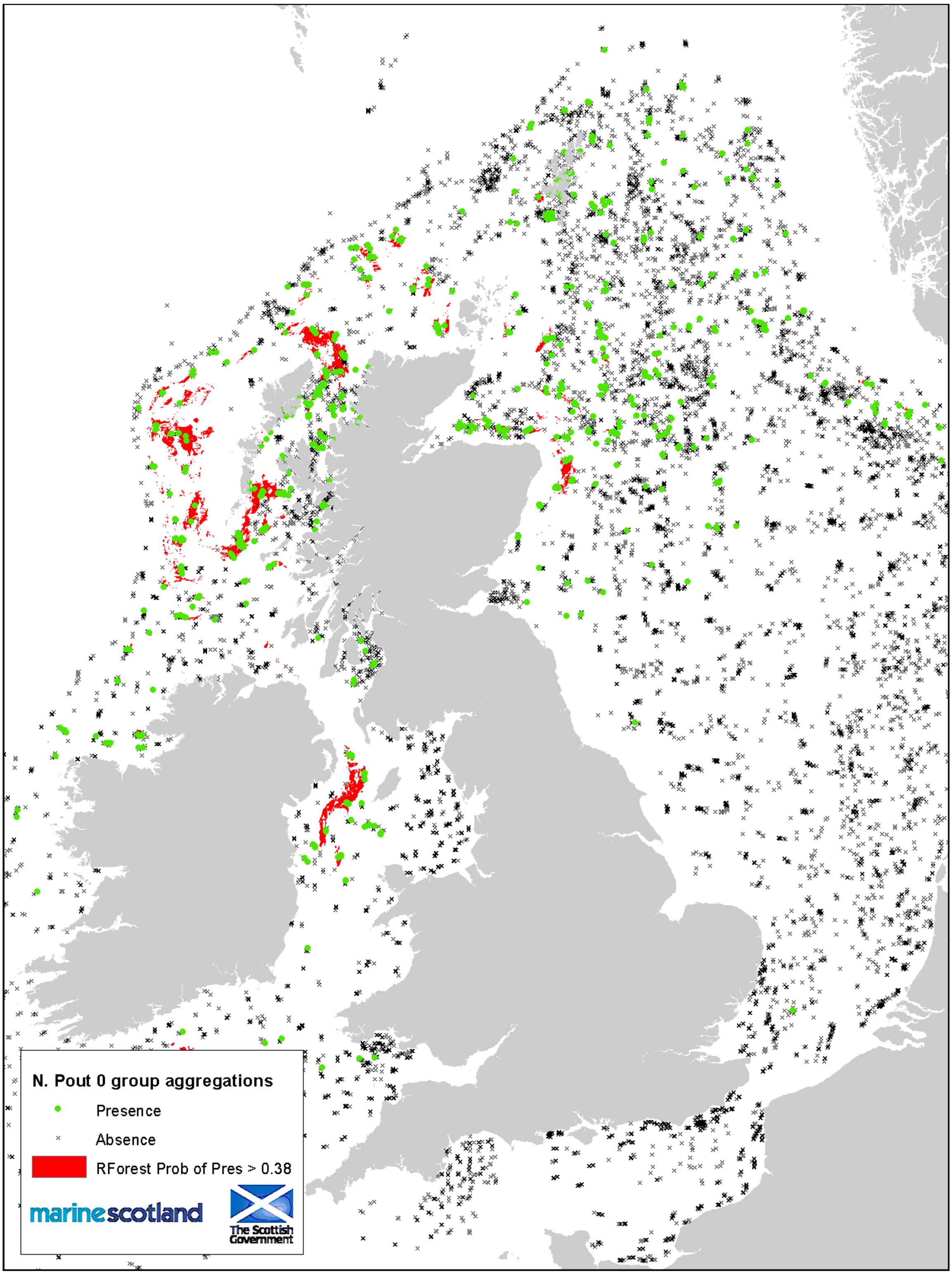

Figure 13: 0 group aggregations and areas of Presence/Absence source data. Norway pout.

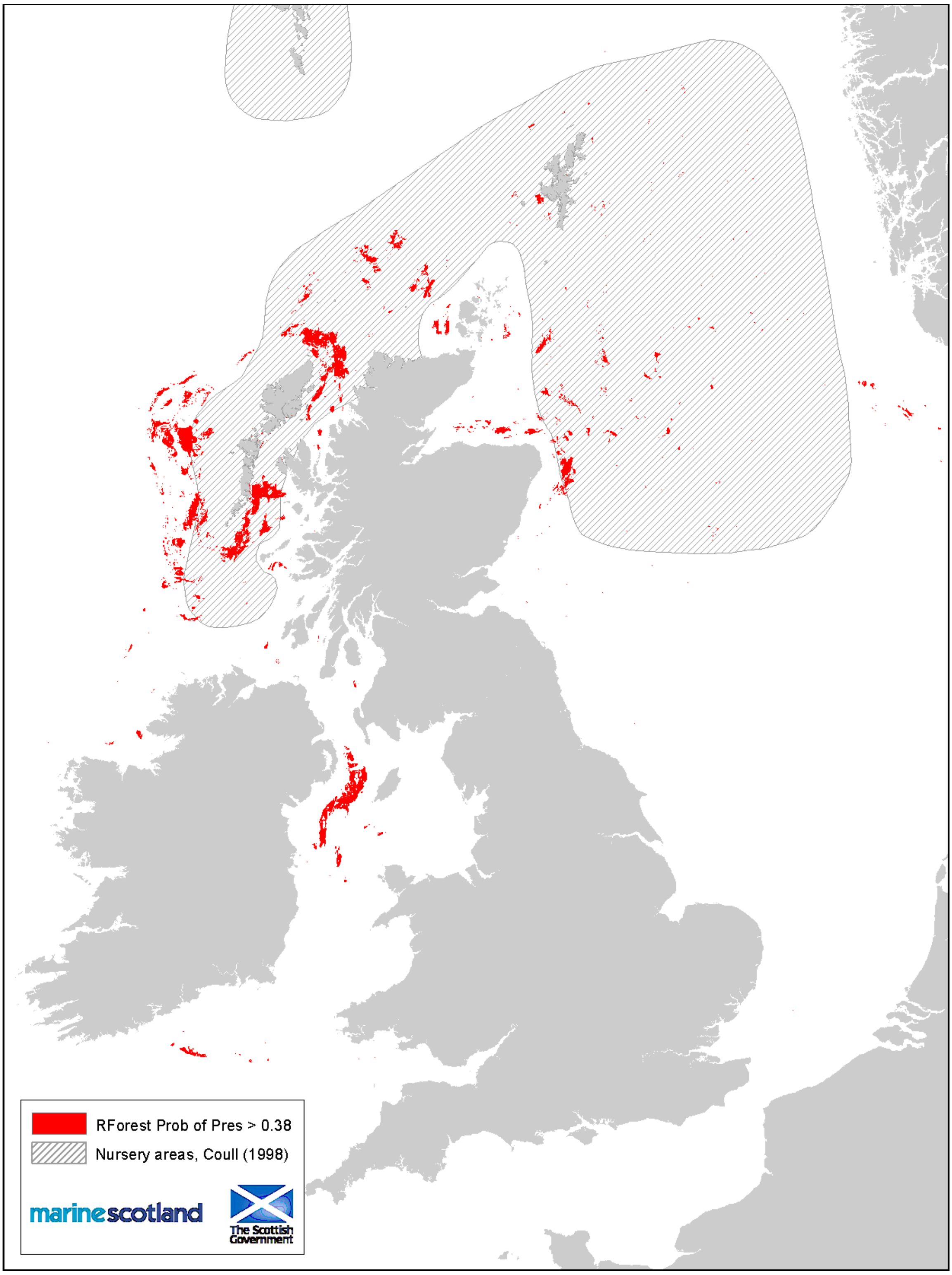

Figure 14: 0 group aggregation areas and Coull (1998) nursery areas. Norway pout.

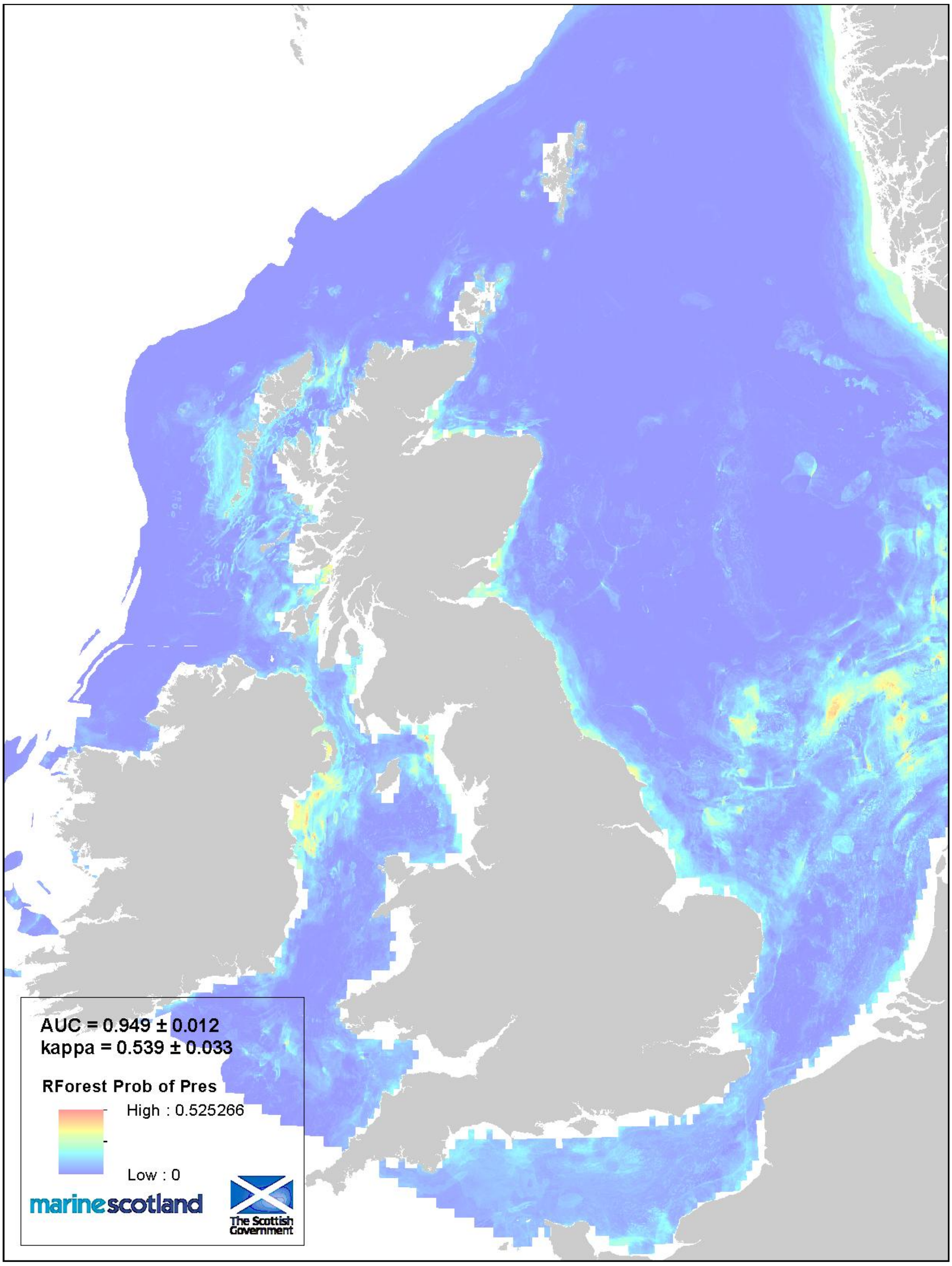

Figure 15: Probability of presence of 0 group aggregations. Herring.

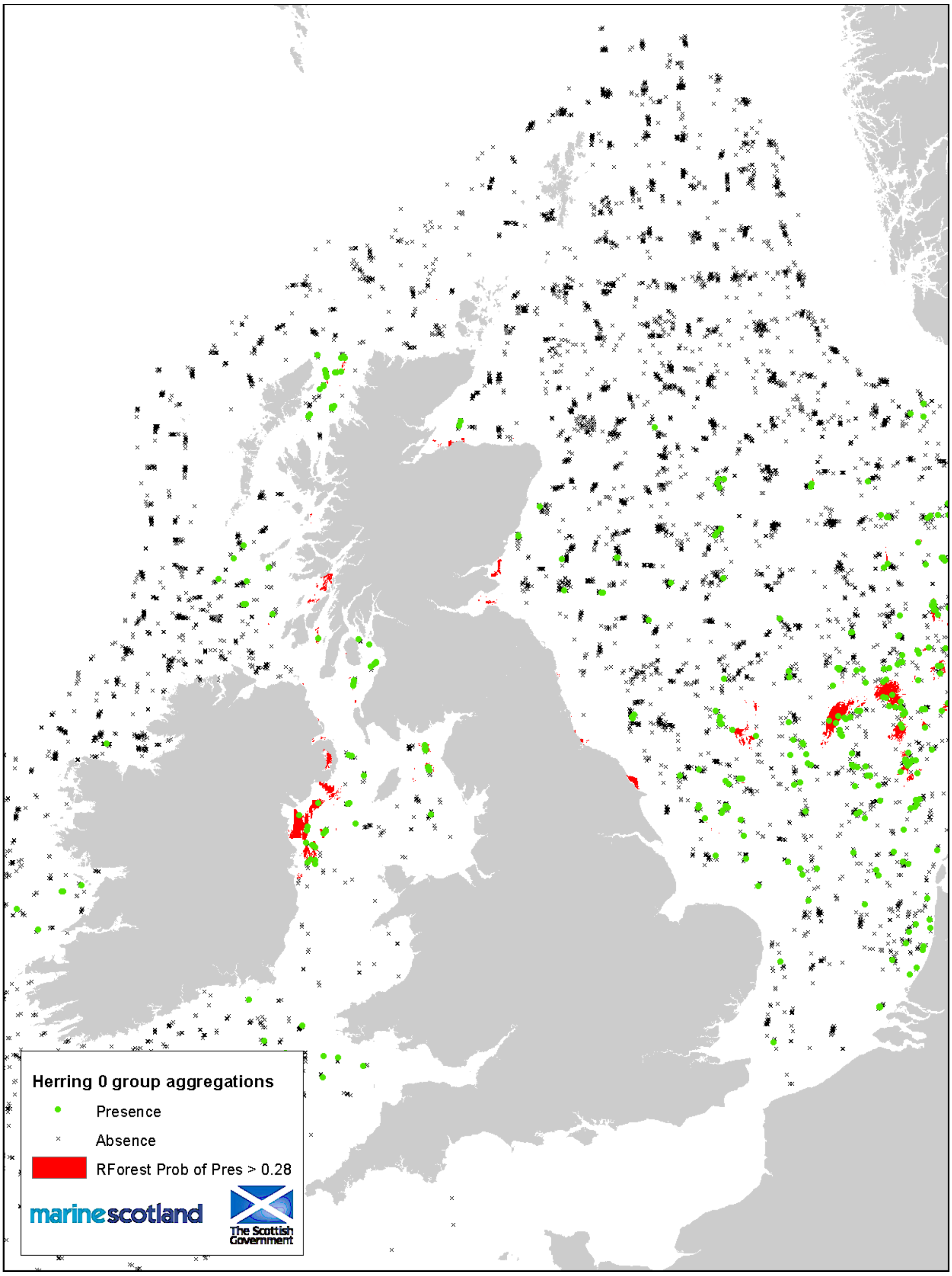

Figure 16: 0 group aggregations and areas of Presence/Absence source data. Herring.

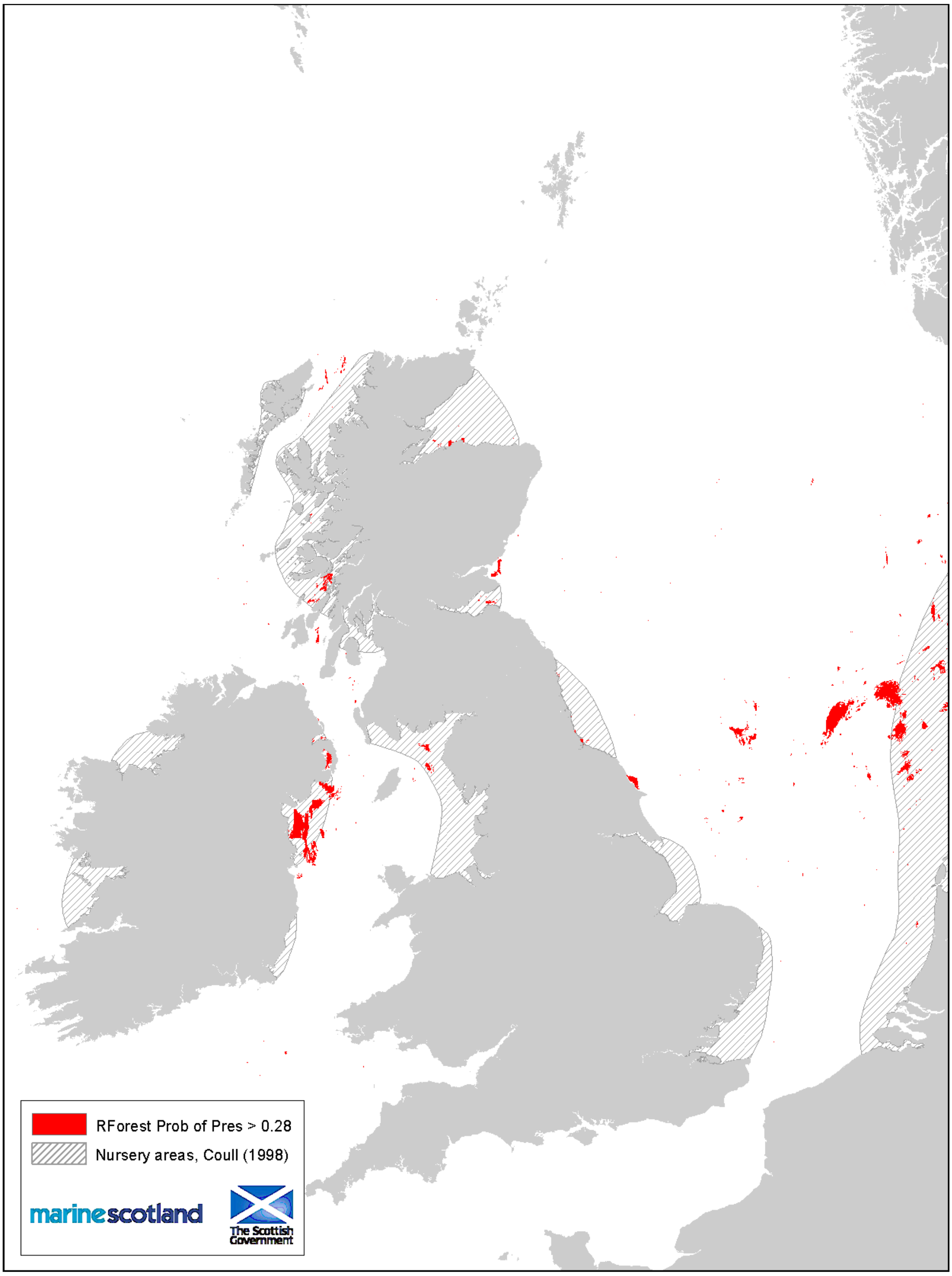

Figure 17: 0 group aggregation areas and Coull (1998) nursery areas. Herring.

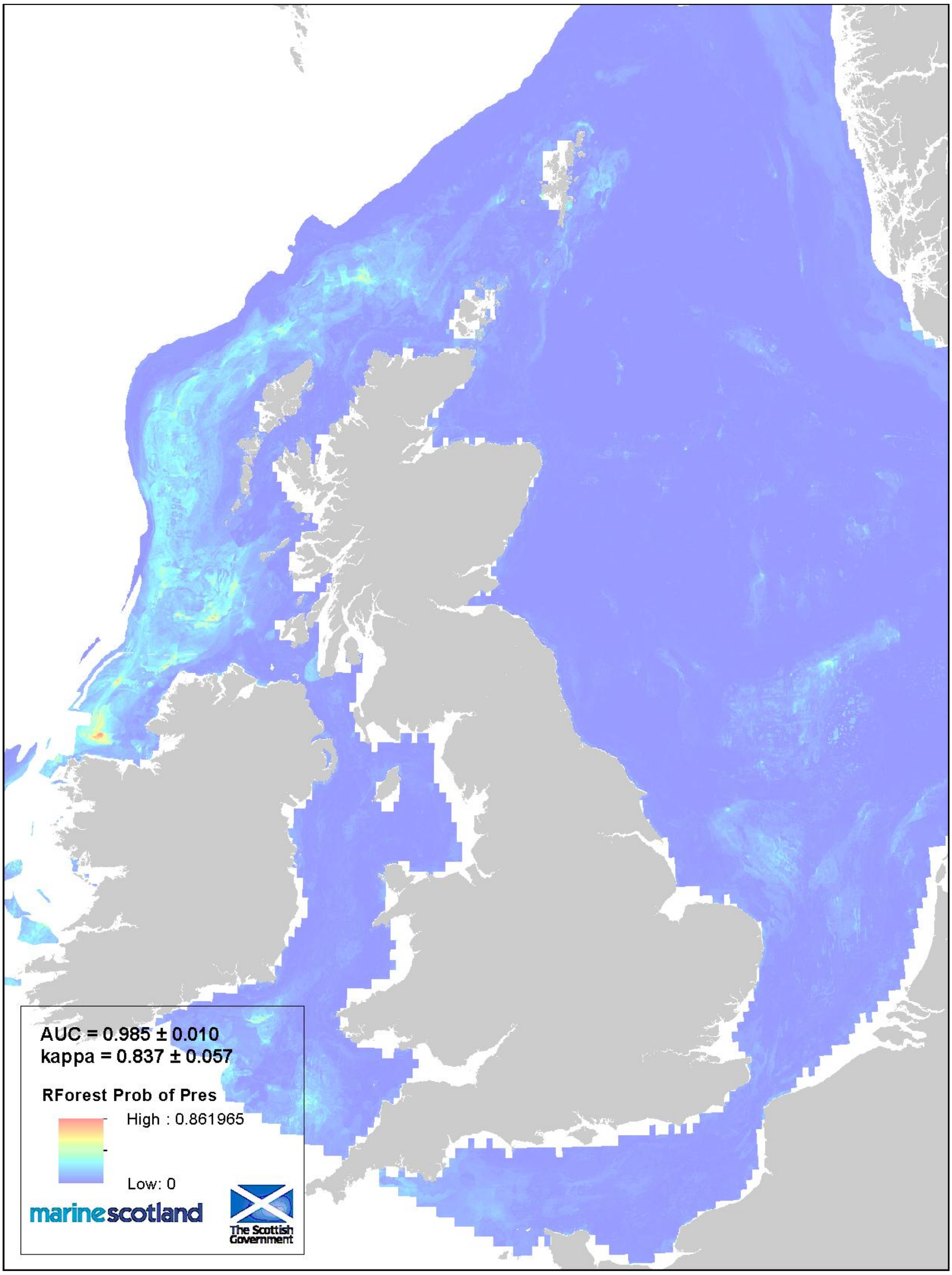

Figure 18: Probability of presence of 0 group aggregations. Mackerel.

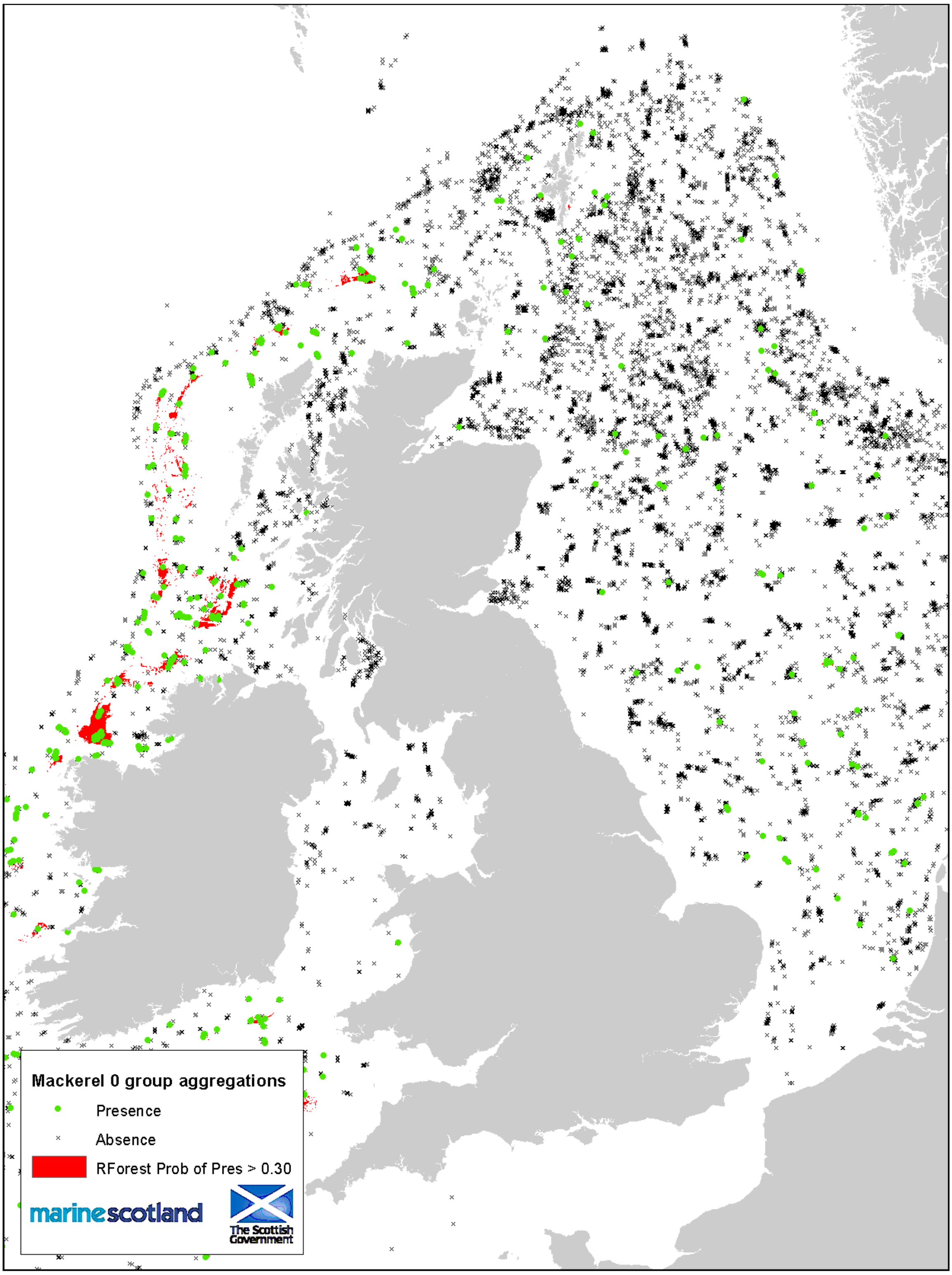

Figure 19: 0 group aggregations and areas of Presence/Absence source data. Mackerel.

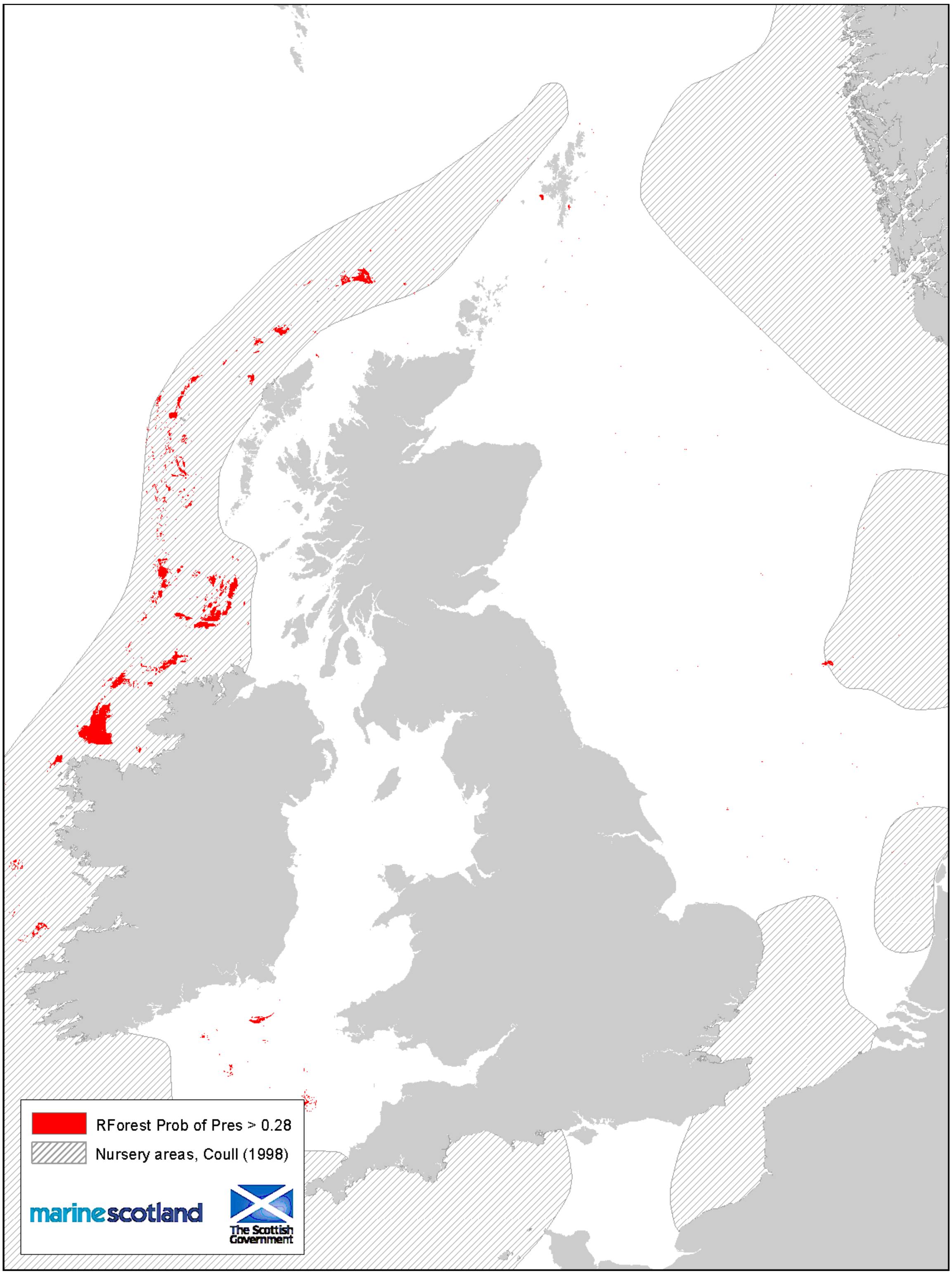

Figure 20: 0 group aggregation areas and Coull (1998) nursery areas. Mackerel.

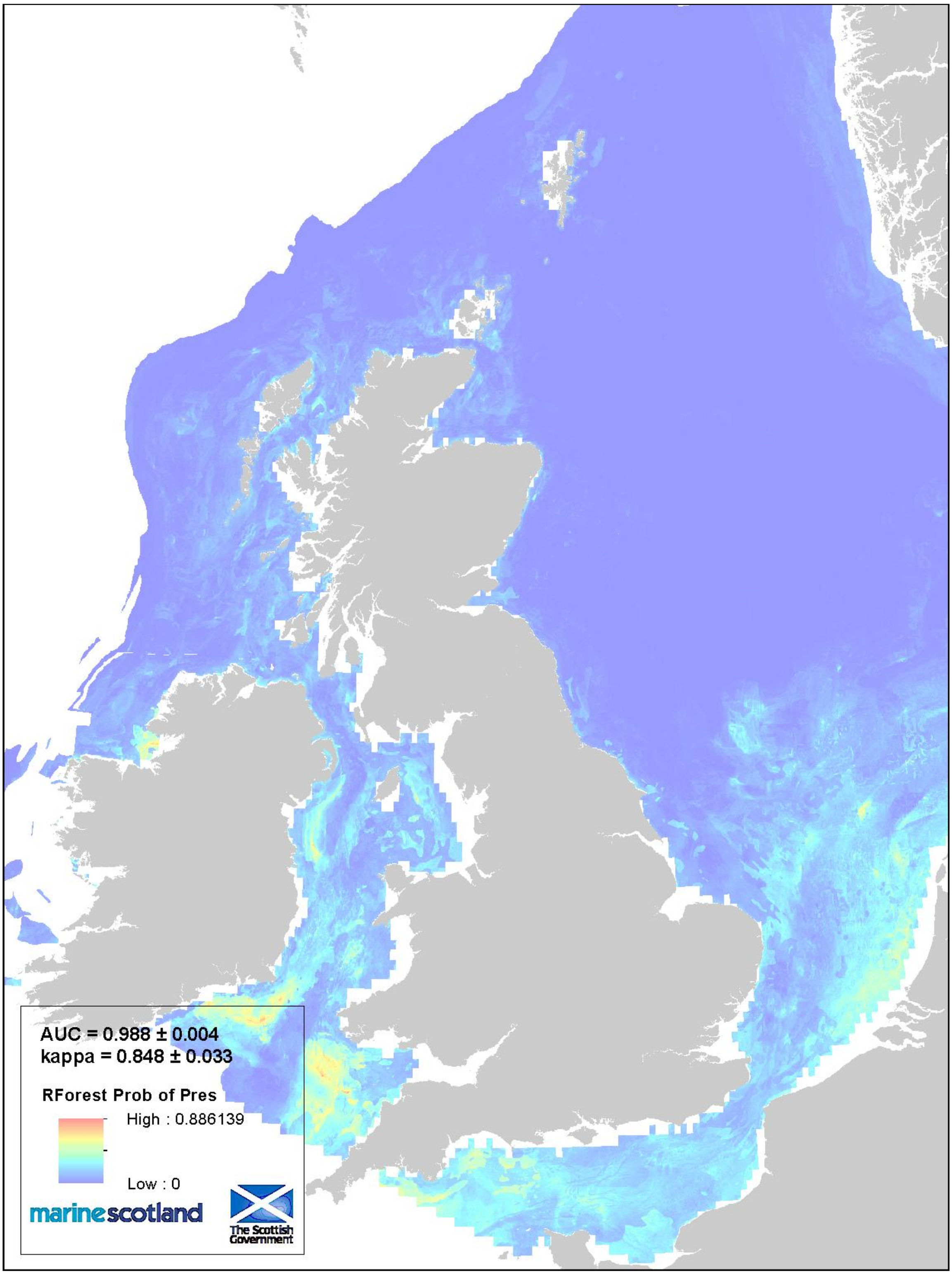

Figure 21: Probability of presence of 0 group aggregations. Horse mackerel.

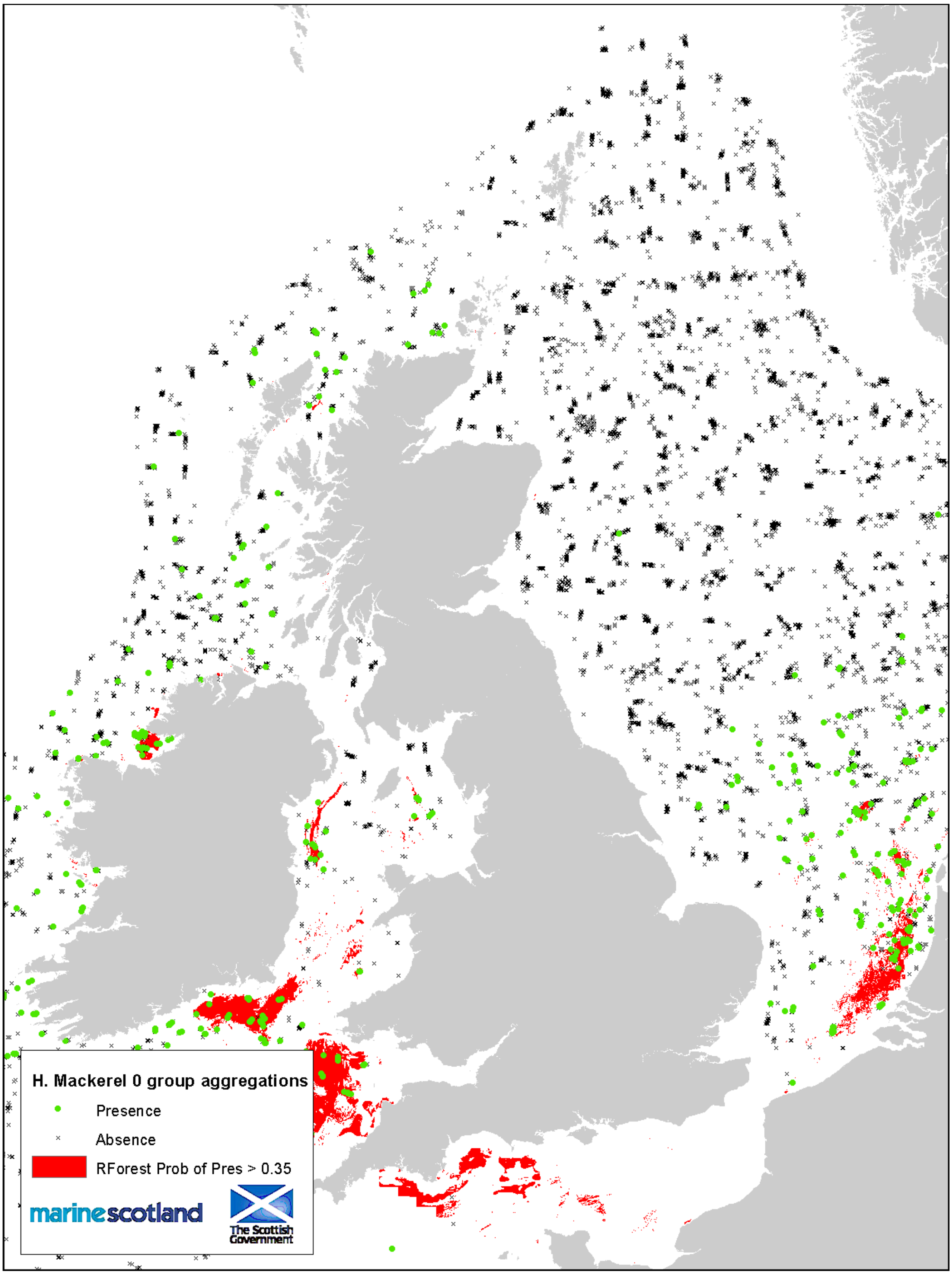

Figure 22: 0 group aggregations and areas of Presence/Absence source data. Horse mackerel.

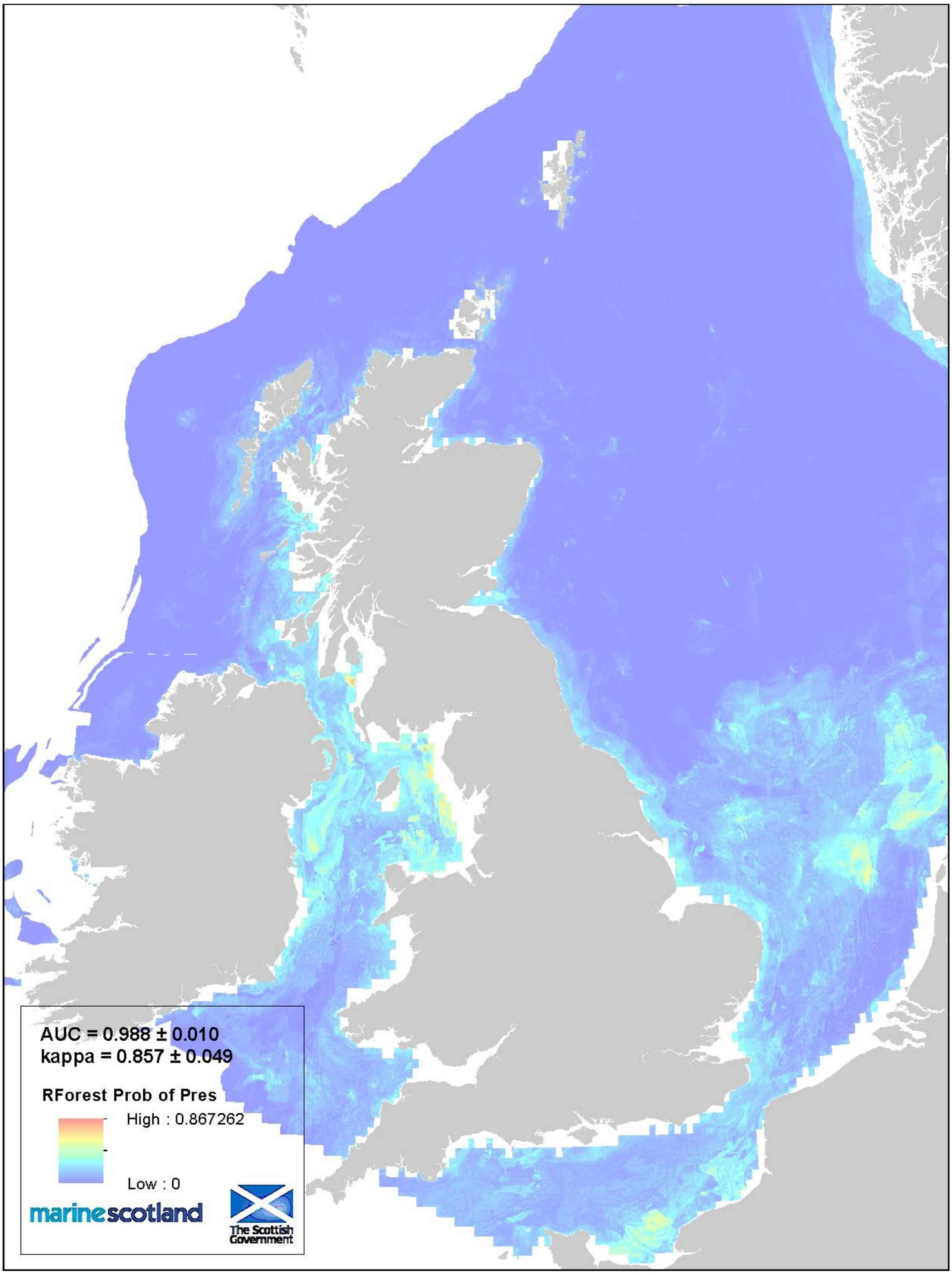

Figure 23: Probability of presence of 0 group aggregations. Sprat.

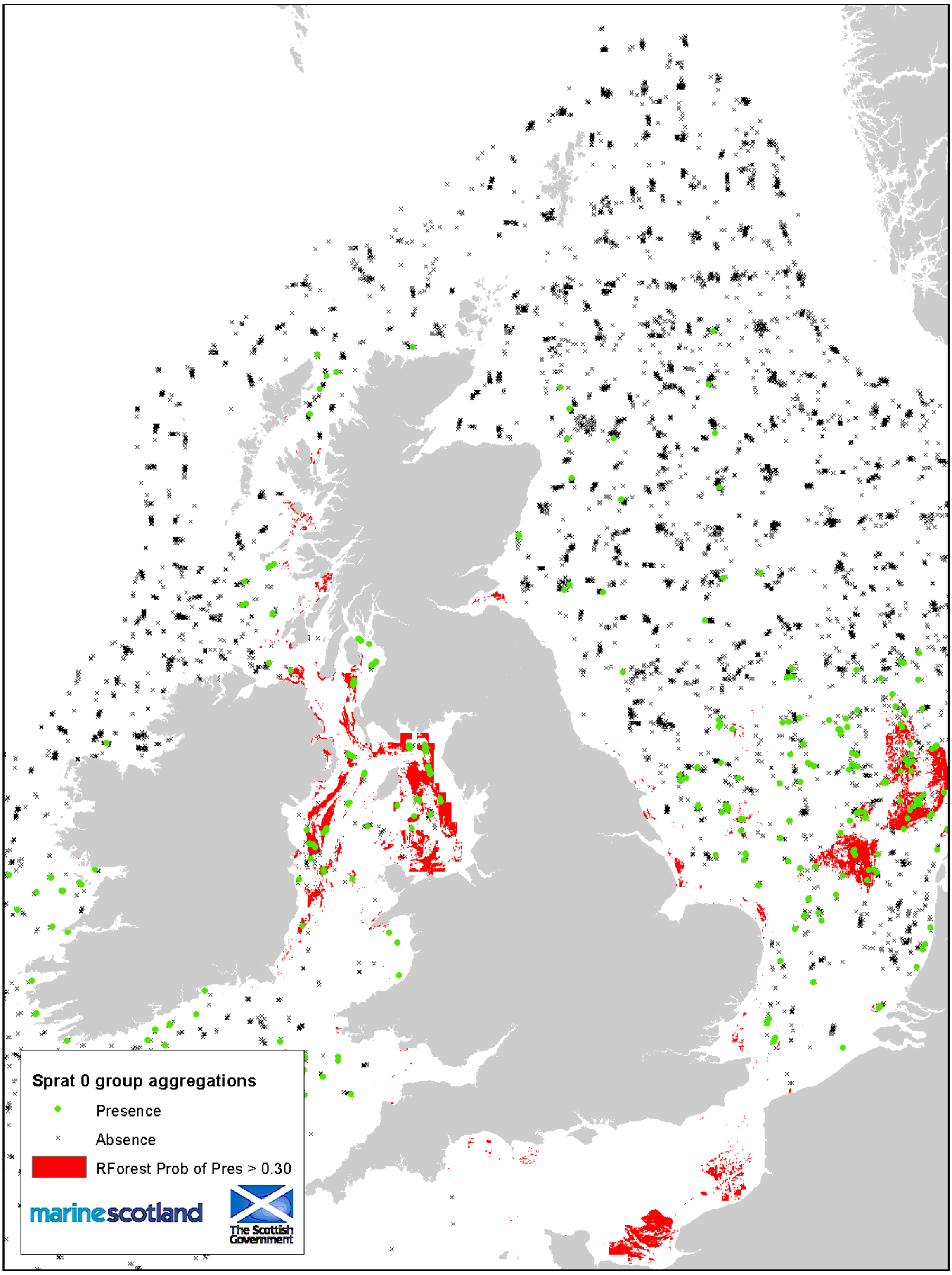

Figure 24: 0 group aggregations and areas of Presence/Absence source data. Horse mackerel.

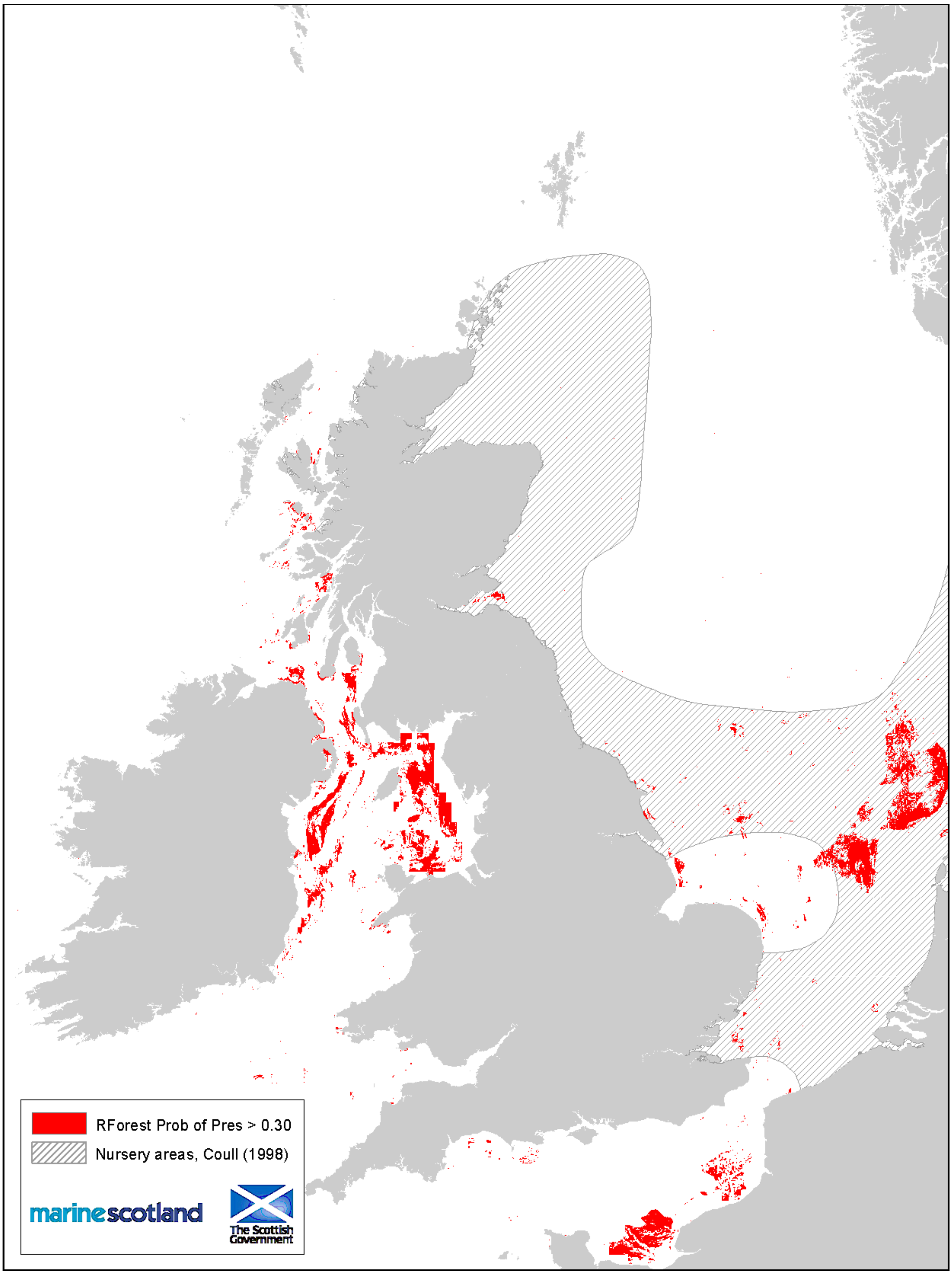

Figure 25: 0 group aggregation areas and Coull (1998) nursery areas. Sprat.

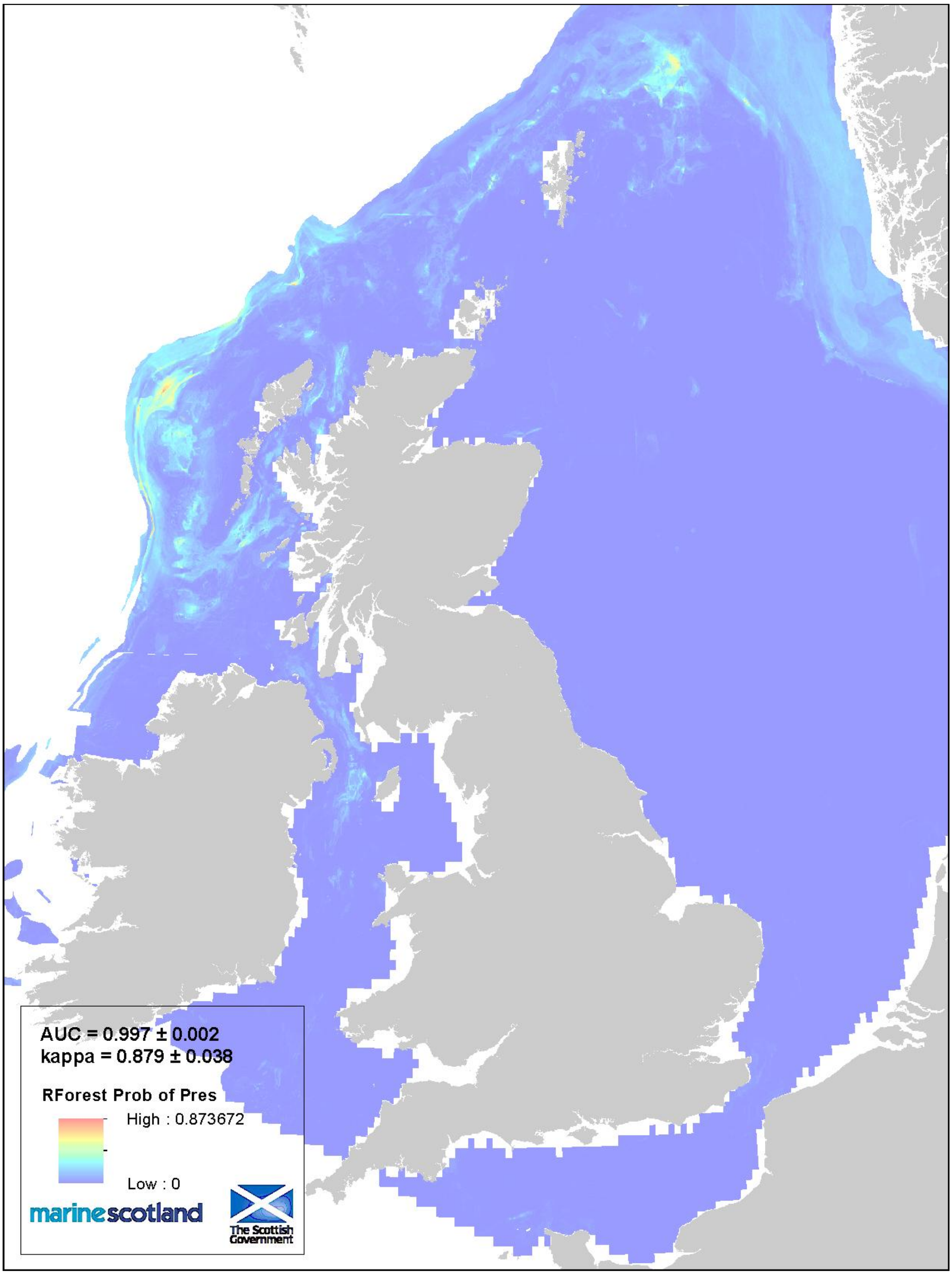

Figure 26: Probability of presence of 0 group aggregations. Blue whiting.

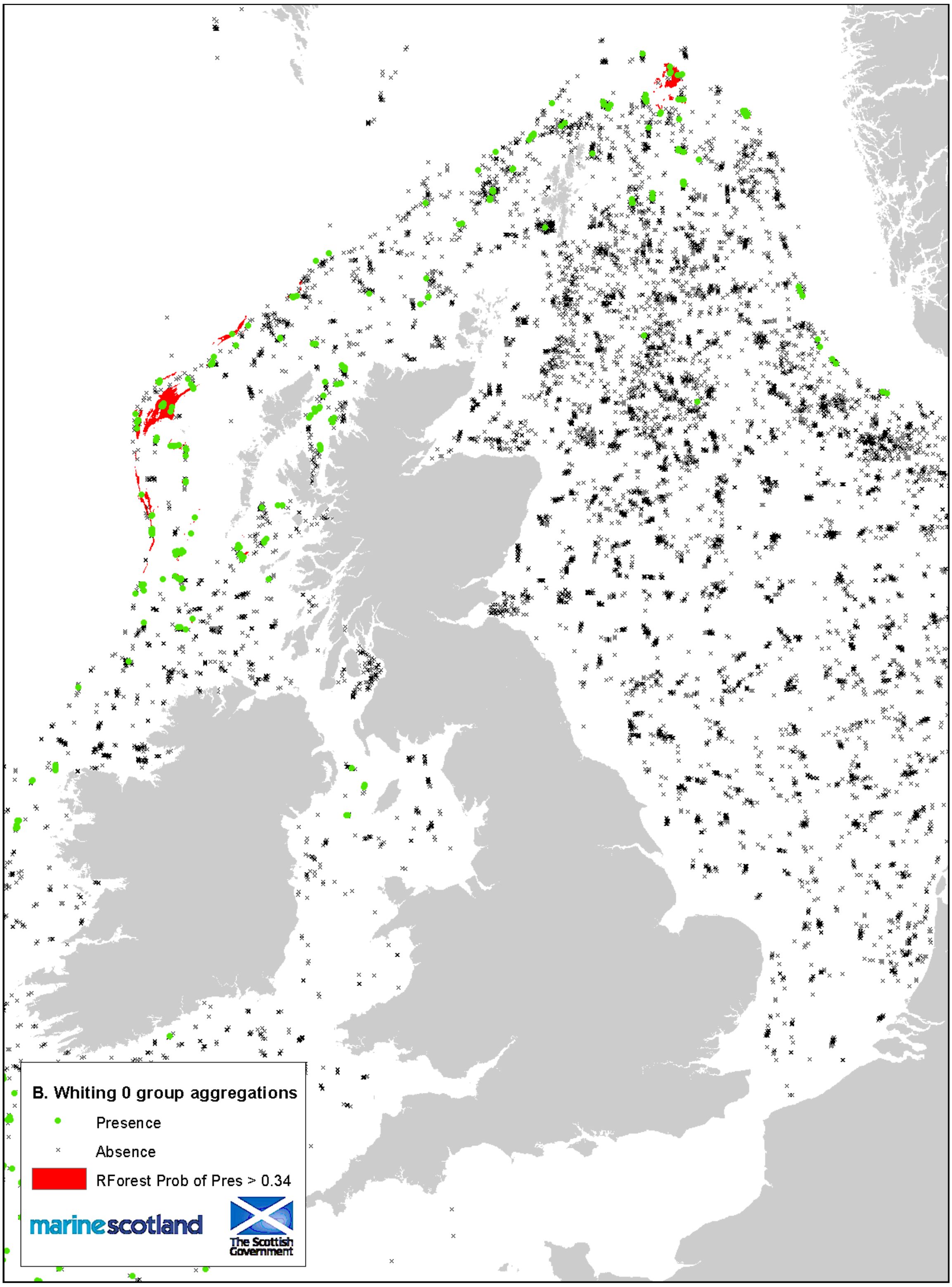

Figure 27: 0 group aggregations and areas of Presence/Absence source data. Blue whiting.

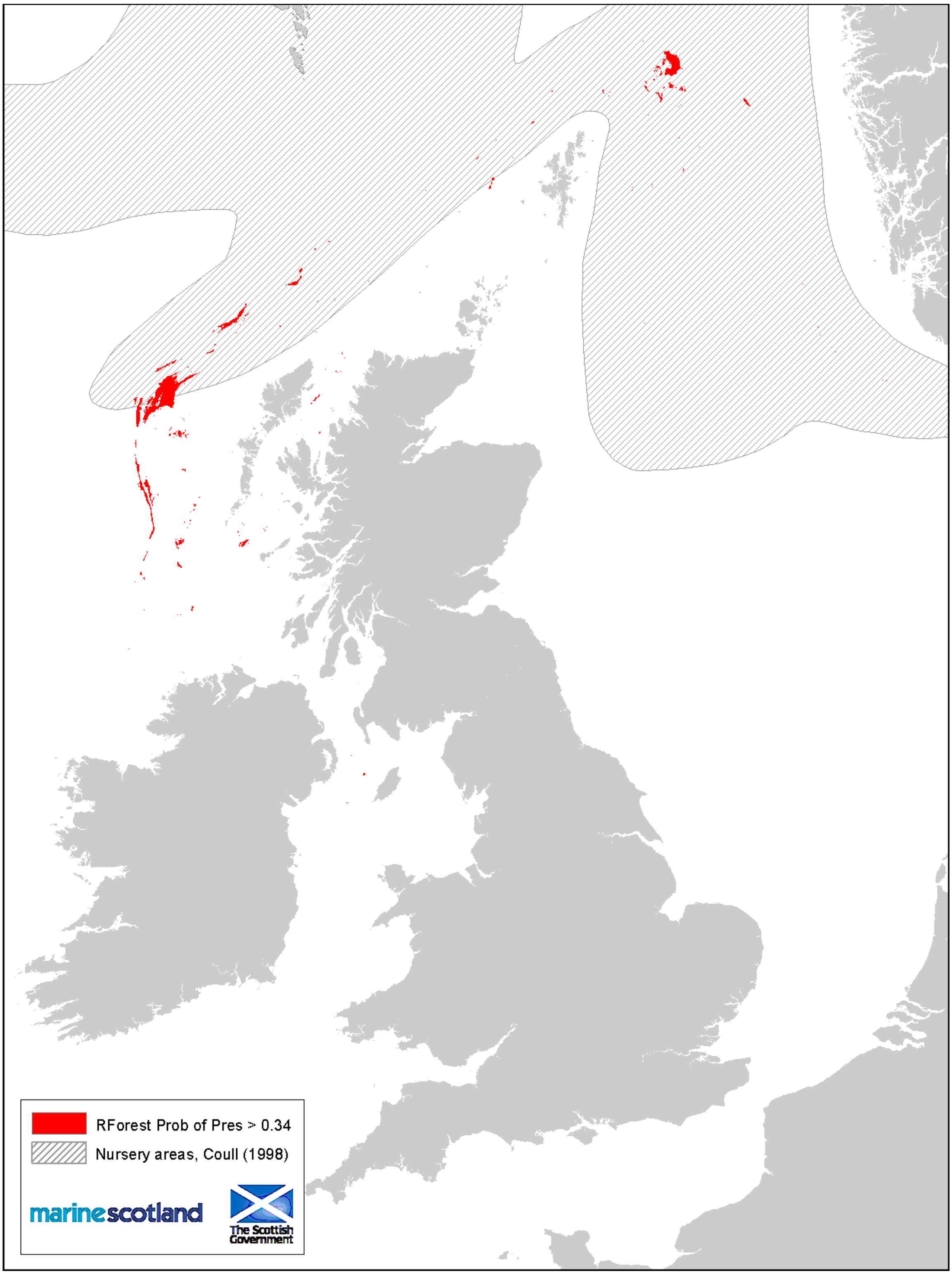

Figure 28: 0 group aggregation areas and Coull (1998) nursery areas. Blue whiting.

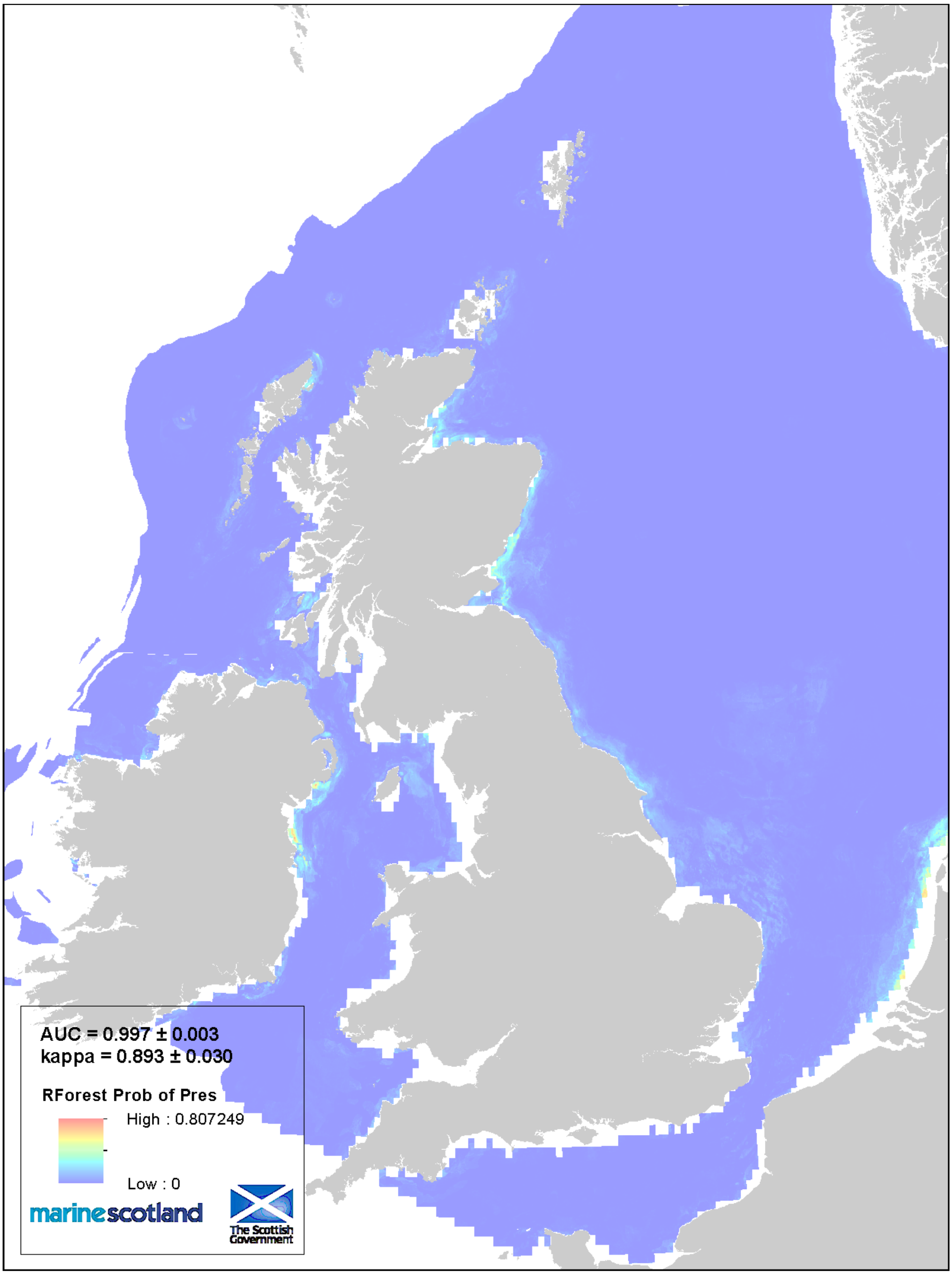

Figure 29: Probability of presence of 0 group aggregations. Plaice.

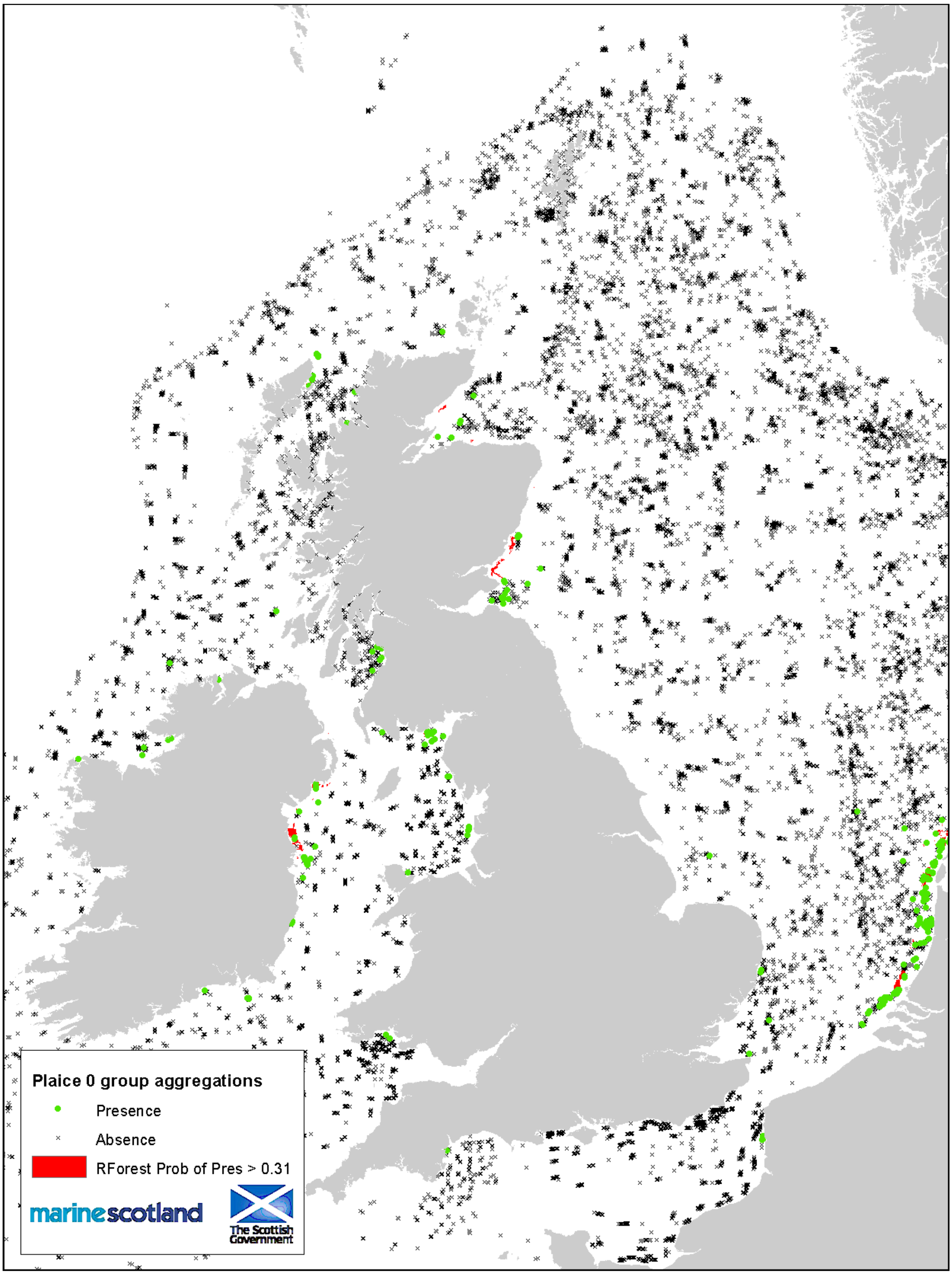

Figure 30: 0 group aggregations and areas of Presence/Absence source data. Plaice.

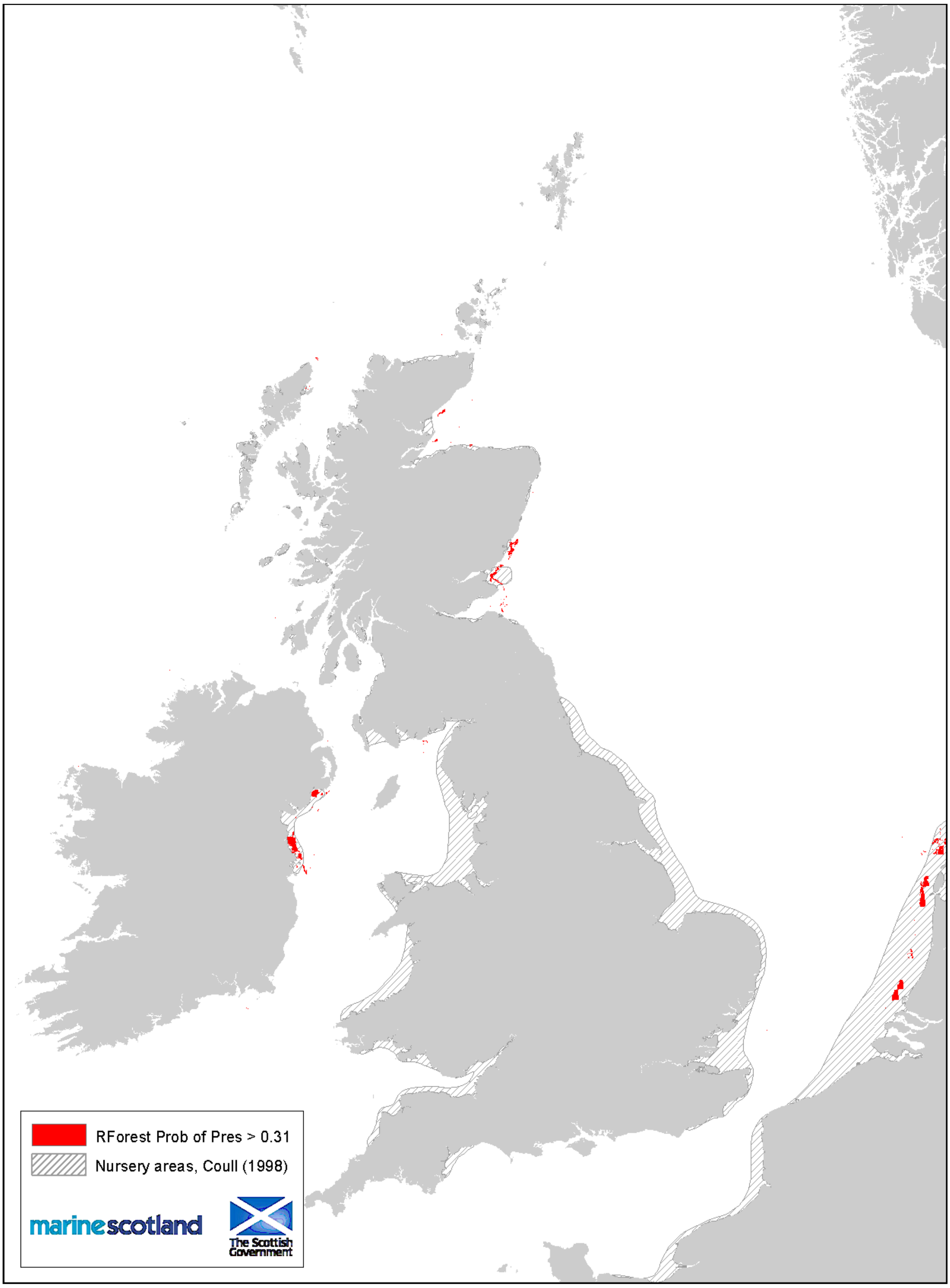

Figure 31: 0 group aggregation areas and Coull (1998) nursery areas. Plaice.

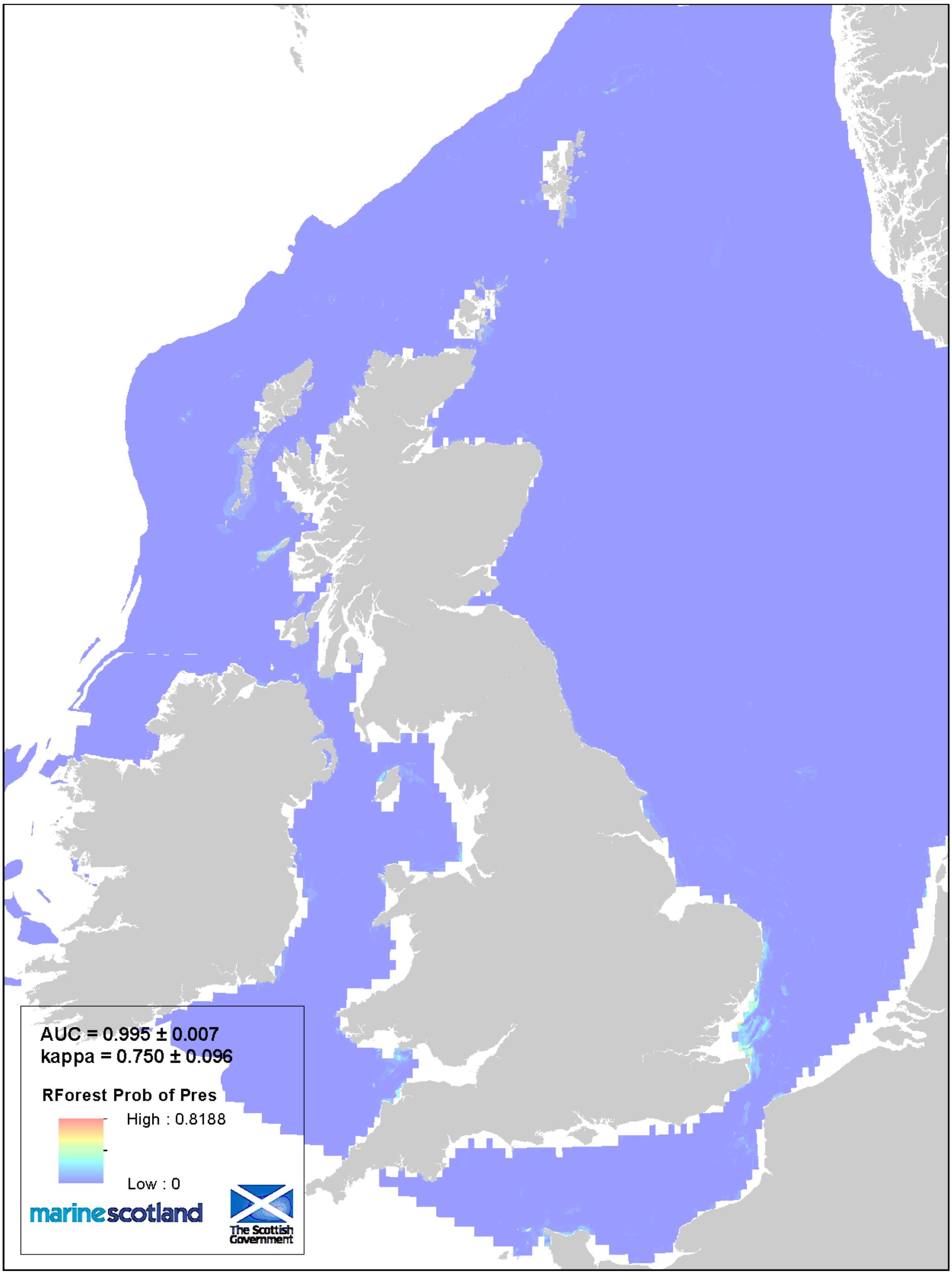

Figure 32: Probability of presence of 0 group aggregations. Sole.

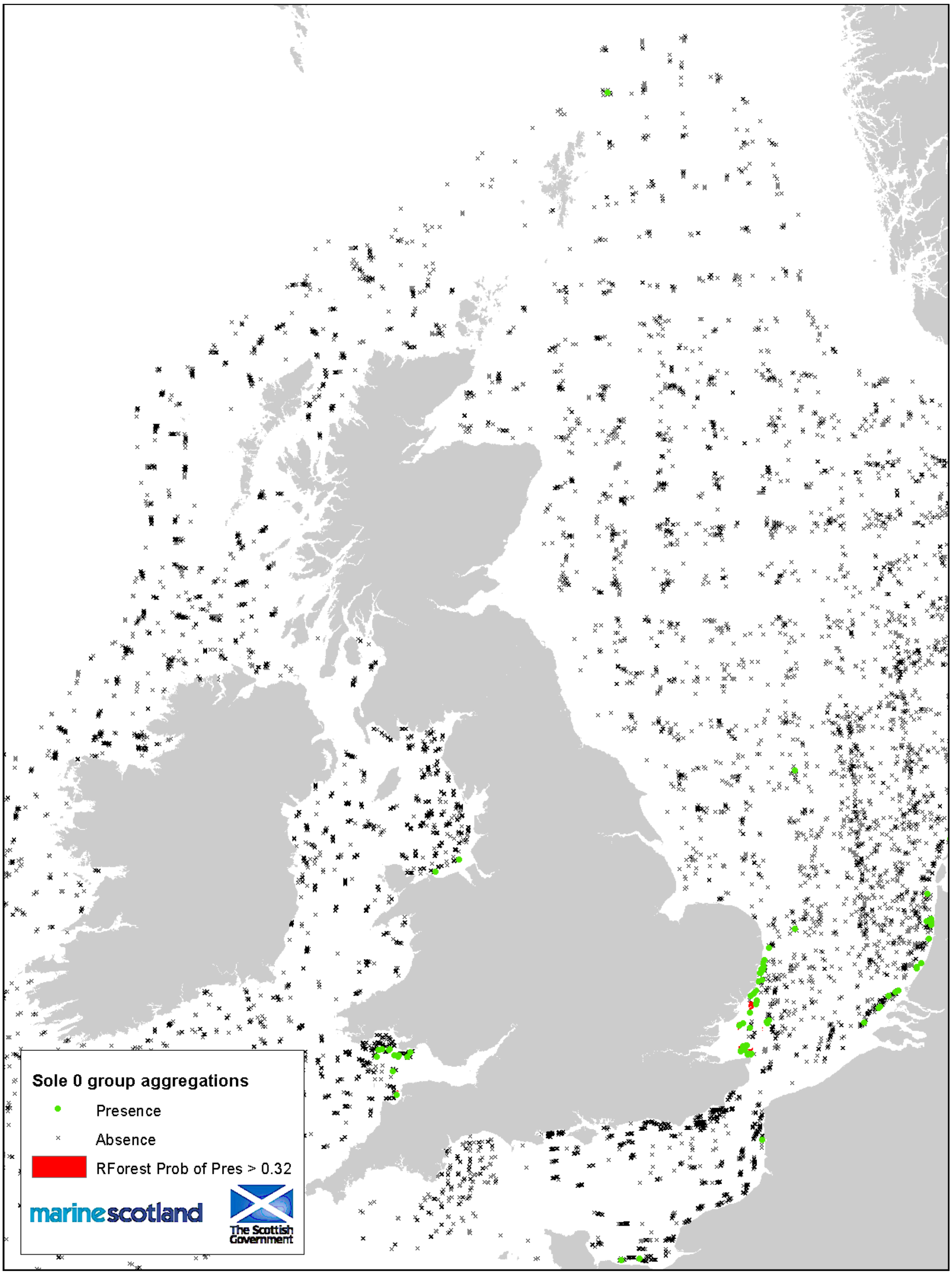

Figure 33: 0 group aggregations and areas of Presence/Absence source data. Sole.

Figure 34: 0 group aggregation areas and Coull (1998) nursery areas. Sole.

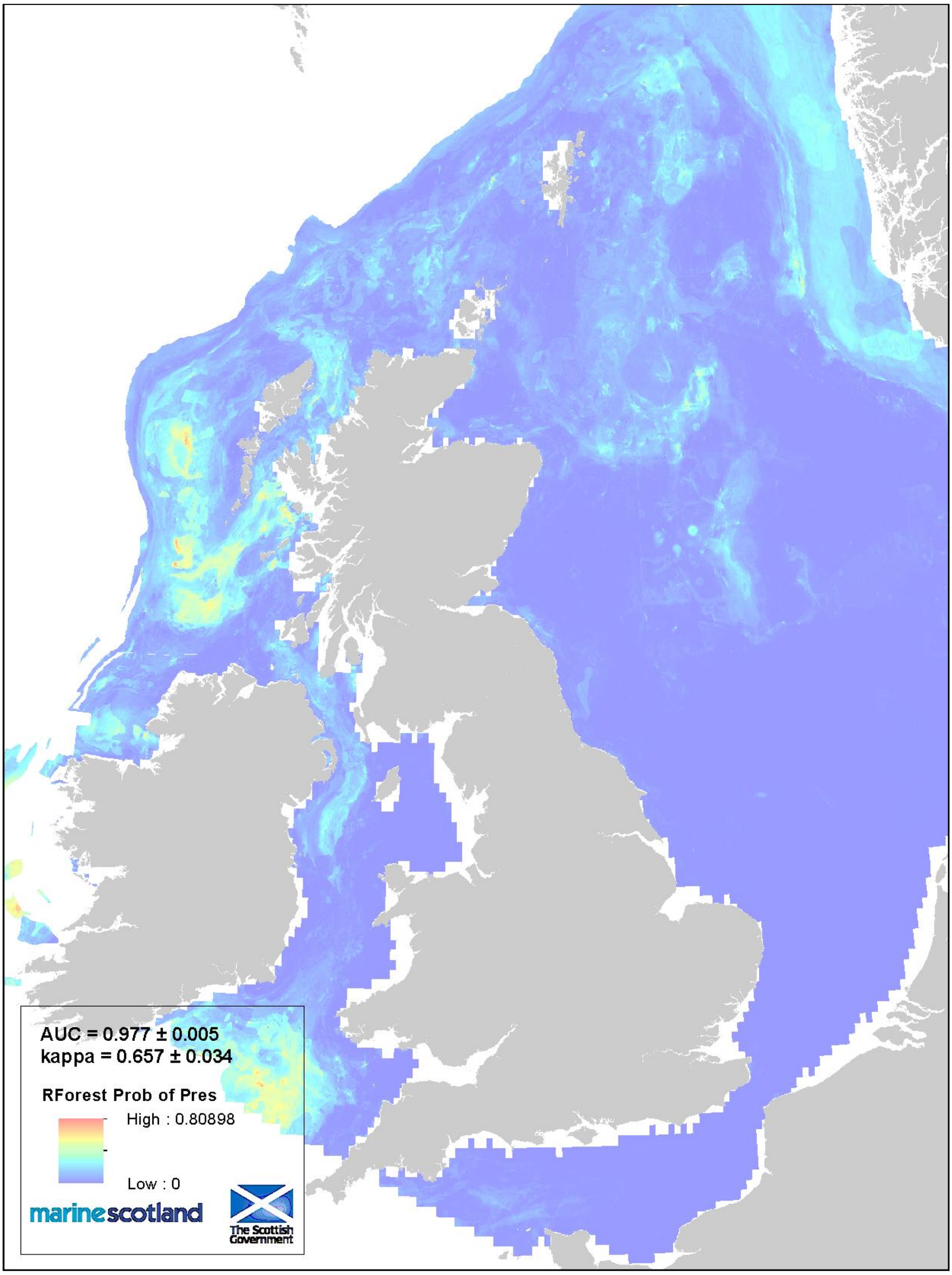

Figure 35: Probability of 0 group presences. Hake.

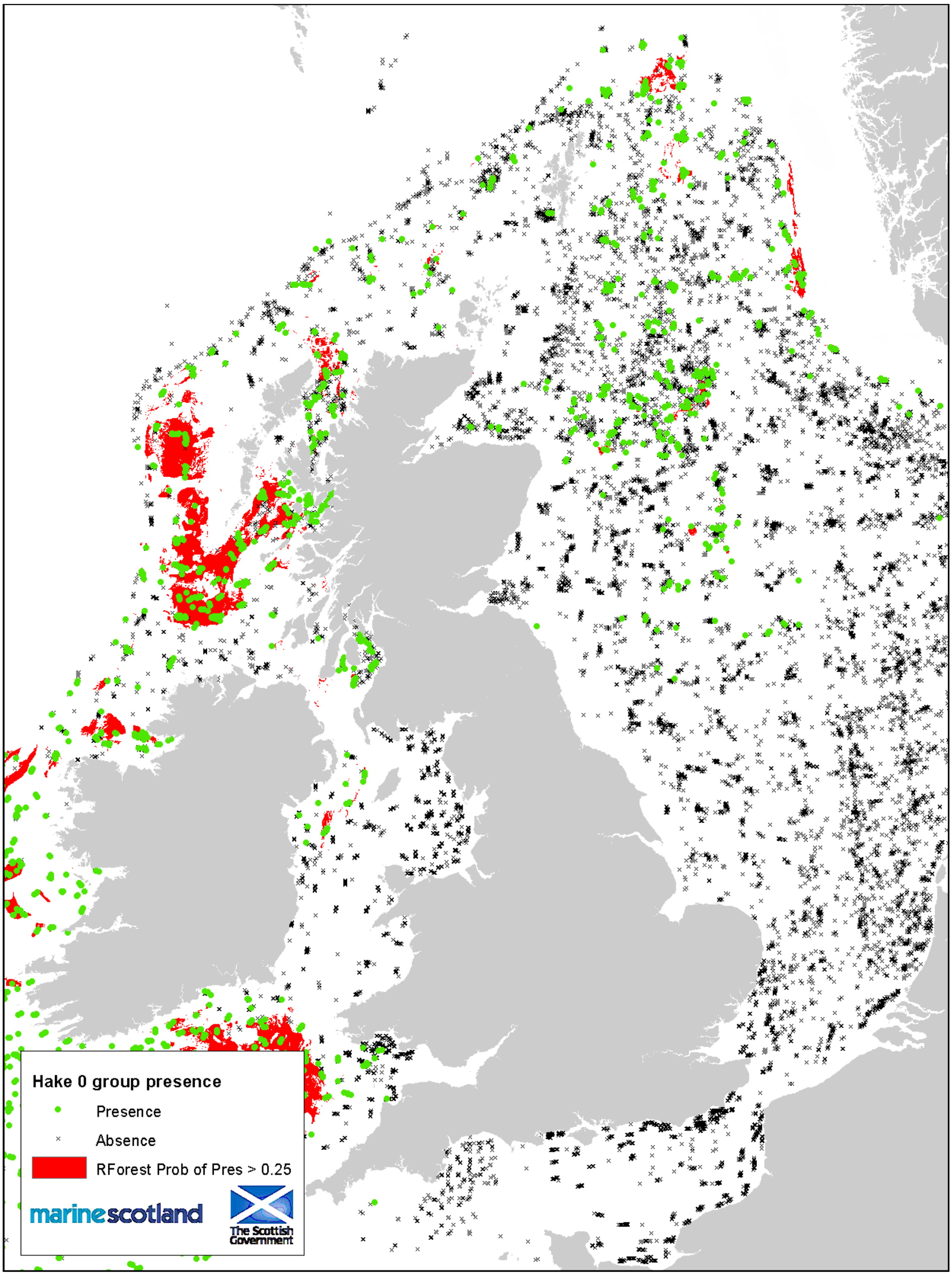

Figure 36: 0 group presence areas and Presence/Absence source data. Hake.

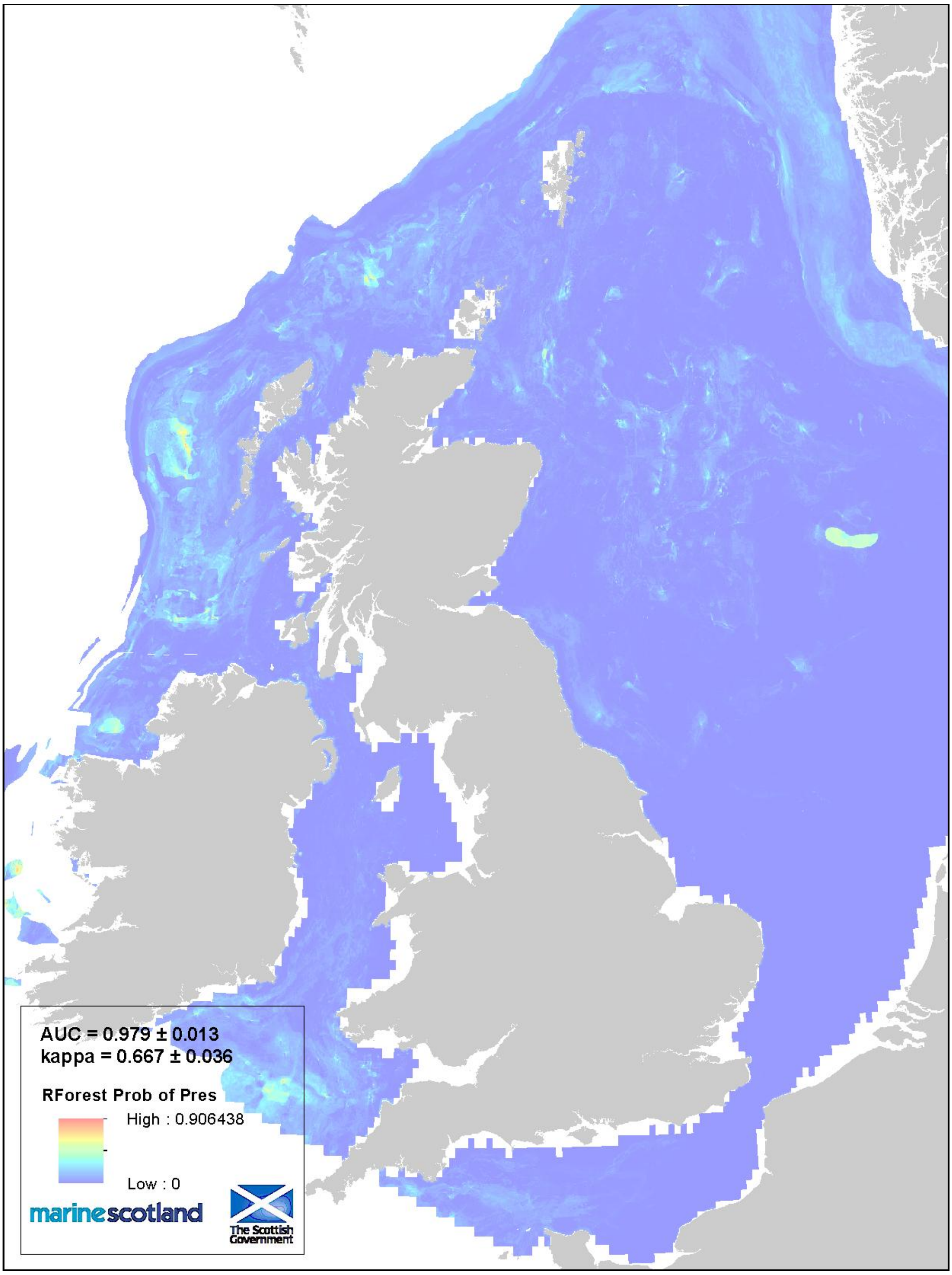

Figure 37: Probability of 0 group presences. Anglerfish.

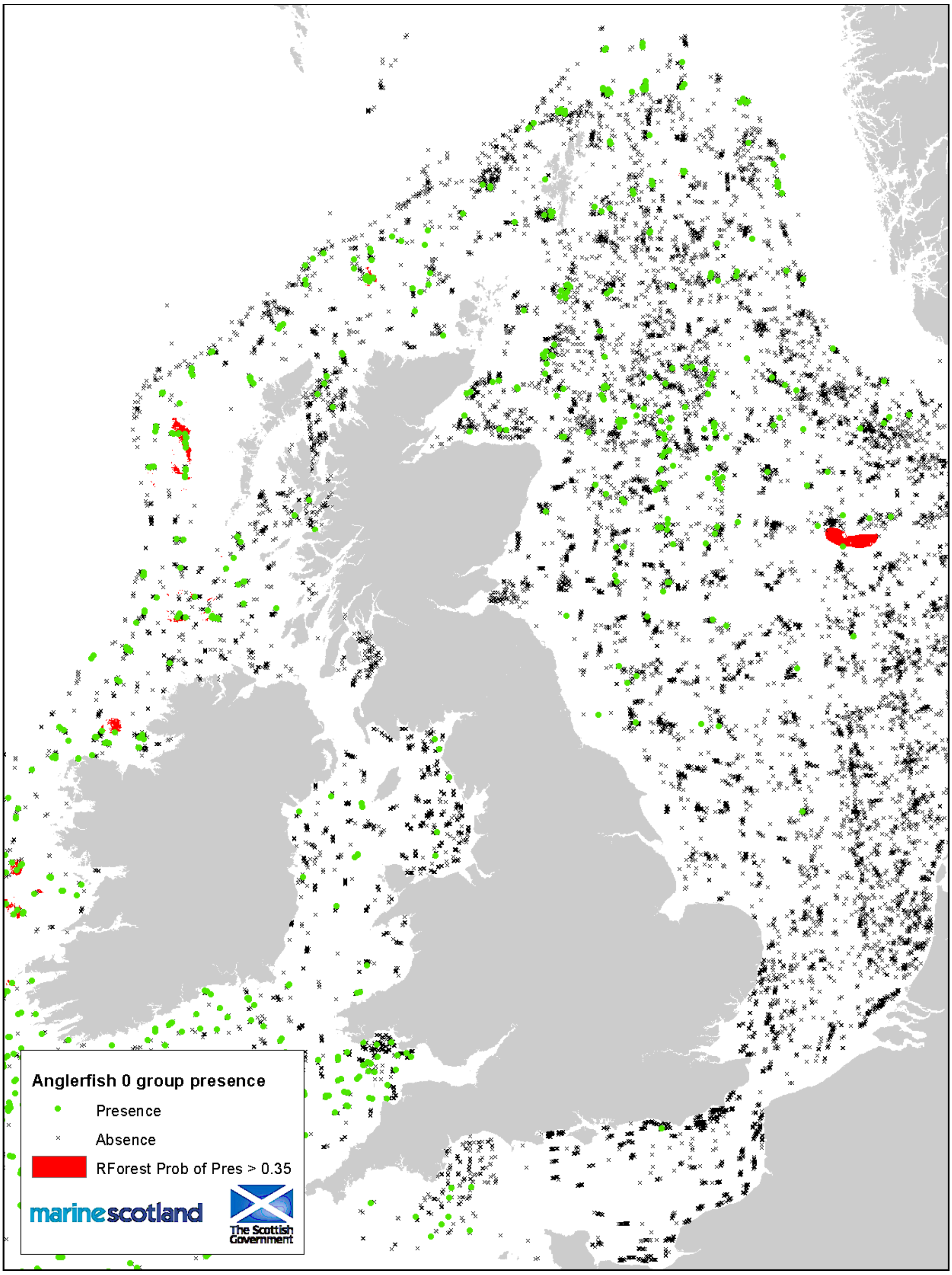

Figure 38: 0 group presence areas and Presence/Absence source data. Anglerfish

3.2 Herring Small Larvae Aggregation Areas

A set of three maps has been created for each of the models, MAXENT and Random Forest:

a) The first map shows the probability of presence of aggregations of small (<10 mm or <11 mm) herring larvae; aggregations were determined as detailed in Section 2.1.2 above.

   The first map also shows information about the performance of the model, evaluated by the AUC and kappa statistics, as explained in Section 2.3 above. A summary of the performance of every model can be seen in Table 8.

b) The second map shows areas with high density of small herring larvae, identified as the areas with a probability of presence above the value at which kappa is maximum – as detailed in Section 2.3 above.

   This map also shows Presence and Absence source data.

c) The third map shows how the newly defined areas of small larvae aggregation for herring compare to the spawning areas defined in Coull *et al.* (1998).

As it has also been explained in Section 2.1.2 above, two separate and independent runs of the models were done for data east and west of the 4°W meridian.

Table 9
Evaluation of models performance: AUC (Area Under the Curve) and kappa statistics.

	AUC		Kappa	
	Value	**Performance**	**Value**	**Performance**
MAXENT - East	0.763 ± 0.017	Good	0.132 ± 0.027	Poor
MAXENT - West	0.762 ± 0.015	Good	0.151 ± 0.027	Poor
RForest - East	0.877 ± 0.009	Good	0.297 ± 0.023	Poor
RForest - West	0.879 ± 0.014	Good	0.319 ± 0.044	Poor

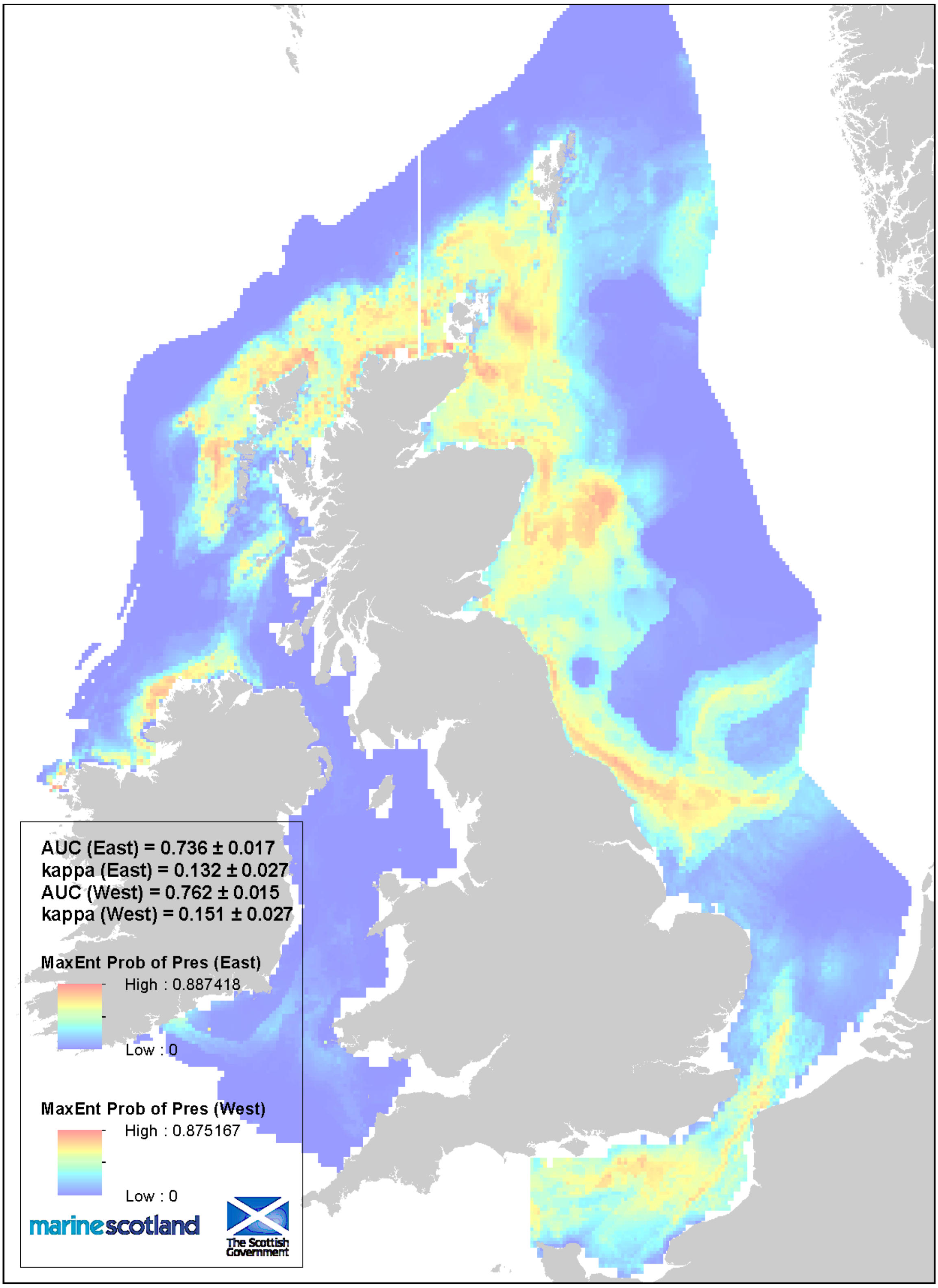

Figure 39: Probability of presence of small larvae aggregations - MAXENT.

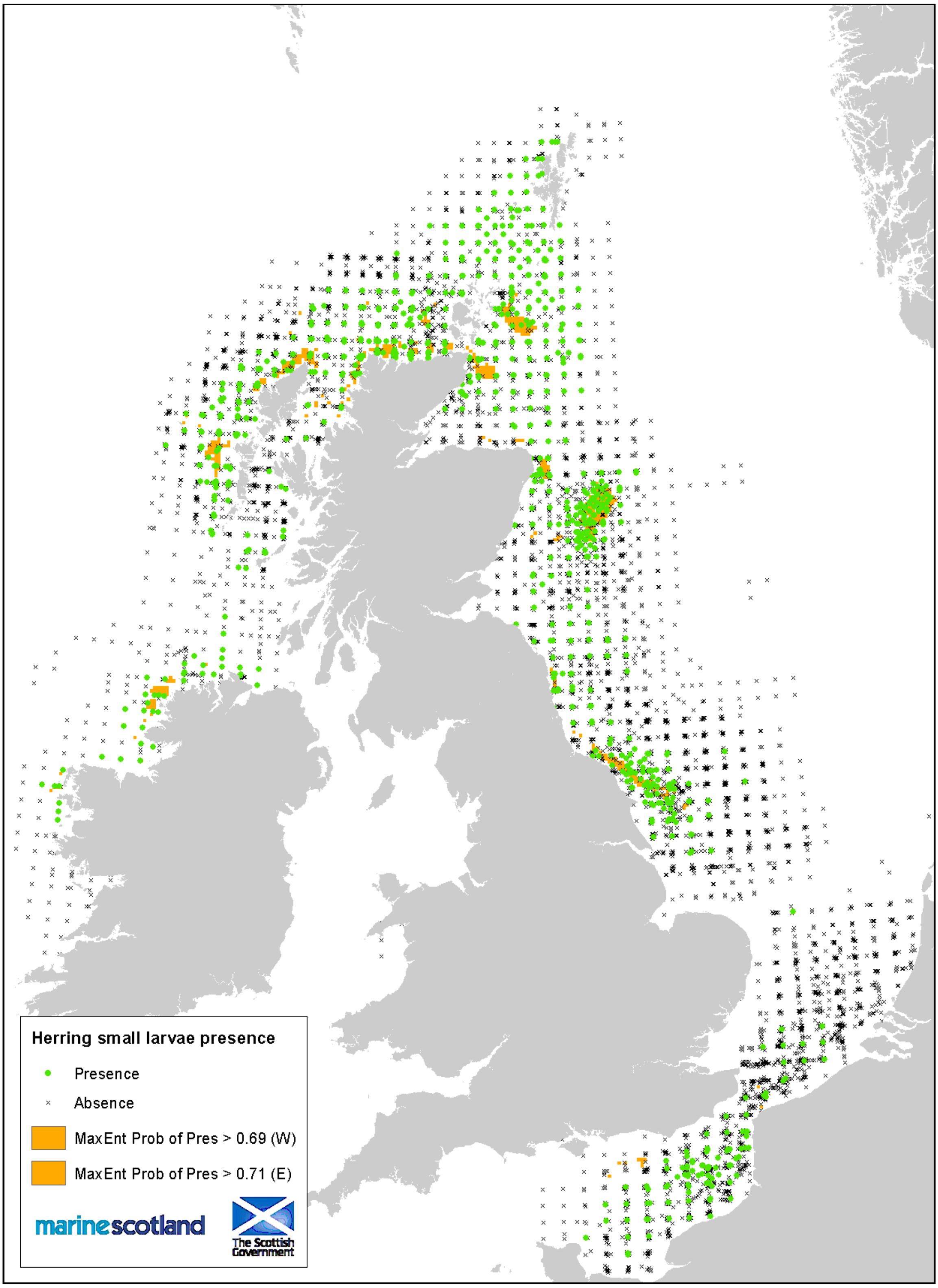

Figure 40: Small larvae aggregation area (MAXENT) and Presence/Absence source data.

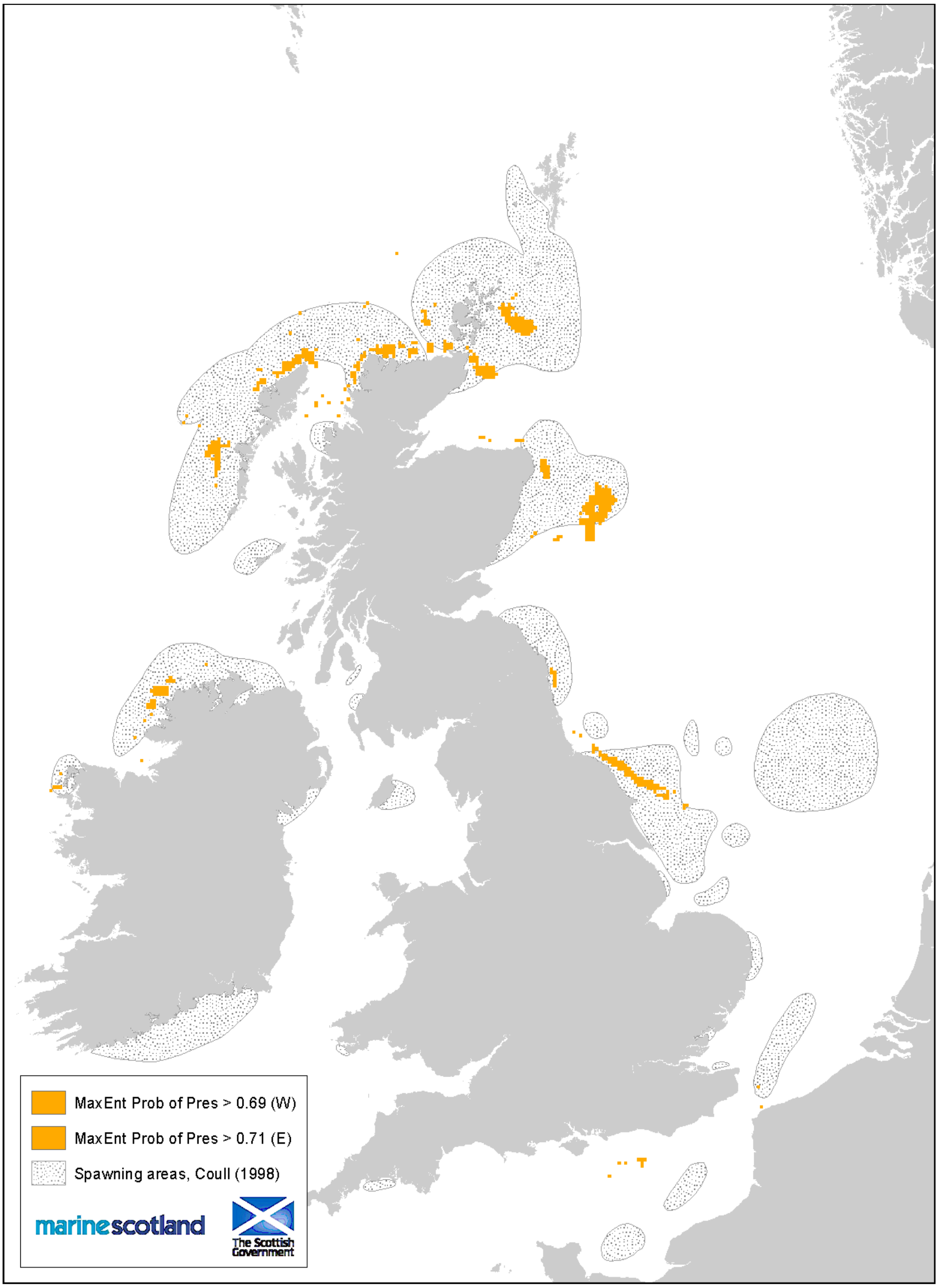

Figure 41: Small larvae aggregation areas (MAXENT) and Coull spawning areas.

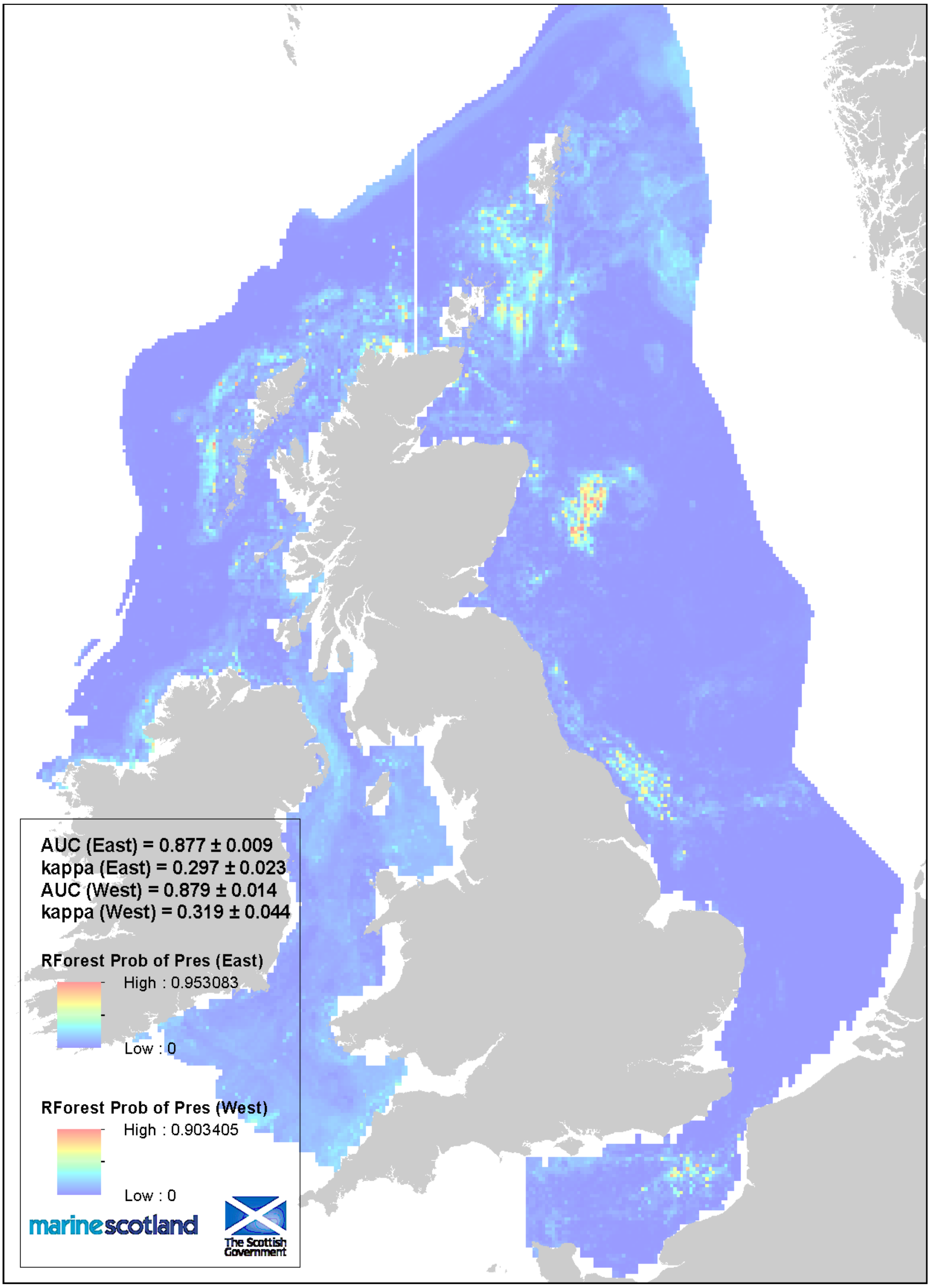

Figure 42: Probability of presence of small larvae aggregations - Random Forest.

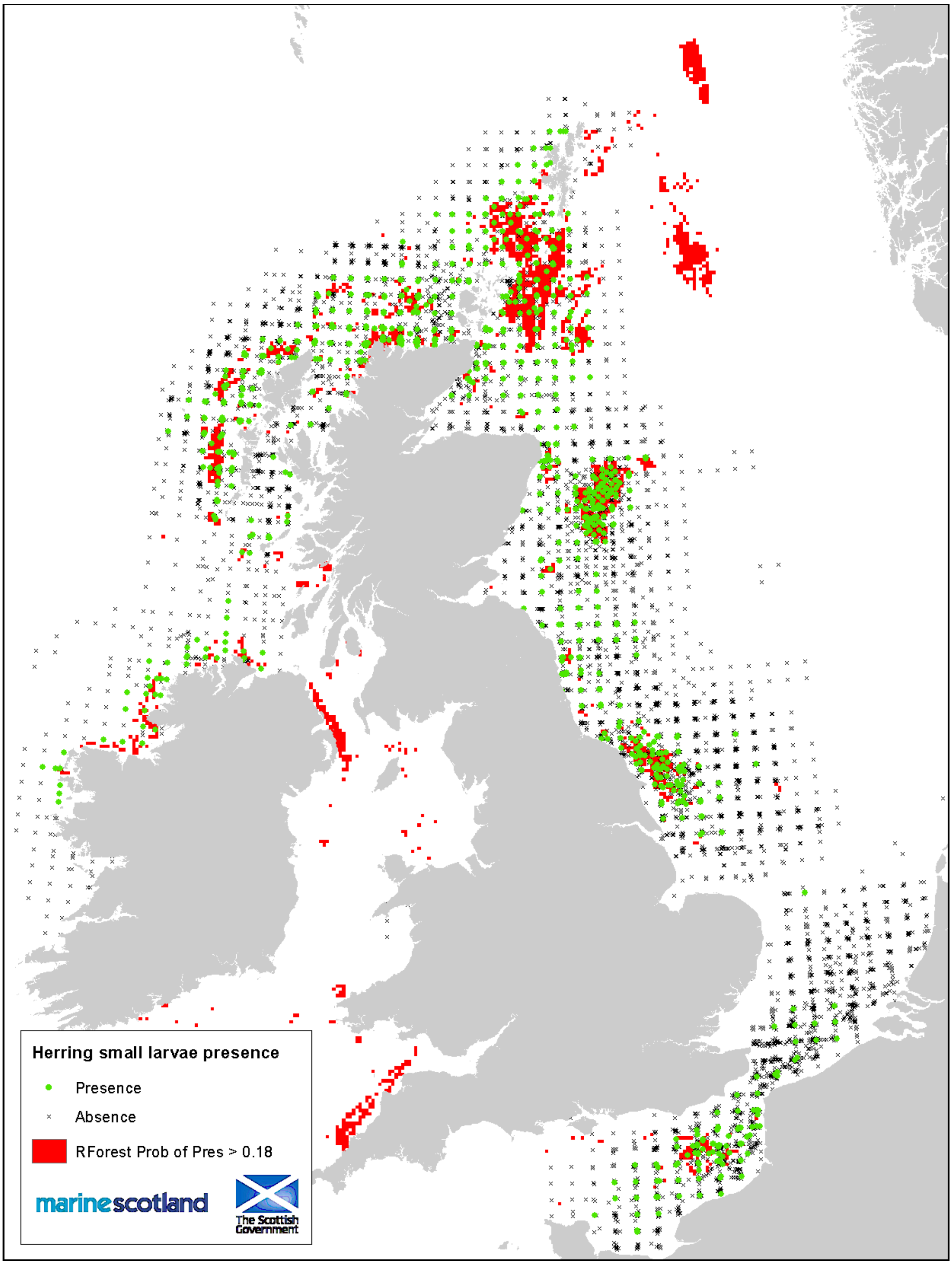

Figure 43: Small larvae aggregation area (Random Forest) and Presence/Absence source data.

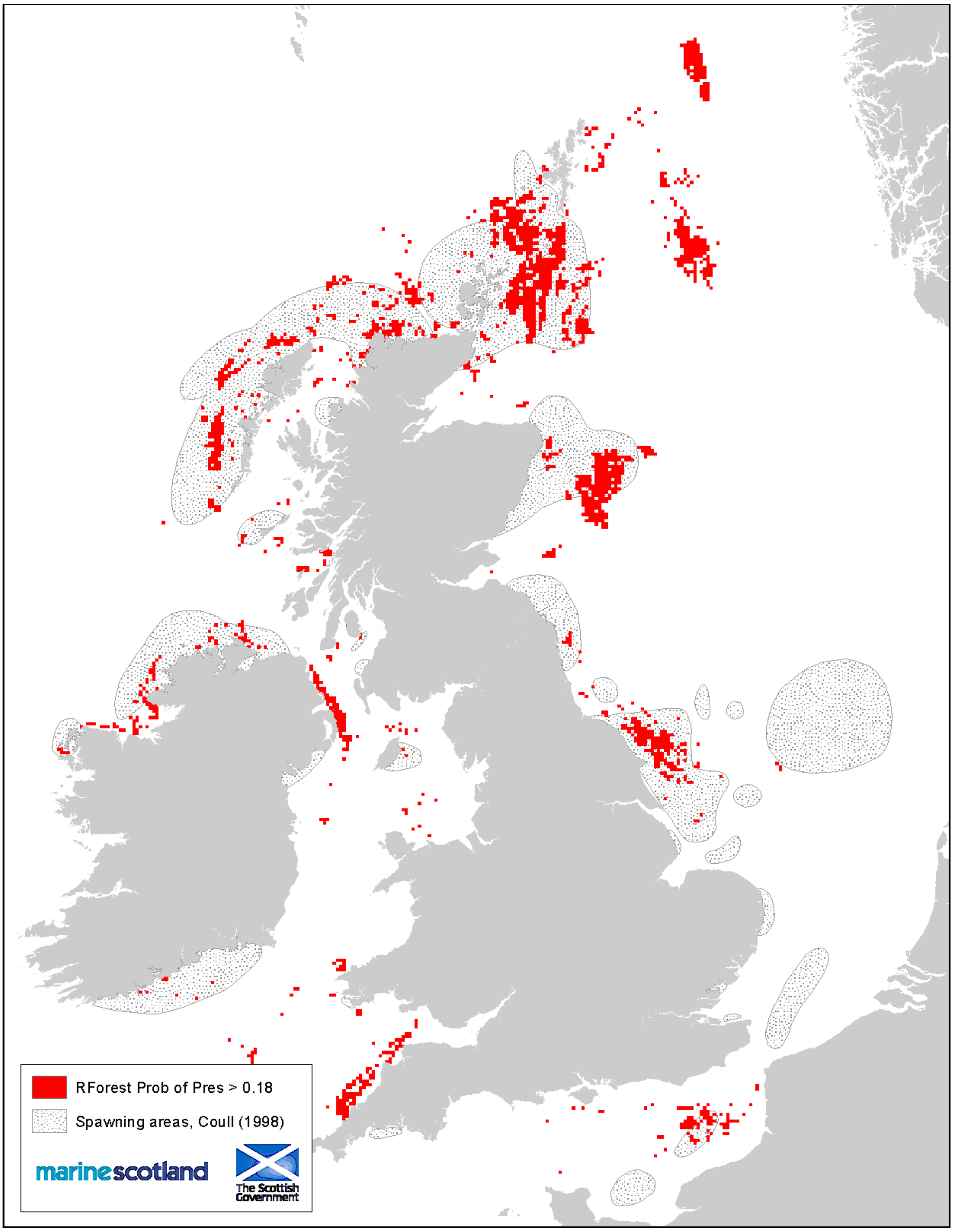

Figure 44: Small larvae aggregation areas (Random Forest) and Coull spawning areas.

4 Discussion and Final Considerations

This work presents a series of 0 group aggregation maps for thirteen commercial species: cod, haddock, whiting, Norway pout, Herring, Mackerel, Horse Mackerel, Sprat, blue whiting, place, sole, hake and anglerfish. Three of these species, horse mackerel, hake and anglerfish, were not present in the previous nursery maps published in Coull *et al.* (1998).

For hake and anglerfish, due to insufficient data, the maps presented here show the probability of presence of 0 group fish and not the probability of presence of 0 group aggregations, this representation could be improved in the future. For saithe and ling there were not enough hauls represented in the survey datasets with 0 group fish present so that aggregations of these could be identified. As the juveniles of both these species stay in their inshore nursery habitats until they are 2-3 years of age (Heessen *et al*. 2006; Rowley, 2008) nursery areas could in the future be modelled using data of age 1 fish.

Much consideration was given to approaches for revising spawning areas. Egg and larvae surveys normally have a sampling design that follows a large grid, with sampling stations being averaged to the centre of very large cells – generally 15 x 15 NM, half of an ICES statistical rectangle (ICES, 2010b; ICES, 2012b). Data with such a coarse resolution cannot be used for species distribution modelling because, as explained in Section 2.3 above, this approach relies on the close relationship between the presence/absence data and the environmental layers at any given location. For this reason, it was only possible to apply the species distribution modelling methodology to herring larvae, as the IHLS sampling design provides for specific sampling locations.

Even so, the performances of both MAXENT and Random Forest models of herring larvae were evaluated as poor by the kappa statistic, see Table 9. Furthermore, environmental variables like seabed sediments and distance to gravel, which were expected to be especially relevant for defining herring spawning grounds (Parrish *et al.*, 1959; Bowers, 1969; Holliday (1958) cited in Rankine, 1986), showed to have very limited contribution to the predictive value of the models. Because of these, the herring larvae maps are only presented here as a first approach to updating the spawning areas, and should not be published and used as spawning maps for herring. Further work is necessary in refining the methodology and improving fitness of the environmental layers used.

Nevertheless, the species distribution modelling approach could in the future be attempted for the remaining species using adult maturity stage data from the fisheries surveys and, when available, interpret this in conjunction with a simpler spatial interpolation of the egg and/or larvae data.

It should be stressed once more that the maps presented here are outputs of models based mostly on survey data, and that the spatial extent of the modelled area is limited by the availability of environmental data. For this reason, it was not possible in the present work to produce model outputs for many inshore areas, particularly for the sea lochs and the intricate coastline of the west of Scotland.

It should also be noted that these outputs have a limited temporal perspective, in the sense that they do not show annual variations in species distribution or persistence at a given site. Instead, they present an average scenario for the studied period which, in most cases, extended for a period of over 40 years (1970-2012). The exception to this was the gadoid species (cod, haddock, whiting, saithe, ling and Norway pout) for which only the period 2000-2012 was analysed. Also, 0 group aggregation models include only data from Quarters 3 and 4, due to the lack of Age-Length-Keys (ALKs) for 0 group fish in Quarters 1 and 2.

Although as much scientific rigour as possible was applied to their production, models only produce outputs as good as the data they are based on. For this reason, these maps should be interpreted with caution and used as an additional tool to complement existing information, and not to replace it.

At this stage, these outputs take no account of anecdotal or industry knowledge and, therefore, their use and interpretation is recommended alongside the Coull *et al.* (1998) maps. Further value can be added to these mapping processes using stakeholder input, particularly from the fishing industry. This will complement the final outputs by communicating the industry's view of where and when, in their experience, the sensitive sites occur. The maps from this report will be provided as spatial layers and will be available for download through the National Marine Plan interactive (http://marinescotland.atkinsgeospatial.com/nmpi/) and the Marine Scotland interactive web portals (http://www.scotland.gov.uk/Topics/marine/science/MSInteractive). The outputs included into these Marine Scotland data sharing portals will be readily updated when new or additional data or knowledge becomes available.

In addition to the 0 group aggregation outputs presented in this report, work is currently being undertaken to model the locations of spawning grounds of some important commercial species. Species Distribution Modelling techniques that use international survey data are also being used for this investigation as in this report.

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6 Technical Annex

6.1 Variable importance

The variable importance in Random Forest is calculated using data “out of the bag”. According to random sampling of observations, regardless whether with or without replacement, a certain percentage of the observations are not used for any individual tree (Gromping et al. 2010), that is, they are “out of the bag” (OOB). The accuracy of a Random Forest prediction can be estimated from these OOB data and in the same way the variable importance can be estimated by quantifying how important the accuracy loss is after permuting this variable (see Gromping *et al.* 2010 for a more detailed explanation). The importance of the variables included in the Random Forest models was calculated and it is shown in Figures A1 to A3.

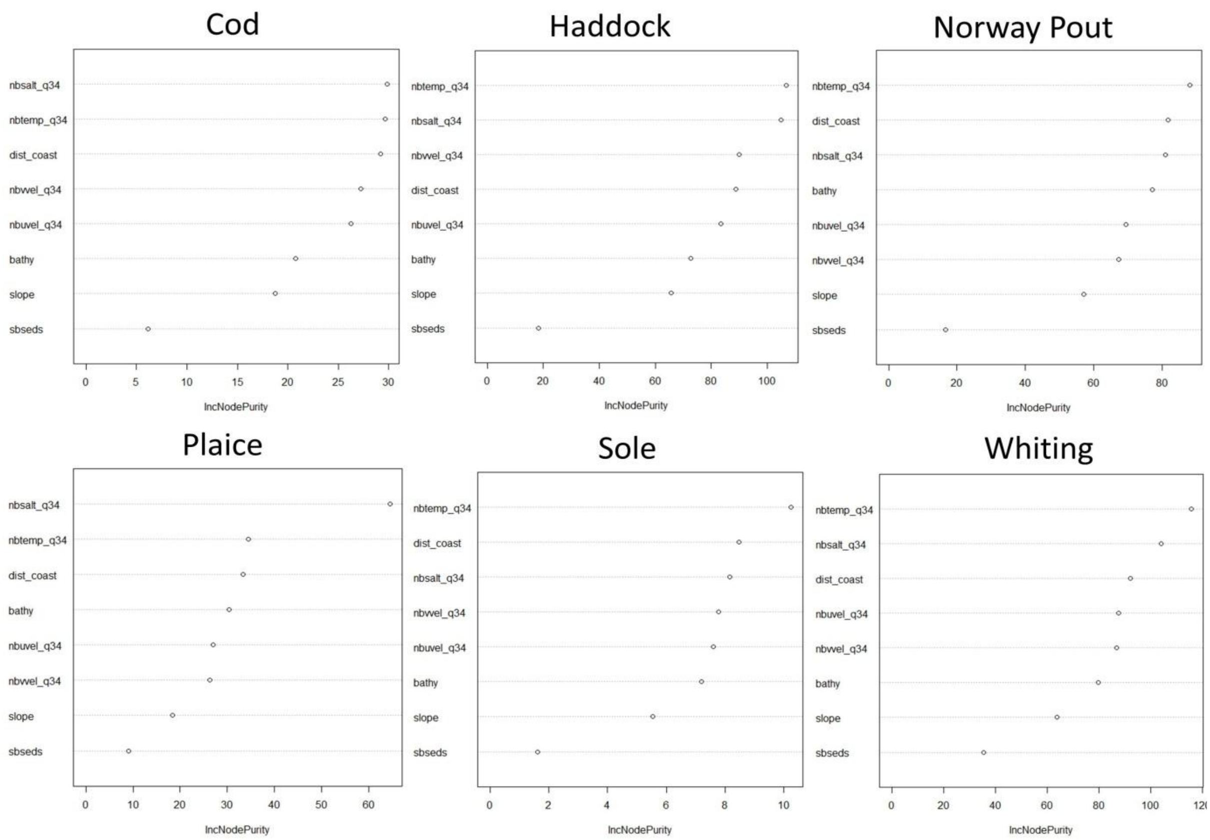

Figure A1: Relative importance of predictor variables used for the 0 group aggregations models of six demersal species. *Bathy* = Bathymetry, *dist_coast* = Distance to coast, *nbsalt_q34* = Salinity near bottom, *nbtemp_q34* = Temperature near bottom, *nbuvel_q34* = Near bottom W-E current speed, *nbvvel_q34* = Near bottom N-S current speed, *sbseds* = Sediment type and *slope* = slope.

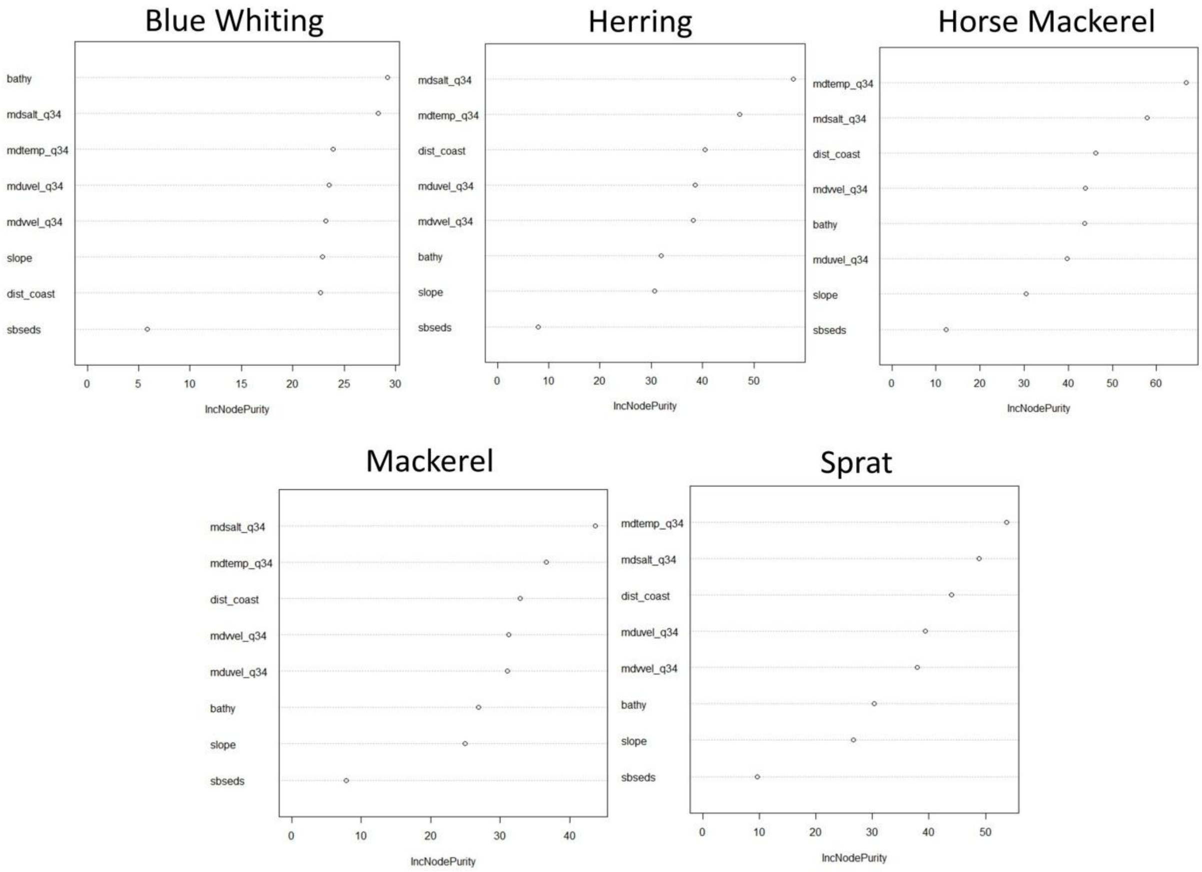

Figure A2: Relative importance of predictor variables used for the 0 group aggregations models of five pelagic species. *Bathy* = Bathymetry, *dist_coast* = Distance to coast, *mdsalt_q34* = Salinity in mid-water, *mdtemp_q34* = Temperature in mid-water, *mduvel_q34* = mid-water W-E current speed, *mdvvel_q34* = mid-water N-S current speed, *sbseds* = Sediment type and *slope* = slope.

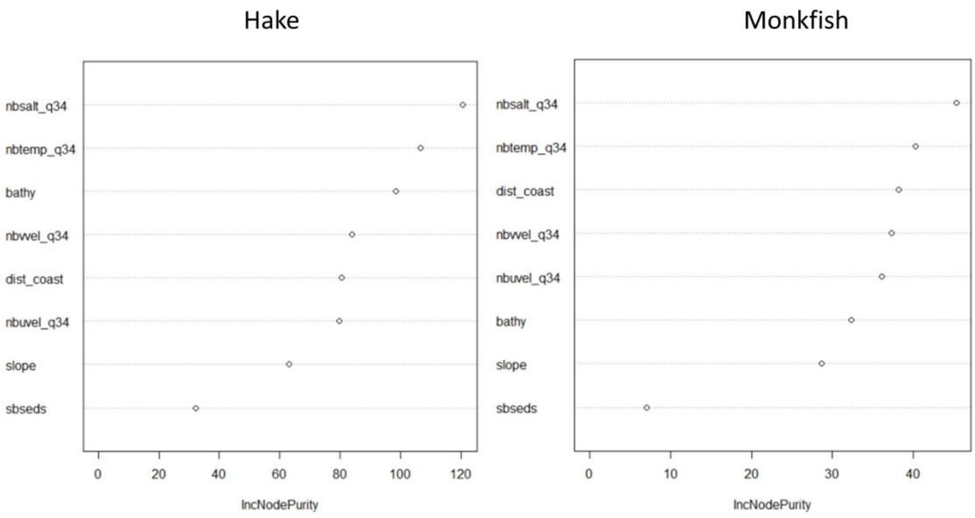

Figure A3: Relative importance of predictor variables used for the 0 group presence models for hake and monkfish (anglerfish).

6.2 Partial plots

The partial dependence is the dependence of the probability of presence on one predictor variable after averaging out the effects of the other predictor variables in the model. This partial dependence can be plotted for different levels of each variable to show the specific effect of this variable in the probability of presence (partial plots). The partial plots for the thirteen species modelled (cod, haddock, Norway pout, plaice, sole, whiting, blue whiting, herring, horse mackerel, mackerel, sprat, hake and anglerfish) are shown in Figures A4-A16.

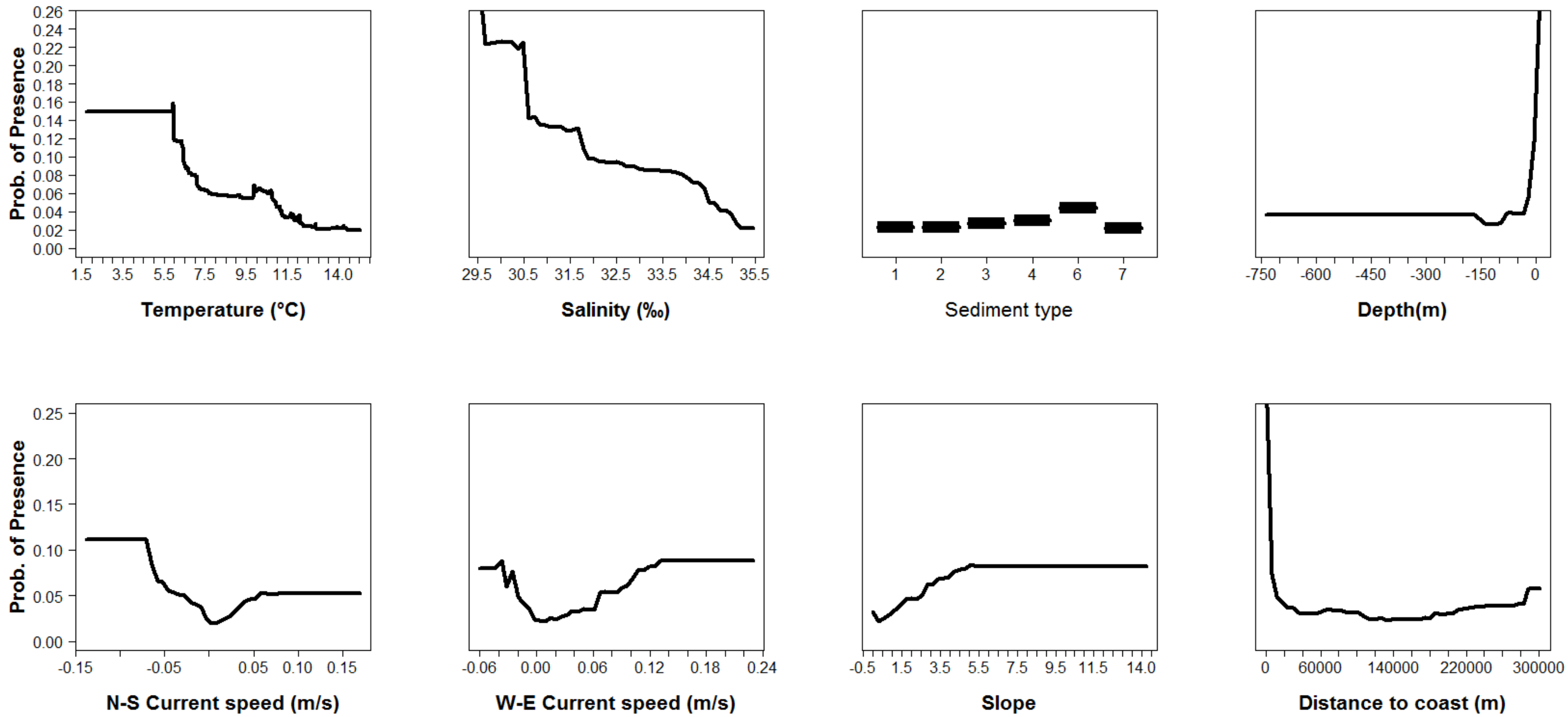

Figure A4: Partial plots from the cod 0 group aggregations model.

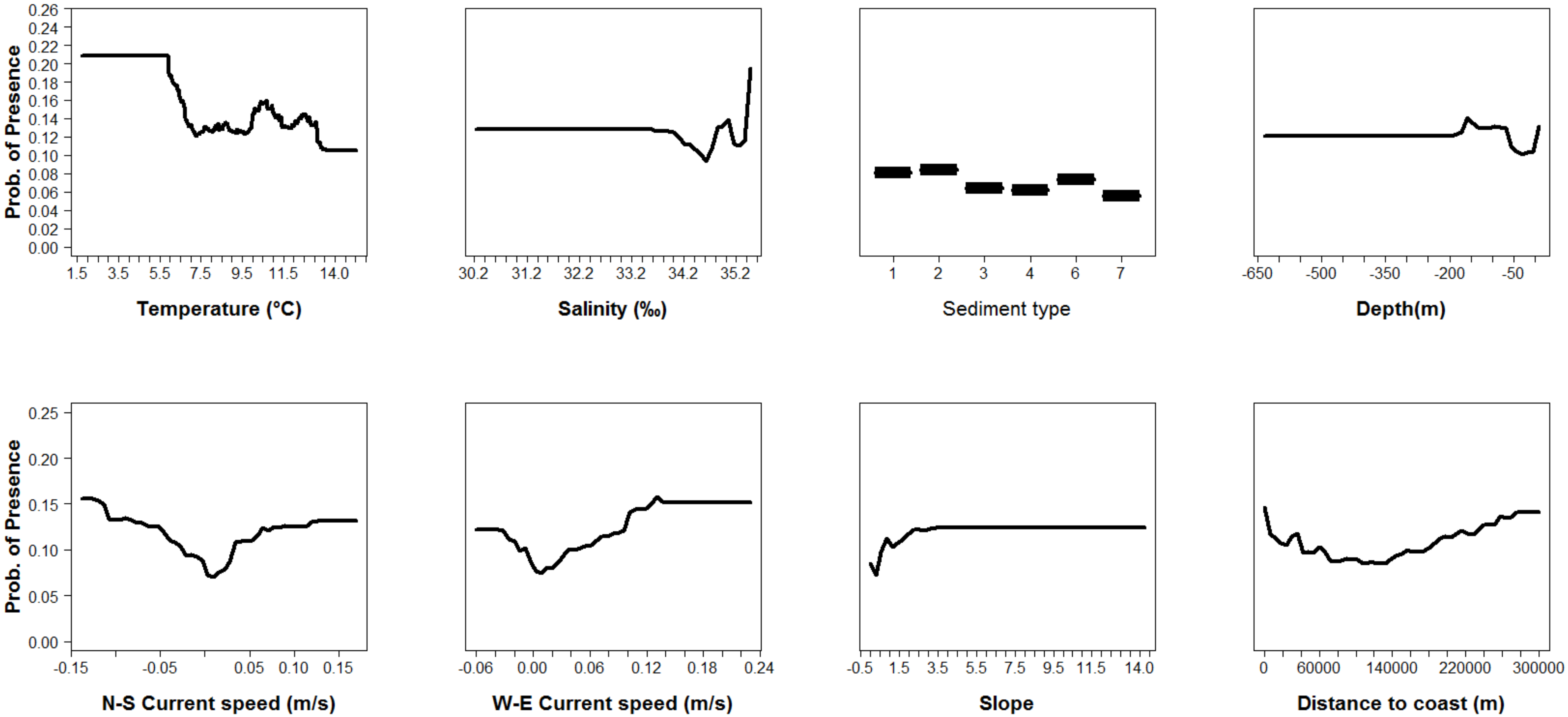

Figure A5: Partial plots from the haddock 0 group aggregations model.

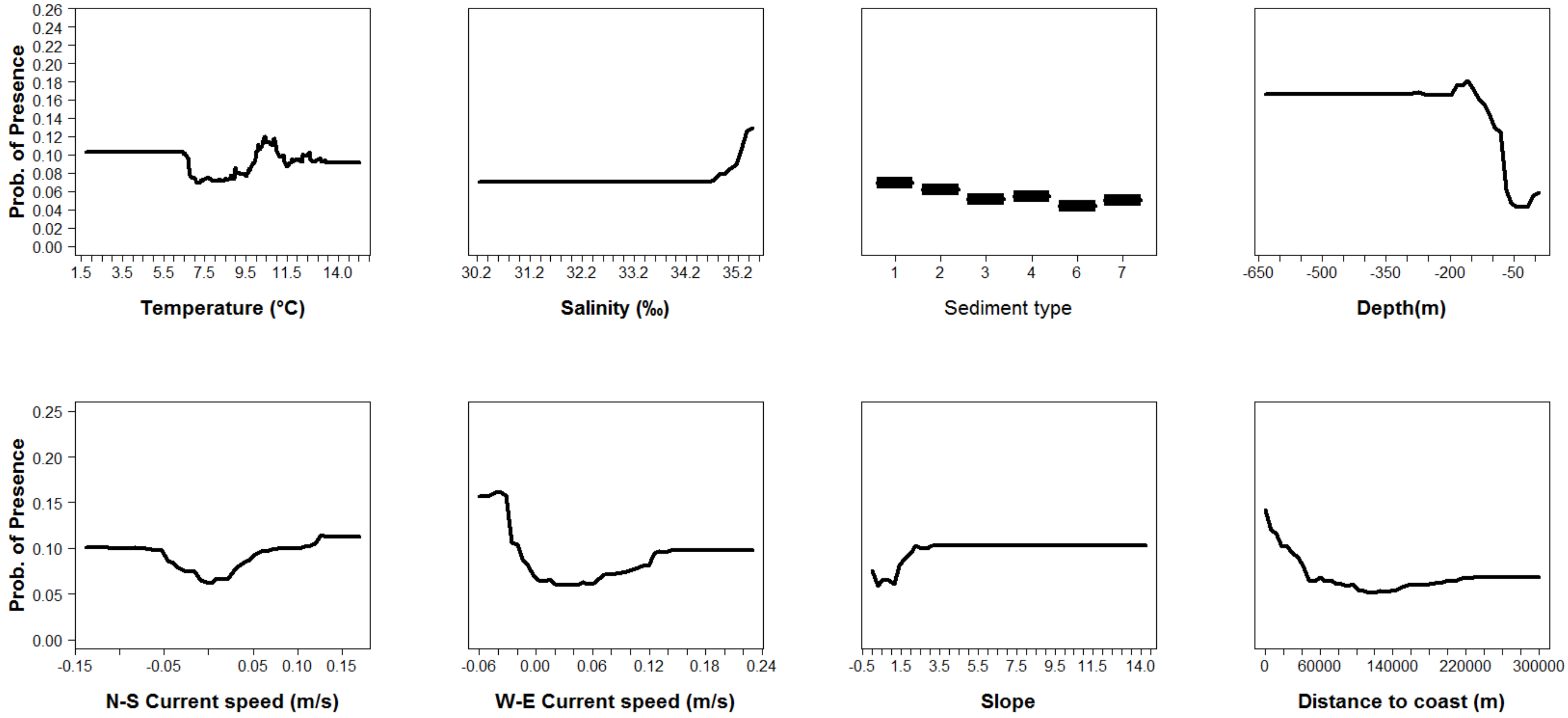

Figure A6: Partial plots from the Norway pout 0 group aggregations model.

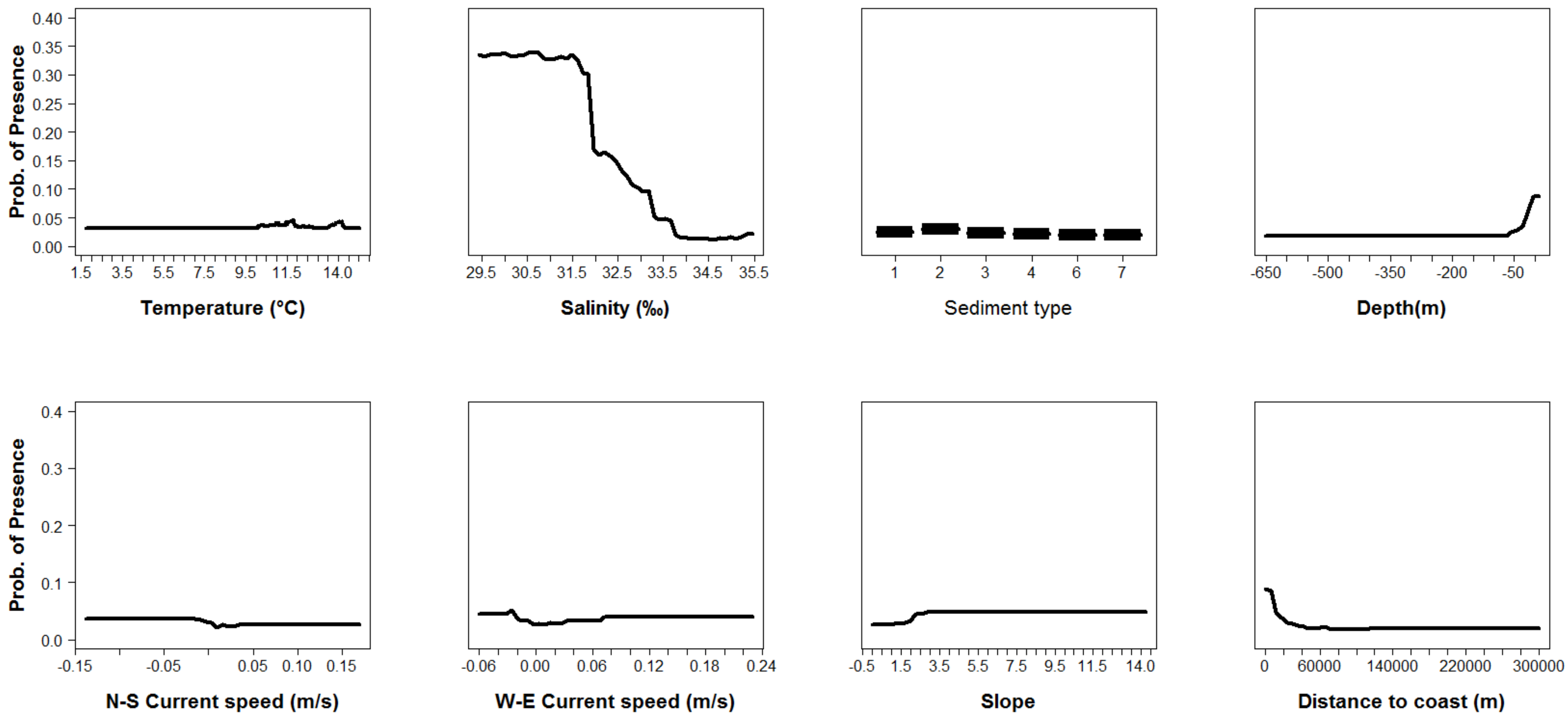

Figure A7: Partial plots from the plaice 0 group aggregations model.

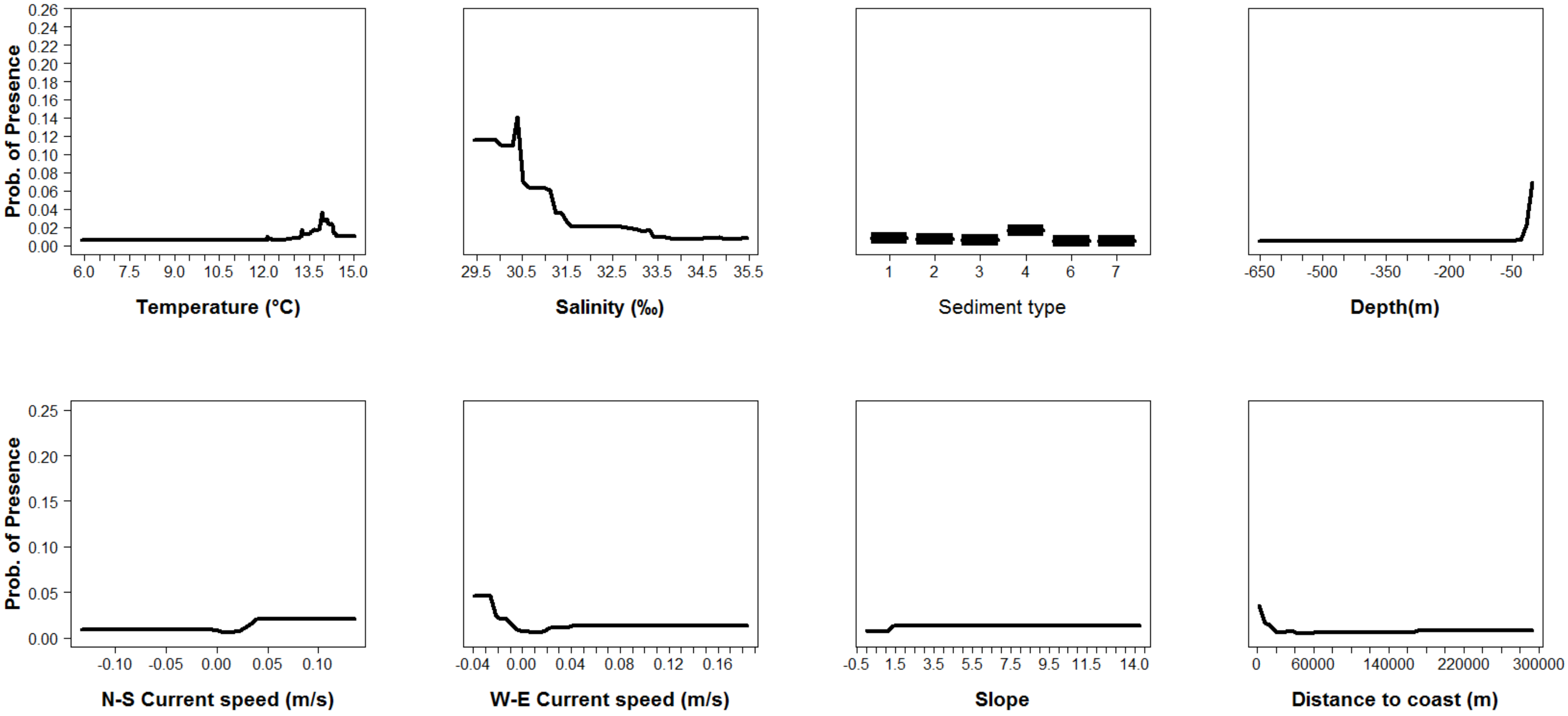

Figure A8: Partial plots from the sole 0 group aggregations model.

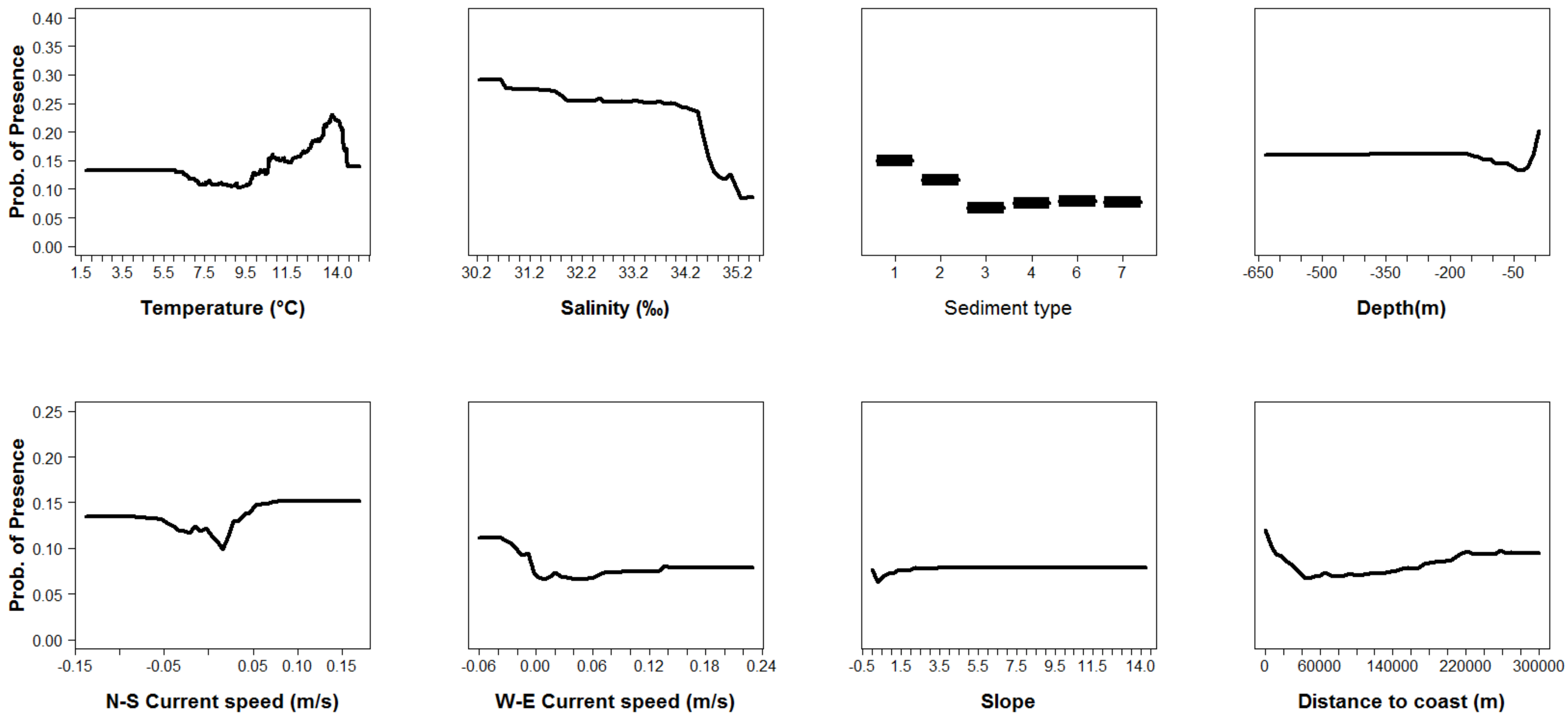

Figure A9: Partial plots from the whiting 0 group aggregations model.

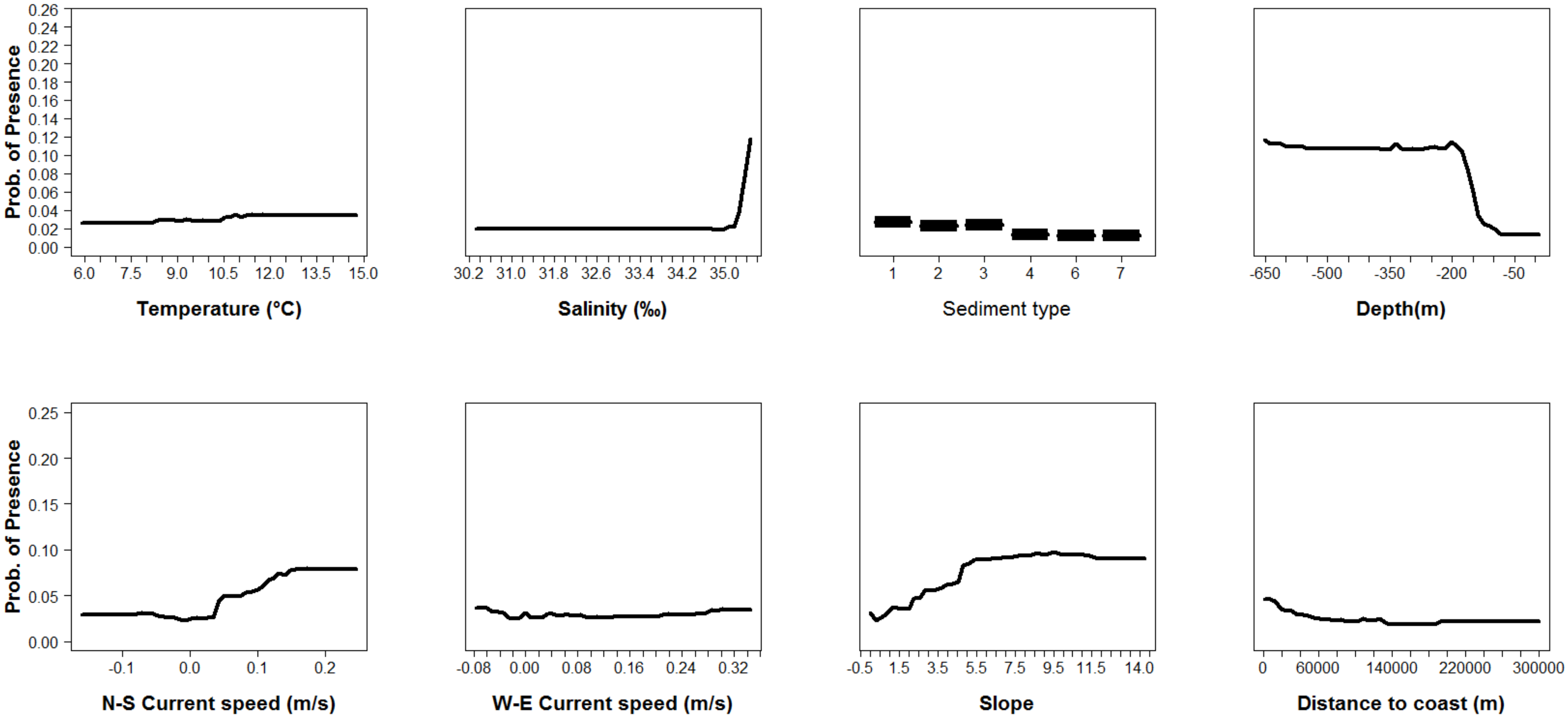

Figure A10: Partial plots from the blue whiting 0 group aggregations model.

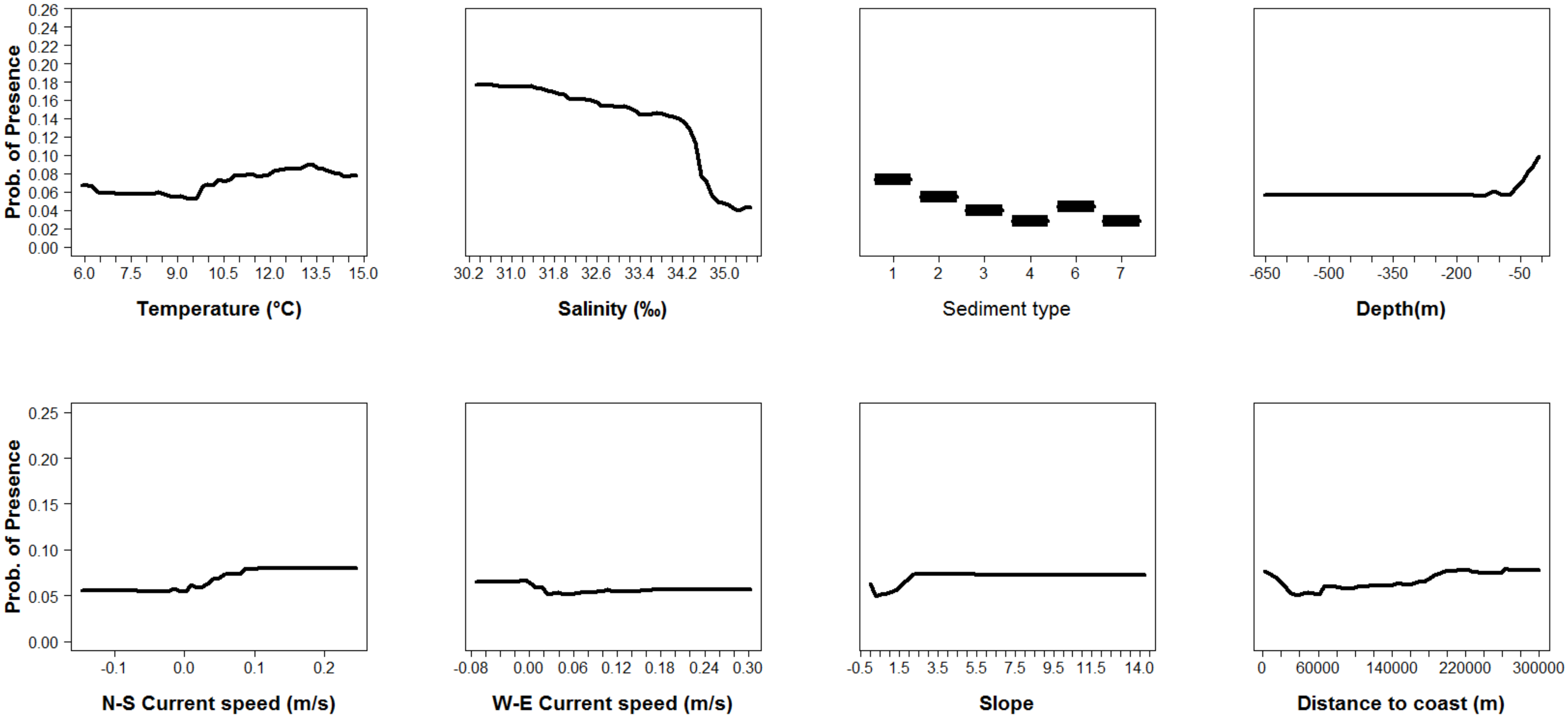

Figure A11: Partial plots from the herring 0 group aggregations model.

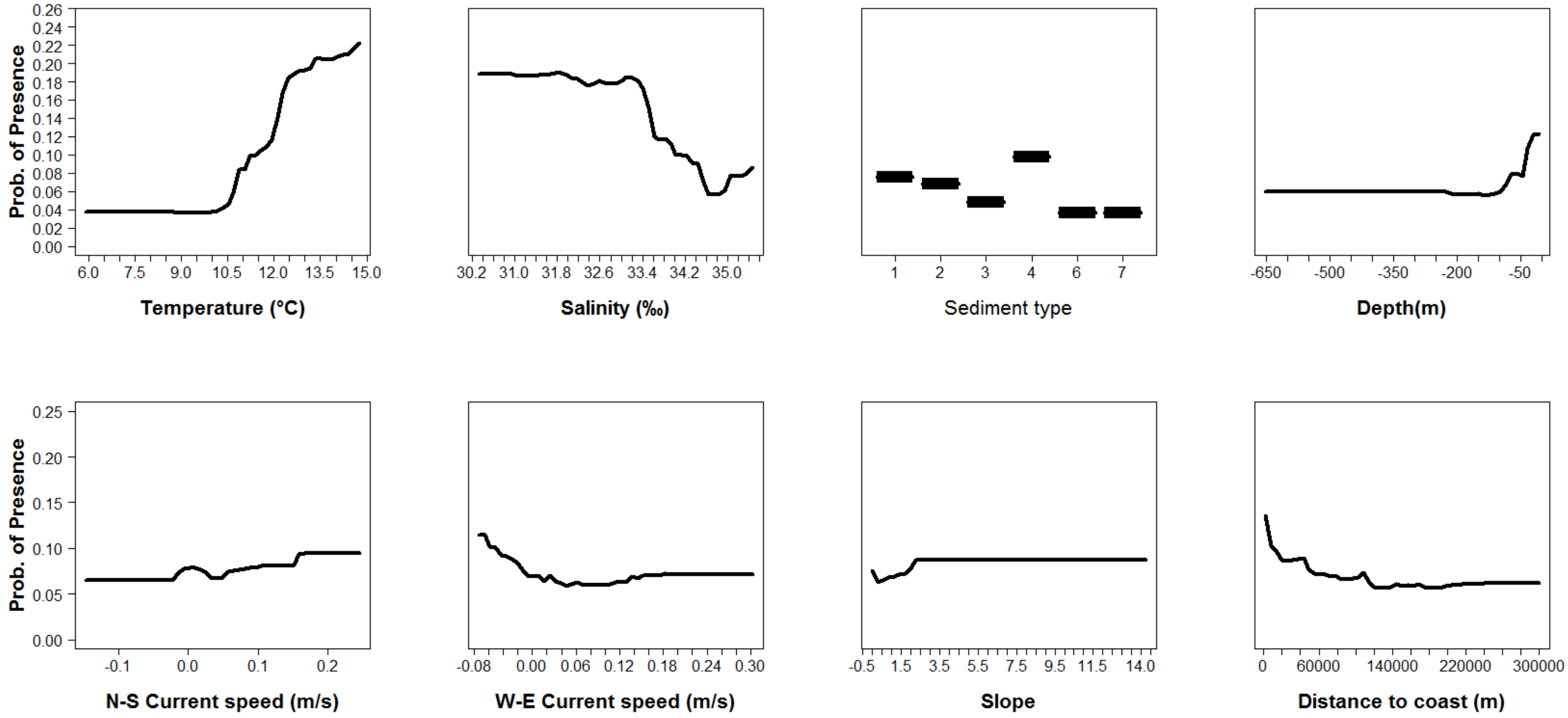

Figure A12: Partial plots from the horse mackerel 0 group aggregations model.

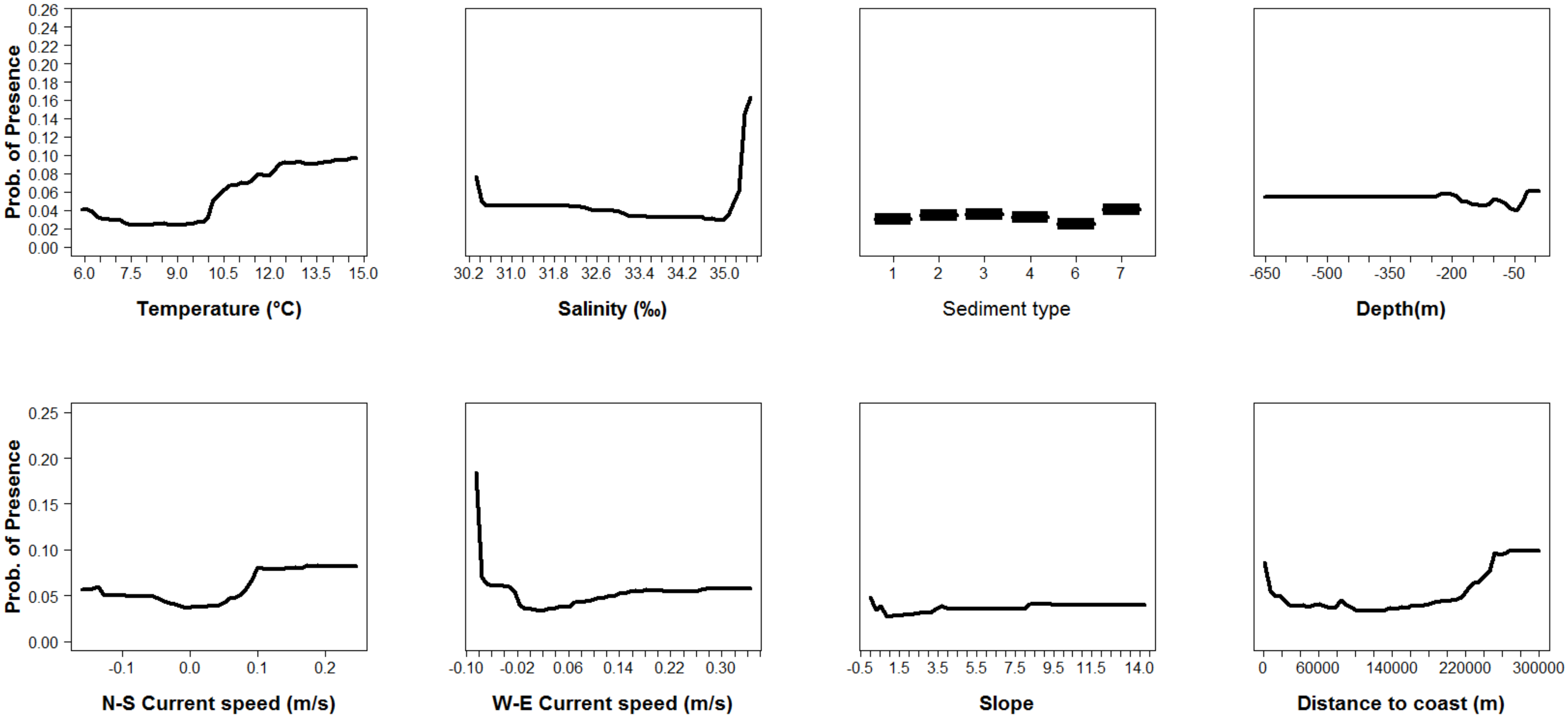

Figure A13: Partial plots from the mackerel 0 group aggregations model.

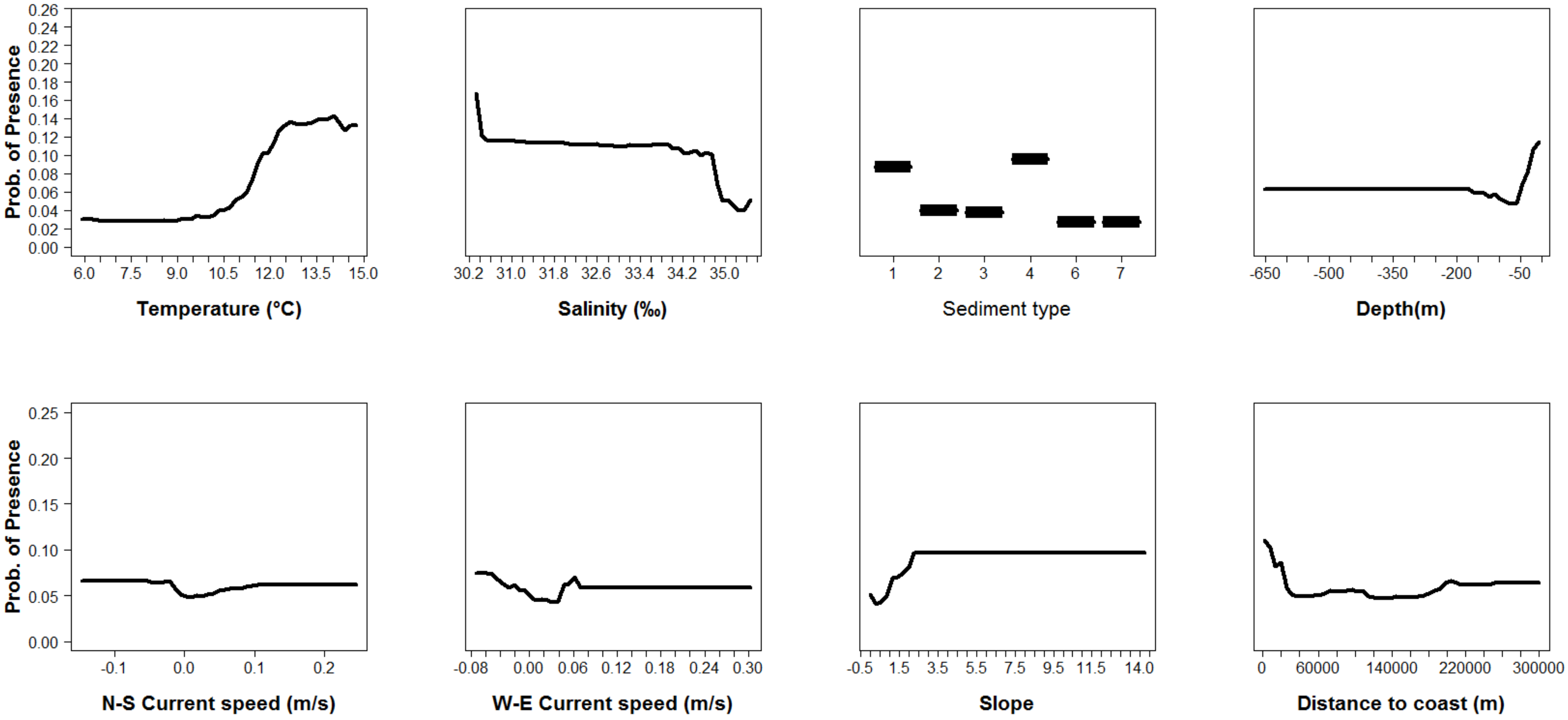

Figure A14: Partial plots from the sprat 0 group aggregations model.

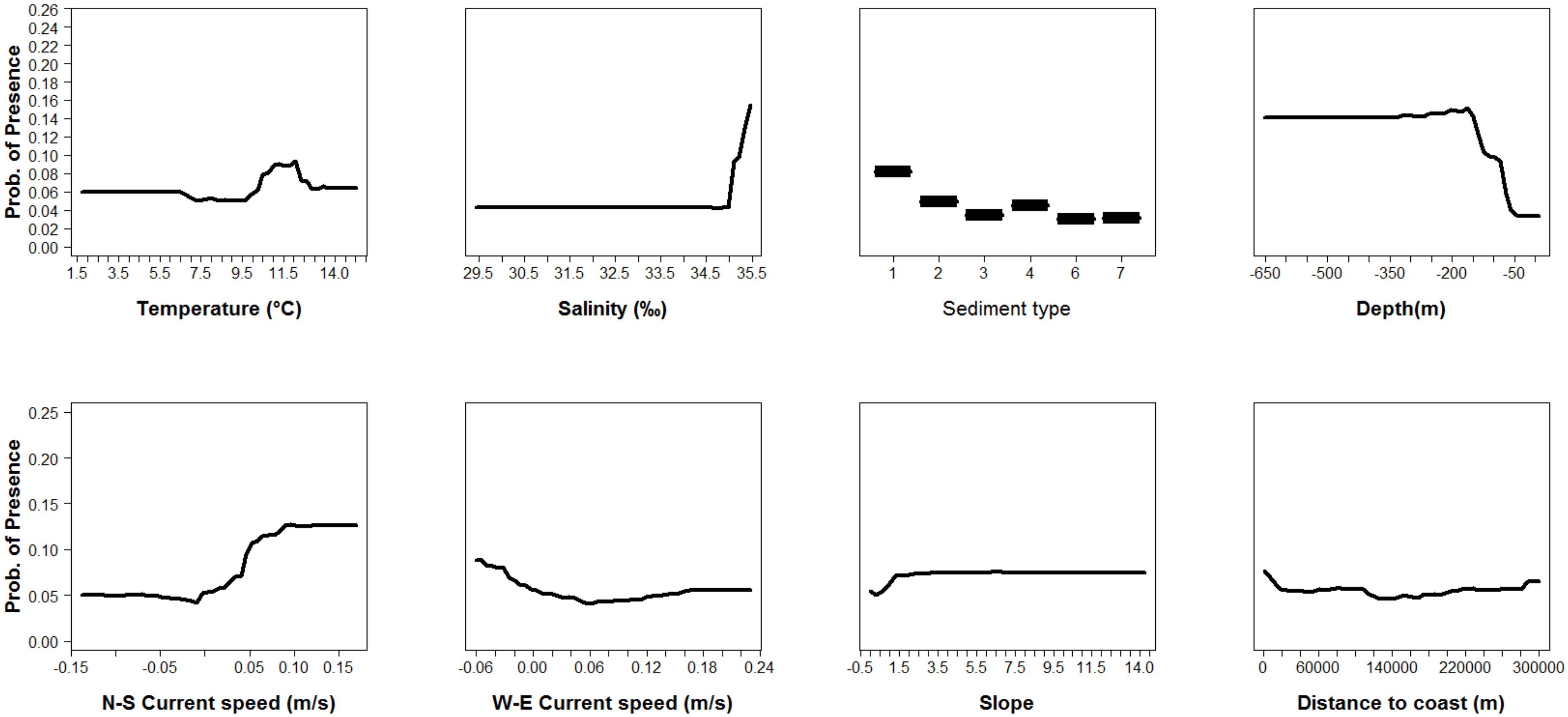

Figure A15: Partial plots from the hake 0 group presence-absence model.

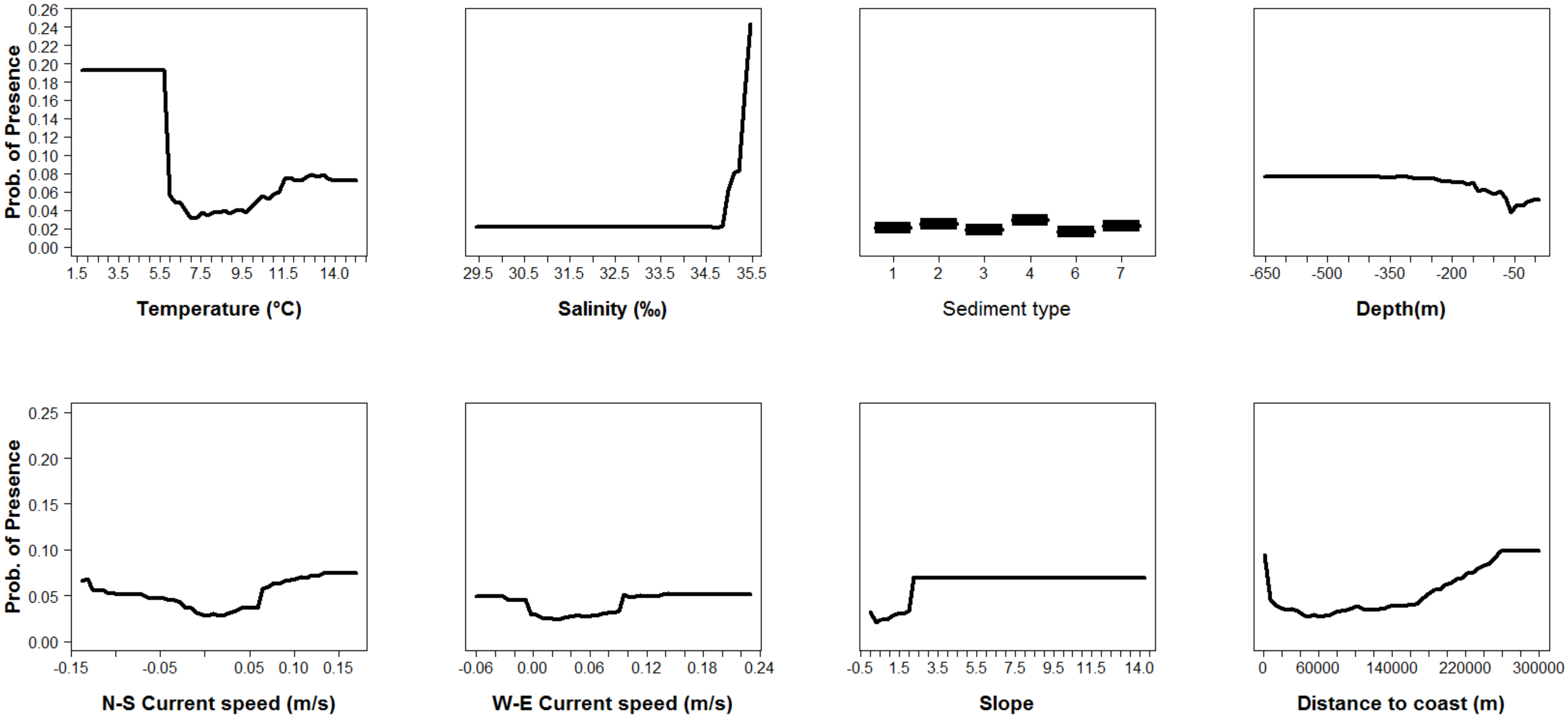

Figure A16: Partial plots from the anglerfish 0 group presence-absence model.

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