Spawning and nursery grounds of forage fish in Welsh and surrounding waters

Distribution of adult and juvenile forage fish species during autumn and winter

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Date: December 2021

This publication is available at www.gov.uk/government/publications

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Recommended citation for this report:	Campanella, F. & van der Kooij, J. (2021). Spawning and nursery grounds of forage fish in Welsh and surroundings waters. Cefas Project Report for RSPB, 65 pp.

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1. Summary

This report provides information on the forage fish community in Welsh- and surrounding waters, including the Irish and Celtic Seas and the western English Channel. The forage fish populations inhabiting these waters provide a key source of prey for many predators, such as marine mammal and seabird species, including several of conservation concern, that either breed or overwinter in the study area. Given that several forage fish species in the northeast Atlantic have shown major changes in distribution and abundance, up-to-date information on their recent distribution patterns is important, including on where the main nursery and spawning grounds are presently located. This information is provided for eleven fish species that are prey to marine mammals and seabirds: herring, sprat, sardine, anchovy, sandeel, horse mackerel, mackerel and garfish as well as the gadoid species poor cod, whiting and cod.

For each species, a summary of the ecology, distribution and status was provided from a literature review. In addition, using survey data from 2008 to 2020, hotspot maps were created for adults and juveniles of each of the species and these were discussed in context of spawning and nursery areas. Data on most of the species was sparse and some of the gears used in fisheries surveys were not designed to catch the target species. However, a hotspot methodology allowed data from different gears to be standardised and combined into a composite map which covered most of the study area during two periods of the year (Quarter 1 and Quarter 4).

Maps largely corresponded to those previously reported although several new species were included for which no or limited historic maps were available, specifically sprat, poor cod and garfish. The report also provided the first maps of warm-water species in the study area: sardine and anchovy. The distributions of both species appeared to have increased in recent years and both are more prevalent in the area compared to previously. Juvenile and adult life stages of all species were present in the study area, confirming a rich diversity of forage fish and suggesting the presence of resident populations. The results provided an updated, and in several cases, first insight in the forage fish distribution in the area. The up-to-date maps of nursery and spawning grounds for the eleven forage fish species in Welsh and surrounding waters, may serve to better understand the recent population dynamics of the region's important seabird populations.

Crynodeb

Mae'r adroddiad hwn yn darparu gwybodaeth parthed y gymuned pysgod porthi yn nyfroedd Cymru a'r cyffiniau, gan gynnwys Môr Iwerddon a'r Môr Celtaidd a gorllewin Môr Udd. Mae'r boblogaeth bysgod porthi sy'n byw yn y dyfroedd hyn yn darparu ffynhonell brae allweddol ar gyfer sawl math o ysglyfaethwr, fel mamaliaid morol ac adar y môr, gan gynnwys nifer sy'n peri pryder cadwriaethol, sy'n un ai yn bridio neu'n treulio'r gaeaf yn ardal yr astudiaeth. Gyda sawl rhywogaeth o bysgod porthi yng ngogledd-ddwyrain yr Iwerydd wedi dangos newidiadau enfawr yn eu niferoedd a'u dosbarthiad, mae gwybodaeth gyfredol ar eu patrymau dosbarthiad diweddar yn hollbwysig, gan gynnwys

ymhle y lleolir eu prif silfeydd a magwrfeydd ar hyn o bryd. Darperir gwybodaeth yma parthed un rhywogaeth ar ddeg sy'n ysglyfaeth i famaliaid morol ac adar y môr: pennog, corbennog, sardîn, brwyniad, llymrïen, marchfacrell, macrell a'r cornbig yn ogystal â'r rhywogaethau penfrasol y codyn Ebrill, y môr-wyniad a'r penfras.

Ar gyfer pob rhywogaeth ceir crynodeb o ran ecoleg, dosbarthiad a statws, a ddarparwyd o adolygiad llenyddiaeth. Yn ychwanegol, gan ddefnyddio data arolygon a gasglwyd rhwng 2008 a 2020, crëwyd mapiau o'r llecynnau gorau parthed oedolion a physgod ifanc ar gyfer pob un o'r rhywogaethau, wedi eu trafod yng nghyd-destun silfeydd a magwrfeydd. Prin oedd y data ar y rhan fwyaf o'r rhywogaethau, ac roedd peth o'r offer a ddefnyddiwyd ar gyfer arolygon pysgodfeydd heb ei ddylunio i ddal y rhywogaeth oedd o dan sylw. Serch hynny, drwy ddefnyddio methodoleg llwyddwyd i safoni data o offer gwahanol a'i gyfuno mewn map cyfansawdd oedd yn ystyried y rhan helaethaf o'r ardal astudiaeth dros ddau gyfnod o'r flwyddyn (Chwarter 1 a Chwarter 4).

Roedd y mapiau ar y cyfan yn cyfateb i'r ardaloedd adroddwyd arnynt yn y gorffennol, er i nifer o rywogaethau newydd gael eu cynnwys nad oedd prin unrhyw fapiau hanesyddol ar gael ar eu cyfer, sef yn benodol y corbennog, y codyn Ebrill, a'r cornbig. Darparodd yr adroddiad hefyd y mapiau cyntaf o rywogaethau dŵr twym yn ardal yr astudiaeth: y sardîn a'r brwyniad. Ymddengys i ddosbarthiad y ddau rywogaeth fod wedi ehangu yn y blynydoedd diweddar, gyda'r ddau yn llawer mwy cyffredin yn yr ardal o'i gymharu â'r gorffennol. Roedd oedolion a physgod ifanc o bob rhywogaeth yn bresennol yn yr ardal astudiaeth, gan gadarnhau bod iddo amrywiaeth gyfoethog o bysgod porthi ac yn awgrymu bod iddo boblogaeth breswyl. Darparodd y canlyniadau fewnwelediad cyfredol, am y tro cyntaf mewn nifer o achosion, o ddosbarthiad pysgod porthi yn yr ardal. Fe allai'r mapiau cyfredol o silfeydd a magwrfeydd yr un rhywogaeth ar ddeg yn nyfroedd Cymru a'r cyffiniau alluogi gwell dealltwriaeth o ddeinameg poblogaeth diweddar adar morol yr ardal.

2. Introduction

The waters of the UK shelf-seas are used by an increasing number of stakeholders. Effective management of potentially overlapping sectors such as fisheries, renewable energy and Marine Protected Areas, requires accurate spatial data on species distribution and ecological understanding. One group of species, forage fish, are a critical component in the marine environment. They are planktivorous pelagic species that play an important role in transferring energy from lower to higher trophic levels, the latter including finfish, seabirds and marine mammals (Cury et al., 2000, Alder et al., 2008, Bakun et al., 2010, Engelhard et al., 2014). Many forage fish species are short lived, produce many eggs and have populations that can exhibit significant natural fluctuation in size and distribution, driven by environmental conditions as well as anthropogenic factors; in addition, they can exhibit migratory behaviour over long distances. However, existing knowledge about their seasonal distributions is often limited. The location of all life stages, including spawning and nursery areas need to be considered carefully in marine management including as prey source for protected marine species, fisheries management and marine spatial planning.

The coasts and islands of Wales and surroundings contain many important nesting sites for seabirds, including several species of conservation concern and of international importance. The breeding success and population status of seabirds are known to be linked to foraging opportunities in surrounding waters. Other predators of forage fish, such as marine mammals and, more recently, bluefin tuna, also reside in these waters and understanding the spatio-temporal distribution patterns of key forage fish species is important. The present report aimed to provide updated information on eleven forage species present in the waters surrounding Wales.

Several studies have mapped the distribution of fish species in the waters around the UK up until a decade ago (e.g. Lee & Ramster, 1981; Coull et al., 1998; Ellis et al., 2012; Heessen et al., 2015). Since then, changes in some of the species' distributions have been observed and new datasets have become available. This report aims to update distribution maps in Welsh waters and the surrounding areas, with more recent data, focussing on the ecologically important forage fish including species that were previously not considered.

For the purpose of this report we included the key pelagic species, herring, sprat, sardine, anchovy, sandeels, horse mackerel, mackerel and garfish as well as some of the most important gadoid species known to be important in top predators' diet: poor cod, and (juvenile) whiting and cod (Table 2). For each of these eleven species, existing information about their ecology, management, (new) maps of nursery- and spawning areas, as well as gaps in knowledge are presented in separate sections (Chapter 4). It is important to note that despite the additional surveys being conducted in the area, gaps still exist for many fish species, and many coastal, continental shelf, and shelf edge waters are still to be surveyed for ichthyoplankton and juveniles. This is discussed in the final chapter (Chapter 5). A summary of ICES areas as well as most commonly referred to geographic areas is provided in Appendix 1.

3. Data Collation

3.1. Definition Spawning and Nursery areas

Spawning areas are defined as those areas where fish aggregate to spawn. Because most forage fish undertake broadcast spawning, which involves shedding eggs and sperm into the water column, their spawning areas tend to be more extensive compared to those species which deposit eggs on the seabed. From surveys, spawning areas of most species are best detected by sampling eggs (and larvae). Staging of the sampled eggs is critical to ensure only the location of newly spawned eggs is considered to identify spawning areas as, depending on environmental conditions, older eggs may have dispersed. Several species considered in this study (herring, sandeels and garfish), deposit eggs on seabed in which case grab samples of the seabed substrate can provide information on spawning activity. Alternatively, distribution of larvae and adults (including maturity staging) combined with high-resolution maps of the seabed substrates (relevant to species specific spawning habitat), will provide a suitable source of spawning location. In the absence of egg or larvae data, the presence of higher and consistent densities of adults during known peak spawning times can provide an alternative indicator (Ellis et al., 2012).

Nursery areas are defined as those areas where juvenile fish aggregate. In addition to higher densities of juvenile fish, nursery areas are also characterised by reduced rates of predation and faster growth rates than in other habitats (Beck et al., 2003; Heupel et al., 2007), although these features are difficult to monitor during routine fisheries surveys. However, the higher density, greater site fidelity and inter-annual consistency in presence of juveniles in nursery areas (Heupel et al. 2007) provide a practical solution to identify nursery grounds during monitoring surveys (Ellis et al., 2012).

3.2. Survey data

The focus of this study was spawning and nursery areas of forage fish in Welsh waters and surrounding shelf sea waters of the Celtic Sea, Irish Sea and the western English Channel. Publicly available data from international fisheries-independent surveys were supplemented by data collected on surveys by Cefas.

Data from three different types of surveys were considered for this study: pelagic (acoustic), demersal otter trawl (also referred to as bottom trawl) and beam trawl surveys (Table 2). Small pelagic fish are patchily distributed in dense schools and are best surveyed using fisheries acoustic methods which monitor the whole water column at high vertical and horizontal (metres to centimetres respectively) resolution. Pelagic or mid-water trawls are then used to validate species composition of echotraces. A dedicated pelagic survey started in 2013 and was included in this study (PELTIC), covering the western English Channel, eastern Celtic Sea and, in 2020, Cardigan Bay. In addition to acoustic and trawls methods, this survey also collects ichthyoplankton data, mainly on sardine.

Other pelagic surveys are conducted in the study area (ICES 2021f) but could not be included as species level data were not publicly available. Demersal otter trawl surveys also capture small pelagic fish and in some cases are used to tune pelagic stock assessments (HAWG, ICES 2021a). They are mainly conducted to monitor the demersal fish community, which acoustic surveys do not sample, therefore providing an excellent source for both the small pelagic and gadoid fish community. The third type of survey used in this study were beam trawl surveys. These are specifically designed to sample smaller demersal fishes, including flatfish, and provided data on gadoids in areas and periods for which no other survey was available. Beam trawls have a limited vertical opening (<0.5 m) and are therefore not suitable to reliably sample mid-water small pelagic fish. However, they do catch small numbers in areas of high densities (van der Kooij et al., 2011), and, although not designed for this purpose, they also catch small numbers of sandeels, by disturbing the substrate in which they are buried. Beam trawl survey data on all species were therefore included in this study, to provide the necessary spatial coverage during both periods.

Table 1 – Forage fish taxa included, including scientific name and length threshold used to separate juvenile from adult fish.

Species	Scientific name	Juvenile fish length threshold (cm)
Atlantic herring	*Clupea harengus*	≤17
European sprat	*Sprattus sprattus*	≤7
European sardine	*Sardina pilchardus*	≤16
European anchovy	*Engraulis encrasicolus*	≤12
Sandeels	Ammodytidae	≤12
Horse mackerel	*Trachurus trachurus*	≤14
Atlantic mackerel	*Scomber scombrus*	≤23
Garfish*	*Belone belone*	NA
Poor cod	*Trisopterus minutus*	≤13
Whiting	*Merlangius merlangus*	≤19
Cod	*Gadus morhua*	≤22

*For garfish adults and juveniles were combined due to the low number of observations

For the beam- and demersal otter trawl surveys, numbers of fish at length at each station, standardised by haul duration, were extracted. Thorough quality control processes were in place ensuring that identification errors during collection or when populating the database, are unlikely for most of the species considered in this study. The only exception are sandeels (Ammodytidae) for which the level of taxonomic accuracy achieved during surveys was insufficient to provide information at species level and all sandeel records were therefore combined (Ellis et al., 2012). From the acoustic survey, numbers of fish at length for each 1 nautical mile sampling unit along the acoustic transects were extracted (Doray et al., 2021). Egg numbers from the pelagic survey were available in number of eggs/m^2 at between 70-100 plankton stations. Nursery and spawning grounds of the forage fish were determined by mapping the density distribution of juvenile and adult fish (where no egg data were available) respectively. A length-based threshold (Table 2) was used to separate juveniles (fish younger than one year) and adults (ICES, 2009 and Ellis et al., 2012). As previously noted (Ellis et al., 2012), using a single length threshold across the different times of the year meant that fish of just over one year of age may have been included.

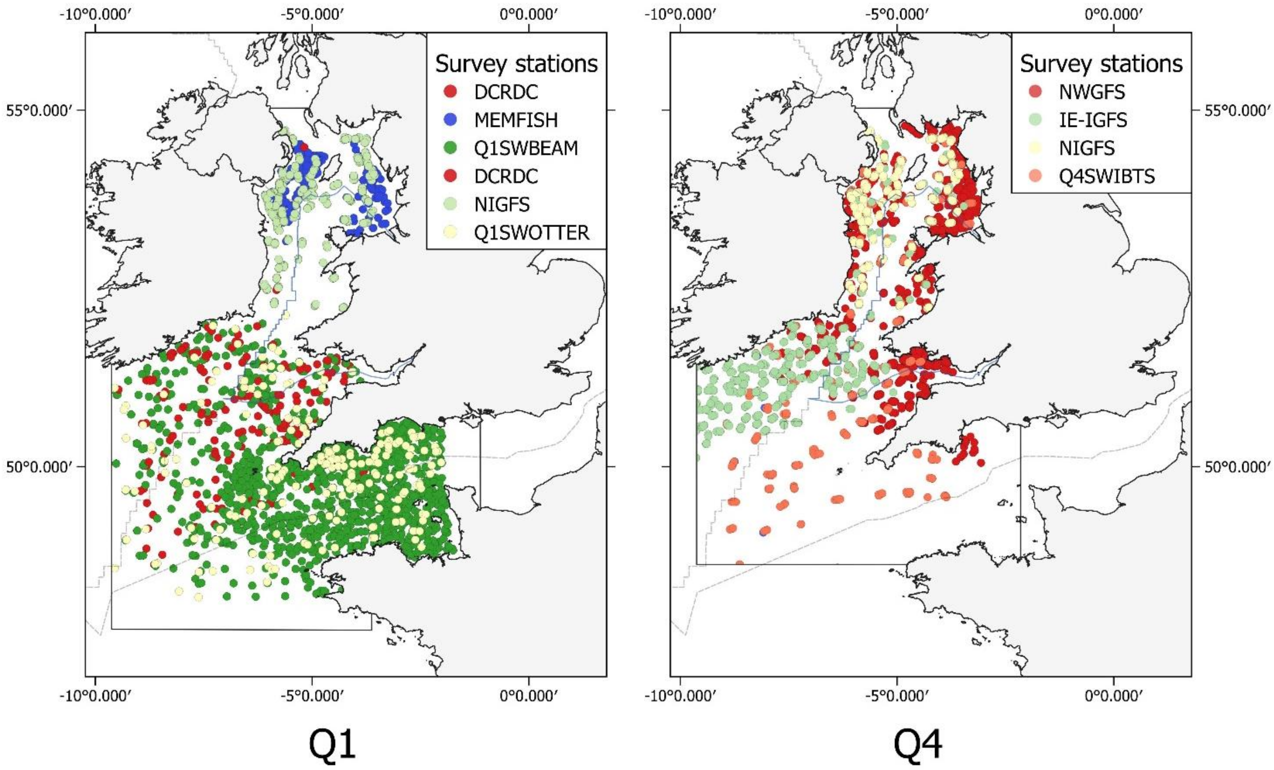

Figure 1 – Distribution of all stations included, colour-coded by survey for Quarter 1 (February-April) and 4 (September-December). Survey codes explained in **Table 2**

Only data from 2008 onwards were considered as this was the last year included in a previous study (Ellis et al., 2012) and ensured that potential recent changes in the distributional patterns of forage fish species were captured.

Table 2 Details of the fisheries independent surveys included in this study, including period for which data were collected (year), gear used and data source. More details for each of the surveys are provided in reference column.

Survey acronym	Survey description	Year	Period	Type	Target species	Source	Ref.
Q1SWBEAM	Q1 South-West Beam trawl survey	2008-2021	Q1 (Mar-Apr)	Beam trawl survey	All	Cefas Fishing Survey System (FSS)	ICES, 2019
MEMFISH	Macro-ecology of marine fish in UK waters	2008	Q1 (Feb-Mar)	Beam trawl survey	All	Cefas Fishing Survey System (FSS)	MEMFISH metadata link
MEMFISH	Macro-ecology of marine fish in UK waters	2008-2011	Q1 (Feb-Mar)	Otter trawl survey	All	Cefas Fishing Survey System (FSS)	MEMFISH metadata link
DCRDC	Data Collection Regulation Survey	2008-2010	Q1 (Feb-Mar)	Otter/Beam trawl survey	All	Cefas Fishing Survey System (FSS)	DCRDC metadata link
Q1SWOTTER	Q1 Southwest Otter trawl survey	2018-2020	Q1 (Feb-Mar)	Otter trawl survey	All	Cefas Fishing Survey System (FSS)	NA
NWGFS	North-West Groundfish Survey	2008-2020	Q4 (Sep-Oct)	Beam trawl survey	All	Cefas Fishing Survey System (FSS)	ICES, 2019
IGFS	Irish Groundfish Survey	2008-2020	Q4 (Sep-Oct)	Otter trawl survey	All	DATRAS	ICES, 2017
Q4SWIBTS	Q4 South-West International Bottom Trawl Survey	2008-2011	Q4 (Nov-Dec)	Otter trawl survey	All	Cefas Fishing Survey System (FSS)	ICES, 2009
PELTIC	Pelagic ecosystem survey in the western Channel and	2012-2020	Q4 (Sep-Nov)	Acoustic-trawl survey/egg survey	Anchovy, Sardine, Sprat, Herring; sardine (eggs)	ICES acoustic-trawl survey database /	Doray et al., 2021
NIGFS	Northern Ireland	2008-2020	Q1 (Mar-Apr) Q4 (Oct-Nov)	Otter trawl survey	All	DATRAS	ICES, 2017

The available surveys included in this study covered two periods, between February and April and between September and December. To ensure the largest possible spatial coverage, surveys in either period were pooled and termed Quarter 1 and Quarter 4. Distribution of juveniles in both Quarters (chapter 4) was considered representative of the nursery grounds for the species. However, the distribution of adult fish was only assumed to represent spawning areas during the Quarter that coincided with the spawning period. For some species the peak spawning periods fell outside the survey periods in which case no spawning maps could be produced. However, the adult fish distribution maps during both Quarters were included in this report. Specific details are discussed for each of the species (chapter 4).

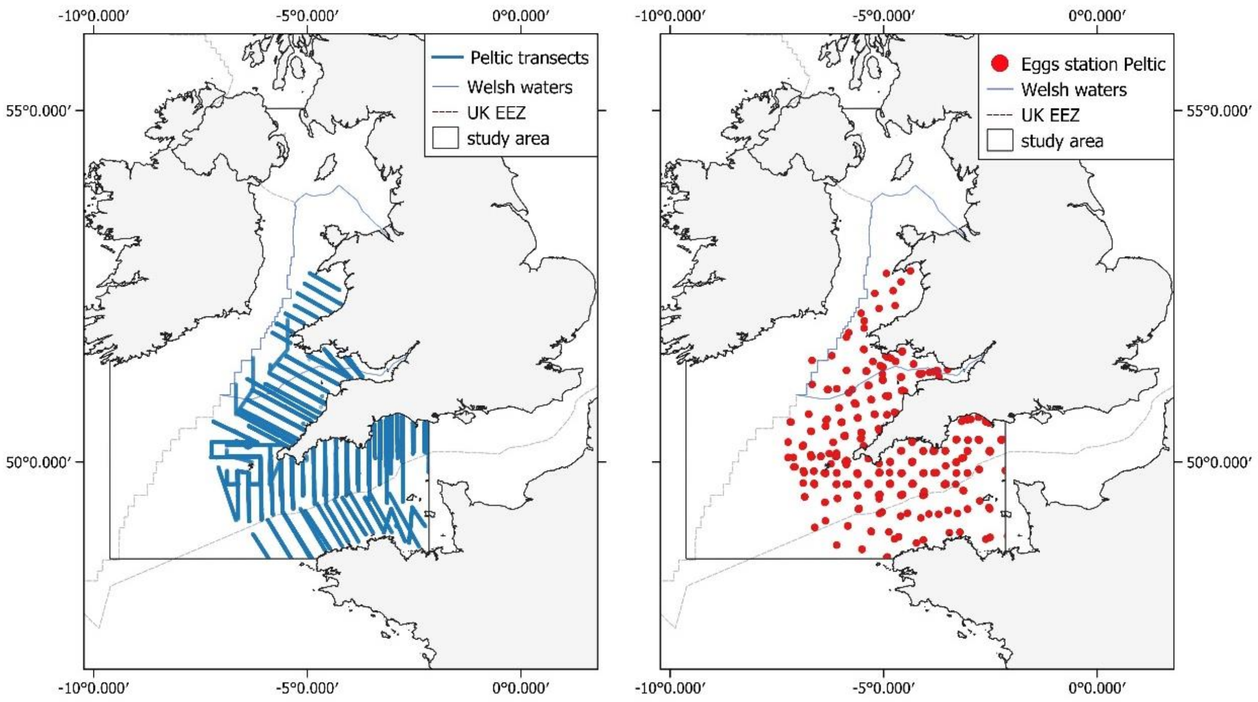

Figure 2 – Distribution of the acoustic transects (left, blue) and ichthyoplankton stations (right, red) from the PELTIC survey (Quarter 4: October-November). Note that coverage and location of transects has changed over the 2013-2020 timeseries.

In combination, the pelagic, demersal otter and beam trawl surveys provided good spatial coverage of most of the study area in both Quarters (Figure 2). However, for some areas spatio-temporal coverage was more restricted or limited to only one gear type, which needs to be considered when interpreting the results presented. In Quarter 1 (Figure 2), the Irish Sea was exclusively sampled by demersal otter trawl surveys; the Celtic Sea and western English Channel had excellent beam trawl coverage but were only surveyed by bottom trawl for three years. Therefore, all forage fish were well sampled in the Irish Sea but further south, data on small pelagic fish were more limited. In Quarter 4 (Figure 2), the Irish Sea was surveyed by both demersal otter and beam trawl gear; the northern Celtic Sea by bottom trawl gear; the rest of the Celtic Sea and English Channel were sampled by a demersal otter trawl survey for three years only and at low spatial resolution. While a pelagic survey covered the western Channel, and eastern Celtic Sea and provided good coverage on the clupeoids, information on gadoid forage fish was limited.

The survey data used in this work are limited to waters more than ~20 m deep and the maps of the spawning and nursery areas in this report are therefore not representative of estuarine and transitional waters.

3.3. Mapping

No single survey (gear) covered the whole study area and therefore to achieve optimal spatial coverage in each Quarter, records of forage fish sampled using different survey gears were combined. However, as the catchability of species varies by survey and, particularly, gear type, averaging the species abundance data from different surveys, would not have been appropriate. To compensate for differences between surveys in gear selectivity, we created distribution maps for each species and size category by using a hotspot approach. This was based on a threshold, applied to the abundance data for each survey year separately. For each species and size category, these binary hotspot maps were then averaged across the surveys and years within a period (Quarter). To achieve this, the following steps were taken.

Gridding: The spatial position and number of survey stations varied significantly between year and gear, making it difficult to merge multiple survey years. Therefore, the first step involved creating a standardized smoothed grid map with average numbers of fish (separately for each size category) by year and survey (gear), using the block averaging methodology (Petitgas et al. 2009, 2014). A grid is defined with its origins selected at random. Within each grid cell the average numbers of fish are calculated, excluding areas (in years) for which no data are available. This process is repeated 200 times after which a final single mean and standard deviation are computed for a final grid cell. These values are smoothed estimates of neighbouring data points, which avoid typical border effects occurring when averaging data points over a fixed grid, and accounts for spatial autocorrelation (Doray et al., 2013).

Thresholding: Areas of fish/eggs hotspots where identified by applying a threshold to each grid map. The threshold was calculated based on Cumulative Relative Frequency Distributions curves (CRFD, Bartolino et al., 2011). A CRFD curve is plotting the relative value of the variable (number of fish/eggs) against the frequency distribution of the same variable. The CRFD for a random process will approximate a 45° line but many biological processes, such as those that drive pelagic fish distribution, will produce curves with an upper asymptote. The hotspot threshold was selected as the variable value corresponding to a 45° slope tangent to the CRFD curve. The 45° slope tangent will identify the areas characterized by the highest values of the variable and by a rate of accumulation along the *x*-axis (variable) higher than that along the *y*-axis (cumulative frequency). The main advantage of this method is that no arbitrary or subjective thresholds are selected *a priori* and that, under the assumption of spatial autocorrelation, the method identifies a global threshold that considers the local spatial structure of the fish density distribution. A full description of this methodology can be found in Bartolino et al. (2012). Figure 3 shows an example of CRFD curve and the resulting hotspot map. The grid cells of the hotspot maps are equal to 1 if the number of fish/eggs is greater than the threshold and 0 otherwise.

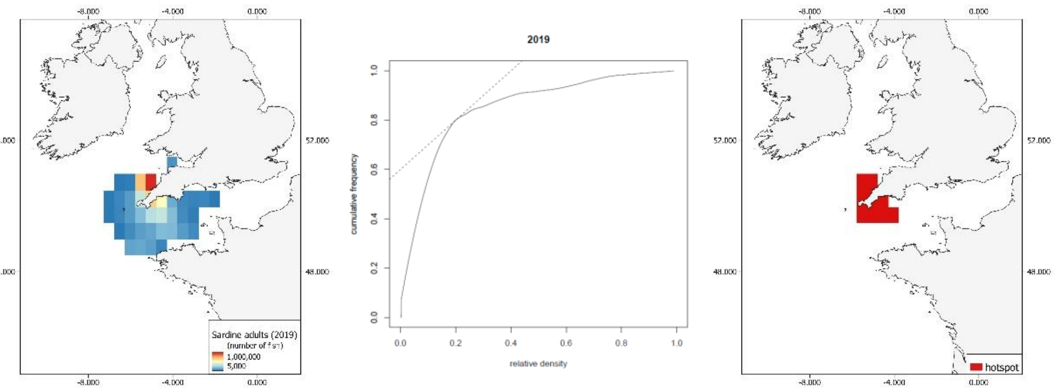

Figure 3 – Stepwise process of estimating hotspot map. From left to right: example of a gridded fish density map, the corresponding Cumulative Relative Frequency Distribution curve (CRFD) with tangent line identifying the density threshold and resulting binary hotspot map.

Merging gear types: The hotspot maps estimated for the different gear types corresponding to the same year, species and life stage were overlapped. The grid cell of the resulting hotspot map had a value of 1 if at least one of the overlapping cells corresponding to the different gear types was equal to 1. If all the overlapping grid cells were equal to 0 the grid cell of the merged hotspot map would be 0.

Averaging years: For each cell *i* in the study area, we calculated an index of hotspot/persistence (I), as follows:

$$I = \frac{1}{n}\sum_{j=1}^{n} \delta_{ij}$$

Where n is the number of years (separated by Quarter) considered in the time series and δ_{ij} is the hotspot presence/absence (0 absence, 1 presence) for the year j in the cell *i*. The index will range from 0 (hotspot never present in the time series) to 1 (hotspot present in all years of the time series). In some instances, no data were available for a particular grid-cell in a survey year. These “no-data” points were not considered in calculating the mean hotpot of that grid-cell.

A high hotspot index is indicative of persistent presence (across survey and year) of (relatively) high numbers of a particular species in that area and Quarter and is not necessarily representative of high abundance. Grid-cells for which no data were available in a particular Quarter (for a species) were left blank with a point in the centre.

4. Forage fish spawning and nursery grounds

4.1. Atlantic Herring *Clupea harengus*

4.1.1. Ecology, distribution, status

Herring is a medium-sized (max length of 40 cm) planktivorous forage fish species that belongs to the Clupeidae family. It is an important commercial species that is widely distributed throughout the cooler waters of the North Atlantic. Herring are found in large schools and generally migrate between spawning and wintering grounds located in coastal waters and feeding grounds which are primarily found offshore. Herring normally show stable migration patterns over the years although environmental conditions and population size may affect this (Corten, 2002). The western English Channel represents the southern-most boundary of the cold-water NE Atlantic herring distribution and historic records of low herring abundance in this area have been linked to warmer periods (Southward et al., 1988).

Contrary to other clupeid species, herring is a demersal spawner and releases a ribbon of sticky eggs that sink to the bottom and adhere to the substrate. Around the British Isles this is usually on gravel or rocky bottoms in well-oxygenated waters. The timing of spawning varies around the UK, with main peaks occurring in spring, autumn and winter (Dickey-Collas et al., 2010). Most of the known spring spawning populations around the UK are small and localised in inshore areas, including estuaries. In the study area the main autumn and winter spawning grounds are known from both the western and eastern Irish Sea (Ellis et al., 2012) and the coastal waters south of Ireland (northern Celtic Sea).

Herring is a facultative zooplanktivorous filter-feeder and its diet is dominated by planktonic crustaceans in particular copepods, but other prey include amphipods, euphausiids, fish eggs, and juvenile fish (Segers et al., 2007).

Clupeid species, including herring, are important prey for a range of predators, including fish (Engelhard et al., 2014), seabirds (Stienen et al., 2006) and, in the study area, baleen whales (Volkenandt et al., 2016).

Management. Three herring management units are considered in the area. In the north, Irish Sea herring (7a North) SSB (Spawning Stock Biomass) and recruitment have increased since the mid-2000s, with a stabilizing trend in the most recent years. Celtic Sea herring (7a South, 7g, h, j, k) SSB has been declining since 2010 and reached very low levels in recent years which has led to closure of the main fishery (ICES, 2021a). The two stocks are separated based on the otolith microstructure, which is different due to different spawning times, although there is significant mixing with juvenile Celtic Sea herring occurring in the Irish Sea (Molloy et al., 1993, Brophy and Danilowicz, 2002). A third management unit encompasses herring which occur in the Bristol Channel and western English Channel (7 e and f); it is based on limited scientific basis and is managed by a precautionary Total Allowable Catch (TAC). Results from recent pelagic surveys suggest that at least some of the juvenile Celtic Sea herring are found in the Bristol Channel (van der Kooij, 2018). Finally, recent genetic studies have confirmed the presence of a number of spring spawning stocks located in the area, in addition to the Milford Haven herring stock (Clarke and King, 1985). None of these are managed and it is likely that fish from these populations mix with some of the autumn and winter spawning fish during some seasons.

4.1.2. Nursery area

Based on the hotspots maps (Figure 4), juvenile herring were found to be widespread although the main nursery areas were in the coastal waters of the northern Irish Sea and around the Bristol Channel area and were similar in both Quarter 1 and Quarter 4. These results largely correspond with those identified in previous studies (Coull et al., 1998; Ellis et al., 2012). The Bristol Channel nursery ground is identified for the first time which is likely due to the inclusion of new data from the dedicated pelagic survey. Another area with juvenile herring is the south coast of England.

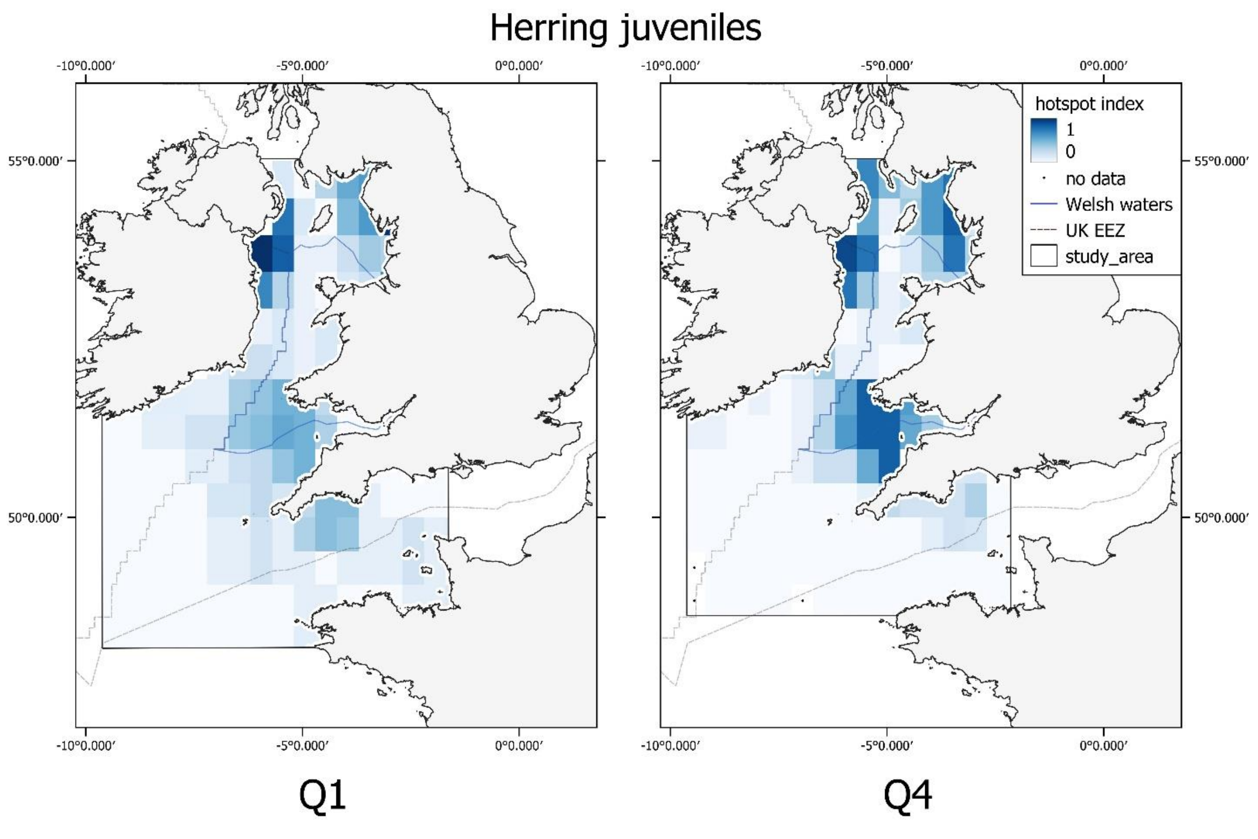

Figure 4 - Hotspot maps of juvenile herring (*Clupea harengus*) in Welsh and surrounding waters in Quarters 1 (February-April) and 4 (September-December). Please note that Grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.1.3. Spawning area

Both Quarters coincided with the main autumn and winter spawning periods in the area and the adult hotspot maps were expected to be representative for spawning locations. However, the distribution of adult herring included more offshore areas (Figure 5), despite most known spawning grounds being predominantly located inshore. The adult hotspot maps corresponded with reported spawning areas in coastal waters (east and west) in the Irish Sea (Ellis et al., 2012).

Winter spawning grounds known from along the southern Irish Coast were not captured in the maps and while Quarter 4 showed some medium hotspot, highest values were found further offshore in the Celtic Sea, extending to the Celtic Deep. This may be due to lack of data from the isolated spawning grounds. However, this observation could also be explained by a strong reduction in spawning stock biomass for the Celtic Sea stock during most of the period considered in this report (ICES, 2021a). The area from the southern Irish coast to the Bristol Channel in Q4 and expanding to the coastal water of the western Channel in Q1 was characterised by intermediate hotspot index values. The most important area for the adults, characterised by high hotspot values in particular in Q4, was located in the northern Irish Sea around the Isle of Man. The low index of herring at the southern end of the study area, in both Quarters, suggested the southern boundary of NE Atlantic herring distribution is captured.

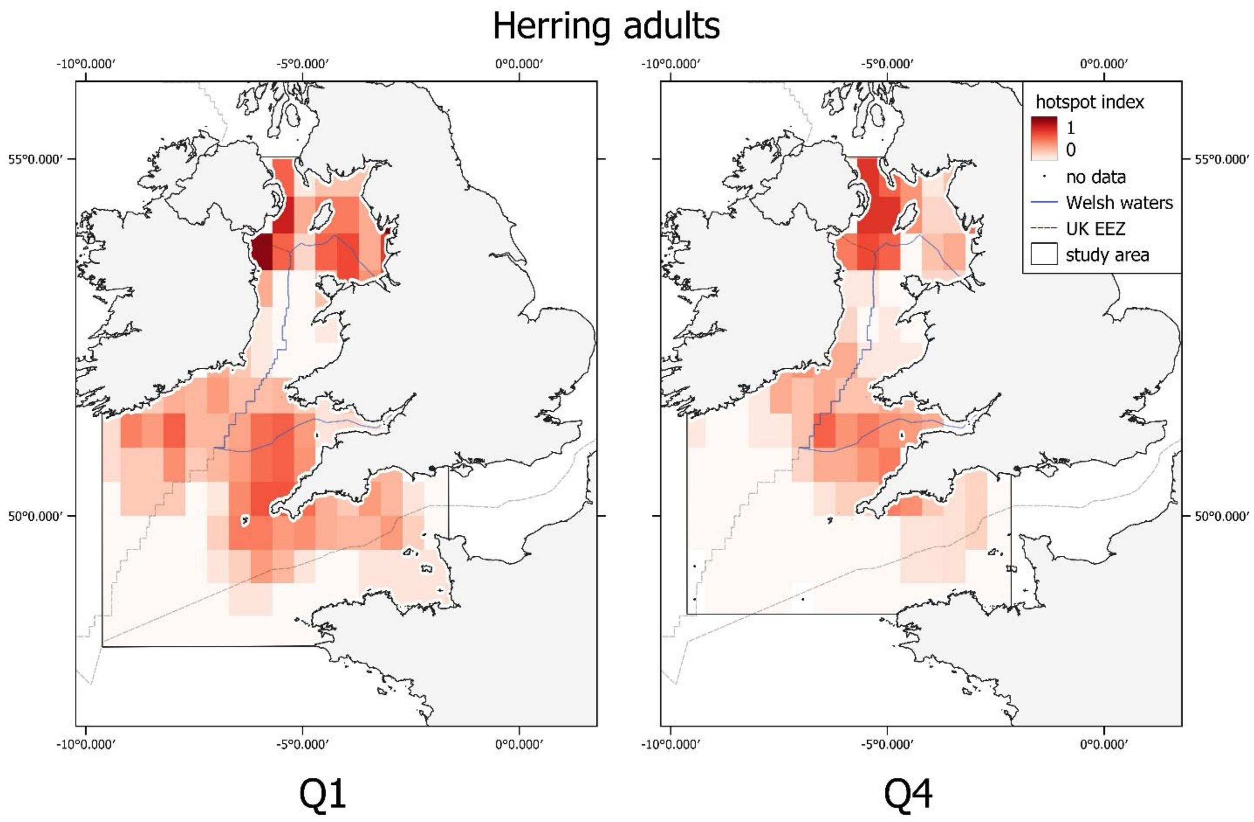

Figure 5 - Hotspot maps of adult herring (*Clupea harengus*) in Welsh and surrounding waters in Quarters 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.1.4. Gaps

Despite the fact that herring is one of the best studied small pelagic fish in the UK, and several dedicated herring surveys operating in the study area, the population structure of this species is complex and not well understood. As has been reported in the North Sea, it is likely that the different stocks mix spatially during certain times of the year, which complicates both monitoring and fisheries management. Genetic studies are a potential useful tool to distinguish between the different populations and have shed new light also on herring in the study area.

The causes of the reported decline in Celtic Sea herring are poorly understood (ICES, 2021a) although the lack of fishing effort in recent years suggests it is likely to be environmentally driven. Given the apparent increase of warm water sardine in the area as well as historic evidence that the abundance of the two species show opposite trends (Southward et al., 1988), it is possible that warmer conditions have also contributed to a reduction the Celtic Sea herring population.

4.2. European sprat *Sprattus sprattus*

4.2.1. Ecology, distribution, status

Sprat *Sprattus sprattus* is a small (max length 16 cm) clupeid species, distributed from the Norwegian fjords in the North to the Moroccan coasts in the South, including the Baltic, north-western Mediterranean and Black Seas (ICES, 1990; Limborg *et al.*, 2009). Sprat is considered a boreal species and, south of the English Channel, tends to be found in isolated populations. It is often found in coastal waters and sometimes near river plumes which have been suggested to provide favourable spawning areas (Carpentier *et al.*, 2009; Certain *et al.*, 2011; Limborg *et al.*, 2009).

Sprat is short-lived with large inter-annual fluctuations in stock biomass, which is thought to be largely driven by recruitment variability including survival of early life stages (Peck et al., 2013); it does not appear to be strongly influenced by the observed levels of fishing effort in areas where it is targeted.

Sprat spawning ranges from January to July peaking between February-March in the English Channel (Milligan, 1986; Brechon et al., 2012) and March-May in the eastern North Sea (Limborg et al., 2009) and is likely to be similar in the Celtic and Irish Seas. Sprat is a serial batch spawner: Females spread oocyte batches several times during the spawning season (Milligan, 1986; ICES, 1990).

Sprat adults are often found in schools just off the seabed whereas juveniles of less than one year old can be found in numerous small schools high up in the water column, particularly in coastal waters.

Sprat diet mainly consists of crustacean zooplankton like copepods (Carpentier *et al.*, 2009; Kanstinger and Peck, 2009). Sprat are an important food source for a range of predators, including fish (Engelhard et al., 2014), diving seabirds (Stienen et al., 2006) and, in the study area, baleen whales (Volkenandt et al., 2016).

Management. In the study area, two management units are considered for sprat, one in the English Channel (spr.27.7de) and one including the much wider area west of Scotland and the southern Celtic Sea (spr.27.6, 7a-cf-k SA). Trends in biomass of the English Channel stock have shown a decline since 2015 although this has stabilised more recently. The fishery consists of a small number of inshore vessels and is managed by annual catch limits (TAC). Although treated as a single management unit, Celtic Sea sprat is likely to consist of several sub-populations. While biomass values estimated for some areas have reportedly been significant (200kt, PELTIC), currently no coherent or complete fisheries independent information is available for this “stock”.

4.2.2. Nursery area

The most important areas that supported persistent and high densities of juvenile sprat in both Quarters were located in the Bristol Channel and in coastal areas of the northern Irish Sea (Figure 6). Interannual variability in juvenile sprat distribution in the Bristol Channel (PELTIC survey, not shown) suggested that juveniles migrate from the Celtic Sea into this area in the autumn to overwinter. Juvenile sprat were absent or only present sporadically in the western English Channel and southern Celtic Sea. Historic maps of spawning and nursery areas around the British Isles did not include the study area (Coull et al., 1998) so no comparison could be made with historic nursery grounds.

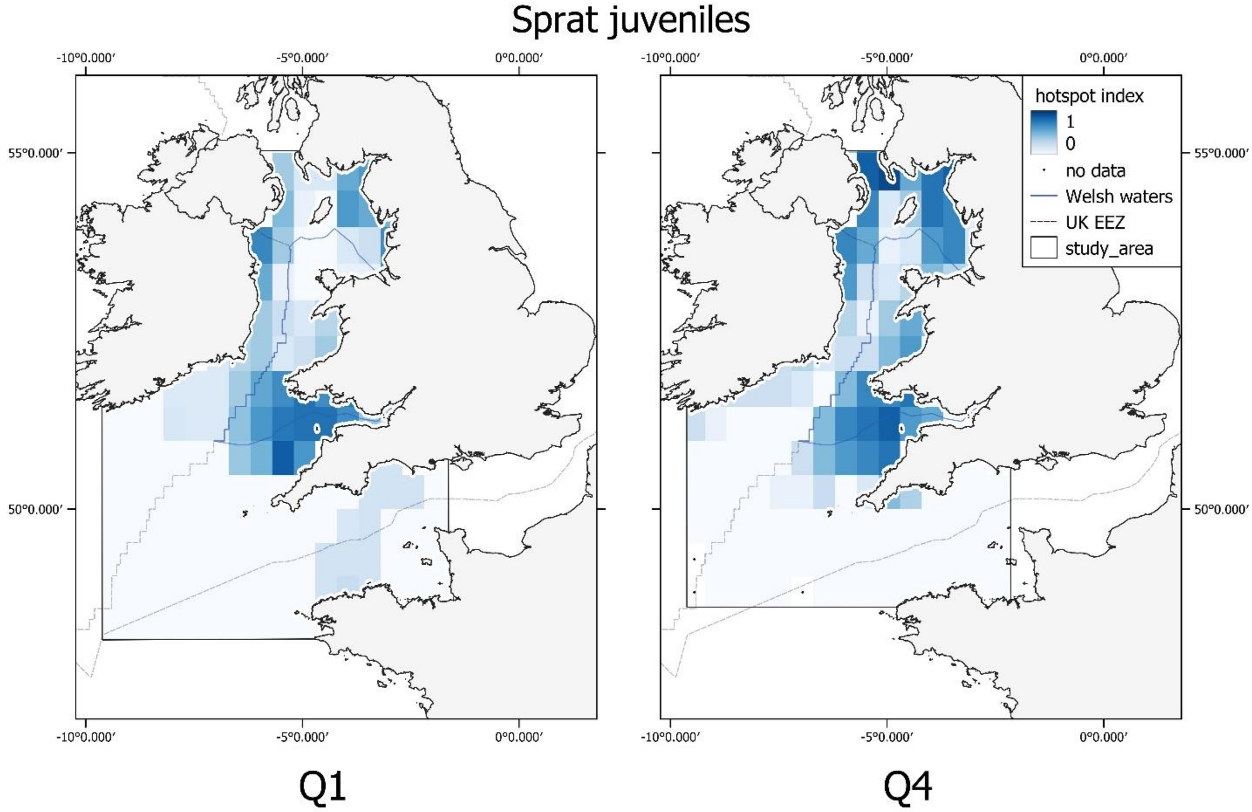

Figure 6. – Hotspot maps of juvenile sprat (*Sprattus sprattus*) in Welsh and surrounding waters in Quarters 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.2.3. Spawning area

No egg data were available for sprat in the study period and therefore the hotspot maps for sprat adults in Quarter 1, which corresponds to the spawning period, provided the most likely spawning areas. These suggested the main spawning areas were distributed along the English coast of the western English Channel and in coastal waters of the northern Irish Sea (Figure 7). These match previous findings (Demir & Southward, 1974; Milligan 1986). Other possible spawning areas included the waters along the south coast of Ireland and the Bristol Channel, particularly the south coast of Wales. Outside the spawning period (Quarter 4), the distribution of adult sprat followed a similar pattern of the juveniles in that period with the main hotspot areas located in the Bristol Channel, Cardigan Bay and the coastal areas of the northern Irish Sea.

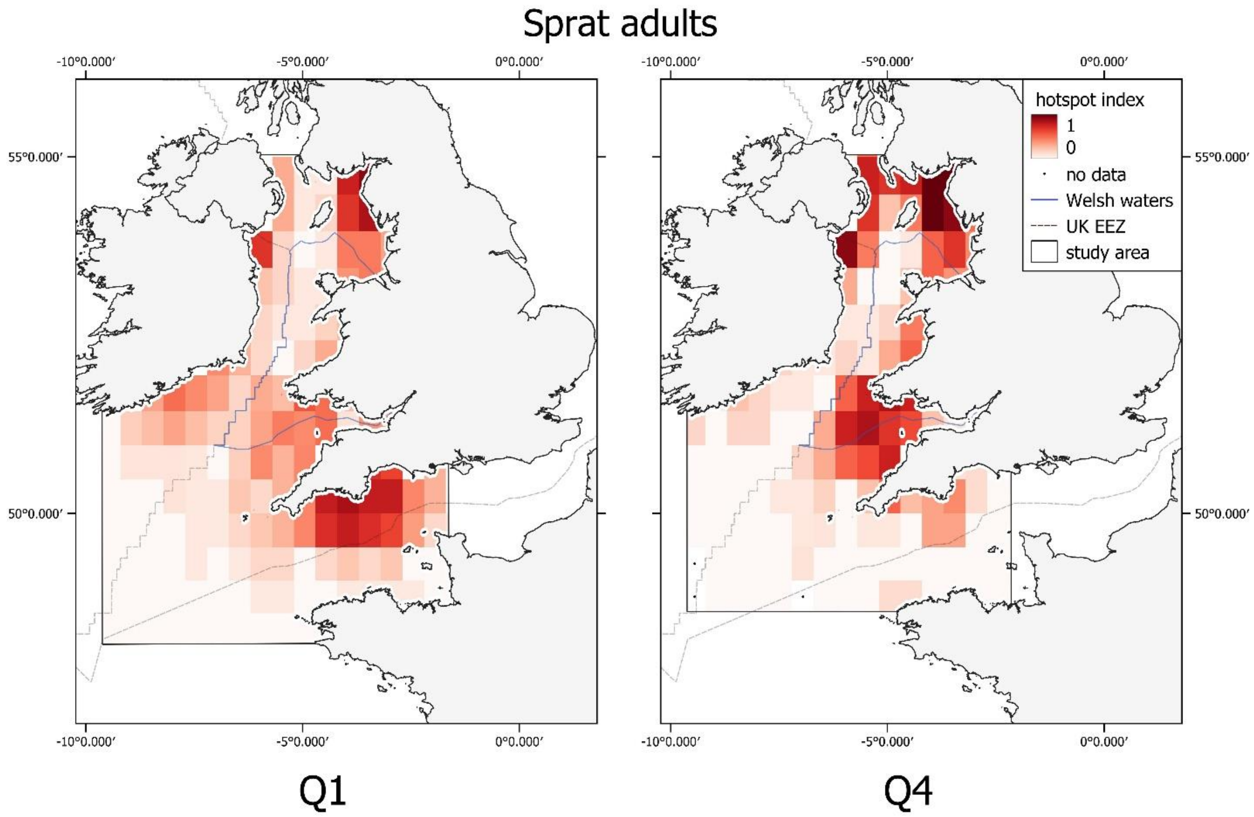

Figure 7 - Hotspot maps of adult sprat (*Sprattus sprattus*) in Welsh and surrounding waters in Quarters 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.2.4.Gaps

Sprat from both the English Channel and the Celtic Sea are data limited stocks (ICES 2021) and there are many gaps in fundamental understanding of this species' ecology in the area. While English Channel sprat is now monitored by a fisheries independent survey (from 2013), the state of the sprat stock in the Celtic Sea, and much of its ecology, is currently unknown. Genetic studies (McKeown et al 2020) have not been able to distinguish between sprat across the study area, suggesting significant gene flow, likely caused by migration. Better data on the stock structure would provide the foundation for improved assessment models. These could also consider mortality due to predation as is applied in North Sea sprat assessment (ICES 2021a): sprat is one of the important prey species for fish, mammals and seabirds. In contrast to North Sea, at present, there are no data available on the total amount of sprat, or more generally of other pelagic species, taken by seabirds in the Celtic Seas Ecoregion.

There is no recent detailed information on the distribution of eggs and early life stages of sprat in the study area and the effects of environmental factors on the distribution and abundance of sprat are largely unknown. Like herring, sprat is a boreal species and possible impacts of temperature on particularly the southern range of this species may affect its populations in the region.

4.3. European Sardine *Sardina pilchardus*

4.3.1. Ecology, distribution, status

Sardine *Sardina pilchardus* is a small (max length 29 cm), short-lived pelagic fish, found from the North Sea down to Senegal and in the Mediterranean Sea (Stratoudakis *et al.*, 2007; Carpentier *et al.*, 2009). Sardine is considered a Lusitanian species and its presence is traditionally rare north of the English Channel (Beare *et al.*, 2004; Coombs *et al.*, 2006; Coombs *et al.*, 2010). However, since the mid-'90s, an increase of sardine presence was observed in the north-western North Sea (Beare *et al.*, 2004) and evidence emerged of recent spawning activity in the southern North Sea (Kanstinger and Peck, 2009). The sardine spawning period varies across its distribution (Coombs *et al.*, 2006), and in the Celtic Sea and English Channel, sardine has two distinct spawning peaks, one in late spring and the second in the autumn (Stratoudakis *et al.*, 2007; Carpentier *et al.*, 2009; Coombs *et al.*, 2010). These peaks are correlated with temperature and increased seasonal plankton production (Coombs et al., 2006). Since the early 2000s, the autumn spawning period has become more important (Coombs et al., 2010). Sardine mature at age 1 and are iteroparous batch spawners with asynchronous ovarian organisation and an indeterminate fecundity (i.e. no initial oocytes stock for the spawning season, all batch oocytes matured all along the season) (Murua and Saborido-Rey, 2003).

Sardine is a non-selective filter feeder and its main prey consists of zooplankton including crustacean (copepods), mollusc larvae or fish eggs and larvae (Carpentier *et al.*, 2009; Kanstinger and Peck, 2009). In contrast to other local pelagic forage fish, sardine diet includes significant amounts of phytoplankton, which are retained by adapted gill rakes (Bode *et al.*, 2004).

No information on the role of sardine in the diet of predators is available for the study area. However, sardine is one of the most important prey for most top predators in the Mediterranean Sea (Cardona et al., 2015) and the reliance of many seabirds on clupeid prey (sprat and herring, Engelhard et al., 2014 and references therein) around the British Isles suggests sardine is likely to play a role also, particularly as numbers increase.

Management. Up until 2017, sardine in the English Channel and Celtic Sea (ICES area 7) was assessed as part of the Bay of Biscay population (ICES area 8). New evidence of different sardine growth rates between the two areas led to the northern component (area 7) being considered a separate population. Due to insufficient data no advice could be set until in 2021, when a short timeseries of annual autumn biomass estimates for ICES area 7, collected during a new survey, were deemed appropriate to provide the basis for the first assessment in 2021 (ICES 2021c). The biomass in the last few years has increased to around 300 kt suggesting sardine is the most abundant small pelagic fish in the south of the study area.

4.3.2.Nursery area

The most persistent hotspots for sardine juveniles in Quarter 1 were located in the western English Channel around Eddystone Bay, extending to the French side. A separate hotspot was in the northern Irish Sea (Figure 8). Many of the juveniles identified in Quarter 1 were likely the young-of-the-year (YoY) born during the autumn spawning peak. In Quarter 4 the Bristol Channel was the main hotspot. Despite the highest average numbers of sardine being found in the western Channel during the acoustic survey, it was characterized by intermediate values of hotspot index, driven by inter-annual variability in juvenile sardine distribution. The autumn (Quarter 4) juvenile distribution is likely associated with the YoY born during the spring spawning peak.

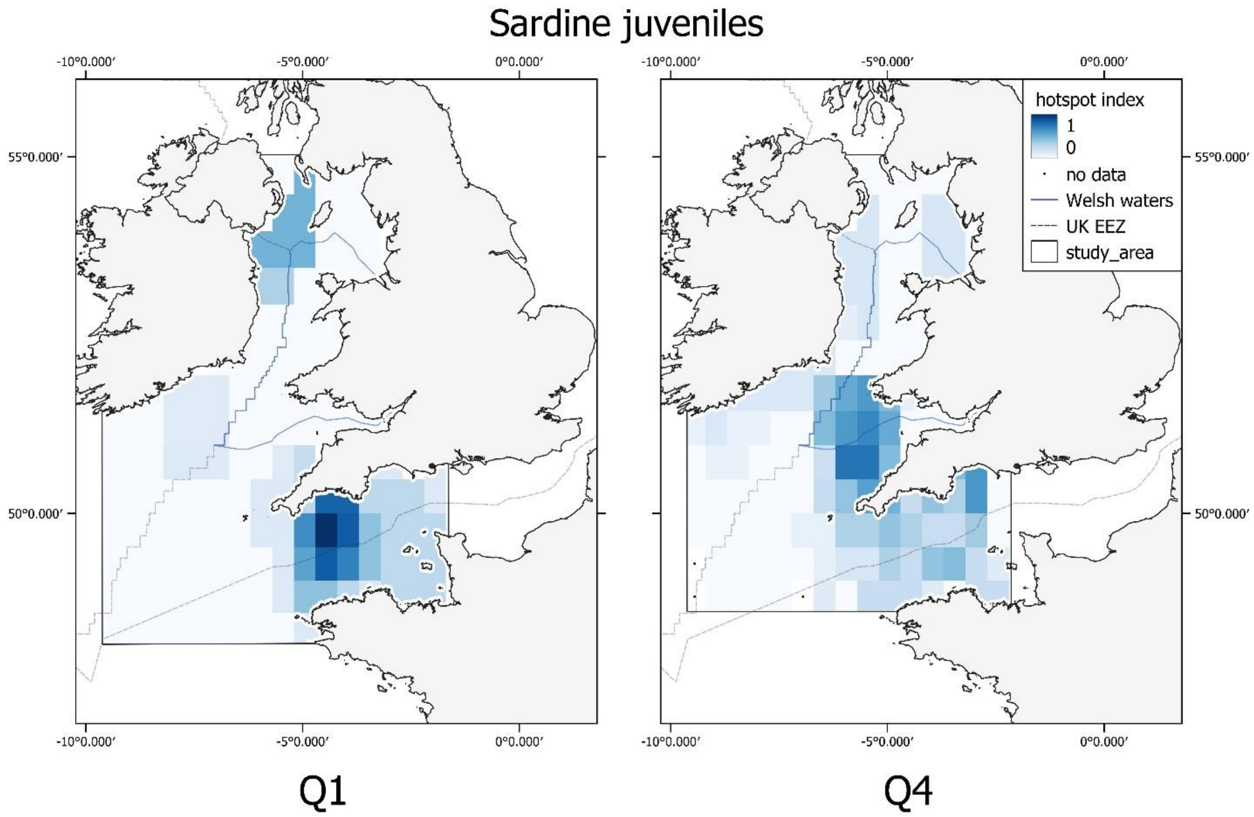

Figure 8 - Hotspot maps of juvenile sardine (*Sardina pilchardus*) in Welsh and surrounding waters in Quarters 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.3.3.Spawning area

Sardine egg data were available for the western Channel and eastern Celtic Sea during the autumn (Quarter 4), providing an accurate description of the spawning area during the most important spawning period (Coombs et al., 2010). The main autumn sardine spawning area was in the western Channel (particularly the south coast of England; Figure 9) which is similar to historic records of summer spawning (Cushing, 1957; Wallace and

Pleasants, 1972; Demir and Southward, 1974; Southward, 1974; Haynes and Nichols, 1994). Over the relatively short time series, egg numbers north of the Cornish Peninsula increases annually from very low numbers at the start of the time series (not shown), suggesting an expansion of the spawning habitat northwards. Medium hotspot areas south of Ireland and in the coastal waters of the western Irish Sea are based on the presence of adults from trawl surveys. Small amount of eggs have been reported in these areas previously (Wallace and Pleasants, 1972), although their role as spawning area is likely to be limited.

Quarter 1 falls outside either of the two main spawning seasons and could represent distribution during sardine feeding period. This would explain a more widespread distribution compared to during spawning although both the western Channel and the northern Irish Sea still represented the highest hotspot index values. This suggests that "northern" sardine may largely remain in the area throughout the year.

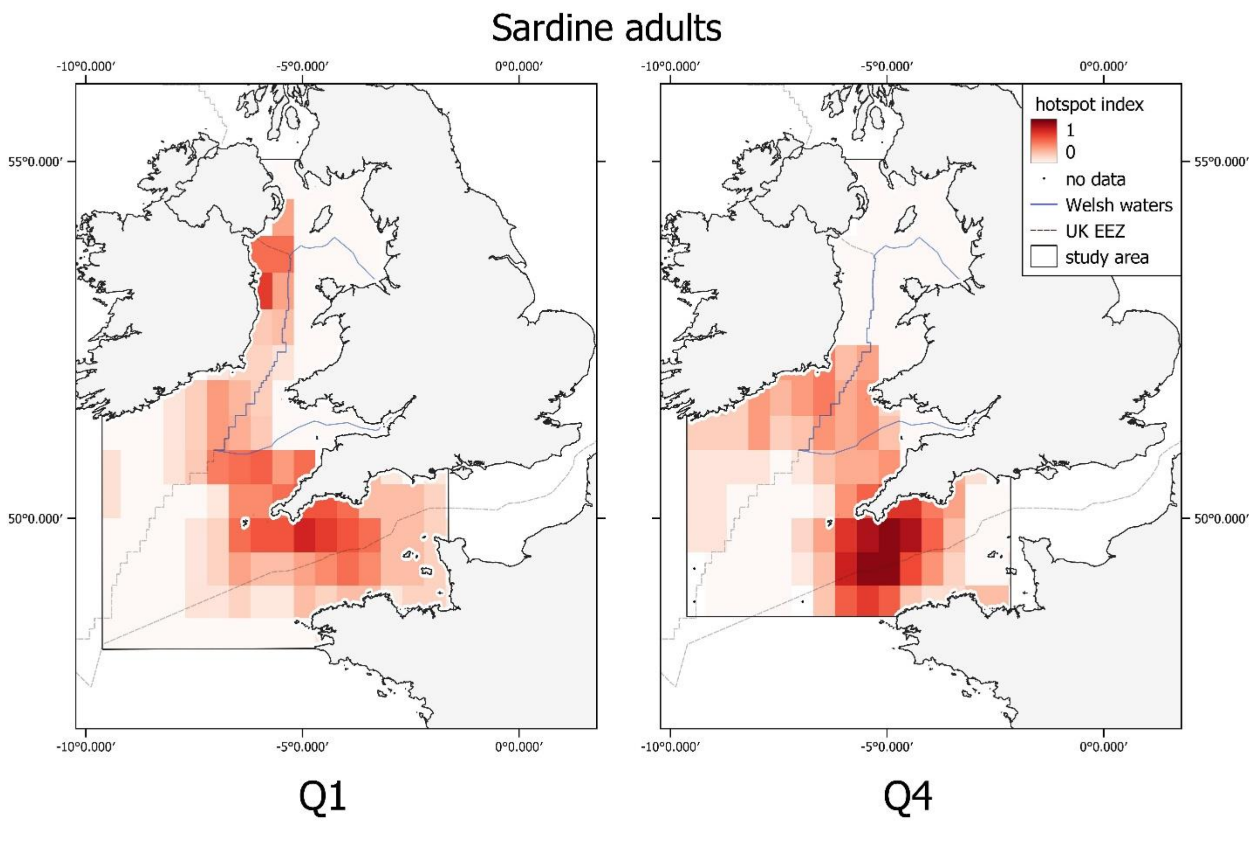

Figure 9 - Hotspot maps of adult sardine (*Sardina pilchardus*) in Welsh and surrounding waters in Quarters 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.3.4. Gaps

Further understanding of the stock structure of sardine in the area is required, which should include genetic studies, further exploration of growth rates, otolith morphology and knowledge about sardine distribution outside the autumn spawning season. The hotspot maps suggested that the distribution in both periods is similar which may indicate limited migration away from the area. However, gaps remain in some seasons, including during the spring spawning period. Dedicated pelagic survey data for the wider area do exist although these are currently not routinely processed for sardine.

4.4. European Anchovy *Engraulis encrasicolus*

4.4.1. Ecology, distribution, status

Anchovy *Engraulis encrasicolus* (Engraulid Family), is a Lusitanian species typically associated with warmer waters of the Mediterranean Sea and the Bay of Biscay and is found down to Morocco and in the Black Sea (Carpentier *et al.*, 2009). In the north, anchovy has historically also been reported in the English Channel and southern North Sea, although its presence there appears to be periodic (Aurich 1953, Alheit et al., 2012). After several decades of absence, increasing numbers of anchovy were reported from the late ‘90s, both in the North Sea (Boddeke and Vingerhoed, 1996; Beare *et al.*, 2004; Raab *et al.*, 2011, Petitgas et al., 2012) in the English Channel, and in the Irish Sea (Quigley, 1997; Armstrong *et al.*, 1999). The causes of these observations were linked to climate variability (Alheit et al., 2012) which have led to expansion of suitable thermal windows for life cycle closure (Petitgas et al., 2012). Recent genetic studies confirmed that these “northern” anchovy were a separate population from those in the Bay of Biscay (Huret et al., 2020), rather than caused by a northwards range expansion.

Anchovy are short-lived and sexually mature at age 1. They spawn in the summer in much of their range, peaking in May-June in the Bay of Biscay and probably in July-August in the southern North Sea (Kanstinger and Peck, 2009). The spawning habitat in the southern North Sea appears to be shallow, inshore sand banks (Boddeke and Vingerhoed, 1996, Heessen et al., 2015). After the spawning season, both juvenile and adult anchovy are thought to move into the deeper waters of the English Channel to overwinter (Huret et al., 2020), after which they return to the southern North Sea to spawn the following year. There are no confirmed spawning areas for anchovy in the study area. In part this could be due to the lack of recent egg surveys during the summer period, particularly covering likely inshore spawning habitat. Small numbers of eggs have previously been found in the Bristol Channel (Wallace and Pleasants, 1972) and it is likely that there may be further isolated spawning locations in coastal waters of the Irish Sea, where adults have been reported during the summer (Armstrong et al., 1999).

Anchovy is zooplanktivorous, principally feeding on planktonic crustaceans (copepods and their nauplii) (Carpentier *et al.*, 2009; Kanstinger and Peck, 2009). There are no reports of anchovy in diets of local predators, possibly reflecting its relatively recent (re) appearance in the study area. However, anchovy is an important prey for predators in the Bay of Biscay and Mediterranean Sea including other fish species like horse mackerel (Trenkel et al., 2014), albacore (Goñi et al., 2011) and bluefin tuna (Logan et al., 2011). Given the importance of other Clupeoids in diets of predators around the British Isles, it is likely that an increasing anchovy population plays an important role as forage fish.

Anchovy was not included in previous studies exploring the nursery and spawning areas of fishes around the British Isles (Coull et al., 1998; Ellis et al., 2012), due to a lack of data and their low abundance in previous decades.

Management. To date, anchovy has not been assessed in the study area, due to historic low numbers found and the absence of a dedicated fishery. It is likely that this will need to be addressed in the near future: biomass estimates from a new pelagic survey in the area (ICES 2020) as well as increased opportunistic landings of anchovy by local sardine and sprat fishers along the English south west coast, strongly suggest that this genetically distinct population (Huret et al., 2020) is increasing.

4.4.2. Nursery area

Anchovy juveniles were widespread in waters less than 100 m deep in the study area with particular hotspots in the western English Channel, and in the western Irish Sea in Quarter 1, and in the Bristol Channel, and the east coast of the Irish Sea in Quarter 4 (Figure 10). Despite being found in high numbers in the western English Channel in the autumn (Q4) the map only shows medium hotspot values. This is due to low anchovy numbers at the start of the pelagic survey (2013) which gradually increased over the time series (ICES, 2020a). Also, interannual variability in the timing of the westward migration into the English Channel resulted in the pelagic survey capturing anchovy at different locations (not shown).

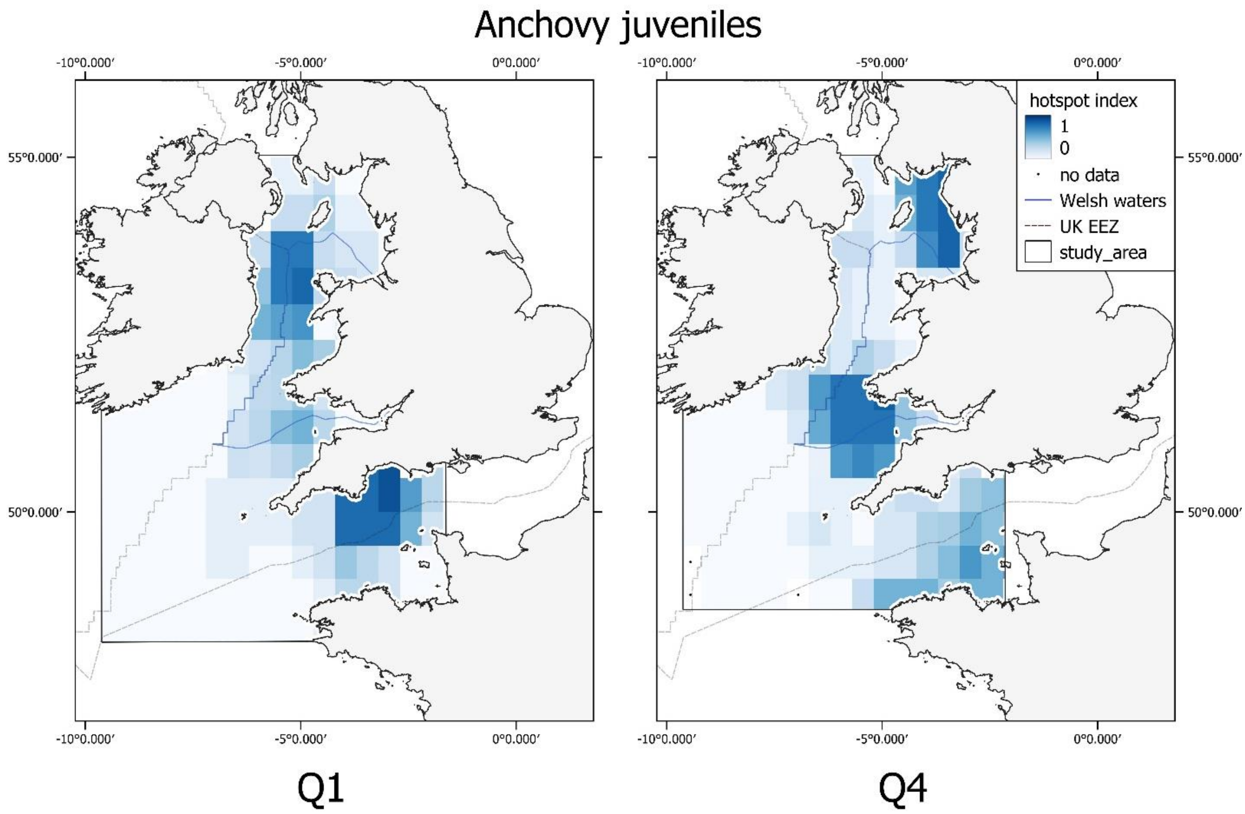

Figure 10 - Hotspot maps of juvenile anchovy (*Engraulis encrasicolus*) in Welsh and surrounding waters in Quarters 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.4.3. Spawning area

Both Quarter 1 and 4 fall outside the spawning period of anchovy and, as mentioned previously, there are no confirmed spawning areas in the study area. No anchovy eggs or larvae were found in the English Channel during the autumn, nor during a one-off pelagic summer survey (not shown), excluding the possibility of spawning here. The adult hotspot maps therefore reflect the location of overwintering grounds. Adult anchovy distributions in both seasons were similar to those for juveniles (Figure 11). The persistent presence of anchovy in the Irish Sea, including in early autumn, suggest that possible local spawning areas may exist in the shallow coastal waters of the Irish Sea and Bristol Channel, where eggs have previously been reported (Wallace and Pleasants 1972).

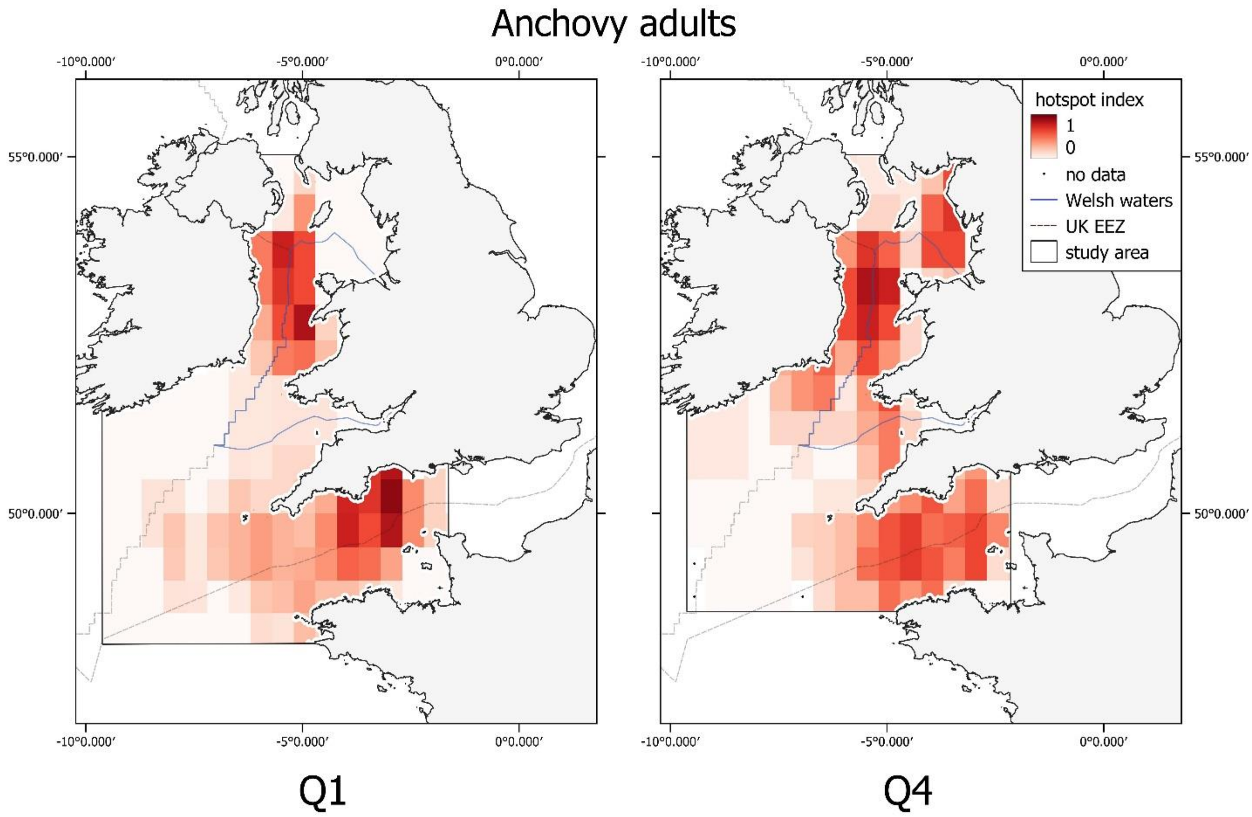

Figure 11 - - Hotspot maps of adult anchovy (*Engraulis encrasicolus*) in Welsh and surrounding waters in Quarter 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.4.4.Gaps

Anchovy stock structure and status in the English Channel, Celtic Sea and Irish sea is unknown and the PELTIC survey is currently the only fishery-independent survey that targets anchovy in the area. There are no studies on eggs and larvae distribution in the area during anchovy spawning period and the understanding of the effects of the environment on the distribution and abundance of anchovy are lacking.

4.5. Sandeels Ammodytidae

4.5.1.Ecology, distribution, status

Sandeels are small pelagic fish (family Ammodytidae) of which five species are thought to be present in the study area: lesser sandeel (*Ammodytes marinus*), small sandeel (*A. tobianus*), smooth sandeel (*Gymnammodytes semisquamatus*), greater sandeel (*Hyperoplus lanceolatus*), and Corbin's sandeel (*H. immaculatus*). Due to difficulties in identifying sandeels accurately, many records refer to genus and family level (Heessen et al., 2015). For that reason, all the species were grouped together for the purpose of this work and will be referred to as sandeel. However, most studies on sandeels have focussed on the lesser sandeel in the North Sea and although very limited information is available for this group in the study area, recent eDNA sampling suggested lesser sandeel is likely to also be the dominant species in the Celtic Sea (Ratcliffe et al., 2021). The ecology of sandeels in this section will therefore be described in context of this species, unless otherwise stated.

Sandeels exhibit unique behaviour, being partly pelagic and partly benthic, spending most of their life buried in the seabed. In spring and summer sandeels emerge from the seabed during the day to from large mid-water schools and feed on zooplanktonic prey (Winslade 1974; Freeman et al., 2004; van der Kooij et al., 2008). At night they return to the seabed, preferring well oxygenated substrates like coarse sand and gravel, and avoiding silt and mud. From the autumn they remain buried in the seabed until spring, only briefly emerging to spawn between November and February when they deposit their eggs on the seafloor. Sandeels are short lived and are sexually mature at age 1. Spawning times for *H. immaculatus* are similar to those described for *A. marinus*, although extending into April, for *G. semisquamatus* and *H. lanceolatus* spawning is from late spring to summer and for *A. tobianus* in both spring and autumn. Due to their strong association with specific seabed substrates, sandeels tend to not be found far from their seabed habitats (van der Kooij et al., 2008), although they may disperse more widely during planktonic stages (Proctor et al., 1998).

Sandeel diet consists mainly of zooplankton, preferring large calanoid copepods such as *Calanus finmarchicus*. Greater sandeels mainly feed on fish (Macer, 1966). Sandeels are one of the most important forage fish prey for pelagic and demersal fish, such as horse mackerel and haddock (Engelhard et al., 2014), marine mammals, such as seals (Reijnders et al.,2010) and minke whale (Windsland et al., 2007) and breeding seabirds like kittiwakes (Frederiksen et al., 2004), terns (Stienen, 2006) and auks (Mitchell et al., 2004; Wanless et al., 2005). The availability of sandeels for many of these predators has been linked to fitness, survivability and breeding success (e.g. Pomeroy et al., 1999; Engelhard et al., 2013; Wanless et al., 2005). Their contribution to diets of many predators is due to their high calorific content combined with their behaviour: sandeels are available to demersal predators when emerging or burying in the seabed and to pelagic predators when schooling in mid-water. Finally, tidally driven hydrographic conditions, such as internal waves, may drive pelagic sandeel schools to the surface waters where they become available to surface feeding birds like kittiwakes (Embling et al., 2012).

Management. Within the study area, there is no assessment for any of the sandeel stocks and their status is unknown. No commercial fishery targets sandeels in the area and sandeels are not routinely reported as bycatch in other fisheries. Sandeel larvae records from the Continuous Plankton Recorder showed an increase in the Irish Sea and a decrease in the Celtic Sea (Lynam et al., 2013).

4.5.2. Nursery area

Juvenile sandeels were widespread in shelf waters of the study area, although the central Irish Sea was the most consistent hotspot, present during both Quarter 1 and 4 (Figure 12). Other, less important nursery areas were located in the western English Channel and north of the Cornish peninsula (in Quarter 1) and in Liverpool Bay (Quarter 4). No sandeels were reported during the autumn pelagic survey (Quarter 4) which is likely due to sandeels having returned to their benthic habitats. All the sandeel records contributing to these maps were caught in the bottom and beam trawls and, given time of year, were likely captured as they were disturbed by the gear making ground contact. This suggests that they are representative of the most important sandeel areas. Restricted groundfish survey coverage in the western Channel is a likely reason for the limited number of records during Quarter 4.

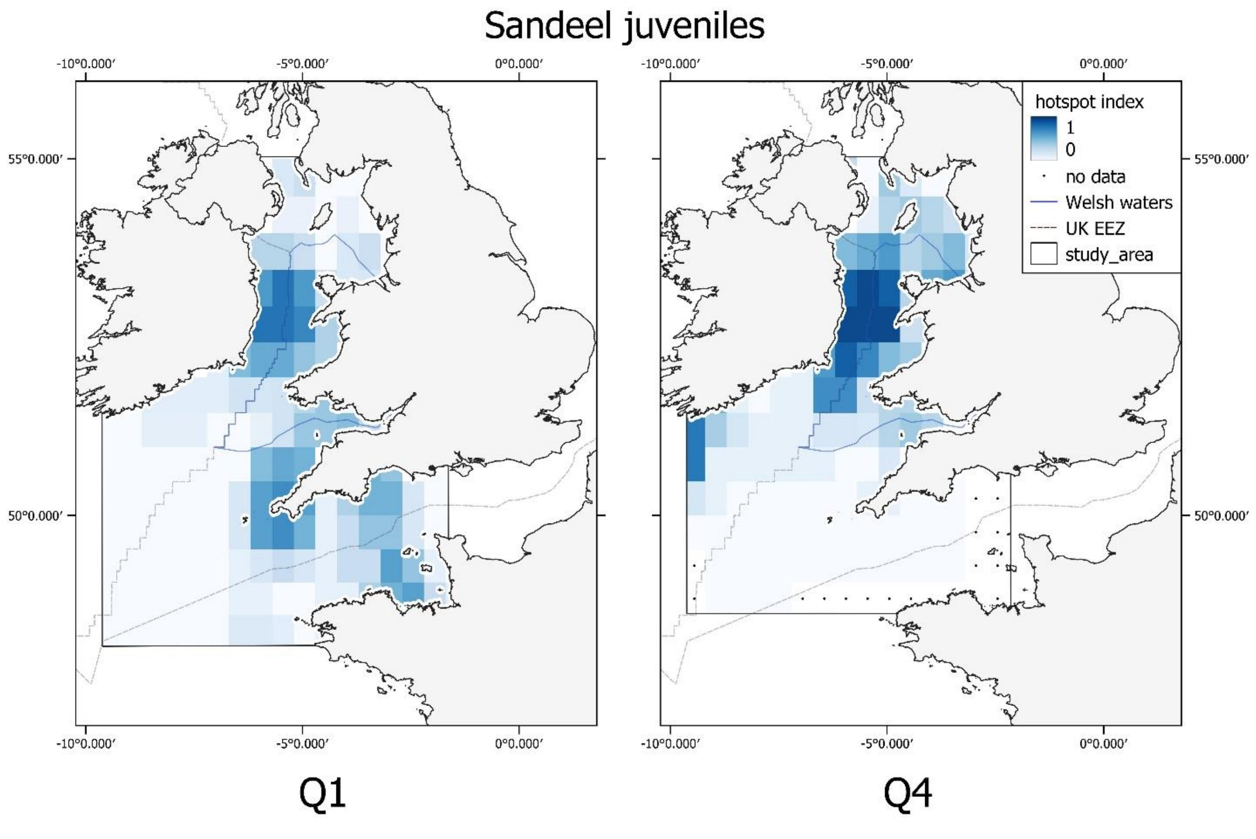

Figure 12 - Hotspot maps of juvenile sandeel (multiple species) in Welsh and surrounding waters in Quarters 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.5.3. Spawning area

Because the sandeel category consisted of several species, with different peak spawning periods, adult sandeel maps do not necessarily represent spawning areas. However, given reported site fidelity throughout the year, the maps should provide a reasonable indication.

It was however unexpected to find differences between juvenile and adult hotspots and between seasons (Quarters). These discrepancies could be due to several factors, including: the use of a single length threshold to separate juveniles and adult, which would not necessarily apply to all sandeel species; or species-specific differences in habitats and phenology.

Adult sandeels were widespread in Q1, with the main hotspot area in the western English Channel up to the Bristol Channel. Other areas of some importance were located around Anglesey, in the Northwest of the Irish Sea and south of Ireland, as far as the Celtic Deep. The western English Channel hotspot persisted also in Quarter 4, albeit smaller, and another hotspot was present in Liverpool Bay (Figure 13).

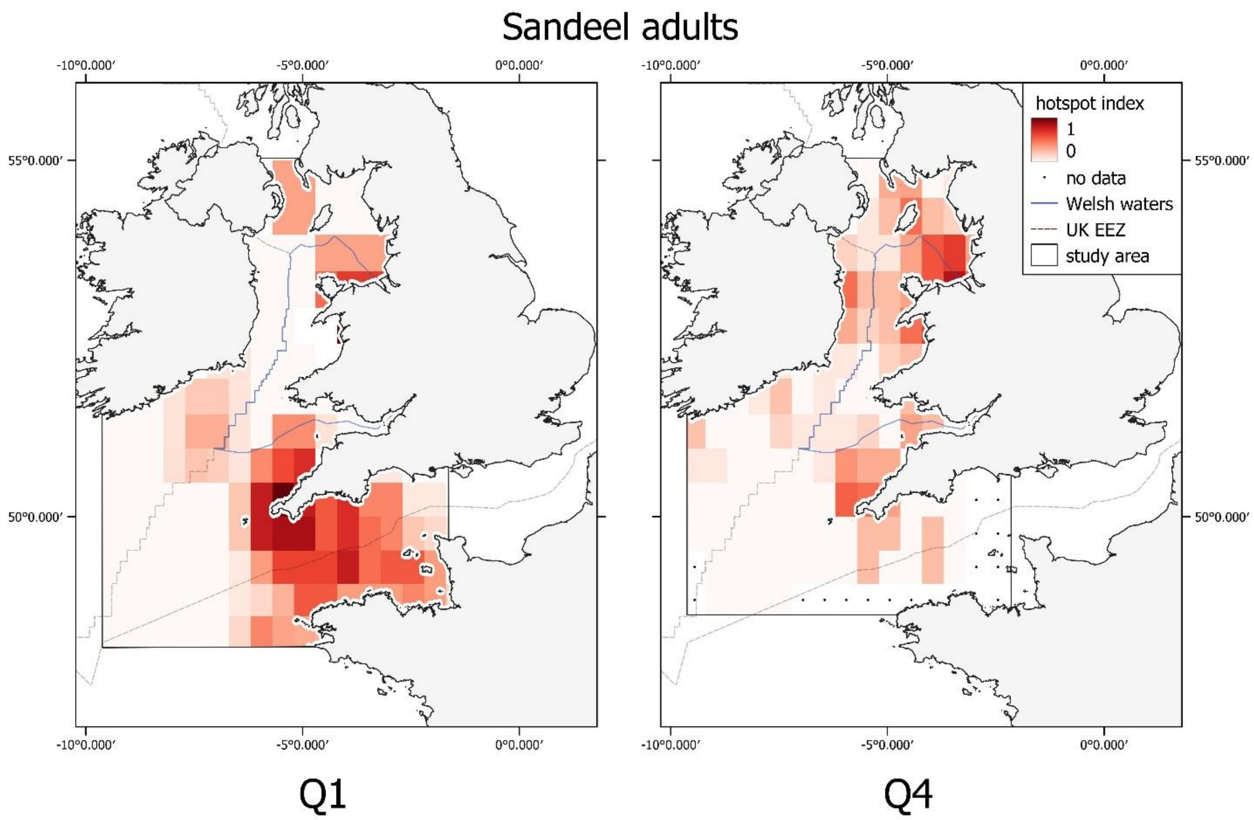

Figure 13 - Hotspot maps of adult sandeel (multiple species) in Welsh and surrounding waters in Quarter 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.5.4.Gaps

Little is known about sandeels in the study area and more accurate species identification during fisheries surveys would help improve distribution maps. The number and size of population(s) is unknown and monitoring the fluctuations in the size of the population is necessary to understand possible implications to predators. Using high-resolution seabed substrate data (specifically silt content) can aid in predicting distribution of sandeels in the region (Langton et al., 2021). Strong site fidelity suggests that several local, relatively isolated populations may exist in the area, as is the case in the North Sea (Pedersen et al., 1999).

4.6. Horse Mackerel *Trachurus trachurus*

4.6.1. Ecology, distribution, status

Atlantic Horse Mackerel is a medium-sized (max length 60 cm) pelagic schooling species of the Carangidae family that is widely distributed over the eastern Atlantic continental shelf, from Norway to South Africa and in the Mediterranean Sea (Froese and Pauly, 2015).

Horse mackerel grow fast in the early years after which growth slows down (Heessen et al., 2015). They become sexually mature between 2 and 4 years old and are asynchronous batch spawners with an indeterminate fecundity (Gordo et al., 2008; Ndjaula et al., 2009). In the northeast Atlantic area, the horse mackerel population as a whole has an 8-month long spawning season (Abaunza et al., 2003; Dransfeld et al., 2005), although the duration of an individual's spawning period is unknown (Van Damme et al., 2014).

Horse mackerel in the northeast Atlantic is divided into three components: the southern stock, found in Atlantic waters west of the Iberian peninsula, the western stock, stretching from the Bay of Biscay to Norway and the North Sea stock, distributed in the eastern English Channel and southern North Sea . Peak spawning for the western stock occurs in June and takes place predominantly along the western shelf edge of the Bay of Biscay, Great Britain and Ireland, although eggs have historically also been found on the shelf in the Celtic Sea and Irish Sea (Wallace and Pleasant, 1972). It has been hypothesised that in winter the North Sea spawning horse mackerel migrate to the Western English Channel to overwinter, whilst the western spawning horse mackerel migrate from the feeding ground off Norway and the northern North Sea to the continental slope southwest of Ireland (Heessen et al., 2015).

Although considered a pelagic schooling fish, high catch rates in bottom trawl survey gear suggest horse mackerel use much of the water column, including near the seabed as also observed during pelagic surveys (Doray et al., 2021).

Juvenile horse mackerel mainly feed on zooplankton while the diet of larger individuals increasingly consists of demersal prey and small fish, including sandeels, sprat and herring (Engelhard et al., 2014). Horse mackerel are likely to be an important prey and evidence exists they are part of bluefin tuna diet (Logan et al., 2011).

Management. The western stock of horse mackerel (ICES divisions 2.a, 5.b, 3.a, 4.a, 6.a, 7.a–c, 7.e–k and 8.a–e.), is the main management unit relevant to the study (ICES 2021b). Horse mackerel egg numbers in the latest triennial mackerel survey carried out in 2019, yielded very low production estimates indicating low stock abundance (ICES 2021g). Although questions were raised about the coverage of the survey, low recruitment was observed by a bottom-trawl derived recruitment index (ICES 2021b), providing further evidence that the stock is at low biomass levels.

4.6.2. Nursery area

Juvenile horse mackerel were found across most of the study area in Quarter 1, especially in the western Irish Sea and in the western English Channel. In Quarter 4 juveniles were more spatially restricted with main hotspots further east in the study area: coastal waters around the Bristol Channel and the English coast of the western Channel (Figure 14). The more restricted range may in part have been driven by more limited survey coverage during Quarter 4. The omnipresence of juvenile horse mackerel apparent in this study is in line with previous observations that there is no specific nursery habitat (Ellis et al., 2012), although hydrographical features such as temperature and prey availability may affect the annual distribution (Corten and van der Kamp, 1996). High catches in bottom trawl gear suggest that at least a significant component of juvenile horse mackerel reside near the seabed, something also observed during pelagic surveys.

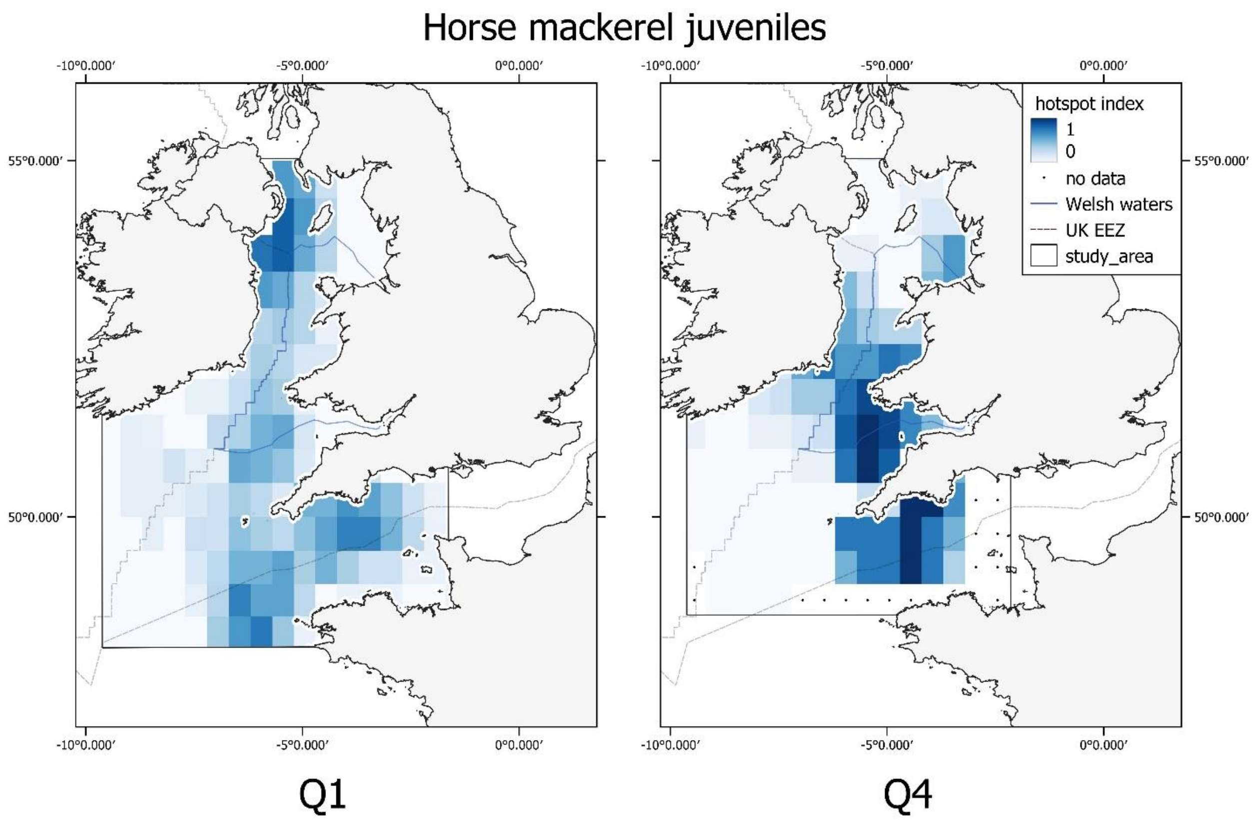

Figure 14 - Hotspot maps of juvenile horse mackerel (*Trachurus trachurus*) in Welsh and surrounding waters in Quarter 1 (February-April) and 4 (September-December). Please note that

grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.6.3.Spawning area

Western horse mackerel spawning starts in December and continues until September although the main peak is in May/June (Macer, 1974) and is mainly situated along the western shelf edge. Nevertheless, spawning activity has been reported off the Cornish Peninsula Head and in the Irish Sea (Wallace and Pleasants, 1972; Ellis et al., 2012). The adult distribution maps in both Quarters should therefore not be considered as representative for spawning areas. The age at which sexual maturity is reached is later than for clupeids and more variable, which, combined with the long spawning period, suggested that the fixed length threshold used here to distinguish between juveniles and adults, is less accurate. The main hotspot areas for adult horse mackerel in Quarter 1 were located in the north-western Irish Sea around the Isle of Man and in a large area in the western English Channel and south-western Celtic Sea. In Quarter 4 adults preferred the coastal areas of Wales and of the English side of the Western Channel in particular around the Cornish peninsula (Figure 15).

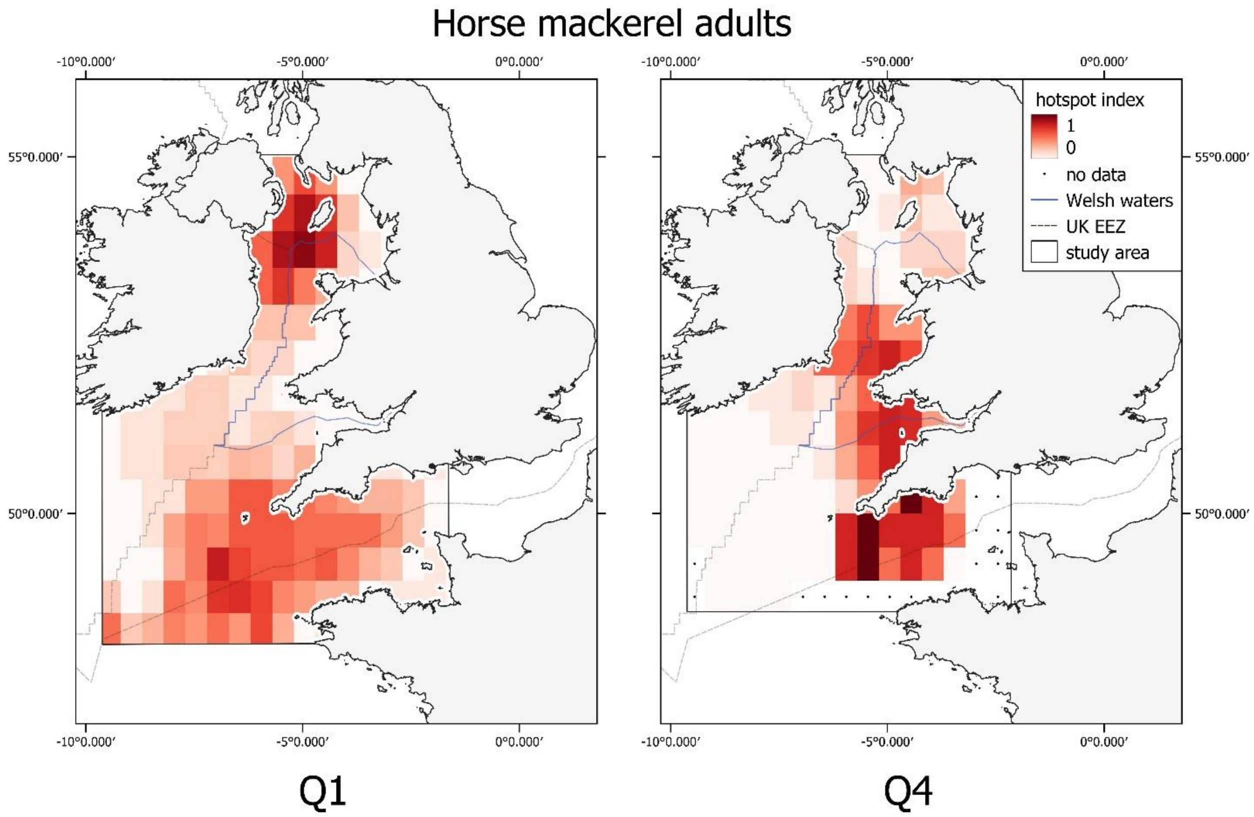

Figure 15 - Hotspot maps of adult horse mackerel (Trachurus trachurus) in Welsh and surrounding waters in Quarters 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.6.4. Gaps

Horse mackerel eggs are sampled along the shelf edge every three years during the triannual mackerel egg survey. However, these surveys do not include the shelf waters, which are also used by horse mackerel to spawn.

4.7. Atlantic Mackerel *Scomber scombrus*

4.7.1. Ecology, distribution, status

Atlantic mackerel (*Scomber scombrus*) is a widely distributed, highly migratory pelagic fish. It plays an important ecological role in oceanic and coastal ecosystems and supports one of the most valuable fisheries in the north Atlantic Ocean. Mackerel become mature at 2-3 years old and the mature individuals carry out seasonal migrations. After spawning off the continental shelf in early summer, mackerel migrate north to the northern North Sea and Norwegian Sea, as far as Svalbard in recent years (ICES, 2013, Nøttestad et al., 2016) to feed. Late summer they aggregate through autumn and early winter along the continental shelf edge. From March, the location of a relatively warm shelf edge current consequently guides mackerel back south towards the main spawning area (Jansen et al., 2012). Juveniles generally do not follow the same migration pattern of the adults and tend to remain close to the nursery areas in coastal areas (Uriarte et al., 2001). Western mackerel eggs and larva drift east with prevailing westerly winds and settle in shelf waters.

During the last decades, several changes have been observed in the temporal and spatial patterns of mackerel (Jansen et al., 2012; ICES, 2013). Most recently, changes in the summer distribution were reported: commercial ladings around Iceland increased significantly and 0 and 1 year old fish were found in local scientific surveys for the first time in good numbers (Astthorsson et al., 2013). This northward expansion (van der Kooij et al., 2016), coincided with spawning activity off the shelf shifting further north and west compared to historic observations (ICES 2011).

Mackerel feed on a variety of prey, from (larger) zooplankton to small fish, including forage fish like sandeels (Engelhard et al., 2008).

Mackerel are a key prey for predators such as oceanic seabirds like northern gannet (Hamer et al., 2007), cetaceans (De Pierrepont et al., 2005) and pelagic sharks (Stevens, 1973; Ellis and Shackley, 1995). As juveniles are found in coastal waters, they may also be taken by breeding seabirds but there is limited information on this.

Management. Northeast Atlantic mackerel is assessed by ICES as a single stock but it has been divided into three separate spawning components: southern, western and North Sea, although recent evidence suggested that significant mixing between the latter two spawning components takes place (Jansen and Gislason, 2013). After a period of very high biomass, the stock size has seen a decreasing trend although not yet reaching the low values prior to 2007. In the study area, one of the key nursery grounds, the shelf waters around the Cornish peninsula, received protection with the introduction of the Mackerel Box in 1984; within this (67,000 km2) area, pelagic trawling and purse seining for mackerel was prohibited, and directed effort was only permitted using size selective gears like gillnets or handlines (Lockwood, 1988). Limited information on mackerel within the Mackerel Box has been available and no recent studies have monitored the influence of such measure on the mackerel stock, in light of the recent stock expansions.

4.7.2. Nursery area

Mackerel juveniles in Quarter 1 were widely distributed within the study area, in particular in the western English Channel and northern Irish Sea even though no clear hotspots were present. In Quarter 4 the main hotspot area was located around the Cornish peninsula. Less persistent hotspot areas were found in the coastal waters of the southern Irish Sea, including Cardigan Bay, although the latter is based on one year of survey data (Figure 16). During Quarter 4 juvenile mackerel were found more in coastal waters compared to Quarter 1. These observations correspond broadly with those previously reported (Coull et al., 1998; Ellis et al., 2012).

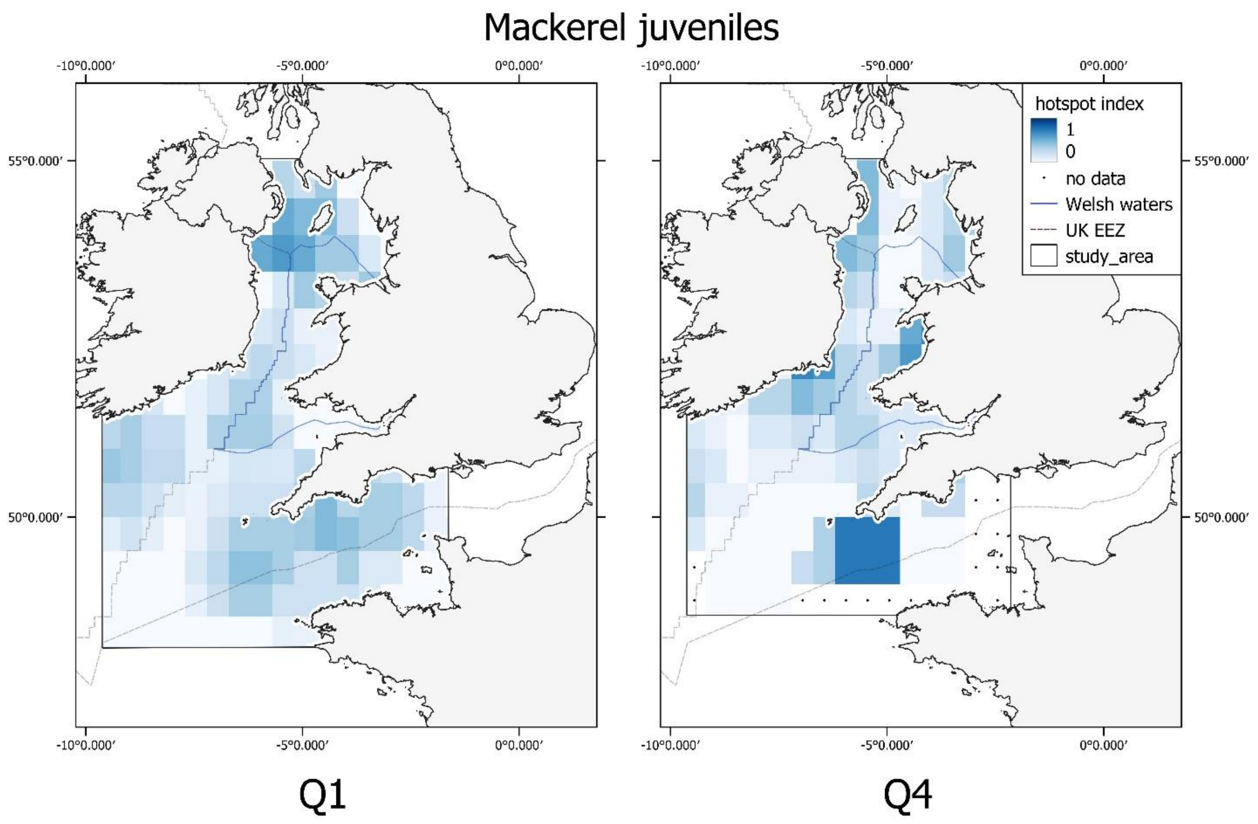

Figure 16 - Hotspot maps of juvenile mackerel (*Scomber scombrus)* in Welsh and surrounding waters in Quarter 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.7.3.Spawning area

The main spawning area for western mackerel is off the shelf edge west of Ireland and takes place during late spring. However, further spawning activity has been reported in the Celtic Sea (particularly off the Cornish Peninsula) and in the Irish Sea (Wallace and Pleasants, 1972; Ellis et al., 2012). The adult hotspot maps therefore do not necessarily represent spawning areas. Mackerel adult distribution was similar that of the juveniles: distributed over almost the entire study area in Quarter 1 albeit with low values of hotspot index except for an area in the western English Channel around Eddystone Bay and in the northern Irish Sea. In Quarter 4 the English coastal waters of the western English Channel was the main hotspot areas (Figure 17). The lack of areas with high hotspot index is likely due to spatial variability in its annual occurrence in bottom trawl catches, due to its migratory and schooling behaviour. The distribution of adult mackerel during both Quarters may be representative of overwintering areas.

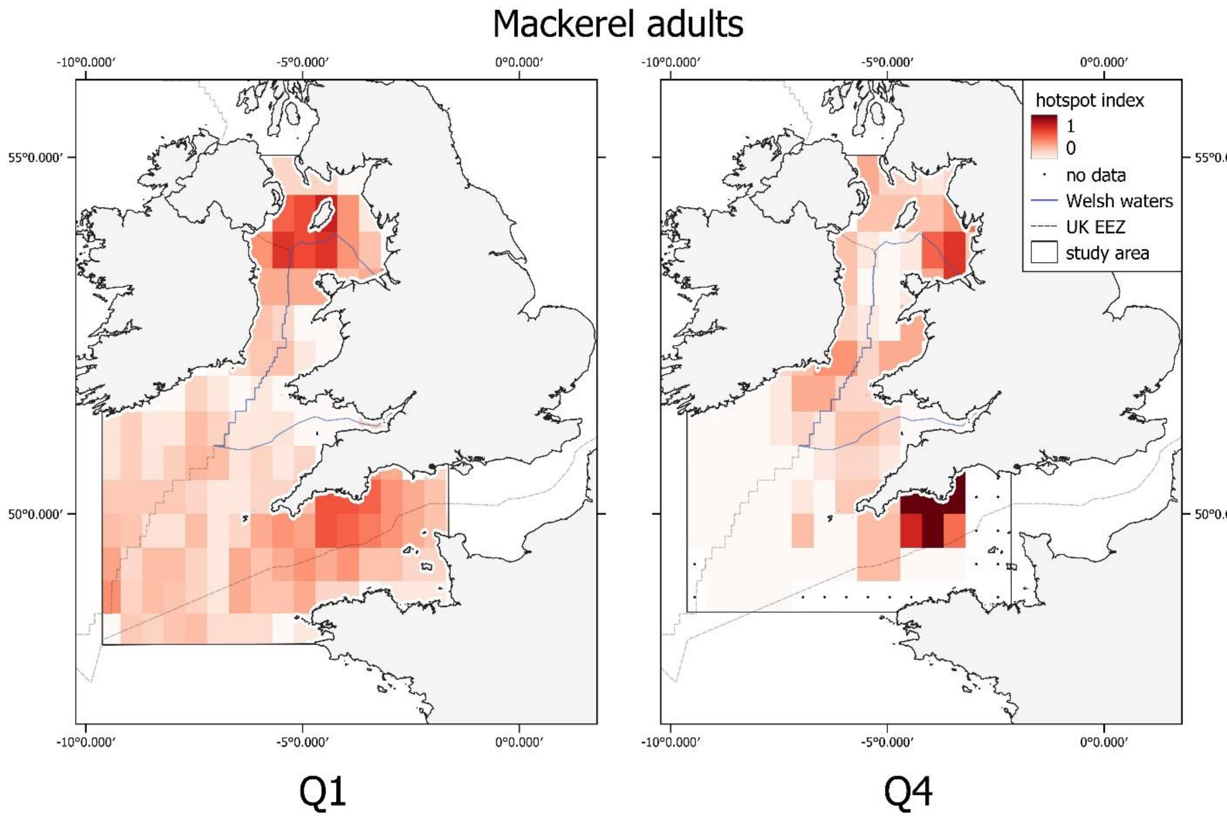

Figure 17 - Hotspot maps of adult mackerel (*Scomber scombrus*) in Welsh and surrounding waters in Quarters 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.7.4.Gaps

Due to its wide distribution and significant commercial importance, mackerel is one of best studied pelagic fish. However, detailed information about the study area is limited. The ecological drivers for some of mackerel's historic changes in migratory behaviour are also poorly understood.

4.8. Garfish *Belone belone*

4.8.1. Ecology, distribution, status

Garfish (max length 104 cm) is an epipelagic migratory species, widely distributed in the northeast Atlantic Ocean. Information on its ecology and distribution is very limited. It is mainly found in offshore areas except during the spawning period when fish migrate into the coastal areas of the British Isles and southern North Sea. Garfish spawn during May and June in seagrass beds and their eggs have long sticky filaments that adhere to seagrass blades. The juveniles stay in shallower waters until they reach sexual maturity (Langmead, 2008).

Garfish are opportunistic feeders and their diet includes a variety of zooplankton prey and fish (Dorman, 1988). Garfish are an important prey for a range of top predators including northern gannet (Scales et al., 2014), bottlenose dolphin (Ingram and Rogan 2002) and bluefin tuna. Their presence in shallow coastal waters during the summer makes garfish an accessible prey for breeding seabirds, although observations of this are limited.

Management. There is no significant directed fishery for garfish, although it is often caught as bycatch, and there is no management plan. There is no information on the structure or size of the population.

4.8.2. Garfish distribution area

Because of its epipelagic habitat, none of the survey gears used in this study were appropriate to provide any quantitative information on garfish and available catches of this species were very sparse. For this reason, the data were not separated into juveniles and adults. Previous efforts to explore the survey catches of this species found no records during the early part of the year (Heessen et al., 2015) and data on the two Quarters were therefore presented separately. Based on this limited information garfish was found primarily around the French coast of the western English Channel and in some offshore areas of the northern Celtic Sea during Quarter 1. In Quarter 4 garfish were more widely distributed with some more persistent records from the Bristol Channel and in the central Irish Sea (Figure 18).

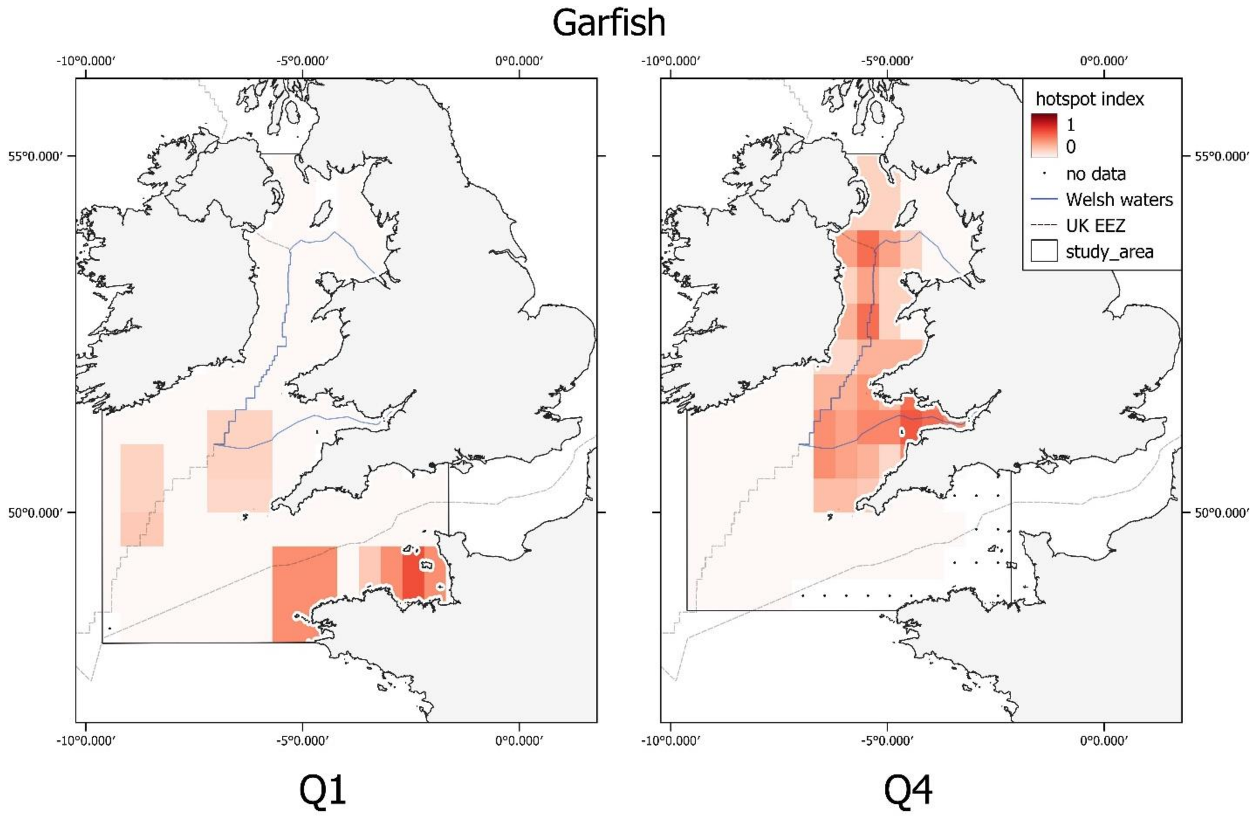

Figure 18 - Hotspot maps of garfish (*Belone belone*) distribution in Welsh and surrounding waters in Quarter 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.8.3. Gaps

Information about garfish distribution in the study area is sparse and the stock status, spawning dynamics and environmental drivers are currently unknown. Garfish are not reliably sampled by any existing surveys.

4.9. Poor cod *Trisopterus minutus*

4.9.1. Ecology, distribution, status

Poor cod is a relatively small gadoid species (max length 26 cm) that is widely distributed in the eastern Atlantic and Mediterranean Sea. It is bentho-pelagic and is usually found at depths between 10 and 300 m; in the study area it favours waters deeper than 70 m where it aggregates in schools over muddy and sandy bottoms and in mid-water (Heessen et al., 2015).

Poor cod is short-lived and maturity may be reached at 2 years of age. The spawning season spans from February to March in the English Channel (Cohen et al., 1990). There is limited information on the locations of spawning and nursery areas, although the species is widespread and abundant in the study area (Heessen et al., 2015).

Poor cod is an opportunistic predator, feeding on crustaceans, polychaetes and small demersal fish. Its role as prey to other predators is unknown; due its preference for deeper water it may not represent an important prey for seabirds. A similar gadoid species in the North Sea, Norway pout (*Trisopterus esmarkii*), is a key prey for several predatory fish species as well as cetaceans (Engelhard et al., 2013).

Management. Poor cod is not targeted by any fishery in the area although it is often caught as by-catch, presumably due to its wide distribution and aggregative behaviour. The status and structure of the population are unknown.

4.9.2. Nursery area

Distribution of poor cod juveniles was similar in both Quarters with large hotspots mainly located in the western English Channel, in the southern Irish Sea and around the Isle of Man (Figure 19).

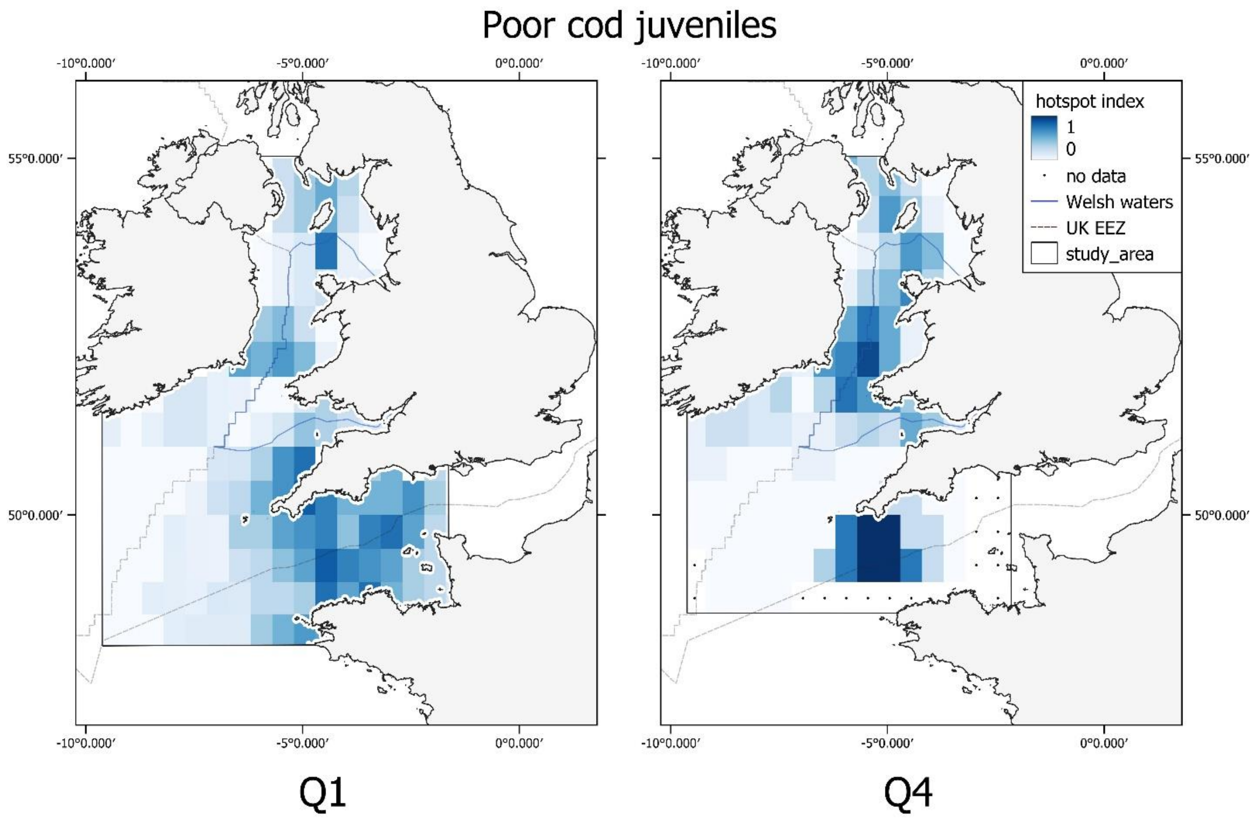

Figure 19 - Hotspot maps of juvenile poor cod (*Trisopterus minutus*) in Welsh and surrounding waters in Quarter 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.9.3. Spawning area

Quarter 1 coincided with the known spawning period in the study area (February-March) and the adult poor cod distribution may therefore be representative of the spawning areas. No spawning areas have previously been identified so this could not be confirmed. Poor cod adults were widespread in that period with the main hotspots in the western English Channel and in the northern Irish Sea. In Quarter 4, the adults were most consistently found in the central Irish Sea, including off Anglesey, off the south coast of Ireland and the transition area between the Celtic Sea and western English Channel (Figure 20).

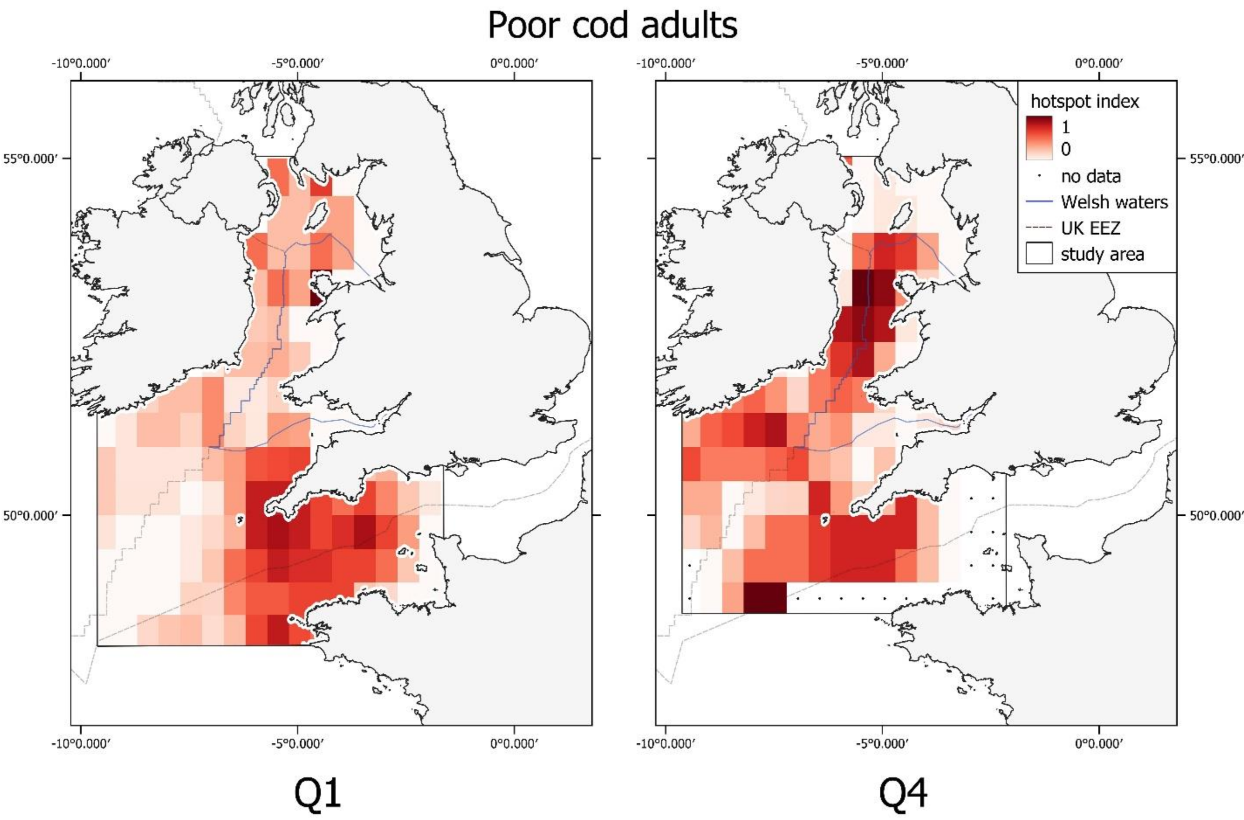

Figure 20 - Hotspot maps of adult poor cod (*Trisopterus minutus*) in Welsh and surrounding waters in Quarter 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.9.4. Gaps

No stock assessment exists for poor cod, most likely because there is no targeted fishery. Demersal trawl surveys appear to effectively capture its distribution and could provide the basis for a biomass trend. However, this would require a better understanding of the population structure in the area.

4.10. Whiting *Merlangius merlangus*

4.10.1. Ecology, distribution, status

Whiting is a medium sized (max length of 70 cm) bentho-pelagic fish belonging to the Gadidae family. It is widely distributed in the Northeast Atlantic from the northern coast of

Portugal to Iceland and the south-western Barents Sea and is also present in the Mediterranean and Black Sea. Whiting depth range goes from 10 to 200 m but it is usually found at depths of 30-100 m. Immature whiting are more likely to be found close inshore (5-30 m), including in estuaries (Ellis et al., 2012). They favour a range of seabed substrates, including mud and gravel, but also sand and rock (Whitehead et al., 1986).

Whiting is a fast-growing species reaching sexual maturity by their second year. They are batch spawners and have a high fecundity compared to other gadoids. The long spawning season extends from January to September with a spawning peak around April-May in Irish and British waters. Previous spawning areas had been reported from most coastal areas in the study area (Coull et al., 1998), with the exception of Cardigan Bay, although subsequent egg surveys suggested spawning extending further offshore than first thought (Ellis et al., 2012).

Young whiting feed on zooplankton prey, targeting larger crustaceans and juvenile fish as they grow larger and reach pelagic stage. Older whiting are active predators feeding both near the seabed and up in the water column targeting a range of prey including fish (Hislop et al., 1991). Whiting is a significant predator of forage fish in the North Sea, including sandeels, herring and sprat (Engelhard et al., 2008).

Whiting are taken by predators, particularly during juvenile stages when residing in estuarine and coastal habitats. However, also larger specimens may be predated on, including by seabirds, as whiting are not exclusive demersal and can be found high up in the water column.

Management. Genetic studies have highlighted that whiting in the North Sea is composed of several population units, while whiting in the waters west of the British Isles can be considered as a single metapopulation (Charrier et al., 2007). In the study area, two management units have been considered for the assessment: one in the southern Celtic Sea and western English Channel (division 7b-c, 7 e-k) and the other in the Irish Sea (7a). In both areas, in recent years there has been a decline in the recruitment index and the Spawning Stock Biomass (SSB) (ICES, 2020b).

4.10.2.Nursery area

Juvenile whiting hotspots in Quarter 1 were mainly located in the Bristol Channel, Liverpool Bay and Lyme Bay (western English Channel). In Quarter 4 juveniles were mainly distributed in the Bristol Channel and inshore along both the eastern and particularly the western coast of the northern Irish Sea (Figure 21). Coastal waters of the northern Irish Sea have previously been identified as the most important whiting nursery areas, while other parts of the study area were considered of lower importance (Coull et al., 1998, Ellis et al., 2012). It appears the Bristol Channel (Q1) and the waters of St David’s Head are also important, based on the results of this study.

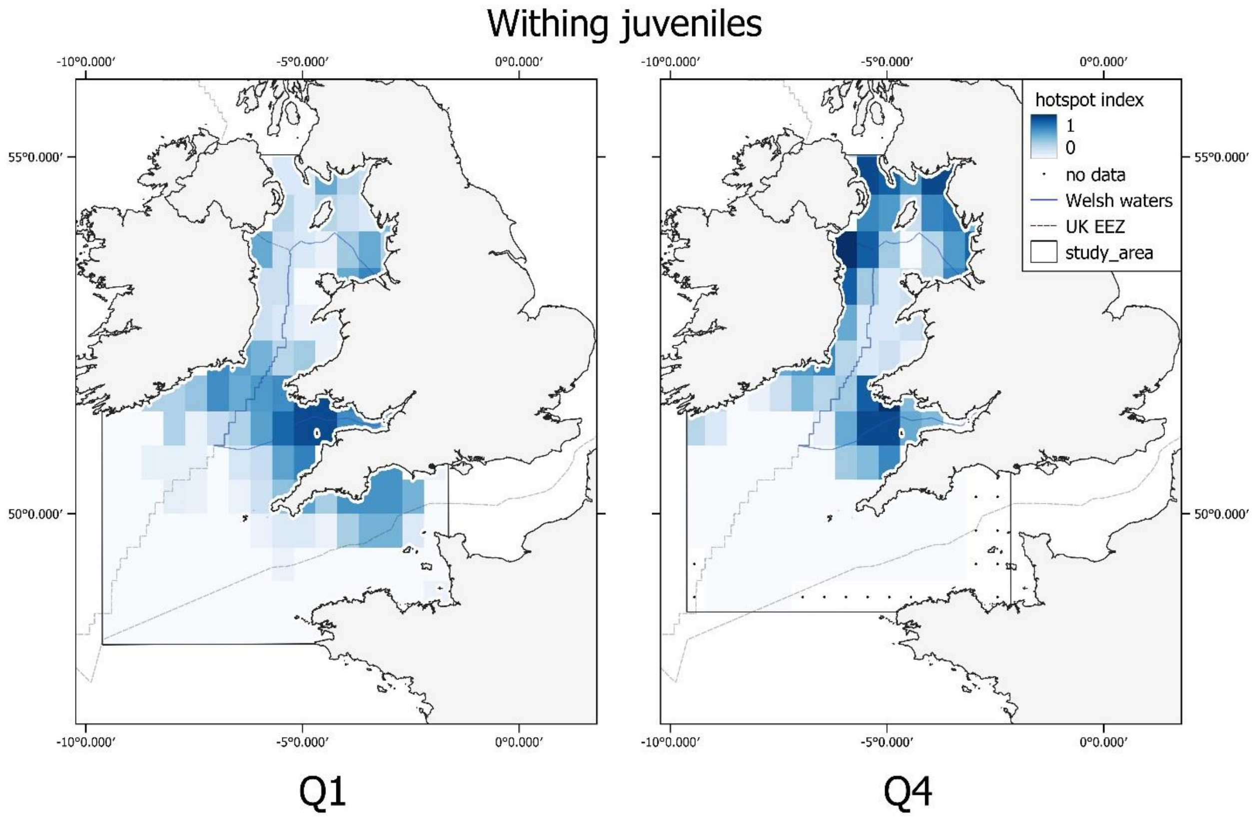

Figure 21 - Hotspot maps of juvenile whiting (*Merlangius merlangus*) in Welsh and surrounding waters in Quarter 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.10.3. Spawning area

Although peak spawning is in the summer, the spawning season starts in January and the Quarter 1 map were therefore likely to be representative of the spawning areas. In that period, whiting was widespread in waters less than 100 m with higher persistency around the Cornish Peninsula, into the Bristol Channel, the southwest coast of Ireland and around the Isle of Mann (Figure 22). Adult hotspot maps also confirmed possible spawning activity along the southwest coast of Cornwall (Coull et al., 1998). Results of this study support previous observations (Ellis et al., 2012) that whiting spawning may be more widespread than previously thought (Coull et al., 1998). In Quarter 4 adult whiting preferred the central and southern Irish Sea, Liverpool Bay and northern Celtic Sea (Figure 22).

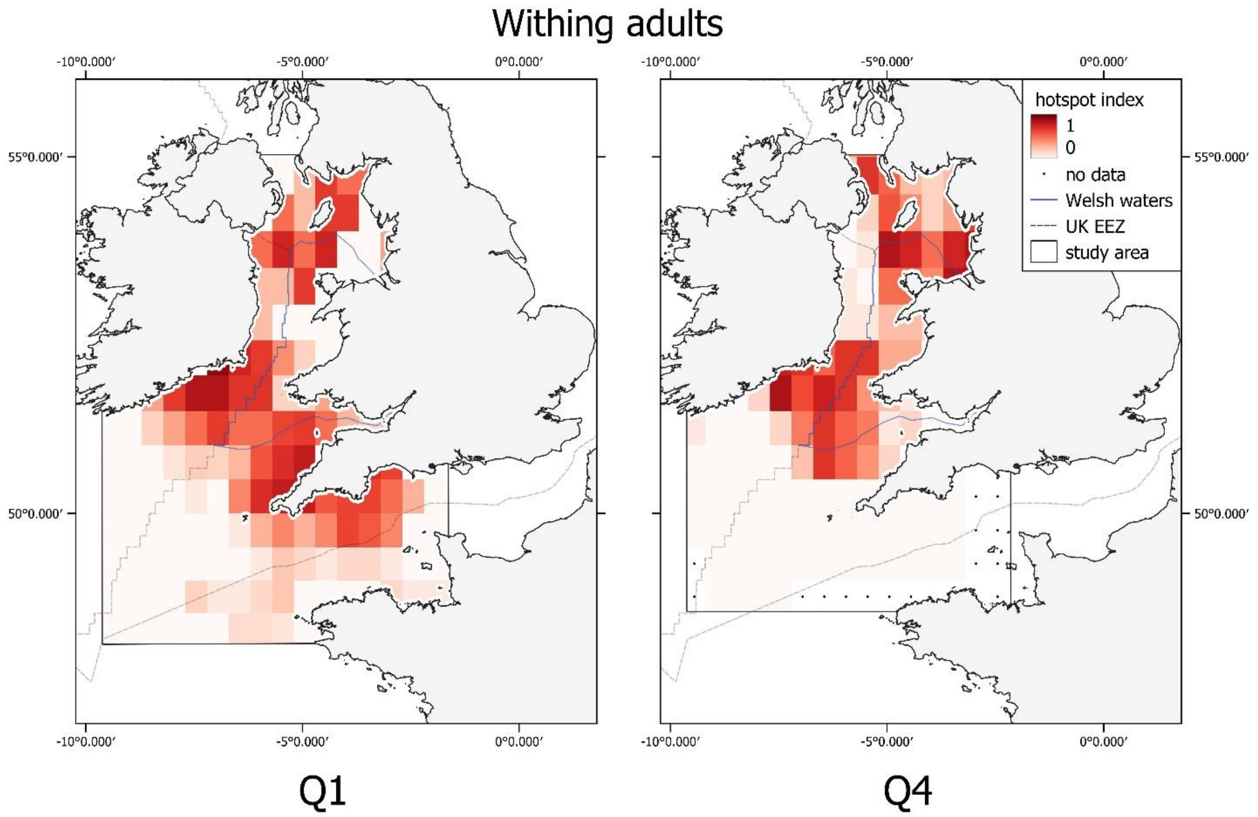

Figure 22 - Hotspot maps of adult whiting (*Merlangius merlangus*) in Welsh and surrounding waters in Quarters 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.10.4. Gaps

Demersal survey data provided good coverage of this species with the exception of the south of the study area in Quarter 4. The causes behind the recently observed decline in both management units are not known although fishing mortality, mainly as bycatch in the *Nephrops* fishery, is likely to be a contributory factor.

4.11. Cod *Gadus morhua*

4.11.1. Ecology, distribution, status

Atlantic cod is a large (max length 200 cm) commercially important fish species belonging to the Gadidae family and is one of the most extensively studied fish species, although information from within the study area is relatively limited. It is widely distributed in the northern Atlantic. In the eastern Atlantic the distribution range extends from the northern Bay of Biscay (off Brittany) up to the Barents Sea and it is mostly found within continental shelf areas in depths of less than 200 m (Coen et al., 1990).

Cod appear to be tolerant to a wide temperature range (-1.5 to 19°C) although it is narrower (1-8 °C) during spawning (Righton et al., 2010). While some cod mature in their second year, it is not until age 6 that all cod are sexually mature (Heessen et al., 2015). The spawning season varies across the distribution range. In the study area, the spawning period runs approximately from January to May with spawning peaks in March – April. The main known spawning grounds for cod in the Celtic Sea and western English Channel are located around the Bristol Channel throughout the area west of 4°30′W, in the western Channel and in the southeast Irish coast. In the Irish sea spawning occurs on both the eastern and western coastal areas (ICES, 2005).

Cod smaller than 5 cm feed predominantly on zooplankton after which they switch to larval fish (Rob and Hislop, 1980). Once juveniles have settled on the bottom, diet is dominated by crustaceans (Heessen et al., 2015) but as they grow, fish, including forage fish are an increasingly important part of the diet.

While large adult cod may be taken by seals and other large predators, it is predominantly the earlier life stages of cod that are likely to provide important prey for predators. Although limited information is available about their behaviour in the study area, in the North Sea during pelagic larval and post-larval stages cod are found in higher densities near frontal zones (Munk et al., 1999, 2002). Young cod also tend to be found in more shallow waters (< 20 m). Both habitats make them more available to avian predators.

Management. Around the British Isles, cod are managed as four main management units, two of which are in the study area: the Celtic Sea stock, and the Irish Sea stock. Cod has been subject to heavy exploitation for many decades at the end of the last century (Pope & Macer 1996; Cook, Sinclair & Stefansson 1997) resulting in very low level of recruitment and biomass in the recent years (ICES, 2021d-e).

4.11.2.Nursery area

The main nursery area for cod was the northern Irish Sea, both in Quarter 1 and Quarter 4. This closely matches previous reports (Coull et al., 1998, Ellis et al, 2012), although the hotspot presented here was slight further north. In Quarter 1 the southwest coast of Ireland was also important while in Quarter 4 juveniles preferred primarily the coastal areas of the western Irish Sea and the St Georges Channel (Figure 23). Previous records identified the east coast of the Irish Sea as a hotspot which was not found in this study. Also, the Bristol Channel is demonstrated to be a hotspot for juvenile cod using data from 2008, which has not previously been reported.

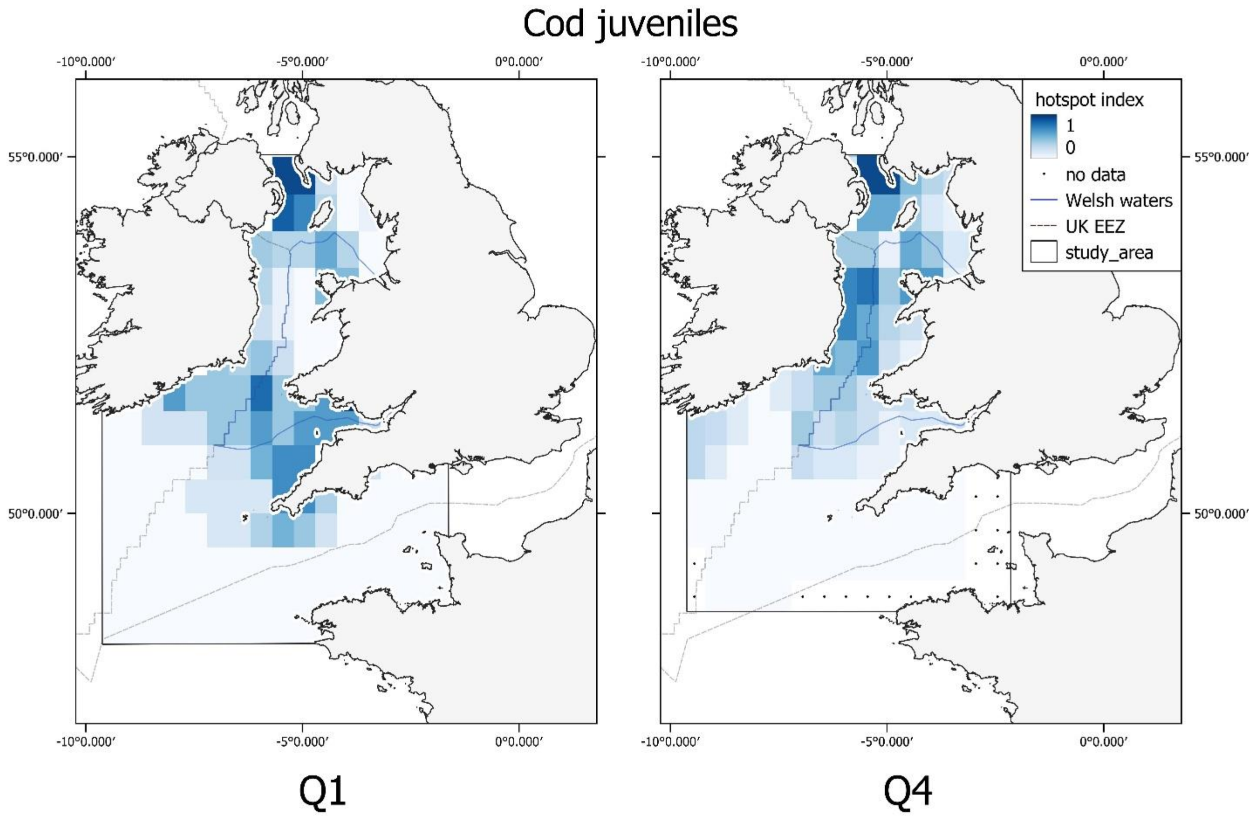

Figure 23 - Hotspot maps of juvenile cod (*Gadus morhua*) in Welsh and surrounding waters in Quarters 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.11.3. Spawning area

Data from Quarter 1 overlapped with the spawning period and the adult hotspot map was therefore considered representative of the spawning areas. The most important spawning hotspot was a large area between the southwest coast of Ireland and the Bristol Channel (Figure 24), which is larger than the previously reported localised spawning areas along the southwestern Irish coast and north of the Cornish Peninsula (Coull et al., 1998). It is not clear whether the expanded area indicates an expansion of cod spawning habitat or whether using adult fish rather than more reliable egg or larvae data has introduced inaccuracies; as cod mature at variable ages, catch data from immature cod will have been included in the maps. The cod spawning areas in the Irish Sea were mainly around the Isle of Man, which closely matched previous reports (Coull et al, 1998). Adults in Quarter 4 tended to be widely distributed along the whole Irish Sea and central Celtic Sea with highest values of hotspot index around the deeper waters of the central Irish Sea (Figure 24).

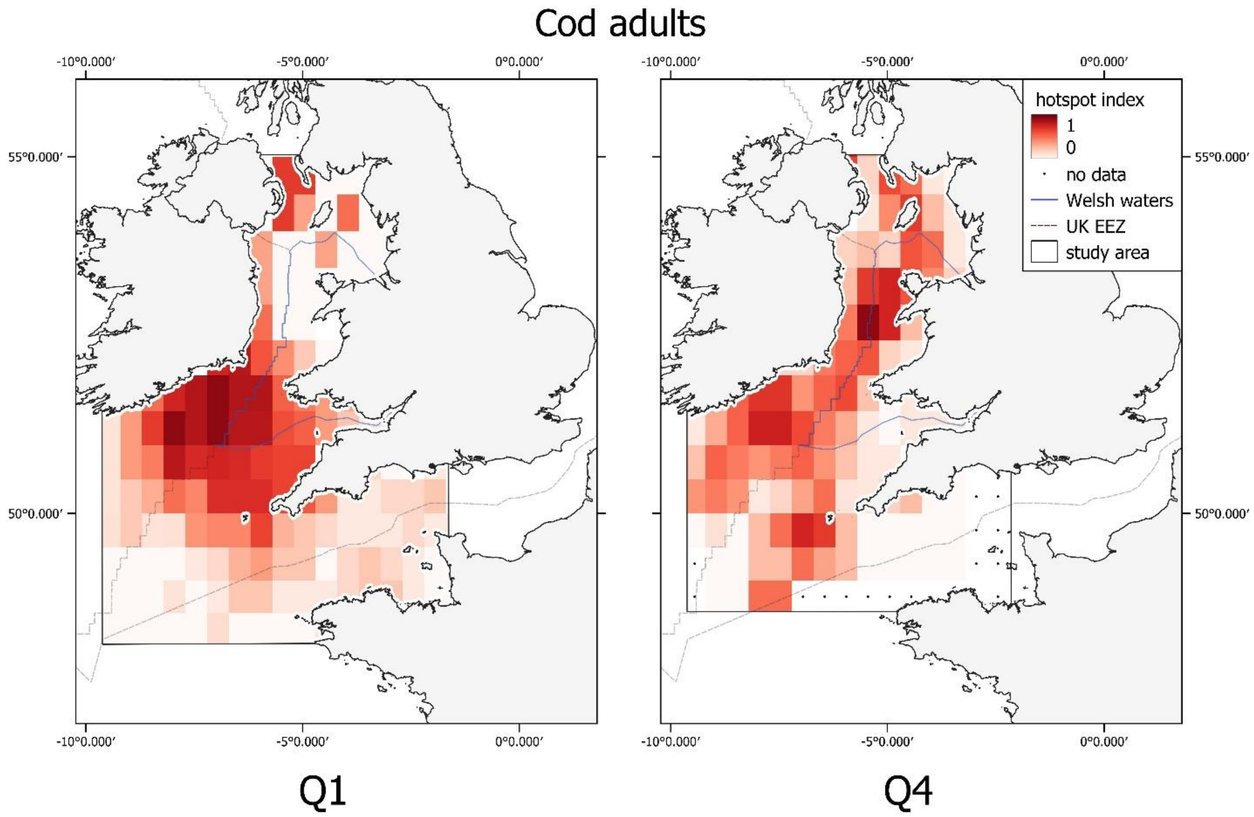

Figure 24 - Hotspot maps of adult cod (*Gadus morhua*) in Welsh and surrounding waters in Quarters 1 (February-April) and 4 (September-December). Please note that grid-cells for which no data were available in a particular Quarter are left blank with a point in the centre.

4.11.4.Gaps

Cod is relatively well studied throughout its range and is captured effectively in the demersal surveys used in this study. The English Channel includes some of the southern-most known spawning areas of this species and the contribution of these sites to the local stock is still unknown. It is likely that warming temperatures in this area adversely impact the spawning conditions and local abundance of this boreal species.

5. Discussion and gaps

The details presented in this study provided an updated and, for several species, novel insight into the adult and juvenile forage fish hotspot areas across the shelf waters of the Irish and Celtic Seas and the western English Channel. The methods applied allowed data from different surveys to be merged to provide large scale coverage during two Quarters, and identified persistent areas of their presence (in relatively high numbers over a period of time), an important feature of both nursery and spawning areas.

For most species, the juvenile hotspot maps provided a useful proxy for nursery areas, as results were similar to those in previous studies (Coull et al., 1998; Ellis et al., 2012). There are caveats to using a length threshold to select juvenile fish, as some older fish may have been included; using maturity and age information would be more accurate but these are not routinely collected for small pelagic fish during the surveys used. Another important limitation of this study is that only data from stations deeper than 20 m were available. Particularly juvenile life stages of many species reside in inshore and estuarine habitats, which are known feeding areas for many breeding seabirds. Data from these inshore areas have been collected for some isolated locations and were explored for inclusion in this study (EA TraC NFPD). However, the lack of specific spatial details, as well as the range of gears (e.g. gill net, beach seine) used during these sampling efforts, and lack of effort information, meant they could not practically be included in the maps. Targeted surveying of inshore areas with suitable gear around key seabird nesting areas would provide relevant information on the composition and changes in local prey availability.

Sardine was the only species for which egg data were available, providing the most accurate indication of the autumn spawning area in the Celtic Sea and western Channel. No ichthyoplankton data were available for the other species and adult distribution during peak spawning periods was used as a proxy. For some species no information was available for peak spawning time or areas (anchovy, mackerel and horse mackerel). Both mackerel and horse mackerel spawning areas are sampled triennially (ICES, 2021g) although this excludes the shelf seas where some spawning occurs. For anchovy, current knowledge in the study area is very limited, most likely as it is a relative newcomer in particularly the Irish Sea. The presence of different life stages in most years suggests that local spawning may occur and targeted sampling of ichthyoplankton in coastal areas with suitable spawning habitat throughout the summer would confirm this. Anchovy is considered a climate change “winner” and the observed local increase is likely to continue.

Most surveys included were designed to target demersal fish and the juvenile and adult maps for the gadoid species (poor cod, whiting and cod), were therefore thought to be representative for nursery and spawning areas respectively. The apparent broader range of adult fish compared to previously reported spawning areas (Coull et al., 1998, Ellis et al 2012) suggested that ichthyoplankton surveys would be needed to identify the spawning range in more detail. In Quarter 4 survey coverage in the south of the study area was limited and should be improved, particularly for cod for which the area is the southern boundary of its distribution.

While not designed to capture small pelagic fish, beam trawl surveys provided some indication of hotspots, although demersal otter trawl surveys provided most of the information with good results. Fisheries acoustic technology used during pelagic surveys are the most accurate pelagic sampling method however. Dedicated pelagic surveys are conducted in the study area and are designed to coincide with peak spawning periods of the target species. They also collect information on age and maturity and could therefore provide a more suitable basis (compared to the demersal surveys used here) for both the nursey and spawning hotspot maps of the small pelagic fish species. Only data from one such survey could be included (PELTIC). Others (e.g. Celtic Sea Herring Acoustic Survey and Irish Sea Herring Survey, ICES, 2021f) could not, because the acoustic data were not resolved at species level. If this is addressed, they should be included in future studies on small pelagic fish. Spatial gaps would remain, as coverage is limited in Welsh waters, despite the expansion of the PELTIC survey into Cardigan Bay in Quarter 4. The St George's Channel is poorly sampled, and Cardigan Bay is also not surveyed in Quarter 1, which is an important period for sprat spawning.

Many herring spawning grounds have been mapped previously although their occupancy by spawning herring may fluctuate between years, depending on the health of the stock (Schmidt et al., 2009). As herring deposit their eggs on substrate, only larval surveys, possibly combined with high resolution geological surveys of seabed substrate data, would provide insight into the spawning activity. Particularly in Welsh waters gaps remain about the presence of herring spawning grounds, including several spring spawning populations.

Garfish was the most data-limited species in the survey area, largely due to its epipelagic habitat which is not sampled consistently by any of the existing surveys. Inshore netting surveys, and ichthyoplankton data could improve understanding of this species' nursery and spawning areas.

While the distribution of sandeel nursery and spawning areas matched those previously reported (Ellis et al., 2012), information about this group of species in the study area remained. Most seabirds and marine mammals will feed on schooling sandeels (in the water column) and no information about their pelagic distribution was available for the study area. None of the surveys used in this study were designed to monitor sandeels. However, ground-contact by bottom and beam trawls appeared to have sampled sandeels at their overwintering grounds, which are likely to also be representative for other seasons. Given the presence of several sandeel species in the area, with different habitats and phenology, accurate identification to species level during surveys could improve the ecological information. Dedicated multi-disciplinary sandeel surveys are needed to further the study of ecological drivers of sandeels in the study area, and should include monitoring of sandeel condition (fat content, weight and length at age).

6. Acknowledgement

This work was conducted for RSPB Cymru and was funded by Natural Resources Wales. We are grateful to scientists and crew onboard research vessels, for the collection of fish data. Thanks are due also to Georg Engelhard, Richard Nash, Jim Ellis and John Pinnegar for valuable discussions.

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8. Appendix 1

Map of the study area including delineation of ICES areas and most commonly referred to geographic areas.