Evidence on the distribution and population structure of Atlantic cod (*Gadus morhua*) in Welsh waters

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Author Name: Stacy, R., Mele, I., Vella, E., Pearce, J., and Davie, S.

Author Affiliation: MRAG Ltd

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Crynodeb gweithredol

Mae yna amrywiaeth eang o gynefinoedd gwely'r môr a'r golofn ddŵr yn nyfroedd Cymru, sy'n cynnal nifer o rywogaethau o bysgod y môr sydd o werth cadwraeth, ecolegol, masnachol a hamdden. I fwydo i mewn i'n cyngor ar gadwraeth natur, mae Cyfoeth Naturiol Cymru (CNC) yn ceisio defnyddio'r dystiolaeth orau sydd ar gael o ran ble mae'r rhywogaethau hyn o bysgod i'w cael, lleoliadau pwysig ar gyfer y rhywogaethau, a sut mae'r rhywogaethau'n defnyddio dyfroedd Cymru ar hyd eu cylchoedd bywyd.

Yn yr adroddiad hwn, caiff y dystiolaeth sydd ar gael ar ddosbarthiad a strwythur poblogaeth y penfras (*Gadus morhua*) yn nyfroedd Cymru ei hadolygu a'i chyfosod. Mae'r adroddiad yn cynnig sylfaen dystiolaeth wedi'i choladu ar gyfer y rhywogaeth hon at ddefnydd CNC, a hefyd yn nodi bylchau allweddol yn y dystiolaeth.

Dewiswyd y rhywogaeth hon fel rhywogaeth flaenoriaeth gychwynnol ar sail ein hanghenion o ran cyngor cadwraeth, ac oherwydd ei bod wedi'i rhestru o dan Adran 7 o Ddeddf yr Amgylchedd (Cymru) 2016 Rhestr Adran 7: rhywogaethau a chynefinoedd o bwysigrwydd pennaf yng Nghymru | LLYW.CYMRU. Gallai'r dystiolaeth sydd yn yr adroddiad hwn fod yn ddefnyddiol hefyd i sefydliadau eraill wrth iddynt reoli penfras yng Nghymru, neu i asesu'r effeithiau ar y rhywogaeth.

Mae'r adroddiad yn cyfuno adolygiad systematig o'r llenyddiaeth academaidd ac adroddiadau technegol, a chefnogir hynny gan waith dadansoddi penodol o setiau data cyfredol o arolygon sy'n gysylltiedig a heb fod yn gysylltiedig â physgodfeydd, ynghyd â thystiolaeth anecdotaidd lle bo ar gael. Mae'r setiau data a ddadansoddwyd yn cynnwys rhaglenni arolygu rhyngwladol sy'n dal i fynd rhagddynt, a gaiff eu cydlynu gan y Cyngor Rhyngwladol ar gyfer Archwilio'r Môr (ICES), ynghyd â rhaglenni arolygu cenedlaethol a gaiff eu cydlynu gan Ganolfan Gwyddor yr Amgylchedd, Pysgodfeydd a Dyframaethu (Cefas) ac CNC. Dadansoddwyd setiau data hanesyddol hefyd.

Mae'r adolygiad yn canolbwyntio ar ddyfroedd Cymru a'r ardaloedd cyfagos ym Môr Iwerddon, y Môr Celtaidd a Môr Hafren, gan gydnabod pwysigrwydd cysylltedd rhanbarthol. Mae'r dystiolaeth wedi'i dadansoddi a'i chyflwyno yn ôl camau bywyd allweddol a phrosesau allweddol yn y cylch bywyd (wyau, larfâu, pysgod ifanc, meithrinfeydd, oedolion a silio) er mwyn gallu cymharu rhwng camau bywyd a rhywogaethau.

Yn ystod y gwaith adolygu, sylwyd ar batrwm o ran cysylltedd rhwng camau bywyd, gyda meithrinfeydd yn nyfroedd Cymru yn cyfrannu at boblogaethau o oedolion yn y rhanbarth yn ehangach. Nodwyd bod dyfroedd ar lannau arfordir gogledd Cymru ac o amgylch Ynys Môn yn ardaloedd pwysig i larfâu a phenfreision ifanc. Mae baeau mewndirol, aberoedd a chynefinoedd cysgodol ar yr arfordir yn chwarae rhan allweddol fel meithrinfeydd, gan gefnogi penfreision ifanc o amgylch arfordir Cymru, gan gynnwys Môr Hafren ac, yn arbennig, Bae Caerfyrddin ac aber afon Hafren. Ar y cyfan, mae llai o ddata ar gael a lefel is o doreithrwydd wedi'i chofnodi ar gyfer y rhywogaethau hyn yn ystod camau bywyd y pysgod ifanc a'r oedolion ym Mae Ceredigion.

Ar y cyfan, mae unigolion llawndwf yn llai cyffredin yn nyfroedd glannau Cymru, ac maent wedi'u dosbarthu'n ehangach ac yn fwy dwys ymhellach allan o'r lan yn nyfroedd Cymru a'r tu allan i ddyfroedd Cymru ym Môr Iwerddon a'r Môr Celtaidd. Lle bo'r oedolion yn bresennol yn nyfroedd glannau Cymru, mae hynny'n aml ar adegau penodol, a gall fod yn gysylltiedig â symudiadau tua'r arfordir er mwyn silio, sy'n adlewyrchu cysylltedd ehangach y boblogaeth.

Cafwyd bod cwmpas ac ansawdd y dystiolaeth a nodwyd yn ystod yr adolygiad yn amrywio yn ôl ardal. Mae Môr Iwerddon (gan gynnwys Bae Lerpwl) yn gymharol gyfoethog o ran data ar gyfer y penfras, ac mae nifer o setiau data yn dangos patrymau cyson mewn llawer o achosion. Ar y llaw arall, mae'r wybodaeth ar gyfer Bae Ceredigion, Môr Hafren a'r Môr Celtaidd yn fwy cyfyngedig. At hynny, mae llai o gynefinoedd bas, ar y glannau, neu sy'n anodd eu samplu yn y data ar y cyfan. Mae cwmpas y data o ran cyfnodau amser yn amrywio, gyda llawer o arolygon blynyddol ond yn cael eu cynnal yn ystod tymor penodol bob blwyddyn, sy'n cyfyngu ar ein dealltwriaeth o amrywioldeb ar draws tymhorau a blynyddoedd, a phrin yw'r arolygon hynny sy'n cynnig cyfres amser lawn a pharhaus o ddata. Yn olaf, mae yna ansicrwydd ynghylch union leoliad a chwmpas mannau silio, sy'n adlewyrchu'r gwahaniaeth yn y ffynonellau data a'r dulliau.

At ei gilydd, mae'r adroddiad yn cynnig tystiolaeth o ardaloedd pwysig yn nyfroedd Cymru ar gyfer y penfras, yn arbennig ar gyfer camau bywyd cynnar. Mae'r adroddiad wedi amlygu bylchau clir yn y dystiolaeth a'r data ar gyfer dyfroedd Cymru mewn cysylltiad â'r rhywogaeth hon, gan gynnwys yr ardaloedd a'r tymhorau y mae diffyg samplau ar eu cyfer. Er mwyn llenwi'r bylchau hyn, byddai angen gwaith monitro penodol, cyson a hirdymor, a allai yna gael ei integreiddio â gwybodaeth amgylcheddol ehangach.

Executive summary

Welsh waters have a diverse range of seabed and water column habitats that support many marine fish species of conservation, ecological, commercial and recreational value. To inform our nature conservation advice, Natural Resources Wales (NRW) aims to use the best-available evidence on where these fish species occur, where important areas for the species are located and how the species use Welsh waters across their life cycles .

This report has reviewed and synthesised the available evidence on the distribution and population structure of Atlantic cod (*Gadus morhua*) within Welsh waters. The report provides a collated evidence base for this species for use by NRW, and also identifies key evidence gaps.

This species was selected as initial priority species based on our conservation advice needs and as it is listed under Section 7 of the Environment (Wales) Act 2016 Section 7 list: species and habitats of principal importance in Wales | GOV.WALES. The evidence contained within this report may also be useful for other organisations when managing, or assessing impacts upon, cod in Welsh waters.

The report has combined a systematic review of published academic literature and technical reports, supported by targeted analysis of existing fisheries-independent and dependent survey datasets, and anecdotal evidence where available. The survey datasets that have been analysed include ongoing international survey programmes coordinated by the International Council for the Exploration of the Sea (ICES) and national survey programmes coordinated by Centre for Environment, Fisheries and Aquaculture Science (Cefas) and NRW, as well as historical datasets.

The review has focused on Welsh waters and adjacent areas of the Irish Sea, Celtic Sea, and Bristol Channel, recognising the importance of regional connectivity. The evidence has been analysed and presented by key life stages and life cycle processes (eggs, larvae, juveniles, nursery grounds, adults and spawning) to allow comparison between life stages and species.

A pattern of connectivity between life stages has been identified during the review, with nursery areas in Welsh waters contributing to adult populations at wider regional scales. Inshore waters off the North Wales coast and around Anglesey are identified as areas of high importance for larval and juvenile cod. Inshore bays, estuaries and sheltered coastal habitats play a key role as nursery areas supporting juveniles around the Welsh coast, including in the Bristol Channel and notably Carmarthen Bay and the Severn Estuary. There is generally less data available and lower recorded abundance of these species during their juvenile and adult life stages in Cardigan Bay.

Larger, mature individuals are generally less concentrated in inshore Welsh waters, being more widely distributed with higher densities occurring farther offshore in Welsh waters and outside of Welsh waters in the Irish Sea and Celtic Sea. Where adults are present in inshore Welsh waters, this is often seasonal and may include spawning-related inshore movements, reflecting broader population connectivity.

The coverage and quality of evidence identified during the review has been found to vary spatially. The Irish Sea (including Liverpool Bay) is relatively rich in data for cod, with multiple datasets showing consistent patterns in many cases. In contrast, information within Cardigan Bay, the Bristol Channel and the Celtic Sea is more limited. Shallow, inshore or difficult to sample habitats are also generally less well represented within the data. Temporal coverage of the data varies, with many annual surveys only carried out during a specific season each year which limits understanding of seasonal and interannual variability, and with few surveys providing a complete and ongoing time-series of data. Finally, there is uncertainty in the precise location and extent of spawning grounds, reflecting differences in data sources and methods.

Overall, the report provides evidence identifying important areas within Welsh waters for cod, particularly for early life stages. The report has highlighted clear gaps in evidence and data for Welsh waters for this species including in under sampled areas and seasons. To fill these gaps, consistent and long-term targeted monitoring would be necessary which could then be integrated with wider environmental information.

1 Introduction

Welsh waters encompass parts of the Irish Sea, Celtic Sea, Bristol Channel, St George's Channel and Cardigan Bay, and ICES areas 7a, 7f and 7g (Figure 1). They support a diverse assemblage of marine fish species that are integral to the functioning of marine ecosystems and the sustainability of marine fisheries. Seabed and water column habitats in Welsh waters provide a wide range of environmental conditions and support many different marine fish species of conservation, ecological and commercial value.

To inform our nature conservation advice, Natural Resources Wales (NRW) aims to use the best-available evidence on where these fish species occur, where important areas for the species are located and how the species use Welsh waters across their life cycles.

To provide a collated evidence base for use by NRW, and identify evidence gaps, this report has reviewed and synthesised the available evidence on the distribution and population structure of Atlantic cod (*Gadus morhua*) within Welsh waters.

This species is listed under Section 7 of the Environment (Wales) Act 2016 Section 7 list: species and habitats of principal importance in Wales | GOV.WALES and was selected by NRW as an initial priority species based on a combination of its conservation, ecological and commercial value, as well as relevance to current NRW conservation advice needs.

Cod has depleted populations in Welsh waters and is under pressure from multiple factors, including climate change, habitat degradation, and fishing mortality. The species fulfils an important trophic role and position in marine food webs, including as a key prey species for a range of predators such as piscivorous fish, seabird, and marine mammal species. Finally, the species is of commercial and recreational importance in fisheries in Welsh and wider UK waters.

This report presents the results of the analysis of identified literature and data sources, which have been reviewed and synthesised to present evidence on the distribution and population structure of cod in Welsh waters. The evidence has been analysed and presented for the species by key life stages and life cycle processes (eggs, larvae, juveniles, nursery grounds, adults and spawning) to allow comparison between life stages.

Welsh inshore waters have been defined in this report as fully-marine and estuarine waters within 12 nautical miles of baselines, and Welsh offshore waters have been defined in this report as all waters outside 12 nautical miles of baselines to the limit of the Welsh Zone. Both Welsh inshore and offshore waters are also shown on Figure 1.

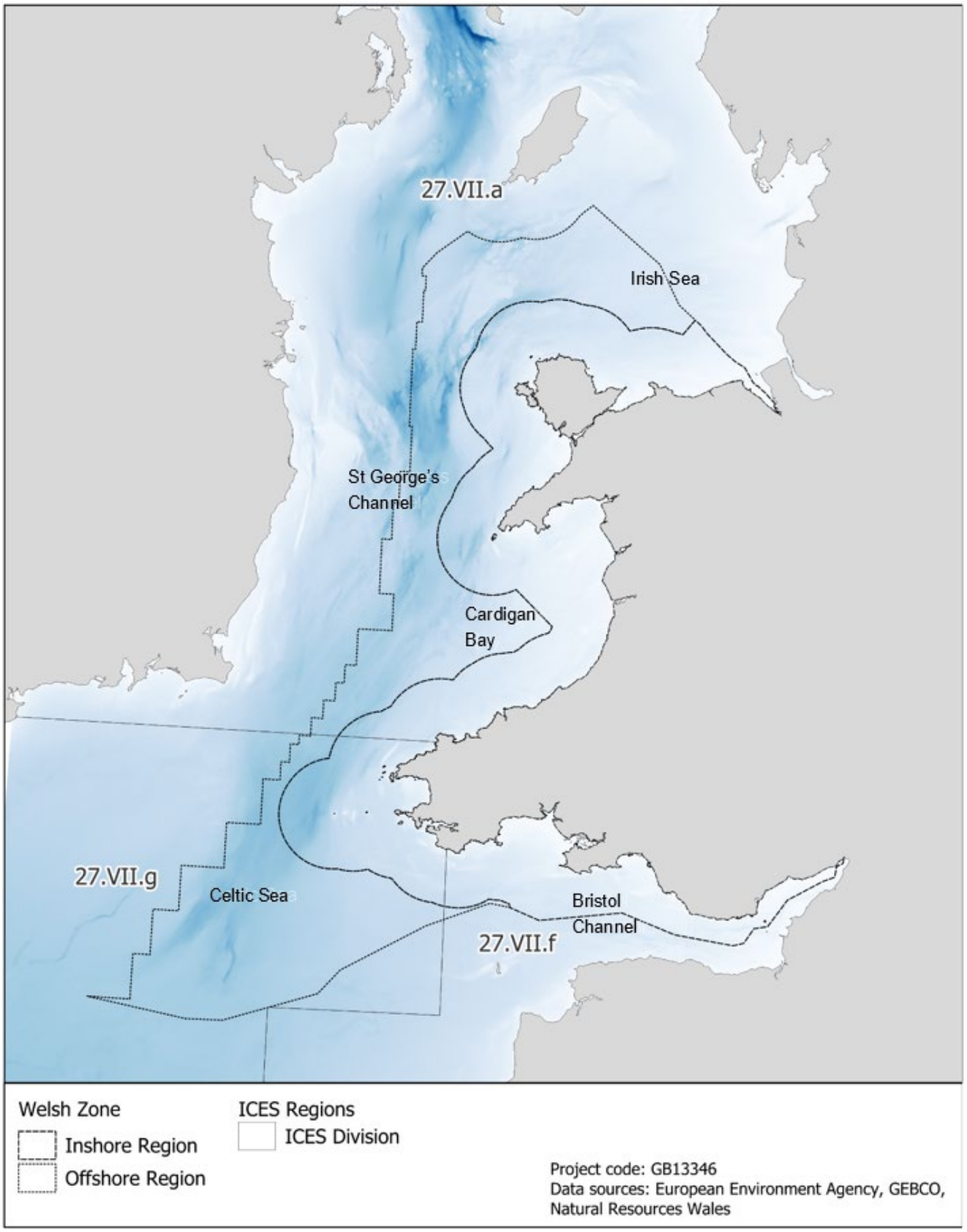


Figure 1. Map of the Welsh Zone and adjacent waters, including ICES areas 7a, f and g.

2 Evidence review methodology

2.1 Literature search

A literature review was conducted to identify published evidence sources relevant to cod in Welsh waters. All literature searches were undertaken using Google Scholar. Search strings were developed to capture key biological, ecological, behavioural, environmental, and fisheries-related themes relevant to each species. The full list of search terms used is provided in Appendix 1.

Five distinct search strings were applied for the literature search. For each search string, the first 50 search results were downloaded. Each search result was tagged according to the search string from which it was identified to retain information on search provenance.

All search results were imported into a Zotero reference library. Duplicate records were identified and removed based on title matching. Where duplicate records were identified across multiple search strings, tags were merged to ensure that papers captured by more than one search string retained all relevant search term identifiers.

Records were then screened sequentially by title and abstract to assess their relevance to the project. During screening, studies were considered relevant if they

(i) focused on populations within the assessment area (Irish and Celtic Seas recognising the importance of regional connectivity);

(ii) provided biological, ecological, behavioural, or fisheries-related information applicable to the life stages included in this study; or

(iii) addressed themes directly aligned with the project objectives (e.g. spatial distribution, habitat use and environmental drivers).

Studies lacking geographical, stock-specific, life-stage, or thematic alignment were excluded at this stage.

All search results that passed title and abstract screening were subsequently reviewed in full. Relevant information was extracted and synthesised, with findings incorporated into the report under the appropriate thematic sections. No formal meta-analysis was undertaken; instead, the review aimed to provide a structured synthesis of the available evidence to support interpretation and discussion of species distributions at various life stages.

Within the project Zotero database developed to support the literature review, references were tagged according to search origin and search strategy. References cited within the report have been provided separately in Appendix 2 with associated confidence scores based on a defined confidence assessment scoring framework.

Confidence was assessed using two criteria:

(1) type and quality of source, and

(2) applicability of the evidence to Welsh waters.

Source type and quality was categorised as either High (peer-reviewed literature or official government scientific publications), Medium (scientific grey literature), or Low (non-scientific sources such as media or blog content).

Applicability of the evidence was categorised as either High (data collected specifically within Welsh waters or at a scale explicitly including Welsh waters), Medium (data from adjacent or ecologically comparable waters), or Low (broad NE Atlantic-scale data where Welsh waters form only a small component and spatial resolution limits direct inference).

Each confidence category was assigned a numerical score (High = 5, Medium = 3, Low = 1) and scores were summed to produce an overall confidence rating of Low, Medium, or High.

2.2 Online data sources and data handling

Data on the distribution of cod in Welsh waters was identified through targeted searches of online data repositories, supplemented by information shared by NRW. Key sources included fisheries landings and recreational sea-angling data, NRW estuarine fish survey datasets, the Cefas Data Hub, Marine Scotland Directorate data, Marine Institute data, ICES data repositories (Database of Trawl Surveys (DATRAS) and egg and larvae datasets), and AquaMaps. These sources provide a mixture of fishery-dependent, and fisheries-independent data, monitoring datasets and environmental observations covering Welsh waters and adjacent areas.

ICES DATRAS data were accessed using the ICES Datras R package (ICES, 2024). Surveys intersecting Welsh waters from the database (including Beam Trawl Survey (BTS), Irish Groundfish Survey (IE-IGFS), Northern Ireland Groundfish Survey (NIGFS), Évaluation Halieutique de l'Ouest Européen (EVHOE), Scottish West Coast Groundfish Survey (SCOWCGFS), and Scottish West Coast Bottom Trawl Survey (SWC-IBTS)) were downloaded for the period 2000–2025, covering all available quarters of the year. Both haul-level and length-frequency data were retrieved for the target species. Haul positions were spatially filtered to a broad bounding box encompassing Welsh waters (longitude −8° to −2°, latitude 50° to 56°) to ensure consistency.

Length data from all datasets were used to classify individuals into juvenile and adult life stages using size thresholds reported by Campanella and van der Kooij (2021): with juveniles being classified as having a total length of ≤22 cm for cod. Additionally, data on cod <10 cm total length has also been presented to capture the distribution during very early post-settlement life stages of this species. This approach allowed for a consistent separation of life stages across datasets where length information was available.

Spatial outputs derived from data sources were summarised using simple aggregations appropriate to the structure of each dataset. Several datasets and publications report sampling periods with reference to the quarter in which the samples were taken. To ensure consistency, we use calendar Quarters throughout this report: Quarter 1 (Q1) spans January–March, Quarter 2 (Q2) April–June, Quarter 3 (Q3) July–September, and Quarter

4 (Q4) October–December. For DATRAS data, haul-level information was summarised by quarter and aggregated across all available years to illustrate broad seasonal spatial patterns. Where egg or larval data included developmental stages, these were mapped separately. Finally, where data were reported only by period or quarter, spatial outputs reflect those reporting structures.

Where possible, original source data were mapped directly in QGIS. In some instances, data were first processed in R to combine and/or summarise inputs before mapping. The content and resolution of spatial data and mapping varied depending on the underlying data source, with outputs designed to reflect the level of detail supported by the data.

Egg and larval data were also explored through ICES web query tools (ICES, 2025c), with additional plankton survey datasets relevant to the Celtic Sea, Irish Sea, and Bristol Channel identified (including the English Channel and Celtic Sea Sardine and Anchovy plankton survey, Eastern Irish Sea (EIS) Smart Buoy Samples Project Plankton Survey and Zooplankton abundance data derived from the Plankton Imager system from the Western English Channel and Eastern Irish Sea from 2016 to 2019). However, coverage for cod within Welsh waters was extremely limited within these data. Available records were sparse, sometimes spatially inconsistent, and in several cases lacked species-level resolution or associated length or developmental information. As a result, these datasets were not analysed further for the project.

Spatial data for the project is provided in Appendix 4.

2.2.1 Common data sources

There are several data sources that are used for multiple lifestages in this report. These data sources are primarily the results of surveys conducted in or around Welsh waters. The surveys may have been single year surveys, or conducted across multiple years using the same data collection principles each time to allow changes over time to be identified. The spatial and temporal coverage of these overarching data sources are provided in Table 1, and described as follows:

- **Fisheries spawning and nursery areas in British waters (Coull *et al.*, 1998)** – This dataset provides GIS layers of the main spawning and nursery grounds for 14 commercially important species (including cod, haddock, whiting, herring, mackerel, plaice, sole, sandeels, sprat, and Norway lobster) around the UK. The maps were compiled from data collected by Fisheries Research Services (FRS) and Cefas during the 1990s and represented the widest known distribution of spawning and nursery areas based on egg, larval, juvenile, and adult fish surveys, sediment sampling, and acoustic techniques at the time. Data are presented at ICES rectangle resolution and include species-specific spawning periods and indicative nursery grounds, alongside additional layers on fishing effort and relative economic value.
- **Spawning and nursery grounds of selected fish species in UK waters (Ellis *et al.*, 2012)** – This dataset updates and complements the original Fisheries Sensitivity Maps in British Waters (Coull *et al.*, 1998) by incorporating more recent

ichthyoplankton and groundfish survey data and expanding coverage to additional species of commercial and conservation interest. There are GIS layers for spawning and nursery grounds of 21 species, including cod, herring, whiting, plaice, sole, mackerel, sandeels, and several elasmobranchs (e.g. spurdog, tope, skates, rays). Spawning grounds were inferred from egg and larval distributions in ichthyoplankton surveys, while nursery grounds were identified from juvenile occurrence and catch rates in fishery-independent trawl surveys. Data are mapped at half ICES statistical rectangle resolution, with additional layers indicating sites of higher importance where evidence permitted.

- **Spawning and nursery grounds of forage fish in Welsh and surrounding waters (Campanella and van der Kooij, 2021)** – This study used fisheries-independent acoustic and trawl survey data from 2008–2020 to map key spawning and nursery areas of forage fish across Welsh and adjacent marine waters (Irish Sea, Celtic Sea, western English Channel). A hotspot approach combined multiple surveys and years in Quarters 1 and 4, to identify persistent areas where adults and juveniles were repeatedly recorded, producing indices maps of spawning and nursery grounds.
- **Species spawning and nursery areas (Marine Institute, 2018; revised 2024)** – This dataset provides polygonal locations of spawning and nursery grounds for commercially important species, including cod, herring, haddock, mackerel, and monkfish. Methodological details on how the areas were determined are not provided.
- **Annual Egg Production Method (AEPM) surveys 1995 and 2000 (Cefas 1995; 2000)** – Surveys in 1995 and 2000 collected plankton samples across the Irish Sea to estimate stock size using counts of fish eggs and larvae. They mapped spawning activity of key species (e.g. cod, sole, plaice) and provide historical evidence on species distribution.
- **Highly mobile fish species distributions in UK waters (Cefas and ABPmer, 2010)** – This dataset provides mapped distributions for 40 taxa (22 teleosts, 17 elasmobranchs, and leatherback turtle) in UK waters, collating data from multiple fishery-independent groundfish and beam-trawl surveys conducted around the UK using GOV trawl, Portuguese High Headline Trawl (PHHT), and 4-m beam trawl gears. The surveys cover a long time-series, from the early 1980s to the late 2000s (e.g. 1982–2008 depending on survey and area), and the dataset includes presence/absence by ICES rectangle for all three gear types, relative abundance (mean individuals per one-hour tow) using GOV trawl at rectangle level, and species abundance per hour tow using PHHT and beam trawl at quarter-rectangle level.
- **Assessment of potential predators of plaice eggs and larvae in the Irish Sea (Cefas, 2023)** – This dataset originates from a Cefas-led study examining potential predators of plaice *(Pleuronectes platessa)* eggs and larvae on a well-defined spawning ground off the north Wales coast in the Irish Sea during February 2008 and 2009. The study combined vertically hauled plankton sampling, acoustic surveys, and targeted trawl sampling to characterise both early life stages and the associated fish community present on the spawning grounds. Plankton samples

were preserved and systematically sorted to identify fish eggs and larvae, while trawl data provided information on the composition and spatial distribution of potential predator and co-occurring fish species. Survey coverage extended across coastal waters within the 12-nautical-mile boundary of north Wales and into adjacent Irish Sea waters off the coast of Ireland.

- **Irish Sea Fish Egg Production Surveys (ISFEPS) (Cefas, 2010)** – This data source combines Cefas-led surveys conducted in the Irish Sea in 2006, 2008, and 2010. The surveys were carried out on a planned sampling grid covering the full Irish Sea, including waters within the 12-nautical-mile boundary of north Wales, and involved systematic plankton sampling at fixed stations during multiple research vessel cruises. The dataset provides station-level counts of fish eggs and larvae, together with associated positional data and volumes filtered.
- **Sea Angling Diary catch records 2016-2024 (Cefas, 2025)** – This dataset comprises raw recreational sea angling diary records provided by Cefas. The data consist of individual fishing-session records submitted by volunteer anglers through the Sea Angling Diary programme and include information at the event level, including year (2016 – 2024), fishing session ID, fishing platform, gear type, ICES rectangle of capture, session length (hours), species recorded, whether fish were kept or returned, and reported lengths. The dataset represents primary catch records and associated fishing effort information at the scale of individual angling trips. The Sea Angling Diary survey is not designed to collect data at the ICES rectangle spatial resolution and so may not be spatially representative, so results should be treated as indicative only.
- **Commercial fisheries landings and discards data (MMO, 2025)** – This dataset contains species-level weights of retained and, where available, discarded catch for cod from fisheries operating within Welsh waters over the most recent 10-year period (2014–2024). The data are disaggregated by year, month, gear type, vessel characteristics (particularly vessel length), catch position (at ICES statistical sub-rectangle level), and landing port. No raising of these data has been conducted with the discards data presented as supplied from the MMO.
- **DATRAS Fisheries-independent trawl survey data (ICES, 2025a)** – This database includes demersal and pelagic trawl fisheries-independent surveys using consistent survey designs, gear specifications, and haul protocols, primarily conducted under the ICES International Bottom Trawl Survey framework. Data typically span multiple decades (generally from the early 1980s onwards, depending on survey and area) and provide haul-level information on species composition, abundance (numbers and weight per haul), length-frequency distributions, survey timing, gear type, and precise spatial location (latitude–longitude and ICES statistical rectangles).
- **WFD Transitional fish surveys** (**NRW, 2025**) – This dataset comprises individual length measurements for cod collected through WFD sampling programmes across Welsh marine waters. Sampling was conducted at over 100 unique sites using a range of gears, including otter trawls, beam trawls, fyke nets, and seine nets. Each record includes site identifiers, sampling date, species name, and measured fish length, with associated metadata on sampling effort and gear characteristics.

- **Essential Fish Habitats project data (Marine Directorate, 2023)** – This dataset provides spatial predictions of Essential Fish Habitats (EFH) for 17 fish and shellfish species and life stages in Scottish waters. Offshore EFH distributions were derived using species distribution models calibrated with scientific survey catch data and environmental predictors (e.g. temperature, salinity), while inshore areas were assessed using habitat proxies based on EUNIS habitat types and expert review. Modelled and proxy-derived predictions were validated against independent survey data and expert feedback.
- **AquaMaps standardized species distribution maps (Reygondeau *et al.*, 2025)** – This database contains basic range data for fish species based their environmental "envelope" as provided by Aqua-X at the Rosenstiel School of Marine, Atmospheric, and Earth Science at the University of Miami, Florida. https://www.aquamaps.org/
- **Species occurrence records in Welsh waters (OBIS, 2025)** – The Ocean Biogeographic Information System (OBIS) is a global repository of georeferenced marine species occurrence records compiled from scientific surveys, museum collections, and citizen science observations. Records include species identification, observation date, and location (latitude–longitude), providing fisheries-independent evidence of species presence. For this study, OBIS data for cod were extracted within Welsh waters using spatial queries, and filtered to remove DATRAS survey records to avoid double-counting with other survey datasets.

Table 1. Summary of common data sources providing evidence of occurrence for cod in Welsh waters.

Source	Years	Spatial Coverage of Welsh waters	Purpose
Coull *et al.* (1998)	<1998	All Welsh waters	To produce maps of spawning and nursery areas.
Ellis *et al.* (2012)	1990 – 2008	All Welsh waters	To produce maps of spawning and nursery areas.
Campanella and van der Kooij (2021)	2008 to 2020	All Welsh waters	To produce maps of spawning and nursery areas.
Marine institute (2024)	-	All Welsh waters	To produce maps of spawning and nursery areas.
Cefas (1995; 2000)	1995 and 2000	Irish Sea (Cardigan Bay only in 1995)	To improve stock assessment for cod and plaice.
Cefas / ABPmer (2010)	1982 – 2008	All Welsh waters	To aid the selection of Marine Conservation Zones (MCZs) in England and Wales.
Cefas (2023)	2008 – 2009	Irish Sea	To provide data on fish counts, lengths and stomach contents analysis.
Cefas (2010)	2006, 2008, 2010	Irish Sea	To determine the distribution and abundance of cod, haddock, and plaice eggs.
Cefas (2025)	2016 – 2024	All Welsh waters	To estimate the number of sea anglers, how often they fish and their catch.
MMO (2025)	2014 – 2024	All Welsh waters	To report commercial fish catch.

Source	Years	Spatial Coverage of Welsh waters	Purpose
ICES (2025a)	2000 – 2024	All Welsh waters	To provide fisheries independent metrics of species abundance.
NRW (2025)	1997 – 2024	Welsh Estuaries	To provide data on estuarine fish species presence and abundance.
Marine Directorate (2023)	-	All Welsh waters	To provide spatial layers of Essential Fish Habitats.
AquaMaps (2025)	-	All Welsh waters	To provide species distributions based on environmental parameters.
OBIS (2025)	1912 – 2022	All Welsh waters	To provide information about the distribution and abundance of living species in the ocean.

3 Synthesis of evidence

This section presents the available evidence identified on the distribution and population structure of cod in Welsh waters. It begins with a summary of historical information on the species and general species context, followed by a summary of the evidence sources reviewed. Subsequent subsections describe population distribution within Welsh waters for life stages and associated life-cycle processes, including eggs, larvae, juveniles, nursery grounds, adults, and spawning grounds. Each life stage subsection includes relevant ecological background, spatial distribution, key results and the supporting literature or survey data. Population and genetic structuring is addressed in the next subsection, followed by a summary of important uncertainties and knowledge gaps.

3.1 Historical data and information

Cod have a long history of being fished in Welsh waters, with sources indicating that the species were once far more abundant and locally important to fisheries than today.

Moore *et al.* (2024) describes a pattern of fluctuations in cod abundance in the 1700s and 1800s. There was a period of low abundance in the early-1700s followed by a documented period of substantial abundance in the mid-1700s, including the former cod fishery off Anglesey where heads were reportedly used as fertiliser (Morris, 1740-1747, cited in Moore *et al.* 2024), and “vast quantities” taken on the Hyle Sands (outer Dee estuary/Liverpool Bay) (Pennant, 1796).

Following indications of reduced availability in the late-1700s to early-1800s, cod abundance appears to have increased again by the mid-1800s with “plenty of cod on the coast” (Report of the Commissioners, 1865, cited in Moore *et al.* 2024), supporting diverse longline and trawl fisheries into the 1900s (Buckland and Walpole, 1879; Davies, 1885; Kneeshaw, 1918, cited in Moore *et al.* 2024). Gubbay (2009) notes that 1800s trawl fisheries occasionally landed exceptionally large numbers of sizeable cod, with one Cardigan Bay haul capturing 87 fish averaging around 20lb (9 kg) each. Another decline followed shortly thereafter in the early-1900s, with fishers noting that cod had “forgotten their former haunts” (Kneeshaw, 1918, cited in Gubbay, 2009).

These fluctuations mirror wider patterns of cod distribution in the North Atlantic shaped by long-term exploitation, climatic variability and multispecies dynamics (e.g. Alheit *et al.*, 2014; Brander, 1980; Engelhard, 2014). This historical information provides important context to the contemporary evidence on cod distribution in Welsh waters.

Olsen’s Piscatorial Atlas (1883) shows cod were widely distributed with much of Welsh waters indicated as a place where cod were *“caught in abundance*” (Figure 2). This indicates a historically high prevalence across much of the area, including offshore waters of the Irish Sea and Celtic Sea. The upper Severn Estuary is depicted with a lighter shading consistent with “*general distribution”* (Figure 2) suggesting a lower relative occurrence compared to surrounding marine areas.

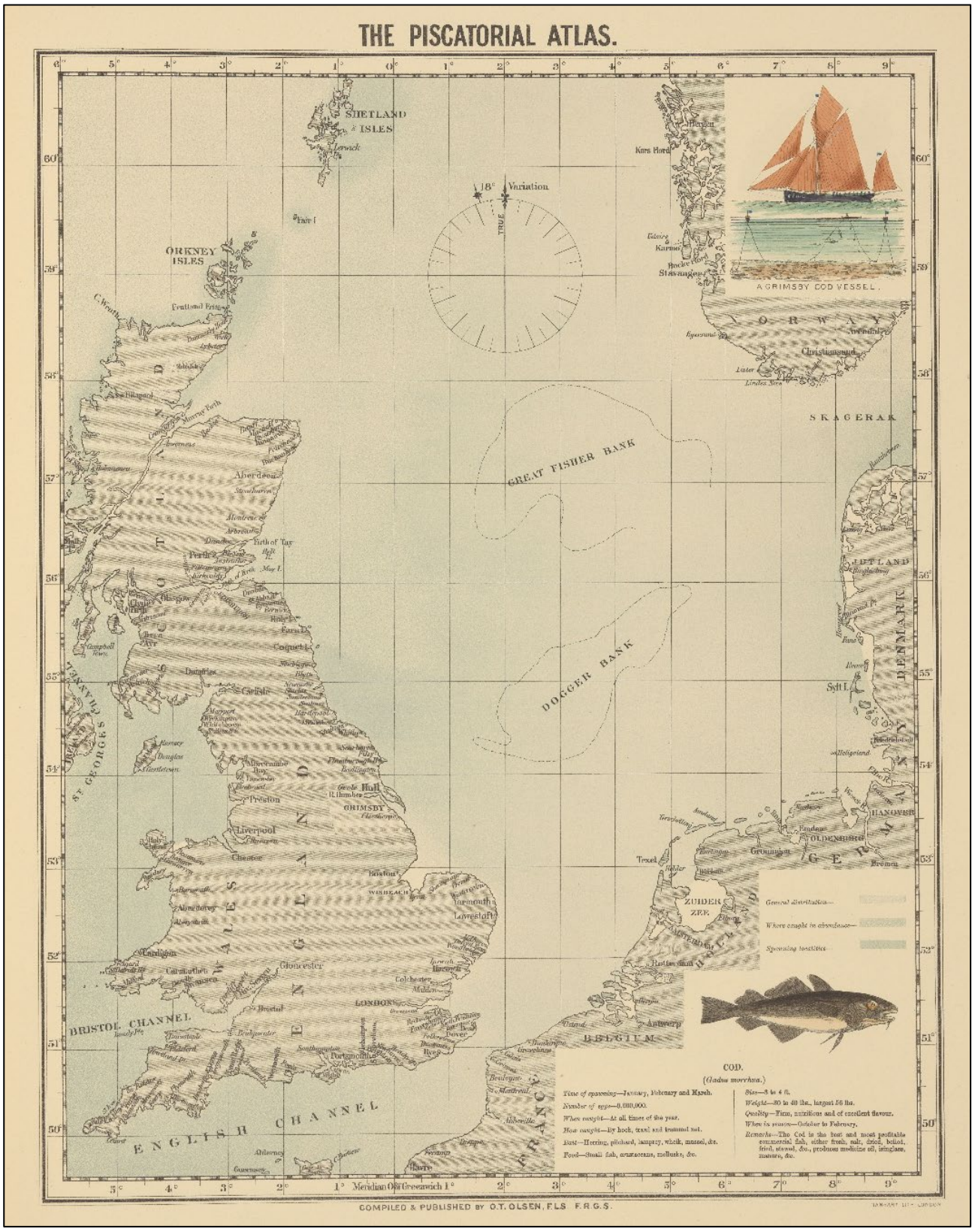


Figure 2. Olsen's Piscatorial Atlas – cod distribution. Cod distribution is depicted using qualitative shading to indicate *general distribution*, *where caught in abundance*, and *spawning localities* (Source: Olsen, 1883).

3.2 Summary of evidence sources reviewed

The literature review initially identified 250 academic papers and technical reports relating to the defined search terms for cod. After removing 107 duplicates, 143 unique records remained. Screening by title excluded a further 67, and abstract screening reduced the list to 31 papers considered likely to contain information relevant to this study, though not all ultimately did. A PRISMA 2020 flow diagram for the review is included in Appendix 1.

One specific reference identified through this systematic review, Kulatska *et al.* (2024), contained a number of relevant references to the Northwest European shelf cod stocks, 11 of which were identified as potential sources of information and included within the associated Zotero library. These were subsequently screened for relevance following the same criteria applied to the main dataset. Four additional sources were provided by NRW and incorporated to supplement the evidence base and address identified information gaps. Sources of digital spatial data used in this study have been summarised by life stage and life cycle process in Table 2.

Table 2. Source of digital spatial data collated from online sources and data portals summarised by lifecycle and process stage for cod. “A” represents absence of evidence and “P” represents presence of evidence.

Source	Egg	Larvae	Juvenile	Nursery	Adult	Spawning
Fisheries spawning and nursery areas in British waters (Coull *et al.*, 1998)	A	A	A	P	A	P
Spawning and nursery grounds of selected fish species in UK waters (Ellis *et al.*, 2012)	P	P	P	P	A	P
Spawning and nursery grounds of forage fish in Welsh and surrounding waters (Campanella and van der Kooij, 2021)	A	A	P	A	P	P
Species spawning and nursery areas (Marine Institute, 2018; revised 2024)	A	A	A	P	A	P
Annual Egg Production Method (AEPM) surveys 1995 and 2000 (Cefas 1995; 2000)	P	P	A	A	A	A
Highly mobile fish species distributions in UK waters (Cefas / ABPmer, 2010)	A	A	A	A	P	A
Assessment of potential predators of plaice eggs and larvae in the Irish Sea (Cefas, 2023)	P	P	A	A	A	A
Irish Sea Fish Egg Production Surveys (ISFEPS) (Cefas, 2010)	P	P	A	A	A	A
Sea Angling Diary catch records 2016-2024 (Cefas, 2025)	A	A	P	A	P	A
Commercial fisheries landings and discards data (MMO, 2025)	A	A	A	A	P	A
DATRAS Fisheries-independent trawl survey data (ICES, 2025a)	A	A	P	A	P	A
WFD Transitional fish surveys (NRW, 2025)	A	A	P	A	P	A
Essential Fish Habitats project data (Marine Directorate, 2023)	A	A	A	A	A	P
AquaMaps standardized species distribution maps (AquaMaps, 2025)	A	A	A	A	P	A
Species occurrence records in Welsh waters (OBIS, 2025)	A	A	A	A	P	A

3.3 Population distribution

This section describes cod population distribution in Welsh and surrounding waters in the Irish and Celtic Seas. The evidence is presented through sequential life stages and life cycle processes.

3.3.1 Life stage – eggs

In the Celtic and Irish Seas, cod spawning typically occurs from January to May, with peak activity between March and April (Campanella and van der Kooij, 2021). The timing of spawning interacts with environmental conditions, particularly water temperature and oxygen concentration, both of which influence embryonic development rates.

Atlantic cod eggs require specific, stable environmental conditions for successful fertilization and development, with ideal spawning temperatures of 5—7^{o}C and high salinity (>11 psu, typically 29.5–33 psu in the North Atlantic). Cod eggs are pelagic, requiring buoyancy achieved at high salinities and oxygen levels greater than 2 ml/l.

Cod egg development is conventionally divided into six morphological stages ranging from early cleavage to the pre-hatch phase. Geffen *et al.* (2006) modelled the duration of each developmental stage across temperatures from 6–12°C, interpreting egg survey data. Within the temperature range typical of the region, cod eggs are likely to drift for one to three weeks after spawning, with dispersal shaped by prevailing currents and local hydrographic conditions. As such, observed egg distributions may represent a combination of spawning locations and subsequent transport.

Data related to the distribution of cod eggs in Welsh waters were identified through four geospatial datasets as well as a paper by Heffernan *et al.* (2004). The datasets reviewed comprise of:

- Annual Egg Production Method (AEPM) surveys 1995 and 2000 (Cefas 1995; 2000);
- Irish Sea Fish Egg Production Surveys (ISFEPS) (Cefas, 2010);
- Assessment of potential predators of plaice eggs and larvae in the Irish Sea (Cefas, 2023); and
- Spawning and nursery grounds of selected fish species in UK Waters (Ellis *et al.*, 2012).

Further detail on each dataset is provided in Appendix 3.

3.3.1.1 Synthesis of egg distribution evidence

Evidence describing the spatial distribution of cod eggs in Welsh and adjacent waters is derived from multiple fisheries-independent ichthyoplankton surveys spanning the Irish Sea, Bristol Channel and Celtic Sea.

Interpretation of egg distributions must account for the potential influence of transport processes. Following spawning, cod eggs remain pelagic for approximately 1–3 weeks before hatching. During this period, tidal and residual currents can transport early life stages away from their spawning locations. Consequently, the presence of eggs within a given survey area does not necessarily indicate that spawning occurred locally, though consistent concentrations of eggs in samples, especially early development stages, will indicate spawning activity nearby.

In addition, differences in survey timing relative to peak spawning and hatching periods may influence whether eggs are detected in particular areas. Furthermore, while developmental stage information can provide some indication of proximity to spawning, the limited temporal and spatial coverage of surveys in some areas restricts confidence in defining these areas as spawning grounds. These factors should therefore be considered when interpreting spatial patterns in the available datasets.

Evidence on the spatial distribution of cod eggs in Welsh waters is derived from four geospatial datasets, supplemented by a targeted ichthyoplankton survey. Across these sources, there is broad consistency in identifying the principal areas of cod egg occurrence in Welsh waters of the Irish Sea, with particularly high abundances recorded off the North Wales coast to the north and north east of the Great Orme in Welsh inshore waters (Figure 3). This suggests that this area of Welsh waters represents part of an important region of cod egg production and spawning activity within the Irish Sea. In contrast, evidence from Cardigan Bay, the Celtic Sea and the Bristol Channel is comparatively sparse and derives from a small number of historical surveys with limited spatial coverage.

Cod egg presence within Cardigan Bay is supported by two datasets (Ellis *et al.*, 2012; Cefas 1995; 2000); however, these records originate from the same ichthyoplankton cruise conducted in April 1995 and therefore do not represent independent sampling events. While developmental stage information is not reported in Ellis *et al.* (2012), the AEPM data indicate the presence of eggs across all recorded developmental stages (1A, 1B, 2, 3, 4 and 5), suggesting a limited amount of localised egg production rather than solely advected eggs. Nevertheless, across all the cod egg datasets considered, this 1995 survey represents the only recorded sampling effort within Cardigan Bay, and overall station coverage in the area is very limited. As such, egg abundance in Cardigan Bay is likely to be underestimated, and the persistence or interannual consistency of egg presence cannot be fully assessed.

A similar limitation applies to inshore waters of the Bristol Channel, where cod egg presence is represented by a single low-abundance record in Carmarthen Bay originating from the Bristol Channel plankton survey reported in Ellis *et al.* (2012). This record derives from a 1990 survey, and station distribution across the egg datasets indicates very limited survey coverage in this area. Notably, the 1990 survey represents the most recent

ichthyoplankton sampling effort identified within the Bristol Channel, further constraining interpretation of egg presence in this region.

Egg presence in the Bristol Channel is likely to originate from the Trevose head spawning ground off north Cornwall, and there is data available for offshore waters in the Celtic Sea supporting presence of cod eggs and spawning activity in this area.

Overall, inshore waters off the North Wales coast, and the eastern Irish Sea, emerge as clear and repeatedly observed hotspots of cod egg occurrence and likely spawning activity, while sparse evidence from Cardigan Bay and the Bristol Channel highlights significant data gaps rather than clear absence of egg production and spawning activity.

Key results:

- **Cod eggs are consistently recorded off the North Wales coast and in the central–eastern Irish Sea, indicating persistent reproductive activity in these regions.**
- **Egg presence is less consistently recorded further south and west in Welsh waters, with increasing spatial uncertainty likely reflecting reduced survey coverage rather than confirmed absence given wider presence of cod eggs and spawning grounds in the Celtic Sea.**

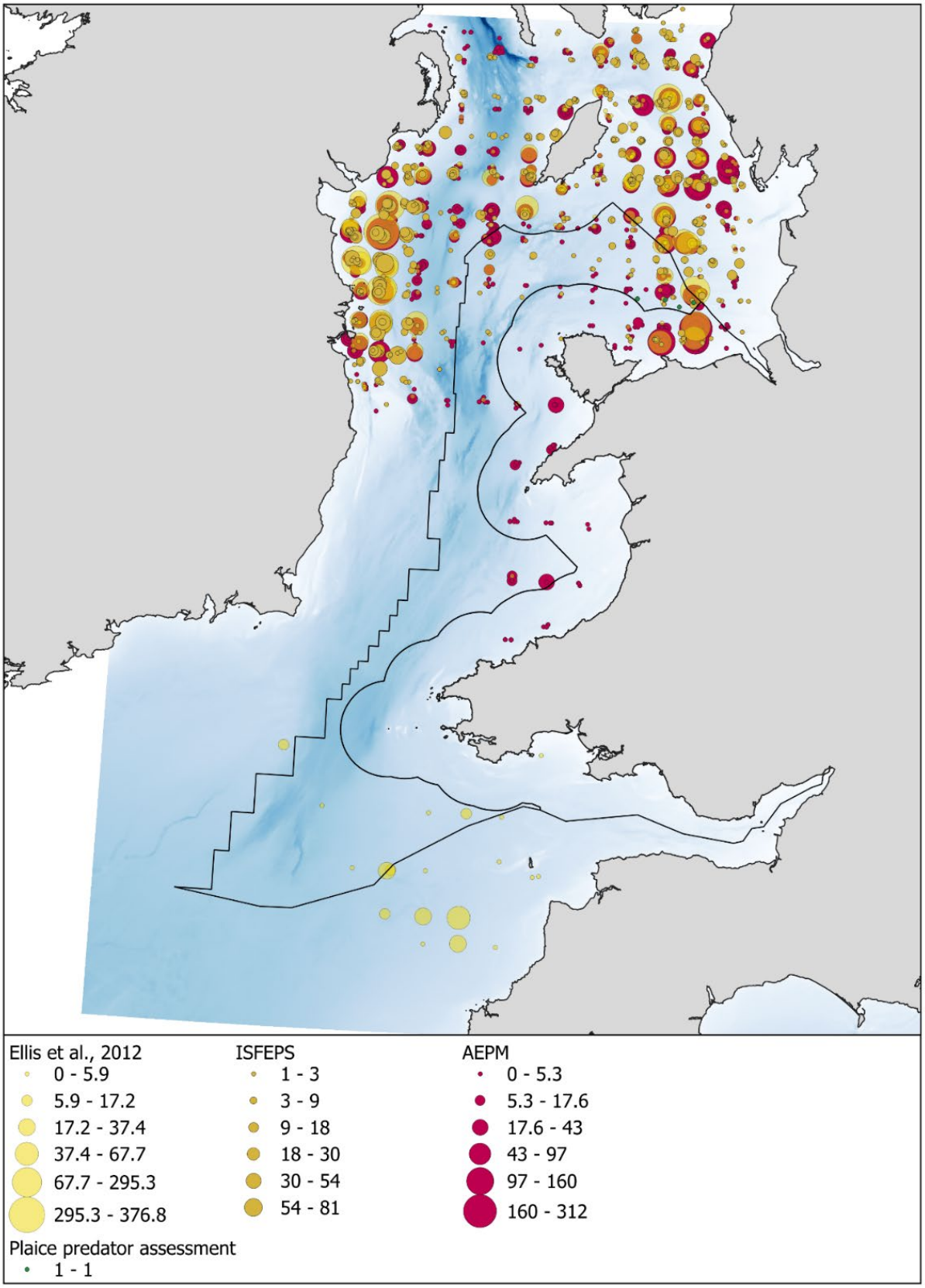


Figure 3. Synthesis map of cod egg data (Sources: Ellis *et al.*, 2012; Cefas, 1995; 2000; 2006; 2008; 2010). Legend units are in numbers of eggs per sample.

3.3.2 Life stage – larvae

To support interpretation of observed spatial patterns, cod larval growth, development time, and the transition from pelagic larvae to settled juveniles must be considered. Laboratory experiments demonstrate that larval growth rates and duration of the pelagic phase are strongly temperature-dependent. Under controlled, well-fed conditions, cod larvae reared at approximately 14°C reached the onset of metamorphosis in around 23 days, compared with more than 56 days at 4°C (Otterlei *et al.*, 1999). These relationships provide a mechanistic baseline for development rates, although development in wild populations is likely to be slower due to fluctuating temperatures, variable prey availability and other environmental factors.

Field-based observations indicate that cod settlement is a gradual process rather than a discrete event. Based on diet shifts from pelagic to benthic prey, Bastrikin *et al.* (2014) identified the onset of settlement at approximately 34 (±2) mm, with juveniles considered fully settled by 49 (±3) mm. During this size range, cod progressively transition from a predominantly pelagic feeding mode to benthic feeding, accompanied by increased use of shallow coastal nursery habitats.

Data relating to cod larval distributions in Welsh waters were identified from fisheries-independent ichthyoplankton surveys and mapped layers, as well as an ichthyoplankton survey report by Dransfeld *et al.* (2004). The datasets reviewed comprise of:

- Annual Egg Production Method (AEPM) surveys 1995 and 2000 (Cefas 1995; 2000);
- Irish Sea Fish Egg Production Surveys (ISFEPS) (Cefas, 2010);
- Assessment of potential predators of plaice eggs and larvae in the Irish Sea (Cefas, 2023); and
- Spawning and nursery grounds of selected fish species in UK waters (Ellis *et al.*, 2012).

Further detail on each dataset is provided in Appendix 3.

3.3.2.1 Synthesis of larvae distribution evidence

Evidence describing the spatial distribution of cod larvae in Welsh and adjacent waters is derived from multiple fisheries-independent ichthyoplankton surveys spanning the Irish Sea, Bristol Channel and Celtic Sea. Across these datasets, larval occurrence patterns show broad similarities with cod egg distributions, while also reflecting the influence of post-hatch transport and survey coverage limitations.

Interpretation of larval distributions must account for the potential influence of transport processes. Following spawning, cod eggs remain pelagic for approximately 1–3 weeks before hatching, after which larvae may remain in the pelagic environment for several additional weeks. During this period, tidal and residual currents can transport early life stages away from their spawning locations. Consequently, the presence of larvae within a given survey area does not necessarily indicate that spawning occurred locally. In addition, differences in survey timing relative to peak spawning and hatching periods may influence whether larvae are detected in particular areas. These factors should therefore be considered when interpreting spatial patterns in the available ichthyoplankton datasets.

In the Irish Sea, cod larvae are most consistently recorded east of the Isle of Man and along the eastern Irish coast (Figure 4). Within Welsh waters, larval occurrence is concentrated primarily in offshore waters, though records of larvae within inshore waters along the North Wales coast are recorded in lower abundances. This spatial pattern closely mirrors the egg distribution evidence, which identifies the eastern Irish Sea and areas off the North Wales coast as key areas of cod reproductive activity, and supports the interpretation that larval presence in this region is linked to regionally persistent spawning rather than isolated advection events.

In the Celtic Sea, larval distributions are based on more temporally-limited data. Ellis *et al.* (2012) report relatively high larval abundances off the north Cornwall coast and extending into Welsh offshore waters, with lower abundances in Welsh inshore waters. This would be consistent with the known cod spawning ground off Trevose Head. However, all of these southern records originate from a single survey conducted in 1990. The absence of comparable larval records in subsequent years indicates that, while cod larvae were present in the outer Bristol Channel and Celtic Sea at that time, the persistence or regularity of larval occurrence in this region cannot be assessed. This contrasts with Welsh waters in the Irish Sea, where larval records are derived from multiple surveys conducted across several years.

Evidence for larval presence in Cardigan Bay and St George's Channel is particularly limited. Only a single low-abundance larval record is identified in Cardigan Bay, originating from survey in 1995. As with the egg datasets, station information indicates that this represents the only ichthyoplankton sampling effort within the bay and therefore provides insufficient evidence to determine whether larval presence is sporadic, persistent, or underestimated due to limited spatial and temporal coverage.

The available evidence does not indicate a consistently broader or more diffuse larval distribution compared with egg distribution. Instead, larval occurrence shows strong spatial overlap with egg distributions, particularly in the eastern Irish Sea and off the North Wales

coast, where both life stages are repeatedly recorded in higher abundances.

While larvae have been observed in the outer Bristol Channel and Celtic Sea, these patterns are largely derived from a single historical survey. As such, any differences between egg and larval distributions may reflect a combination of interannual variability, survey timing, and uneven spatial coverage of surveys, rather than systematic dispersal away from spawning areas. Consequently, larval distributions are interpreted as broadly consistent with the egg evidence at a regional scale, while acknowledging uncertainty in areas where sampling is limited or temporally restricted.

Importantly, the available larval datasets are largely derived from offshore and near-offshore sampling and do not adequately capture inshore waters. As larvae grow and transition towards settlement, they progressively move inshore and increase their use of shallow coastal nursery habitats. The absence of targeted inshore larval and early juvenile sampling within Welsh waters means that this phase of the lifecycle is poorly represented in the evidence base. Consequently, larval occurrence in coastal and nearshore areas is likely to be underestimated, and the connectivity between spawning areas and nursery habitats cannot be fully resolved using the available data.

Overall, the larval evidence broadly reinforces conclusions drawn from egg distributions, highlighting the eastern Irish Sea, areas off the North Wales coast and the outer Bristol Channel and Celtic Sea off the North Cornwall coast as key areas within the regional cod lifecycle for spawning, and egg and larval transport and dispersal. At the same time, the scarcity of records from mid-Wales and inshore areas primarily reflect data limitations rather than confirmed absence.

Key results:

- **Cod larvae show a spatial distribution broadly aligned with egg records, particularly off the north Wales coast and central–eastern Irish Sea.**
- **Ellis *et al.* (2012) records substantially higher larval abundances in the Celtic Sea in Welsh offshore waters and, to a lesser extent, within Welsh inshore waters, compared to corresponding egg records.**
- **This divergence between egg and larval spatial patterns in Welsh waters of the Celtic Sea and Bristol Channel may indicate the influx of advected eggs or larvae from spawning grounds outside Welsh waters, such as the Trevose Head spawning ground, rather than local spawning activity.**
- **In contrast, the close spatial coherence between egg and larval records off the North Wales coast supports local retention and early development in this region rather than reliance on advection from distant spawning areas.**

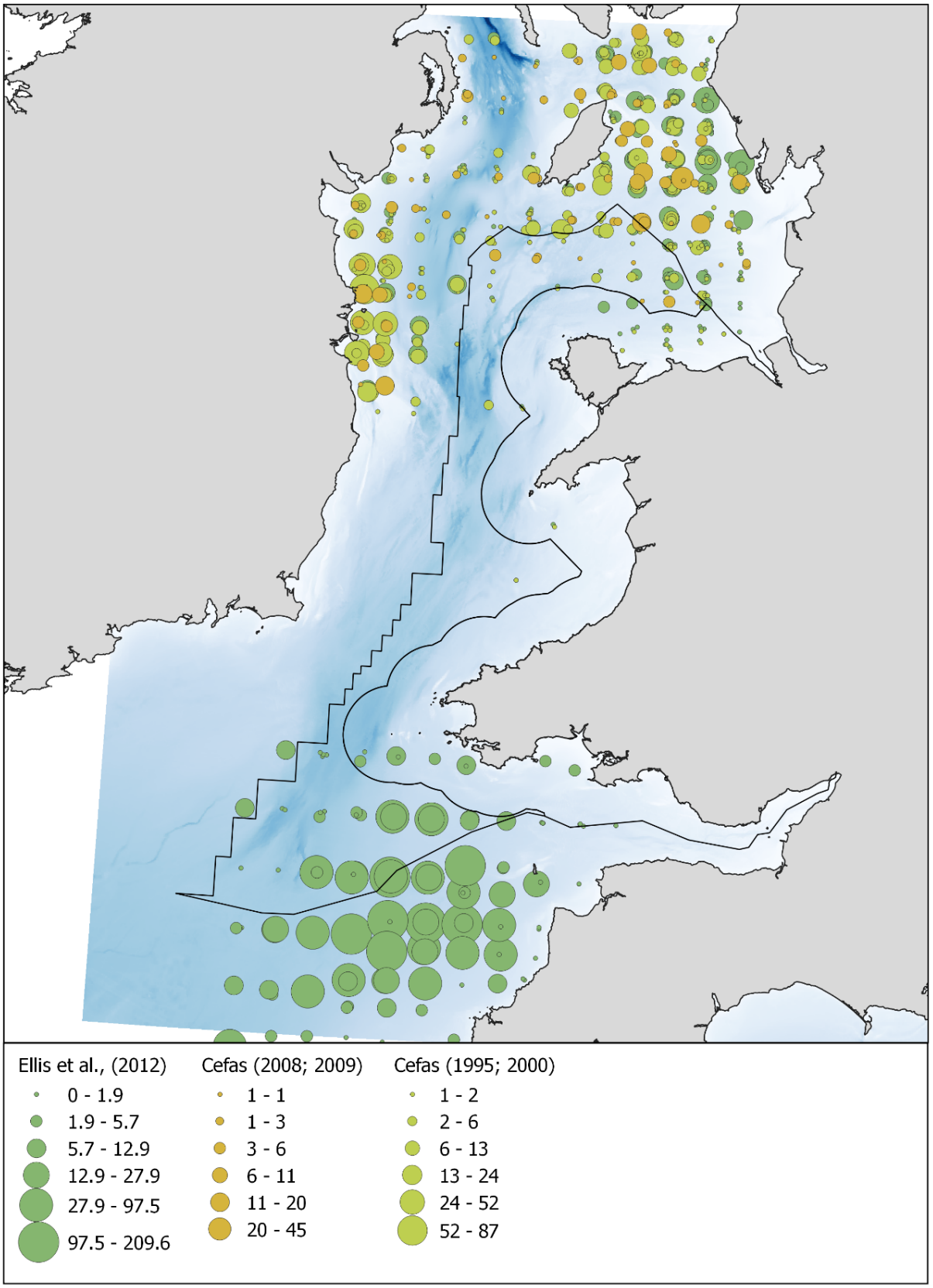


Figure 4. Synthesis map of cod larvae data (Sources: Ellis *et al.*, 2012; Cefas 1995; 2000; 2008; 2009). Legend units are in numbers of larvae per sample.

3.3.3 Life stage – juveniles

Young cod settle from the plankton into shallow coastal waters, using rough ground, seagrass, gravel, and maerl beds as vital protective nursery habitats (Kamenos *et al.* 2004). Cod smaller than 5 cm feed predominantly on zooplankton after which they switch to larval fish (Robb 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 some cod mature in their second year, it is not until age 6 that all cod are sexually mature (Heessen *et al.*, 2015), moving offshore to spawn.

Data relating to juvenile cod distributions in Welsh waters were identified from fisheries-independent trawl and netting surveys, sea angling catch data, as well as an academic paper by Peters *et al.* (2015). The datasets reviewed comprise of:

- WFD Transitional fish surveys (NRW, 2025);
- Spawning and nursery grounds of selected fish species in UK waters (Ellis *et al.*, 2012);
- DATRAS Fisheries-independent trawl survey data (ICES, 2025a);
- Spawning and nursery grounds of forage fish in Welsh and surrounding waters (Campanella and van der Kooij, 2021); and
- Sea Angling Diary catch records 2016-2024 (Cefas, 2025).

Further detail on each dataset is provided in Appendix 3.

3.3.3.1 Synthesis of juvenile distribution evidence

The synthesis of fisheries-independent survey evidence indicates that juvenile cod in the Irish and Celtic Seas exhibit a spatially structured distribution, strongly associated with inshore, coastal and estuarine environments, and characterised by clear ontogenetic shifts with increasing size. When the reviewed datasets are considered collectively and overlaid spatially, the resulting synthesis plot (Figure 5) highlights areas of consistent juvenile occurrence.

Across all datasets, juvenile cod are most frequently recorded in Welsh inshore waters along the North Wales coast (Figure 5), as well as Carmarthen Bay and Swansea Bay. This spatial pattern is consistently evident in long-term trawl survey data (ICES, 2025a; Ellis *et al.*, 2012) and in the estuary-focused dataset provided by Natural Resources Wales. In contrast, Cardigan Bay show comparatively low recorded juvenile occurrence, a pattern that is coherent across datasets but strongly influenced by uneven and limited survey coverage, though some samples from this area have recorded comparatively high numbers of juveniles and separate BRUV studies have recorded their presence in reasonable numbers in nearshore waters of Cardigan Bay.

Estuarine and nearshore environments emerge as particularly important for juvenile cod during early post-settlement stages. NRW survey data demonstrate recurrent juvenile presence in the Severn Estuary, with additional, though less numbers in the Dee and Conwy estuaries and Pembrokeshire estuaries. Early-stage juveniles (<10 cm) are

predominantly recorded during summer months and are spatially concentrated close to the coastline, whereas later-stage juveniles (10–22 cm) are distributed more broadly and appear later in the year, including in deeper waters in estuaries (Figure 5). This progressive spatial expansion with size is consistently observed across estuarine datasets and inshore and offshore trawl sampling.

Habitat-specific observations further support the importance of shallow coastal environments for early juvenile cod. Records of juveniles within subtidal Zostera marina meadows in Tremadog Bay indicate use of structurally complex habitats during early life stages, albeit at low observed frequencies. While spatially limited, these observations align with the broader coastal concentrations evident in the synthesis plot (Figure 5).

Juvenile occurrence derived from DATRAS data reinforces these patterns, identifying inshore waters around Anglesey, Swansea Bay, and the Loughor and Carmarthen Bay areas as areas of relatively high juvenile abundance in Q1 and Q4. The apparent scarcity of juvenile records in Cardigan Bay within Figure 5 should be interpreted with caution, as it likely reflects limited sampling effort rather than confirmed low occurrence.

Juvenile cod distribution from sea angling records concentrated along the North Wales coast and in the Bristol Channel generally support the information available on known areas where sea angling can capture the species. The stretch of the Welsh coast from the two Severn Bridges to Sker Point, including Aberthaw, Nash Point and Southerndown, has long been associated with excellent winter cod fishing. Codling (larger juvenile cod) are believed to move inshore in the Severn Estuary in the winter to feed on shrimp and green shore crab. Further west, Milford Haven and the various reefs within the vicinity of St Anne’s Head also often have large numbers of codling. Similarly In North Wales, they occur in the Menai Strait and Conwy Bay in the winter potentially driven by feeding on peeler crab, and areas around the Llŷn Peninsula such as Trefor Pier, and along the North Wales Coast such as Llandudno Pier are notable locations where they can be caught by anglers.

When considered alongside the egg and larval synthesis information, juvenile distribution patterns appears to reflect a clear movement inshore and to estuarine waters following tidal current movements, from spawning grounds farther offshore as there is a clear coastal/estuarine and nearshore preference for the younger juveniles. Larval records are most persistent off the North Wales coast and eastern Irish Sea waters, and the spatial concentration of juvenile cod nearer inshore in these same regions suggests some shift in distribution between pelagic and post-settlement stages. Further south and west, the available datasets show more variable spatial signals. In areas such as Cardigan Bay, both larval and juvenile records are sparse, suggesting that apparent spatial gaps are likely to reflect limited sampling rather than confirmed absence. In contrast, stronger juvenile signals are evident in parts of the Bristol Channel, including Carmarthen Bay, Swansea Bay and the Severn Estuary, indicating that these areas support regular juvenile occurrence despite more limited larval observations inshore.

Overall, the synthesis indicates that juvenile cod distribution in Welsh and adjacent waters is characterised by a strong coastal and estuarine signal during early juvenile stages, followed by increasing spatial dispersion with growth and seasonality, while remaining

broadly aligned with the regional patterns observed for eggs and larvae. Persistent juvenile presence along the North Wales coastline and around Anglesey, as well as in Carmarthen Bay, Swansea Bay and the Severn Estuary in the Bristol Channel highlights these areas as consistently important within the juvenile phase of the cod lifecycle, while uncertainty remains in less intensively sampled regions, particularly Cardigan Bay and around Pembrokeshire.

Key results:

- **Early post-settlement cod (<10 cm) display strong associations with coastal and estuarine environments, indicating reliance on shallow habitats during early post-settlement stages, with older juveniles (10-22 cm) show increasing spatial dispersion with growth and seasonality, while remaining broadly aligned with the regional patterns observed for eggs and larvae**
- **Records of early post-settlement cod (<10 cm) are limited in offshore survey datasets, likely reflecting sampling bias in trawl-based programmes such as DATRAS, which are not well suited to shallow coastal habitats or very small size classes.**

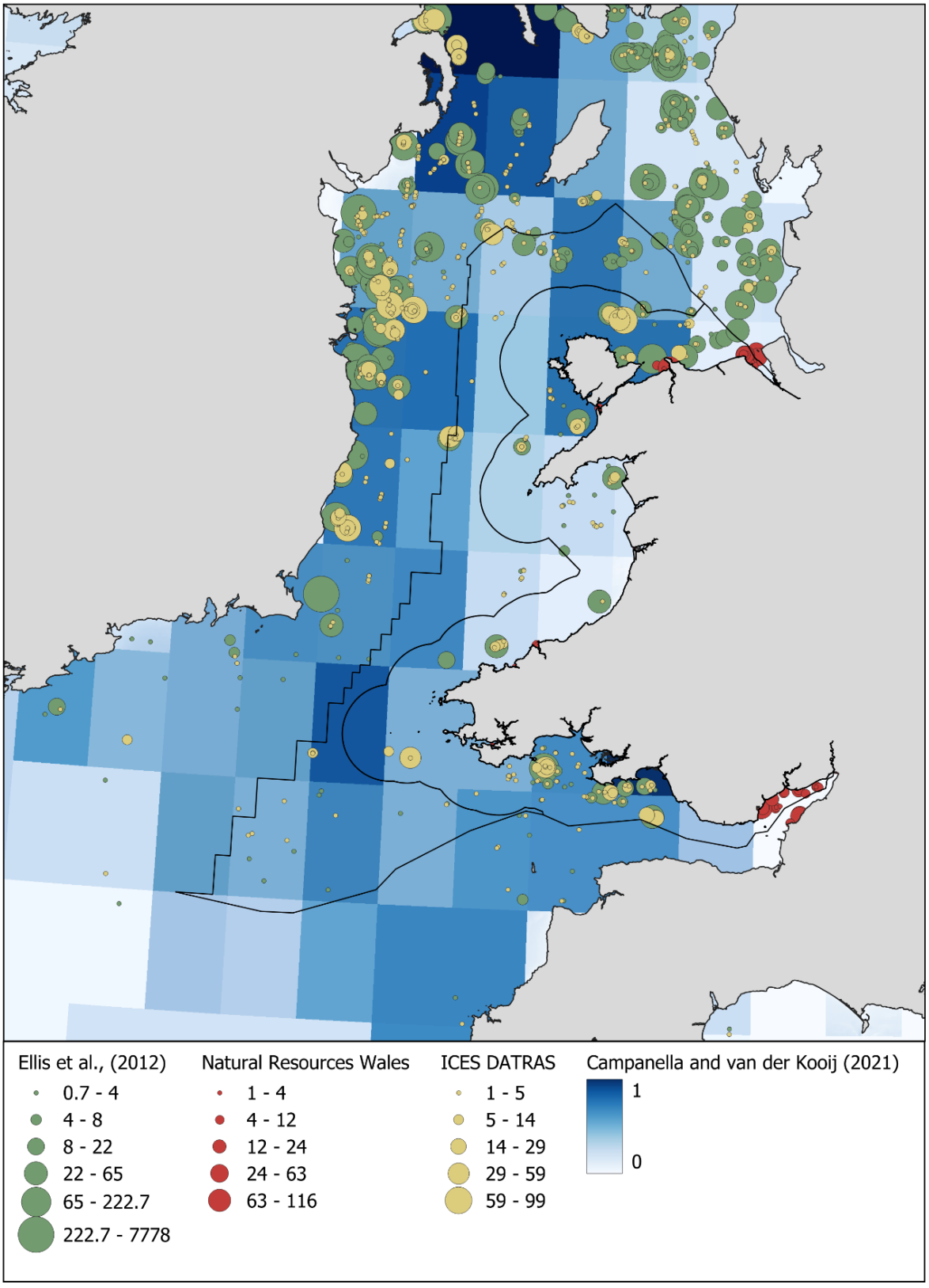


Figure 5. Synthesis plot of juvenile cod (Sources: Ellis *et al.*, 2012; NRW, 2025; ICES, 2025a; Campanella and can der Kooij, 2021). Legend units are in numbers of juveniles per sample.

3.3.4 Life cycle process – nursery grounds

Data relating to cod nursery areas in Welsh waters were primarily identified from efforts to map spawning and nursery layers from regional marine / fisheries authorities. The datasets reviewed comprise of:

- Species spawning and nursery areas (Marine Institute, 2018; revised 2024);
- Fisheries spawning and nursery areas in British waters (Coull *et al.*, 1998); and
- Spawning and nursery grounds of selected fish species in UK waters (Ellis *et al.*, 2012).

Further detail on each dataset is provided in Appendix 3.

3.3.4.1 Synthesis of nursery ground distribution evidence

The available evidence describing the spatial distribution of cod nursery grounds in the Irish and Celtic Seas is derived primarily from mapped products derived from survey data. Some direct, site-specific juvenile survey data which is reported separately in Section 3.3.3 and includes numerous records from south Wales coastal waters and the Severn Estuary are not consistently reflected in mapped nursery ground polygons. When these datasets are considered collectively and overlaid (Figure 6), they indicate a coherent but spatially generalised picture of nursery area distribution within Welsh and adjacent waters, with strongest agreement in the Irish Sea. The results differ from the juvenile synthesis (Section 3.3.3.1), which identifies significant juvenile occurrence not only in north Wales but also in Carmarthen Bay, Swansea Bay and the Severn Estuary.

Across all sources, cod nursery areas are most consistently identified along the north Wales coastline and adjacent waters of the Irish Sea (Figure 6). Both Coull *et al.* (1998) and Ellis *et al.* (2012) delineate nursery areas in this region, with the latter providing the most detailed spatial representation. Ellis *et al.* (2012) identifies an extensive nursery area along the entire north Wales coast, comprising a higher-intensity zone east of 4°W and a broader, lower-intensity area surrounding Anglesey and extending offshore into Welsh offshore waters. This spatial pattern dominates the combined synthesis and reflects repeated identification of juvenile cod presence across multiple surveys and years.

The Fisheries Sensitivity Maps dataset (Coull *et al.*, 1998) provides partial support for this northern signal, identifying a discrete nursery area north and east of Anglesey that overlaps with both inshore and outer Welsh waters. Although the accompanying report does not depict cod nursery areas within Welsh waters, the spatial dataset itself indicates a clearly defined nursery polygon in this region, as well as a much larger nursery area along the Irish coast that marginally intersects with Welsh offshore waters. This discrepancy highlights uncertainty in the original documentation but does not contradict the broader spatial pattern evident in the synthesis.

The Marine Institute (2018) dataset further reinforces the identification of nursery areas within Welsh waters, although at a much coarser spatial resolution. Much of Welsh inshore waters is identified as nursery habitat, limiting the ability to distinguish discrete or high-

intensity areas. Nevertheless, when incorporated into the synthesis map (Figure 6), this dataset broadly aligns with the signal identified by the other sources for the areas around the North Wales coast.

In contrast, there is limited and inconsistent evidence for *distinct* cod nursery areas along the South Wales coast and within Cardigan Bay. Ellis *et al.* (2012) does not define any nursery polygons in these regions, despite the presence of juvenile cod indicated by point-based records and recurrent early-stage estuarine observations in the Severn Estuary. Coull *et al.* (1998) similarly does not identify discrete nursery areas along the south coast or within Cardigan Bay. The Marine Institute (2018) dataset does include much of Welsh inshore waters, including these areas, within a broadly inferred nursery extent; however, its coarse spatial resolution limits the identification of discrete or higher-intensity nursery zones and results in limited spatial overlap with the more constrained nursery areas defined by other sources.

The absence of clearly delineated nursery grounds in Cardigan Bay and the Bristol Channel should therefore be interpreted with caution, as it likely reflects differences in mapping approaches, application of density and persistence criteria, and uneven survey coverage, rather than a confirmed lack of nursery function. Shallow inshore waters in these regions, particularly the Severn Estuary and bays in Bristol Channel, are likely functioning as nursery habitat. This is corroborated by juvenile cod observations in the Severn Estuary and along the south Wales coast, demonstrating that shallow inshore waters in these regions are occupied by significant numbers of resident juveniles even where mapped nursery areas are not formally defined.

Overall, the synthesis of mapped nursery ground evidence indicates that cod nursery areas within Welsh and adjacent waters are most consistently identified along the North Wales coast and around Anglesey, with decreasing clarity and agreement in Cardigan Bay and the Bristol Channel. The nursery synthesis (Figure 6) is characterised by relatively broad polygons inferred from multiple data sources and expert judgement, reflecting the scale and purpose of the original mapping exercises. While these datasets provide a valuable regional overview, they also highlight uncertainty in areas where juvenile occurrence is low or sporadic and where spatial resolution is coarse, underscoring the need to interpret nursery delineations alongside finer-scale juvenile distribution evidence presented in earlier sections. This is especially important for Cardigan Bay and the Bristol Channel.

Key results:

- **Nursery ground mapping products consistently identify the north Wales coast and waters around Anglesey, as well as areas such as Carmarthen Bay and the inner Bristol Channel, as the most coherent and persistent nursery regions within Welsh waters.**
- **Available analyses of nursery grounds broadly align in spatial pattern, although the contribution of shallow coastal and estuarine habitats is likely underestimated due to survey and gear limitations.**

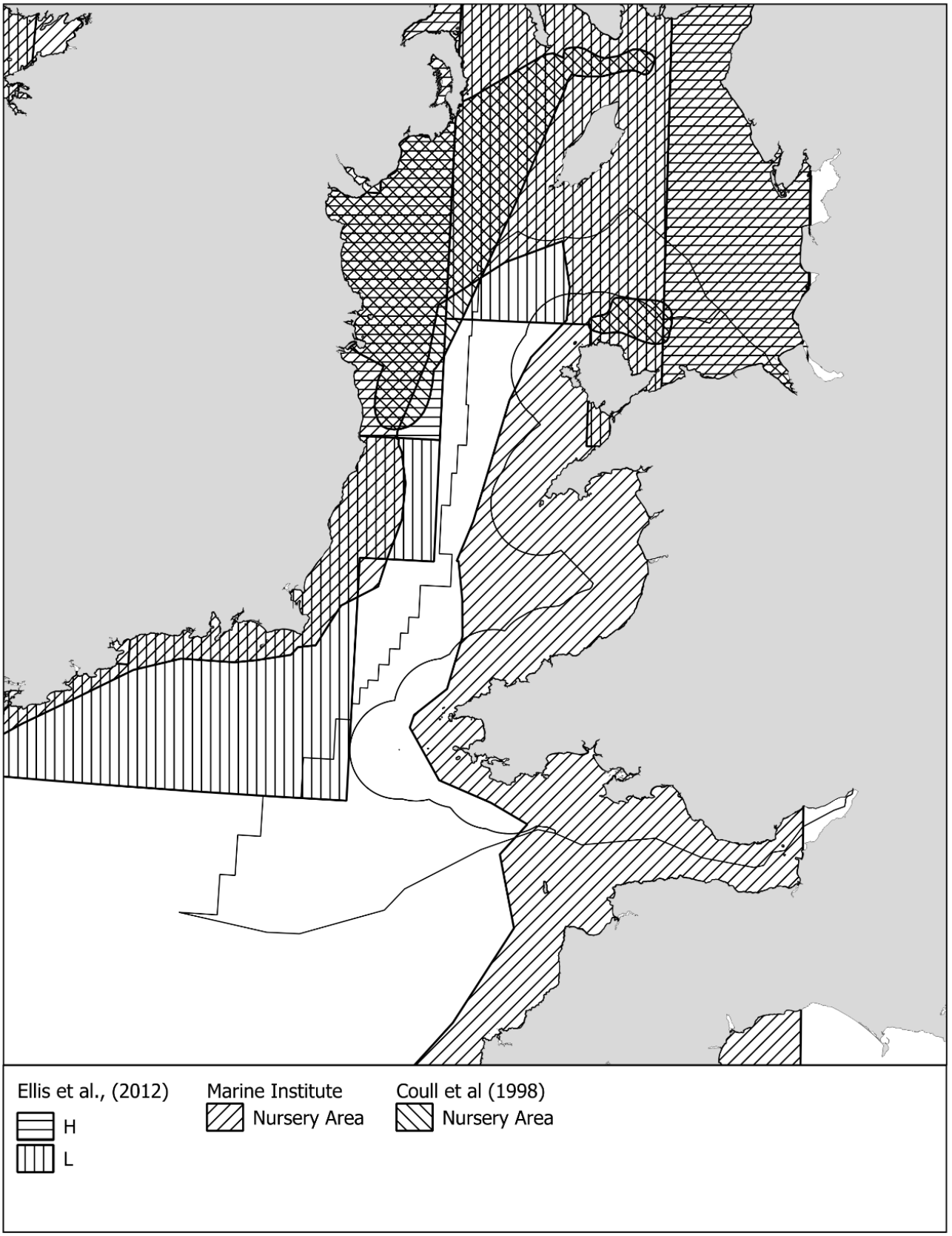


Figure 6. Synthesis map of cod nursery areas (Sources: Ellis *et al.*, 2012; Coull *et al.*, 1998; Marine Institute, 2018)

3.3.5 Life stage – adults

Once mature, cod are bentho-pelagic with a wide depth range and are most common between the shore and depths of 600m (Wheeler, 1969). Adult cod in the Celtic Sea exhibit seasonal movements between offshore feeding habitats and more coastal spawning areas. Tagging studies indicate that mature cod typically occupy deeper offshore habitats, including wrecks and reef-associated grounds, during summer months, before moving into shallower inshore areas during winter to spawn. Following the spawning period, adults disperse more widely offshore to feeding grounds. These movements are generally regional rather than long-distance migrations, with tagging evidence indicating limited exchange with adjacent stock areas (Connolly *et al.*, 2000).

Data relating to adult cod in Welsh waters were collated from a range of sources including fisheries-independent surveys and records collection, periodical reviews of species distributions including essential fish habitats, as well as commercial catch data collected by fisheries authorities and recreational sea angling catch data, as well as an academic paper by Ellis *et al.* (2024). The datasets reviewed comprise of:

- Spawning and nursery grounds of forage fish in Welsh and surrounding waters (Campanella and van der Kooij, 2021);
- Species occurrence records in Welsh waters (OBIS, 2025);
- DATRAS Fisheries-independent trawl survey data (ICES, 2025a);
- Sea Angling Diary catch records 2016-2024 (Cefas, 2025);
- AquaMaps standardized species distribution maps (AquaMaps, 2025);
- Highly mobile fish species distributions in UK waters (Cefas/ABPmer, 2010);
- WFD Transitional fish surveys (NRW, 2025); and
- Commercial fisheries landings and discards data (MMO, 2025).

Further detail on each dataset is provided in Appendix 3.

3.3.5.1 Synthesis of adult distribution evidence

The spatial distribution of adult cod in Welsh and adjacent waters is informed by multiple sources, including fisheries-independent surveys, commercial catch records, and global biodiversity databases. Collectively, these datasets depict a broadly consistent pattern of adult cod presence, highlighting areas of recurrent occurrence, seasonal shifts, and variable offshore and inshore occupancy.

Spatial syntheses, such as Campanella and van der Kooij (2021), highlight persistent adult cod hotspots in Welsh offshore waters in St George's Channel, with additional modelled hotspots around Anglesey. These patterns are consistent with DATRAS survey data (2000–2025), which show elevated adult abundances in winter (Q1) in offshore areas south of the Isle of Man and around northeast Anglesey, whereas in summer and autumn (Q3–Q4) adults are more frequently recorded closer to shore, including in Carmarthen Bay and around Anglesey. DATRAS observations indicate that adult cod tend to move seasonally between inshore and offshore areas, reflecting behavioural shifts outside the spawning period.

Fisheries-independent survey datasets from Cefas (2010) and Ellis *et al.* (2024) broadly corroborate these patterns. Both sources suggest elevated densities around Anglesey relative to Cardigan Bay and the Celtic Sea, aligning with the persistent signal observed in Campanella and van der Kooij (2021). Ellis *et al.* (2024) also highlight minor westward and southward shifts in Irish Sea cod centre of gravity over recent decades, although these movements are modest and potentially influenced by sampling bias.

Point-based occurrence data from OBIS (2025) and Natural Resources Wales (NRW, 1997–2024) reveal localised adult presence within Welsh inshore waters, particularly in the upper Severn Estuary, the Bristol Channel, and around the Dee Estuary. These records, though sparse, demonstrate that adults continue to occupy inshore estuarine and coastal areas, consistent with the broader coastal concentration observed for eggs, larvae, juveniles and nursery areas. However, the spatial density of adult records in Cardigan Bay remains low across datasets, mirroring the limited egg, larvae juvenile and nursery signals in this region, and likely reflects both genuine low abundance and uneven sampling coverage.

Commercial catch data from MMO (2014–2024) indicate generally low landings and discards across Welsh waters, with notable exceptions in the Bristol Channel and around Pembrokeshire. Cardigan Bay and the North Wales coast consistently show low catches, whereas the highest catches intersect with Welsh offshore waters along the east coast of Ireland. This pattern aligns with adult occurrence observed in survey datasets, reinforcing the interpretation of relatively sparse adult cod in northern and western inshore areas compared with localized offshore concentrations.

Adult cod distribution from sea angling records concentrated along the North Wales coast and in the Bristol Channel generally support the information available on known areas where sea angling can capture the species, and also matches juvenile distributions.

When considered alongside earlier life stages, adult cod distribution demonstrates partial continuity with egg, larvae juvenile and nursery patterns. Adults persist around Anglesey and northeast coastal regions, overlapping with the strongest nursery and juvenile signals along the north Wales coast. Seasonal and ontogenetic shifts are apparent, with adults occupying deeper offshore waters during Q4 and Q1, contrasting with the more coastal and estuarine distribution of juveniles.

Overall, the synthesis (See Figure 7), indicates that adult cod in Welsh waters are broadly distributed but occur at relatively lower densities than in adjacent areas outside Welsh waters, with consistent presence in offshore Welsh waters, around Anglesey, and in specific inshore estuaries. Seasonal movements between inshore and offshore habitats are evident, consistent with the wider understanding that cod undertake seasonal inshore–offshore migrations, occupying deeper offshore habitats during summer and moving inshore to spawn in winter (Marine Institute, 2000), and adult distributions partially mirror nursery and juvenile hotspots, suggesting some spatial continuity across life stages. Uncertainty remains in regions of low sampling effort, particularly Cardigan Bay and parts of the Bristol Channel, including especially in inshore and estuarine waters, as well as uneven sampling effort through time and by gear. This highlights the need to interpret adult

occurrence alongside historical records, fisheries-independent surveys, and commercial catch data.

Key results:

- **Adult cod occur at generally low densities within Welsh waters but are more widely distributed than younger life stages.**
- **Seasonal inshore–offshore movements may be evident, with adults persistently present around Anglesey and adjacent offshore areas.**
- **Adult distribution patterns suggest functional connectivity with wider Irish Sea and Celtic Sea populations rather than the presence of a distinct adult population solely resident within Welsh waters.**

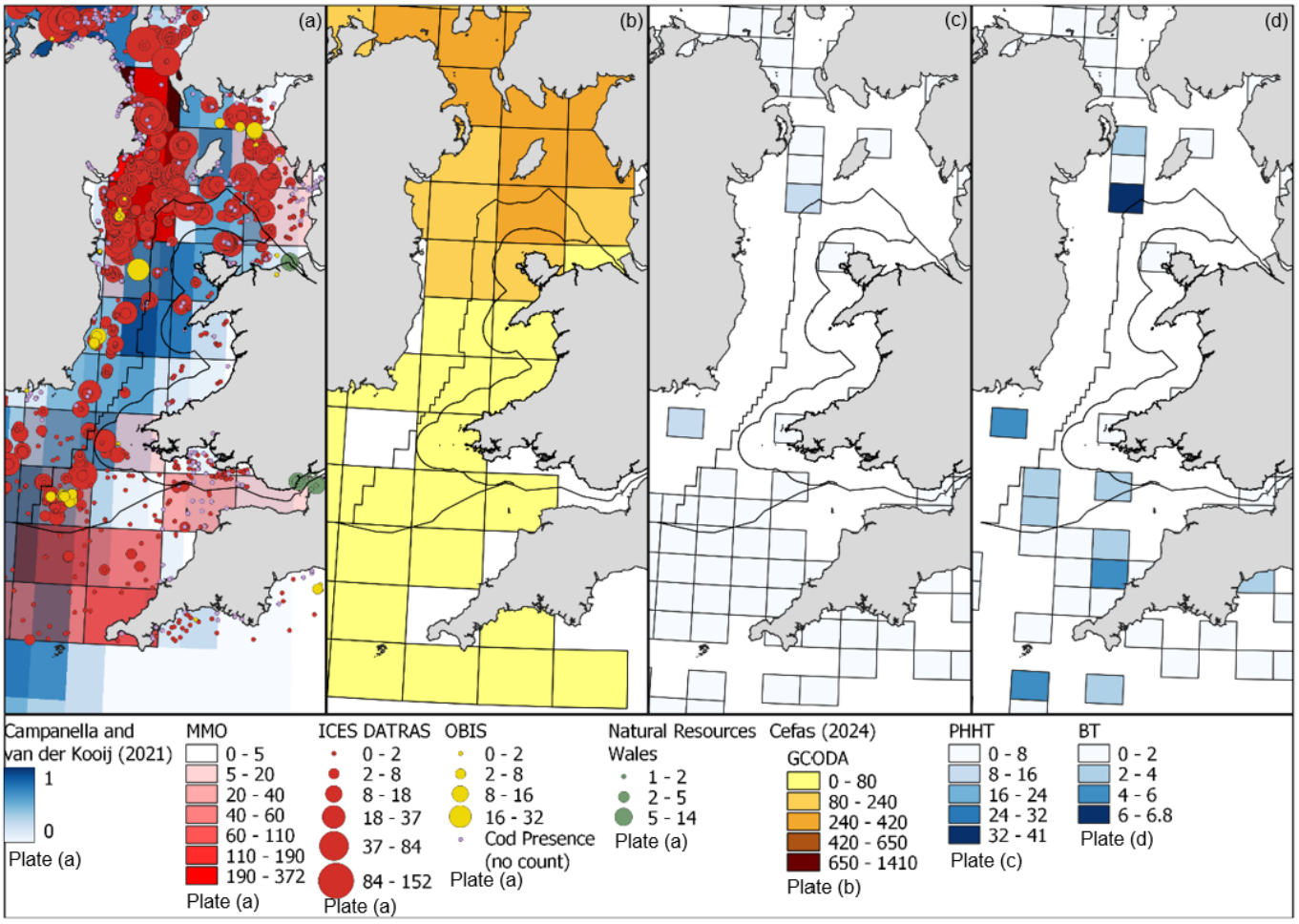


Figure 7. Synthesis map for adult cod showing areas of relative importance from available datasets. Each plate of the figure shows separate datasets on adult cod distribution, with further description of datasets in Appendix 3 (Sources: Campanella and van der Kooij, 2021; ICES, 2025a; Cefas, 2010; Natural Resources Wales, 2025; MMO, 2025, OBIS, 2025).

3.3.6 Life cycle process – spawning grounds

Spawning coastal cod tend to have discrete spawning aggregations (Windle and Rose 2007) and predominantly originate from nearby nurseries (Wright *et al.*, 2006a). Cod tend to remain close to their spawning areas all year (Galley *et al.*, 2006; Neat *et al.,*. 2006; Wright *et al.*, 2006) and this site fidelity to spawning grounds has been demonstrated in Irish Sea cod (Fox *et al.*, 2000, Gibb *et al.*, 2007). Following spawning, cod larvae are carried by prevailing currents into shallow coastal waters. As they develop and reach approximately 2 cm in length, juveniles settle near the seabed and, by late summer, become concentrated in coastal areas (Cefas, 2000b).

In the Celtic and Irish Seas, cod spawning typically occurs from January to May, with peak activity between March and April (Campanella and van der Kooij, 2021). The timing of spawning interacts with environmental conditions, particularly water temperature and oxygen concentration, both of which influence embryonic development rates.

In the Irish Sea a daily cod egg production curve showed that spawning was at its peak in the beginning of March (Dransfeld *et al.*,2004). Most cod in the Celtic Sea spawn off the northern coast of Cornwall during March and April, with additional spawning activity occurring off south-east Ireland and to a lesser extent in the western English Channel.

Data relating to cod spawning areas in Welsh waters were primarily identified from efforts to map spawning and nursery layers from regional marine / fisheries authorities. The datasets reviewed comprise of five geospatial datasets and a paper by Kjesbu *et al.* (2023):

- Fisheries spawning and nursery areas in British waters (Coull *et al.*, 1998);
- Spawning and nursery grounds of selected fish species in UK waters (Ellis *et al.*, 2012);
- Species spawning and nursery areas (Marine Institute, 2018; revised 2024);
- Spawning and nursery grounds of forage fish in Welsh and surrounding waters (Campanella and van der Kooij, 2021); and
- Essential Fish Habitats project data (Marine Directorate, 2023).

Further detail on each dataset is provided in Appendix 3.

3.3.6.1 Synthesis of spawning ground distribution evidence

The available evidence indicates that cod spawning in Welsh and adjacent waters is spatially structured and concentrated in a limited number of recurrent areas (Figure 8). The strongest and most consistent signal occurring in Welsh waters is along the north Wales coast and extending into the central Irish Sea (Figure 8). There is also a known spawning ground in the Celtic Sea off Trevose Head that may partially extend into Welsh waters. When the mapped spawning grounds from Coull *et al.* (1998), Ellis *et al.* (2012), Campanella and van der Kooij (2021), the Marine Institute (2018), Kjesbu *et al.* (2023) and the Marine Directorate (2023) are considered collectively, a coherent pattern emerges despite differences in methodology and spatial resolution.

Across multiple sources, an important spawning area is consistently identified along the north Wales coast, with particular emphasis on waters east of Anglesey, off the Great Orme and extending northwards into the Irish Sea towards the Isle of Man. This area is depicted as a lower-intensity spawning ground by Coull *et al.* (1998), but as a high-intensity spawning area by Ellis *et al.* (2012), based on egg and larval distributions, and the egg and larval data sections presented above support this. Evidence from Campanella and van der Kooij (2021) provides only partial support for this pattern, identifying a limited area of elevated adult persistence during Q1 located north of Anglesey and south of the Isle of Man, straddling Welsh inshore waters and the median line, rather than directly along the north Wales coast. Longer-term changes inferred by Kjesbu *et al.* (2023) suggest a southward shift of spawning activity into Welsh waters between the 1960s and 2000s, while centres of gravity analyses for Irish Sea cod (Ellis *et al.*, 2024) indicate a broader southward and westward movement of adult distributions over time, lending independent support to the continued importance of the north Wales–central Irish Sea region for spawning cod.

Additional spawning areas intersect Welsh waters, although less consistently than the north Wales–central Irish Sea spawning ground. A recurring spawning area southwest of the Isle of Man is identified by both Coull *et al.* (1998) and Ellis *et al.* (2012). While the spawning ground delineated by Coull *et al.* (1998) lies outside Welsh waters, the corresponding area mapped by Ellis *et al.* (2012) extends southwards across the median line into Welsh offshore waters. More recent evidence from Campanella and van der Kooij (2021), based on adult persistence during the spawning period, indicates elevated activity in this area that overlaps with Welsh inshore waters, suggesting that spawning activity associated with this offshore region may extend further south and east than indicated by earlier egg- and larval-based products, although this does not necessarily imply a discrete shift in spawning location.

A further spawning area is identified in the Celtic Sea and outer Bristol Channel, extending largely through Welsh offshore waters and English waters with only limited overlap into Welsh inshore waters. This area extends over the Trevose Bank which is a known spawning ground for the species. While the Marine Institute (2018) dataset depicts a much more extensive spawning area extending into the inner Bristol Channel, this is not strongly supported by the other sources. In the absence of corroborating egg, larval, or fisheries-independent survey evidence, the inshore extent of this spawning area should be interpreted cautiously and may reflect expert judgement applied in data-poor coastal waters rather than confirmed spawning activity, though the area is an important nursery and overwintering ground for juvenile and sub-adult cod.

The spatial extent of spawning grounds varies markedly between datasets, reflecting methodological differences. Egg and larval-based products (Ellis *et al.*, 2012) produce more spatially constrained spawning areas, while adult-based persistence analyses (Campanella and van der Kooij, 2021) suggest broader spawning extents that may overestimate true spawning habitat by including pre- or post-spawning adult presence. Modelled EFH outputs (Marine Directorate, 2023) further contrast with mapped products, indicating a more restricted, predominantly offshore spawning habitat, with high confidence absence across much of Welsh inshore waters, including areas of well documented spawning areas. These differences highlight uncertainty in defining precise spawning

boundaries and emphasise the importance of considering spawning evidence in relation to data type and biological interpretation.

There is also uncertainty regarding the consistency with which individual spawning grounds are used across years. While multiple spawning areas are identified within the Irish Sea, there is no strong evidence of population sub-structure. Cod are known to exhibit fidelity to local spawning grounds, raising the possibility that the same population may utilise different spawning areas in the Irish in different years depending on environmental conditions, rather than all areas being used simultaneously each year. This potential interannual variability is not well resolved by the available datasets but represents an important source of uncertainty when interpreting mapped spawning grounds.

Overall, the synthesis indicates that cod spawning in Welsh and adjacent waters is most strongly associated with the north Wales–central Irish Sea region, with additional spawning areas in the Celtic Sea in Welsh offshore waters and offshore Welsh waters southwest of the Isle of Man. Evidence from Ellis *et al.* (2012) and Coull *et al.* (1998) identifies the northern and offshore sites, while Campanella and van der Kooij (2021) provide recent observations supporting high adult persistence in the Celtic Sea. While long-term trends suggest a general southward shift in adult distributions in the north, patterns in the Welsh offshore waters in the Celtic Sea are less clear and may indicate slight northward or stable tendencies, though this could also reflect sampling variability. Spawning distributions broadly align with adult winter distributions, but uncertainty remains highest in inshore and data-poor areas such as the inner Bristol Channel. These patterns should therefore be interpreted alongside adult distribution evidence and with consideration of methodological differences, potential interannual variability in spawning ground use, and limitations of each dataset.

Key results:

- **Spawning grounds are identified in the north Wales–central Irish Sea region including within some inshore waters, supported by evidence from egg, larval and adult distribution patterns.**
- **Additional spawning activity is indicated in offshore areas of Welsh offshore waters and southwest of the Isle of Man, although spatial extent varies between evidence types.**
- **Several high intensity spawning areas occur adjacent to Welsh waters, which supply egg, larvae and juvenile cod into Welsh waters, such as from the Trevose Head spawning ground.**
- **Differences between egg-, larval-, adult- and model-based products highlight uncertainty in defining precise spawning boundaries and emphasise the need for caution in interpretation.**

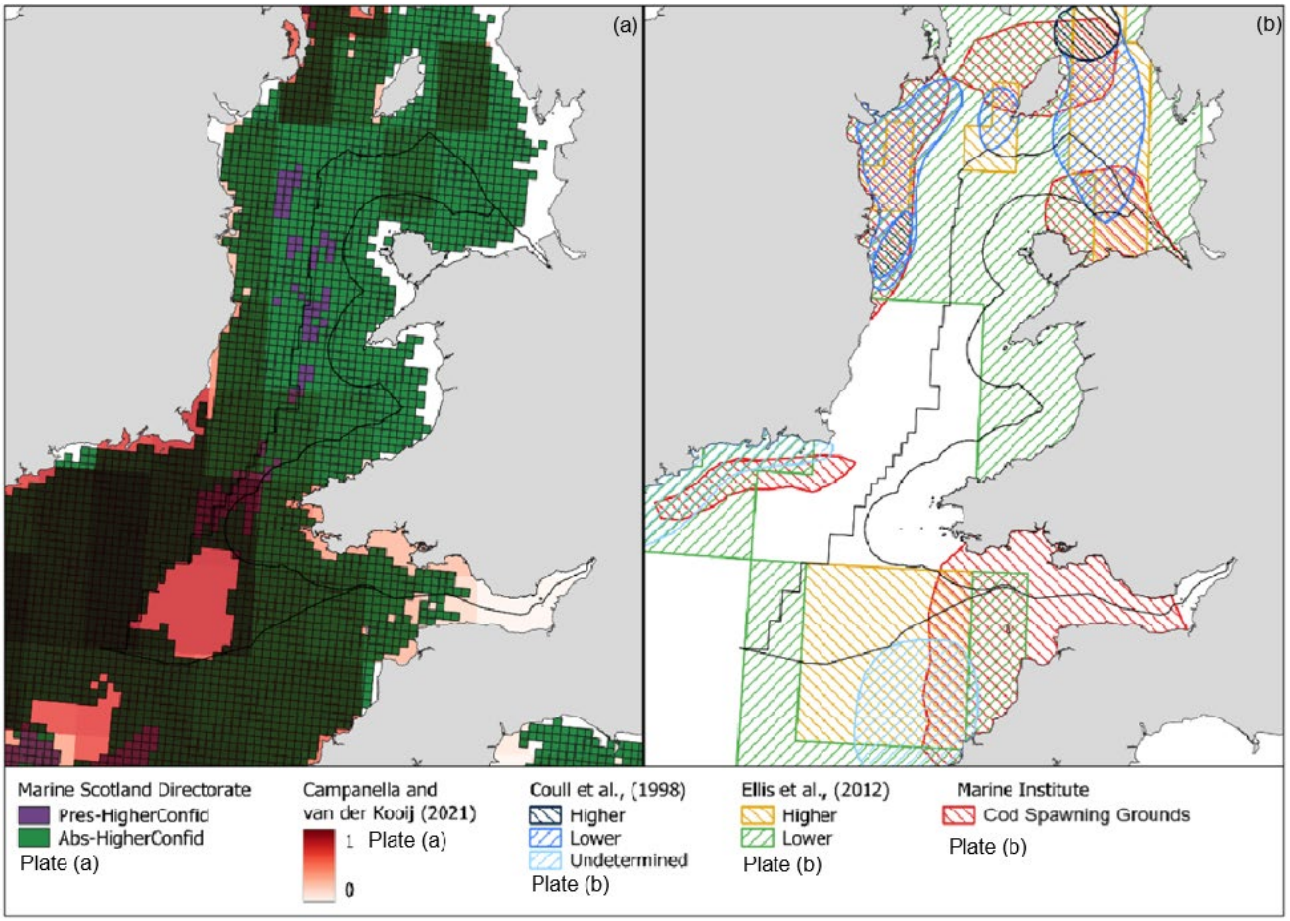


Figure 8. Synthesis map of cod spawning areas by overlaying spatial data layers (Sources: Campanella and van der Kooij, 2021; Ellis *et al.* 2012; Coull *et al.*, 2012; Scottish Marine Directorate, 2023; Marine Institute, 2018).

3.4 Population and genetic structure

This section describes cod population and genetic structure in Welsh and surrounding waters.

3.4.1 Tagging and movement studies

A synthesis of cod tagging studies around the British Isles indicates complex patterns of home range distribution and inter-basin mixing. Neat *et al.* (2014) summarised 1,674 tagged individuals, of which 252 were recovered, categorising fish according to the sea basin of capture. For Welsh waters, the most pertinent data are from individuals released in the Irish Sea, Celtic Sea, and Western Channel. Key findings have been included below and are displayed in Figure 9.

During the spawning period (January–April), home ranges of Celtic Sea cod were largely confined to the South Wales coast. Western Channel cod exhibited broader distributions, extending through Cardigan Bay and along the west coast of Anglesey, occupying a larger area of inner Welsh waters than Celtic Sea fish. Cod originating from the Irish Sea were

distributed throughout outer Welsh waters, with some overlap in inner waters. Notably, there was limited movement between spawning grounds. While some Irish Sea individuals moved south into areas overlapping Celtic Sea cod, Celtic Sea individuals were not observed moving north into the Irish Sea, and evidence for cross-basin spawning exchange remained limited.

Outside the spawning period, home ranges shifted slightly but largely overlapped, except for Celtic Sea and Irish Sea individuals, whose overlap was restricted to the spawning period. Western Channel cod continued to occupy the largest inferred home ranges, although this may partly reflect the spatial distribution of tagging locations rather than actual behaviour. While these patterns indicate some degree of cross-basin mixing, particularly outside spawning, the direction and extent of movement appear limited. Notably, ICES (2025) reports evidence from a major Irish Sea tagging programme (1997–2000) of movement from the Irish Sea into the Celtic Sea, but no movement in the reverse direction. This asymmetry aligns with the conclusions of Neat *et al.* (2014), suggesting that regional fidelity remains a key feature of cod population dynamics, with cross-basin exchange occurring but not sufficient to obscure underlying population structure.

Cardigan Bay may represent a zone of overlap between Celtic Sea and Irish Sea cod, as suggested by the spatial distribution of inferred home ranges from tagging studies, although direct evidence of mixing remains limited.

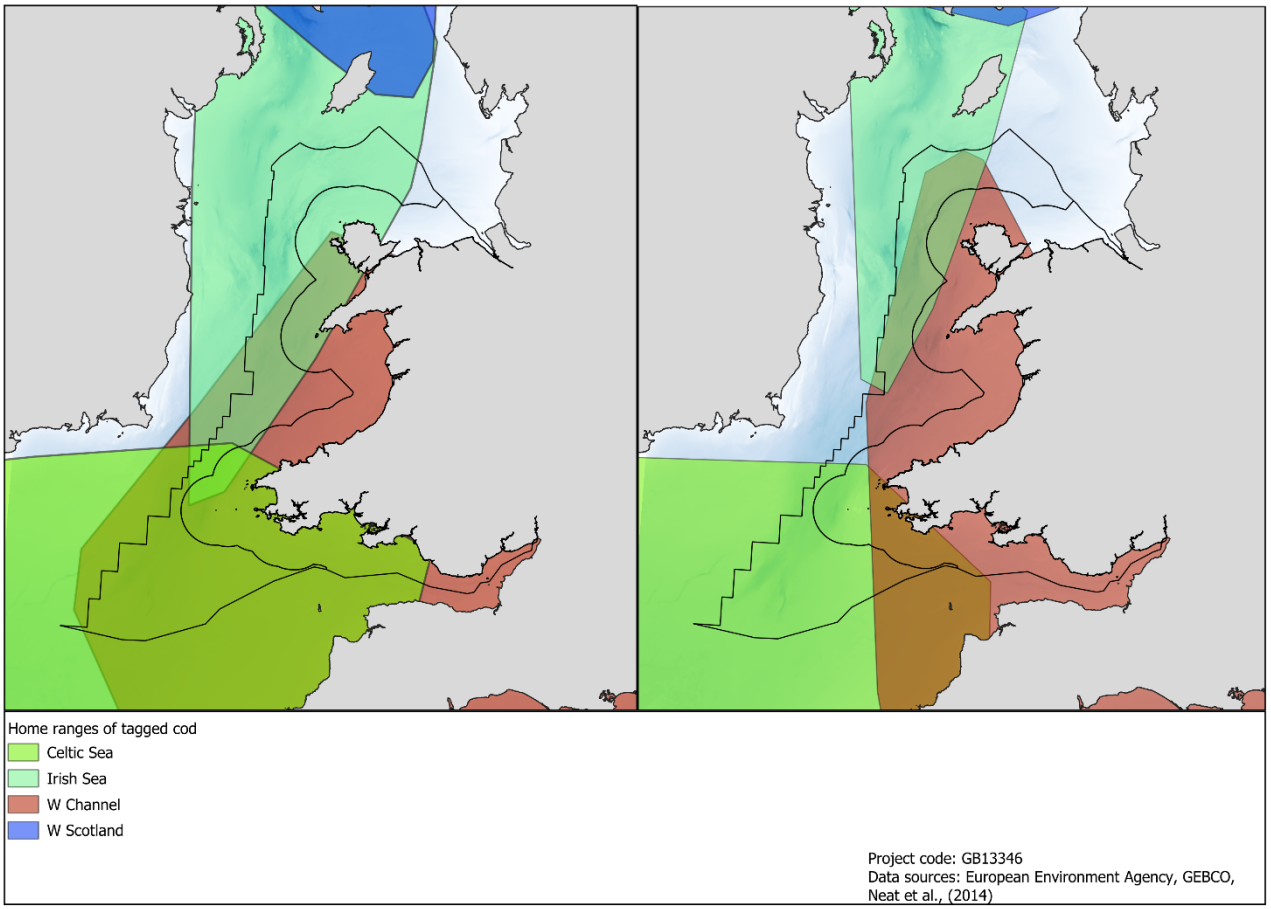


Figure 9. Home ranges of cod within their spawning period (left) and outside of their spawning period (right) (Neat *et al.*, 2014).

3.4.2 Genetic studies

Genetic analyses of cod in the Irish Sea and surrounding waters, including studies of meristic traits, allele frequencies, and microsatellite markers, have not provided unequivocal evidence of genetically isolated populations. However, these studies also do not support complete panmixia. The available evidence suggests that levels of mixing are sufficient to maintain gene flow across the wider region, while the majority of individuals exhibit fidelity to local populations and spawning grounds. As a result, genetic homogeneity likely reflects intermittent exchange rather than extensive demographic mixing. In combination with tagging evidence for regional spawning fidelity, this behavioural structuring supports the treatment of ICES Divisions 7.a (Irish Sea) and 7.e–k (Celtic Sea and Western Channel) as separate management units (ICES, 2025b).

3.4.3 Egg and larval transport

Post-spawning egg and larval distributions are influenced by prevailing tidal and residual current regimes in the Celtic Sea, Irish Sea, and Bristol Channel. Transport pathways from known or inferred spawning grounds may therefore result in the advection of early life stages away from their point of origin. In the wider region, dominant circulation patterns

include northward transport from the south-east coast of Ireland into the Irish Sea, followed by eastward flow towards the Isle of Man, as well as southward transport from the northern Irish Sea towards the Isle of Man. In the Celtic Sea, residual flows from the vicinity of Trevose Head extend eastwards into the Bristol Channel.

These circulation patterns are likely to influence the spatial distributions of eggs and larvae presented in the preceding sections. As a result, the presence of eggs or larvae in a given area does not necessarily indicate local spawning activity, particularly in regions subject to strong tidal advection. Interpretation of egg and larval data therefore carries inherent uncertainty and must be considered alongside information on adult distribution, spawning behaviour, and movement patterns. The integration of early life-stage observations with adult data is necessary to distinguish between areas of spawning activity and areas of passive accumulation driven by physical transport processes.

3.4.4 Synthesis of population and genetic structure evidence

Two nominal stocks of cod may be found in Welsh waters; the South western stock and the Irish Sea stock (Ellis *et al.*, 2010). Taken together, evidence from tagging studies, genetic analyses, and egg and larval transport indicates that cod populations in the Irish Sea–Celtic Sea region are characterised by weak but ecologically meaningful connectivity. Tagging data demonstrate strong fidelity to regional spawning grounds in both the Irish Sea and Celtic Sea, with limited exchange between basins during the spawning period. Outside spawning, some overlap in home ranges occurs, particularly involving Western Channel individuals, but movements remain constrained and do not obscure underlying population structure. Exchange between the Irish Sea and Celtic Sea is asymmetrical, with adult movement predominantly occurring from the Irish Sea southwards, and little evidence of movement in the opposite direction.

Genetic studies are consistent with this pattern, showing no strong genetic differentiation between regions, but also no evidence of complete panmixia. The observed genetic homogeneity is therefore best explained by intermittent exchange sufficient to maintain gene flow, rather than extensive demographic mixing. Behavioural structuring inferred from tagging data reinforces the appropriateness of treating ICES Divisions 7.a and 7.e–k as separate management units, despite the absence of clear genetic isolation.

The distribution of eggs and larvae further reflects the influence of physical transport processes, with prevailing tidal and residual currents capable of advecting early life stages away from spawning grounds. Consequently, the presence of eggs or larvae in a given area cannot be assumed to indicate local spawning activity in isolation and must be interpreted alongside adult distribution and movement data.

Within Welsh waters, Cardigan Bay emerges as a potential zone of overlap between Celtic Sea and Irish Sea cod, reflecting broader regional mixing patterns rather than evidence of a discrete spawning component. Although spawning grounds are not identified within Cardigan Bay, its position relative to inferred home ranges and circulation patterns

suggests it may function as a transitional area for juveniles or feeding adults, rather than a primary reproductive area.

Overall, the combined evidence supports a population structure characterised by localised spawning fidelity, limited and asymmetrical connectivity between basins, and sufficient gene flow to prevent strong genetic differentiation. This integrated interpretation aligns with ICES stock assessments and the findings of Neat *et al.* (2014), highlighting the importance of combining behavioural, genetic, and oceanographic evidence when assessing population structure and identifying functionally important areas.

Key results:

- **Cod show strong regional fidelity to spawning grounds in the Irish Sea, Celtic Sea, and Western Channel, with limited and asymmetrical movement between basins.**
- **Irish Sea to Celtic Sea movement occurs outside spawning, but reciprocal movement is rare; Western Channel cod show broader, overlapping home ranges.**
- **Genetic analyses indicate no strong differentiation but also not complete panmixia; gene flow is likely maintained by intermittent exchange.**

3.5 Summary of uncertainties and evidence gaps

This subsection describes the uncertainties and evidence gaps identified during the review of cod population distribution and structure evidence. Important uncertainties and evidence gaps identified are:

- Inshore waters and estuaries are poorly represented in available datasets with the exception of WFD sampling data in estuaries (NRW, 2025) and Sea Angling Diary data (Cefas, 2025); offshore trawl surveys from wider monitoring are unable to adequately sample early juvenile cod due to gear limitations.
- Depth constraints limit spatial coverage, with some mapped products excluding waters shallower than 20m depth, while offshore survey vessels cannot operate effectively in shallow coastal zones, likely underestimating the importance of nearshore habitats.
- Survey spatial coverage is fragmented, with most programmes focusing on either the Irish Sea or Celtic Sea, rarely both concurrently, and there is sparse data coverage in areas such as Cardigan Bay.
- Temporal limitations are significant, as single-season or short-duration surveys cannot capture seasonal movements or interannual variability in cod distribution and habitat use.
- Spatial uncertainty in spawning extent arises from differences between egg, larval, adult and model-based products, complicating the delineation of spawning grounds.
- Qualitative evidence from recreational sea angling indicates continued cod presence in inshore and coastal waters across multiple seasons, but these records cannot provide quantitative estimates of abundance or recruitment.

4 Conclusions and discussion

This section synthesises the evidence collated for cod to identify broad spatial patterns, data availability, and key uncertainties in their use of Welsh waters. This section focuses on life-stage connectivity, spatial structure, data coverage, and highlights implications for future monitoring and management.

The methodological approach taken to this review could be applied to additional species in future work. Cod are, however, a relatively data-rich species in Welsh waters and so data gaps and uncertainties may be more significant for other species.

4.1 General trends in life stages and spatial distribution

Cod have spawning and nursery grounds in Welsh waters of the Irish Sea and Celtic Sea indicating the importance of Welsh waters at maintaining wider Irish Sea and Celtic Sea populations.

Inshore bays, estuaries, and sheltered coastal habitats in Welsh waters of both the Irish Sea and the Bristol Channel serve as primary nursery grounds, supporting juveniles before offshore seasonal migrations commence and wider dispersal occurs in sub-adult and adults phases.

Adult densities in Welsh waters are generally lower than juvenile densities, with adults showing a wider distribution and higher abundance in deeper Irish Sea and Celtic Sea waters. Adults show seasonal movements into and through Welsh waters, reflecting broader metapopulation connectivity rather than long-term residency.

Connectivity between life stages and between areas inside and outside Welsh waters is a consistent pattern: eggs and larval movements into nursery grounds from spawning grounds is evident, along with juvenile dispersal from nursery grounds to wider adult populations across the Irish Sea and Celtic Sea.

4.2 Spatial coverage and data strengths

The Irish Sea off the North Wales coast are the well characterised regions for cod, with alignment in evidence across multiple datasets for many of the life stages of the species reviewed.

Historical datasets and older analyses of cod abundance and distribution complement contemporary analysis of the latest survey data, allowing insights into temporal changes in spatial distribution and also verification of conclusions through time.

Genetic, otolith, and tagging studies provide evidence of population connectivity, regional mixing, and metapopulation structure, which informs understanding of broader stock dynamics.

4.3 Limitations and key uncertainties

Survey effort and spatial coverage is uneven. Many studies only focus on parts of Welsh waters, making the ability to compare data across Welsh waters complex. Furthermore, Cardigan Bay, the Bristol Channel and the Celtic Sea are underrepresented in egg, larval, juvenile, and adult sampling compared to the Irish Sea.

Temporal and interannual replication is also limited across datasets. While surveys such as ICES DATRAS provide annual coverage, sampling is concentrated in specific quarters (primarily Q1, Q3 and Q4), with limited representation of Q2 and transitional periods. Many other datasets provide only short-term or seasonally restricted sampling. This constrains interpretation of seasonal habitat use, larval abundance, and juvenile dispersal, particularly in Cardigan Bay and the Bristol Channel where long-term monitoring over multiple seasons is sparse.

Standard trawl-based surveys using larger vessels are limited in their ability to sample shallow or structurally complex habitats, which may lead to further underrepresentation of these areas in available datasets.

Egg-stage data exist for cod derived from fisheries-independent sampling. However, these egg datasets are from limited sampling effort relative to larval, juvenile and adult fish.

Spawning ground mapping shows inconsistencies across sources. Differences in observed distributions may reflect methodological variation, variable survey effort, and temporal changes. Older sources may be documenting areas that were historically relevant but no longer function as key spawning grounds, which requires further investigation.

Environmental and ecological drivers such as water temperature, prey availability, and seabed substrates, are recognised as important for recruitment and dispersal of cod but are inconsistently integrated across datasets, limiting predictive capability.

4.4 Recommendations

Overall, enhancing and expanding established long-term survey programmes and datasets, offers a robust pathway for improving stock assessments and understanding spatial population dynamics.

Recommendation 1. Expand survey coverage:

- Target under-sampled regions, particularly Cardigan Bay, other inshore/estuarine areas, and areas with complex seabed habitats, for all life stages considering non-destructive sampling methods for sensitive habitats.
- Conduct egg and larval sampling via ichthyoplankton trawls to more closely identify spawning grounds of the species.
- Recent ichthyoplankton and fish sampling has been conducted at a local scale for development projects in the Severn Estuary, Milford Haven, Anglesey and the Dee Estuary. Also, several Welsh universities hold fish survey datasets from historic and

ongoing research and teaching cruises. A recommendation to review and integrate these data is suggested.

Recommendation 2. Standardise life-stage mapping:

- Develop best-practice methods for mapping spawning grounds and nursery grounds for cod, integrating egg, larval and juvenile data with influencing environmental variables such as water depth, water temperature and substrate type.

Recommendation 3. Integrate environmental drivers:

- Incorporate plankton abundance, temperature, hydrodynamics, and substrate type into species distribution models to improve predictions of recruitment and habitat suitability. While some general SDMs exist, bespoke models for cod in Welsh waters have not been identified in this study.

Recommendation 4. Link genetic and demographic data:

- Current ICES stock units (7a, 7b–k, etc.) provide a useful framework for assessment, but they do not fully capture localised connectivity or metapopulation dynamics.
- Genetic evidence, tagging, and otolith microchemistry indicate populations in Welsh waters are influenced by wider Irish Sea and Celtic Sea dynamics. Integrating these data into stock benchmarking could refine management units to reflect ecological connectivity, ensuring that the contribution of nursery and juvenile habitats are properly accounted for in stock management.

Recommendation 5. Implement long-term monitoring and temporal replication:

- Regular, multi-year surveys with spatial and temporal replication would be required to capture interannual variability in nursery ground use, larval abundance, and juvenile dispersal.
- Ensure coverage spans key spawning periods for the species under investigation, allowing temporal comparisons and better understanding of environmental influences on recruitment.
- Improving spatial resolution of commercial and recreational catch data would complement survey-based monitoring, helping to identify size distributions, local abundances, and areas of concentrated juvenile or adult presence.

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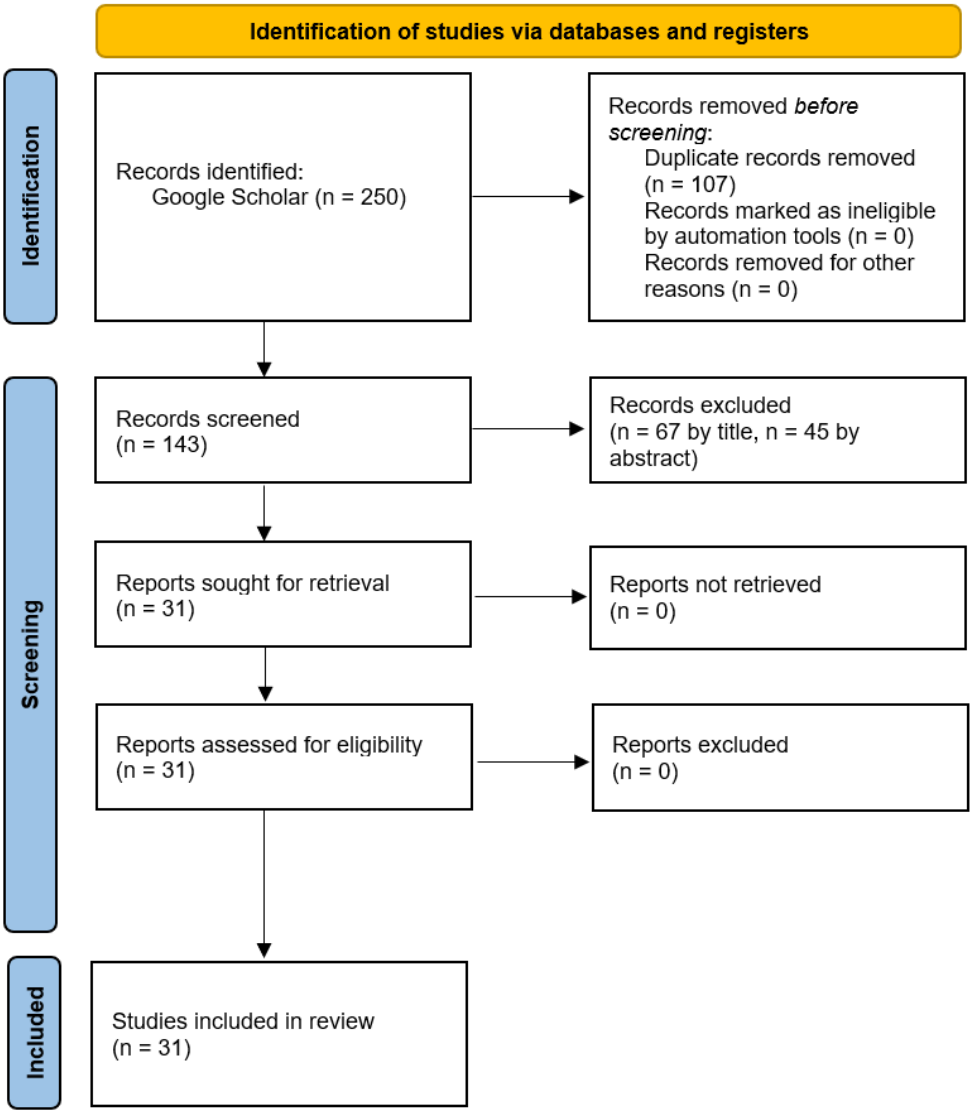
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Appendix 1: Literature search terms used

Atlantic cod (*Gadus morhua*)
(Atlantic cod OR *Gadus morhua*) AND ("Wales" OR "UK" OR "Celtic" or "Irish" OR "VII") AND "distribution"
(Atlantic cod OR *Gadus morhua*) AND ("Wales" OR "UK" OR "Celtic" or "Irish" OR "VII") AND ("egg" OR "larvae" OR "juvenile" OR "adult")
(Atlantic cod OR *Gadus morhua*) AND ("Wales" OR "UK" OR "Celtic" or "Irish" OR "VII") AND ("spawn*" OR "nursery" OR "feeding")
(Atlantic cod OR *Gadus morhua*) AND ("Wales" OR "UK" OR "Celtic" or "Irish" OR "VII") AND ("population" OR "genetic*" OR "migration" OR "home range")
(Atlantic cod OR *Gadus morhua*) AND ("Survey" OR "Sampling" OR "Monitoring")



Appendix 2: Literature confidence scores

Confidence was assessed using two criteria: type and quality of source and applicability of evidence to Welsh waters. For both criteria, scores were assigned numerically as High = 5, Medium = 3, and Low = 1. The two scores were summed to give an overall confidence score (range 2–10), which was then classified as Low (2–4), Medium (5–7), or High (8–10).

Citation	Confidence - type of source (base on evidence type)Quality of source -	Confidence - applicability of location	Overall confidence
Alheit, J., Licandro, P., Coombs, S., Garcia, A., Giráldez, A., Santamaría, M. T. G., Slotte, A., and Tsikliras, A. C. 2014. Atlantic multidecadal oscillation (AMO) modulates dynamics of small pelagic fishes and ecosystem regime shifts in the eastern north and Central Atlantic. Journal of Marine Systems, 131, 21–35. https://doi.org/10.1016/j.jmarsys.2013.11.002.	High	Low	Medium
Bastrikin, D.K., Gallego, A., Millar, C.P., Priede, I.G. and Jones, E.G. 2014. Settlement length and temporal settlement patterns of juvenile cod (*Gadus morhua*), haddock (Melanogrammus aeglefinus), and whiting (*Merlangius merlangus*) in a northern North Sea coastal nursery area. ICES Journal of Marine Science, 71(8), pp.2101-2113.	High	Low	Medium
Brander, K. M. (1977). *The management of Irish Sea fisheries-a review*. Ministry of Agriculture, Fisheries and Food.	High	High	High
Campanella, F., and van der Kooij, J. 2021. Spawning and nursery grounds of forage fish in Welsh and surroundings waters. Cefas Project Report for RSPB. Available at: https://data.cefas.co.uk/view/21465.	High	High	High
Cefas 1995. Irish Sea Annual Egg Production Method (AEPM) plankton survey. Dataset 2633. Centre for Environment, Fisheries and Aquaculture Science (Cefas) Data Portal. Available at: https://data.cefas.co.uk/view/2633 (Accessed: 5 October 2025).	High	High	High
Cefas 2000. Irish Sea Annual Egg Production Method (AEPM) plankton survey. Dataset 2641. Centre for Environment, Fisheries and Aquaculture Science (Cefas) Data Portal. Available at: https://data.cefas.co.uk/view/2641 (Accessed: 5 October 2025).	High	High	High

Citation	Confidence - type of source (base on evidence type)Quality of source -	Confidence - applicability of location	Overall confidence
Cefas 2000b. Fisheries information: Cod, sole, plaice and whiting in the south-west of the British Isles. https://www.cefas.co.uk/publications/files/fishinfo_cspw.pdf	High	Medium	High
Cefas 2006. Irish Sea fish egg production survey 2006. Dataset 3799. Centre for Environment, Fisheries and Aquaculture Science (Cefas) Data Portal. Available at: https://data.cefas.co.uk/view/3799 (Accessed: 5 October 2025).	High	High	High
Cefas 2008. Irish Sea fish egg production survey 2008. Dataset 3798. Centre for Environment, Fisheries and Aquaculture Science (Cefas) Data Portal. Available at: https://data.cefas.co.uk/view/3798 (Accessed: 5 October 2025).	High	High	High
Cefas 2009. Assessment of potential predators of plaice eggs and larvae in the Irish Sea (Dataset 727). Centre for Environment, Fisheries and Aquaculture Science (Cefas) Data Portal. Available at: https://data.cefas.co.uk/view/727 (Accessed: 5 October 2025).	High	High	High
Cefas 2010. Highly mobile fish species distributions in UK waters. Lowestoft: Cefas. Available at: https://data.cefas.co.uk/view/154 (Accessed: 5 October 2025)	High	High	High
Cefas 2010. Irish Sea fish egg production survey 2010. Dataset 2620. Centre for Environment, Fisheries and Aquaculture Science (Cefas) Data Portal. Available at: https://data.cefas.co.uk/view/2620 (Accessed: 5 October 2025).	High	High	High
Connolly, P., Joyce, J., Lordan, C., Molloy, J., Officer, R., Fahy, E., Kelly, C., Clarke, M., Stokes, D., Borges, L. and Moore, S.J., 2000. THE STOCK BOOK.	High	High	High
Coull, K.A., Johnstone, R. and Rogers, S.I., 1998. Fisheries sensitivity maps in British waters. Published and distributed by UKOOA Ltd, 9. Available at: https://data.cefas.co.uk/view/149	High	High	High
Dransfeld, L., Dwane, O., McCarney, C., Kelly, C. J., Danilowicz, B. S., and Fives, J. M. 2004. Larval distribution of commercial fish species in waters around Ireland. Marine Institute.	High	Medium	High

Citation	Confidence - type of source (base on evidence type)Quality of source -	Confidence - applicability of location	Overall confidence
Ellis, J.R., Milligan, S.P., Readdy, L., Taylor, N. and Brown, M.J. 2012. Spawning and nursery grounds of selected fish species in UK waters. Sci. Ser. Tech. Rep., Cefas Lowestoft, 147: 56 pp. Available at: https://data.cefas.co.uk/view/153	High	High	High
Ellis, J.V., Schuchert, P., Scantlebury, D.M., Marshall, C.T. and Fernandes, P.G., 2024. Variable trends in the distribution of Atlantic cod (*Gadus morhua*) in the Celtic seas. Journal of Fish Biology, 105(2), pp.512-525.	High	High	High
Engelhard, G. H. 2014. Climate change and fishing: A century of shifting distribution in North Sea cod. Global Change Biology, 20, 24732483. https://doi.org/10.1111/gcb.1251.	High	Medium	High
Geffen, A. J., Fox, C. J., and Nash, R. D. M. 2006. Temperature-dependent development rates of cod *Gadus morhua* eggs. Journal of Fish Biology, 69(4), 1060-1080.	High	Medium	High
Gubbay, S. 2009. A selective review of historical information about the marine environment around Wales. A report to WWF Cymru.	Medium	High	High
Heffernan, O. A., Danilowicz, B. S., and Milligan, S. P. 2004. Determination of species-specific spawning distributions of commercial finfish in the Irish Sea using a biochemical protein-based method. Marine Ecology Progress Series, 284, 279-291.	High	High	High
Hyder, K, Edwards, W. and Radford, Z. 2024. Sea Angling Diary Catch, Participation and Economic Estimates 2016-2021. Cefas, UK. V1. doi: https://doi.org/10.14466/CefasDataHub.151	High	High	High
ICES. 2024. icesDatras R package, version 1.4.1. Available from CRAN. URL: https://github.com/ices-tools-prod/icesDatras (Accessed: 27/10/2025).	High	High	High
ICES, 2025a. ICES Database on Trawl Surveys (DATRAS), ICES, Copenhagen, Denmark. https://datras.ices.dk	High	High	High
ICES. 2025b. Stock Annex: Stock Annex: Cod (*Gadus morhua*) in Division 7.a (Irish Sea). ICES Stock Annexes. 20 pp. https://doi.org/10.17895/ices.pub.24495970	High	High	High
ICES. 2025c. Eggs and larvae dataset. Available at: https://eggsandlarvae.ices.dk (Accessed: 5 October 2025	High	High	High

Citation	Confidence - type of source (base on evidence type)Quality of source -	Confidence - applicability of location	Overall confidence
Kjesbu, O.S., Alix, M., Sandø, A.B., Strand, E., Wright, P.J., Johns, D.G., Thorsen, A., Marshall, C.T., Bakkeplass, K.G., Vikebø, F.B. and Skuggedal Myksvoll, M., 2023. Latitudinally distinct stocks of Atlantic cod face fundamentally different biophysical challenges under on-going climate change. Fish and Fisheries, 24(2), pp.297-320.	High	High	High
Kulatska, N., Howell, D., Wright, P. J., and Jónsdóttir, I. G. (Eds.). 2024. Biology and Ecology of Atlantic Cod. CRC Press.	High	Medium	High
Marine Institute. 2000. The stock book 2000. http://hdl.handle.net/10793/615	High	High	High
Marine Institute 2018. Species spawning and nursery areas. Available at: https://atlas.marine.ie (Accessed: 27/10/2025).	High	High	High
Moore, A. B., Brander, K., Evans, S., Holm, P., and Hiddink, J. G. 2024. Century-scale loss and change in the fishes and fisheries of a temperate marine ecosystem revealed by qualitative historical sources. Fish and Fisheries, 25(5), 876-894.	High	High	High
Natural Resources Wales 2025. NRW Marine Fish Surveys 1997–2024: Species counts and length measurements. Available at: https://datamap.gov.wales/layergroups/geonode:nrw_marine_fish_surveys (Accessed: 30 January 2026).	High	High	High
Neat, F.C., Bendall, V., Berx, B., Wright, P.J., Ó Cuaig, M., Townhill, B., Schön, P.J., Lee, J. and Righton, D., 2014. Movement of Atlantic cod around the British Isles: implications for finer scale stock management. Journal of Applied Ecology, 51(6), pp.1564-1574.	High	High	High
OBIS 2025. Ocean Biodiversity Information System. Intergovernmental Oceanographic Commission of UNESCO. Available at: https://obis.org (Accessed: 27/10/2025).	Medium	High	High
Olsen, S. 1883. The piscatorial atlas of the North Sea, English Channel and St George's Channel. Fishing News (Books) Ltd, London. (Original work published 1883).	High	High	High
Otterlei, E., Nyhammer, G., Folkvord, A. and Stefansson, S.O., 1999. Temperature-and size-dependent growth of larval and early juvenile Atlantic cod (*Gadus morhua*): a comparative study of Norwegian coastal cod and northeast Arctic cod. Canadian Journal of Fisheries and Aquatic Sciences, 56(11), pp.2099-2111.	High	Low	Medium

Citation	Confidence - type of source (base on evidence type)Quality of source -	Confidence - applicability of location	Overall confidence
Peters, J. R., McCloskey, R. M., Hinder, S. L., and Unsworth, R. K. F. 2015. Motile fauna of sub-tidal Zostera marina meadows in England and Wales. Marine Biodiversity, 45(4), 647-654.	High	High	High
Reygondeau, G., Egorova, Y., Boerder, K., Tittensor, D.P., Kaschner, K., Kesner-Reyes, K., Bailly, N. and Cheung, W.W., 2025. AquaX: An enhanced and revised AquaMaps framework to model marine species distributions and biodiversity. bioRxiv, pp.2025-10.	High	Medium	High
Scottish Government, Marine Directorate. 2023. Essential Fish Habitats Project Data. doi: 10.7489/12450-1	High	High	High

Appendix 3: Population distribution datasets

A3.1. Life stage – eggs

A3.1.1. Annual Egg Production Method (AEPM) surveys 1995 and 2000 (Cefas 1995; 2000)

Spatial coverage: Irish Sea and Cardigan Bay. Cardigan Bay was sampled once in 1995

The Irish Sea AEPM surveys were conducted in 1995 and 2000 and provide egg-stage information relevant to cod in Welsh and adjacent waters. Both surveys were designed to quantify egg production for the purpose of estimating spawning stock biomass and therefore consist of point-based plankton station data rather than gridded distribution products. The 1995 survey (carried out between February and May) provides counts of fish eggs and larvae collected across the Irish Sea together with associated plankton and environmental measurements, offering broad coverage of early life-stage occurrence during that period. The 2000 survey, carried out between August and September, followed a similar sampling approach with a planned grid of stations and plankton tows, recording egg counts, larval counts, station positions and standard tow metadata.

AEPM surveys conducted in both 1995 and 2000 indicate a widespread, low count distribution of eggs across the Irish Sea, including within Welsh inshore and offshore waters (Figure 10 and Figure 11). Stations sampled in 1995 also show low counts of eggs present within Cardigan Bay, but Cardigan Bay was not sampled in 2000. Of all the stations sampled in the 1995 survey, the stations with the highest relative abundance of eggs were found in Welsh inshore waters, north and north-east of the Great Orme. However, this same pattern of high egg abundance off the North Wales coast was not found 5 years later in 2000, although this is likely to be due to differences in timing of the survey (Feb – May in 1995 vs Aug – Sept in 2000) meaning the survey in 2000 would be less likely to capture cod eggs. The stations with the highest counts of cod eggs in 2000 were in the central Irish Sea, around the Isle of Man.

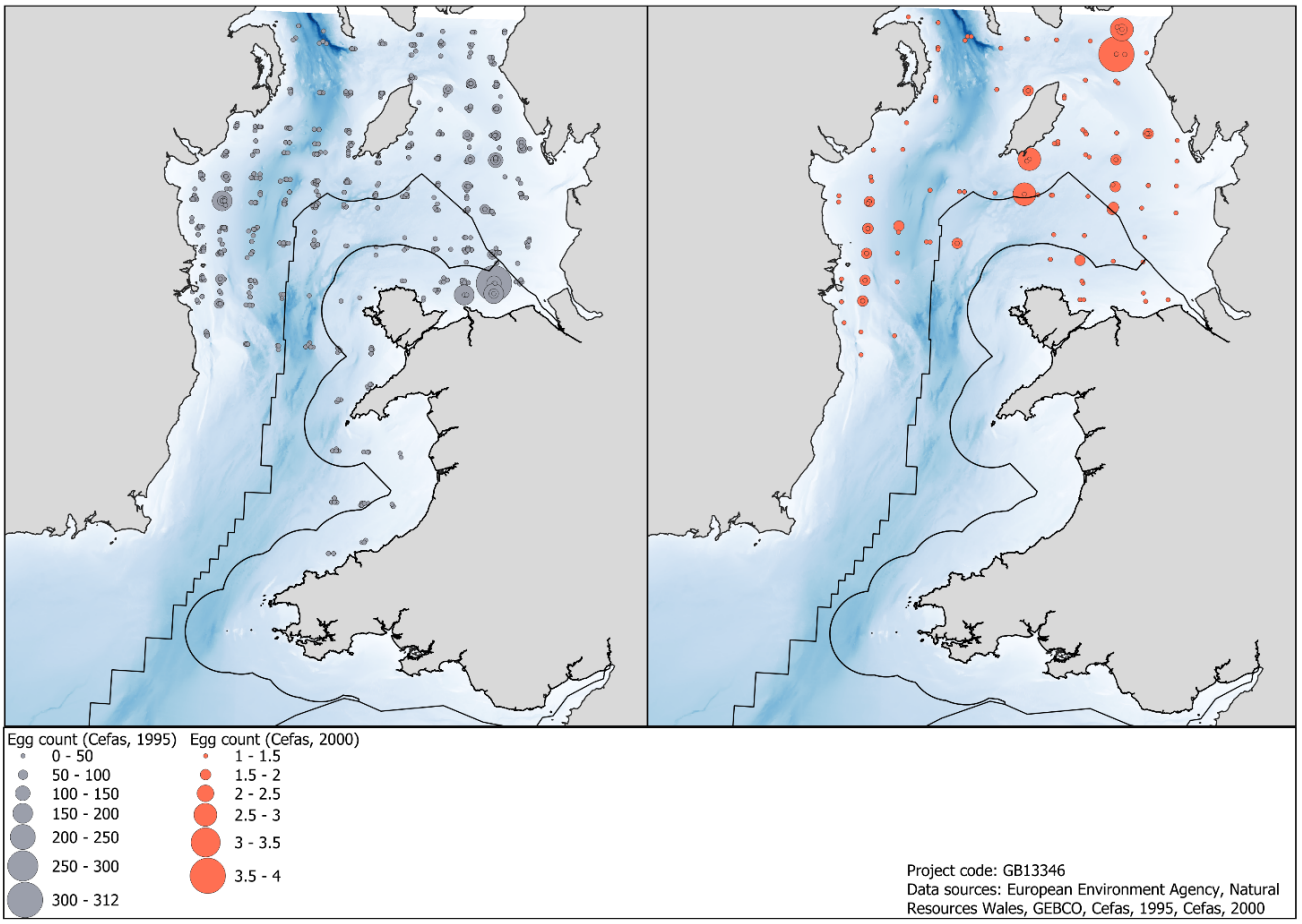


Figure 10. Egg distribution abundance from Irish Sea AEPM Plankton Survey (Source: Cefas, 1995; Cefas, 2000).

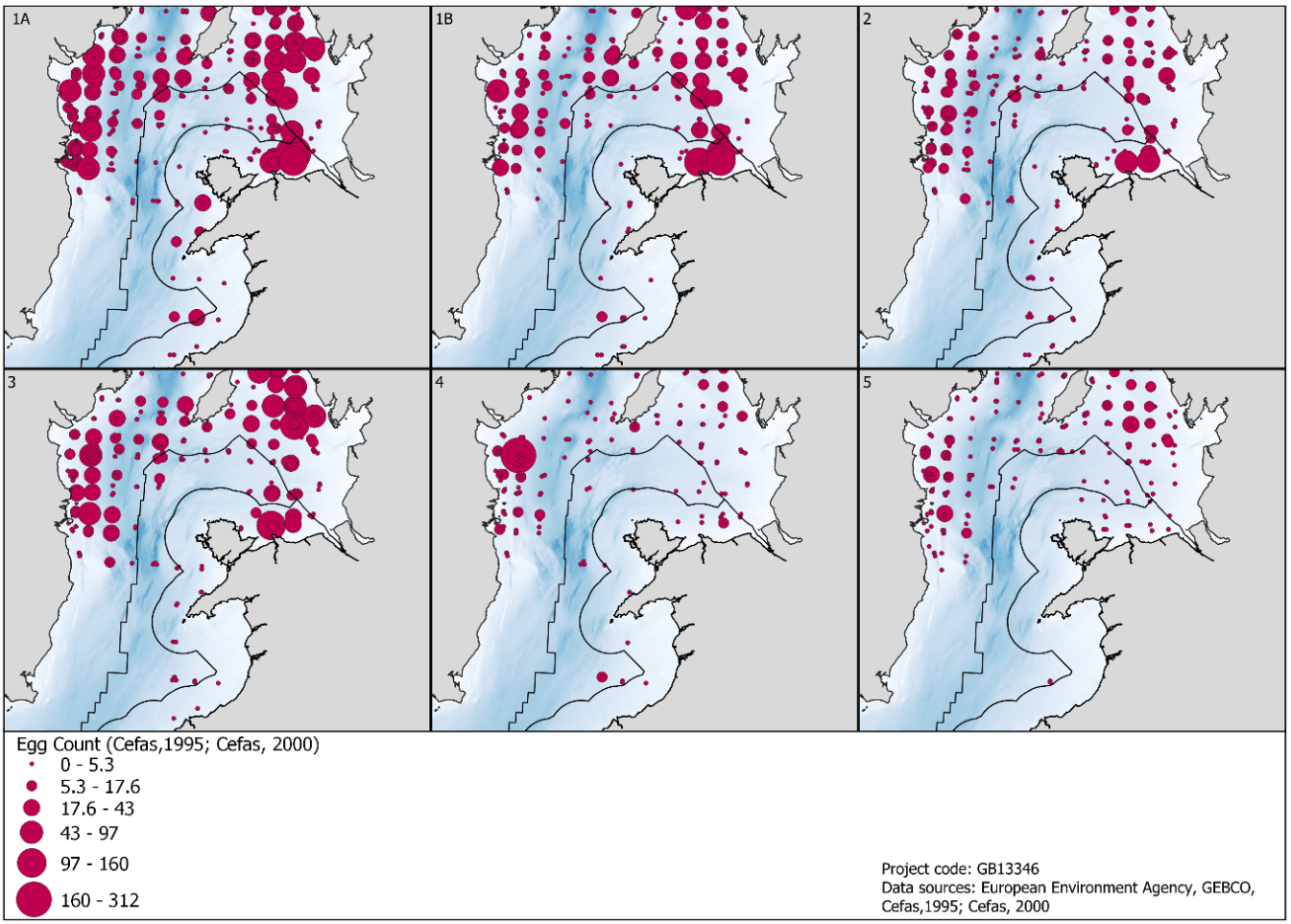


Figure 11. Egg distribution abundance from Irish Sea AEPM Plankton Survey by egg morphological stage (1A, 1B, 2, 3, 4 and 5) (Source: Cefas, 1995; Cefas, 2000).

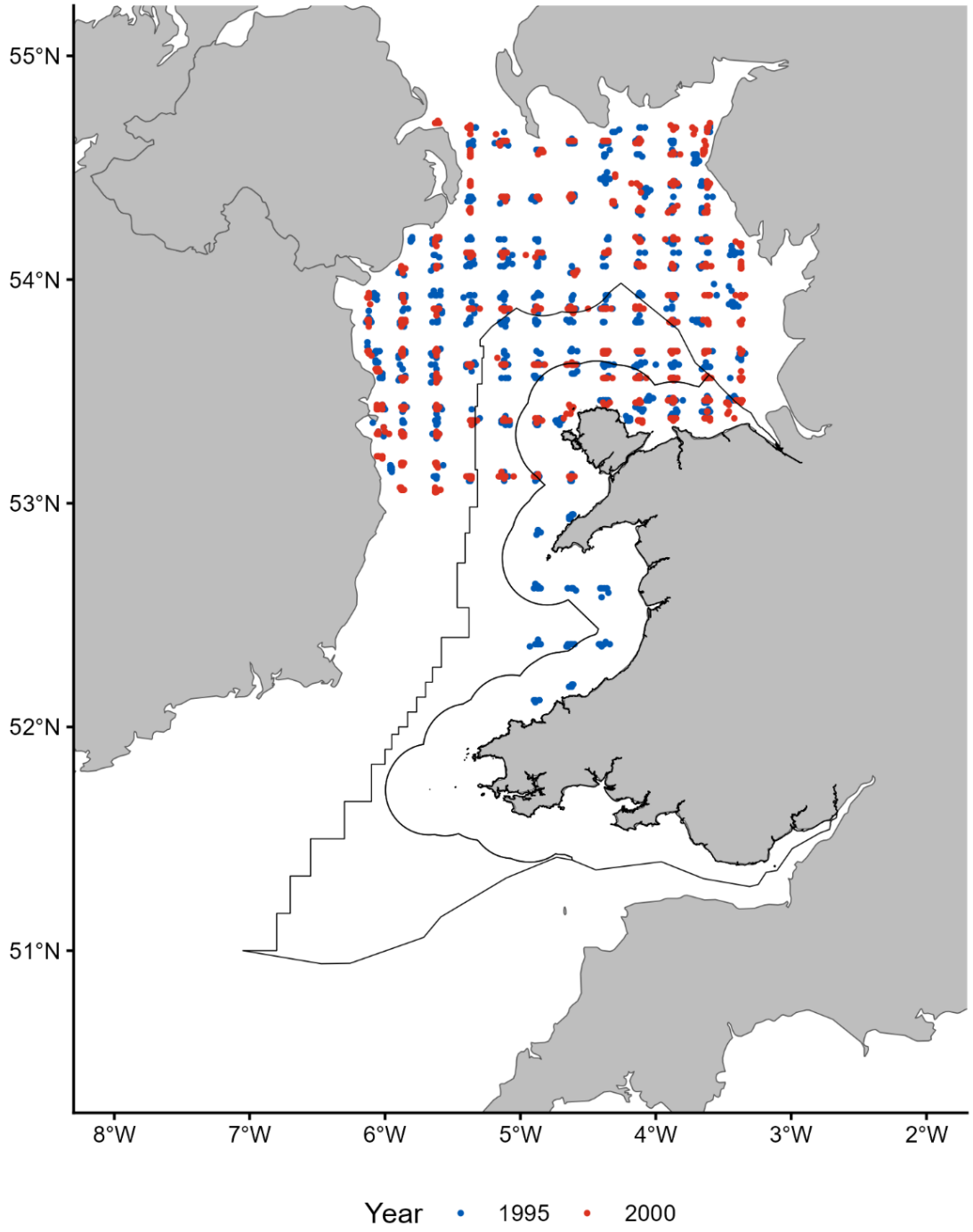


Figure 12. AEPM sampling stations from 1995 and 2000 surveys (Source: Cefas, 1995; Cefas, 2000).

A3.1.2. Irish Sea Fish Egg Production Surveys (ISFEPS) (Cefas, 2010)

Spatial coverage: Irish Sea

The Irish Sea Fish Egg Production Survey (ISFEPS) was conducted over 15 research voyages between January and May in 2006, 2008 and 2010. Using an 80-micron fine-mesh plankton sampler, the survey aimed to map the distribution and abundance of cod, haddock and plaice eggs.

Data from the ISFEPS show that stations with the highest cod egg counts occur in similar locations across all three years of available data. The greatest concentrations are found off the east coast of Ireland and in the area to the east and south-east of the Isle of Man. (Figure 13).

Stations with cod eggs are recorded within Welsh waters in each year, although counts are consistently low compared with the core high-abundance areas of the Irish Sea. Nevertheless, cod eggs appear to be regularly present in Welsh waters off the North Wales coast.

Figure 14 shows the distribution of cod eggs at the six developmental stages. Across the three years of surveys, most eggs recorded in Welsh waters and across the whole survey area were in stages 1A, 1B, and 5. No stage 2 or stage 3 eggs were observed, and only a small number of samples contained stage 4 eggs.

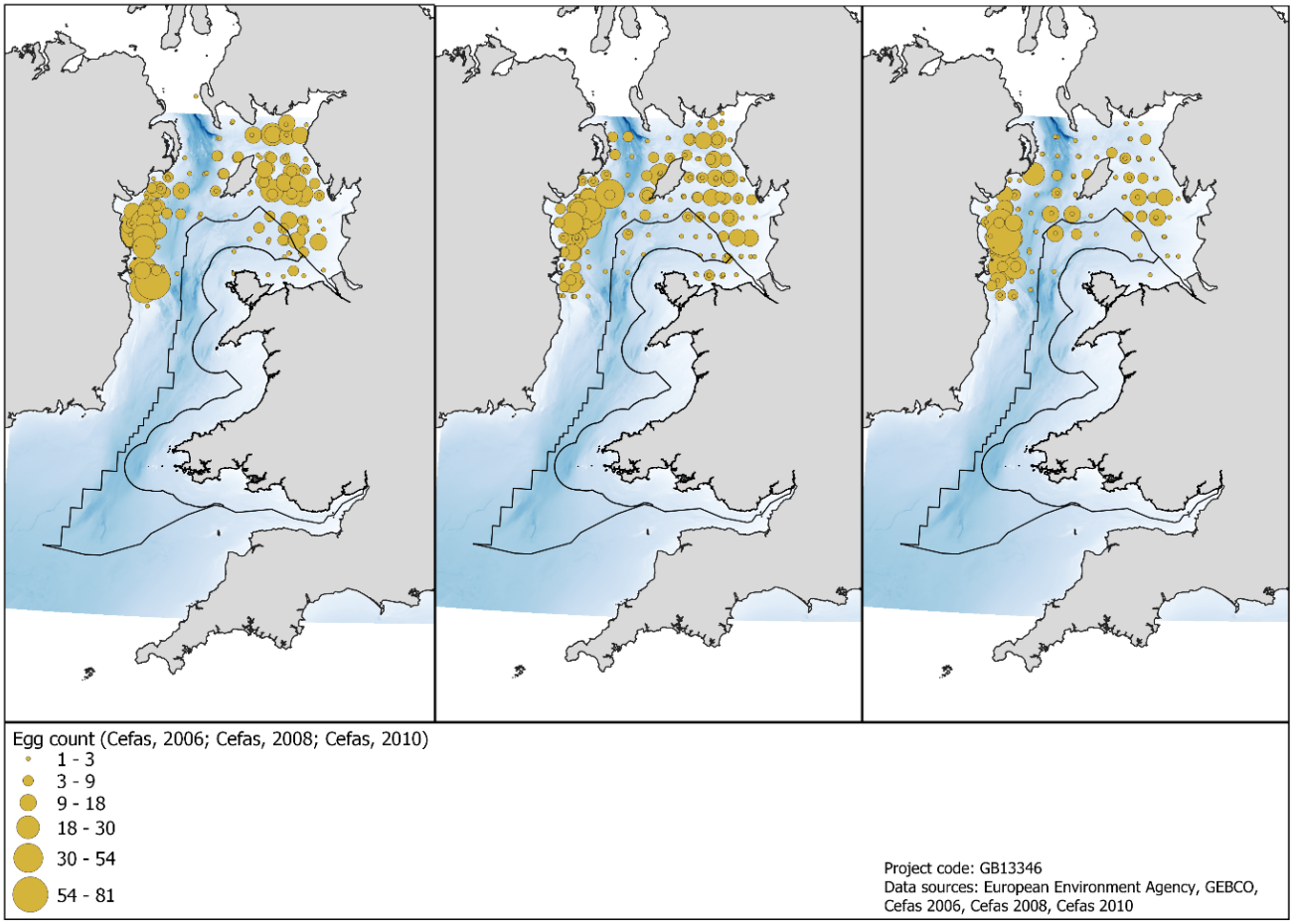


Figure 13. ISFEPS cod egg counts in surveys conducted in 2006 (left), 2008 (middle) and 2010 (right). (Source: Cefas, 2006; Cefas, 2008; Cefas, 2010).

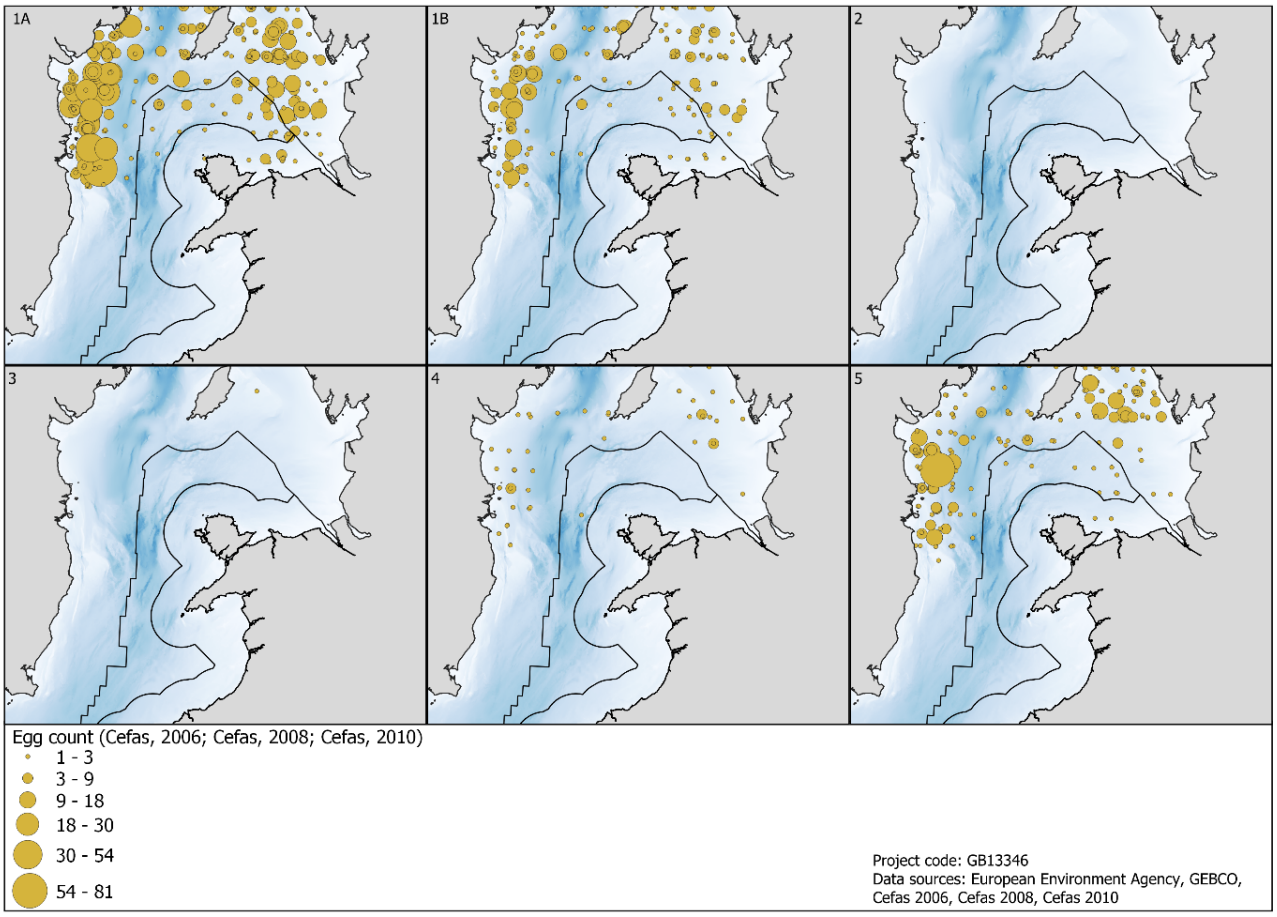


Figure 14. ISFEPS cod egg counts in surveys conducted in 2006, 2008 and 2010 by egg stage (Source: Cefas, 2006; Cefas, 2008; Cefas, 2010).

A3.1.3. Assessment of potential predators of plaice eggs and larvae in the Irish Sea (Cefas, 2023)

Spatial coverage: Irish Sea

The study assessed potential predators of plaice eggs and larvae in the Irish Sea in February 2008 and 2009, on a well-described plaice spawning ground off the North Wales coast. While the primary aim was to characterise species capable of preying on plaice eggs, plankton samples were also collected and preserved, providing occurrence information on cod eggs (Figure 15).

Few samples contained cod eggs, recorded exclusively in 2009 and in low abundances, with counts of no more than one egg per m^3 in sampling. The stations where cod eggs were present were located on the boundary between the Welsh inshore and offshore areas in the Irish Sea. At the four stations where cod eggs were recorded, egg density did not exceed 1 egg m^{-3}. All but one egg was assessed as stage 5, with a single egg classified as stage 4.

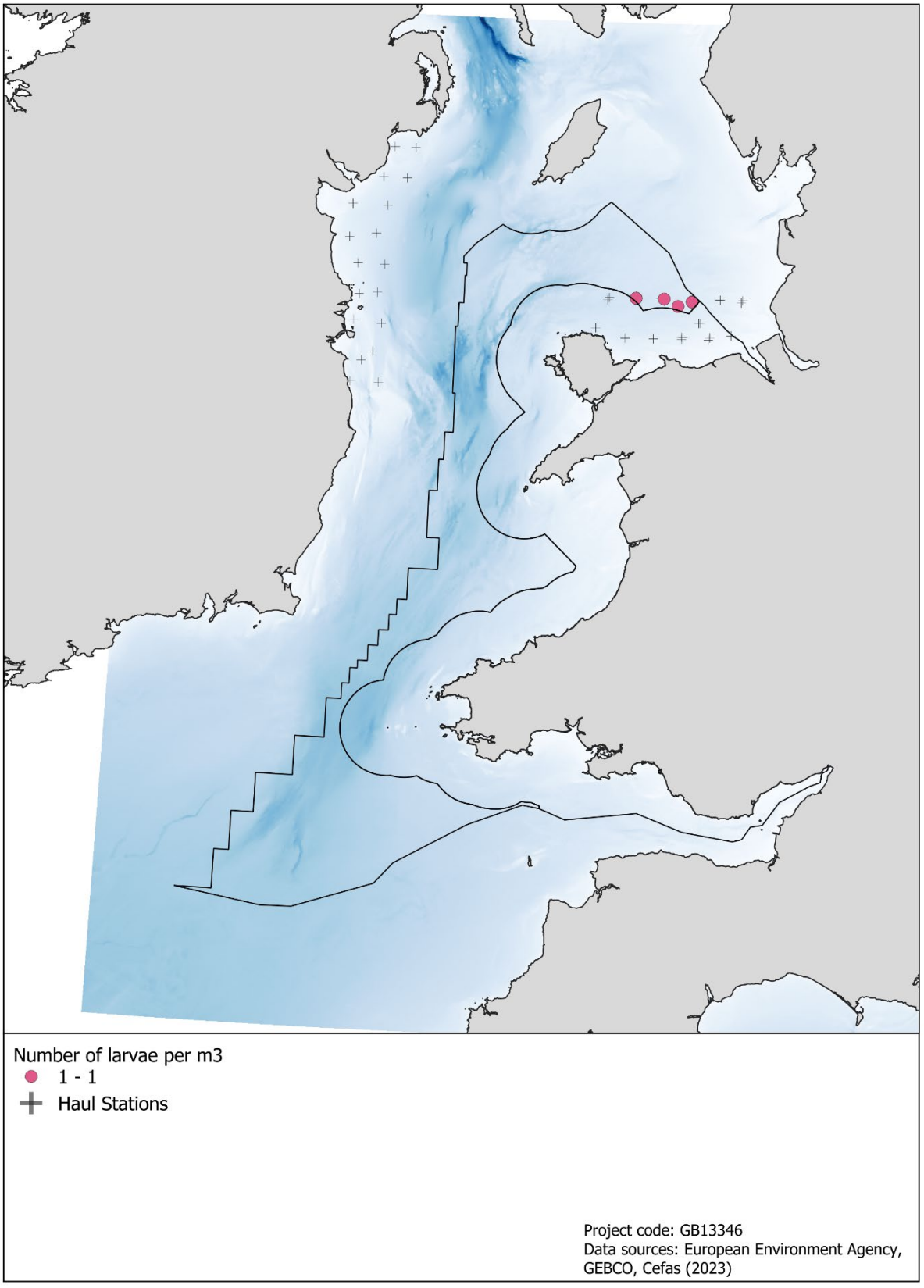


Figure 15. Number of cod eggs sampled by Cefas in the Assessment of Plaice Predators in the Irish Sea (Source: Cefas, 2023).

A3.1.4. Spawning and Nursery Grounds Layers for Selected Fish in UK Waters in 2010 (Ellis *et al.*, 2012)

Spatial coverage: All Welsh waters, excluding close inshore and estuaries.

The surveys incorporated into this report include:

- **The Bristol Channel plankton survey (1990)**, providing early-season ichthyoplankton information for the southern approaches to the Welsh coast.
- **The 1991 Sole Survey**, undertaken across four cruises during 1991, which collected ichthyoplankton and egg data alongside demersal fish observations from the English Channel and Southern Bight.
- **Irish Sea Plankton Surveys (1995, 2000, 2006, 2008)**, providing repeated coverage of egg and larval distributions for a range of commercial and non-commercial species.
- **The Eastern Irish Sea Plaice Egg Surveys (2001–2003)**, targeted at plaice spawning areas but including bycatch records of other species' eggs and larvae.
- **North Sea winter–spring cruises (December 2003–April 2004)**, which sampled egg and larval distributions in offshore waters relevant to migratory species entering the Irish Sea.
- **The International Herring Larval Survey (IHLS, 2008)**, a coordinated international survey providing spatially explicit abundance indices for herring eggs and larvae. Extensive UK coverage, mainly in the North Sea, around Scotland and north and west of Ireland, Welsh waters coverage is limited.
- **The Triennial Mackerel Egg Survey (2007)**, which provides high-resolution ichthyoplankton data for mackerel and associated species in the Celtic and Irish Seas.

Figure 16 shows the spatial distribution of cod egg relative abundance points, derived from the combined dataset covering all 18 available survey years. These data indicate presence of cod eggs off the North Wales coast and in the Celtic Sea. Only one station sampled in Welsh inshore waters of South Wales, in Carmarthen Bay, contained cod eggs in minimal abundance. Higher relative abundance is seen in Welsh offshore waters in the Celtic Sea. The highest abundance can be seen along the North Wales coast, particularly north of the Great Orme, in inshore Welsh waters.

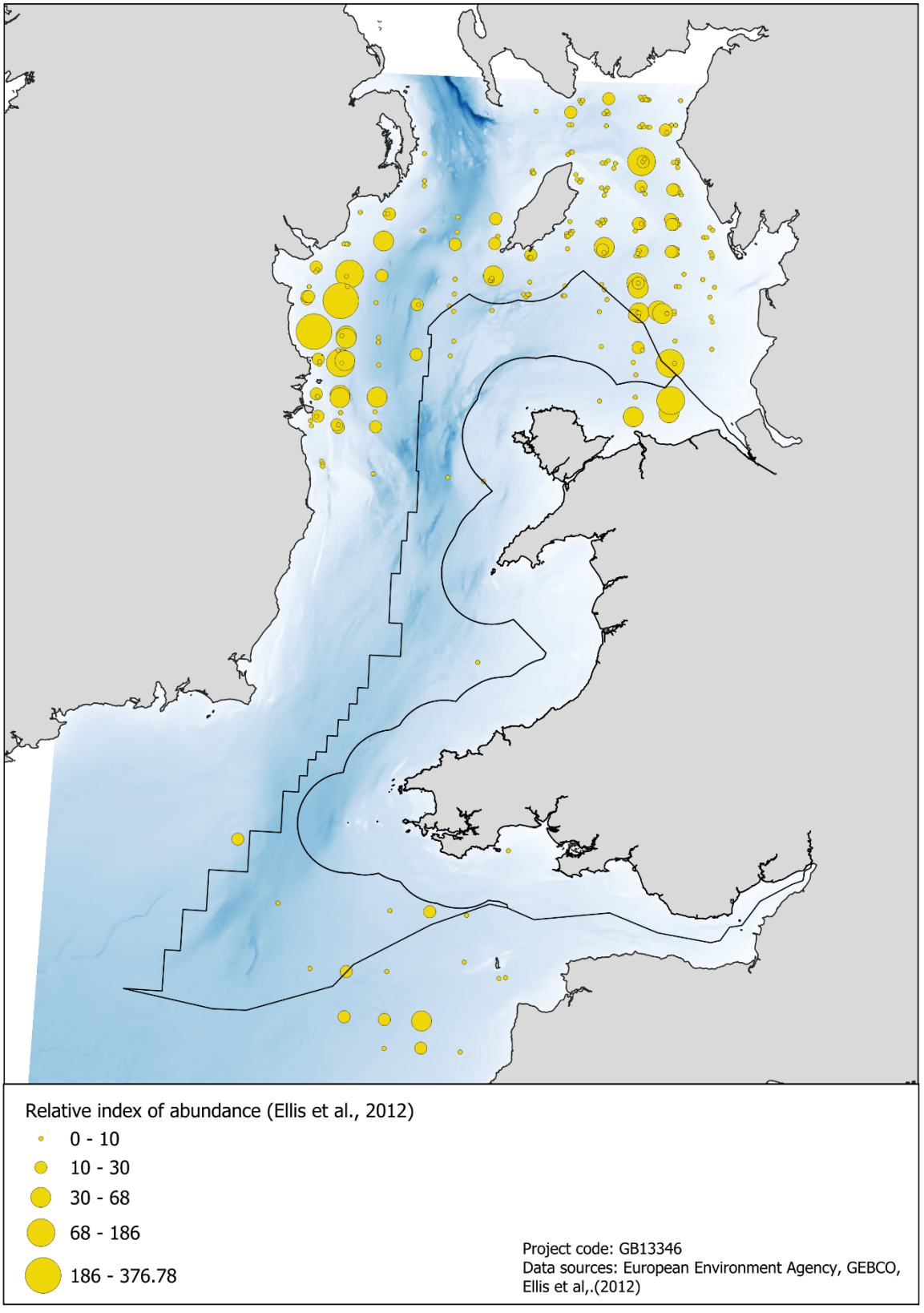


Figure 16. Relative abundance index of cod eggs (Source: Ellis et at., 2012).

A3.1.5. Determination of species-specific spawning distributions of commercial finfish in the Irish Sea using a biochemical protein-based method (Heffernan *et al.* 2004)

Spatial coverage: Irish Sea

During 6 consecutive ichthyoplankton surveys in the Irish Sea from February to May 2000, pelagic fish eggs were sampled from 105 ICES rectangle-based stations and identified through iso-electric focusing and histochemical staining of isozymes (Heffernan *et al.*, 2004).

Stage IA cod eggs were identified through five survey periods: early March, late March, early April, late April and early May. Their relative abundance was spatially mapped at each of these time periods (Figure 17). These data show that in early March densities of cod eggs were low in Welsh waters with the highest densities seen in Irish waters and north of the Great Orme. In late March the highest densities of cod eggs were in Welsh inshore waters north of the Great Orme and east of Anglesey. In early and late April these high densities appear to move closer to the North Wales coast and Conwy Bay and by early May have moved further offshore.

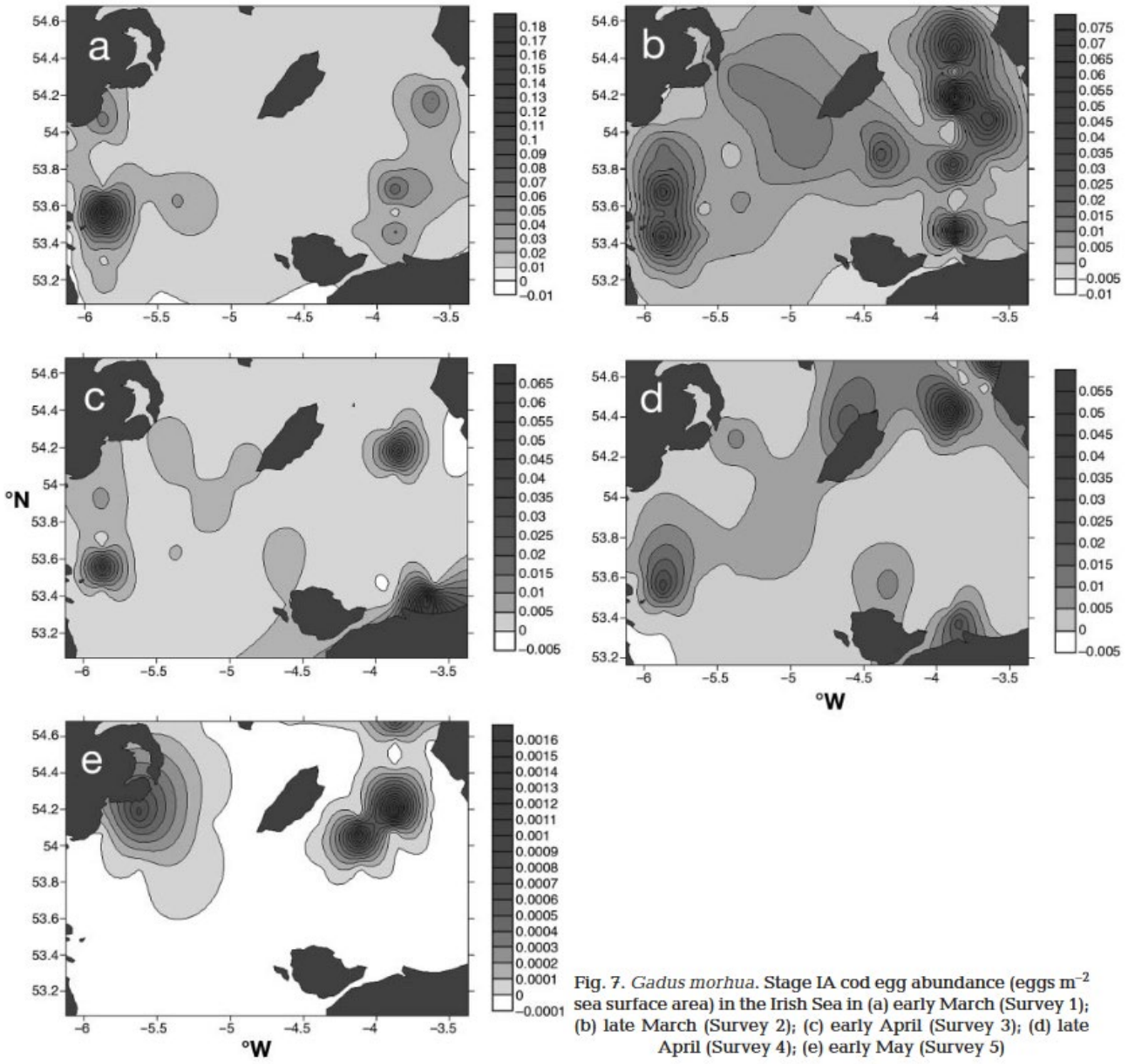


Fig. 7. *Gadus morhua*. Stage IA cod egg abundance (eggs m^{-2} sea surface area) in the Irish Sea in (a) early March (Survey 1); (b) late March (Survey 2); (c) early April (Survey 3); (d) late April (Survey 4); (e) early May (Survey 5)

Figure 17. Stage IA cod egg abundance (eggs m2 sea surface area) in the Irish Sea in (a) early March (survey 1); (b) late March (survey 2); (c) early April (survey 3); (d) late April (survey 4); (e) early May (survey 5) (Source: Heffernan *et al.*, 2004).

A3.2. Life stage – larvae

A3.2.1. Annual Egg Production Method (AEPM) surveys 1995 and 2000 (Cefas 1995; 2000)

Spatial coverage: Irish Sea

The AEPM surveys represent some of the earliest ichthyoplankton records available, with surveys conducted in 1995 and 2000. The highest relative abundances occur outside

Welsh waters and are concentrated along the Irish coast. Cod larvae were recorded at 11 stations within Welsh inshore waters across both survey years, although at relatively low abundance compared with those observed in the wider Irish Sea. There is persistent larvae occurrence within Welsh inshore waters, particularly north of the Great Orme, the same as for cod eggs. A similar pattern is observed in the Welsh offshore waters, where low abundance for larvae is present in both 1995 and 2000 (Figure 18).

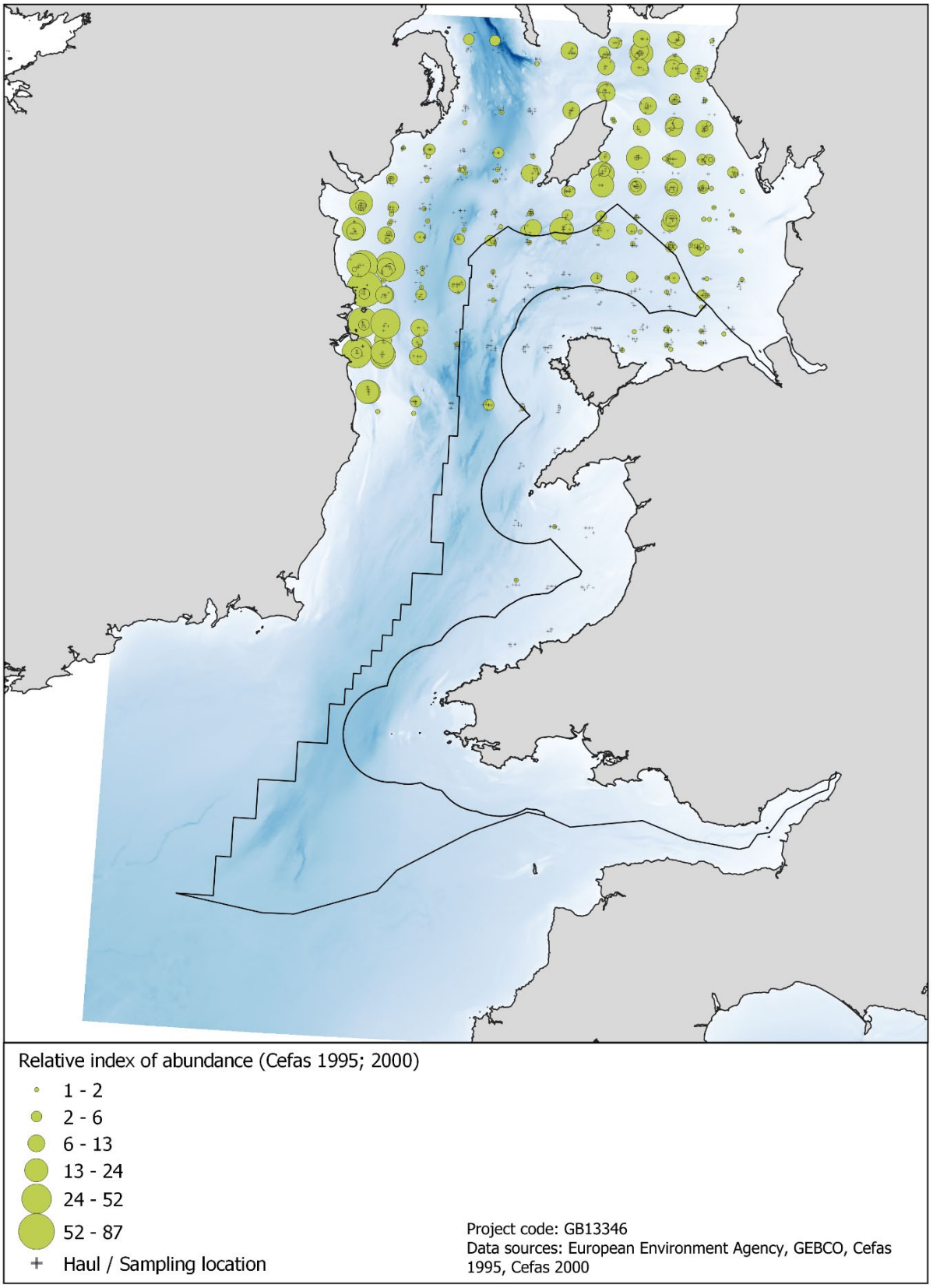


Figure 18. Relative abundance indices of larvae occurrence (Source: Cefas, 1995; Cefas, 2000).

A3.2.2. Irish Sea Fish Egg Production Surveys (ISFEPS) (Cefas, 2010)

Spatial coverage: Irish Sea

A review of the ISFEPS data found cod larvae at stations surveyed in 2006 and 2008, with no larval records in the 2010 survey. Survey coverage was extensive across the Irish Sea extending south to the Llyn Peninsula (Figure 19). No cod larvae were found within Welsh inshore waters and low numbers were found in Welsh offshore waters. The areas of highest larval density were found in Scottish waters, to the east of the Isle of Man and the Irish coast. Highest concentrations in Welsh waters were recorded offshore north of the Great Orme and north west of Anglesey.

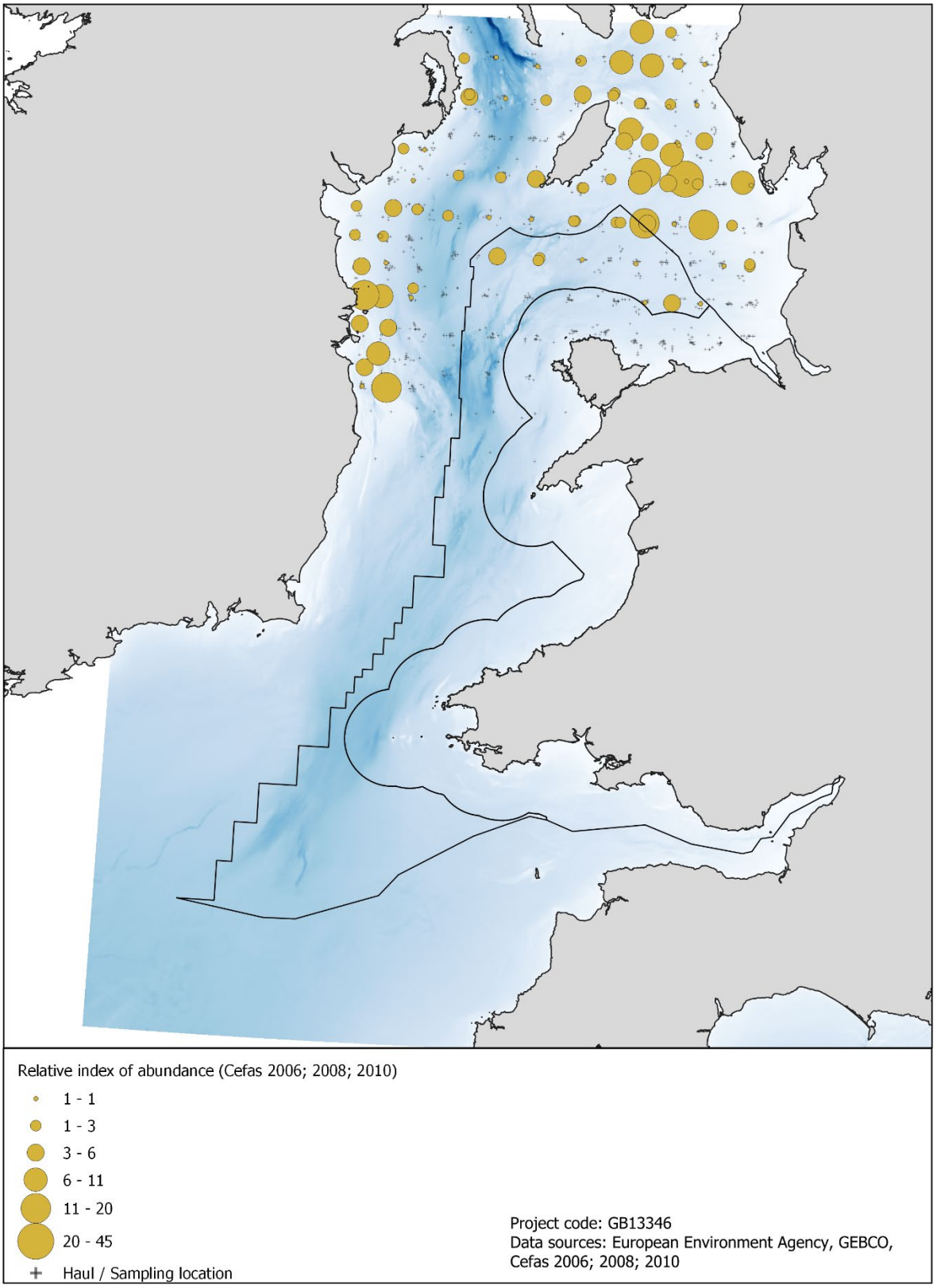


Figure 19. Irish Sea Fish Egg Production Survey (ISFEPS) larvae distribution and relative abundance from surveys carried out in 2006, 2008 and 2010. (Source: Cefas, 2006; Cefas, 2008; Cefas 2010).

A3.2.3. Assessment of potential predators of plaice eggs and larvae in the Irish Sea (Cefas, 2023)

Spatial coverage: Irish Sea

The surveys carried out as part of the assessment of potential predators of plaice eggs and larvae in the Irish Sea in February 2008 and 2009 yielded few cod larvae, with only three records located off the North Wales coast in both Welsh inshore and offshore waters.

A3.2.4. Spawning and nursery grounds of selected fish species in UK waters (Ellis *et al.*, 2012)

Spatial coverage: All Welsh waters, excluding close inshore and estuaries.

The data presented by Ellis *et al.* (2012) describe the distribution of cod larvae based on surveys undertaken in 1990, 1995, 2000, 2001, 2002 and 2003 across three survey series: the Bristol Channel Plankton Survey; the Eastern Irish Sea Survey; and ISEPS (Figure 20).

The highest relative abundances in the outer Bristol Channel and Celtic Sea occur off the North Cornwall coast near the Trevose Head spawning ground, outside of Welsh waters, although notable concentrations are also present within Welsh offshore waters at several stations. All of these southern records originate from the 1990 survey.

In the Irish Sea, larvae are more abundant within Welsh offshore waters, though numerous occurrence records also occur within inshore waters. In contrast to the Celtic Sea, Irish Sea occurrence is recorded from surveys conducted across multiple years.

Only a single, low-abundance record is found in Cardigan Bay from sampling in 1995, reflecting very limited sampling effort.

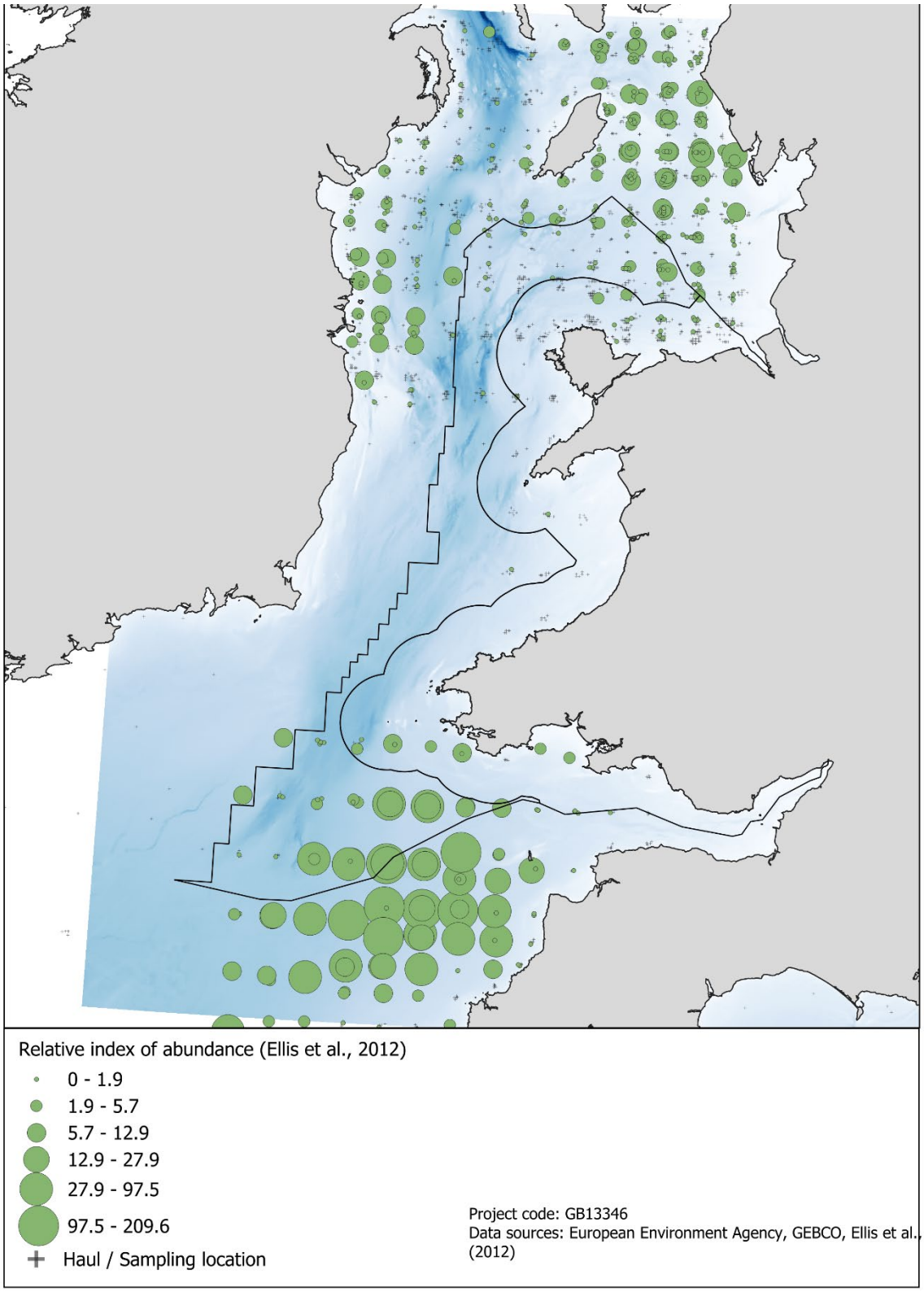


Figure 20. Index of abundance of cod larvae compiled across multiple surveys between 1982 and 2008 (Source: Ellis *et al.*, 2012).

A3.2.5. Larval distribution of commercial fish species in waters around Ireland (Dransfeld *et al.* 2004)

Spatial coverage: Celtic Sea and St George's Channel

An ichthyoplankton survey conducted between April and May 2000 across 162 stations in the Irish and Celtic seas found cod larvae at 18 stations, representing an occurrence percentage of 11% (Dransfeld *et al.*, 2004). Larvae were mostly identified in the Celtic Sea, with concentrations generally low (maximum 12 larvae per m²). Most larvae were observed near the Saltees and Smalls fishing grounds, west of Pembrokeshire in the Celtic Sea. The study highlights eggs and larvae were previously observed in these areas in surveys in 1938, 1939, 1953 and 1990, suggesting cod spawning areas in this region are persistent (Figure 21).

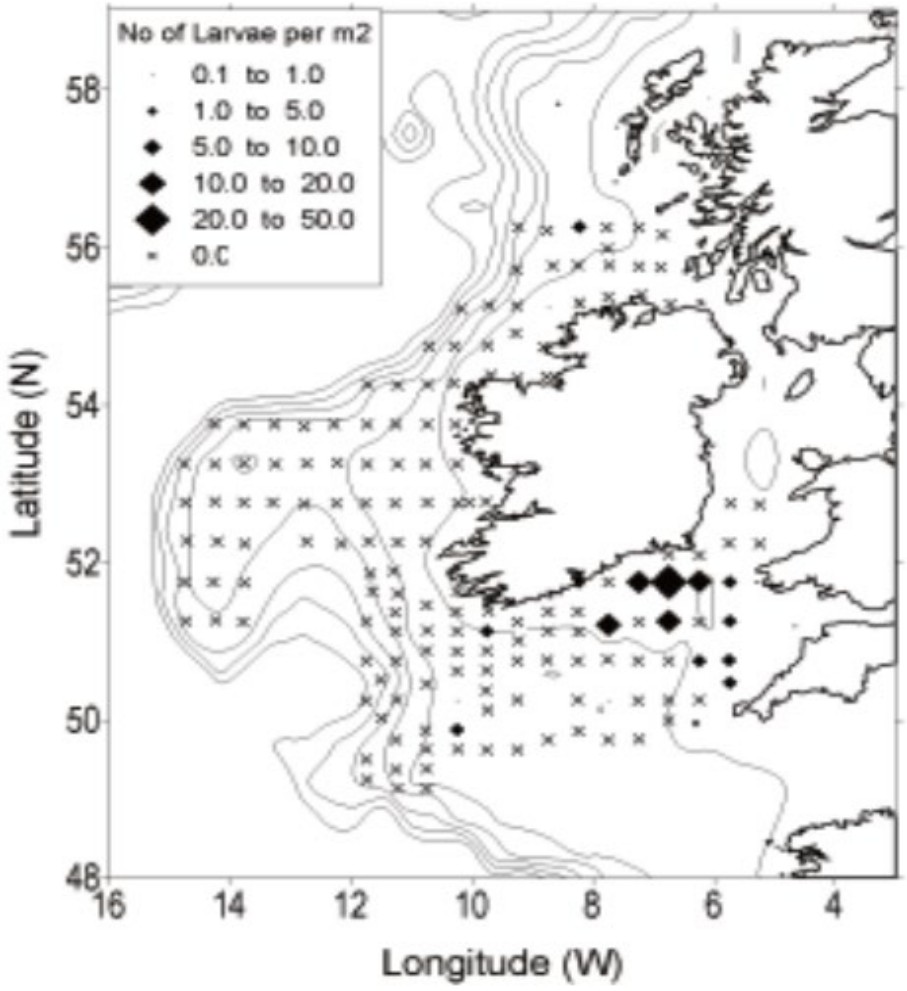


Figure 21. Distribution of cod larvae from surveys conducted in April and May in 2000, across 162 stations (Source: Dransfeld *et al.*, 2004).

A3.3. Life stage – juveniles

A3.3.1. WFD Transitional fish surveys (NRW, 2025)

Spatial coverage: Welsh Estuaries

Spatial data provided by NRW from estuarine WFD sampling were reviewed and consist of point records of juvenile cod, with associated length measurements, collected between 1997 and 2024. The dataset indicates that juvenile cod (<22 cm) were primarily recorded in the upper reaches of the Severn Estuary, particularly around Cardiff and Beachley (Figure 22). Additional records occur at the mouths of the Conwy and Dee estuaries (Figure 23) and juvenile cod were also recorded in estuaries around Pembrokeshire, although in low numbers.

To distinguish spatial patterns between early-stage (<10 cm) and late-stage (10–22 cm) juveniles, Figure 22 and Figure 23 present the number of individuals sampled in the Severn and Conwy and Dee estuaries.

In the Dee and Conwy estuaries, early-stage juveniles were sampled in June and September, with late-stage juveniles generally sampled later in the year, between July and November. Early-stage juveniles were primarily recorded in intertidal or nearshore sampling locations, whereas late-stage juveniles were also recorded in deeper estuarine waters, indicating a broader distribution across estuarine habitats as individuals grow.

In the Severn Estuary, juvenile cod were recorded between 1998 and 2015. The spatial distributions of early- and late-stage juveniles are broadly similar, with most records occurring close to the coastline. However, late-stage juveniles were also sampled further offshore in deeper estuarine waters, whereas early-stage juveniles were primarily recorded in intertidal and nearshore sampling locations. This pattern is consistent with observations from the Dee estuary and may reflect both ontogenetic shifts in habitat use and differences in survey sampling locations.

Within the Milford Haven estuary, two records were identified from sampling conducted in June 2005 and September 2010. The Nevern Estuary also contained two records from 2008 and 2012, while two records were recorded in the Teifi estuary in 2013 and 2014. The River Dyfi similarly contained two juvenile records from 2005 and 2006.

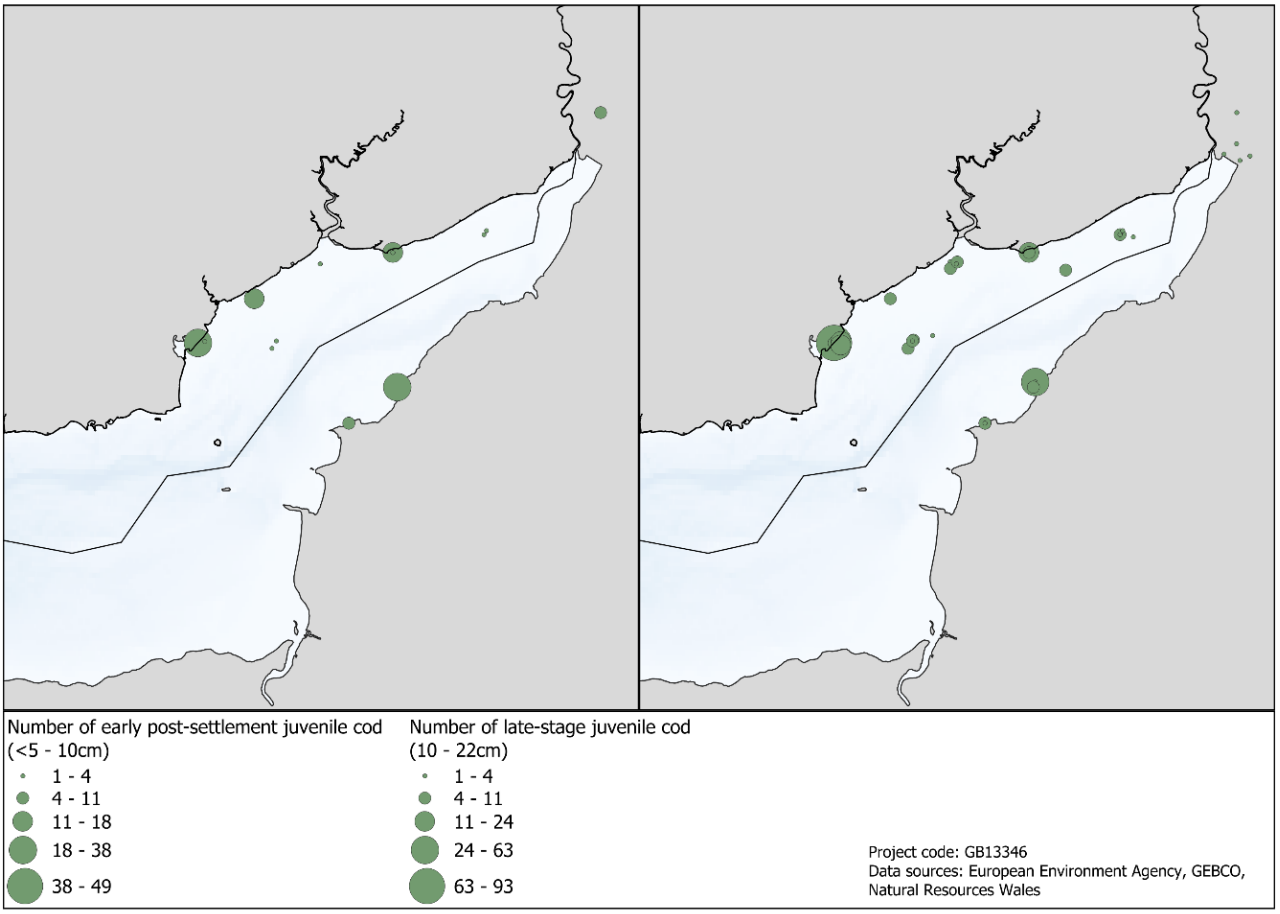


Figure 22. Early post-settlement (left) and late-stage (right) juvenile cod detected at sites in the Bristol channel (Source: NRW, 2025).

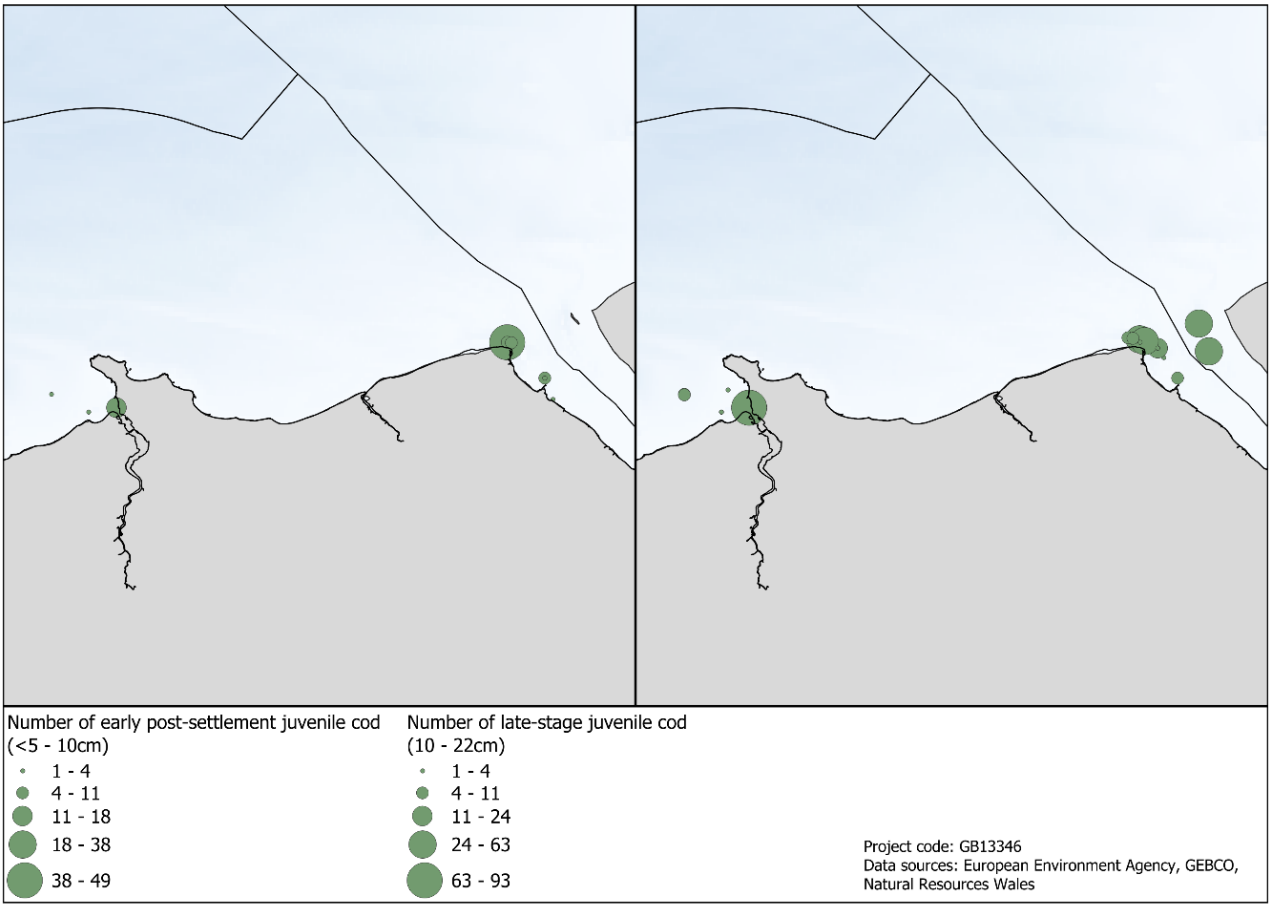


Figure 23. Early post-settlement (left) and late-stage (right) juvenile cod detected at sites off the North Wales coast, in the Dee Estuary to the east and Conwy Bay to the west (Source: NRW, 2025).

A3.3.2. Spawning and nursery grounds of selected fish species in UK waters (Ellis *et al.*, 2012)

Spatial coverage: All Welsh waters, excluding close inshore and estuaries.

The spatial distribution of cod juveniles compiled from surveys between 1982 and 2008 are shown in Figure 24. Within Welsh waters, the highest density of sampling stations are in the Irish Sea, with lower station densities across Cardigan Bay, the Celtic Sea and the Bristol Channel. Stations within the Bristol Channel and off the South Wales coast were sampled in 1990 while those in Cardigan Bay were sampled in 1995. Stations to the east of Anglesey and across the Irish Sea include sampling events between 1990 and 2008.

These compiled surveys show that the highest maximum abundances of cod juveniles were recorded along the coastal inshore waters of the Irish Sea including off the North Wales coast in Welsh waters, and in generally higher abundances within inshore waters. Juvenile cod were also sampled in higher abundances in Cardigan Bay, Carmarthen Bay and off the south coast of the Gower Peninsula in the Bristol Channel.

Due to the low spatial and temporal sampling resolution within Cardigan Bay and the Bristol Channel and Celtic Sea, the presence value metric of juvenile cod from the data appears low, although, this is likely due to the limited sampling replication. In Welsh waters of the Irish Sea off the North Wales coast, juvenile cod are persistently sampled, particularly in Welsh offshore waters, where more than 70% of hauls contained juvenile cod.

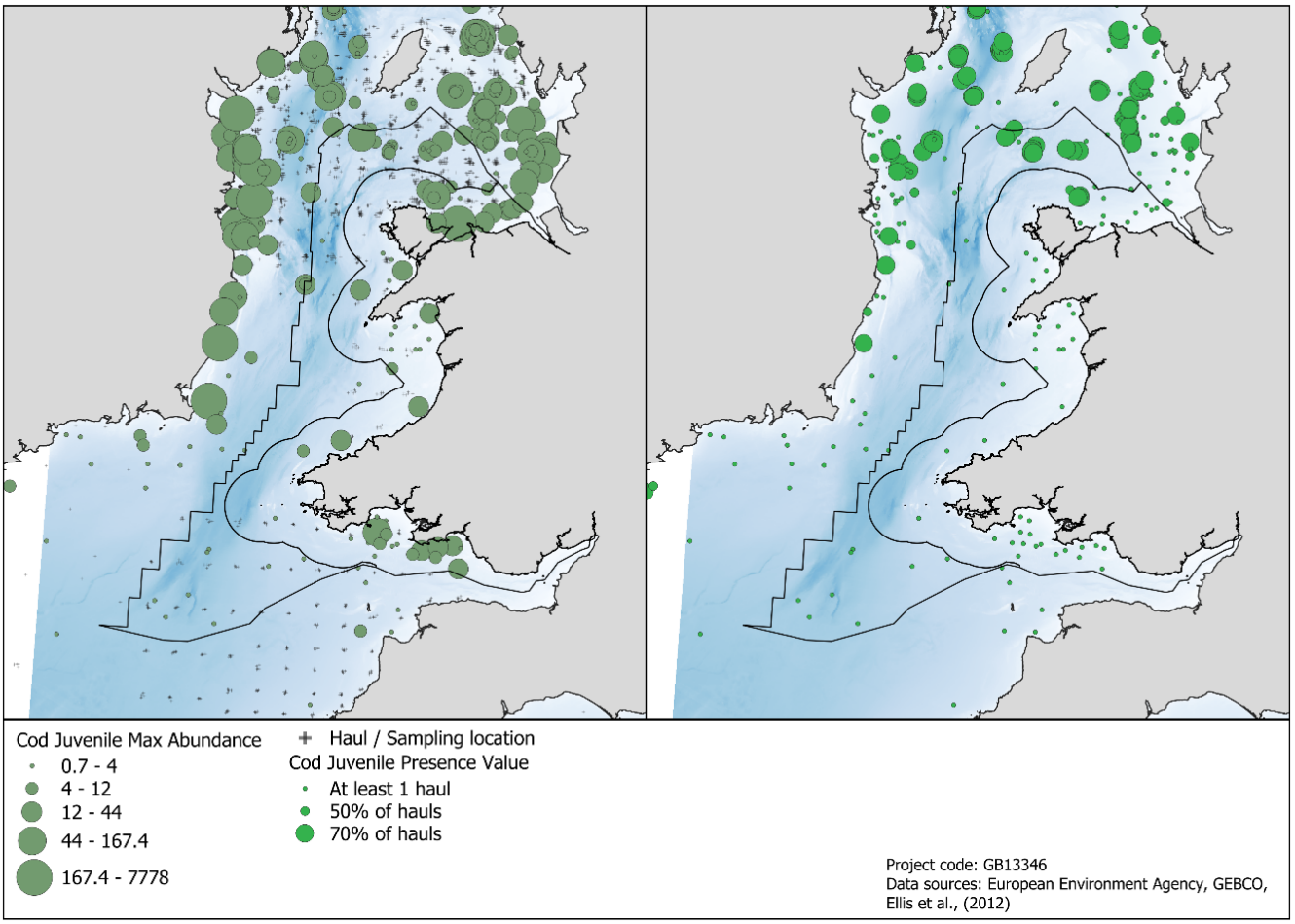


Figure 24. Juvenile cod maximum abundance recorded at each station (left) and presence value (right) (Source: Ellis *et al.*, 2012).

A3.3.3. DATRAS Fisheries-independent trawl survey data (ICES, 2025a)

Spatial coverage: All Welsh waters, excluding close inshore and estuaries.

Cod occurrence data were retrieved from the DATRAS database (ICES, 2025a). Data were available for all years between 2000 and 2024, although the most recent years contained fewer records. Records of juvenile cod are available in Q1 (January – March), Q3 (July – September) and Q4 (October - December). Figure 25 provides an overview of the spatial distribution of juvenile cod in Welsh and surrounding waters as an aggregate,

showing occurrences for all years and quarters with points size graduated by the counts of juvenile cod found in survey hauls.

The data shows cod juveniles in Welsh inshore waters around the coast, though with less sampling effort in Cardigan Bay and the Severn Estuary.

The DATRAS database includes individual length measurements, which were used to distinguish between adult and juvenile life stages, and to further classify juveniles into early post-settlement (<10 cm) and later juvenile (10–22 cm) stages. The dataset also records the survey quarter in which samples were collected. These data have been mapped in Figure 26 and Figure 27, illustrating the spatial distribution of early- and late-stage juvenile cod across Q1, Q3, and Q4 over the full 20- year time series. No surveys were conducted in Q2 during this period.

Early post-settlement juvenile cod were predominantly recorded in Q3, although occurrences were generally sparse. This may be due to sampling gear types' inability to capture very small individuals. No early post-settlement individuals were identified in Q1 (and are therefore not mapped), nor within Welsh waters in Q4. In Q3, low numbers of early-stage juveniles were sampled within Welsh inshore waters, with greatest numbers recorded in the Bristol Channel and around Anglesey.

Later-stage juveniles (10–22 cm) were sampled in substantially greater numbers than early post-settlement cod (Figure 27). The highest abundances of later-stage juveniles within Welsh inshore waters were recorded in Q3 (autumn), particularly in Swansea Bay, Carmarthen Bay, Tremadog Bay, Caernarfon Bay and north east of Anglesey including Red Wharf Bay. In Q1, relatively few later-stage juveniles were sampled off the South Wales coast, with the highest abundances across observed around Anglesey. The spatial pattern in Q4 was broadly similar to that in Q1, characterised by a concentration of higher-abundance records around Anglesey and comparatively few observations elsewhere within Welsh waters.

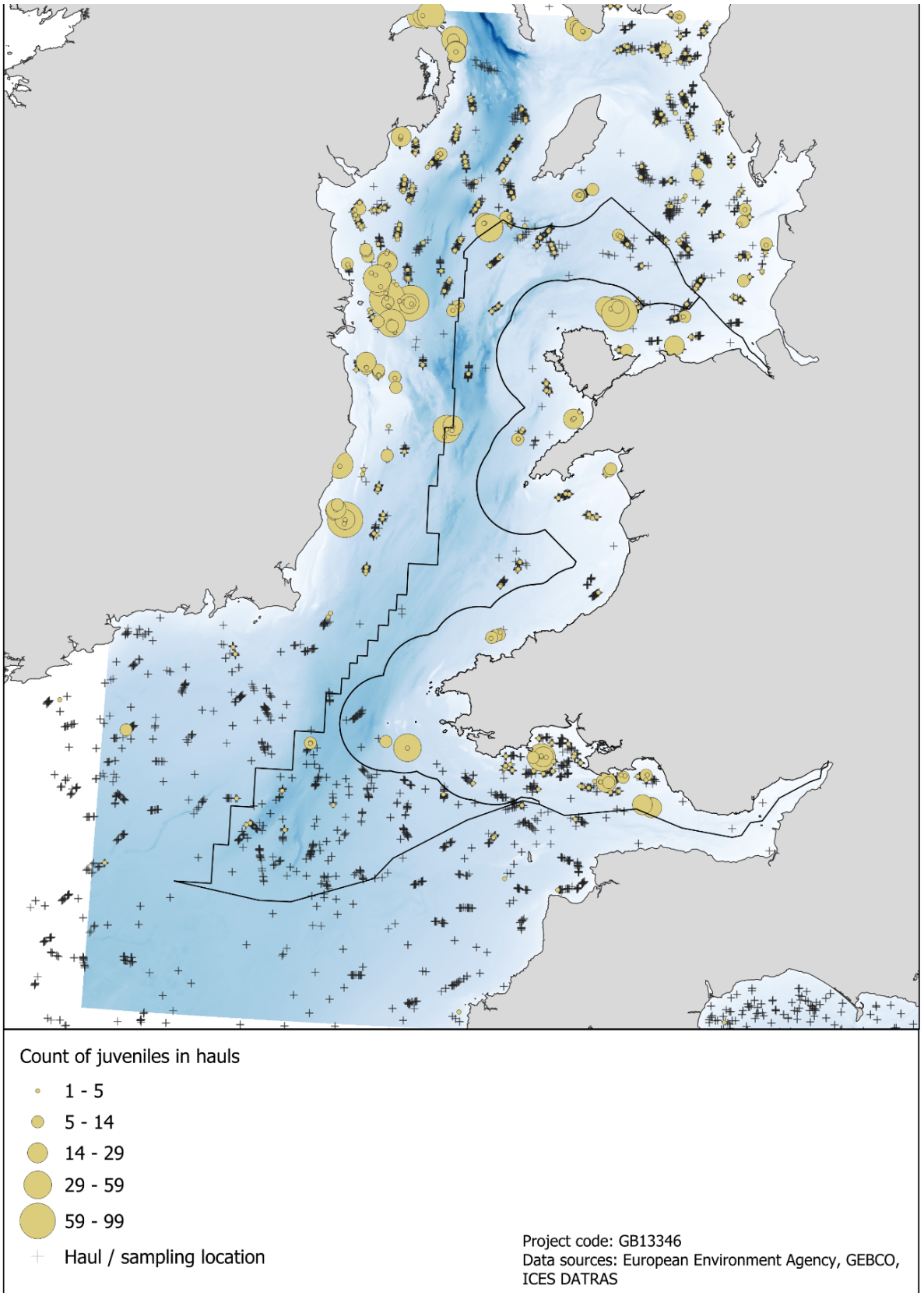


Figure 25. Points graduated in size by counts of juvenile (<22 cm) cod in survey hauls from the DATRAS database, aggregated across all years and quarters (Source: ICES, 2025a).

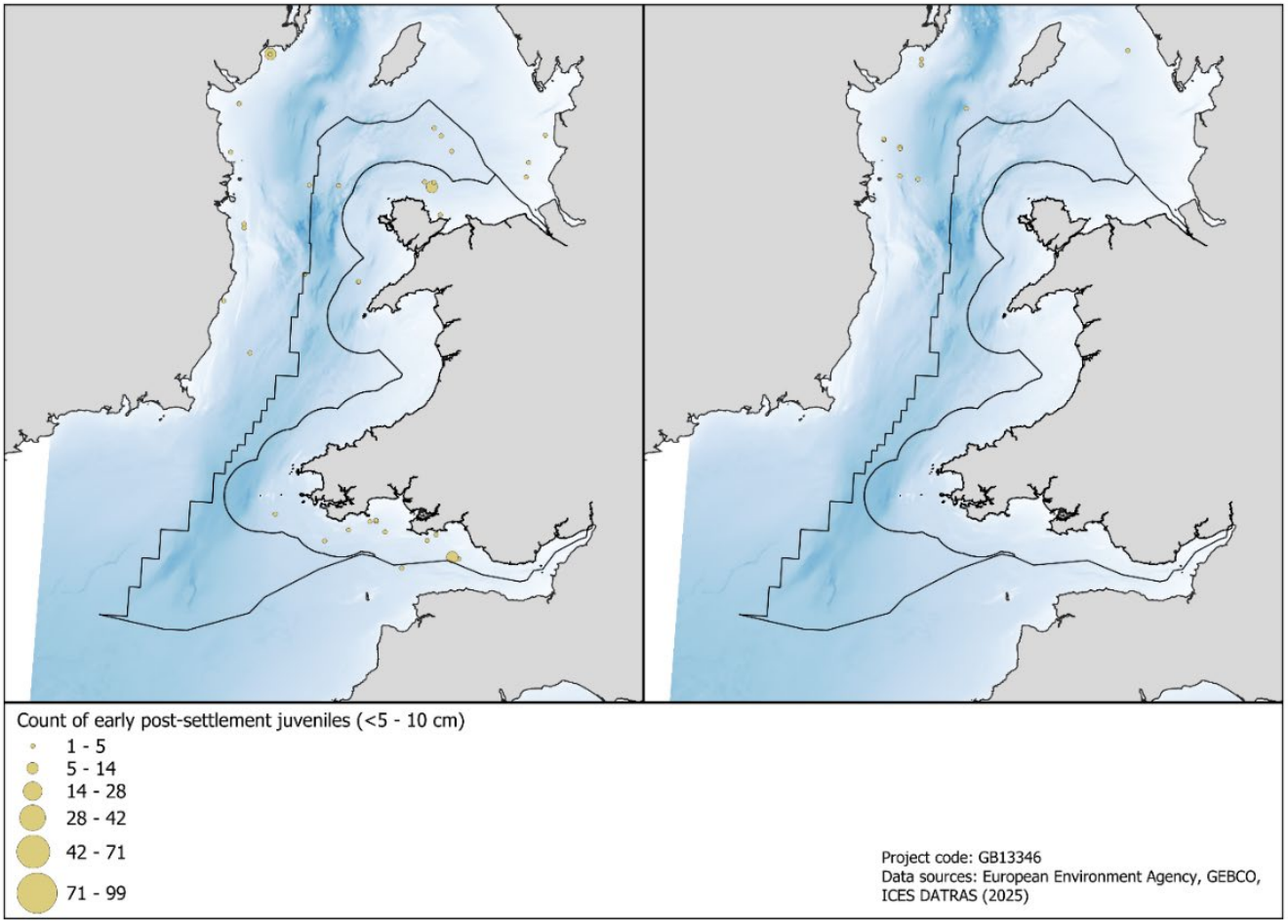


Figure 26. DATRAS data on numbers of early post-settlement stage cod juveniles (<10 cm) in Q3 (left) and Q4 (right) for the period 2000-2024 (Source: ICES, 2025a).

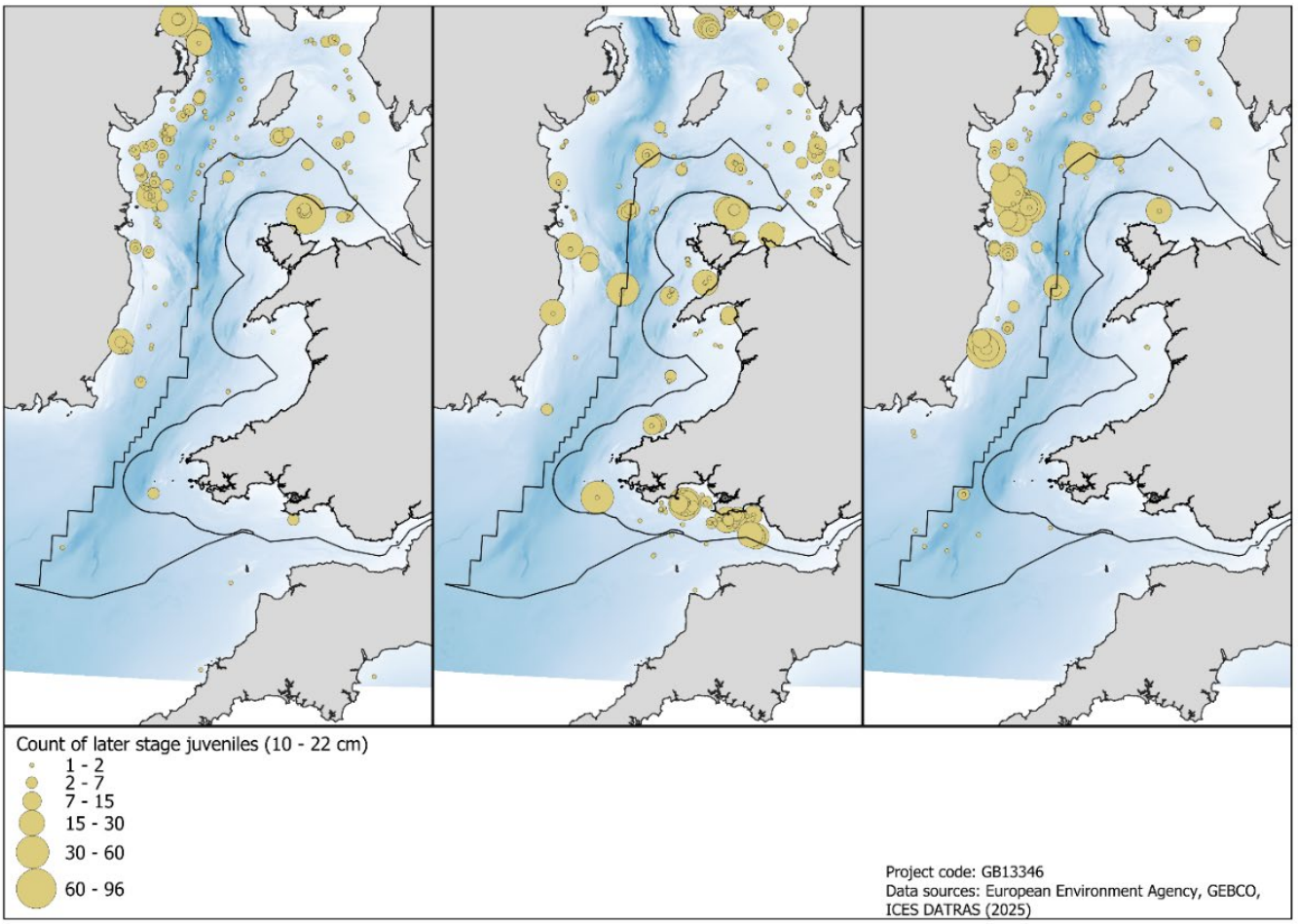


Figure 27. DATRAS data on numbers of late stage cod juveniles in Q1 (left) Q3 (middle) and Q4 (right) for the period 2000-2024 (Source: ICES, 2025a).

A3.3.4. Spawning and nursery grounds of forage fish in Welsh and surrounding waters (Campanella and van der Kooij, 2021)

Spatial coverage: All Welsh waters, excluding close inshore and estuaries.

Figure 28 shows the distribution of juvenile cod hotspots in Q1 and Q4, with juvenile cod defined as individuals less than 22 cm in length. In Q1, Swansea Bay and Carmarthen Bay in the Bristol Channel are identified as persistent hotspots, with moderate persistence also evident in the wider Bristol Channel and in Welsh offshore waters off Pembrokeshire. A further notable hotspot occurs in Welsh inshore waters around Anglesey. In contrast, Cardigan Bay appears to show limited juvenile cod hotspots, although this is likely influenced by reduced survey coverage.

In Q4, juvenile cod hotspots are generally less prominent in the Bristol Channel and off Pembrokeshire compared to Q1, though some low-level persistence remains. The waters around Anglesey continue to exhibit the highest and most consistent hotspot persistence across Welsh waters in Q4.

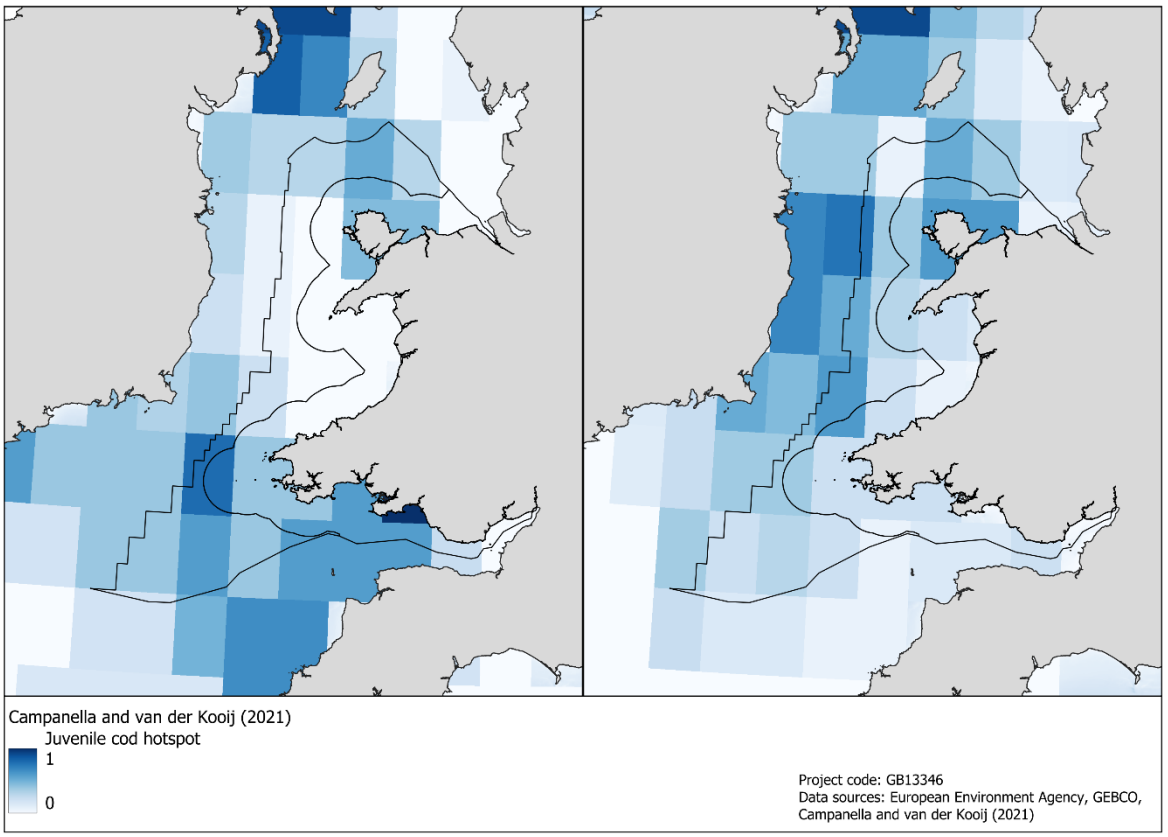


Figure 28. Hotpot map of juvenile cod in Welsh and surrounding waters in Q1 (left) and Q4 (right) (Source: Campanella and van der Kooij, 2021).

A3.3.5. Sea Angling Diary catch records 2016-2024 (Cefas, 2025)

Spatial coverage: All Welsh waters

Sea Angling Diary data record 212 juvenile cod (≤22 cm) across six ICES rectangles covering Welsh waters (Figure 29) between 2016 and 2024. Most individuals fall within the 15–22 cm length range, with fewer fish recorded in smaller size classes. Only a small number of fish are recorded below 10 cm, indicating that the dataset is largely composed of larger juveniles or pre-adults. Overall, the spatial pattern shows that juvenile cod records are concentrated along the North Wales coast, with additional occurrences in parts of the Bristol Channel and limited records elsewhere.

Juvenile cod are most frequently recorded in ICES rectangle 31E6, covering the inner Bristol Channel, which contains the highest number of individuals across multiple size classes, particularly within the 15–22 cm range. Moderate numbers of juveniles are also recorded in the Severn Estuary (ICES rectangle 32E7), where fish occur across several length classes including the 5–10 cm category.

Additional occurrences are observed along the North Wales coast in ICES rectangle 35E5 around Anglesey, where several individuals between 10 and 20 cm are recorded. Elsewhere, juvenile cod occur at lower frequencies, with a small number of records in 32E6 and only isolated individuals recorded in 32E4 and 35E6.

Overall, the distribution suggests that juvenile cod recorded in the Sea Angling Diary data are primarily concentrated in North Wales and parts of the Bristol Channel, with occasional records around the west Wales coast.

Table 3. Number of juvenile (≤22 cm) cod caught and recorded in Sea Angling Diary data (2016 – 2024).

Length Class (cm)	ICES Rectangle 31E6	ICES Rectangle 32E4	ICES Rectangle 32E6	ICES Rectangle 32E7	ICES Rectangle 35E5	ICES Rectangle 35E6
[5,10)	0	0	11	0	0	0
[10,15)	26	0	0	8	7	1
[15,20)	47	0	0	29	11	0
[20,22)	45	1	1	20	4	1
Total measured	118	1	12	57	22	2

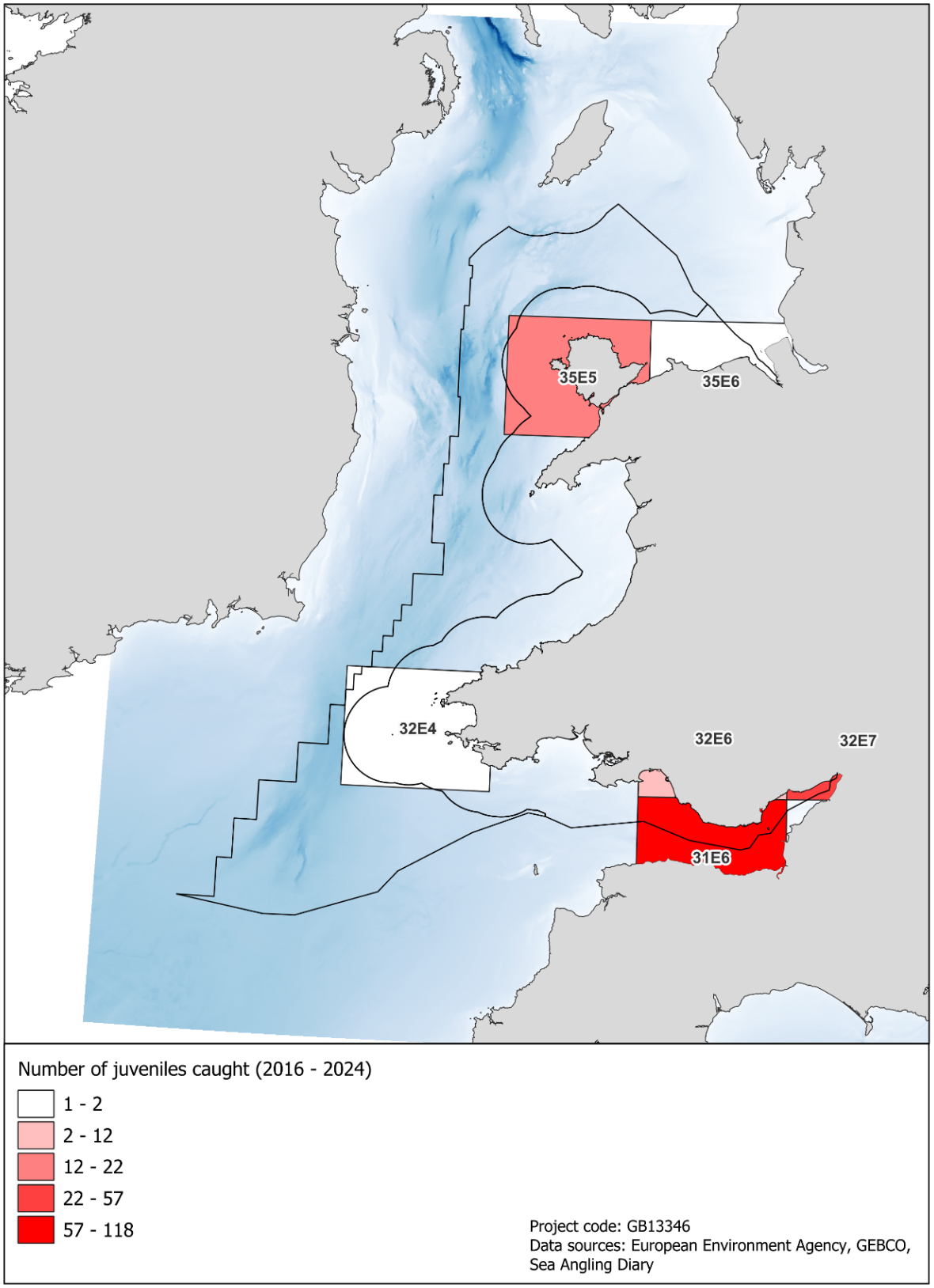


Figure 29. Number of juvenile (≤22 cm) cod caught and recorded in Sea Angling Diary data (2016 – 2024).

A3.3.6. Motile fauna of sub-tidal Zostera marina meadows in England and Wales (Peters *et al.*, 2015)

Spatial coverage: Tremadog Bay and Llŷn Peninsula

A study using Baited Remote Underwater Video (BRUV) identified juvenile cod presence in shallow (3–6 m) sea-grass meadows (Peters *et al.*, 2015). Sampling took place in October 2012 and June and July 2013 from two sites in Tremadog Bay in North Wales, Criccieth and Pen y Chain where cod were found in 8% of the 12 two hour video samples taken. No spatial data of these sites was available, but the recorded presence inshore in Cardigan Bay is important given the limited sampling coverage in this area from other survey programmes.

A3.4. Life Cycle Process – Nursery Grounds

A3.4.1. Species spawning and nursery areas (Marine Institute, 2018; revised 2024)

Spatial coverage: All Welsh waters

The Marine Institute's published spatial dataset of spawning and nursery areas includes several nursery sites within Welsh waters (Marine Institute, 2018). However, the resolution of this dataset is relatively coarse, resulting in much of the inner Welsh maritime area being identified as nursery grounds for juvenile cod. Although the dataset is included within the associated spatial dataset, an individual map has not been produced from it for this report but is included within the nursery synthesis map.

A3.4.2. Fisheries spawning and nursery areas in British waters (Coull *et al.*, 1998)

Spatial coverage: All Welsh waters

The report does not identify any cod nursery areas within Welsh waters, with the nearest off the east coast of Ireland. In contrast, the associated spatial dataset identifies a cod nursery area within Welsh inshore waters. This area covers approximately 559 km² and lies north east of Anglesey, around 4km from the coast, extending into Welsh offshore waters (Figure 30). A much larger nursery area is shown along the east coast of Ireland and extending to north of the Isle of Man.

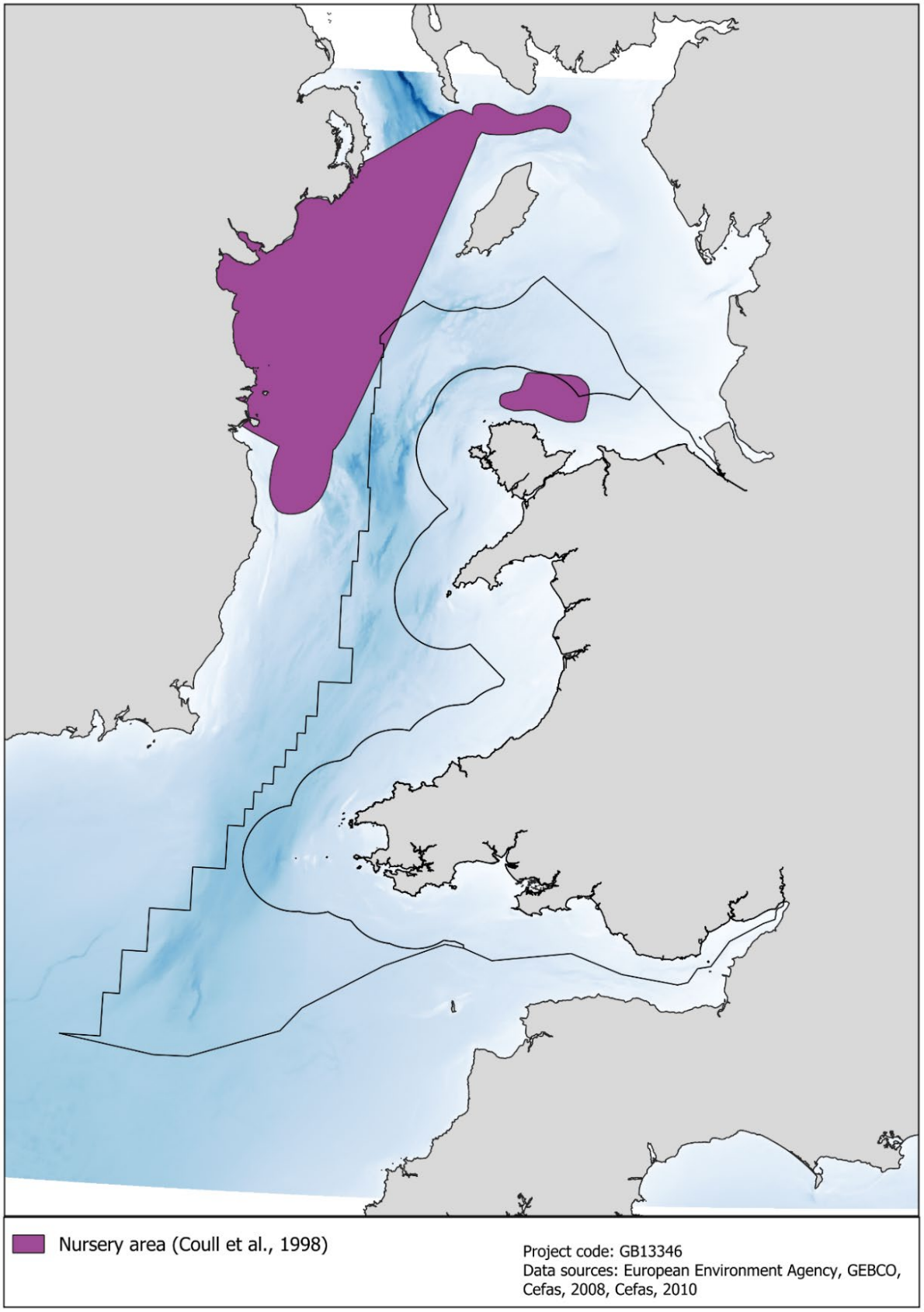


Figure 30. Cod nursery grounds (Source: Coull *et al.*, 1998).

A3.4.3. Spawning and nursery grounds of selected fish species in UK waters (Ellis *et al.*, 2012)

Spatial coverage: All Welsh waters

A report and publicly available spatial dataset published by Ellis *et al*., (2012) also provides shapefiles of areas identified as nursery areas and explicitly builds upon those presented by Coull *et al.,* (1998). The polygons were delineated by compiling multiple data-sources (historical survey data of juvenile and larval fish distributions, commercial catch/landings data, expert judgement and bibliographic evidence), then applying defined criteria (for example minimum juvenile density thresholds, persistence over years, and separation from other areas) to define contiguous zones mapped as nursery areas.

Figure 31 shows polygons depicting inferred areas of high and low intensity juvenile nursery grounds. These data indicate that waters off the entire North Wales coastline functions as a nursery area for cod. A high-intensity nursery area extends along the North Wales coast east of 4°W in both inshore and offshore waters, while a lower-intensity nursery area occurs west of 4°W, around Anglesey in both inshore and offshore waters. No nursery areas were identified In Cardigan Bay or the Bristol Channel. A small, low-intensity nursery area along the Irish coast also intersects with Welsh offshore waters in the Celtic Sea.

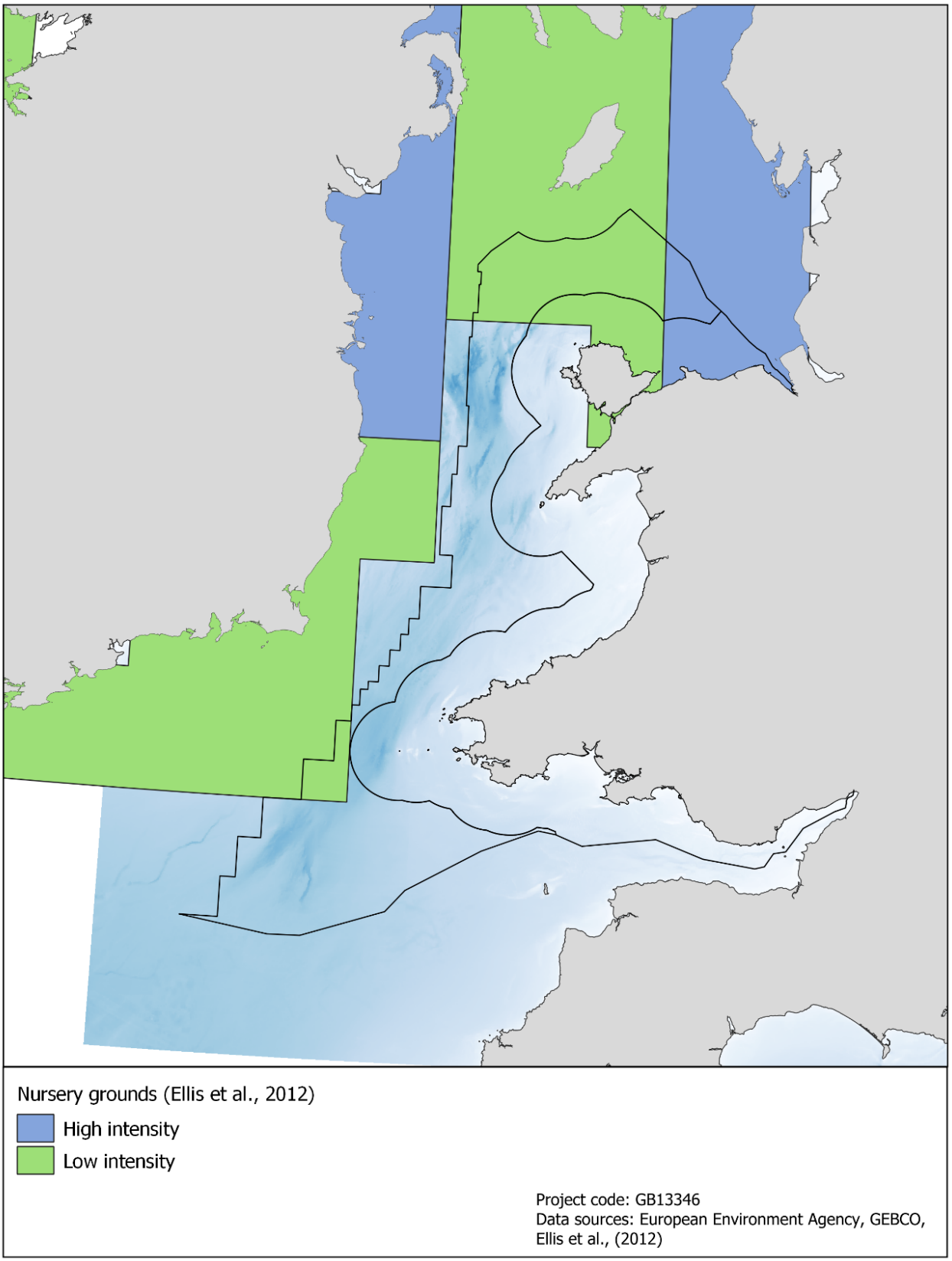


Figure 31. Inferred areas of high and low intensity cod nursery grounds (Source: Ellis *et al.*, 2012).

A3.5. Life stage – adults

A3.5.1. Spawning and nursery grounds of forage fish in Welsh and surrounding waters (Campanella and van der Kooij, 2021)

Spatial coverage: All Welsh waters, excluding close inshore and estuaries.

Campanella and van der Kooij (2021) presents an adult cod hotspot map for Q4 based on occurrence persistence analysis. Although the authors include Q4 adult distributions in their spawning-grounds discussion, for this project we treat the Q4 map within the adults section, as the Q4 survey period does not overlap with the known regional spawning season for cod.

Adult cod distribution for Q1 from this study, is presented in Section 3.3.6 for spawning grounds, as this presents the distribution of adults through their spawning period. Other quarters are not mapped because only the Q1 and Q4 survey periods were included in the original analysis. The most persistent area lies in the St George's Channel, with high adult occurrence also seen within Welsh inshore waters, west of the Llŷn Peninsula and around Anglesey (Figure 32).

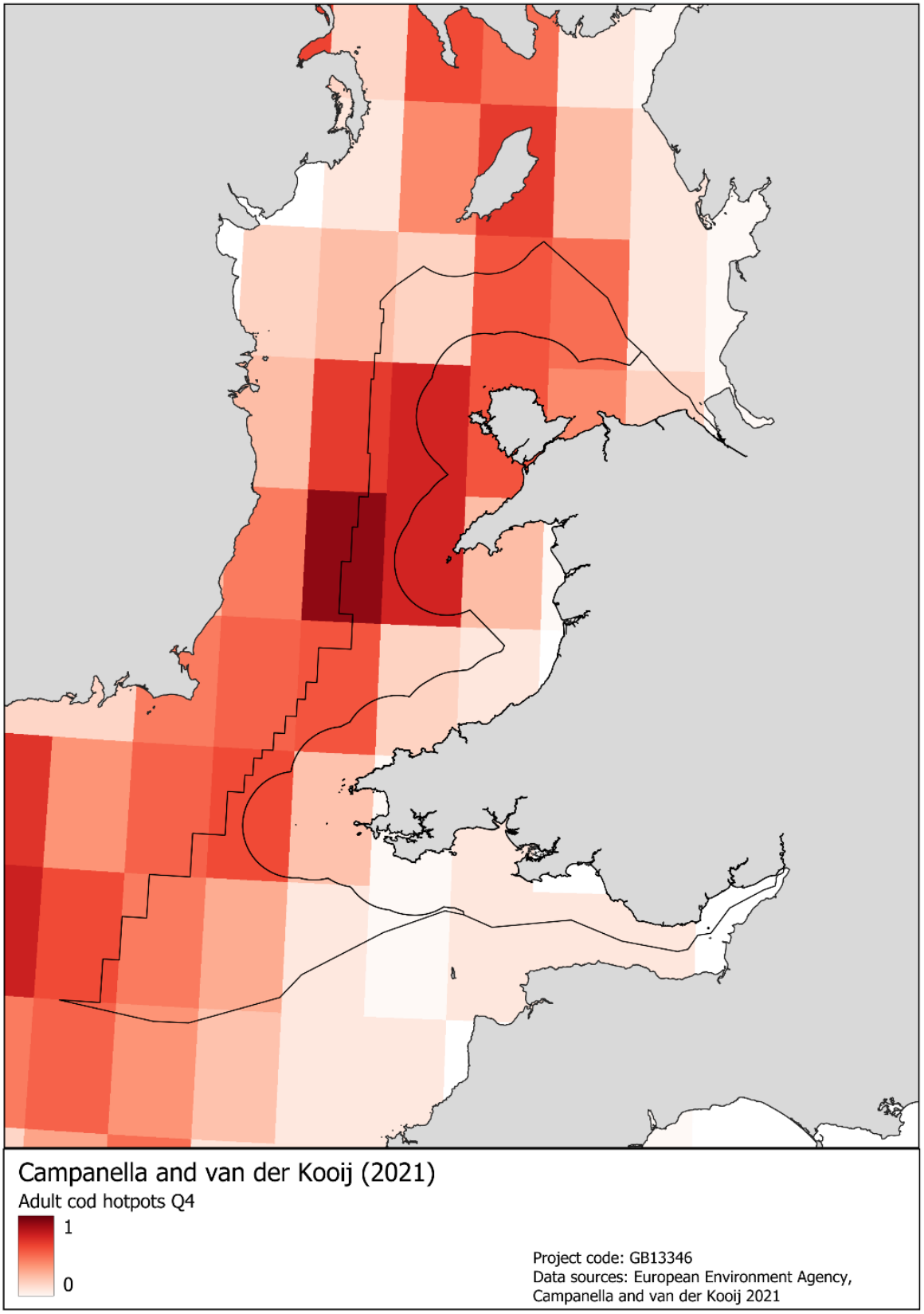


Figure 32. Hotspot map of adult cod in Welsh and surrounding waters in Q4 (Source: Campanella and van der Kooij, 2021).

A3.5.2. Species occurrence records in Welsh waters (OBIS, 2025)

Spatial coverage: All Welsh waters

Records of cod occurrence in Welsh and adjacent waters from the OBIS database begin with a single entry in 1912, followed by a gap until 1973, after which records appear almost annually until the most recent record from 2022. Records do not contain life stage nor length information and thus are presented here within the adult section. Records which included individual counts were less common and records with no associated count data were assumed to be single individuals (Figure 33).

Within Welsh waters, most occurrence records of cod are found within inshore waters, in Swansea Bay, Carmarthen Bay and around the Pembrokeshire Coast. Several records can also be seen around Anglesey and off the North Wales coast with few records of cod occurrence present within the Cardigan Bay area. Additionally, there are a cluster of cod records that can be seen in Welsh offshore waters in the Celtic Sea. This cluster of records originate from the ICES DOME (Marine Environment) programme.

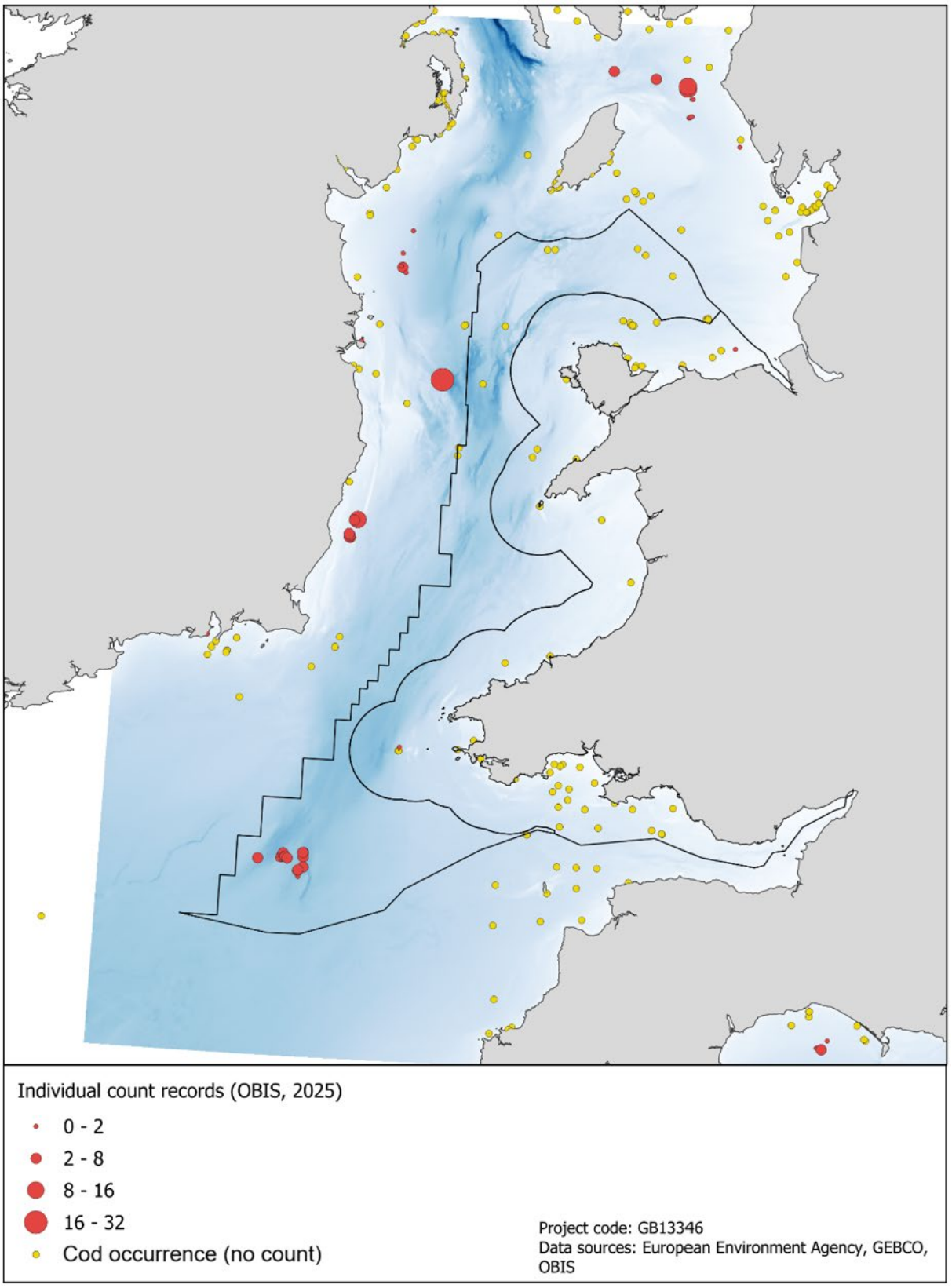


Figure 33. Cod occurrence points (1912, 1973-2022). Red points are graduated in size by individual count, where available. Yellow points represent occurrence where no counts were recorded (Source: OBIS, 2025).

A3.5.3. DATRAS Fisheries-independent trawl survey data (ICES, 2025a)

Spatial coverage: All Welsh waters, excluding close inshore and estuaries.

Haul data obtained from the ICES DATRAS database included 2,143 hauls containing cod of both adult and juvenile sizes. Linking these hauls to the associated length data resulted in 8,568 individual length frequency measurements from 461 sampling stations in Welsh waters collected between 2000 and 2025. A map depicting the adult cod distribution as an aggregate across all years is shown in Figure 34.

These data appear to show that between 2000 and 2024 the greatest numbers of adult cod were sampled to the northeast of Anglesey and offshore in the Celtic Sea. Additionally, north of Anglesey in Welsh offshore waters there are a cluster of records with high adult counts. Adult cod occurrence in the Bristol Channel is recorded in low numbers along most of the south coast between Swansea and Pembrokeshire.

Figure 35 presents quarterly maps based on the aggregated distribution shown in Figure 34. These plots display the spatial distribution of adult cod for Q1, Q3, and Q4 across the 25-year DATRAS dataset (2000–2025). No DATRAS sampling occurs in Q2, so this quarter is absent.

In Q3 (July–September), adult cod are recorded in lower abundance across Welsh waters. Most observations occur close to shore within Welsh inshore waters, particularly in Carmarthen Bay and around Anglesey.

By Q4 (October–December), the number of records within Welsh inshore waters decreases, though the area around Anglesey again appears as a recurrent hotspot. Higher abundances and more offshore records are visible within Welsh offshore waters, especially in the Celtic Sea, suggesting a seasonal movement of adult cod away from inshore areas during this period.

Q1 (January–March) shows the highest adult abundances and the greatest number of records across the time series. As in other quarters, inshore waters around Anglesey again support relatively high adult occurrences; however, Welsh offshore waters south of the Isle of Man and in the Celtic Sea contain the greatest concentrations of adult cod overall, indicating these areas may be particularly important for adult distribution during winter and during the spawning season.

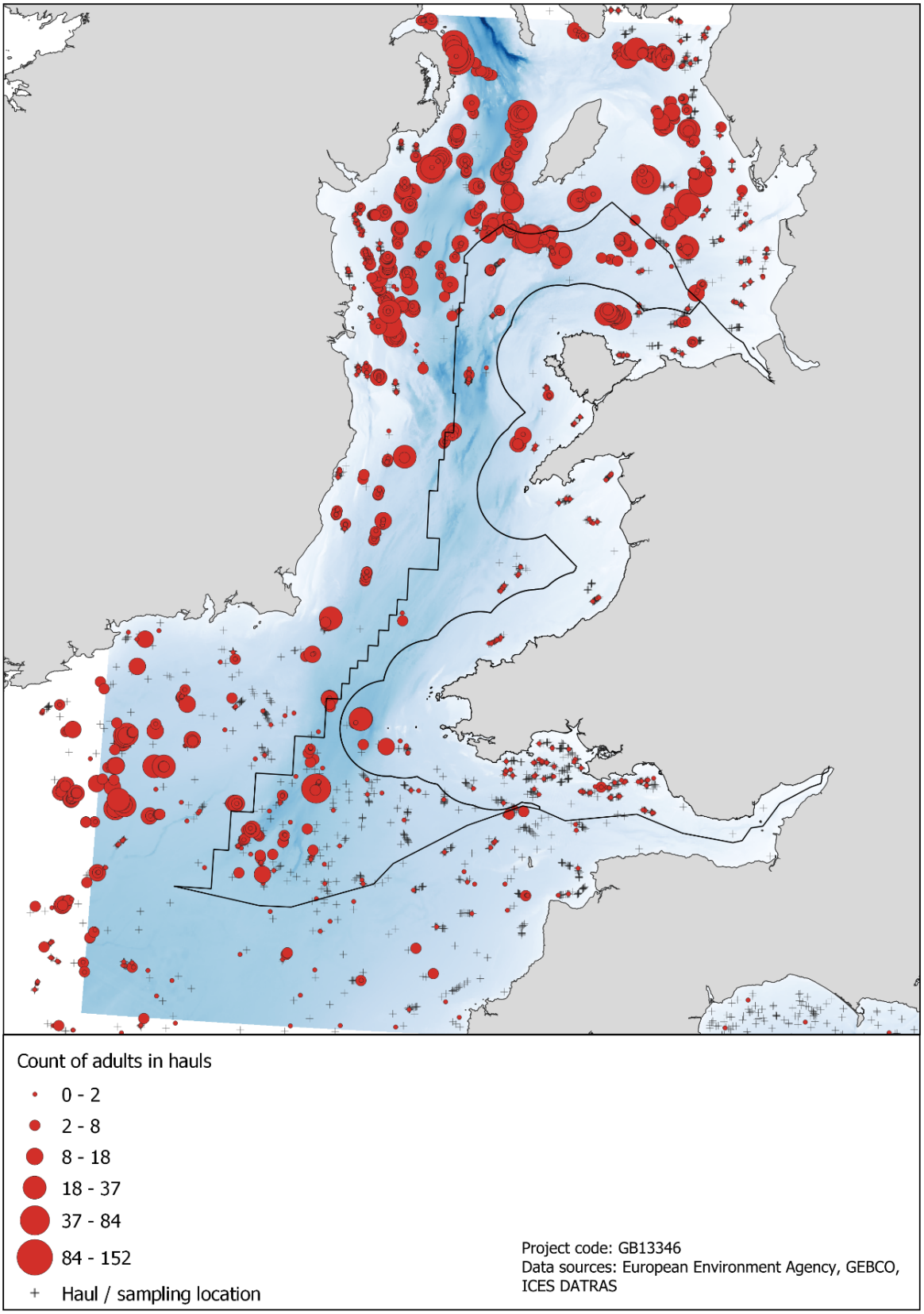


Figure 34. Points graduated in size by counts of adult (>22 cm) cod in survey hauls retrieved from the DATRAS database (2000 – 2025) (Source: ICES, 2025a).

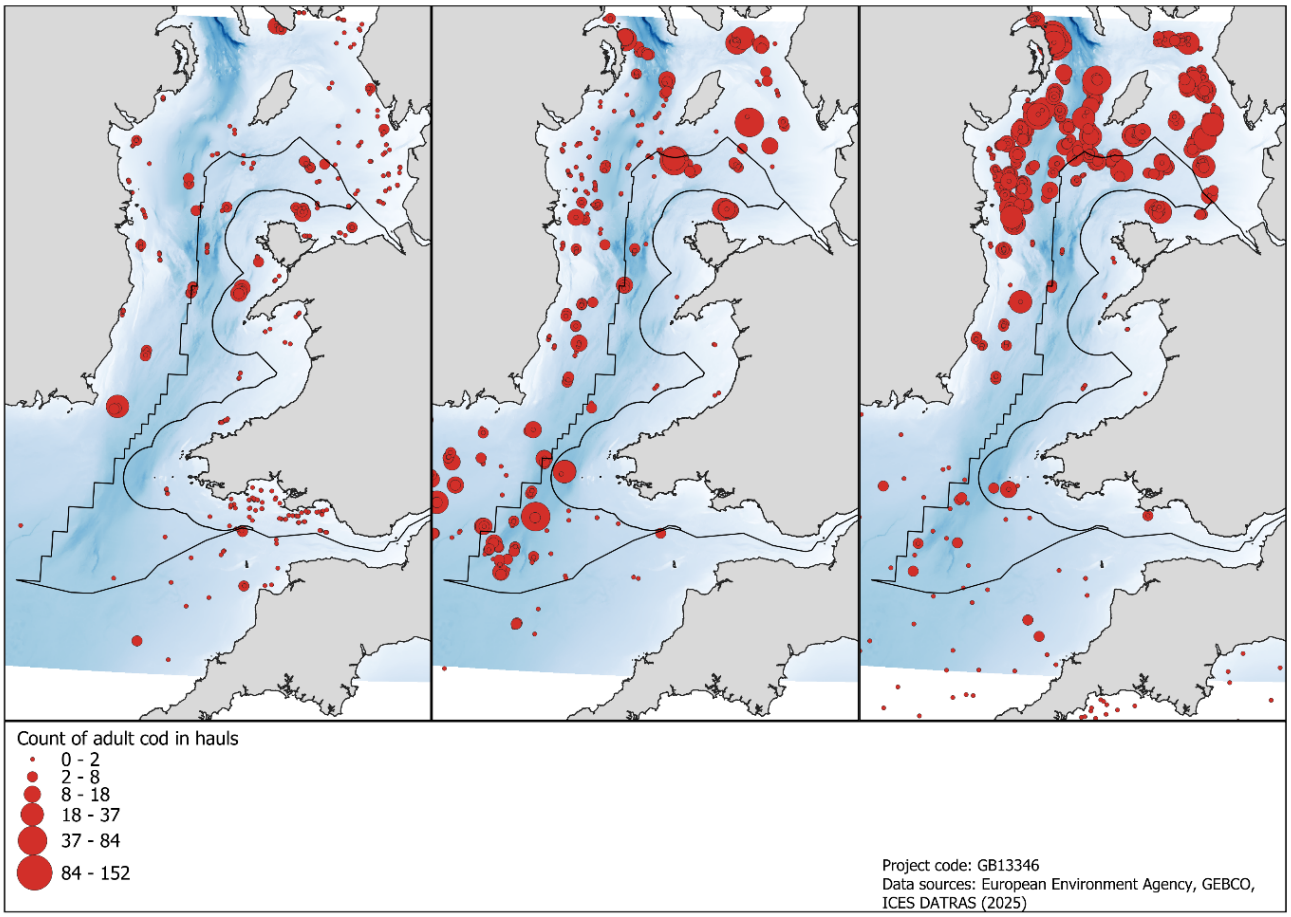


Figure 35. Points graduated in size by counts of adult (>22 cm) cod in survey hauls retrieved from the DATRAS database (2000 – 2025), split by quarter chronologically. Left = Q3 (July - Sept), Middle = Q4 (Oct - Dec), right = Q1 (Jan – Mar) (Source: ICES, 2025a).

A3.5.4. Sea Angling Diary catch records 2016-2024 (Cefas, 2025)

Spatial coverage: All Welsh waters

Sea Angling Diary data record 755 adult cod (≥22 cm) across several ICES rectangles (Table 4, Figure 36 and Figure 37) between 2016 and 2024. Most individuals fall within the 25–40 cm length range, with progressively fewer fish recorded in larger size classes. Individuals exceeding 60 cm are relatively uncommon, although several larger specimens are recorded, including a small number exceeding 100 cm caught in the Bristol Channel.

The spatial pattern indicates that adult cod are most frequently recorded in the Bristol Channel and Severn Estuary, particularly in ICES rectangles 31E6 and 32E7, which contain the highest numbers of individuals across multiple size classes. These areas include a broad size distribution, ranging from smaller adults in the 22–30 cm classes to larger individuals exceeding 60 cm, suggesting the presence of mixed ages in these areas.

Areas around the Pembrokeshire coastline (32E4) records the next highest number of individuals, with cod occurring across several size classes, although overall abundance is notably lower than in the Bristol Channel and Severn Estuary.

Along the North Wales coast, ICES rectangles 35E6 and 35E5 contain moderate numbers of adult cod. Records from these areas are dominated by smaller adults (25–40 cm), with fewer individuals recorded in the larger size classes.

Elsewhere, adult cod occur at lower frequencies, with relatively small numbers recorded in 32E5, 32E6, 33E5 and 34E5. Overall, the Sea Angling Diary data indicate that adult cod are most commonly recorded in the Bristol Channel and Severn Estuary, with additional occurrences around the Pembrokeshire peninsula and North Wales coast.

Table 4. Number of adult (>22 cm) cod caught and recorded in Sea Angling Diary data by ICES rectangle (2016 – 2024).

Length classes (cm)	31E6	31E7	32E4	32E5	32E6	32E7	33E5	34E5	35E5	35E6	36E5
[22,25)	19	0	2	0	1	14	0	0	1	1	0
[25,30)	117	0	2	9	2	66	7	0	4	4	0
[30,35)	104	0	3	3	2	36	0	4	4	8	0
[35,40)	76	0	0	1	0	9	4	0	1	4	0
[40,45)	48	0	3	0	4	26	2	2	1	3	0
[45,50)	26	0	3	1	0	34	0	8	0	1	0
[50,55)	12	0	11	1	0	5	0	0	1	1	0
[55,60)	13	0	1	0	0	2	0	1	0	0	0
[60,65)	8	0	1	0	2	2	0	0	0	0	0
[65,70)	2	0	0	2	0	0	0	0	9	0	0
[70,75)	4	0	0	0	0	0	0	1	0	0	0
[75,80)	0	0	1	0	0	1	0	0	0	0	0
[80,85)	1	0	0	0	0	0	0	0	0	0	0
[95,100)	1	0	0	0	0	0	0	0	0	0	0
[105,110]	2	0	0	0	0	0	0	0	0	0	0
Adult Total	**433**	**0**	**27**	**17**	**11**	**195**	**13**	**16**	**21**	**22**	**0**
Unmeasured	394	4	16	5	7	31	1	69	71	20	5

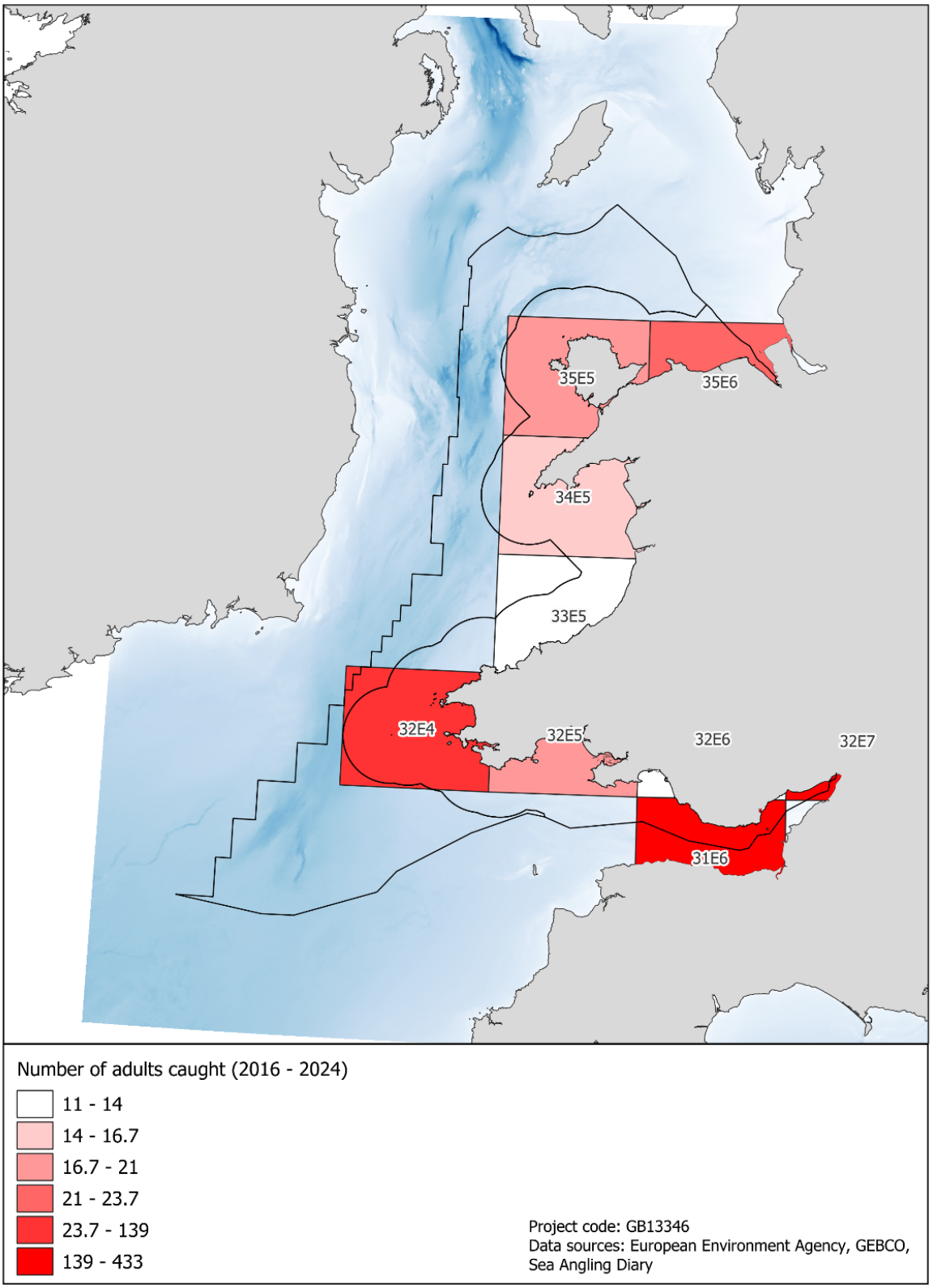


Figure 36. Number of adult (>22 cm) cod caught and recorded in Sea Angling Diary data (2016 – 2024) (Source: Cefas, 2025).

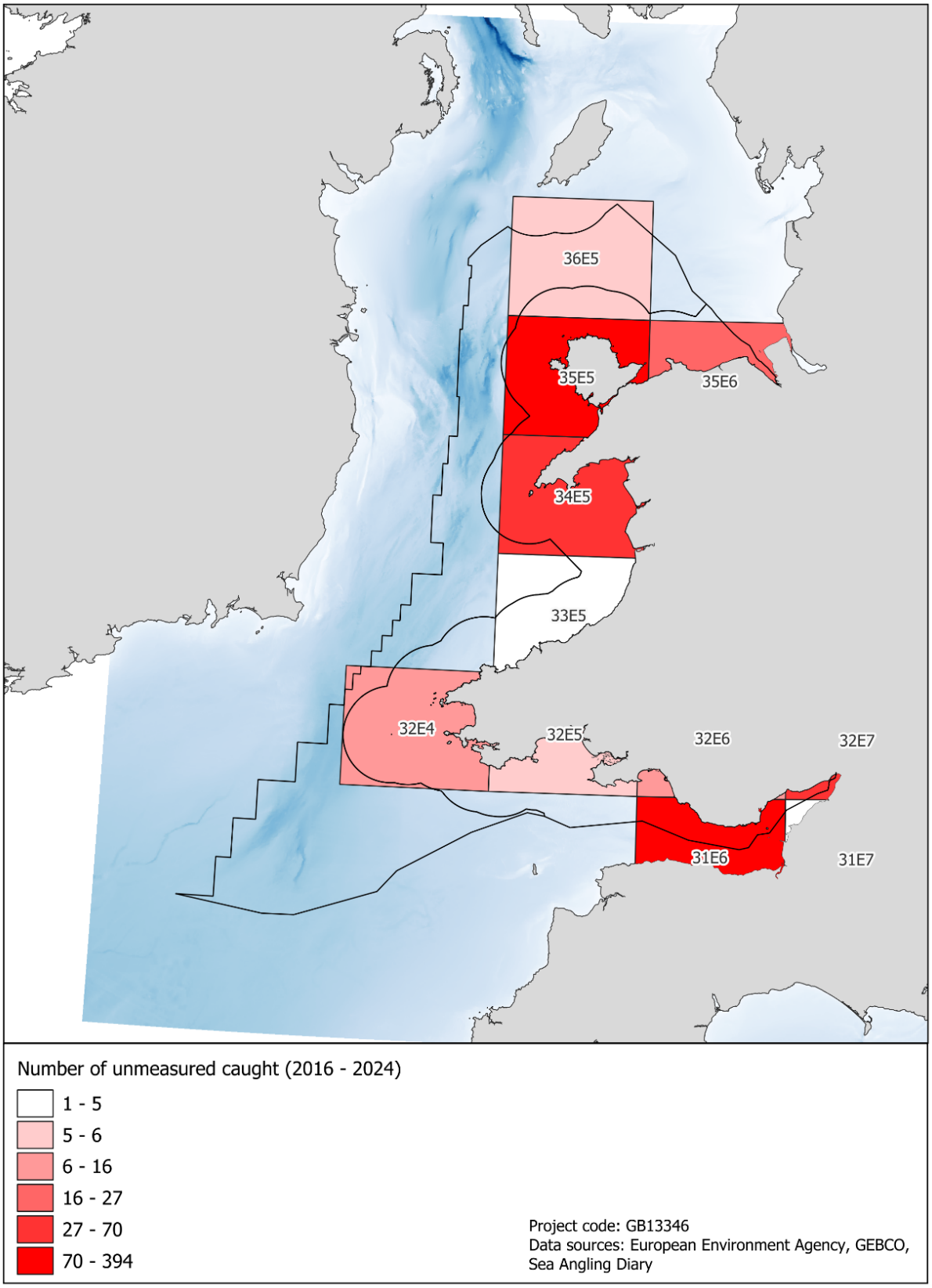


Figure 37. Number of unmeasured cod caught and recorded in Sea Angling Diary data (2016 – 2024) (Source: Cefas, 2025).

A3.5.5. AquaMaps standardized species distribution maps (AquaMaps, 2025)

Spatial coverage: All Welsh waters

Data requested from Aquamaps yielded little variation in the distribution of cod in Welsh waters and are not included as a figure, although have been included within the spatial dataset. The occurrence statistic used to define cod presence is available on a 0.05 degree grid with the entire inner and outer Welsh waters having near 100% probably of occurrence and thus offer little useable information.

A3.5.6. Highly mobile fish species distributions in UK waters (Cefas/ABPmer, 2010)

Spatial coverage: All Welsh waters

Cod distribution within this dataset is represented through multiple spatial layers. Figure 38 shows cod abundance aggregated to ICES statistical rectangle scale, based on average catch per unit effort (CPUE; number per one-hour tow) derived from GOV otter trawl surveys. Coverage across Welsh waters is good at this resolution, with cod presence recorded in all ICES rectangles within Welsh waters based on combined presence–absence information from Portuguese high headline trawl, beam trawl and GOV surveys.

Abundance patterns at the ICES rectangle scale indicate generally low CPUE across Welsh waters, with partial coverage along the south Wales coast and consistently low abundances in Welsh offshore waters. Cod abundance in Cardigan Bay, from inshore waters to the median line, is similarly low, while rectangles to the north of Anglesey show comparatively higher CPUE within Welsh waters, with waters around Anglesey exhibiting elevated values relative to Cardigan Bay and the Bristol Channel.

Finer-resolution information is provided by quarter ICES rectangle layers, which present abundance estimates from Portuguese high headline trawl (P_COD_A) and beam trawl (B_COD_A) surveys (Figure 39). These panels show limited survey coverage within Welsh waters and indicate low cod abundance across sampled areas relative to adjacent regions outside Welsh waters. Across both panels, cod abundance within Welsh waters is consistently low, with no ICES statistical rectangles showing elevated CPUE values; although variation in colour intensity is visible, this reflects small differences within an overall low abundance range.

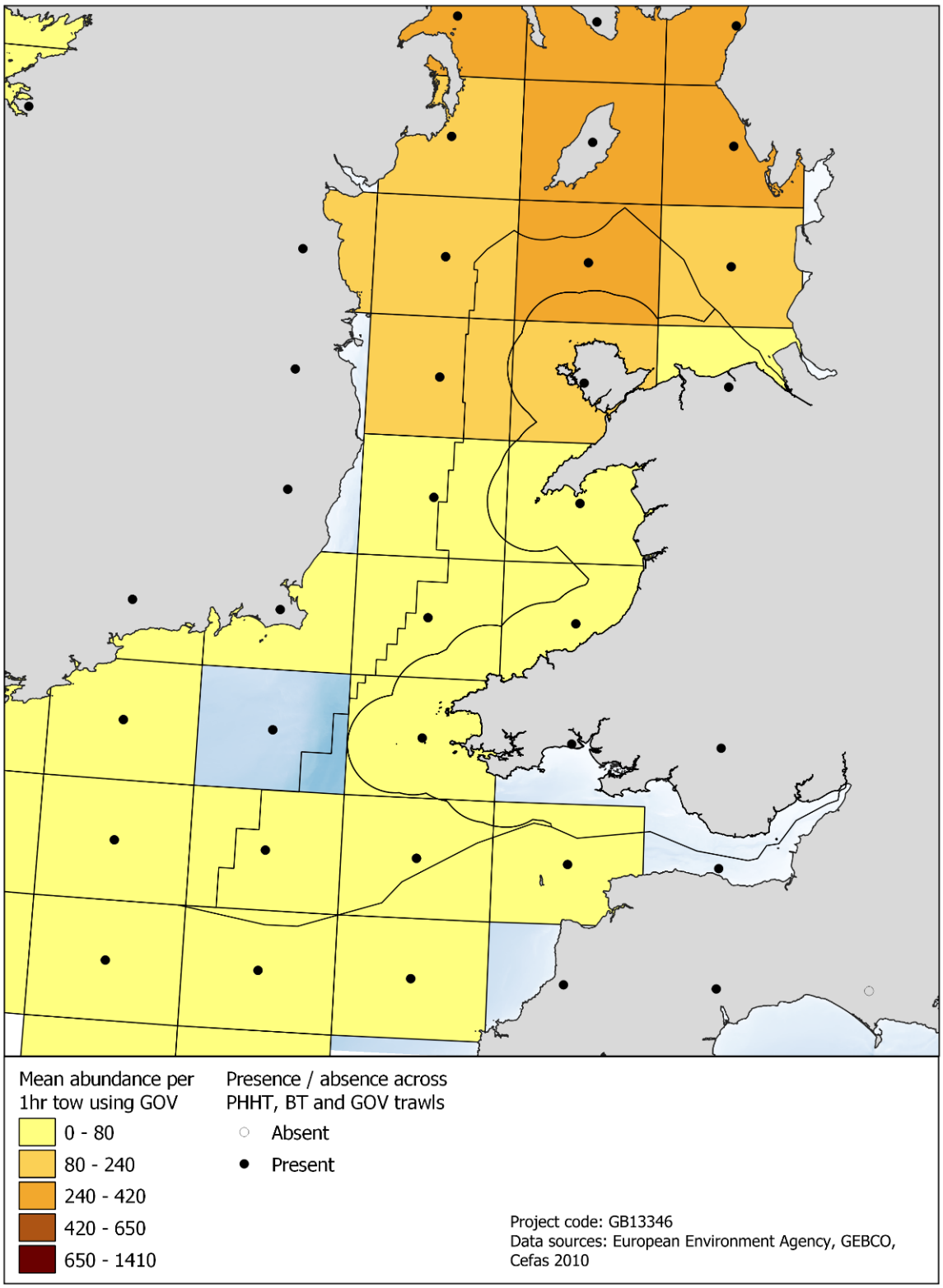


Figure 38. Distribution of cod by ICES statistical rectangle, based on fisheries-independent groundfish survey data. Values represent average abundance (CPUE) per one-hour tow derived from GOV otter trawl surveys, aggregated to the ICES rectangle scale (Source: Cefas/ABPmer, 2010).

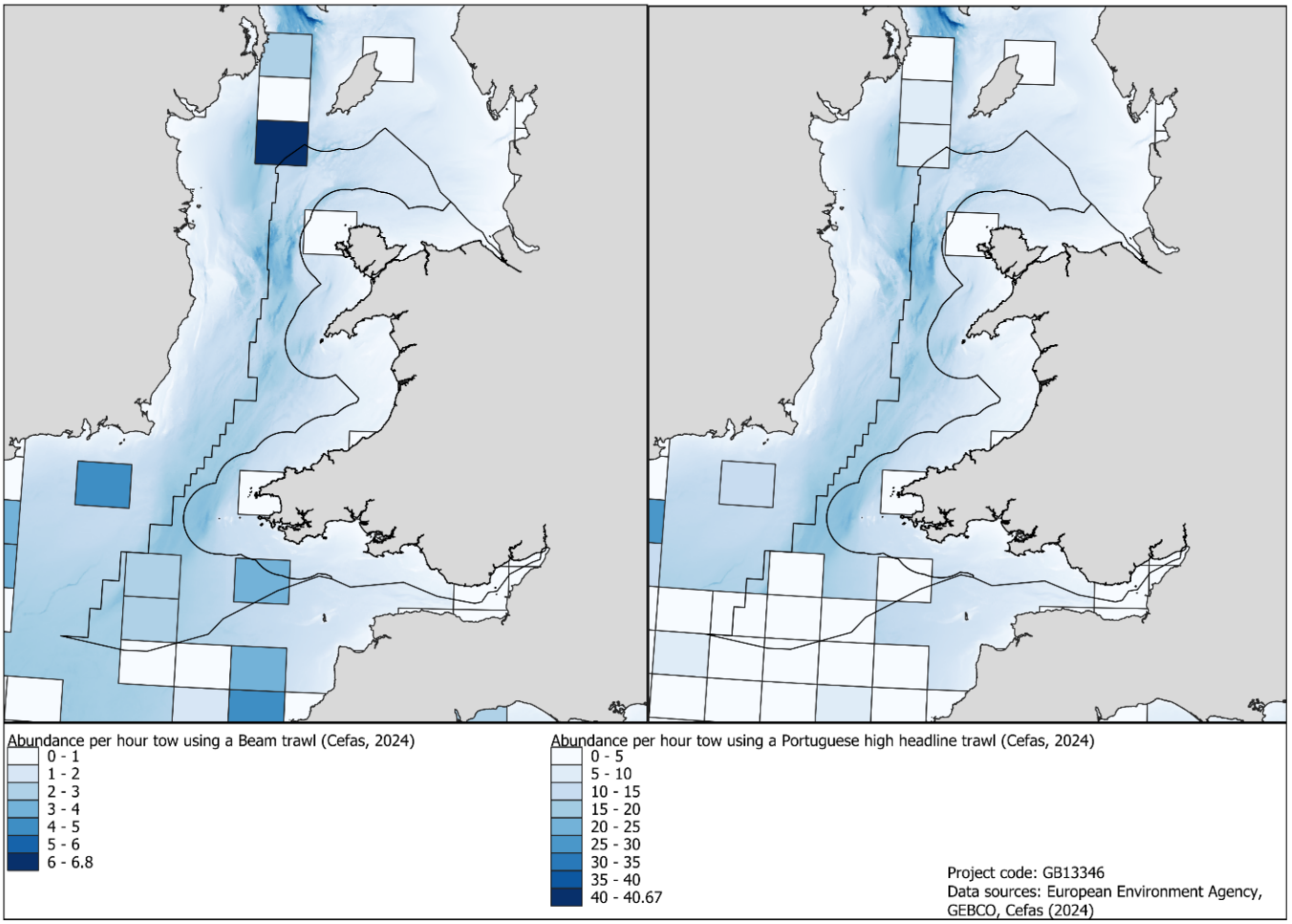


Figure 39. Abundance of cod per hour tow using beam (left) and Portuguese high headline trawls (right) (Source: Cefas/ABPmer, 2010).

A3.5.7. WFD Transitional fish surveys (NRW, 2025)

Spatial coverage: Welsh estuaries

Spatial data received from NRW containing WFD surveys was mapped and contains point data of cod with associated lengths over the period 1997 to 2024. Within the dataset provided, adult cod (>22 cm) were recorded at 16 of 106 distinct sampling sites. These occurrences were primarily concentrated in the higher reaches of the Severn Estuary, including areas around Cardiff and Beachley (Figure 40). Records of adult cod occurrence at these sites in the Bristol Channel date from 1997 to 2015, although not in all years. The only other sites where adult cod were found was in inner Welsh waters at the mouth of the Dee Estuary at the Mostyn Bank Otter Trawl site in 2002, 2003, 2008 and 2009.

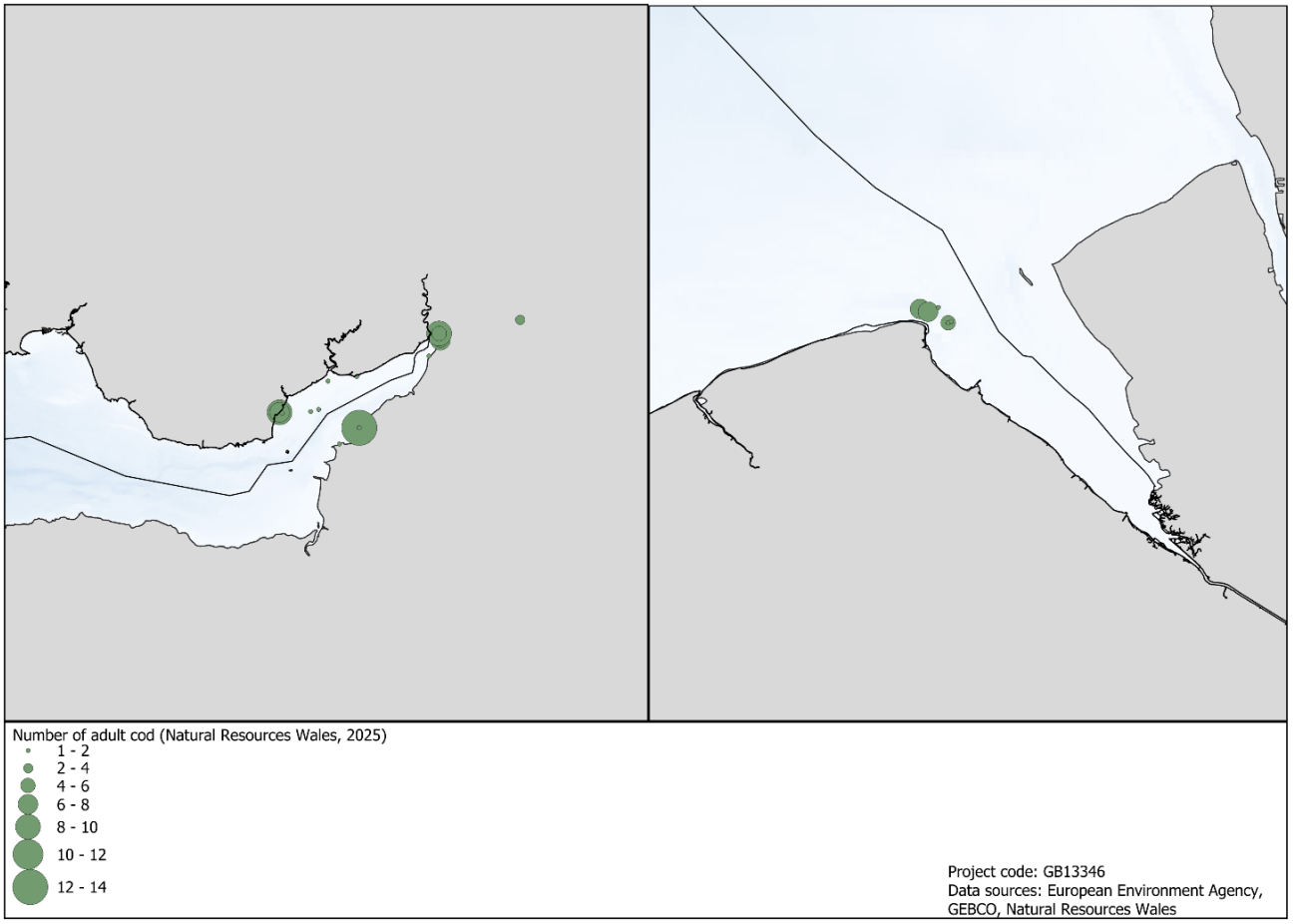


Figure 40. Adult cod presence in the Severn Estuary (left) and the Dee Estuary (right) (Source: NRW, 2025).

A3.5.8. Commercial fisheries landings and discards data (MMO, 2025)

Spatial coverage: All Welsh waters

Aggregated MMO commercial catch data for cod (landings and discards, 2014–2024) show generally low catches across most of Welsh waters. The most notable areas of elevated catch occur in the Bristol Channel and within inshore waters around Pembrokeshire, where several ICES sub-rectangles record higher total volumes compared with surrounding areas (See Figure 41). Cardigan Bay and the North Wales coast also have consistently low aggregated catches throughout the dataset. The highest catch overall occurs off the east coast of Ireland and in the southern Celtic Sea, intersecting with Welsh offshore waters.

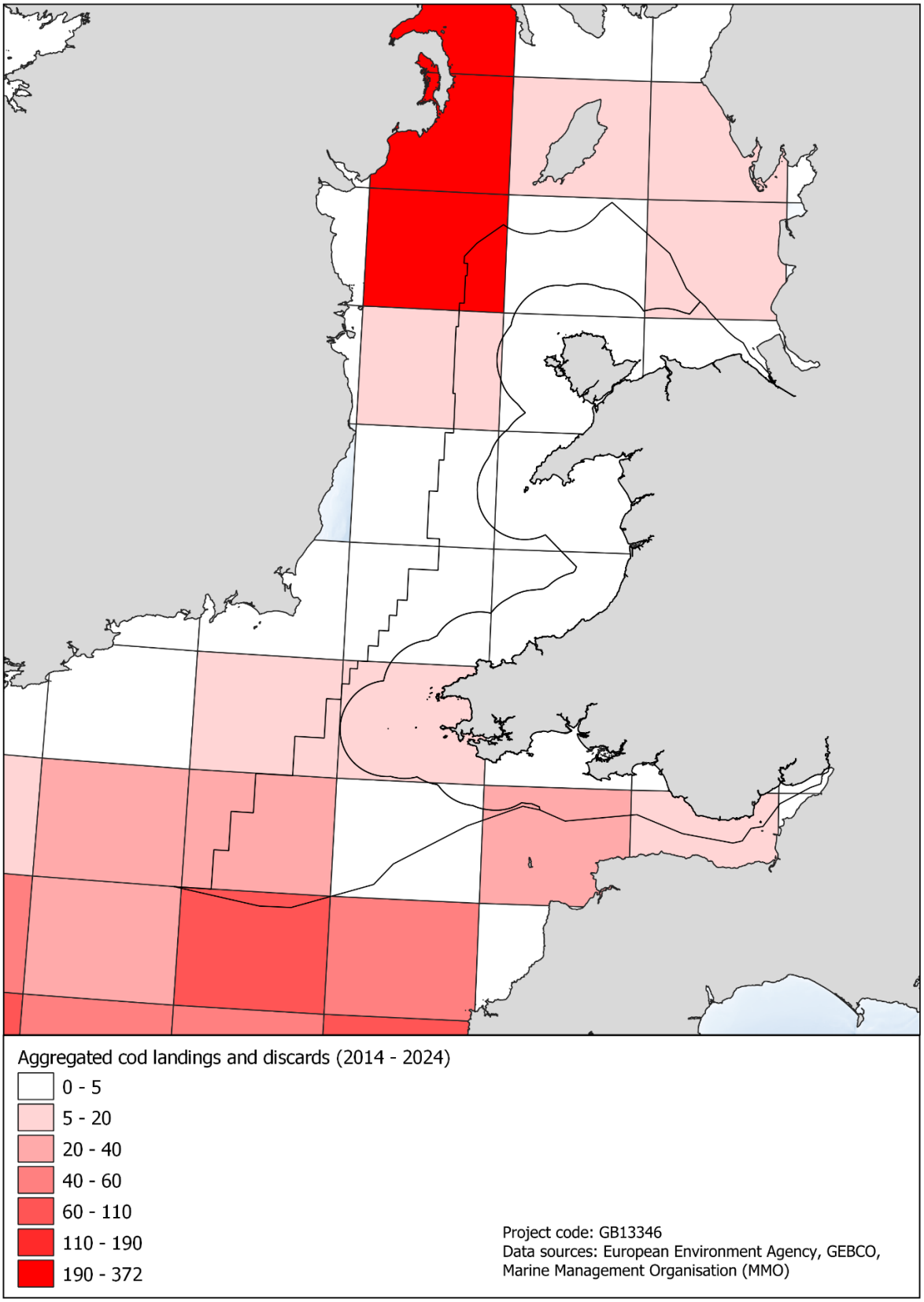


Figure 41. Aggregated landings and discards (tonnes) by ICES subrectangle, 2014 to 2024 (Source: MMO, 2025).

A3.5.9. Variable trends in the distribution of Atlantic cod (*Gadus morhua*) in the Celtic seas (Ellis *et al.*, 2024)

Spatial coverage: All Welsh waters

This report used groundfish survey data from the ICES DATRAS database and examined the distribution of cod in the Celtic and Irish seas to determine if distribution has shifted over time (Ellis *et al.*, 2024). The study mapped densities of cod annually (1990 – 2021) as well as conducted a centre of gravity analysis to determine spatio-temporal changes in distribution. Annual heatmaps from their analysis are provided in Appendix 3 showing annual densities of cod (adult and juvenile) in the Celtic Sea.

In addition, Figure 42 presents interpolated cod density (kg nmi^{-2}) maps for Q4 at two-year intervals from 1997 to 2021, derived from the same DATRAS dataset but displayed in a more compact format suitable for the body of the report. As with the Appendix 3 figures, variations in cod densities within Welsh and surrounding waters are difficult to visually discern.

Despite these limitations, Ellis *et al.* (2024) found no clear evidence of the range of cod stocks shifting outside their management areas in the Irish or Celtic Seas, although changes in distribution were evident within stock management areas (Figure 43). Within the Irish Sea, cod showed a slight westward and southward shift over time; however, the authors note that the apparent southerly movement in the stock's centre of gravity may be influenced by sampling bias.

The centre of gravity analysis nevertheless indicates that some of the highest cod densities in the Irish Sea consistently occur off the North Wales coast, particularly west of Anglesey in Q4 and northwest of Anglesey in Q1, coinciding with spawning periods. In the Celtic Sea, movements were less directionally consistent, with substantial longitudinal and latitudinal variability across ICES Divisions 7.j, 7.g and 7.f, although centres of gravity were frequently located towards the southern portion of Division 7.g.

Across both the Irish and Celtic Seas, cod densities declined over time and became increasingly confined to smaller areas. The two-year interval maps shown in Figure 42 support this pattern, illustrating a contraction of higher-density areas since the mid-2010s, with Celtic Sea cod becoming increasingly separated from Irish Sea concentrations and higher densities shifting westwards within the Celtic Sea. These trends suggest a progressive spatial concentration of cod populations in areas that continue to include Welsh and adjacent waters, despite overall declines in abundance.

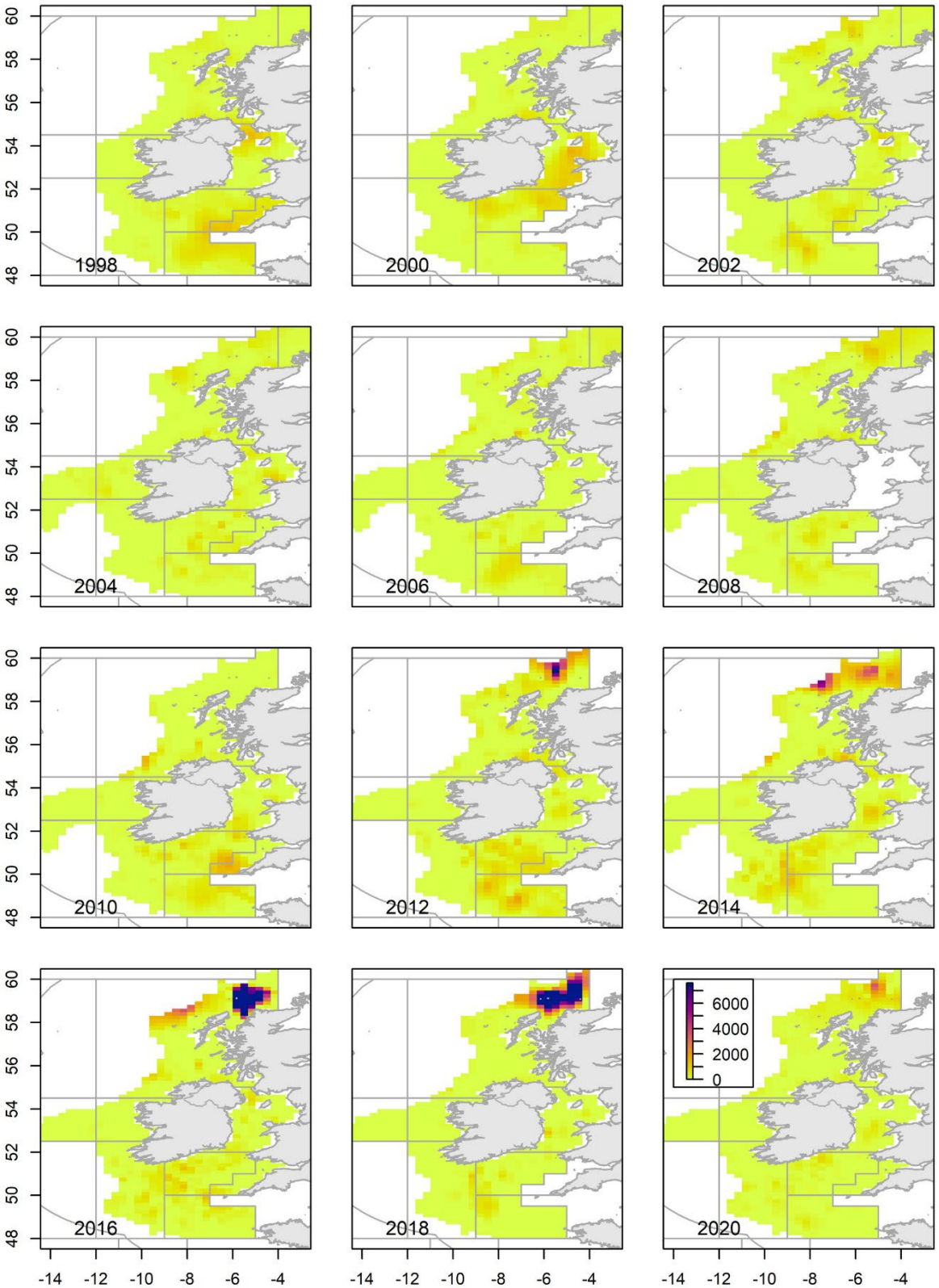


Figure 42. Maps of the Celtic Seas showing the interpolated cod density (kg/nmi^2) in 2-year intervals from 1997 to 2021 in Q4. The colour scale ranges from 0 to over 5930 kg/nmi^2 (Source: Ellis *et al.,* 2024).

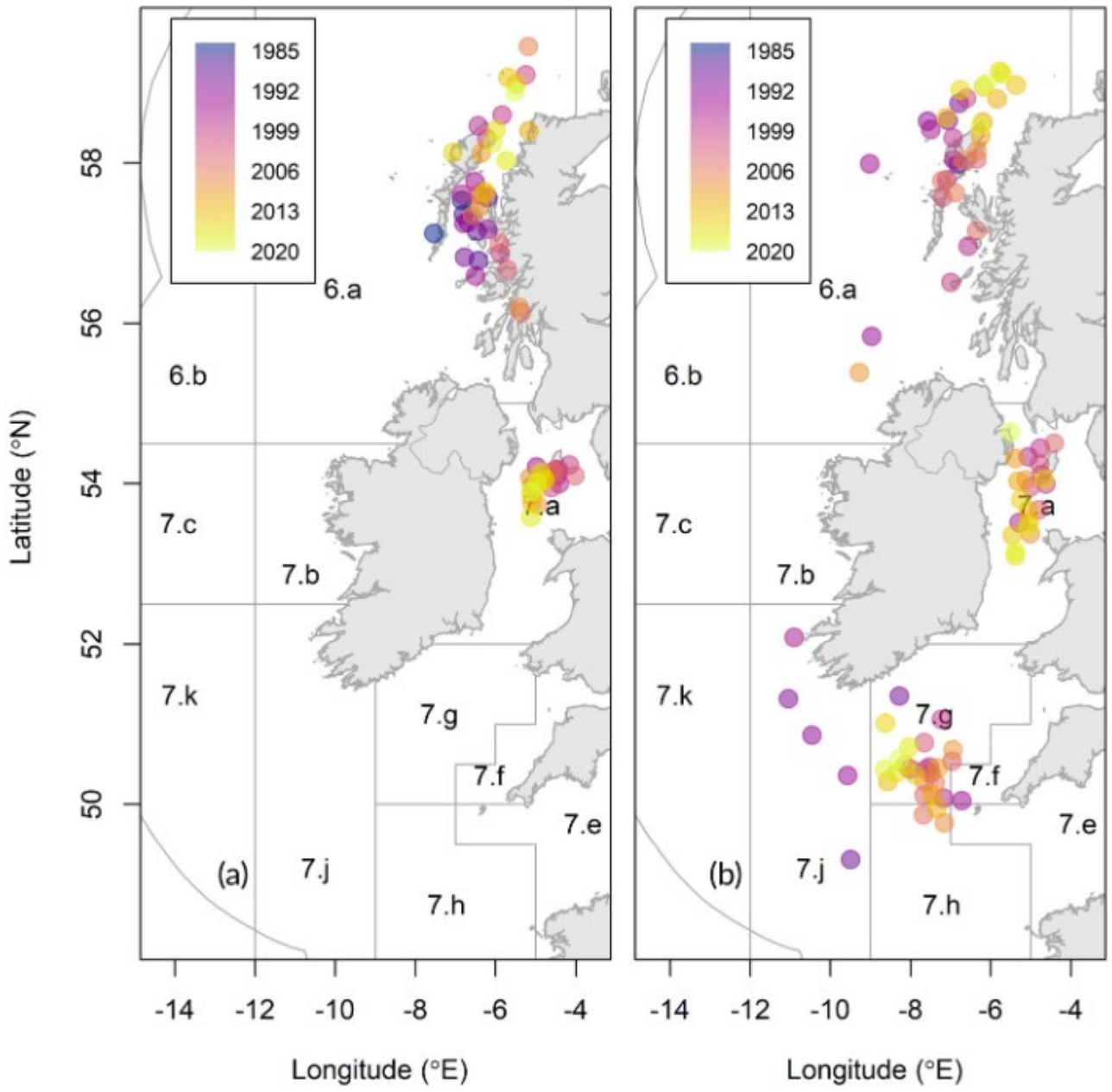


Figure 43. Maps of the western British Isles showing the positions of the centres of gravity as points over time for the West of Scotland (6.a), Irish Sea (7.a) and Celtic Sea (7.f-j) for Q1 (a) and Q4 (b). Points are coloured according to year from purple to yellow (Source: Ellis *et al.*, 2024).

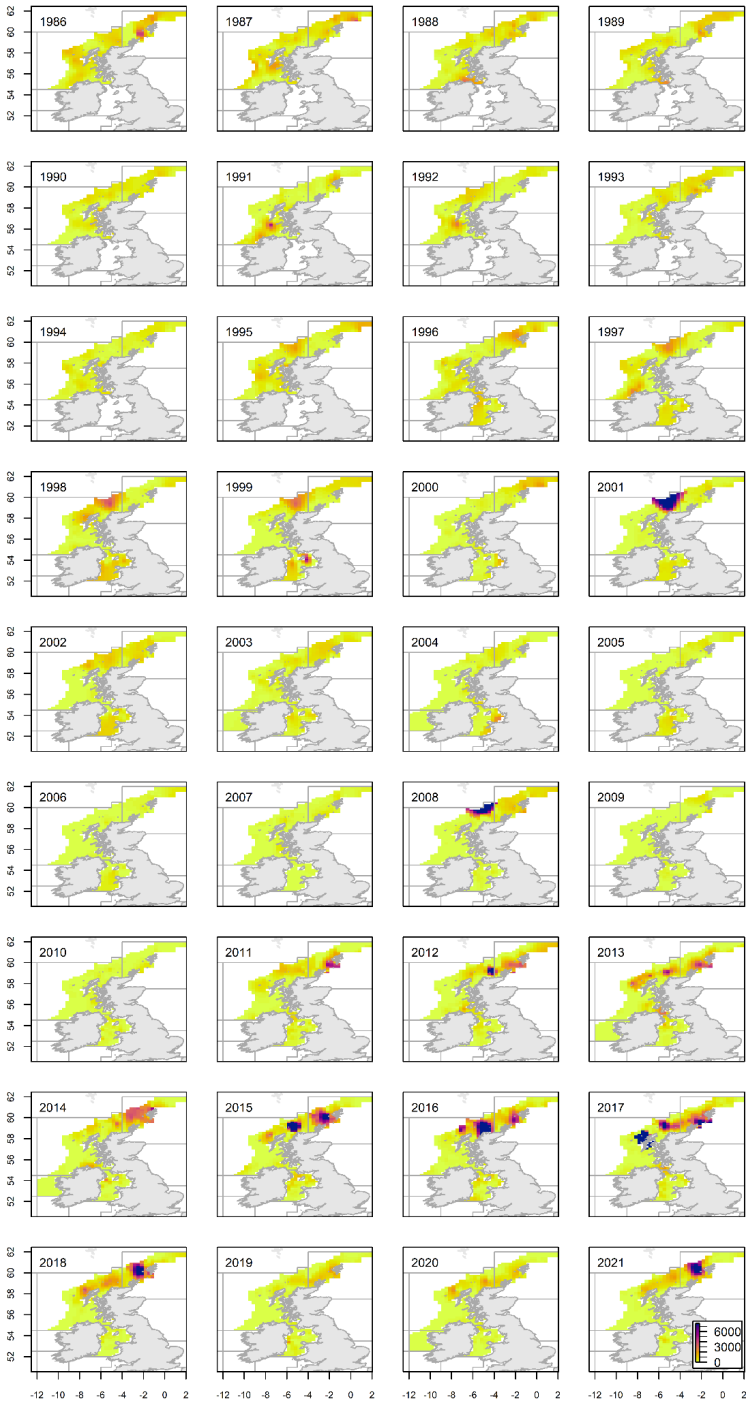


Figure 44. Maps showing interpolated cod densities (kg/nmi^2) over the study areas from 1985 to 2021 in Q1.

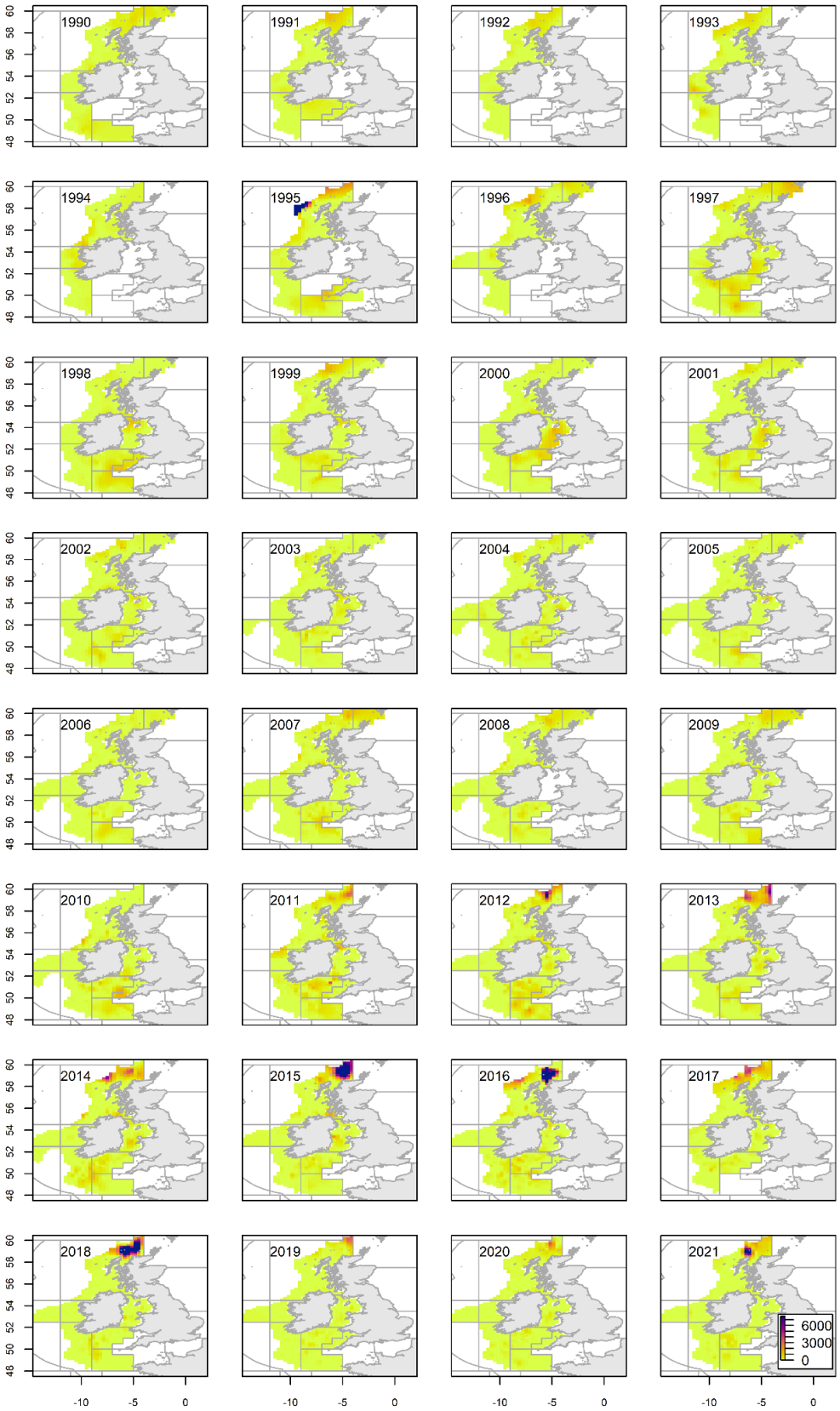


Figure 45. Maps showing interpolated cod densities (kg/nmi^2) over the study areas from 1990 to 2021 in Q4.

A3.6. Life cycle process – spawning grounds

A3.6.1. Fisheries spawning and nursery areas: Fishery Sensitivity Maps in British Waters (Coull *et al.*, 1998)

Spatial coverage: All Welsh waters

The report and associated spatial data indicate a lower intensity cod spawning area in the Irish Sea in Welsh waters extending north to the area east of the Isle of Man (Figure 46), while a higher spawning intensity is noted at Trevose Head off the North Cornwall coast and off the Irish coast.

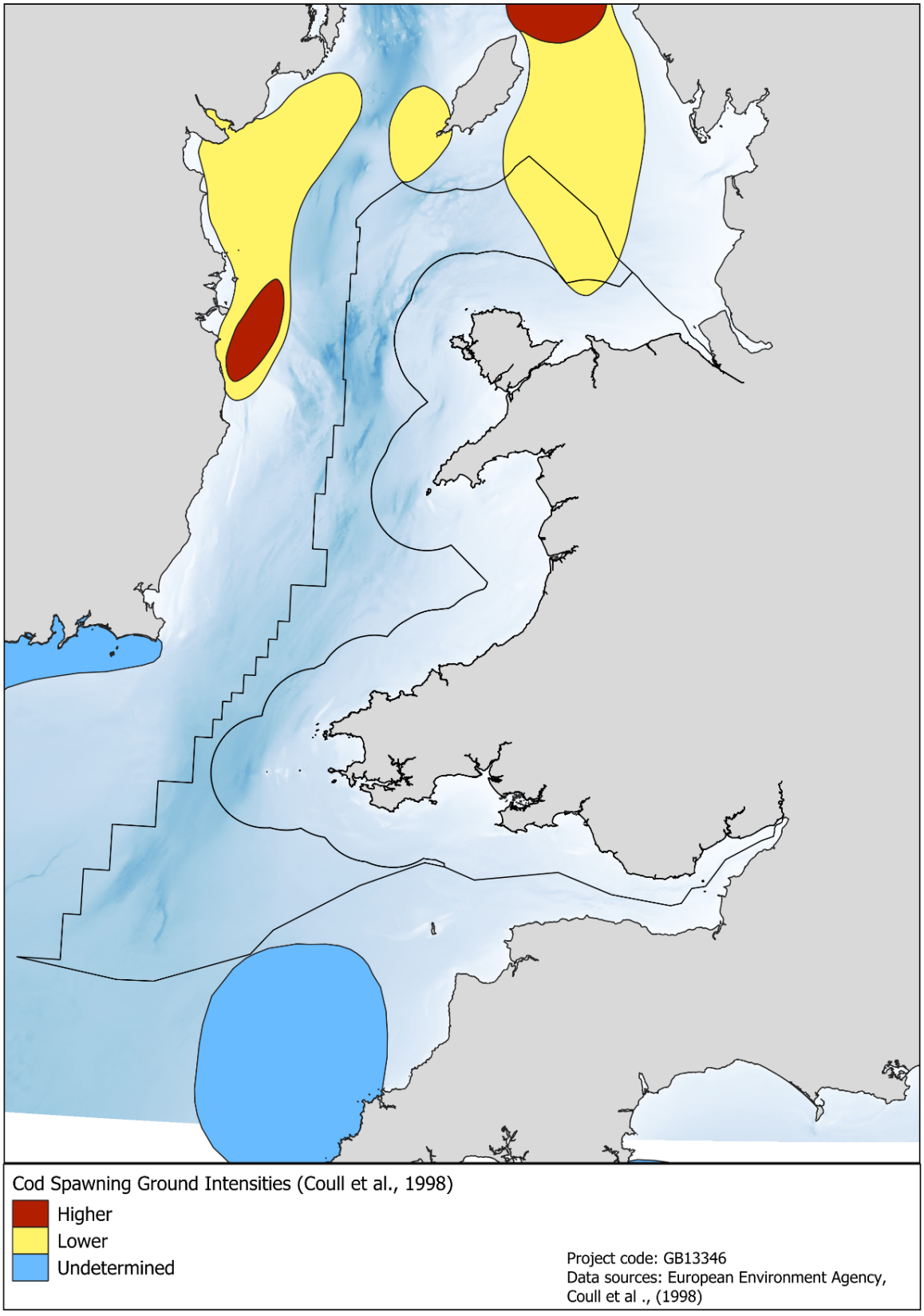


Figure 46. Spawning ground of cod presented for areas of higher, lower and undetermined intensity (Source: Coull *et al.*, 1998).

A3.6.2. Spawning and nursery grounds of selected fish species in UK waters (Ellis *et al.*, 2012)

Spatial coverage: All Welsh waters

Spawning grounds have been identified from egg and larvae data in the report by Ellis *et al.*, (2012) with spawning areas of high and low intensity presented in Figure 47. The data show much of Cardigan Bay and the Irish Sea categorised as low intensity spawning areas.

High intensity spawning areas include:

- Off the North Wales coast between the Great Orme and the River Clwyd (covering both inshore and offshore Welsh waters and more widely into the Irish Sea);
- near the west coast of the Isle of Man and part of Welsh offshore waters in the central Irish Sea.
- Over Trevose Bank in the Celtic Sea in Welsh offshore waters and off the north coast of Cornwall in English waters. The area around Trevose Bank also has surrounding low intensity spawning areas mainly in English waters but also in inshore Welsh waters in the Bristol Channel.

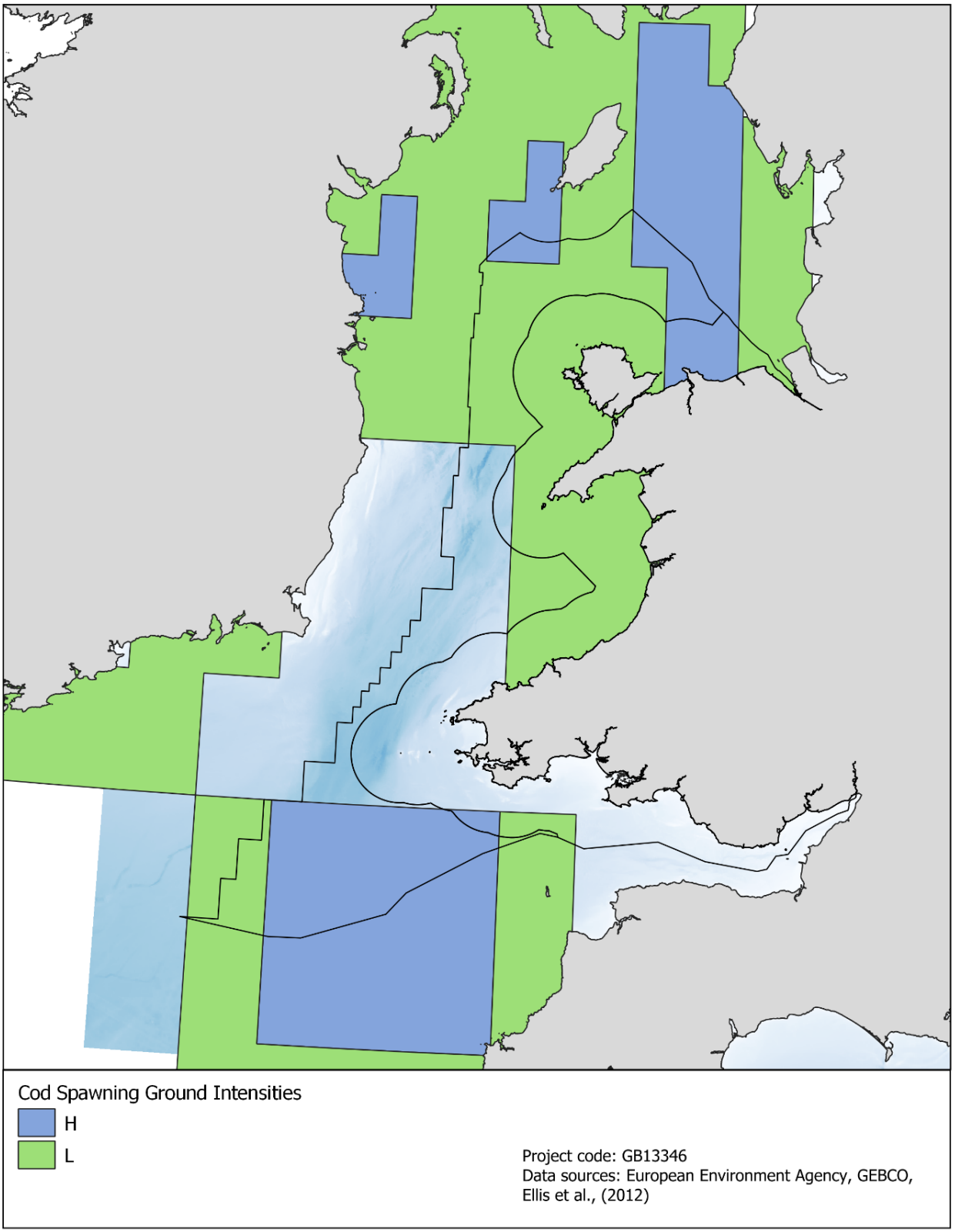


Figure 47. High and low intensity cod spawning areas (Source: Ellis *et al.*, 2012).

A3.6.3. Spawning and nursery grounds of forage fish in Welsh and surrounding waters (Campanella and van der Kooij)

Spatial coverage: All Welsh waters, excluding close inshore and estuaries.

Campanella and van der Kooij (2021) analysed data from ten fisheries-independent surveys conducted between 2008 and 2020 to identify spawning grounds of forage fish in Welsh and surrounding waters.

Data of adults from Q1 represent the spawning period for cod, so Campanella and van der Kooij (2021) use the adult hotspot map at this time period as a representation of spawning areas (Figure 48). The most persistent spawning hotspot identified lies in the Celtic Sea and is partly in Welsh offshore waters. The authors note that their analysis suggests a much larger spawning area than that reported by Coull *et al.* (1998), however the use of adult fish presence during the spawning period, rather than egg and larval data, may have increased the extent of cod spawning habitat inferred. A further area of low-level adult persistence in Q1 inferred as a spawning ground is identified to the north of Anglesey in the Irish Sea.

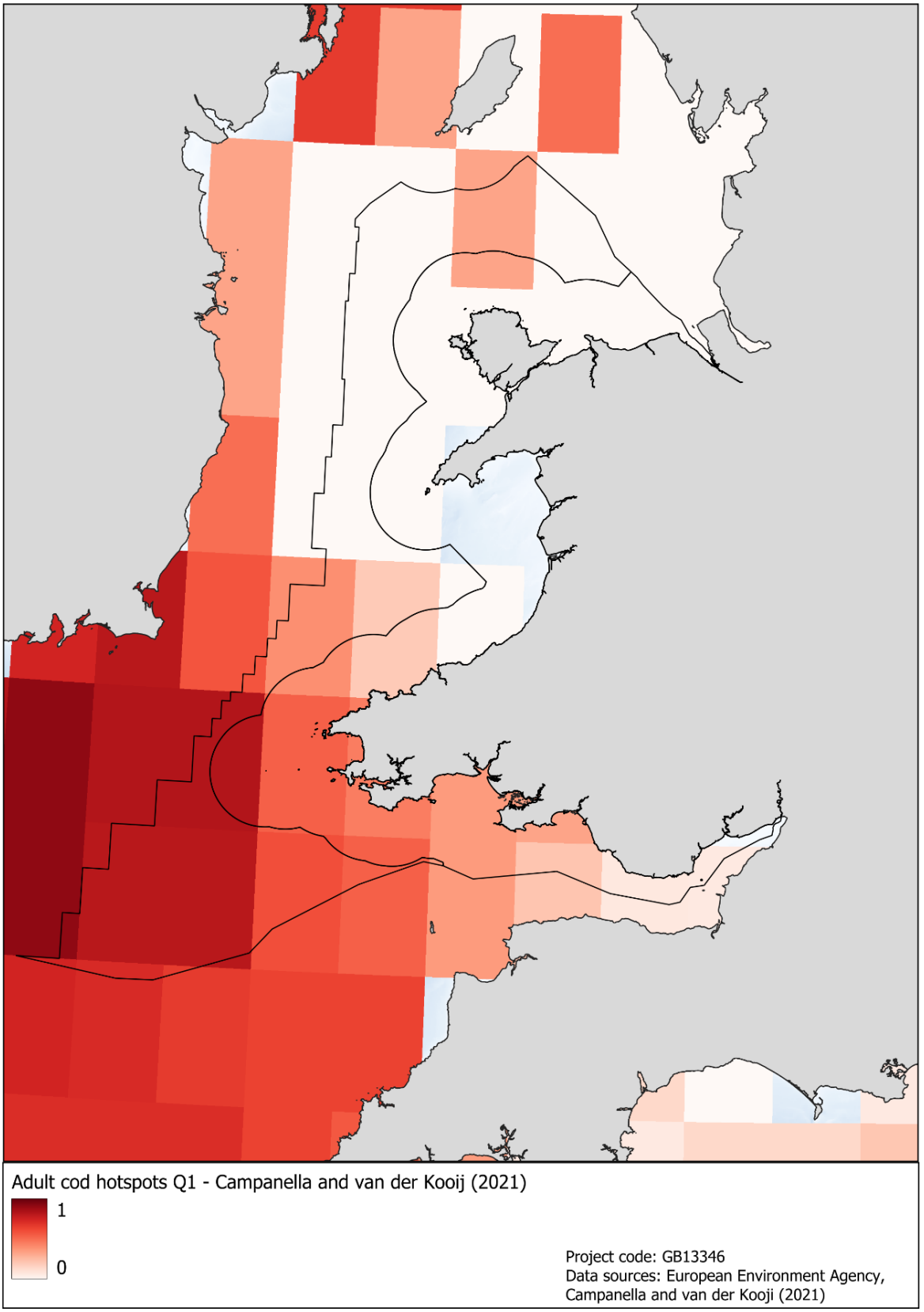


Figure 48. Hotpot map of adult cod in Welsh and surrounding waters in Q1 coinciding with their known spawning period. (Source: Campanella and van der Kooij, 2021).

A3.6.4. Species spawning and nursery areas (Marine Institute, 2018; revised 2024)

Spatial coverage: All Welsh waters

The Marine Institute published a set of spawning and nursery area spatial datasets, which include spawning sites within Welsh waters (Marine Institute, 2018, revised 2024). However, these data are not associated with a published report describing the methodologies used to create the spatial delineations. Nevertheless, they have been included as they appear to corroborate similar findings of other studies used in this report. Two areas within Welsh waters are delineated as a spawning area for cod (Figure 49). The largest of the two extends across nearly the whole of the Bristol Channel, extending to the north Cornwall coast. The smaller of the two is situated off the North Wales coast from north of Anglesey to the Dee Estuary in both Welsh inshore and offshore waters.

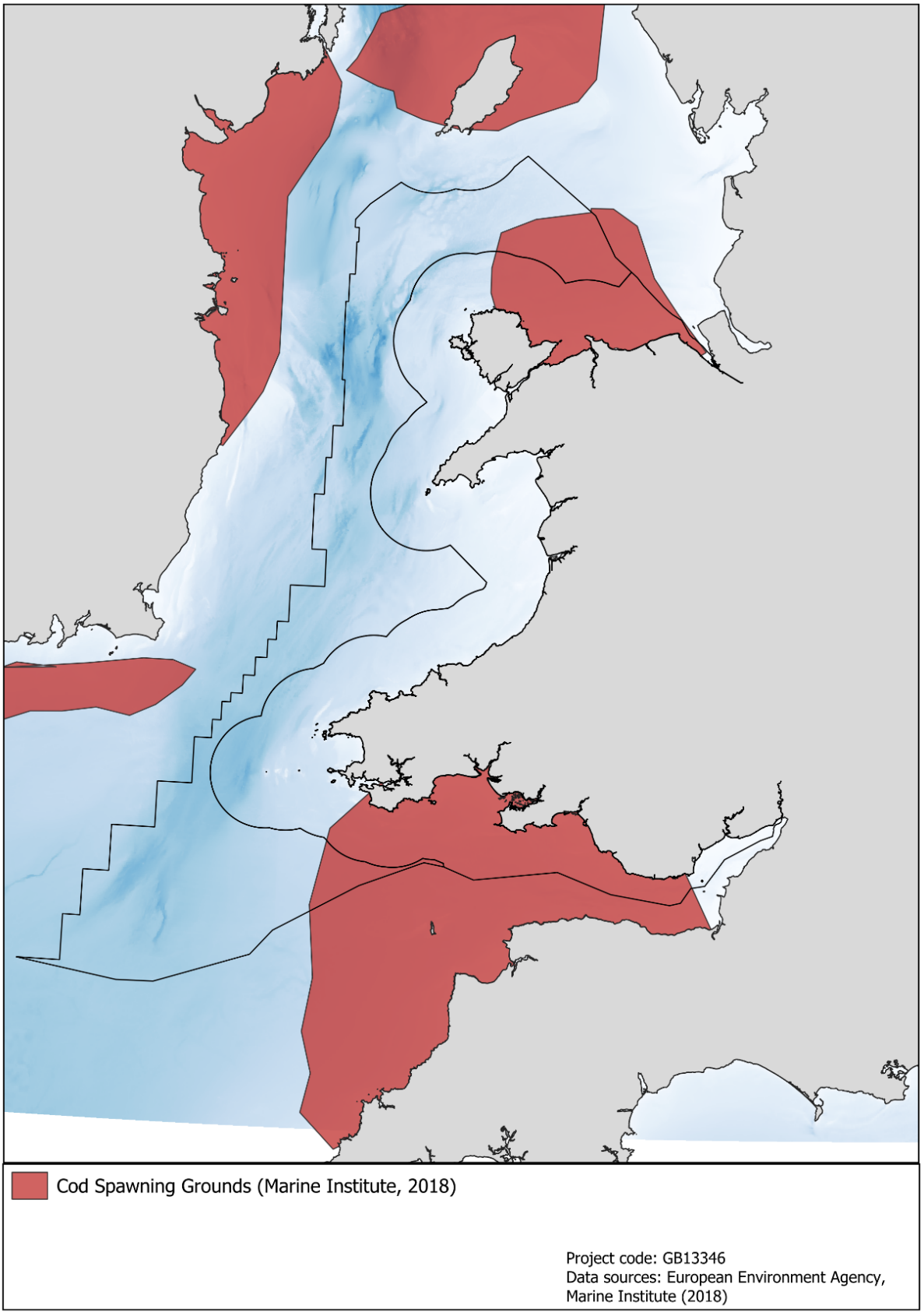


Figure 49. Cod spawning grounds (Source: Marine Institute, 2018, revised 2024).

A3.6.5. Essential Fish Habitats project data (Marine Directorate, 2023)

Spatial coverage: All Welsh waters

The modelled cod spawning EFH layer (Figure 50) from this study shows an offshore area of predicted spawning presence, classified entirely as high-confidence presence, located in St George's Channel. This feature is partly in Welsh offshore waters and at its southern extent, in Welsh inshore waters.

Much of Welsh waters is modelled as spawning absence with high confidence, indicating low predicted suitability for cod spawning across these areas. Nearshore and coastal waters are predominantly classified as 'not assessed' (n.a.), reflecting the lack of model outputs very close to the coast. Overall, the modelled distribution suggests that potential cod spawning habitat is spatially restricted and largely offshore, rather than being widespread across Welsh waters.

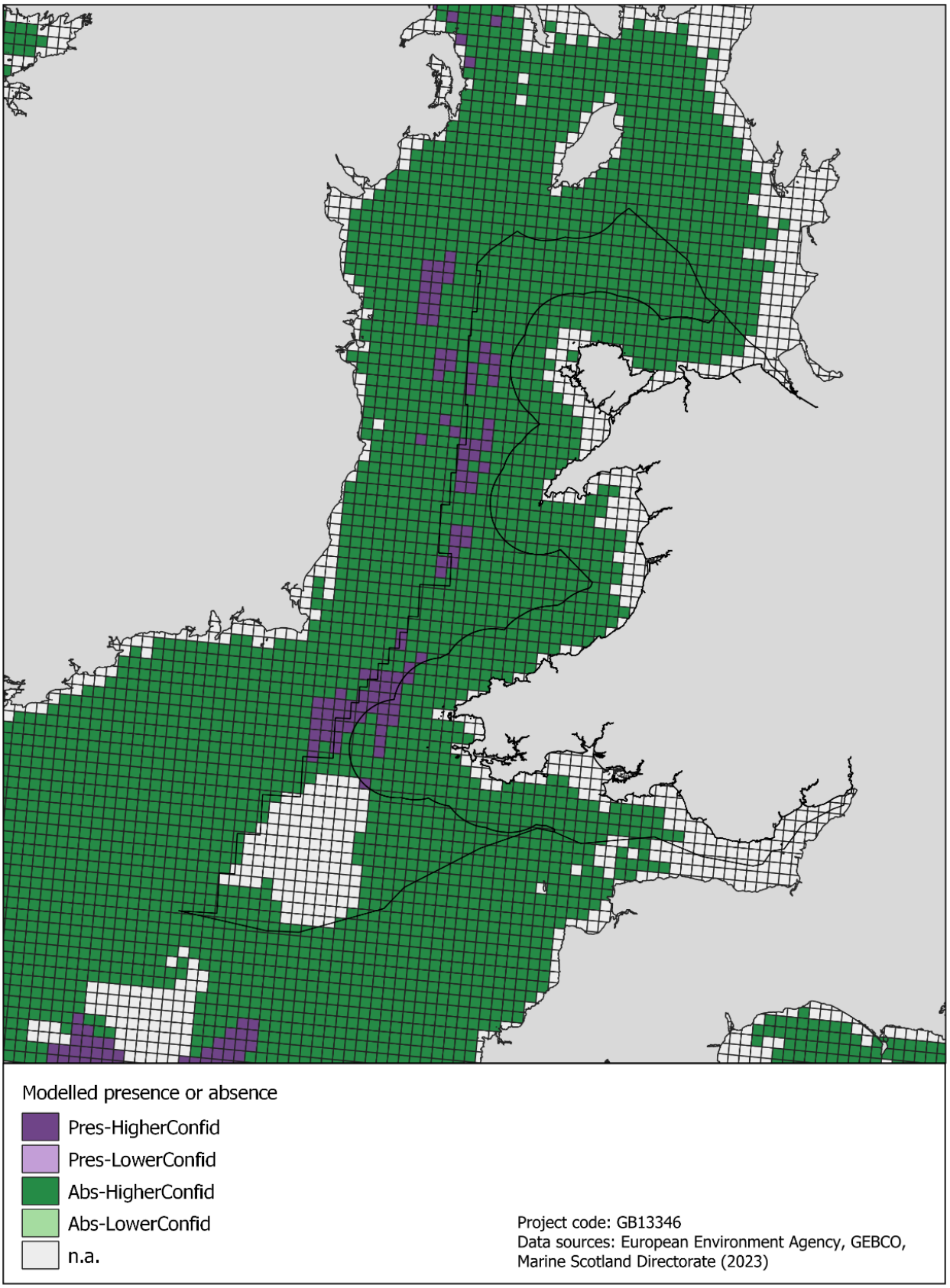


Figure 50. Modelled cod spawning areas (Source: Marine Directorate, 2023).

A3.6.6. Latitudinally distinct stocks of Atlantic cod face fundamentally different biophysical challenges under on-going climate change (Kjesbu *et al.*, 2023)

Spatial coverage: All Welsh waters

A study by Kjesbu *et al.* (2023) modelled the impacts of climate change on cod stocks around the UK. Among their findings are two maps showing shifts in cod spawning grounds between the 1960s and the 2000s. In the 1960s a spawning ground is shown in the Bristol Channel, with the most dense area located off the north Cornwall coast and extending into Welsh waters. By the 2000s, this spawning area was reported to have shifted closer to the Welsh coastline. A similar pattern is observed for the spawning area centred around the east coast of the Isle of Man, which appears to straddle the boundary of Welsh waters in the 1960s and was reported to have moved further south into Welsh waters in the Irish Sea by the 2000s (Figure 51).

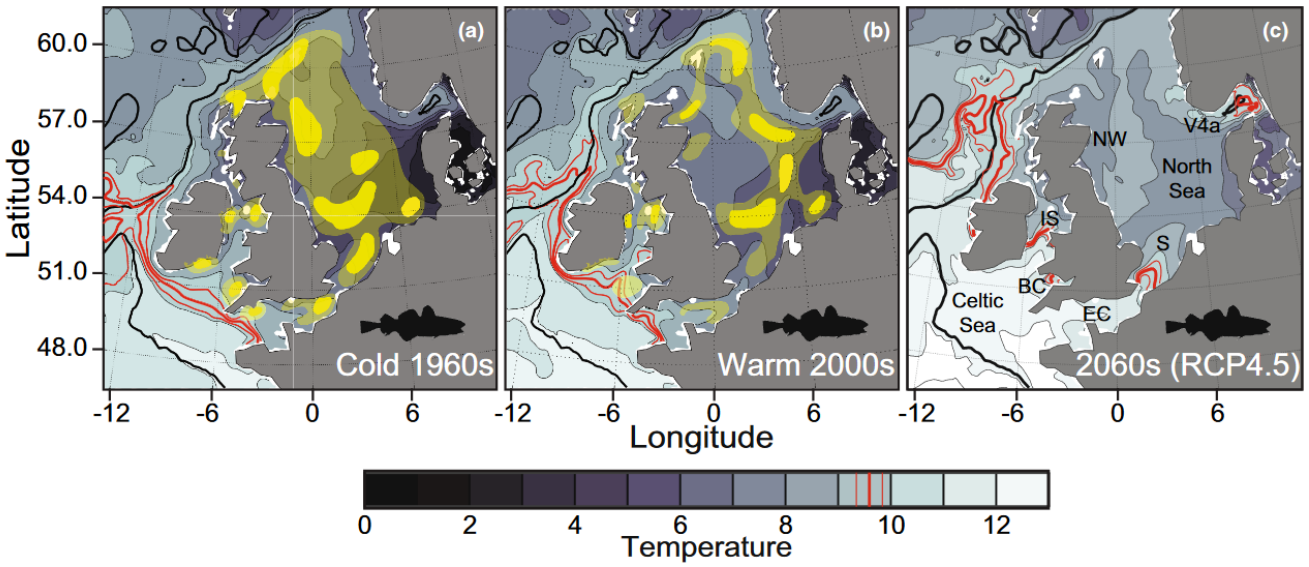


Figure 51. Shifts in cod spawning ground in the Irish and Celtic sea (Source: Kjesbu *et al.*, 2023).

Appendix 4: Data archive appendix

Data outputs associated with this project are archived on server–based storage at Natural Resources Wales, in NRW's internal GIS folders with metadata number NRW_DS161645.

The data archive contains:

[A] The final report in Microsoft Word and Adobe PDF formats.

[B] A GIS geodatabase containing the spatial datasets reviewed in the report.

Metadata for this project is publicly accessible through Natural Resources Wales' Data Discovery Service https://metadata.naturalresources.wales/geonetwork/srv (English version) and https://metadata.cyfoethnaturiol.cymru/geonetwork/cym/ (Welsh Version). The metadata is held as record no NRW_DS161645.

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