Cephalopods under the Marine Strategy Framework Directive

An exploration of available data and definition of possible indicators

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Wageningen Marine Research
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Summary

In 2030, the state of the marine environment will be reassessed using the criteria and indicators of the Marine Strategy Framework Directive (MSFD). To advance the assessment of cephalopods—identified as a priority criterion—it is necessary to evaluate the applicability of existing indicators to cephalopods, to inventory available data, and to determine which steps are required to align data collection with MSFD indicator calculation. This project aimed to identify cephalopod species or species groups for which Good Environmental Status (GES) can be determined and was divided into several tasks.

First, we identified relevant indicators under Descriptor 1 (Biodiversity) and Descriptor 3 (Commercially exploited fish and shellfish). Although applicable indicators could be proposed for most criteria, for several criteria the unique life cycles of many cephalopod species rendered indicator calculation unsuitable. For commercially exploited species, several approaches for assessing population status and fishing mortality were proposed, ranging from data-limited trend analyses based on commercial data to full analytical stock assessment models. Using information on cephalopod occurrences in scientific surveys, we then identified relevant species—or, where taxonomic uncertainty exists, species groups—within the Greater North Sea Ecoregion for which indicators should be calculated. Although data availability is adequate for many species, some species (groups) were encountered so infrequently that attempting a status assessment was not advised.

National data on landings and discards, along with international literature, were examined to determine the most important commercial cephalopod populations in the Greater North Sea Ecoregion. For the Netherlands, most cephalopod landings originated from fisheries targeting Loliginid squid (likely dominated by *Loligo vulgaris*) and *Sepia officinalis* in the eastern English Channel and southern North Sea. Taxonomic issues remain in both landings and discards data.

Data from several scientific surveys (IBTS, BTS, CGFS, DYFS, and SNS) were analysed to evaluate their utility for cephalopod status assessment. An overview of data coverage and quality issues is provided. For the most common species, data quality was generally adequate, although challenges persist—particularly for rare species or those easily confused with others. We explored IBTS, BTS, and CGFS datasets to compute preliminary abundance indices and made recommendations regarding the most suitable surveys for each species (group). Although survey data on size distributions were available, none of the size-based demographic indicators were found suitable for cephalopods due to their short life cycles and rapid growth. Survey data were also used to investigate spatial distributions of relevant species. Additionally, we assessed the potential of alternative data sources, such as citizen science platforms, to contribute to cephalopod status assessments.

An extensive literature review was conducted for species deemed relevant in the Greater North Sea Ecoregion, producing a comprehensive overview of available knowledge on life cycles, migrations, ecology, and responses to anthropogenic pressures. Cephalopods in this region typically exhibit fast growth, short life cycles, and often undertake extensive migrations. Several species rely on hard substrates for egg deposition before passing through pelagic paralarval stages. The review highlights substantial remaining knowledge gaps, particularly concerning population structures and responses to human activities.

Finally, we summarise, for all criteria under Descriptors 1 and 3, the recommended indicators (where applicable) and whether data availability for each identified species (group) is sufficient for indicator calculation. Where data were found to be insufficient, recommendations are provided to address these shortcomings through enhanced sampling efforts or improved awareness during scientific surveys and commercial fishing operations. Implementing these steps will support successful integration of cephalopods in the reassessment of the state of the marine environment under the Marine Strategy Framework Directive in 2030.

Samenvatting

In 2030 zal de toestand van het mariene milieu opnieuw worden beoordeeld aan de hand van de criteria en indicatoren van de kaderrichtlijn mariene strategie (KRM). Om de beoordeling van koppotigen – die als prioritair criterium zijn aangemerkt – te bevorderen, moet worden geëvalueerd of de bestaande indicatoren op koppotigen van toepassing zijn, moet beschikbare gegevens geëvalueerd worden, en moet worden bepaald welke stappen nodig zijn om de gegevensverzameling af te stemmen op de berekening van de KRM-indicatoren. Dit project had tot doel de soorten of soortgroepen te identificeren waarvoor een goede milieutoestand (GES) kan worden vastgesteld en was onderverdeeld in verschillende taken.

Eerst hebben we relevante indicatoren geïdentificeerd onder Descriptor 1 (Biodiversiteit) en Descriptor 3 (Commercieel vis, schaal- en schelpdieren). Hoewel voor de meeste criteria toepasselijke indicatoren konden worden voorgesteld, maakte de unieke levenscyclus van veel soorten koppotigen de berekening van indicatoren voor verschillende criteria ongeschikt. Voor commercieel geëxploiteerde soorten werden verschillende benaderingen voor de beoordeling van de populatiestatus en de visserijsterfte voorgesteld, variërend van trendanalyses op basis van beperkte commerciële gegevens tot volledige analytische modellen voor de beoordeling van de bestanden. Aan de hand van informatie over de aanwezigheid van koppotigen in wetenschappelijke onderzoeken hebben we vervolgens relevante soorten – of, waar taxonomische onzekerheid bestaat, soortgroepen – binnen de Greater North Sea Ecoregion geïdentificeerd waarvoor indicatoren moeten worden berekend. Hoewel de beschikbaarheid van gegevens voor veel soorten voldoende is, kwamen sommige soorten (groepen) zo zelden voor dat het niet raadzaam is om een statusbeoordeling uit te voeren.

Nationale gegevens over aanlandingen en discards, samen met internationale literatuur, werden onderzocht om de belangrijkste commerciële koppotigen in de Greater North Sea Ecoregion te bepalen. Voor Nederland waren de meeste aanlandingen van koppotigen afkomstig van visserijen die zich richtten op Loliginidae (waarschijnlijk gedomineerd door *Loligo vulgaris*) en *Sepia officinalis* in het oostelijke Kanaal en de zuidelijke Noordzee. Er blijven taxonomische problemen bestaan in zowel de gegevens over aanlandingen als die over discards.

Gegevens uit verschillende wetenschappelijke surveys (IBTS, BTS, CGFS, DYFS en SNS) werden geanalyseerd om hun bruikbaarheid voor de beoordeling van de status van koppotigen te evalueren. Er wordt een overzicht gegeven van de gegevensdekking en kwaliteitsproblemen. Voor de meest voorkomende soorten was de gegevenskwaliteit over het algemeen voldoende, hoewel er nog steeds uitdagingen zijn, met name voor zeldzame soorten of soorten die gemakkelijk met andere kunnen worden verward. We hebben de datasets van IBTS, BTS en CGFS onderzocht om voorlopige abundantie-indexen te berekenen en aanbevelingen gedaan met betrekking tot de meest geschikte surveys voor elke soort (groep). Hoewel er onderzoeksgegevens over grootteverdelingen beschikbaar waren, bleek geen van de op grootte gebaseerde demografische indicatoren geschikt voor koppotigen vanwege hun korte levenscyclus en snelle groei. De onderzoeksgegevens werden ook gebruikt om de ruimtelijke verspreiding van relevante soorten te onderzoeken. Daarnaast hebben we het potentieel van alternatieve gegevensbronnen, zoals burgerwetenschapsplatforms, beoordeeld om bij te dragen aan de beoordeling van de status van koppotigen.

Er is een uitgebreid literatuuronderzoek uitgevoerd voor soorten die relevant worden geacht in de Greater North Sea Ecoregion, wat een uitgebreid overzicht heeft opgeleverd van de beschikbare kennis over levenscycli, migraties, ecologie en reacties op antropogene druk. Koppotigen in deze regio vertonen doorgaans een snelle groei, korte levenscycli en ondernemen vaak migraties. Verschillende soorten zijn afhankelijk van harde substraten voor het afzetten van eitjes, voordat ze een pelagisch paralarvaal stadium doorlopen. Het overzicht wijst op aanzienlijke resterende kennishiaten, met name wat betreft populatiestructuur en de impact van menselijke activiteiten.

Ten slotte vatten we voor alle criteria onder Descriptoren 1 en 3 de aanbevolen indicatoren (indien van toepassing) samen en geven we aan of de beschikbaarheid van gegevens voor elke geïdentificeerde soort (groep) voldoende is voor de berekening van indicatoren. Waar de gegevens ontoereikend bleken, worden aanbevelingen gedaan om deze tekortkomingen aan te pakken door middel van verbeterde bemonsteringsinspanningen of een groter bewustzijn tijdens wetenschappelijke onderzoeken en commerciële visserijactiviteiten. De uitvoering van deze maatregelen zal bijdragen aan succesvolle integratie van koppotigen in de herbeoordeling van de toestand van mariene milieu onder de kaderrichtlijn marien in 2030.

1 Introduction

In 2030, the state of the marine environment will be reassessed based on the criteria and indicators of the Marine Strategy Framework Directive (MSFD), including for Descriptor 1 (Biodiversity) and Descriptor 3 (Commercially harvested fish and shellfish). For cephalopods, no assessment indicators have been established for any criteria, which means that it is not yet possible to assess the current status of cephalopods. The last review of assessment indicators was in 2024. As part of the MSFD reporting cycle, a review of the monitoring strategy will follow in 2026.

The Commission Decision on the Marine Strategy Framework Directive (MSFD) of 17 May 2017 states that assessing the good environmental status (GES) of cephalopods is a “primary” criterion. In order to be able to make progress in the assessment of some of these criteria by 2030, it is necessary to address how GES assessments for cephalopods may be achieved through the 2026-2032 monitoring strategy. It is therefore necessary to assess the applicability of the established indicators for various criteria for cephalopods, to make an inventory of the available data, and to determine what steps (in data collection) need to be taken to bring data collection in line with the calculation of the appropriate indicators.

Cephalopods differ from most other commercially exploited marine species in that they have short, semelparous life cycles and exhibit highly variable abundance driven by environmental factors such as currents and water temperature (Arkhipkin et al., 2021). Because marine science has traditionally focused on long-lived fish species, substantial knowledge gaps remain regarding the status of both exploited and unexploited cephalopod populations (Bobowski et al., 2023). In recent years, however, growing recognition of the commercial and ecological importance of cephalopods has stimulated enhanced sampling efforts across Europe—within existing monitoring programs and through the development of new research initiatives (Rosa et al., 2025). Consequently, more data on cephalopods are available now than ever before, creating opportunities to improve assessments of their environmental status in European waters.

2 Assignment

The project consisted of several tasks, aimed at ultimately determining for which species (groups) GES can be determined and which steps in data collection ought to be taken to achieve this for species where this is currently not possible.

Task 1 – Problem definition
The first task aimed to identify possible indicators and relevant species (groups) of cephalopods.

Task 1.1 – Evaluation of criteria and indicators under MSFD Descriptors 1 and 3
- Determine which Criteria are considered under MSFD Descriptors 1 and 3;
- Identify possible indicators for each criterion, where possible with reference points, that are suitable for the assessment of GES for cephalopods;

Task 1.2 – Identification of relevant species (groups)
- Identify relevant cephalopod species or species groups in the Dutch Continental Shelf and surrounding waters (Greater North Sea Ecoregion (GNSE), including the North Sea, eastern English Channel and Skagerrak), and determine to what extent these species (groups) are sampled in scientific surveys;

Task 2 – Information on landings and discards
- Summarise available information that can be used to calculate relevant indicators from scientific surveys (for criteria under Descriptor 1) and fisheries-dependent data sources (for criteria under Descriptor 3);

Task 3 – Information from scientific surveys
- Summarise available information on cephalopods from scientific surveys from ICES’ DATRAS database, where all trawl surveys in the GNSE are taken into account, assess data quality for the purpose of calculating D1 indicators;

Task 4 – Alternative information sources
- Investigate alternative sources of data that could be used to calculate relevant indicators, such as citizen science platforms (e.g., waarneming.nl);

Task 5 – Information on demographic structure
- Assess available information on size and age of cephalopod individuals and populations to determine for which species indicators on demographic characteristics may be determined.

Task 6 – Literature review
- Summarise available information from scientific publications on the biology and ecology of cephalopods in the GNSE, including information on the effects of human activities (hard substrates, climate change) on these species;

Task 7 – Synthesis
- Advise for which species (groups) GES can be determined and which steps in data collection ought to be taken to achieve this for species where this is currently not possible.

3 Materials and Methods

3.1 Problem definition

In order to determine the extent to which the Good Environmental Status of cephalopods can be assessed under the Marine Strategy Framework Directive in Stage 1 (starting in 2030), an evaluation was carried out of available criteria under MSFD descriptors 1 (Marine Biodiversity) and 3 (Commercially exploited fish and shellfish). Next, a list of cephalopod species relevant for the MSFD in Dutch waters and the surrounding area was composed.

3.1.1 Evaluation of criteria for MSFD descriptors 1 and 3

For each of the criteria under D1 and D3, we compiled operational indicators from previous MSFD assessments (Mariene strategie (deel 2), 2020) for other groups (marine mammals, birds and fish), as well as literature on non-operational but possible future indicators for fish and cephalopods (ICES, 2024a; Bobowski et al., 2023). We also identified possible threshold values, or reference points, for these indicators. For each indicator identified in this literature review, the suitability for cephalopods was assessed, taking into account their specific life cycle; as an example, indicators that work with the presence or abundance of old individuals are not meaningful to inform on the environmental status of most cephalopods as their life cycles are notably short (often one year). The assessment of suitability was based both on literature and on expert judgement. International experts of ICES' Working Group on Cephalopod Fisheries and Life History (WGCEPH) were consulted on the proposed list of indicators.

3.1.2 Identification of relevant taxa

The starting point for the identification of relevant taxa was all survey data in the period 2000-2025 from the Q1 and Q3 International Bottom Trawl Survey (IBTS), Beam Trawl Survey (BTS), Channel Ground Fish Survey (CGFS), Demersal Young Fish Survey (DYFS), and Sole Net Survey (SNS). Species were classified as either common, uncommon, or sporadic, based on the absolute numbers caught and time range of occurrence. For sporadically occurring species, data availability was seen as too low to compute meaningful indicators. For common and uncommon species, data availability was discussed with survey experts to give an expert judgement on whether meaningful indicators can be derived from survey data. We also assessed to what extent calculation of indicators would be possible at species-level, given both the occurrence and possible issues in identification. For certain uncommon or regularly misidentified species, we proposed an assessment of GES at a higher taxonomic level.

3.2 Fisheries-dependent information

3.2.1 Landings data

Landings data from logbooks of the Dutch fleet for the period 2020-2024 were collected and for each metier (FAO metier level 4, gear code) reported landings of cephalopods were quantified. Specifically, the taxonomic level at which cephalopod landings are reported was identified and discussed for each metier. Other sources of landing information, such as sampling by commercial partners and additional market sampling, were also investigated. The importance of cephalopod groups for commercial fisheries was assessed, resulting in a prioritization of species (groups) to be assessed under D3. Gaps in data needed to assess GES of prioritized species (groups) were identified. We focused on landings in the GNSE. Landings in logbooks are reported by 3-alpha code, where each code refers to a specific species or higher taxonomic group (***Table 1***). We also reported on 3-alpha codes that were not used in Dutch logbooks in the studied period, but that apply to commonly landed species (groups) or families.

Table 1 *FAO 3-alpha codes for cephalopods landed by Dutch vessels or codes used by Dutch vessels.*

3-alpha code	Scientific name	English name	Code used?
CTC	*Sepia officinalis*	Common cuttlefish	Yes
EOI	*Eledone cirrhosa*	Horned octopus	Yes
OCC	*Octopus vulgaris*	Common octopus	Yes
OMZ	Ommastrephidae	Ommastrephidae squids	No
SQC	*Loligo* spp.	Common squids NEI*	No
SQE	*Todarodes sagittatus*	European flying squid	Yes
SQI	*Illex illecebrosus*	Northern shortfin squid	Yes
SQF	*Loligo forbesii*	Veined squid	No
SQM	*Illex coindetii*	Broadtail shortfin squid	Yes
SQR	*Loligo vulgaris*	European squid	Yes
SQS	*Martialia hyadesi*	Sevenstar flying squid	Yes
SQU	Loliginidae, Ommastrephidae	Various squids NEI*	Yes
SQZ	Loliginidae	Inshore squids NEI*	No

*Not Elsewhere Identified

3.2.2 Discard data

To address D1C1 (Mortality rate from incidental bycatch) and D3C1-3, information on discards of cephalopods from Dutch commercial discard sampling programs was compiled from 2020 to 2024 (***Table 2***). We assessed the occurrence (percentage of sampled hauls in which cephalopods were sampled) and discard rate (numbers/hour discarded, by quarter) for each fleet segment, at metier level 4. This information was used to assess whether discards are likely to be an important source of mortality for any of the species (groups) considered.

Table 2 *Dutch discard sampling programs for which data on cephalopods was studied, including the metier (level 4) that is sampled in the time period of available data.*

Sampling program	Description	Metier (level 4)	Time period
DISBT	Beam trawl (self) sampling program	TBB	2002-present
DISCRAN	Beam trawl (self) sampling shrimp fleet	TBB	2021-2023
DISFLY	Demersal seine ('flyshoot') observer program	SSC	2021-2023, present
DISOT	Otter trawl (self) sampling program	OTB/OTT/QUA	2001-present
DISN	Quad rig (self) sampling program Norway lobster fleet	QUA	2007-2024, continued under DISOT
DISGILL	Gill net observer program	GNS	2011-present
DISTRAP	Pots and fykes observer program	FPO, FYK	2017-2022
DISLINE	Hook-and-line observer program	LHP	2017-2019

3.2.3 International data

Reports from the ICES Working Group WGCEPH were consulted for international data on landings and discards of cephalopods in the GNSE (ICES, in prep.).

3.3 Fisheries-independent information

Existing surveys were explored to determine their utility for the assessment of relevant cephalopod species (groups) for the proposed indicators (mainly under D1).

3.3.1 Trawl surveys

Information on cephalopods was extracted from scientific bottom-trawl surveys archived in the ICES DATRAS database for the period 2000–2024. The surveys included in the analysis were:

1. The International Bottom Trawl Survey (IBTS; separated by first and third quarter surveys),
2. The Sole Net Survey (SNS);
3. The Demersal Young Fish Survey (DYFS),
4. The Beam Trawl Survey (BTS), and
5. The Channel Groundfish Survey (CGFS).

Quarter 1 and quarter 3 IBTS data were treated as different surveys to explore interannual temporal patterns. The extracted surveys collectively cover the North Sea and the English Channel and provide the most consistent long-term information available for demersal and epibenthic cephalopod species.

Species names were harmonized across surveys and years to account for changes in nomenclature and differences in national identification practices. Based on discussions with national survey experts, species with inconsistent identification through time or across countries were aggregated to higher taxonomic levels. In accordance with current information indicating the occurrence of only *Alloteuthis media* in the North Sea (Sheerin et al., 2023), all records of *Alloteuthis subulata* were merged under *A. media*. The name *Sepia elegans* was updated to *Rhombosepion elegans* to reflect the currently accepted taxonomic classification. Members of the family Sepiolidae were grouped together due to persistent identification issues in distinguishing between *Sepiola* and *Sepietta* species in routine surveys. The only exception in that family was *Rossia macrosoma*, which was retained as a separate taxon because it is morphologically distinct and generally identified with greater confidence.

All data were downloaded and processed in R using the icesDatras package, and survey haul, catch, and length files (HH, HL, CA) were merged and filtered by year (Millar et al., 2023). Species names and Aphia identifiers were standardized prior to analysis to ensure consistency across surveys and reporting nations.

The analyses focused on the taxa that were identified under Section 3.1.2. For individuals identified at higher taxonomic level than the proposed groups, spatial patterns of occurrence were examined and compared to the known distributions of each species (group) to assign records to the most likely species where possible. This was mainly done for *Loligo* spp. and *Alloteuthis* spp. Specific identification issues are further addressed in Section 4.2.2.1.

For each survey, catch numbers were standardized to a common unit of catch per unit effort (CPUE), expressed as numbers per hour of trawling. These indices were calculated per haul and then averaged by year and country to obtain annual CPUE estimates. Preliminary assessments were made by comparing total catches per country and per year to identify spatial and temporal differences in reporting intensity. Subsequently, presence–absence data were summarized by survey and year to evaluate where and when each taxon was consistently recorded. This allowed identification of the surveys contributing most information for each species and provided a first overview of the potential data coverage available for indicator development.

Time series of CPUE indices were then plotted to visualize interannual variability in abundance and to identify species or taxonomic groups with consistent signals through time. To assess spatial patterns, CPUE indices were mapped by survey and country, illustrating the geographical extent of each species' distribution and the relative contributions of individual surveys. These maps were used to examine potential distributional shifts and to assess whether abundance indices derived from different surveys were spatially coherent. Biological information was extracted from the DATRAS HL (haul length) and CA (catch at age or size) datasets to describe population size structures. Length-frequency distributions were generated to assess whether survey data could be used to support demographic indicators such as D1C3 or D3C3. Where available, length–weight relationships were also examined to explore the potential for deriving simple biomass indices in the absence of direct weight measurements.

3.3.2 Acoustic surveys and ichthyoplankton surveys

To assess the possible future suitability of other surveys, namely acoustic surveys deploying echosounders to locate schools of pelagic fish, and ichthyoplankton surveys, survey experts were consulted. Though no data exploration on these surveys was possible to a lack of (accessible) data, recommendations were made for future use of these surveys for the aims of assessing cephalopod status.

3.3.3 Small national surveys

We explored data from three small national surveys: the year-round monitoring of fish communities in the Wadden Sea, running from 2019 to present (WADVIS) and two bi-annual tidal fixed net ('ankerkuil') surveys in the Western Scheldt estuary (WAV) and Eems-Dollard estuary (EAV), running from 2007 to present. Furthermore, we consulted experts on the Marsdiep daily fyke monitoring by the Royal Netherlands Institute for Sea Research, running from 1959 until present. We assessed the utility of these surveys to determine population abundance indicators for cephalopods by calculating the annual occurrence (percentage of hauls with cephalopods), and relative abundance (numbers/hour) for each species (group).

3.3.4 Citizen science platforms

To assess the suitability of citizen science platforms such as Waarneming.nl, we performed a qualitative assessment on data of several common species, namely *Loligo vulgaris*, *Sepia officinalis, Alloteuthis* spp., and *Todarodes sagittatus*. We also reviewed common statistical methods designed to account for common biases in such citizen science datasets, such as sampling and observation bias, to provide expert opinion on whether Waarneming.nl might be used for the assessment of D1 criteria.

Furthermore, we assessed the information reported by Stichting Anemoon, who maintain a database of diving observations and perform an analysis of abundance for species commonly encountered by recreational divers (Van der Loos & Gmelig Meyling, 2019).

3.4 Literature review

We conducted a literature review to gather knowledge for all species identified under Section 3.1.2. We reviewed available literatures on their biology and ecology in the GNSE and adjacent waters. Relevant publications were identified through comprehensive searches in academic databases, including Web of Science and Google Scholar. Searches combined genus and species names with terms related to key biological and ecological aspects, including 'Habitat', 'Nursery (grounds)', 'Spawning area/timing', 'Life cycle', 'Growth', 'Distribution', 'Migration', 'Reproduction', 'Fecundity', 'Environmental effects', 'Human impacts', 'Climate change', 'Trophic ecology' and 'Economic importance'.

Foundational taxonomic and biological references from the FAO Cephalopods of the World series (Jereb et al., 2015a) and ICES reports were included to ensure consistency in species identification and terminology. Both peer-reviewed journal articles and grey literature, including fisheries reports, theses, and technical surveys, were reviewed to provide a comprehensive overview of species' distributions, life histories, and ecological roles. When historical taxonomic uncertainties existed, for example between closely related species, particular attention was paid to the geographic origin, sampling period, and identification methods of each study to ensure accurate interpretation of species records. This approach allowed a coherent synthesis of biological knowledge across multiple species while accounting for regional variation and methodological differences in the literature.

4 Results

The results of the data are reported with a decimal point (.) instead of a comma (,) (in derogation of the Dutch SI).

First, we discuss the outcome of the first work package, which involved defining the relevant MSFD criteria under Descriptors 1 and 3, proposing indicators that could be used for the assessment of GES for cephalopods, and identifying cephalopod species or species groups for which indicators may be calculated. After this, the results are structured according to the criteria under Descriptors 1 and 3, with results of the data analysis from sections 3.2 and 3.3 addressed under the relevant criteria. Lastly, the results of the literature review on the biology, ecology, and human impacts on the selected species are given, with the main findings relevant to D1C4 – Habitat requirements, being summarised under section 4.2.5.

4.1 Problem definition

4.1.1 Evaluation of criteria for MSFD descriptors 1 and 3

We consulted Dutch MSFD reports and reviewed relevant literature to identify a list of indicators that would be of use for MSFD Descriptors 1 and 3. ***Table 3*** gives an overview of the indicators found to be most suitable for cephalopods. Annex 1 shows the full list of identified indicators and includes reasoning on their applicability for cephalopods. The draft list of selected indicators was shared with international experts from WGCEPH, several of whom provided additional input.

Several considerations are important when selecting indicators for cephalopods. Most cephalopod life histories are characterized by fast and variable growth, high natural mortality rates, and semelparity, meaning individuals reproduce once before dying (Arkhipkin et al., 2021). As a result, most cephalopods have weakly overlapping generations. Furthermore, they are very sensitive to environmental conditions (O’Brien et al., 2018). All these factors lead to large fluctuations in abundance, weak links between stock size and recruitment, and non-linear relationships between size and maturity. These specific characteristics are of importance when selecting appropriate indicators to assess GES for cephalopods. For example, changes in abundance or distribution may be attributed to environmental fluctuations and may not reflect any long-term changes in stock size or suitable habitat (D1C2 and D1C4). Also, concepts that may be applicable to fish stocks, such as a stable Maximum Sustainable Yield (MSY) at equilibrium, may not be appropriate for intrinsically fluctuating cephalopod stocks (Roa-Ureta et al., 2021). Importantly, due to the plasticity in growth and maturity, most of the indicators proposed for D1C3 and D3C3 (Demographic characteristics (size and age distribution)) are not meaningful for cephalopods as relationships between size, maturity, and reproductive success are weak and non-linear (Bobowski et al., 2023). Some of the proposed indicators under Descriptor 3, are dependent on (analytical) stock assessments, which are currently not available for most European cephalopod stocks. We’ve also proposed more simple, but less informative indicators, that do not depend on the development of such models. For most criteria, it is vital to properly consider the temporal scale at which the indicators are computed. For example, squid abundance fluctuates strongly, as almost the entire population replaces itself when post-spawning mortality occurs. Abundance indicators should thus be calculated at a suitable time during the year, or at a finer time-scale (e.g. monthly) over the course of the population’s life cycle.

Table 3 *Proposed indicators for the criteria under Descriptors 1 and 3 of the MSFD, with reference points where available, reasoning for their selection and source.*

Descriptor	**Criterium**	**Proposed indicator**	**(Suggested) Reference point**	**Reasoning**	**Source**
D1: Marine Biodiversity	C1: Mortality rate per species from incidental bycatch	Number and rate of individuals caught as by-catch per species per fishing metier/fleet-area	Not defined	For non-commercial species, only developed for some marine mammals (not for fish, cephalopods, etc.)	Mariene strategie (deel 2), 2020
	C2: Population abundance	Presence and/or abundance (CPUE)	Multi-year trends	Obtained from survey data. Due to the highly dynamic nature of cephalopod stocks, multi-year averages should be used as reference points.	Bobowski et al. (2023)
	C3: Demographic characteristics (size and age distribution)	Not proposed	-	D1C3 indicators are mostly unsuitable for cephalopods due to their short, semelparous and plastic life cycles and rapid response to environmental change.	Bobowski et al. (2023)
	C4: Distributional pattern and range	Distributional range and pattern	Distributional range in reference period	Compares number of spatial units (ICES statistical rectangles) occupied to that occupied in a reference period.	Bobowski et al. (2023); OSPAR (2016)
	C5: Habitat requirements	Not proposed	-	Only relevant for species under the Habitat Directive. See literature review for a summary on habitat preferences.	Mariene strategie (deel 2), 2020
	C6: Pelagic habitat requirements	Not proposed	-	Based on plankton community, not specific to any (cephalopod) species	Mariene strategie (deel 2), 2020
D3: Commercially exploited fish and shellfish	C1: Harvest rate (fishing mortality)	Harvest rate (Yield/Catch-Per-Unit-Effort)	Multi-year trends	Commercial information at high taxonomic scale needed. Temporal scale needs to be considered due to short life cycle.	Bobowski et al. (2023)
		Fishing mortality (F)	F_{MSY}	Dependent on the development of stock assessments, of which surplus production methods are the most realistic (SPiCT).	Arkhipkin et al. (2021)
		Catch	Mean latent productivity minus	More realistic for intrinsically fluctuating populations than MSY-based targets. Dependent	Roa-Ureta et al. (2021)

Descriptor	Criterium	Proposed indicator	(Suggested) Reference point	Reasoning	Source
			uncertainty buffer	on the development of generalized depletion models.	
	C2: Spawning stock biomass	Catch-Per-Unit-Effort of mature individuals	Multi-year trends	Commercial information at high taxonomic scale needed. Temporal scale needs to be considered due to short life cycle.	Bobowski et al. (2023)
		Spawning stock biomass (SSB)	MSY $B_{trigger}$	Dependent on the development of stock assessments, of which surplus production methods are the most realistic (SPiCT).	Arkhipkin et al. (2021)
		Escapement biomass	Escapement threshold (often arbitrary)	Dependent on the development of depletion models at high temporal resolution.	Beddington et al., (1990)
	C3: Demographic characteristics (size and age distribution)	Recruitment	Above/below long-term geometric mean	ICES (2024) shows that for long-lived species, this is more suitable than other, more complex indicators, in predicting recruitment. Squid biomass is highly dynamic, so between-year changes should be interpreted with caution.	ICES (2024)

4.1.1.1 Stock assessments and GES indicators

Several commonly used indicators for fish, mainly under D3 (Commercially exploited fish and shellfish), are derived from full analytical stock assessments. For cephalopods, we also propose indicators based on such assessments, such as MSY-based reference points from surplus production models (SPiCT) and indicators more applicable to short-lived, fluctuating populations, obtained from generalized depletion models (Roa-Ureta et al., 2021). The latter method is deemed more applicable to cephalopods given that their short, semelparous life cycle and varying productivity means the MSY approach is uniquely unsuited. However, it is also more data intensive and may not be appropriate when stocks have overlapping generations or continuous recruitment, such as for *Loligo forbesii* in Scottish waters (Young et al., 2004). Currently, neither of these methods are fully operational for any stocks in the GNSE, though exploratory work has been done, for example in the development of surplus production models for *S. officinalis* and Loliginid squids in the English Channel (ICES, in prep.). We propose these indicators as development of assessment methods for commercially important species should be a priority in coming years, but they may not be available for the MSFD stage 2 cycle. As an alternative approach, less data-intensive indicators based on landings and effort data are also proposed.

4.1.2 Identification of relevant taxa

Next, a list of species was identified for which calculation of (some of the) GES indicators in the GNSE was possible and meaningful (***Table 4***). This was based on occurrence in the main surveys in the GNSE and consultation with survey experts from the BTS and IBTS. For some species, it was not possible to derive survey information at the species level due to identification issues. For these, higher taxonomic levels were proposed at which assessment is possible, following the approach by IJntema (2023). For a full list of species found in the BTS, IBTS, CGFS and DFS surveys, including those encountered too sporadically to derive meaningful indicators for, see Annex 2.

Table 4 *List of species (groups) for which GES indicator calculation should be attempted, including occurrence in surveys and comments on taxonomy.*

Family	**Genus**	**Species**	**Dutch name**	**GNSE survey occurrence**	**Comment**
Loliginidae	*Alloteuthis*	*media*	Dwergpijl-inktvis	Common	Recent DNA analysis revealed all *Alloteuthis* in the North Sea to be *A. media* (Sheerin et al., 2023). All samples (*A. media, A. subulata* and *Alloteuthis* spp.) were thus considered *A. media*.
	Loligo	*forbesii*	Noordse pijlinktvis	Common	Regularly not identified to species level. *Loligo* spp. could be allocated to either *L. forbesii* or *L. vulgaris* based on location, season and environmental factors.
		vulgaris	Gewone pijlinktvis	Common	
Omma-strephidae	*Illex*	*coindetii*	Slanke pijlinktvis	Common	*I. illecebrosus* are likely misidentifications of *I. coindetii*.
	Todaropsis	*eblanae*	Ierse pijlinktvis	Uncommon	*Todarodes sagittatus* in the BTS are likely misidentifications of *T. eblanae*.
	Todarodes	*sagittatus*	Grote pijlinktvis	Uncommon	Little data available from IBTS, BTS data assumed to be misidentifications.
Sepiidae	*Sepia*	*officinalis*	Gewone zeekat	Common	
	Rhombosepion	*elegans*	Elegante zeekat	Uncommon	Previously known as *Sepia elegans*.
Sepiolidae	*Rossia*	*macrosoma*	-	Uncommon	The only Sepiolid that can be reliably identified during scientific surveys.
Sepiolidae	*Rossia; Sepiola; Sepietta; Rossia*	-	Dwerg-inktvissen	Common	All other GNSE Sepiolids cannot be identified reliably on surveys and should be assessed as a group, as in IJntema (2023).
Eledonidae	*Eledone*	*cirrhosa*	Kleine achtarm	Common	All Eledonidae in the GNSE can be considered *E. cirrhosa.*

4.2 Descriptor 1: biodiversity

For Descriptor 1, on Biodiversity, we assessed data availability to determine for which of the species (groups) in ***Table 4*** the proposed indicators may be calculated and what additional data collection may be needed to make GES assessment possible.

4.2.1 D1C1 – Mortality rate per species from incidental bycatch

We explored the data from several Dutch discard monitoring programs from 2020 to 2024 to determine the levels of discarding of the main cephalopod species (groups). ***Table 5*** gives the total number of hauls sampled under several discard monitoring programs between 2020 and 2024, and the percentage of hauls where cephalopod species (or higher taxonomic levels) were encountered (occurrence). It can be observed that most species occur in the discard samples of only a small percentage of hauls. The most commonly encountered species in discard samples are *A. media* and *L. forbesii* in about 10% of sampled hauls of OTB, *S. officinalis* occurring in 35.8% of sampled SSC hauls, *A. media* and *S. officinalis* in 12.5% and 8.1% of TBB hauls, respectively, and squids (nei) in FPO discards. Sampling of FPO was very limited, at 13 fishing events sampled between 2020 and 2024. Our results show that not all cephalopods encountered in discard samples are identified at species level, with samples regularly being identified to genus or family level (*Loligo* spp. or Loliginidae), or even higher taxonomic levels (Teuthida (squids indet.) and Cephalopoda).

Table 5 *Occurrence (percentage of hauls with species (group)) for sampled hauls from discard sampling programs, including total number of hauls sampled.*

Species (group)	OTB/OTT/QUA	SSC	TBB	GNS	FPO
Total hauls	**1031**	**402**	**1489**	**50**	**13**
A. media	10.8%	1%	12.5%		
E. cirrhosa	0.6%	1.2%	0.1%		
I. coindetii	0.4%	0.2%	0.1%		
L. forbesii	10.7%	2.7%	4.2%		
L. vulgaris	1.2%	7.5%	1.5%	2%	
Loliginidae nei	0.6%	3.2%	2.8%		
O. vulgaris	0.8%		0.1%		
S. officinalis	1.3%	35.8%	8.1%	6%	
Sepiolidae nei	0.9%		1%		
Squids nei	0.7%	0.2%	0.9%	2%	38.5%
T. eblanae		2.2%			
T. sagittatus		1%			
Other	0.1%				

Discard rates (numbers/hour fished) varied between gears, species and quarters throughout the studied period (2020-2024) (Figure 1). For most species and gears, discard rates were very low, with no more than one individual discarded per hour for *E. cirrhosa, I. coindetii, L. vulgaris, O. vulgaris*, Sepiolidae (nei), *T. sagittatus* and *T. eblanae* by all gears. However, discards of *A. media* by TBB vessels exceeded 20 individuals per hour in some quarters, *L. forbesii* is regularly discarded in relatively low numbers by OTB/OTT/QUA and TBB vessels, and *S. officinalis* was found in discard samples of SSC and TBB vessels in significant but still low numbers compared to commonly discarded species such as European plaice (*Pleuronectes platessa*) (Afranewaa et al., 2024).

__Figure 1__ Discard rates (numbers/hour) per metier (level 4) per species (group), by quarter. Calculated from Dutch discard monitoring programs.

The ICES Working Group WGCEPH report that discard rates for all countries combined are generally low and can be considered negligible, at a discard rate of 0.35% for *Sepia* spp. (based on data from Belgium, France, Spain, Sweden, and England) and 2% for Loliginidae (ICES, in prep). Discards of Loliginids in the southern North Sea and eastern English Channel, the two areas with the most catches of Loliginid squids in 2020-2024, were negligible. For Ommastrephidae, discard rates were estimated to be around 1%.

Both in Dutch discard sampling and international studies, occurrence of cephalopod discards is relatively rare and discard rates are very low. This is understandable given the lack of Minimum Conservation Reference Sizes (MCRS) and commercial interest in cephalopods of all sizes and a range of species.

Section 3.2.1 summarises the information on cephalopods from landings data, and thus, of incidental (marketable) bycatch. From this, it can be concluded that besides directly targeted cephalopods – *L. vulgaris* and *S. officinalis* - mortality from commercial fisheries' bycatch is likely low for most species (Table 10).

It is important to note that although total discards and marketable bycatch may be calculated when discard sampling coverage is adequate, mortality rates cannot be determined unless estimates of population abundance are available. Furthermore, reference points for discard mortality rates require knowledge on sustainable levels of exploitation (fishing mortality F), which require analytical stock assessments.

Due to the low discard and bycatch rates, short life cycle and high natural mortality of most cephalopods, it can be assumed that discard and bycatch mortality is negligible, meaning it is unlikely to have significant effects on the population, and no meaningful indicators of discard and bycatch mortality can or should be computed for cephalopods. However, it is important to continue monitoring discard rates as these may change in future. Fishing mortality for commercially exploited species is discussed in Section 4.3.1

4.2.2 D1C2 - Population abundance

For D1C2 (Population abundance), the focus was on survey data for the full list of species (groups). Though trends can be established, reference points for Population abundance cannot be calculated without analytical stock assessments. Trends in abundance are often chaotic due to the short life cycle of most cephalopods. The best alternative to reference points from analytical stock assessments is that applied by WGCEPH, which is comparing multi-year (e.g. three year) means to the previous multi-year period and to the long-term geometric mean.

4.2.2.1 Data quality issues

Data-quality diagnostics were performed for the species with the highest survey catches, namely *Alloteuthis media*, *Loligo forbesii*, *Loligo vulgaris*, *Sepia officinalis*, and *Illex coindetii*. For each taxon, summary tables were produced by country, survey, and year. Additional visual diagnostics (Figures S1–S5) were generated to examine temporal consistency, survey coverage, and country-specific reporting patterns for these priority taxa.

Only a small number of cephalopod taxa contribute substantial information across the monitoring programs. *Alloteuthis media* is by far the most frequently encountered species, both in terms of records and total abundance, followed by *L. forbesii*, *L. vulgaris*, *S. officinalis*, and *I. coindetii* (Table 6). Several other taxa show low numbers of observations or very restricted occurrence across hauls, suggesting limited potential for deriving robust abundance indicators. An important data-quality constraint is that for most cephalopods, survey datasets are sparse, unevenly distributed, or reported at higher taxonomic levels. Consequently, only for a subset of species sufficient information is currently available for feasible D1C2 (abundance) indicator development.

Presence–absence plots further highlight substantial differences in species detectability among surveys (Figure S1). *A. media* shows the most consistent temporal coverage, with regular detections across SNS, BTS, DYFS and both IBTS quarters, reflecting its relatively high abundances and wide spatial distribution. In contrast, *L. vulgaris* is detected most abundantly in French-led CGFS surveys, with less frequent and abundant detections in other programs, which is a pattern supported by annual abundance plots, showing consistently higher catches for France in both CGFS and WCGFS (Figures S4–S5). *L. forbesii* and *I. coindetii* are primarily detected in IBTS_Q1 and IBTS_Q3, with intermittent or absent detection in SNS, DYFS, and BTS, indicating that offshore surveys provide the strongest and most reliable signals for these species.

Table 6 *Records, hauls and total counts for the most common cephalopod taxonomic groups caught in surveys for the combined (IBTS, SNS, DYFS, BTS, CGFS) survey dataset (2000-2024).*

Species	Records	Hauls	Total number
Alloteuthis media	40,948	10,402	19,884,255
Loligo forbesii	22,491	5,060	3,420,640
Loligo vulgaris	14,924	2,576	3,272,129
Sepia officinalis	14,079	4,065	464,567
Illex coindetii	7,792	2,883	278,818
Sepiolidae (excl. *Rossia*)	3,806	3,361	87,837
Cephalopoda (unspecified)	142	79	65,503
Todaropsis eblanae	2,439	1,516	25,451
Eledone cirrhosa	4,459	4,079	16,718
Rossia macrosoma	980	849	3,225
Rhombosepion elegans	959	686	2,555
Todarodes sagittatus	412	246	2,551
Sepia spp. (unspecified)	172	170	119

Several other taxa, including *T. eblanae*, *T. sagittatus*, *R. elegans*, and *R. macrosoma*, show long periods of non-detection or highly irregular presence across surveys (Figures S2 and S3). While some of this variability may reflect actual interannual fluctuations or shifting distributions, the prevalence of zeros and inconsistent reporting across countries suggests significant limitations for indicator development. *Sepia officinalis* and *Eledone cirrhosa* show stronger and more consistent detection patterns overall, but still exhibit survey-specific gaps-particularly in SNS and DYFS for *S. officinalis* and in DYFS and CGFS for *E. cirrhosa*. Sepiolids (excluding *Rossia*) are detected broadly but often inconsistently across surveys. However, these patterns cannot be confidently interpreted as reflecting accurate abundances due to limitations regarding catchability and handling challenges (Figures S2 and S3).

Inspection of haul-level records highlights two survey-specific issues relevant for data interpretation. First, Norwegian *E. cirrhosa* catches showed a moderate peak in 2017; however, haul-level data showed that this increase resulted from small numbers of individuals occurring across many IBTS hauls, with no inflated raising factors or anomalous values. This pattern therefore reflects genuine low-level bycatch rather than a data artefact. Second, French IBTS_Q1 hauls in 2011–2012 contained exceptionally high catch totals for Sepiolidae (excluding *Rossia*), including several hauls with more than 5,000 individuals. These values represent survey-specific outliers likely reflecting unusually dense catches of small-bodied sepiolids, but caution is required when interpreting them, as they do not reflect patterns observed in other years or surveys and are unlikely to provide a reliable basis for estimating broader abundance trends.

Clear differences were observed between countries in the extent and resolution of cephalopod reporting. Species such as *Alloteuthis media* and *Loligo forbesii* were reported widely across most nations, whereas *Loligo vulgaris* and *Sepia officinalis* were dominated by French and UK records, reflecting both spatial patterns and differences in identification capacity (Table 7). Several countries frequently reported zero total counts despite numerous records (e.g. Belgium for *Alloteuthis media* and *Sepiolidae*), suggesting that some datasets contain presence-only or unquantified records (Table S1). Species-level reporting was also inconsistent: France reported most *Loligo vulgaris* records at species level, while other nations mostly used aggregated categories or rarely recorded the species.

Table 7 *Records, hauls and total counts for the five most common taxonomic cephalopod groups caught in surveys broken down by country, for the combined (IBTS, SNS, DYFS, BTS, CGFS) survey dataset (2000-2024).*

Species	Country	Records	Hauls	Total count
Alloteuthis media	DE	14,759	1,821	9,342,693
	GB-SCT	5,805	1,054	5,034,583
	NL	8,687	3,293	1,758,113
	DK	4,206	800	1,663,992
	NO	1,403	337	1,030,253
	FR	880	809	416,271
	SE	1,799	524	409,708
	GB	3,040	1,395	224,277
	BE	369	369	4,363
Loligo forbesii	FR	4,069	838	1,194,349
	NO	5,780	775	587,181
	DK	2,603	509	572,412
	SE	1,488	327	393,646
	GB	3,663	1,160	331,177
	DE	2,660	621	237,771
	GB-SCT	523	116	81,060
	NL	1,676	685	22,749
	BE	29	29	292
Loligo vulgaris	FR	12,310	1,360	3,215,576
	NL	1,148	373	41,024
	DE	384	174	8,797
	GB	496	341	2,677
	DK	398	187	2,389
	BE	160	124	1,582
	NO	27	16	82
	SE	1	1	2
Sepia officinalis	FR	3,679	787	350,931
	GB	8,947	2,630	99,266
	BE	779	272	8,374
	NL	606	326	5,822
	DK	37	25	81
	DE	14	9	65
	GB-SCT	13	13	20
	NO	4	3	8
Illex coindetii	FR	763	151	151,068
	DE	1,095	367	43,059
	NO	1,569	470	32,319
	DK	799	242	21,885
	GB-SCT	1,819	937	13,252
	NL	770	236	11,522
	SE	352	157	3,491
	GB	625	323	2,222

To assess potential identification issues, we compared species labels in the original HL table against the harmonized species dataset after applying all recoding rules specified in section 2.3. Most corrections were associated with the historical *Alloteuthis/Loligo subulata* species names, which was re-assigned to *Alloteuthis media* in NS-IBTS, BTS, DYFS and SNS datasets from Germany, the Netherlands, Denmark, Norway, Sweden and Scotland. A second major group of corrections involved mixed *Loligo* spp. that were standardized to *L. forbesii*, mostly in the NS-IBTS, BTS and DYFS surveys and mainly from Norway, GB, Germany and Denmark. Smaller but still notable adjustments included harmonization of Sepiolids (grouped together and reassigned to "Sepiolidae (excl. *Rossia*)") and updates to the outdated species name *Sepia elegans* (now *Rhombosepion elegans*) primarily in the British BTS and NS-IBTS series, as well as the correction of a small number of implausible *Illex illecebrosus* records.

Table 8 *Number of changes made per country from the combined (IBTS, SNS, DYFS, BTS, CGFS) survey dataset (2000-2024).*

Country	Change type	N
DE	Loligo/Alloteuthis subulata → Alloteuthis media	14,516
NL	Loligo/Alloteuthis subulata → Alloteuthis media	8,681
GB-SCT	Loligo/Alloteuthis subulata → Alloteuthis media	5,805
NO	Loligo aphia group → Loligo forbesii	4,363
DK	Loligo/Alloteuthis subulata → Alloteuthis media	4,206
GB	Loligo/Alloteuthis subulata → Alloteuthis media	3,040
GB	Loligo aphia group → Loligo forbesii	2,625
SE	Loligo/Alloteuthis subulata → Alloteuthis media	1,799
NL	Aphia sepiolids → Sepiolidae (excl. Rossia)	1,433
NO	Loligo/Alloteuthis subulata → Alloteuthis media	1,124
DE	Loligo aphia group → Loligo forbesii	1,077
GB-SCT	Illex aphia group → I. coindetii	1,007
GB	Sepia elegans → Rhombosepion elegans	907
DK	Loligo aphia group → Loligo forbesii	757
DE	Aphia sepiolids → Sepiolidae (excl. Rossia)	726
FR	Aphia sepiolids → Sepiolidae (excl. Rossia)	643
GB	Aphia sepiolids → Sepiolidae (excl. Rossia)	596
NL	Loligo aphia group → Loligo forbesii	470
BE	Loligo/Alloteuthis subulata → Alloteuthis media	369
FR	Loligo aphia group → Loligo forbesii	324

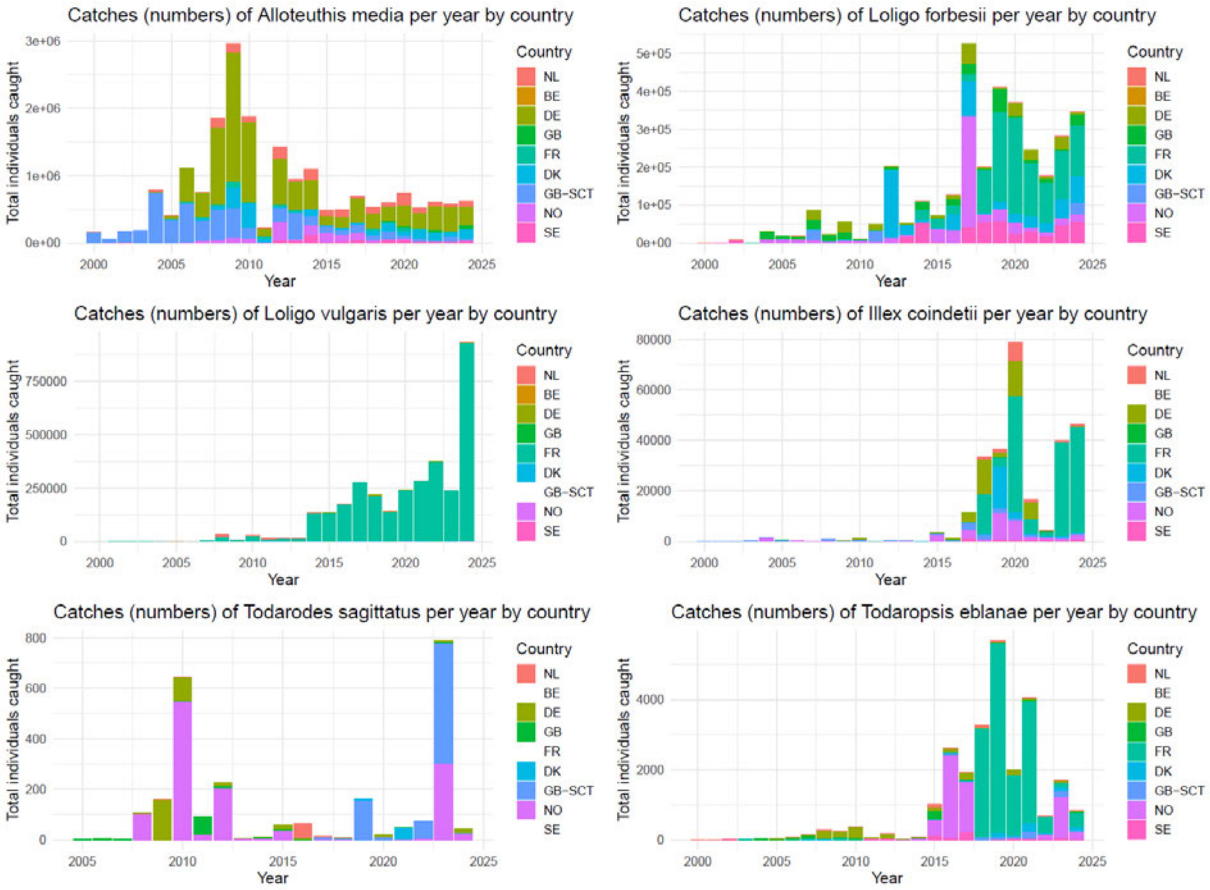
Overall, the combined evidence from summary tables, annual abundance plots, and the species-harmonization (Tables 6–8, Figures S1–S5) shows that only a limited subset of cephalopod taxa is consistently and reliably represented across countries and survey programs in the Greater North Sea. Survey design, geographic coverage, and national taxonomic practices all contribute to substantial heterogeneity in reporting, with several datasets relying heavily on higher-level identifications that required post-processing harmonization. These data-quality issues suggests that cautious species selection for MSFD D1C2 abundance indicators is recommended.

4.2.2.2 Indices of abundance

To determine which survey datasets are most appropriate for each cephalopod species, preliminary comparisons were made across all available North Sea programs (IBTS Q1, IBTS Q3, BTS, DYFS, SNS, and CGFS). Presence–absence plots (Supplementary Figures S1 – S3) provided a first indication of where species were most frequently encountered, while total annual catches per survey highlighted which programs contribute the majority of records. Survey spatial coverage (further detailed under Section 4.2.4) and biological sampling information (Section 4.2.3) were also considered to evaluate which datasets offer the best representation of each species' population structure and range.

The IBTS and BTS surveys offer the most extensive spatial coverage within the North Sea, with the IBTS primarily sampling demersal species near the bottom, and the BTS, using beam trawl gear, targeting more benthic fauna. Seasonal differences between IBTS Q1 and Q3 are particularly relevant for cephalopods given their short life cycles and rapid seasonal turnover.

Overall, annual survey catches of cephalopods in the North Sea show high interannual variability across taxa and countries, reflecting the naturally fluctuating population dynamics typical of short-lived cephalopods (Figure 2). Patterns differ between species groups: *A. media* catches peaked in 2009 and *Loligo* spp. and *I. coinetii* show generally increasing trends in catches in recent years, with most data coming from France. Catches of cuttlefish (*S. officinalis*) and horned octopus (*E. cirrhosa*) also show intermittent increases, but remain lower overall compared to Loliginid squids. For other taxa, such as *R. macrosoma*, *R. elegans*, and grouped Sepiolidae, catches remain sporadic and low, often concentrated in a few national surveys (Figure 2).



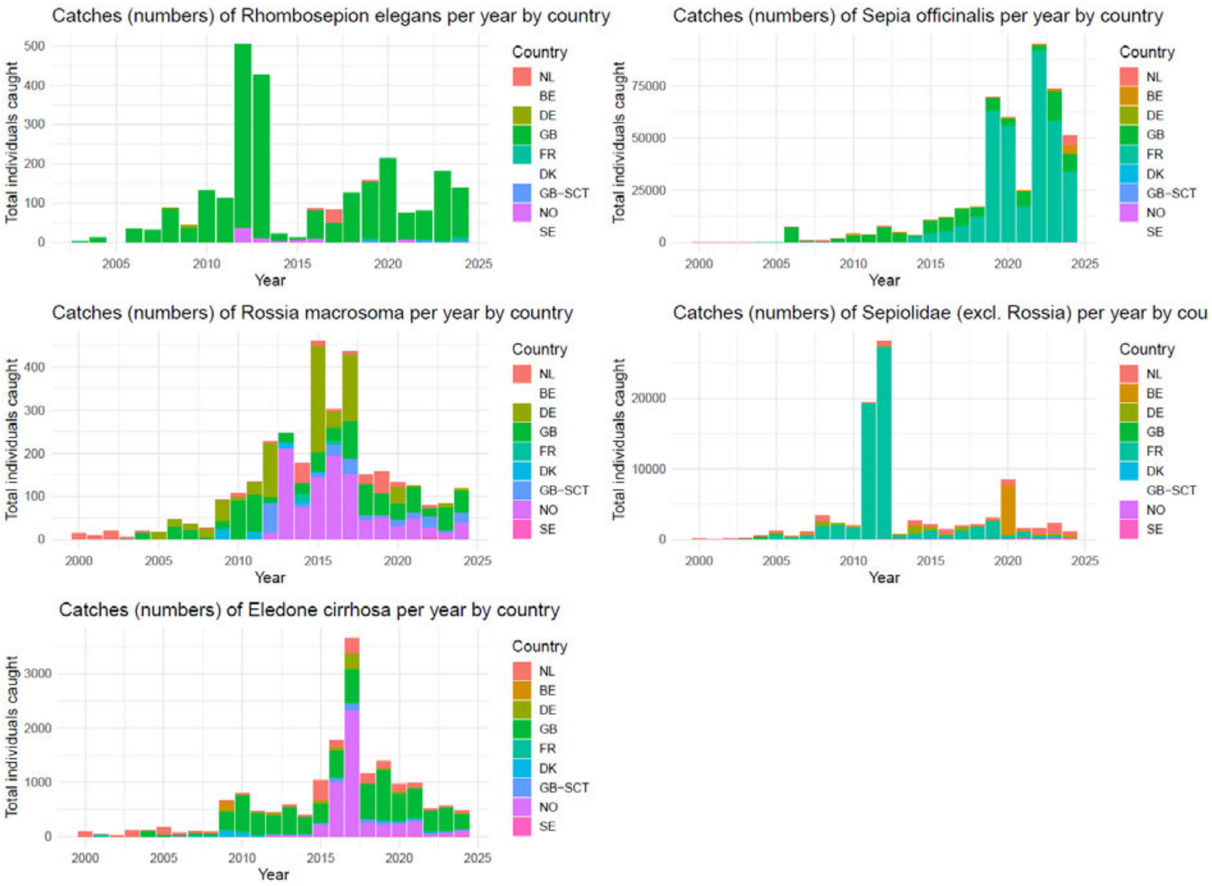


Figure 2 *Annual catches (number of individuals) caught per year for the selected cephalopod taxonomic groups. Colors indicate the reporting country. Data are aggregated across different survey programs conducted in the North Sea.*

Basic abundance indices (numbers per hour) were developed from standardized survey data across the main Greater North Sea bottom trawl survey programs (IBTS Q1 and Q3, BTS and CGFS). These indices provide an initial overview of temporal variability in cephalopod abundance and the potential suitability of survey data to support the D1C2 indicator. Indices for *S. officinalis* and *R. elegans* were derived from the BTS due to their benthic characteristics while all other taxonomic groups derived their indices from the IBTS. For *L. vulgaris*, *L. forbesii* and *S. officinalis*, indices were also derived from the CGFS.

In the IBTS, quarter 1 and quarter 3 surveys capture the similar broad multi-year fluctuations, suggesting that IBTS provides a consistent signal of relative abundance across seasons (Figures 3 and 4). However, quarter 1 is thought to represent early-season or overwintering individuals, while quarter 3 better represents post-spawning or juvenile phases.

A. media and *L. vulgaris* are consistently well represented in both quarters, with *A. media* showing higher mean CPUE in Q1 and more variable catches in Q3 (Figures 3 and 4). *L. forbesii* appears more in Q3, whereas *I. coindetii* and *T. eblanae* show occasional sharp peaks in both quarters, reflecting sporadic influxes of these individuals in the North Sea. *E. cirrhosa* and *R. macrosoma* are detected in both quarters but at low and irregular abundance, suggesting limited suitability for quantitative indices. Sepiolidae (excluding *Rossia*) exhibit infrequent but pronounced CPUE peaks, driven primarily by a small number of French quarter 1 IBTS hauls with exceptionally high catches in 2011–2012; these survey-specific events do not represent broader regional trends and should be interpreted cautiously (Figures 3 and 4).

Both IBTS quarters contribute complementary information for assessing population abundance. Future indicator development may therefore benefit from integrating data from both quarters in a combined index using the appropriate statistical corrections (i.e. cyclic splines to link temporal differences) to capture the full annual life cycle of key species.

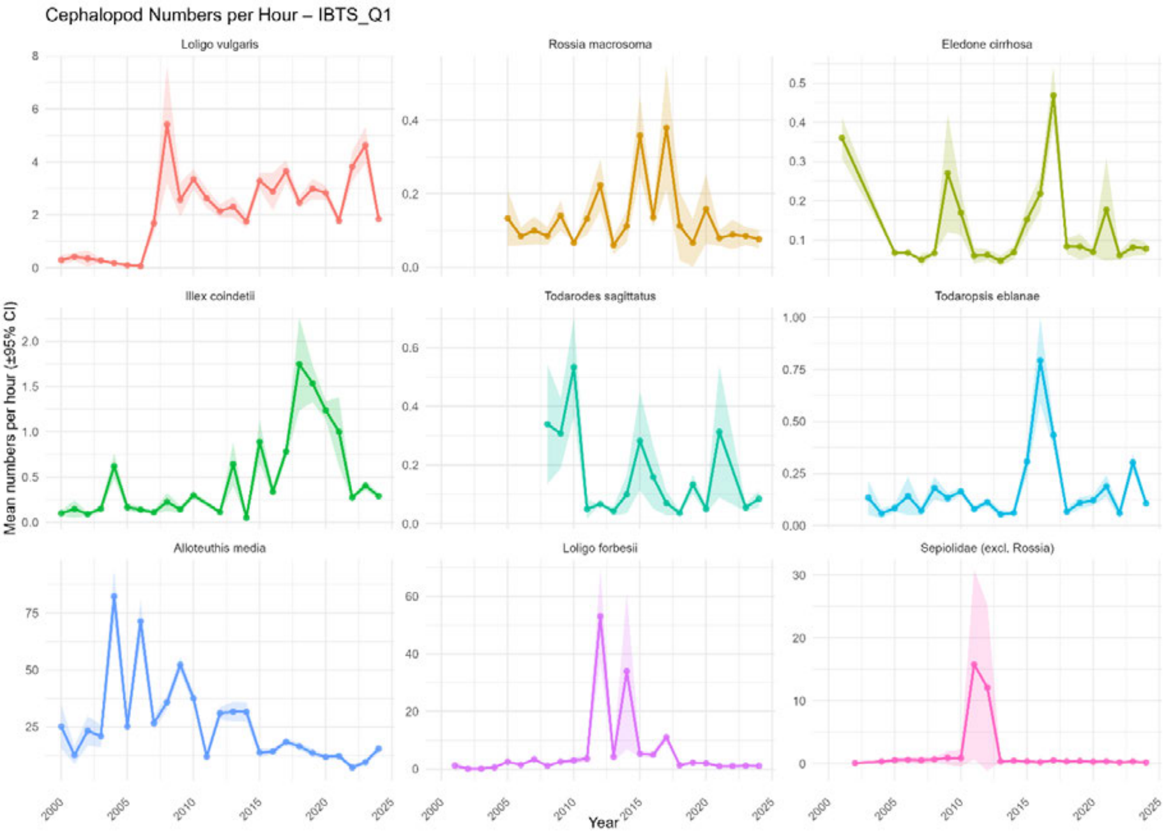


Figure 3 *Mean CPUE (numbers per hour) time series for selected cephalopod species from the IBTS Quarter 1 survey. Indices were standardized by haul duration, and shaded areas represent 95% confidence intervals. The plotted taxa correspond to species for which the IBTS provides consistent and representative sampling coverage.*

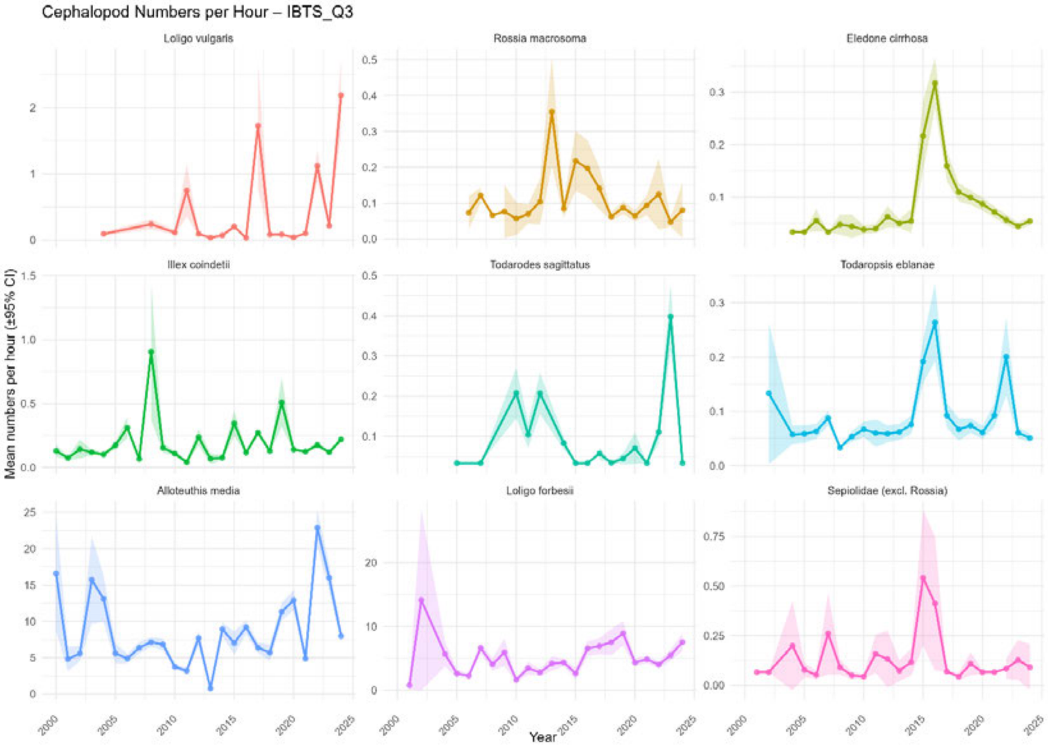


Figure 4 *Mean CPUE (numbers per hour) time series for selected cephalopod species from the IBTS Quarter 3 survey. Indices were standardized by haul duration, and shaded areas represent 95% confidence intervals. The plotted taxa correspond to species for which the IBTS provides consistent and representative sampling coverage.*

The BTS data show consistent annual catches for *S. officinalis* and *R. elegans*, confirming that this survey is particularly suited to monitoring more benthic cephalopods. For *S. officinalis*, CPUE values fluctuate between years but show a gradual increase toward 2025 while R. elegans shows more interannual variability (Figure 5). Overall, the BTS provides a complementary perspective to IBTS surveys by sampling habitats where cuttlefish and other sepiids are more common. Future indicator development could therefore prioritize BTS data for *S. officinalis* and *R. elegans*, while relying on IBTS data for the more pelagic or demersal squid species.

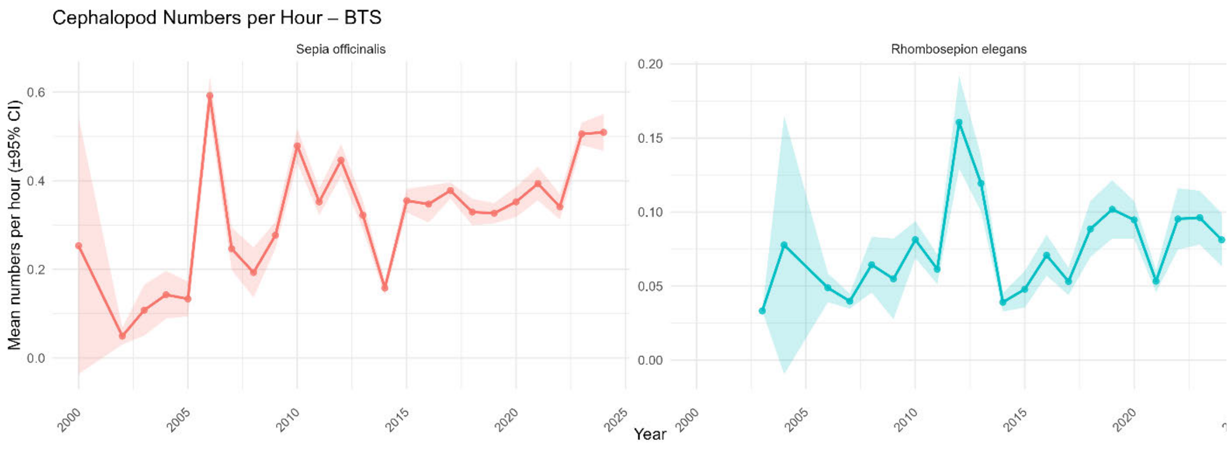


Figure 5 *Mean CPUE (numbers per hour) time series for Sepia officinalis and Rhombosepion elegans from the BTS Quarter 3 survey in the North Sea. Indices were standardized by haul duration, and shaded areas represent 95% confidence intervals. The plotted taxa correspond to species for which the BTS provides the most consistent and representative sampling coverage.*

The CGFS indices provide complementary information for squid and cuttlefish species that are more strongly associated with the English Channel. *L. vulgaris* shows the clearest and most consistent signal within the CGFS, with CPUE values displaying high interannual variability but generally increasing toward 2025 (Figure 6). *Loligo forbesii* also exhibits a coherent time series, although with higher uncertainty in some years. *Sepia officinalis* is detected regularly in the CGFS and shows moderate interannual variability, with peaks around 2019 and 2022 followed by a slight decline.

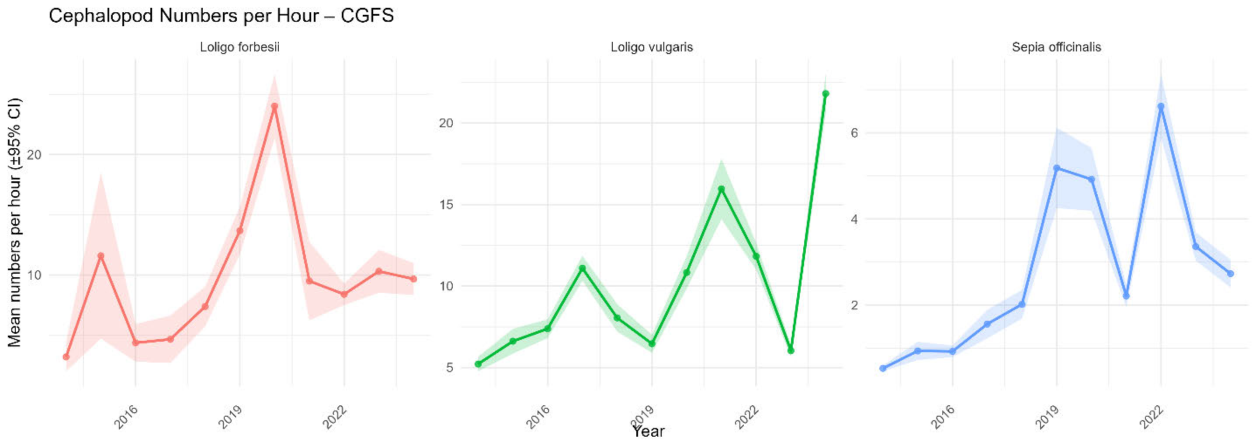


Figure 6 *Mean CPUE (numbers per hour) time series for Loligo forbesii, Loligo vulgaris and Sepia officinalis from the CGFS Quarter 3 survey in the English Channel. Indices were standardized by haul duration, and shaded areas represent 95% confidence intervals. The plotted taxa correspond to species for which the CGFS provides consistent and representative sampling coverage.*

Additionally, the coastal DYFS and SNS surveys can provide complimentary information on certain taxa, albeit only when combined with other surveys such as the IBTS or BTS which cover the broader spatial range of the respective stocks. The DYFS tends to capture smaller *A. media* individuals (4-10 cm) with the SNS recording small numbers of larger *A. media* individuals. Similar patterns can be found with *L. forbesii* with the DYFS accounting for only the smallest individuals caught while *L. vulgaris* shows higher numbers recorded in the SNS compared to the DYFS survey (see section 4.2.3). Smaller *S. officinalis* individuals are also caught in the DYFS which may compliment the BTS survey for this particular population. Finally, the DYFS seems to be particularly relevant for individuals of the Sepiolidae family excluding *R. macrosoma*, which is likely due to the smaller mesh size used in this survey.

Next, we describe possible issues and specific conditions of using survey data to compute indicators of population abundance for the identified species (groups). For this, we based ourselves on expert opinion from survey experts, occurrence in surveys as described above, and spatial distribution of survey occurrence as described in section 4.2.4.

4.2.2.3 Loliginidae – *Alloteuthis media*

For *A. media,* the IBTS surveys are most suitable to derive an indicator of abundance. *A. media* is regularly caught in both the Q1 and Q3 IBTS, with a wider range of occurrence in Q1. Q1 and Q3 seem to give contrasting views on abundance, with abundance in Q1 seemingly decreasing in recent years and abundance in Q3 increasing.

It's possible for small individuals of the genus *Loligo* to be misidentified as *Alloteuthis*. It is also important to note that although sampling of *Alloteuthis* occurs on surveys, they are small and easily missed. The mesh sizes used by surveys means they are likely to escape. Numbers and raising weights may be unreliable, though it may be possible to derive general trends and use surveys for the mapping of distributions.

4.2.2.4 Loliginidae – *Loligo vulgaris*

Catchability of *L. vulgaris* in Q1 IBTS and CGFS is good, and indices of abundance may be derived from these surveys. Given that the boundary between the English Channel and North Sea lies in the middle of the area of greatest abundance for *L. vulgaris*, a joint index for both areas is recommended. Q3 IBTS is likely too early in the season to yield a reliable index of abundance for *L. vulgaris*.

4.2.2.5 Loliginidae – *Loligo forbesii*

L. forbesii is caught consistently in the Q3 IBTS and CGFS (mostly in the western English Channel) and indices of abundance can be derived from these surveys. There may be misidentifications of *L. forbesii* in the southern North Sea in IBTS Q1, as these are more likely to be *L. vulgaris* given the timing and location. An index of abundance is best calculated at the population level, which likely includes the areas west of Scotland and Celtic Seas. For this, data from the Irish Ground Fish Survey could be used (not presented in this work).

4.2.2.6 Loliginidae – *Loligo* spp.

Loligo are often identified to species level but also regularly to genus level. Identification becomes difficult when tentacles have been broken off (the suction cups on the tentacles are the main trait to distinguish *L. vulgaris* and *L. forbesii*). Individuals assigned to *Loligo* spp. may be assigned to species based on parameters such as location, depth, temperature and season.

4.2.2.7 Ommastrephidae – *Illex coindetii*

Illex coindetii was very uncommon in the North Sea, however, in recent years a spawning stock has established itself in the Northern part of the North Sea (Oesterwind & Schaber, 2020). Before this sudden increase in abundance in the North Sea, it's possible that sporadically occurring *I. coindetii* were not correctly identified. It is therefore recommended to only take into account the years since the establishment of the North Sea spawning population, 2015 onwards. The Q3 IBTS is recommended.

Individuals identified as *Illex* spp. are most likely *I. coindetii. Illex illecebrosus* is rare in the North Sea as it is mainly an oceanic species, occurring in the western Atlantic Ocean and as far east as western Ireland.

4.2.2.8 Ommastrephidae – *Todarodes sagittatus*

T. sagittatus is caught in limited numbers in the IBTS, mainly in Q1, from which an indicator abundance may be calculated. It is important to use surveys that align with the distribution of the population, which may include western waters.

4.2.2.9 Ommastrephidae – *Todaropsis eblanae*

Both the Q1 and Q3 IBTS catch *T. eblanae* in limited numbers and may be used for indices of abundance. It also occurs in the western English Channel. It is important to use surveys that align with the distribution of the population, which may include western waters.

4.2.2.10 Sepiidae – *Sepia officinalis*

S. officinalis is regularly caught, with high catchability in beam trawl surveys. It is mainly caught in the BTS in the southern North Sea and English Channel. It is also caught in large numbers by the CGFS. Indices of abundance can be calculated from these surveys. Indicators are best calculated separately for the English Channel and North Sea, as these are thought to represent semi-independent populations (Laptikhovsky et al., 2023).

4.2.2.11 Sepiidae – *Rhombosepion elegans*

R. elegans is caught in small numbers, mainly by beam trawl surveys in western waters. Indicators should be calculated taking into account the distribution of the species, also including surveys in the Celtic Seas Ecoregion.

4.2.2.12 Sepiolidae – *Rossia macrosoma*

R. macrosoma mainly occurs in the northern North Sea and western English Channel, being caught mainly in the Q1 and Q3 IBTS and CGFS.

It is also important to note that although sampling of *Rossia* occurs on surveys, they are small and easily missed. The mesh sizes used by surveys means they are likely to escape. Numbers and raising weights may be unreliable, though it may be possible to derive general trends and use surveys for the mapping of distributions.

4.2.2.13 Sepiolidae – Sepiolidae excl. *Rossia*

All other sepiolidae are difficult to distinguish with the naked eye. Catchability in the surveys is also low given the mesh sizes and small size of these species. An indicator could be developed from Q1 and Q3 IBTS for the grouped Sepiolidae (save *R. macrosoma*) but the quality and informativeness of this indicator are questionable. In the Q1 IBTS from France, there are two years with exceptionally high abundance of Sepiolids though this is the result of unusually high numbers from few hauls and is not reflected in the rest of the data.

4.2.2.14 Eledonidae – *Eledone cirrhosa*

An indicator of abundance may be calculated for *E. cirrhosa* from the BTS. The IBTS surveys may also be used, though given the species’ benthic lifestyle, the BTS is assumed to be more suitable. Given the association with rocky habitats, it’s most common in the western English Channel, Irish Sea and northern North Sea.

4.2.3 D1C3 – Demographic characteristics (size and age distribution)

It is important to note that the short life cycles of most cephalopods make survey data quite unsuitable for the calculation of demographic characteristics, as the timing of the survey and slight changes in the timing of the life cycle due to environmental changes may influence the outcome of such indicators more than the actual dynamics of the population. Continuous monitoring (most plausibly from commercial sampling) may capture these seasonal changes better. However, even with such intensive data collection, cephalopods are known to display weak, non-linear relationships between, size, age, maturity and reproductive success. Therefore, it is unlikely that any meaningful size- or age-based indicators can be determined to assess the demographic characteristics of cephalopods.

Length–frequency distributions were examined across surveys to evaluate data quality and the suitability of existing sampling programs for assessing demographic characteristics. As expected, the distributions reflect the short life spans and rapid growth typical of most cephalopods, with clear modal peaks corresponding to single cohorts rather than overlapping age classes.

Smaller-bodied taxa such as *A. media*, *R. elegans*, *R. macrosoma* and the grouped Sepiolidae (excluding *Rossia*) show narrow length ranges (typically <10 cm). In contrast, larger squid species (*L. forbesii*, *L. vulgaris*, *I. coindetii*, *T. eblanae*, *T. sagittatus*) display broader and sometimes bimodal size distributions, suggesting that surveys capture different life-history stages at different times or in different areas. For *I. coindetii* and *T. eblanae*, the largest individuals appear mainly in the IBTS Q3 survey, suggesting more mature cohorts and may be most appropriate for tracking adult biomass.

S. officinalis shows a wide range of mantle lengths (up to 25 cm) mainly in the BTS and CGFS surveys (Figure 13). In contrast to the unimodal (~10-12 cm) distributions found in the BTS, the CGFS displays a clear bimodal pattern (5-7 cm and 12-18 cm; Figure 13), possibly reflecting the presence of both juvenile and adult groups in southern waters as sex differences only show slightly larger males than females (Figure S4). For the octopus *E. cirrhosa*, length–frequency distributions vary considerably between surveys, with the IBTS Q3 showing a clear left-skewed pattern dominated by small individuals (<5 cm mantle length), while the IBTS Q1 captures a broader size range centred around 6–10 cm. Although this pattern may suggest that Q3 coincides more with a recruitment period for this species while Q1 samples older cohorts that survived through winter, such interpretations must be treated cautiously (Figure 17). Mantle-length measurements for *E. cirrhosa* are known to be inconsistently recorded across surveys. Octopod mantles are difficult to measure in a standardized way and many survey participants only record numbers of *E. cirrhosa*.

No age information on cephalopods is routinely collected. Although this is possible by counting day rings from statoliths or beaks, given the short life cycle of often ~ 1 year (Oesterwind et al., 2019), this data would be of limited value to the assessment of GES indicators.

Although these length data provide useful context on survey catch composition and can aid in identifying which programs best sample particular size classes, they are not suitable for developing robust demographic indicators. The observed size variability primarily reflects survey timing and spatial distribution rather than true demographic structure. Nevertheless, the data remain valuable for verifying species identification, examining seasonal growth patterns, and supporting the selection of the most representative survey for abundance and distribution indicators.

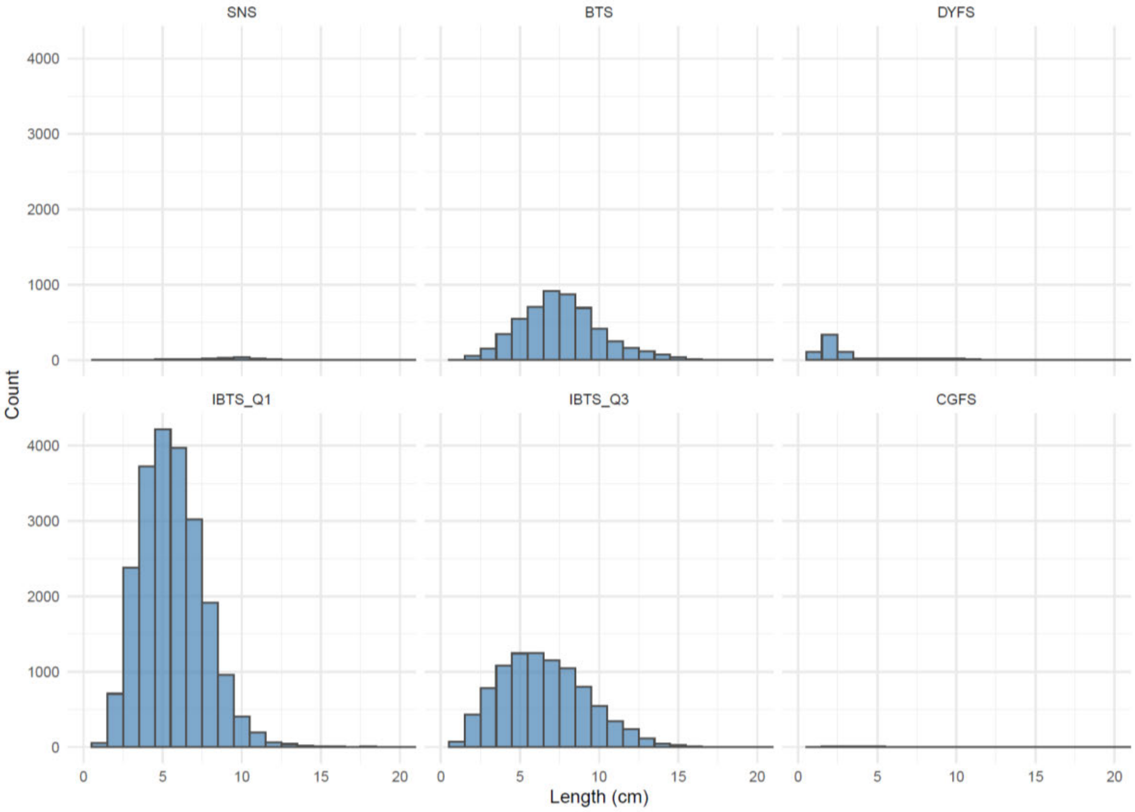


Figure 7 *Length–frequency distributions for Alloteuthis media recorded in Greater North Sea surveys. Counts represent the number of individuals per 1 cm length class, standardized by haul.*

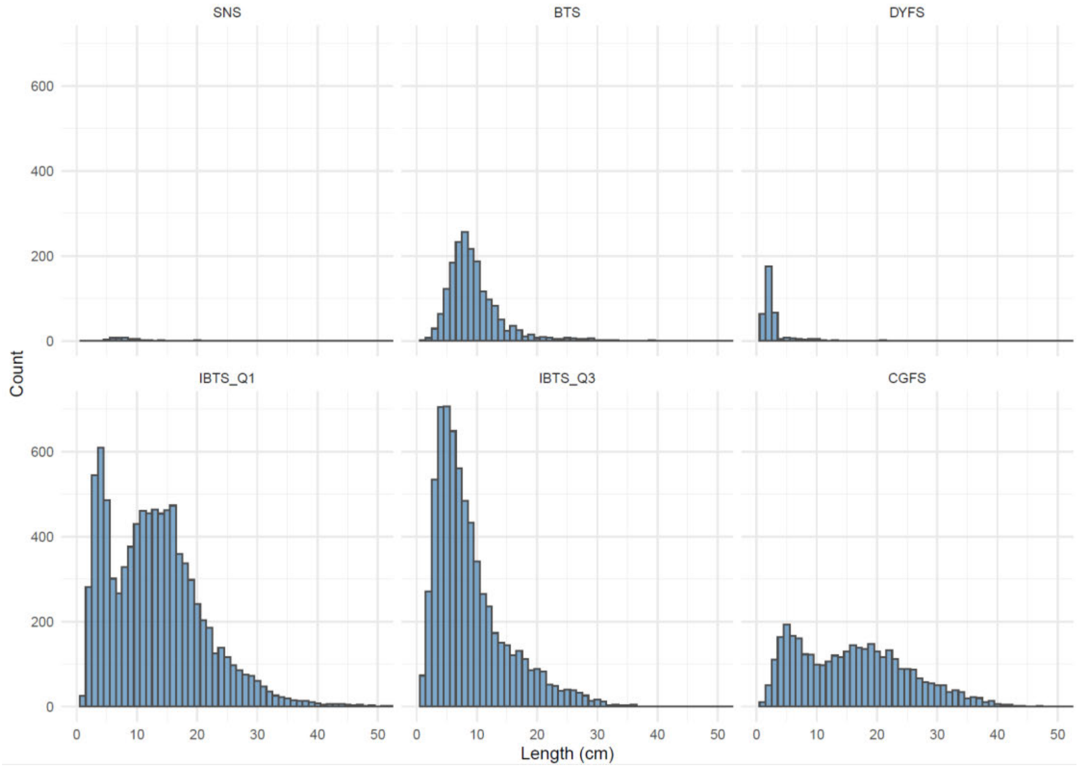


__Figure 8__ Length–frequency distributions for Loligo forbesii recorded in Greater North Sea surveys. Counts represent the number of individuals per 1 cm length class, standardized by haul.

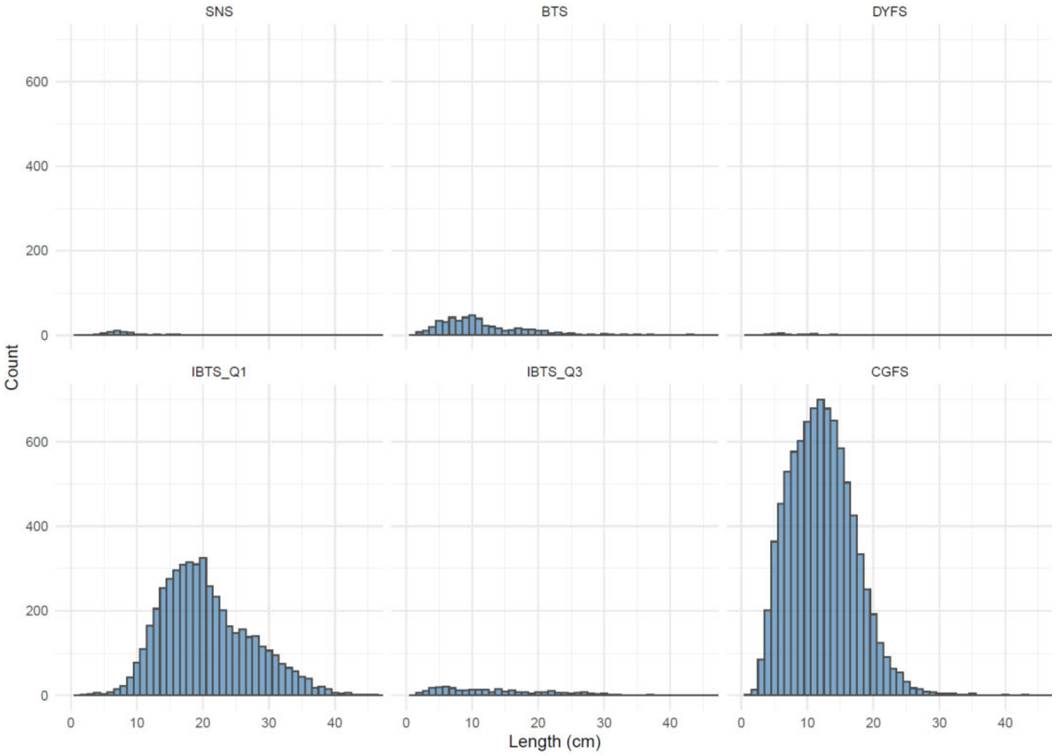


__Figure 9__ Length–frequency distributions for Loligo vulgaris recorded in Greater North Sea surveys. Counts represent the number of individuals per 1 cm length class, standardized by haul.

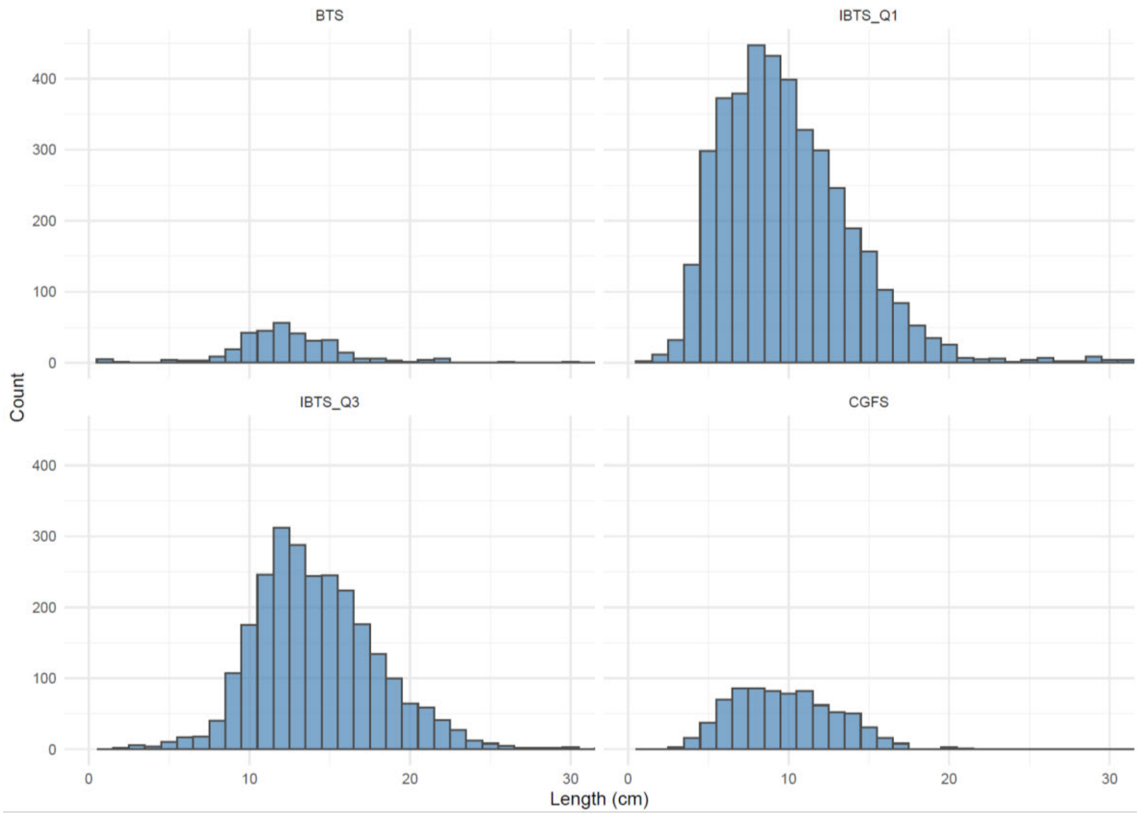


Figure 10 *Length–frequency distributions for Illex coindetii recorded in Greater North Sea surveys. Counts represent the number of individuals per 1 cm length class, standardized by haul.*

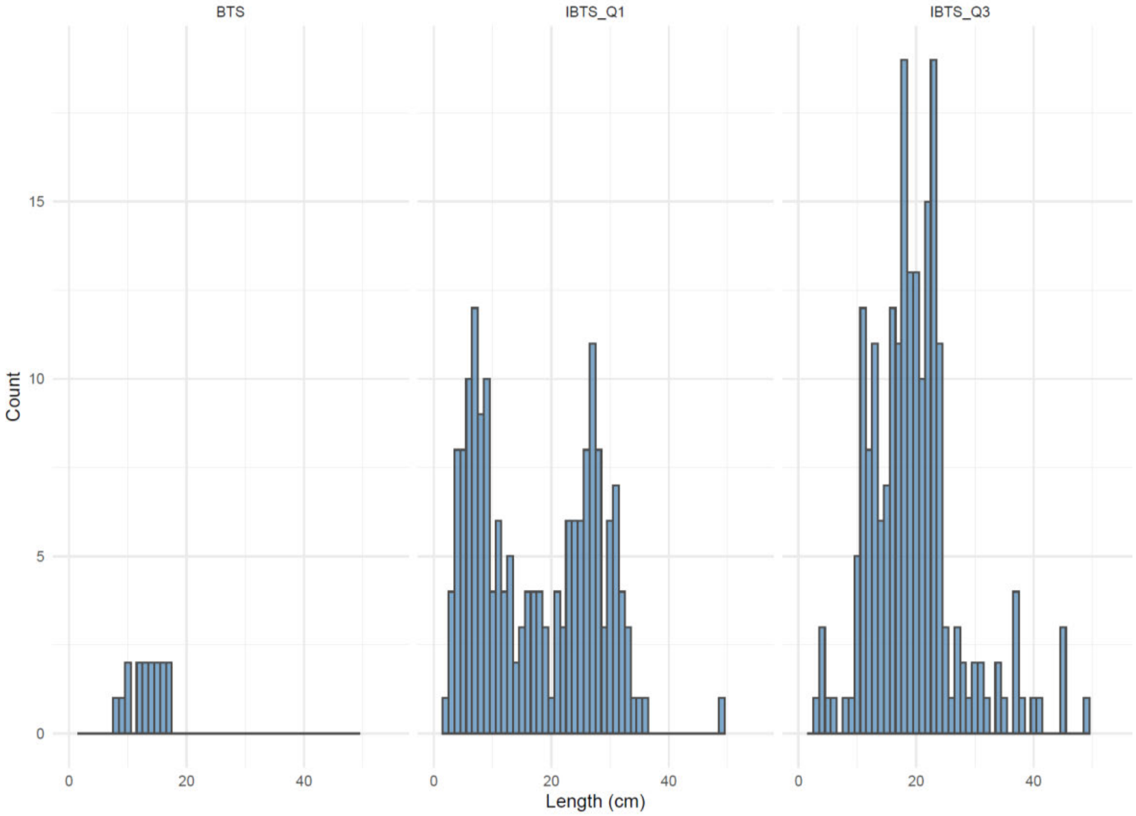


Figure 11 *Length–frequency distributions for Todarodes sagittatus recorded in Greater North Sea surveys. Counts represent the number of individuals per 1 cm length class, standardized by haul.*

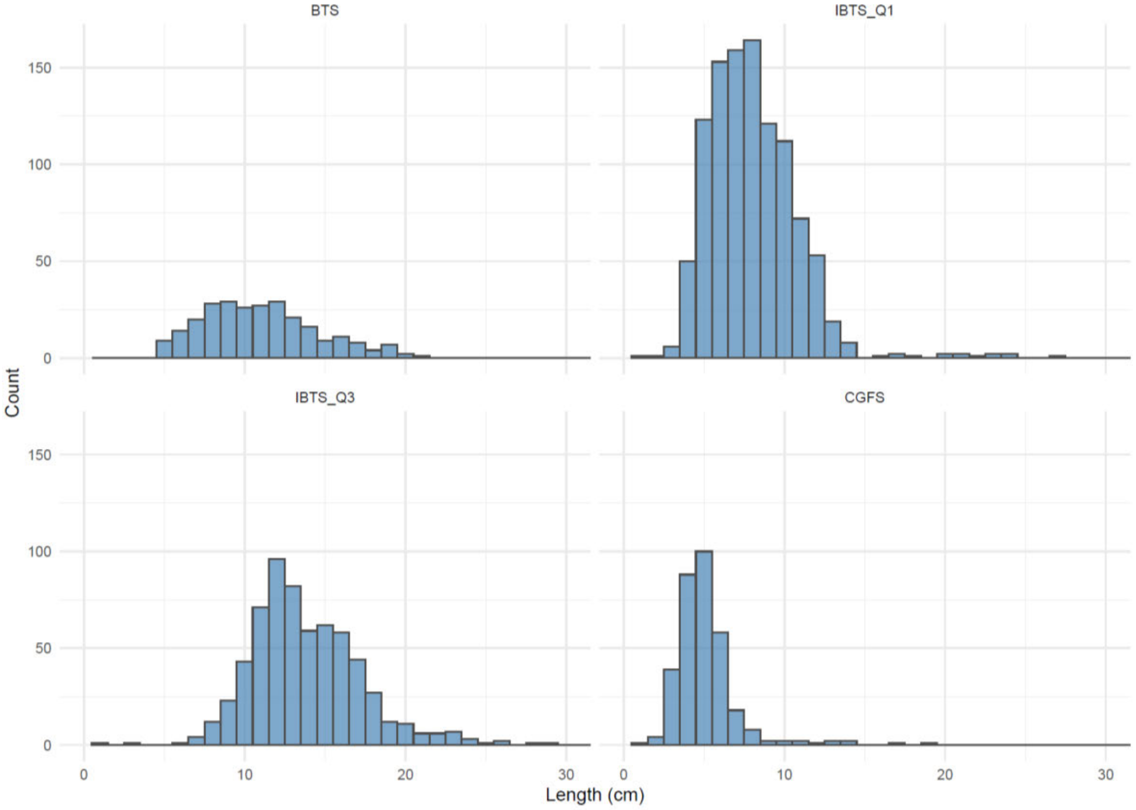


Figure 12 *Length–frequency distributions for Todarodes eblanae recorded in Greater North Sea surveys. Counts represent the number of individuals per 1 cm length class, standardized by haul.*

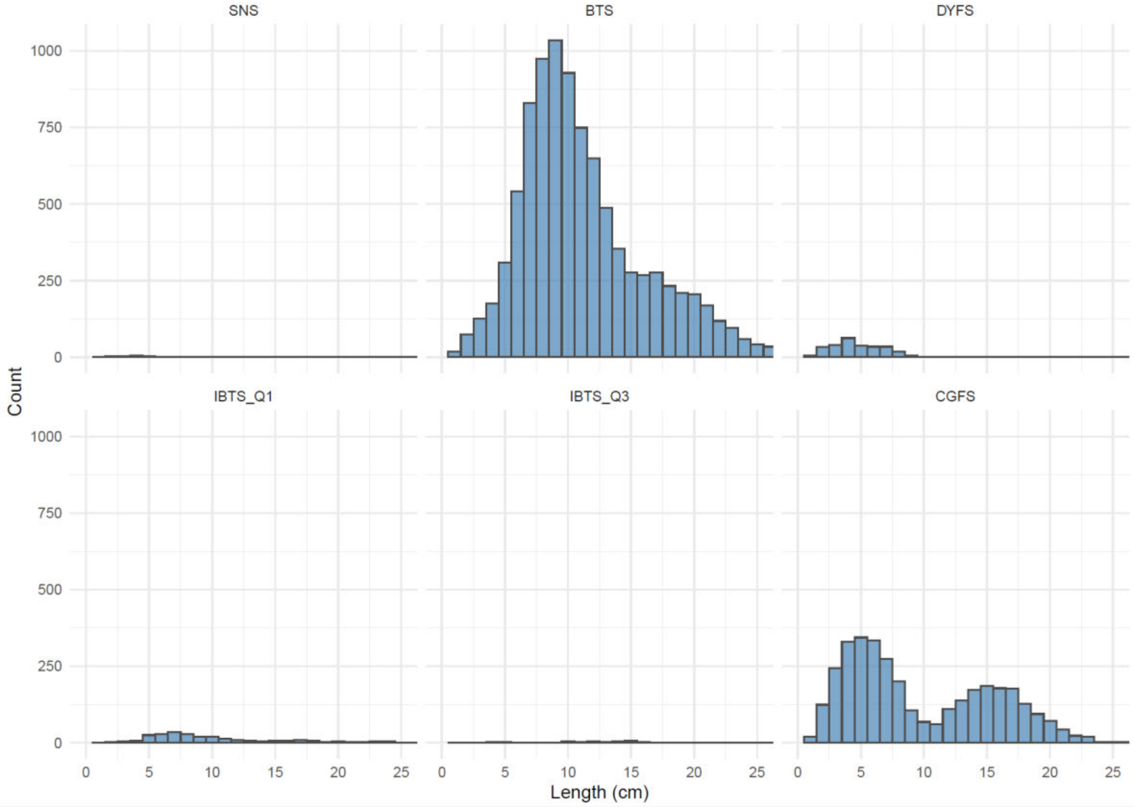


Figure 13 *Length–frequency distributions for Sepia officinalis recorded in Greater North Sea surveys. Counts represent the number of individuals per 1 cm length class, standardized by haul.*

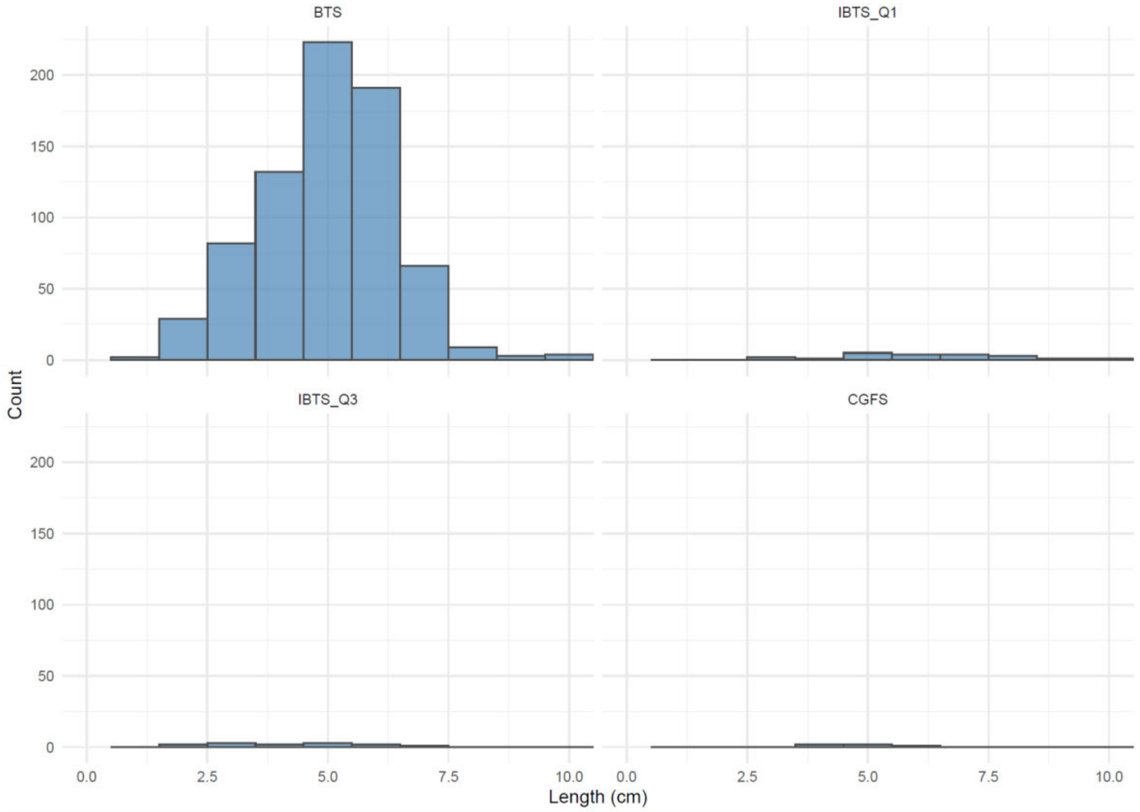


Figure 14 *Length–frequency distributions for Rhombosepion elegans recorded in Greater North Sea surveys. Counts represent the number of individuals per 1 cm length class, standardized by haul.*

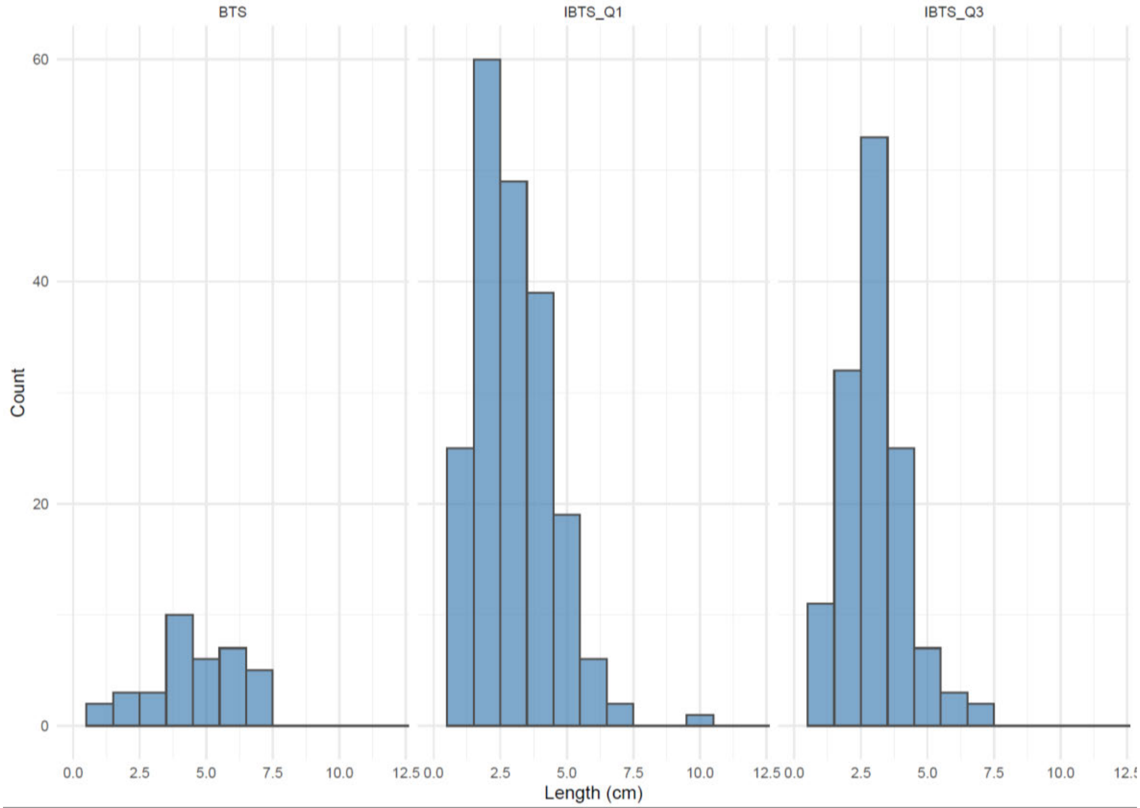


Figure 15 *Length–frequency distributions for Rossia macrosoma recorded in Greater North Sea surveys. Counts represent the number of individuals per 1 cm length class, standardized by haul.*

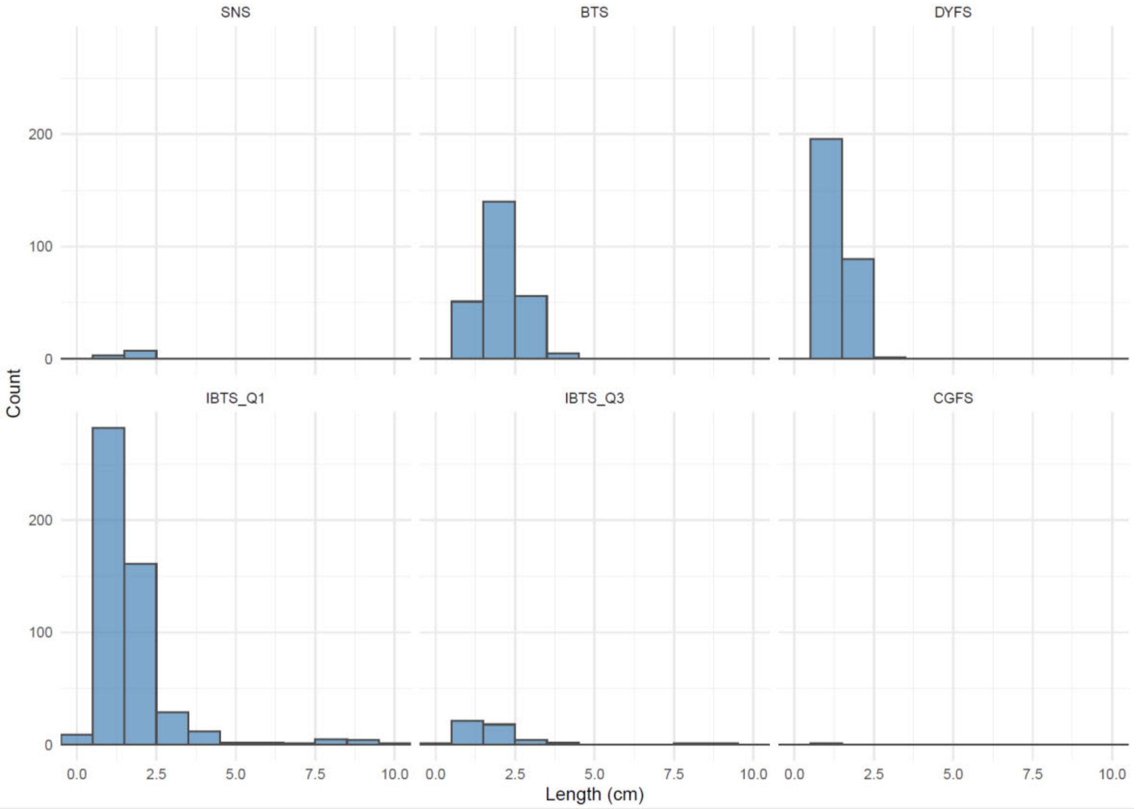


Figure 16 *Length–frequency distributions for Sepiolidae (excluding Rossia macrosoma) recorded in Greater GNorth Sea surveys. Counts represent the number of individuals per 1 cm length class, standardized by haul.*

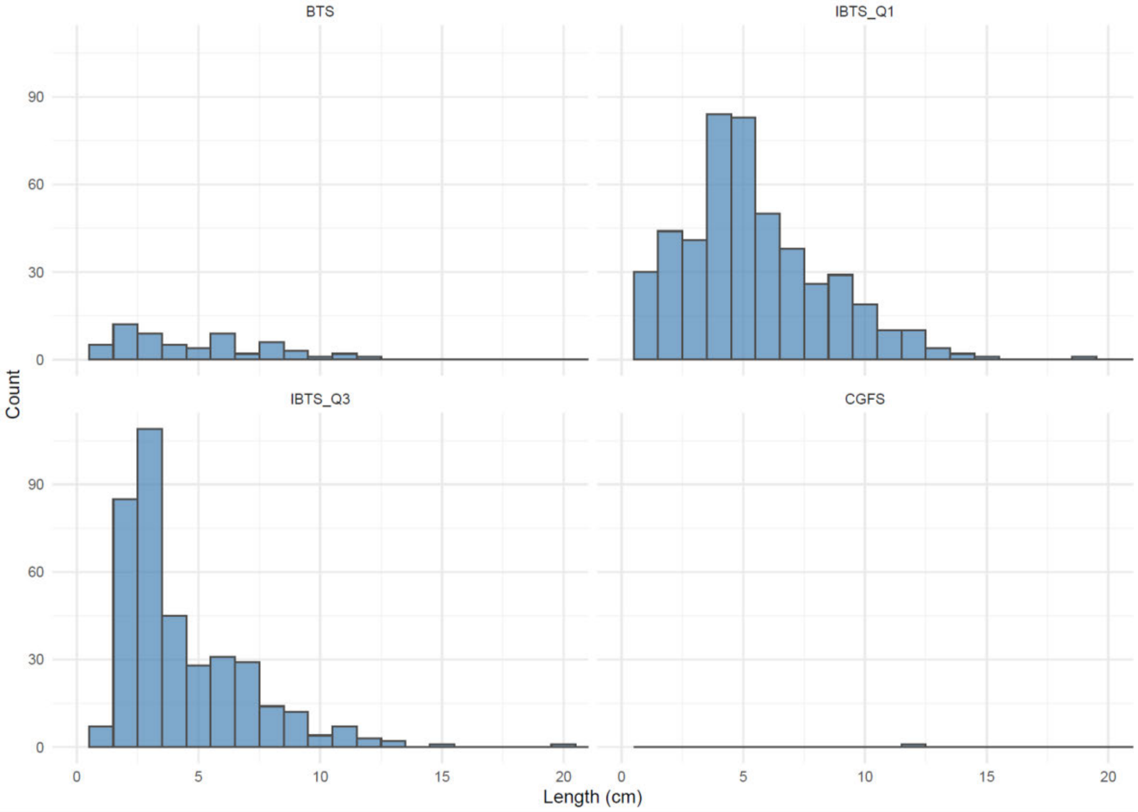


Figure 17 *Length–frequency distributions for Eledone cirrhosa recorded in Greater North Sea surveys. Counts represent the number of individuals per 1 cm length class, standardized by haul.*

Length–weight data extracted from DATRAS CA files (biological information) were more limited but provide an additional perspective on population structure where available (Figure 18 and S5). The relationships observed generally follow the expected allometric pattern ($W = a L^b$), with larger individuals increasing disproportionately in weight relative to mantle length. *S. officinalis*, *L. forbesii*, and *T. eblanae* show clear positive allometric growth, reflected by steep, well-defined curves, particularly in the BTS and CGFS surveys. In contrast, *I. coindetii* and *R. macrosoma* exhibit much weaker or poorly defined relationships, likely due to small sample sizes and limited size ranges (Figure 18).

The length–frequency and length–weight analyses show that while current survey data provide valuable insight into cephalopod size structure and some information on growth, they remain limited for developing robust demographic indicators under D1C3. However, these datasets are essential for identifying which surveys capture the most representative size classes and can therefore inform the selection of appropriate data sources for spatial and abundance analyses presented in Section 4.2.4 (D1C4 – Distributional range and pattern).

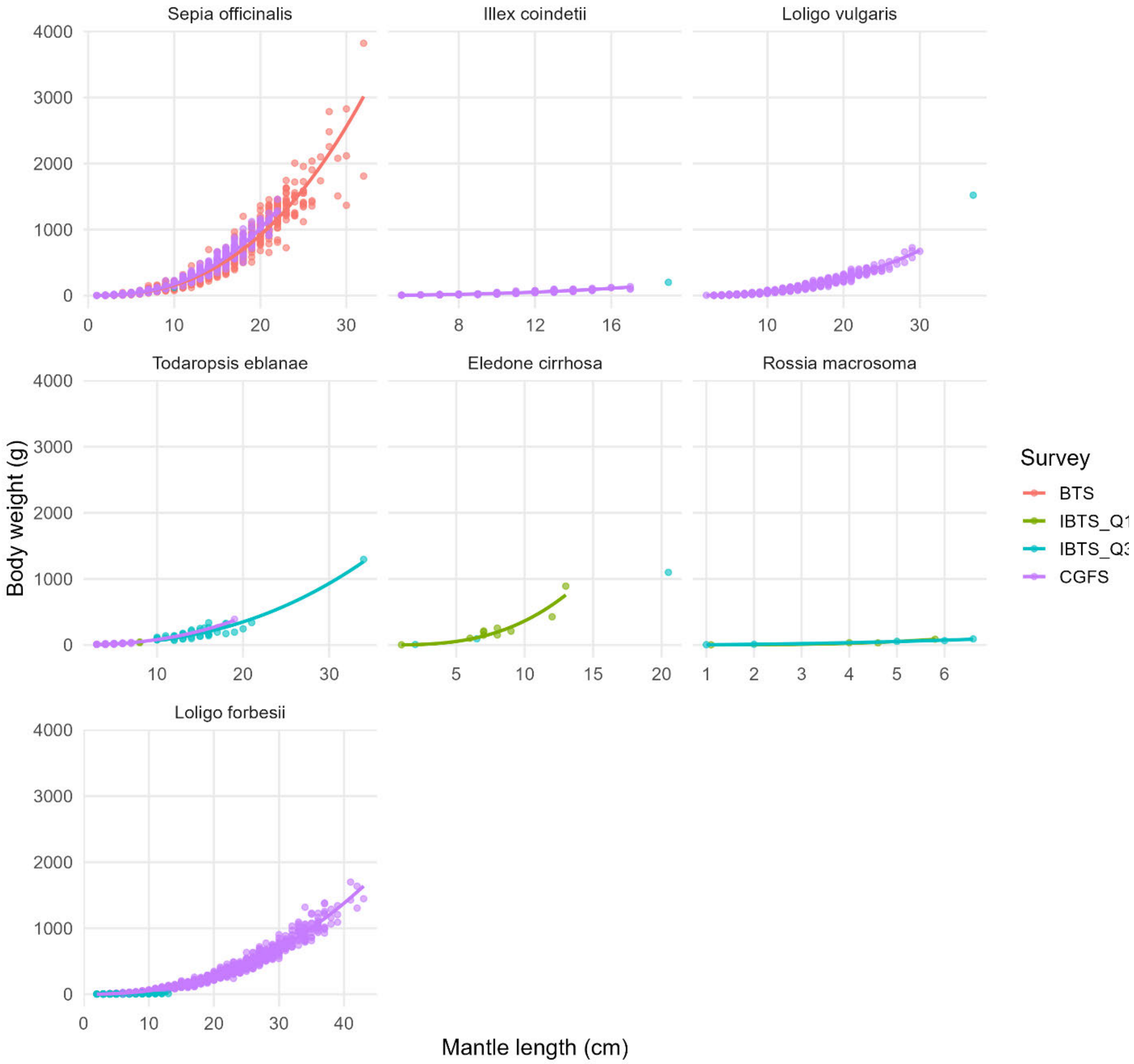


Figure 18 *Length–weight relationships for selected cephalopod species based on DATRAS CA (catch-at-age/size) data from North Sea and English Channel surveys. Each point represents an individual measurement, and fitted curves illustrate the allometric relationship ($W = a L^b$) between body weight and mantle length. Colors indicate the survey of origin (BTS, IBTS Q1, IBTS Q3, CGFS).*

4.2.4 D1C4 – Distributional range and pattern

The proposed indicator for D1C4 (Distributional range and pattern) is the change in spatial units occupied, e.g. at the level of ICES statistical rectangles, relative to the number of spatial units occupied in a reference period. This is a way of quantifying the total range of a species, without taking into account the specific distribution or shifts due to e.g. habitat changes or climate change.

Many cephalopods, especially Loliginid and Ommastrephid squids, are highly mobile and react rapidly to environmental changes (FAO, 2010; O'Brien et al., 2018). This makes their distributional ranges and patterns difficult to interpret. When assessing changes in their distribution, it is therefore recommended to assess multi-year (e.g. three year) periods, to reduce some of the noise caused by distributional responses to short-term, reversible environmental changes.

Across all species, distributions show clear spatial patterns between the English Channel and North Sea, reflecting both ecological preferences and survey effort. *A. media* appears widely across beam trawl surveys (BTS, DYFS, SNS) as well as in IBTS quarter 1 compared to quarter 3 (Figure 19). However, these patterns largely reflect the underlying survey footprints rather than true differences in species distribution, as similar occurrences are found wherever appropriate sampling effort is available. Both *Loligo* species exhibit high concentrations in the CGFS English channel survey (demersal otter trawl) though the quarter 1 (IBTS) information shows *L. forbesii* in more northerly distributions compared to *L. vulgaris* (Figure 20 and Figure 21).

I. coindetii and *T. eblanae* are mainly detected along the western Channel and northern shelf edge, suggesting more oceanic affinities with lower concentrations in shallower southern North Sea waters (Figure 22 and Figure 24). *S. officinalis* are concentrated in the Channel and southern North Sea (Figure 25). *R. elegans* and *R. macrosoma* favor deeper waters while grouped Sepiolidae are found often in shallow coastal areas (Figure 26, Figure 27 and Figure 28). The octopus *E. cirrhosa,* is found in more even distributions across the central and northern North Sea, the Irish sea and western English Channel and is only occasionally identified in shallow southern North Sea waters (Figure 29).

Overall, the maps highlight distinct spatial patterns among cephalopod taxa and confirm that the IBTS and BTS provide the broadest and most consistent spatial coverage for the North Sea, while the CGFS captures complementary information for Channel populations and the DYFS and SNS complementing more benthic data in the southern North Sea. Integrating data from combined surveys therefore provides the most complete spatial picture of cephalopod distribution under Descriptor 1 (Criterion 4). Spatial information may also be used to identify which (additional) surveys may be used for the calculation of D1C2 (population abundance). For example, for some species the distribution is mostly in the periphery of the GNSE, and surveys in the neighboring Celtic Seas Ecoregion need to be considered to properly capture the dynamics of the population. In addition to this, more knowledge on stock identity and population structure is needed to ensure survey data is considered at the proper spatial scale.

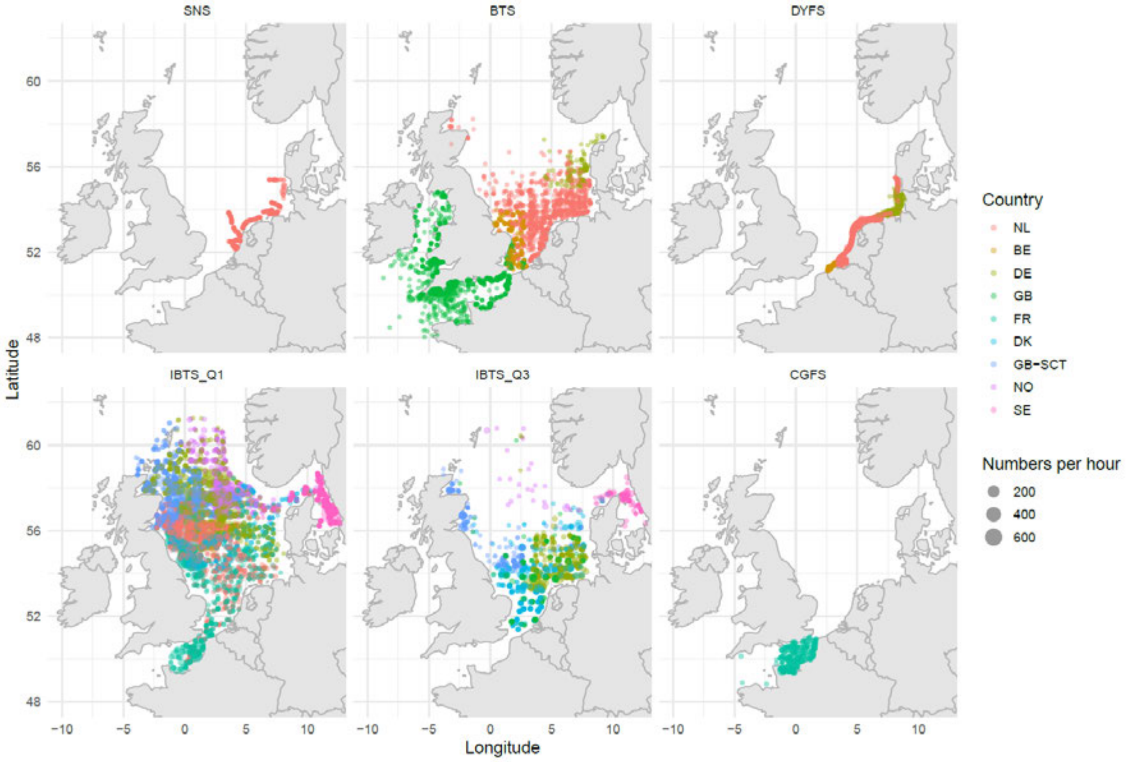


Figure 19 *Spatial distribution (mean CPUE, numbers per hour) of Alloteuthis media recorded in North Sea and eastern English Channel surveys (IBTS Q1, IBTS Q3, BTS, DYFS, SNS, and CGFS). Colors represent countries carrying out the surveys.*

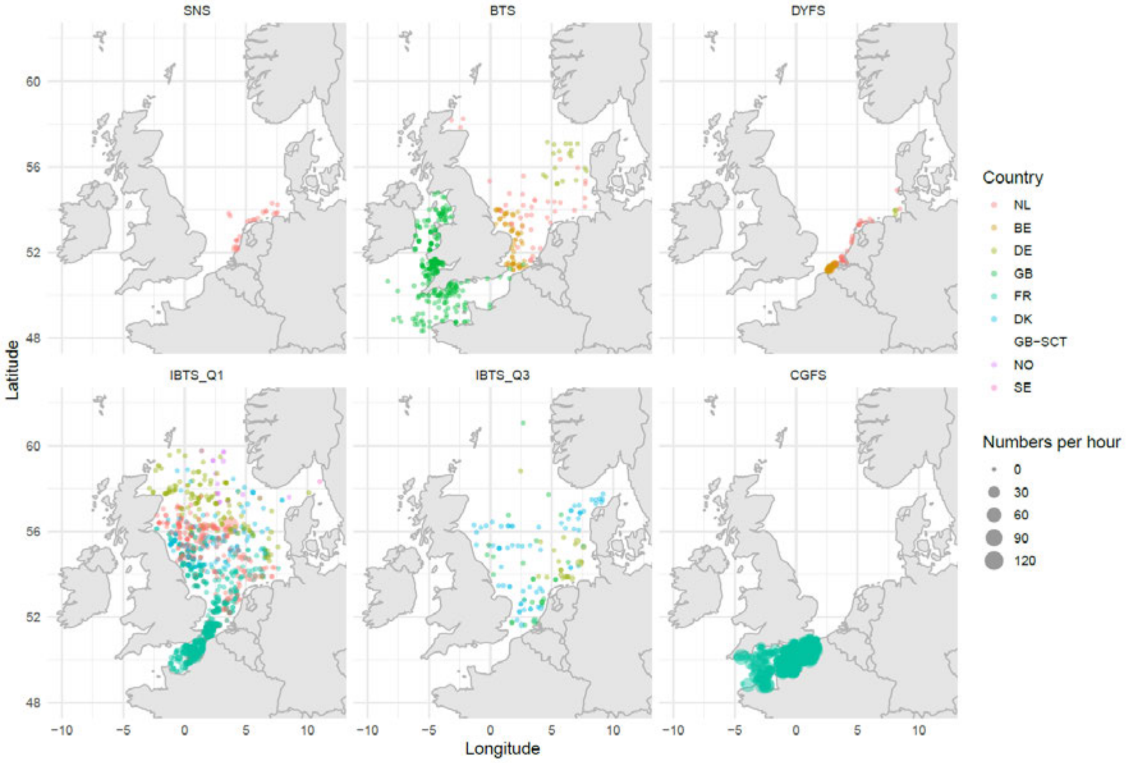


Figure 20 *Spatial distribution (mean CPUE, numbers per hour) of Loligo vulgaris recorded in North Sea and eastern English Channel surveys (IBTS Q1, IBTS Q3, BTS, DYFS, SNS, and CGFS). Colors represent countries carrying out the surveys.*

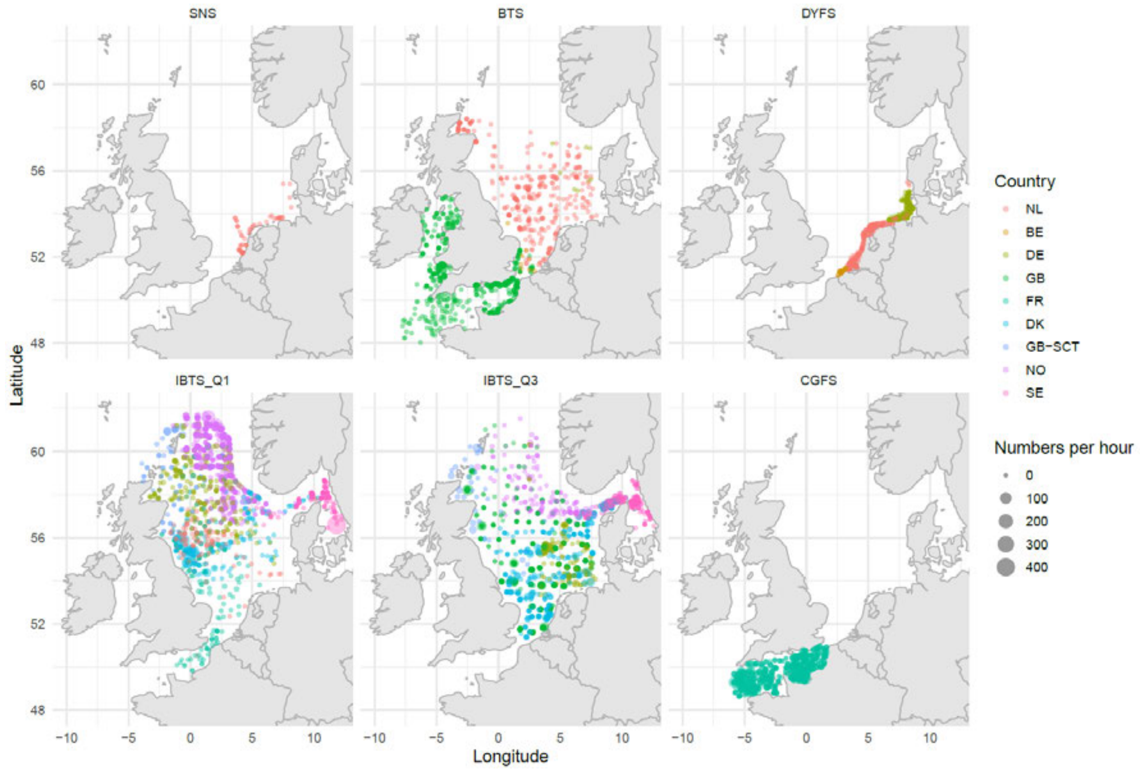


Figure 21 *Spatial distribution (mean CPUE, numbers per hour) of Loligo forbesii recorded in North Sea and eastern English Channel surveys (IBTS Q1, IBTS Q3, BTS, DYFS, SNS, and CGFS). Colors represent countries carrying out the surveys.*

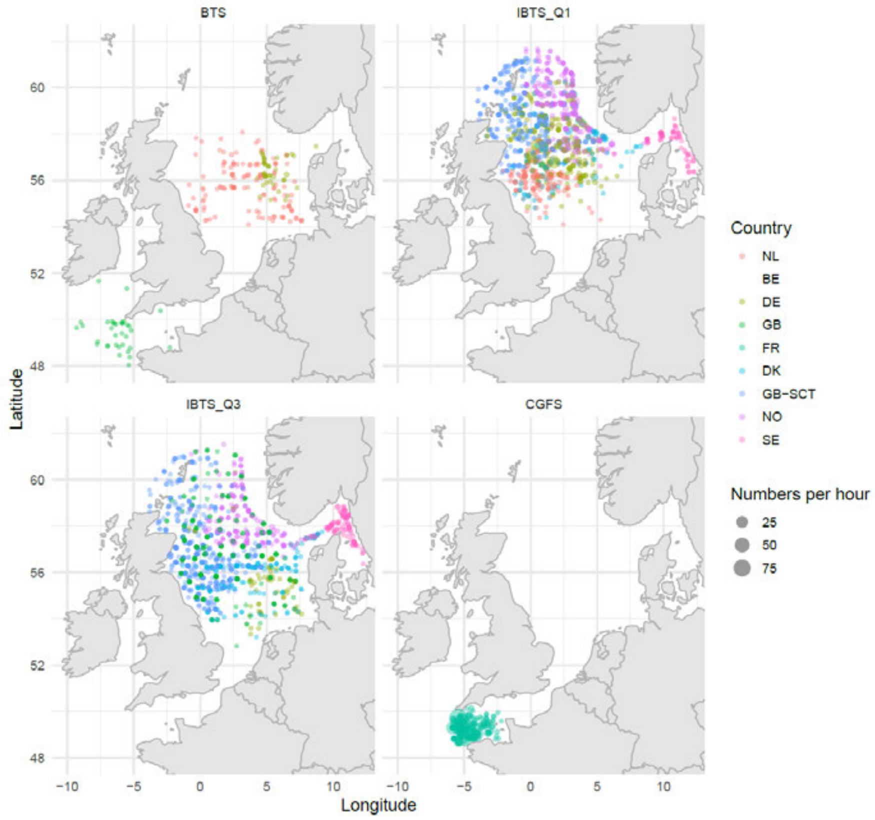


Figure 22 *Spatial distribution (mean CPUE, numbers per hour) of Illex coindetii recorded in North Sea and eastern English Channel surveys (IBTS Q1, IBTS Q3, BTS, DYFS, SNS, and CGFS). Colors represent countries carrying out the surveys.*

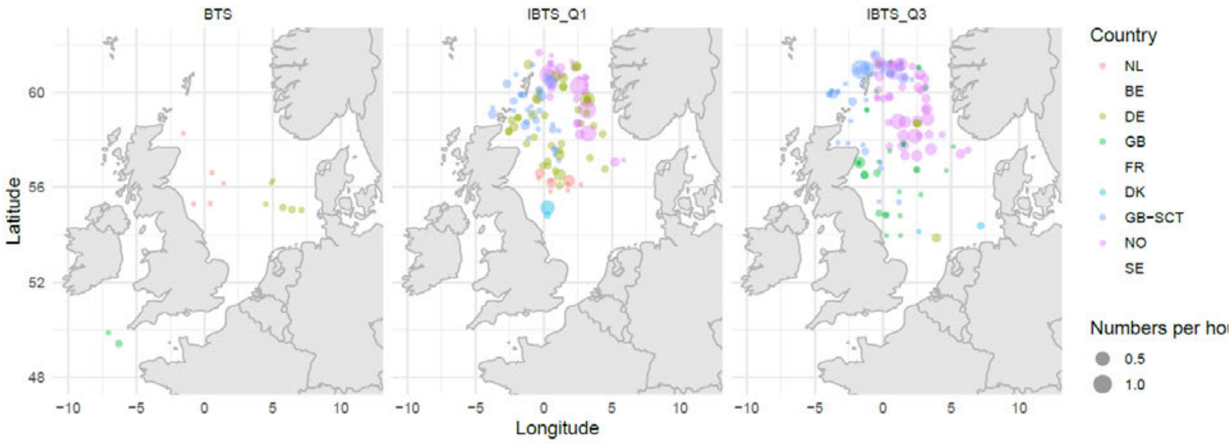


Figure 23 *Spatial distribution (mean CPUE, numbers per hour) of Todarodes sagittatus recorded in North Sea and eastern English Channel surveys (IBTS Q1, IBTS Q3, BTS, DYFS, SNS, and CGFS). Colors represent countries carrying out the surveys.*

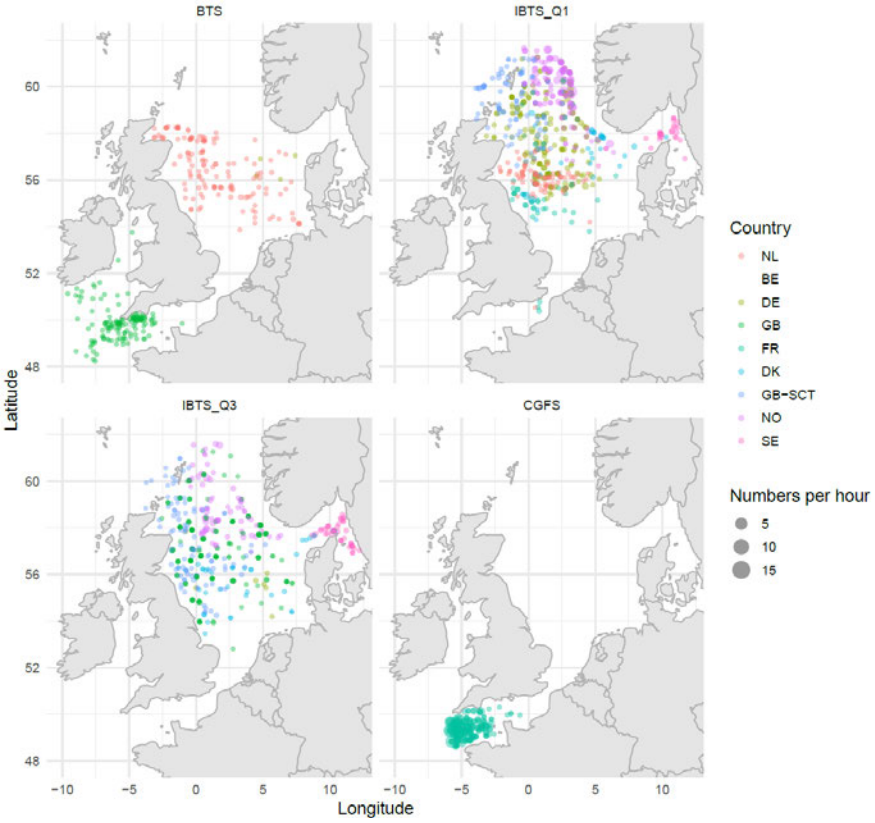


Figure 24 *Spatial distribution (mean CPUE, numbers per hour) of Todaropsis eblanae recorded in North Sea and eastern English Channel surveys (IBTS Q1, IBTS Q3, BTS, DYFS, SNS, and CGFS). Colors represent countries carrying out the surveys.*

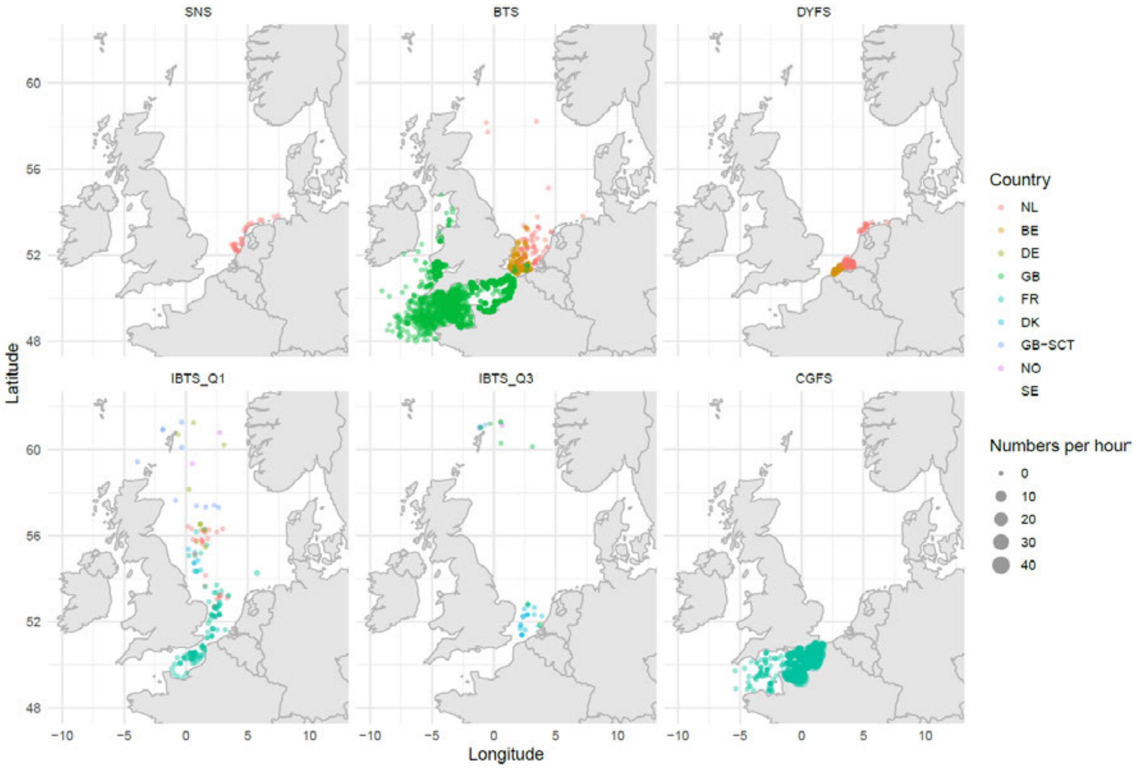


Figure 25 *Spatial distribution (mean CPUE, numbers per hour) of Sepia officinalis recorded in North Sea and eastern English Channel surveys (IBTS Q1, IBTS Q3, BTS, DYFS, SNS, and CGFS). Colors represent countries carrying out the surveys.*

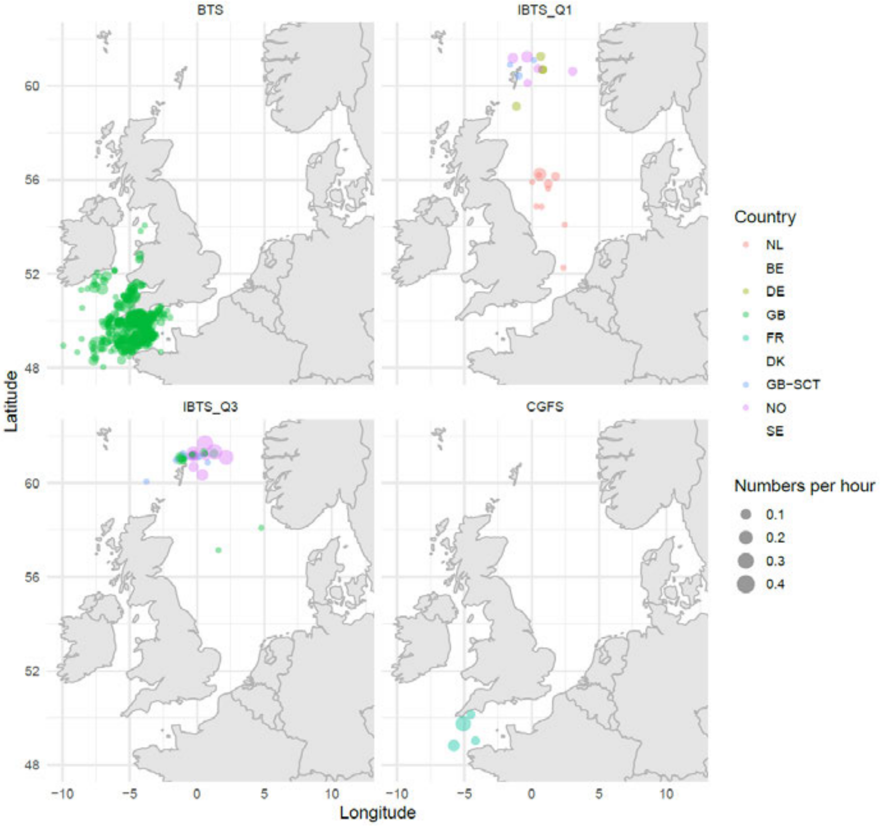


Figure 26 *Spatial distribution (mean CPUE, numbers per hour) of Rhombosepion elegans recorded in North Sea and eastern English Channel surveys (IBTS Q1, IBTS Q3, BTS, DYFS, SNS, and CGFS). Colors represent countries carrying out the surveys.*

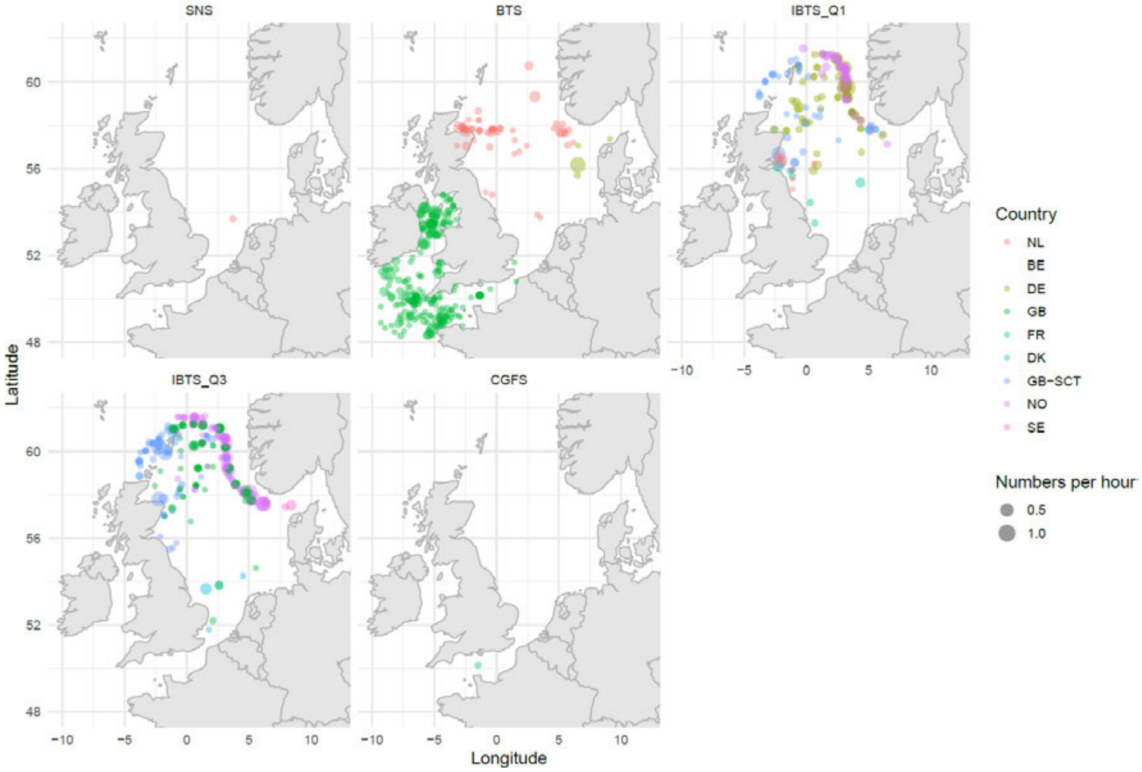


Figure 27 *Spatial distribution (mean CPUE, numbers per hour) of Rossia macrosoma recorded in North Sea and eastern English Channel surveys (IBTS Q1, IBTS Q3, BTS, DYFS, SNS, and CGFS). Colors represent countries carrying out the surveys.*

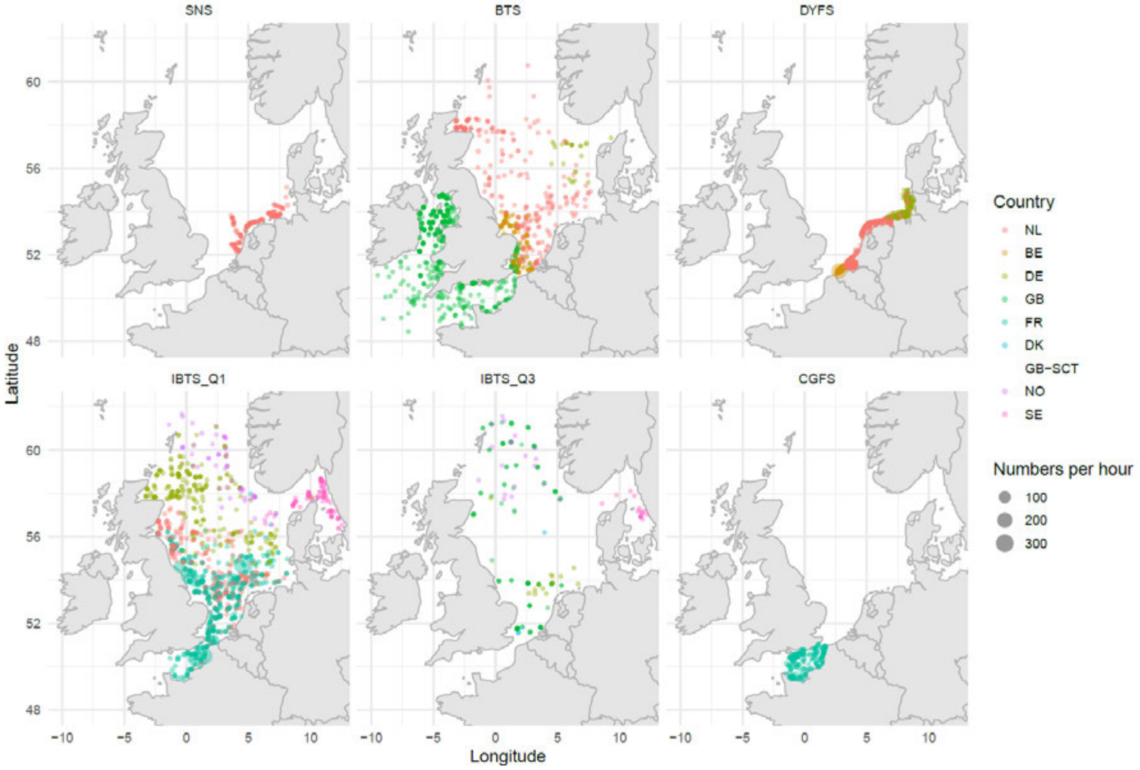


Figure 28 *Spatial distribution (mean CPUE, numbers per hour) of Sepiolidae (excluding Rossia macrosoma) recorded in North Sea and eastern English Channel surveys (IBTS Q1, IBTS Q3, BTS, DYFS, SNS, and CGFS). Colors represent countries carrying out the surveys.*

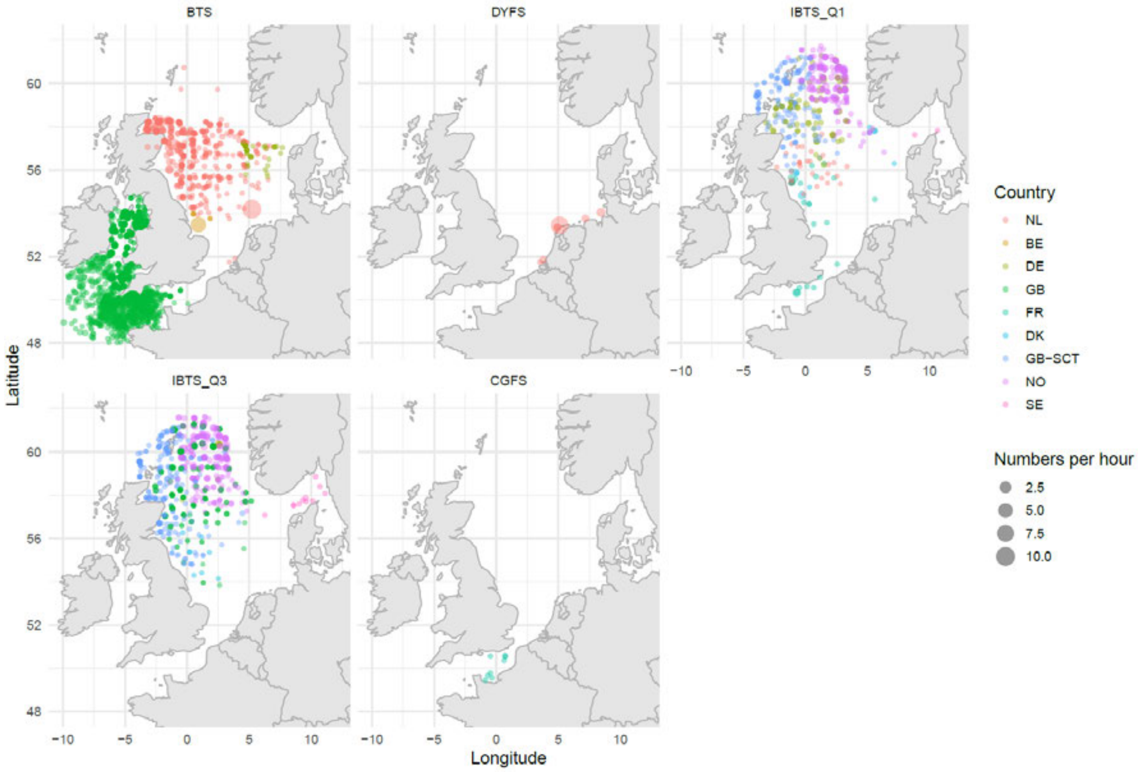


Figure 29 *Spatial distribution (mean CPUE, numbers per hour) of Eledone cirrhosa recorded in North Sea and eastern English Channel surveys (IBTS Q1, IBTS Q3, BTS, DYFS, SNS, and CGFS). Colors represent countries carrying out the surveys.*

4.2.5 D1C5 - Habitat requirements

For fish, the criterion on habitat requirements applies specifically to migratory species, for which barriers in migration routes pose a threat to the population (Mariene strategie (deel 2), 2020). Cephalopods in the GNSE are all fully marine or capable of inhabiting brackish, estuarine environments, meaning barriers to their migration are considered negligible. However, distinct habitat requirements may apply to (certain life stages of) cephalopods, in which case they are listed below. Here, we summarise broader knowledge on habitat requirements and preferences and potential impact of human activities per species (group). Section 4.4 provides a full summary of scientific literature by species, which includes references.

4.2.5.1 Loliginidae – *Alloteuthis media*

A. media is a demersal species inhabiting shallow coastal waters and continental shelf areas, typically between 10 and 150 meters depth. It is often associated with sandy or muddy substrates that support abundant benthic and pelagic prey. The eggs of *A. media* are attached to solid substrates such as rocks, shells, or other firm materials. It’s possible that man-made hard substrates, such as scour protection, increases availability of egg laying sites.

Rising sea temperatures have likely enabled overwintering in the North Sea and expanded the species’ tolerable habitat range, facilitating its spread northward and westward.

4.2.5.2 Loliginidae – *Loligo vulgaris*

L. vulgaris deposits its eggs on various substrates, but likely prefer rocks, vegetation, or hard objects. It’s possible that man-made hard substrates, such as scour protection, increases availability of egg laying sites.

Temperature strongly influences the reproductive ecology and distribution of *L. vulgaris*. While warming due to climate change may exceed optimal limits in southern areas, it creates new suitable conditions in northern waters. Embryos and early life stages, however, remain sensitive to elevated temperature and ocean acidification, which can reduce survival and cause developmental abnormalities.

Artificial sound, such as pile-driving or shipping, could potentially impact the migration, reproduction, and feeding of the species.

4.2.5.3 Loliginidae – *Loligo forbesii*

L. forbesii generally inhabits deeper waters than *L. vulgaris,* on the outer shelf and in shelf-edge waters. Egg masses of *L. forbesii* are attached to fixed substrates such as macrophytes, shells, rocks, ropes, or fishing gear, often in shallow coastal zones. It's possible that man-made hard substrates, such as scour protection, increases availability of egg laying sites.

During winter, the species' distribution is closely associated with sea-bottom temperature (SBT), salinity, and depth. Warming sea-surface and bottom temperatures are thought to have reduced thermal barriers and facilitated northward and westward expansions, into the North Sea. Climate-driven shifts in phenology and habitat use highlight *L. forbesii*'s adaptability to changing environmental conditions.

4.2.5.4 Ommastrephidae - *Illex coindetii*

I. coindetii is typically found on the continental shelf and upper slope at depths ranging from 100-800 m and inhabits muddy, sandy, and debris-rich substrates, often associated with *Funicula* spp. (sea pens). The species is commonly found in association with various demersal crustaceans and fish, particularly the deep-water rose shrimp (*Parapenaeus longirostris*), European hake (*Merluccius merluccius*), and blue whiting (*Micromesistius poutassou*). Its occurrence is more linked to depth than to temperature and salinity. Eggs are laid pelagically in buoyant gelatinous spheres.

Its growing presence in the North Sea, and evidence for local spawning, suggest that climatic and oceanographic changes may be facilitating its expansion eastward and northward.

4.2.5.5 Ommastrephidae – *Todarodes sagittatus*

T. sagittatus is widely distributed, and the species inhabits open ocean and coastal environments, extending from the surface to near-bottom depths of up to 2500 m. Abundance increases significantly with depth. Eggs are laid pelagically in buoyant gelatinous spheres.

Although the species' occurrence in the North Sea has historically been seasonal, recent studies indicate that its presence has become more regular in recent years. This trend may reflect changes in oceanographic conditions, such as increased Atlantic inflow and rising sea temperatures, which could facilitate the northward and eastward expansion of suitable habitat for this highly migratory species.

4.2.5.6 Ommastrephidae – *Todaropsis eblanae*

T. eblanae inhabits sandy and muddy substrates, typically inhabiting depths between 20 and 780 m. Eggs are laid pelagically in buoyant gelatinous spheres.

T. eblanae tolerates a broad range of hydrographic conditions, but its occurrence is strongly shaped by depth and salinity gradients. Its increased abundance in the North Sea has been linked to ongoing climate-driven warming trends and northward shifts in suitable habitat.

4.2.5.7 Sepiidae – *Sepia officinalis*

S. officinalis inhabits shallow coastal and shelf waters, typically between 10 and 200 m depth, but most reproductive activity occurs around 10 m, where eggs are attached to hard substrates such as sea fans, tubeworms, plants, or artificial structures. It's possible that man-made hard substrates, such as scour protection, increases availability of egg laying sites, though only in coastal areas (< 10 m).

Climate change is expected to alter the phenology and distribution of *S. officinalis* rather than cause major range contractions.

Artificial sound, such as pile-driving or shipping, could potentially impact the migration, reproduction, and feeding of the species.

4.2.5.8 Sepiidae – *Rhombosepion elegans*

R. elegans is a sublittoral species typically found on sandy or sandy–muddy bottoms from shallow coastal waters to depths approaching 450 metres. The species tolerates moderate fluctuations in salinity. Eggs are attached to hard substrates such as sea fans, tubeworms, plants, or artificial structures. It's possible that man-made hard substrates, such as scour protection, increases availability of egg laying sites.

Model projections indicate minimal reductions in habitat suitability under future climate scenarios. The species is expected to maintain, and in some cases expand, suitable habitats at higher latitudes and greater depths.

4.2.5.9 Sepiolidae – *Rossia macrosoma*

The species typically inhabits sandy and muddy substrates from depths of about 30 to 600 m, generally preferring deeper waters in winter but ascending to shallower habitats during the spawning season. Females attach their eggs to hard substrates such as rock crevices or beneath overhangs. It's possible that man-made hard substrates, such as scour protection, increases availability of egg laying sites.

Owing to its wide bathymetric range and capacity to occupy deeper, cooler habitats, *R. macrosoma* is expected to be less affected by ocean warming than more strictly shelf-dwelling cephalopods. Recent records of its permanent occurrence in the North Sea suggest that rising temperatures may have facilitated the northward expansion or stabilization of populations previously occurring only seasonally.

4.2.5.10 Sepiolidae – *Sepietta oweniana*

S. oweniana inhabits sandy and muddy bottoms across a wide depth range from 20 m to more than 1000 m, although it is most commonly found between 50 and 300 m in the Northeast Atlantic. The species prefers soft, muddy substrates and is frequently associated with *Rondeletiola minor* and Norway lobster (*Nephrops norvegicus*) grounds. Its salinity tolerance is lower than other Sepiolidae. Eggs are deposited on various solid substrates. It's possible that man-made hard substrates, such as scour protection, increases availability of egg laying sites.

Owing to its wide distribution and bathymetric plasticity, *S. oweniana* shows moderate resilience to climate-driven ocean warming. The expansion of stable populations in the North Sea and its persistence in both deep and shallow habitats indicate adaptability to environmental shifts. However, its relatively narrow salinity tolerance and reliance on oxygen-rich benthic habitats may limit its resilience in areas affected by deoxygenation or altered circulation.

4.2.5.11 Sepiolidae – *Sepiola atlantica*

S. atlantica inhabits the continental shelf and extends to the upper slope, generally between 6 and 150 m depth. It prefers clean sandy bottoms and is mainly epibenthic. The species is stenohaline, being absent from brackish or highly variable salinity environments. Eggs are laid singly but clustered together on hard substrates such as hydroids and bryozoans. It's possible that man-made hard substrates, such as scour protection, increases availability of egg laying sites.

Bottom temperature increases linked to climate change may alter reproductive timing and spatial distribution, potentially pushing populations northward or to deeper waters. It's possible that man-made hard substrates, such as scour protection, increases availability of egg laying sites.

4.2.5.12 Eledonidae – *Eledone cirrhosa*

E. cirrhosa is a soft-bottom, eurybathic species, inhabiting continental shelf and slope regions at depths ranging from the shallow sublittoral down to 700–800 m. Most populations, however, occur between 50 and 300 m. Females aggregate on bathyal hard substrates suitable for egg attachment. It's possible that man-made hard substrates, such as scour protection, increases availability of egg laying sites as well as habitat for older individuals.

4.2.6 D1C6 - Pelagic habitat requirements

D1C6, on pelagic habitat requirements, looks at the planktonic community and is not specifically applicable to cephalopods. For each species (group), we summarise available knowledge on the relationship between their ecology and the planktonic community in Section 4.4. Many cephalopod species have a planktonic paralarval life stage and can thus be considered part of the planktonic community (Roper & Jereb, 2010).

Ottman et al. (2024) show that high cephalopod abundance is strongly influenced by zooplankton productivity, more so than temperature and depth, resulting in highly productive areas for cephalopods in upwelling zones, especially Ommastrephidae and Loliginidae. It is therefore likely that changes in the planktonic community may have (indirect) effects on the abundance (D1C2) and distribution (D1C4) of cephalopods.

4.2.7 Alternative data sources

Besides data from (international) trawl surveys obtained from DATRAS, we also explored alternative data sources to assess data quality and prevalence of cephalopods. This included non-trawl surveys, small national surveys and data from citizen science platform ‘Waarneming.nl’. Ichthyoplankton surveys are discussed under Section 4.3.3.

4.2.7.1 Acoustic surveys

Acoustic surveys employ echosounders to determine the size of (pelagic) fish schools, where fishing occurs opportunistically to study the composition of the schools. These surveys are designed to provide information on abundance of the target species (e.g. blue whiting or herring). Currently, there are no pelagic surveys specifically targeting cephalopods in Europe. Due to their lack of swim bladders, cephalopods are weakly scattering objects on the survey equipment. This poses a challenge for acoustic surveys aimed at yielding good estimates of abundance for cephalopods, though previous work has shown it’s possible to define the acoustic signature of cephalopods (Goss et al., 2001; Zhang et al., 2015). There is also a lack of knowledge on schooling and migration of cephalopods in the GNSE to design such a survey. Existing acoustic surveys for pelagic fish do catch cephalopods. However, the non-random sampling design makes these data mostly unsuitable to derive indices of abundance. Furthermore, many countries do not submit their data on cephalopods to ICES’ acoustic survey data portal.

To assess if current acoustic surveys can be used to assess abundance of cephalopods, a case study is needed, focusing on a species that has good spatial and temporal overlap with an existing acoustic survey, and for which schooling and migratory behaviour is relatively well understood. For this, the Loliginid squids, *L. vulgaris* and *L. forbesii* may be good candidates, though information on the less studied Ommastrephid squid would be more useful, given that these are not as well sampled by trawl surveys. This should also take diurnal (day-night) migrations into account. Survey data should be explored to test if the acoustic signature of these aggregations can be identified. A collaboration with the fishing industry could provide valuable additional data, as pelagic freezer trawlers employ similar equipment.

Acoustic survey data could also potentially be used to identify distribution of cephalopods, especially pelagic species (Ommastrephid squids), though further data exploration, preferably in collaboration with the ICES Working Group on International Pelagic Surveys (WGIPS), is needed. This presence/absence information could be used for the calculation of indicators under D1C4.

4.2.7.2 Small national surveys

We explored data from four small national surveys to assess whether these can be used to quantify abundance of cephalopod species (groups). Results showed that the EAV only reported landings of Sepiolidae nei in two years (2019 and 2022) and that no other cephalopods were reported. Therefore, results for this survey are not discussed further. Cephalopods are rare in the NIOZ fyke monitoring, but given the high temporal resolution, aggregated data may be used to assess long-term local trends in local abundance. Data from this survey were not available at the time of writing.

The WADVIS survey may provide some information on *A. media*. The WAV survey may provide information on *A. media* and Sepiolidae (nei) (Figure 30). For Loliginidae and *S. officinalis/Sepia spp.*, the desired taxonomic resolution is often not achieved, making the data less useful. It may be assumed that individuals reported at the genus level (*Sepia* spp.) belong to *S. officinalis,* given the depth preference of other Sepiid species. Though these surveys may provide information on local abundance of some cephalopods, it is not advisable to use these to assess the status of entire stocks/populations, especially since not much is known about the relative importance of these areas for the overall populations. However, the surveys could potentially be used in combination with other surveys in a modelled index of abundance. The weight given to these surveys in such models would likely be very small due to the small area in which sampling occurred and very limited number of individuals sampled. Due to the small area sampled by these surveys, they cannot be used to inform on D1C4 (Distributional range and pattern).

Table 9 *Occurrence (percentage of hauls reporting species (group)) in two small national surveys: the WADVIS survey, running from 2019 to 2024, and WAV survey, running from 2007 to 2024.*

Survey	Year	Sepiolidae nei	A. media	L. forbesii	L. vulgaris	Loliginidae nei	S. officinalis	Sepia spp.
WADVIS	2019		7%		1.4%	2.8%		
	2020							
	2021		8.5%					
	2022	1.4%	8.5%		1.4%			
	2023		1.4%					
	2024	4.2%	7%			4.2%		
WAV	2007						3.6%	
	2008							
	2009							
	2011					4.3%	17.4%	
	2012	3.4%		6.9%				
	2013	12%		4%				
	2014	9.1%						
	2015							
	2016					6.7%		
	2017	3.3%				3.3%		3.3%
	2018	10%				3.3%	3.3%	
	2019	21.2%				12.1%		9.1%
	2020	25%				18.8%	31.2%	
	2021	10.7%	3.6%					3.6%
	2022	28.1%	3.1%				6.2%	
	2023	16.1%	6.5%				3.2%	
	2024	6.9%	10.3%					
	2025	11.8%					17.6%	

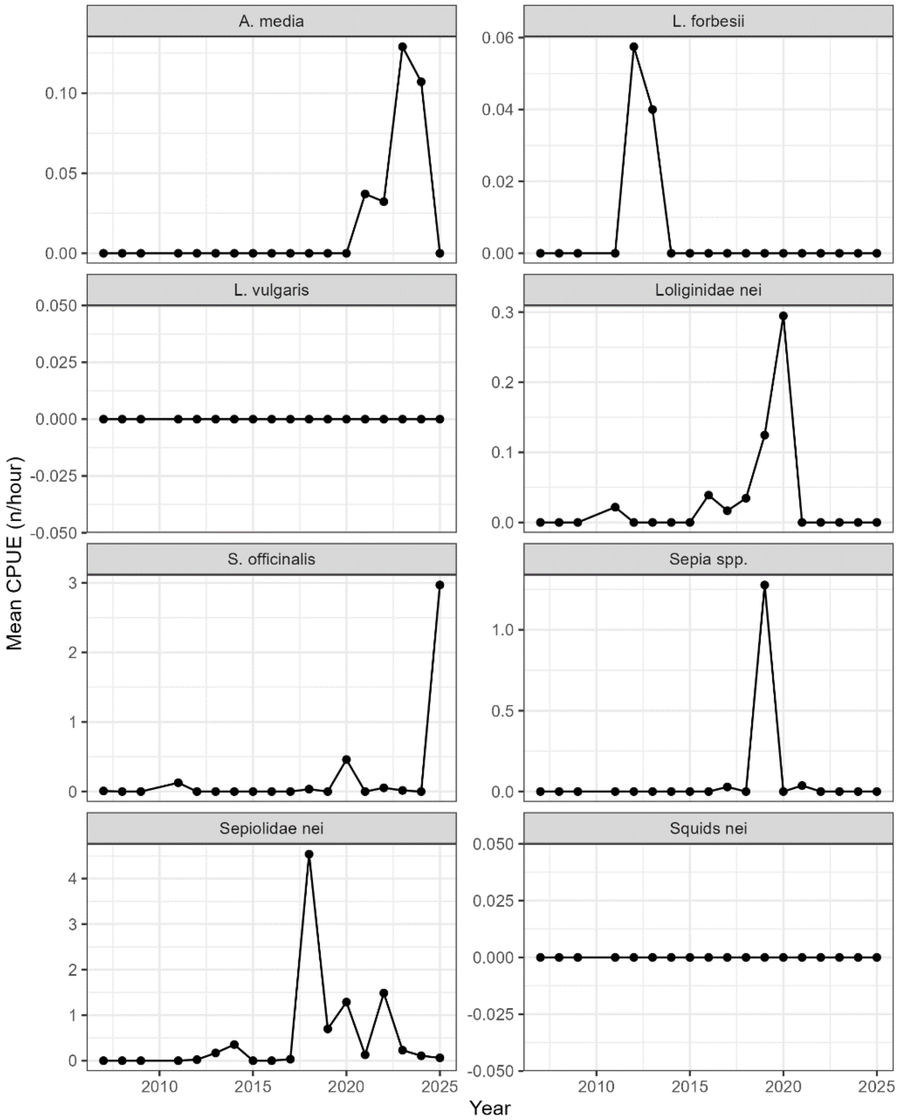


Figure 30 *Mean CPUE (numbers/hour) for species (groups) in the WAV survey.*

4.2.7.3 Citizen science platform

In addition to conventional survey data, we explored the potential of alternative, publicly available data sources for the assessment of Descriptor 1 (D1) indicators related to cephalopods. Specifically, we examined the citizen science platform Waarneming.nl and its international counterpart GBIF (Global Biodiversity Information Facility). These platforms contain opportunistic observation records submitted by the public, which could theoretically contribute to assessing the abundance and distribution of marine taxa. However, several methodological and biological challenges limit their suitability for cephalopods.

A range of statistical and modelling approaches have been developed to extract quantitative information from citizen science data. We reviewed the following commonly applied methods:

- Occupancy/detection-based models: Estimate the proportion of sites occupied by a species while accounting for imperfect detection.
- Species distribution models (SDMs) such as MAXENT: Use presence-only data to estimate environmental suitability and potential distribution.
- Effort-corrected abundance indices: Incorporate measures of observer effort to standardize observation rates.
- N-mixture models and other hierarchical count models: Estimate abundance from repeated count data while accounting for detection probability.
- Bias-correction or background-sampling techniques: Used to reduce spatial or temporal sampling bias in presence-only SDMs.

Despite these methodological options, several characteristics of cephalopod observation data render citizen science platforms poorly suited for robust abundance or distribution assessments:

1. Non-representative observation sources: Most cephalopod observations submitted to platforms such as Waarneming.nl originate from strandings of eggs or dead individuals rather than live animals at sea. Consequently, the reported locations do not reflect the actual spatial distribution of populations, but rather the areas where oceanographic and meteorological conditions cause strandings.
2. Unreliable abundance signals: The number of stranded cephalopods is not indicative of true population size. Increased strandings may instead reflect higher mortality, for example due to storm events, post-spawning die-off, or changes in current patterns. Thus, temporal variation in reported observations may reflect environmental variability rather than population trends.
3. Taxonomic uncertainty: A visual inspection of records on Waarneming.nl revealed frequent misidentifications. For instance, specimens of the genus *Loligo* spp*.* were often reported as *T. sagittatus*, and small *Loligo* spp*.* individuals were misclassified as *A. subulata*. Such errors further compromise data reliability for quantitative assessments.
4. Environmental and observational biases: For certain species, such as *S. officinalis*, indices based on stranded shells could provide limited information on stock size. However, these data are heavily influenced by weather conditions, observer distribution, and reporting effort, which are difficult or impossible to correct for adequately.
5. Lack of standardization and verification: Citizen science data are inherently irregular, opportunistic, and unverified. Without standardized sampling protocols or expert validation, such datasets are unsuitable as the primary basis for assessing environmental status.

While general citizen science platforms can offer qualitative insights into cephalopod presence or unusual events (e.g., mass strandings), they are largely unsuitable for quantitative assessment of abundance or population trends. The spatial, temporal, and taxonomic biases inherent in these datasets—combined with the biology of cephalopods and the nature of their observation records—limit their reliability for D1 indicator evaluation. Citizen science may be very valuable for Descriptor 2 of the MSFD, focusing on non-indigenous species.

In addition to the broader citizen-science platform Waarneming.nl, we assessed information summarized by Stichting Anemoon from observations logged during recreational dives (Van der Loos & Gmelig Meyling, 2019). The design of this data collection addresses several of the methodological limitations noted above. Firstly, these observations are made in-situ, meaning they inform about actual distributions of species (groups), as opposed to strandings. Furthermore, sampling is separated into multiple standard locations (MOO locations), such as wreck sites, that can be visited by divers. Other locations may also be visited by divers. Sampling effort can be more easily standardized by the number of dives per site. Given that the length of dives falls in relatively similar orders of magnitude due to practical limitations, this provides a more standardized measure of sampling effort. Divers also log absence of species (groups) that they actively monitored for, which provides important information needed to calculate abundances. The form divers fill in contains 172 species (as of 2017), including 4 cephalopod species: *S. officinalis, Alloteuthis* spp*., Loligo* spp*.,* and *Sepiola atlantica*. Kalman filters are applied to test if significant interannual trends in mean abundance can be observed. Because the most visited locations are in the Eastern Scheldt and Lake Grevelingen, data availability to determine mean abundance and trends was higher here than North Sea locations.

The results showed that abundance of *S. officinalis* decreased significantly in the Eastern Scheldt in the period 1994-2018 but has remained stable in the most recent 10 years of the monitored period. A seasonal pattern was observed, with adults mainly occurring in the delta in spring and juveniles in late summer. Abundance of *S. atlantica* in Lake Grevelingen remained stable in the period 1994-2018. Limited observations of *Alloteuthis* spp*.* and *Loligo* spp*.* meant trends could not be determined with certainty. However, it is clear that both species mainly occur in the Zeeland delta in April-May.

These results show that even with in situ observations and a good quantification of sampling effort, incidence of most cephalopods, except for local populations of *S. officinalis* and *S. atlantica,* is low. Although this information can be used to assess trends locally, they should not be extrapolated to the total population. Conventional survey data or dedicated monitoring programs remain essential for robust assessments of cephalopod status.

4.3 Descriptor 3: Commercially exploited fish and shellfish

For species of high commercial interest, indicators were proposed to assess their environmental status under D3 (Commercially exploited fish and shellfish). In this section, we discuss data availability to calculate these indicators and identify species (groups) that are commercially exploited and should be assessed under D3.

4.3.1 D3C1 - Harvest rate (fishing mortality)

Besides indicators derived from stock assessments discussed in section 4.3.1.4, the main proposed indicator for D3C1 Harvest rate is the yield (or catch weight) over the catch-per-unit-effort (Y/CPUE). Here, CPUE serves as a relative index of stock size in absence of high-quality, high-resolution abundance estimates from surveys. In other words, the indicator expresses in relative terms what portion of a population is removed through fishing and can be used to compare multiyear (or even within-year) variations in fishing pressure. For this, data on landings of cephalopods is needed at the appropriate temporal and taxonomic scale. Other indicators proposed for D3C1 depend on the development of analytical stock assessments and their data requirements are discussed in section 4.3.1.4.

4.3.1.1 Landings

Table 10 provides an overview of Dutch logbook-reported landings of cephalopods, and which 3-alpha code is used by fishers, in the period 2020-2024. From this, we can see that high landings of *S. officinalis* (CTC) were reported by vessels using OTB, SSC and TBB gear in each year. It is very likely that these are correct identifications of *S. officinalis*, given that the other cuttlefish species, *R. elegans*, is not found in the eastern English Channel and southern North Sea (Section 4.2.4). Both octopus species, *E. cirrhosa* and *O. vulgaris*, were reported in small amounts, mainly by vessels with metier TBB. Given the small amounts of landings of octopus, and the lack of a significant (targeted) octopus fishery by Dutch vessels, no D3 indicators can be calculated. It cannot be confirmed whether these landings were correctly identified. For squid, several codes are used that may not correspond to the taxonomy of the landed species, as was also reported by Brunel et al. (2025). Most squid in the landings is reported as *L. vulgaris*. However, on vessels or at fish auctions, squid is not identified to species level. It's possible that other species, mainly *L. forbesii*, but also Ommastrephid squid such as *I. coindetii*, are reported under this 3-alpha code (SQR). Historically, SQS, which represents a southern hemisphere squid species, was used erroneously by skippers in the demersal fleet, due to a naming issue in the digital logbook system. This issue was fixed in 2023 and from 2024 onwards, SQS is no longer used. It can be assumed that these landings belong to the same species (groups) as the landings reported as SQR by the same fleet segments. For the Ommastrephid squids, *I. illicebrosus* (SQI), *I. coindetti* (SQM) and *T. sagittatus* (SQE), it is not known whether these are correct identifications, misidentifications within the family or even misidentifications of Loliginid squids. However, given the relatively small landed amounts, lack of a targeted fishery and sporadic nature of reporting, it is unlikely that a meaningful indicator of fishing mortality can be calculated for these species.

The spatial distributions of landings (Figure 31***Figure***) shows that *E. cirrhosa* (EOI) was mainly reported in small amounts in the central North Sea, near Denmark. *O. vulgaris* (OCC) was mainly reported from the western English Channel, through the eastern English Channel and southern North Sea, with higher concentrations in the central North Sea. Given the southerly distribution of *O. vulgaris*, it is likely that these northern landings reported as OCC are actually *E. cirrhosa*. SQE, the 3-alpha code for *T. sagittatus*, was mainly reported in the eastern part of the North Sea. *T. sagittatus* is an oceanic species which occurs sporadically in the northwestern North Sea, making it unlikely that these landings belong to this species. SQM is the 3-alpha code for *I. illecebrosus*. This is a western Atlantic species that may occur as far east as the West of Ireland and the UK. However, it is more likely that these catches belong to *I. coindetii*, or another species of squid, especially the landings reported in the North Sea. SQM, or *I. coindetii*, was mostly reported in 6.a (West of Scotland), and in the Channel-North Sea boundary. *I. coindetii* is the most common short-finned squid in the North Sea. However, given the distribution of the stock, it is unlikely that these landings in 7.d and 4.c are actually *I. coindetii*, rather than a misregistration of *Loligo* spp.. Both SQR and SQS have been used for the demersal targeted fishery in the Channel and North Sea, which is mostly for *L. vulgaris*. *L. forbesii* (for which the 3-alpha code, SQF, was not used in logbooks) overlaps with *L. vulgaris* but occurs mainly in deeper, colder waters. It is likely that SQR landings west of Ireland, in the western English Channel and northern North Sea belong *to L. forbesii*. However, these codes may also be used for any other (long- or short-finned) squid. The 3-alpha code SQU, representing various Loliginid and Ommastrephid squids, was only used West of Scotland.

Table 10 *Dutch landings (kg) of cephalopods by metier (level 4) and 3-alpha code, for the years 2020-2024. Obtained from logbooks. 3-alpha codes represent S. officinalis (CTC), E. cirrhosa (EOI), O. vulgaris (OCC), T. sagittatus (SQE), I. illecebrosus (SQI), I. coindetii (SQM), Loligo vulgaris (SQR), Martialia hyadesi (SQS, incorrectly assigned) and Various squids NEI (SQU).*

Metier level 4	Year	CTC	EOI	OCC	SQE	SQI	SQM	SQR	SQS	SQU
OTB	2020	4,500			424	129		46,002	50,111	
	2021	1,144		7				113,469	15,264	
	2022	24,716			55			289,114	54,033	
	2023	8,623	5	8	490			567,751	33,109	
	2024	15,435		5	2,437			791,248		
OTM	2020					195		16,431		
	2021					2,638	8,320	14,862		
	2022						6,969	65,474		
	2023						5,182	31,541		23,713
	2024						2,829	42,681		16,606
OTT	2020							6,655	4,176	
	2021							1,081	85	
	2022							570	36	
	2023	222			530			2,654	125	
	2024	75				53		4,408		
QUA*	2020							5,435	338	
	2021	17						1,768	50	
	2022			2				467		
	2023	5						2,959	103	
	2024	34						1,335		
SSC	2020	336,479		314	38	863		775,577	98,597	
	2021	299,229		143	203			581,545	69,727	
	2022	729,251		112	2,080			1,057,437	101,414	
	2023	593,942		79	25			1,340,905	48,292	
	2024	634,914		77				1,200,306		
TBB	2020	327,970	639	870	8,314	230		100,738	11,712	
	2021	216,097	1,709	1,062	2,248			48,978	5,079	
	2022	266,113	46	289	2,627			95,818	10,126	
	2023	403,421	14	5	440			130,786	11,432	
	2024	512,874		3	34	10		116,319	16	

*Not an official FAO metier. Quadrig bottom otter trawl. Corresponding FAO metier would be OTP (Multiple bottom otter trawls).

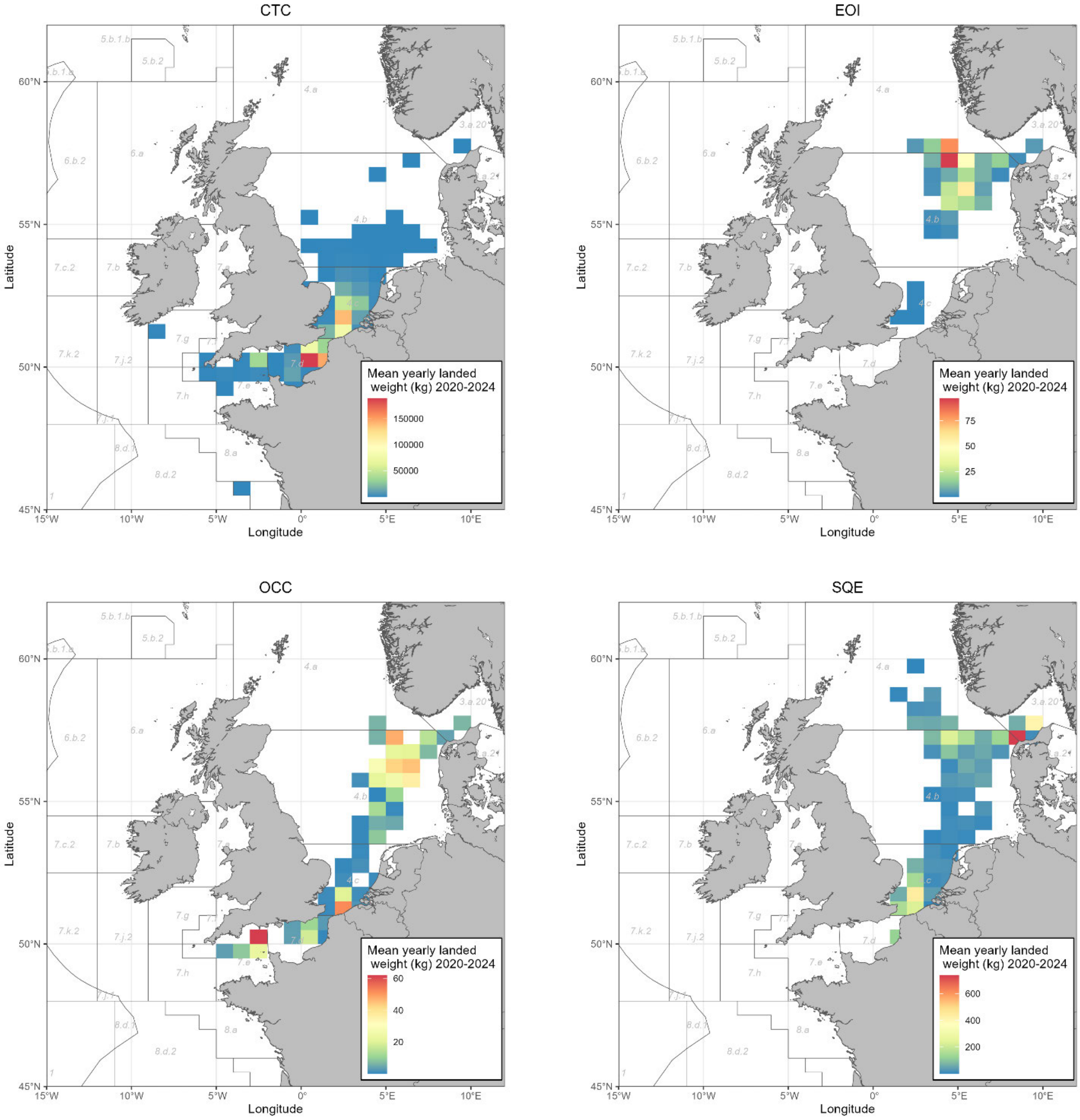


Figure 31 *Map of Dutch mean annual landings of cephalopods per 3-alpha code by ICES rectangle, in the period 2020-2024. Obtained from logbooks. 3-alpha codes represent S. officinalis (CTC), E. cirrhosa (EOI), O. vulgaris (OCC) and T. sagittatus (SQE).*

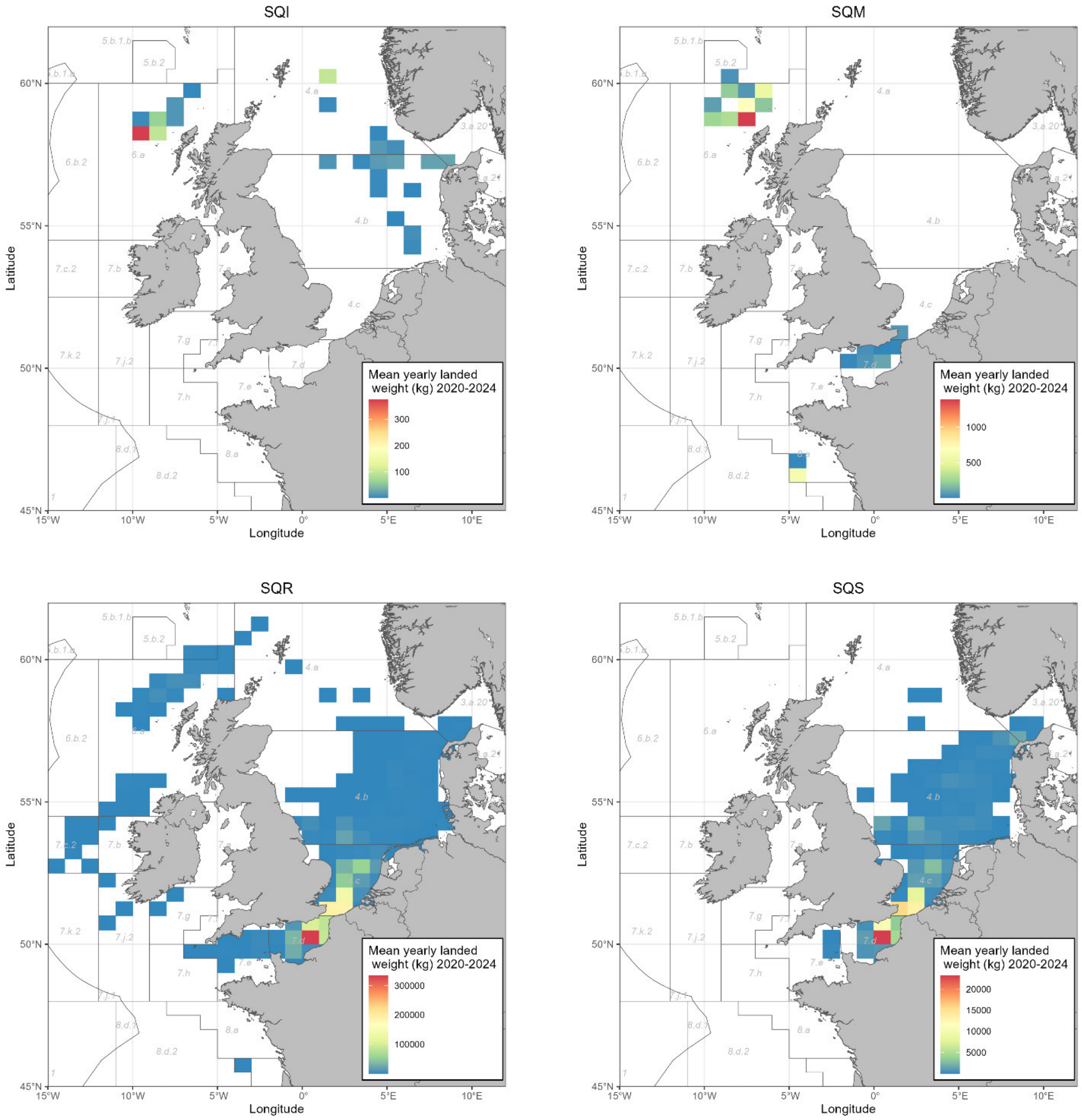


Figure 31 (continued) *Map of Dutch mean annual landings of cephalopods per 3-alpha code by ICES rectangle, in the period 2020-2024. Obtained from logbooks. 3-alpha codes represent I. illecebrosus (SQI), I. coindetii (SQM), Loligo vulgaris (SQR) and Martialia hyadesi (SQS, incorrectly assigned).*

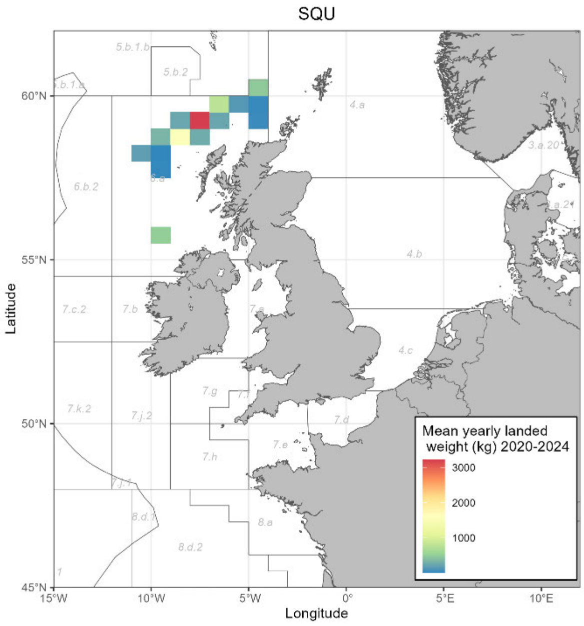


Figure 31 (continued) *Map of Dutch mean annual landings of cephalopods per 3-alpha code by ICES rectangle, in the period 2020-2024. Obtained from logbooks. 3-alpha code represent Various squids NEI (SQU).*

A novel market sampling program for squid that was set up in 2024 has provided strong suggestions that the (Loliginid) squid landings of the demersal fleet (OTB, SSC, and TBB) in the southern North Sea (4.c) and eastern English Channel (7.d) belong exclusively to *L. vulgaris*, as out of 1469 squid sampled from Dutch fish auctions between October 2024 and April 2025, all were *L. vulgaris*. This fishery represents the majority of squid landings reported as SQR and SQS. However, more sampling is needed, especially further West in the English Channel, to confirm this. Data from market sampling can also be used to convert landings reported in weight to numbers, which may aid in the development of (generalized) depletion models.

For cephalopods of high commercial interest, *S. officinalis* and Loliginid squids (mainly *L. vulgaris*), more intensive sampling at fish auctions can provide taxonomic certainty. For this, sampling should focus on the targeted fishery in the main fishing areas and seasons. The TBB metier is the only one with significant squid landings from non-targeted bycatch. The majority of cephalopods was landed in a small number of ICES rectangles. For all squids (regardless of 3-alpha code used in the logbooks), the eastern English Channel and southern North Sea represented 92.1% of all landings in 2020-2024, with 56.4% coming from just four rectangles. For cuttlefish, this was 95.3% of all Dutch landings and 54.3% came from just three ICES rectangles. Sampling should focus on these areas, as these represent the only targeted cephalopod fishery by the Dutch fleet.

Furthermore, it would be useful to spread awareness among fishers on the use of 3-alpha codes, especially so easy identifications, for example distinguishing short- and long-finned squids (OMZ and SQZ), are registered in logbooks.

4.3.1.2 **Effort**

The proposed indicator of fishing mortality, as well as proposed analytical stock assessment methods from which indicators may be derived, are highly dependent on accurate information on fishing effort, as CPUE is used as a proxy for population abundance. Given the information in Table 10, the main fleets for which effort should be quantified are the demersal seine (SSC), beam trawl (TBB) and bottom otter trawl (OTB) fleets for Loliginid squids, and the Scottish seine and beam trawl fleets for *S. officinalis.* An important aspect of this is taking into account if and when vessels land cephalopods as target and as bycatch species. The beam trawl fleet can be assumed to only land squid and cuttlefish as bycatch when they fish for flatfish such as sole and plaice. Therefore, all fishing effort can be included in the calculation of a potential indicator. For the Scottish seine fisheries, squid and cuttlefish are among the most important target species, especially in late fall-early spring (Van de Pol et al., 2023). Given that these vessels fish with the same demersal seine gear throughout the year, it can be assumed that all fishing effort can be used for indicators. Vessels may move away from areas where cephalopods are often caught. Vessels targeting squid with bottom otter trawls switch to specific gears adapted to the squid fishery. This switch is not always clear from logbooks. For example, vessels may land Norway lobster and plaice in summer, registering their gear as OTB in logbooks, and switch to targeted squid fishery in fall, while still registering OTB gear. They may also interchangeably use other gear codes such as OTT or QUA. Brunel et al. (2025) explored the identification of the targeted squid fishery from the catch assemblage, and squid landings, or CPUE, are the best indicator for the switch to targeted squid fishing. Figure 32 shows two examples for vessels of reported gear use and squid landings by day. For the first, registered gear can be reliably used to identify squid-targeted fishing, in combination with the reported gear width, indicating the use of one or two nets. However, for the second, registered gear is not informative for this.

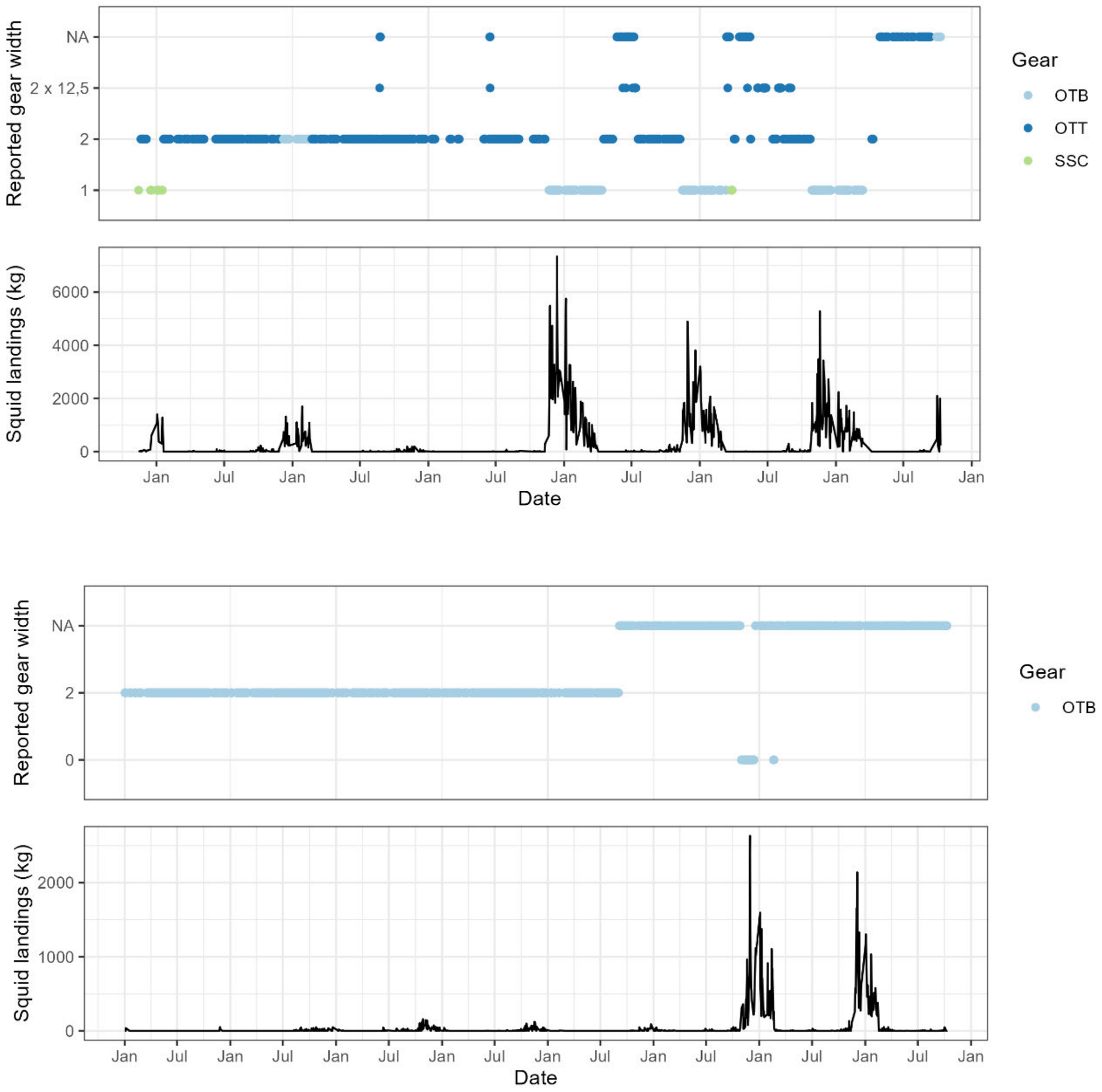


Figure 32 *Examples of logbook registrations for two vessels, illustrating that registered gear can sometimes be used to identify targeted squid fishing (top), but does not always provide enough information (bottom). Years are not shown and squid landings were multiplied by a random number between 0.5 and 1.5 for data privacy reasons.*

Besides accounting for changes in targeting behaviour, it is also important to take mesh size into account, as until 2025, mesh sizes between 40 and 80 mm are allowed when targeting squid (Brunel et al., 2025). To account for this, it would be recommended to divide the fleet into segments based on gear and mesh size (metier level 6). For Scottish seines, rope length is also an important variable determining catch efficiency. However, this is not consistently documented in logbooks.

We recommend that gear codes are used more consistently across the fleet, with single rig otter trawls (mainly used for cephalopods) being registered as OTB, paired rig otter trawls as OTT, and quad-rig otter trawls as QUA (or OTP). This would allow for easier identification of targeted squid fishing. We further recommend that vessels fishing with demersal seines register rope lengths consistently in the logbooks.

Indicators of harvest rates should be calculated at the appropriate temporal scale, taking into account the seasonal nature of the main cephalopod fisheries in The Netherlands. For example, for the targeted fishery of Loliginid squids, the targeted fishery lasts roughly from October until April (Brunel et al., 2025). Y/CPUE should thus be calculated only for these months, either at monthly timesteps or for the whole fishing season combined. The same applies to the fishery for *S. officinalis* in the English Channel, where the main fishing season is July-December (Carleton & Hintzen, 2023). Due to the international nature of both fisheries (they are targeted by vessels from the UK, France, Belgium, The Netherlands and Germany), the indicator is best calculated using data from all relevant countries.

4.3.1.3 Discards

As shown in section 4.2.1, discards of cephalopods are relatively rare and occur at low rates. This can be attributed to the lack of minimum conservation reference sizes and commercial interest in cephalopods of all sizes. When calculating indicators of fishing mortality for commercially valuable stocks, it can therefore be assumed that discards can be ignored.

4.3.1.4 Indicators from stock assessments

Besides Y/CPUE, several of the proposed indicators for Harvest rate (fishing mortality) are derived from analytical stock assessments, which are currently not available for advice for cephalopod species of commercial interest to The Netherlands. ICES provides guidelines for the assessment of data-limited stocks, classified as categories 2 and 3 (ICES, 2024b). This states that in case category 1 (full analytical age-based) assessments are not available, a category 2 SPiCT model is the preferred if data availability is adequate. For short-lived species, confidence intervals on B/B_{MSY} and F/F_{MSY} may be large, but this is not in itself a reason to reject an assessment. An important issue is that these models should only be accepted in case a realistic production curve is produced, which is unlikely given that the MSY approach may be unsuitable for short-lived, environmentally driven cephalopod stocks. The guidelines also state that the applicability of category 3 MSY advice is dependent on the Von Bertanlanffy growth parameter k. Growth rates of cephalopods almost always exceed the threshold value of $k = 0.45$, meaning category 3 MSY advice is not feasible.

The stock assessment methods proposed here have the advantage of also providing reference points and simultaneously producing indicators for D3C2 (spawning stock biomass). The data requirements vary for these methods.

The least data-intensive stock assessment methods are surplus production models, such as SPiCT (Pedersen & Berg, 2017), which only require data on absolute landings and an index of abundance, either from surveys or commercial CPUEs. These could be developed using the same data as the basic Y/CPUE indicator. Of the species of commercial interest to The Netherlands, SPiCT models are in development for the English Channel *S. officinalis* fishery that show promising results (Larivain et al., 2021). This could be extended to include the southern North Sea, or a separate model could be developed for this area given the evidence for several distinct subpopulations (Laptikhovsky et al., 2023). For Loliginid squids in the English Channel, a similar model is under development. However, this model does not make any distinctions between *L. vulgaris* and *L. forbesii* and does not include the southern North Sea Loliginid squid fishery.

Depletion models, that are more data intensive but also deemed more appropriate for cephalopod stocks, require landings and effort data at shorter time intervals (weekly or monthly), as well as information on individual sizes at similar intervals (Roa-Ureta et al., 2021). This would require more intensive data sharing between relevant countries as well as setting up more extensive sampling programs on the size composition of landings.

4.3.2 D3C2 - Spawning stock biomass

The proposed indicator for spawning stock biomass, catch-per-unit-effort (CPUE) of mature individuals, is dependent on much the same data as D3C1 (Harvest Rate). Section 4.3.1 explains in detail the available data on landings and effort and the associated issues. Furthermore, this indicator would require information on the maturity of landed individuals. Such data is being collected for Loliginid squids at Dutch fish auctions under the Dutch DCF program since 2024. Similar data would have to be collected by other countries as well as for other commercially targeted species (*S. officinalis*) and compiled. CPUE of mature individuals should only be calculated during the months in which mature individuals are present in significant numbers, likely towards the end of the fishing season. The determination of maturity for the CPUE indicator is important to determine whether individuals are able to reach sexual maturity before being harvested. An overall CPUE index does not provide information on this. As a less data-intensive alternative, CPUEs could be calculated only for the months where mature individuals are present.

4.3.2.1 Indicators from stock assessments

Like for D3C1 (Harvest rate), several indicators for spawning stock biomass were proposed that are derived from analytical stock assessments. Spawning stock biomass can be derived from surplus production models, which also provide reference points (MSY $B_{trigger}$), though the MSY approach is likely unsuitable for the dynamics of most cephalopod stocks (Roa-Ureta et al., 2021). Other proposed indicators of spawning stock biomass are derived from depletion models. The Falkland squid fishery is managed using such models, where an escapement biomass is calculated. This could be used as an indicator of the amount of individuals that live to the end of their life cycle (and the end of the fishing season) and have the chance to reproduce. It is important to note that reference points for escapement from depletion models are often arbitrary (Maunder & Piner, 2024). Data needs of these models are discussed in section 4.3.1.4.

4.3.3 D3C3 - Demographic characteristics (size and age distribution)

Indicators based on size and age distribution in the population are known to be problematic, even for more long-lived commercial fish species (ICES, 2024a). Of the D3C3 indicators proposed by ICES (2024a) for commercial fish species, most are not meaningful for short-lived, semelparous cephalopods: for example, the proportion of old individuals in a population is not a useful indicator due to life cycles often not exceeding one year. The plasticity of growth and maturity, with individuals maturing at very different sizes, possibly in response to environmental changes, means length- or weight-based indicators are also not informative. The only indicator proposed by ICES that was deemed suitable, was Recruitment.

Given the short life cycle of most cephalopods, recruitment can be seen as either the number of eggs and larvae produced, or the abundance of individuals recruiting to the fishery at the start of each season. The first approach could be derived from egg and larvae surveys that are conducted for recruitment indices of e.g. herring. These surveys also collect cephalopod larvae in small amounts, but these are currently not studied. Exploratory work is needed to determine to what extent these surveys can be used to derive indices of recruitment. Such trials have been carried out for plankton surveys (Collins et al., 2002). Egg and larvae surveys occur throughout the year in the GNSE (Figure 33). Suitability of these surveys is dependent on their location and timing, which has to match with the spawning of relevant cephalopod species.

The second approach, where recruitment is seen as the abundance of individuals recruiting to the fishery, can be derived from multiple sources. Firstly, scientific surveys could provide such information. However, for this the timing of the survey needs to align with the start of the fishing season. It is also unlikely that recruitment occurs in the exact same period every year given the natural fluctuations of cephalopod populations. Secondly, commercial CPUE data could be used, which offers a more flexible approach because it is irrespective of the timing of recruitment. This could include information on the size distribution of the population to assess whether landings constitute a new recruitment wave. Generalized depletion models can also be used to generate recruitment estimates (Roa-Ureta et al., 2021), with recruitment being the abundance at the start of the fishing season. It should be noted that for Loliginid squids, recruitment is often not a singular event but occurs in several pulses across the season. Generalized depletion models have also been developed that take this recruitment pattern into account (Roa-Ureta, 2012).

Due to the intrinsically fluctuating dynamics of many cephalopod stocks, strong variations in recruitment between years or seasons are expected. To account for this, multi-annual means should be compared to the long-term mean.

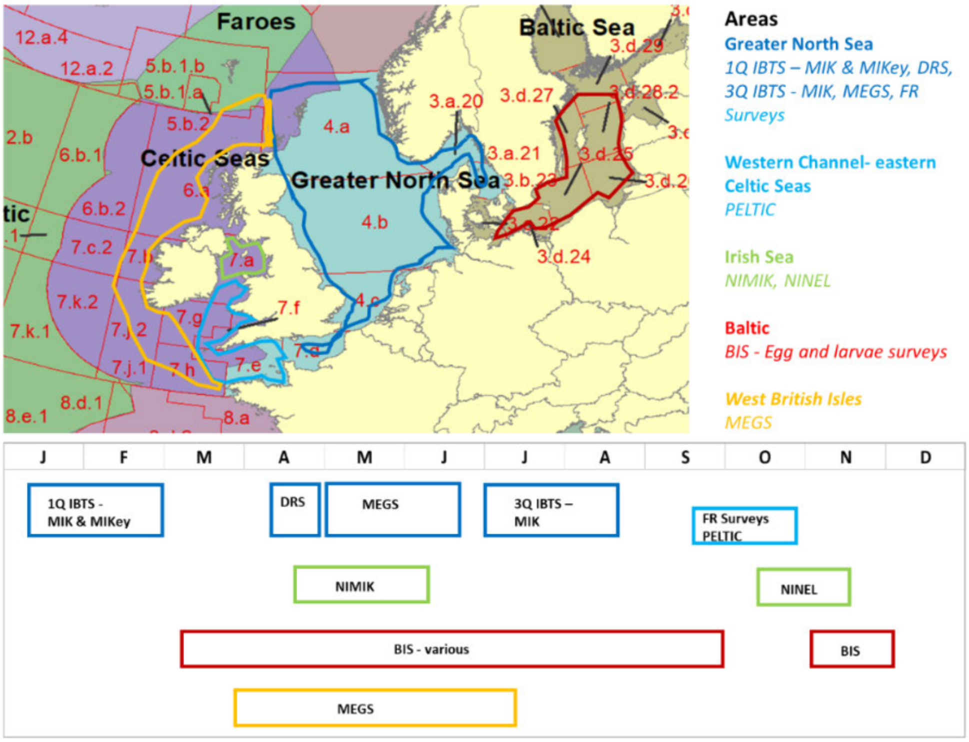


Figure 33 *Spatial and temporal distribution of ichthyoplankton surveys in the GNSE and adjacent waters (from ICES, 2025).*

4.4 Literature review

Results of the literature review on biology, ecology and knowledge on human impacts are given by species, grouped by family.

4.4.1 Loliginidae

4.4.1.1 *Alloteuthis media* (previously *Alloteuthis subulata*)

Alloteuthis media (Lamarck, 1798) is a neritic Loliginid squid widely distributed in the eastern Atlantic Ocean, extending from the northwest African coast northward through the Iberian Peninsula, Mediterranean, the Bay of Biscay, the English Channel, and the North Sea (Anderson et al., 2008; Hastie et al., 2013; Oesterwind et al., 2022). Although early studies referred to *Alloteuthis subulata* in the North Sea and adjacent waters, molecular analyses have demonstrated that all *Alloteuthis* individuals occurring in the North Sea belong to *A. media* (Laptikhovsky et al., 2005; Jereb et al., 2015a). Recent DNA-barcoding and integrative-taxonomy studies indicate that many historical North Sea records assigned to *A. subulata* should be reassigned to *A. media*, so explicit statement of the taxonomic name used by each cited study is essential when interpreting temporal trends (Anderson et al., 2008; Sheerin et al., 2023).

A. media is a demersal species inhabiting shallow coastal waters and continental shelf areas, typically between 10 and 150 meters depth. It prefers temperate to subtropical environments and is often associated with sandy or muddy substrates that support abundant benthic and pelagic prey (Hastie et al., 2013). The species is particularly common in regions with moderate water temperatures, such as the English Channel and the Irish Sea (Rodhouse et al., 1988; Nyegaard, 2001; Anderson et al., 2008; Hastie et al., 2013). Like many Loliginid squids, *A. media* exhibits marked seasonal movements between coastal and offshore habitats. Adults migrate inshore during spring and summer to spawn, while juveniles and some adults move to deeper, relatively warmer shelf waters in autumn and winter. In the North Sea, the species undertakes a seasonal migration, moving northward in winter and returning southward in summer (Oesterwind et al., 2010). Juveniles are often observed migrating from cooling coastal waters to deeper regions in autumn, before returning to coastal spawning grounds of southern Britain, Denmark, Germany, the Netherlands, and Belgium in spring (de Heij & Baayen, 1999).

Reproductive activity in *A. media* is prolonged and varies geographically. In the English Channel, three main spawning groups have been identified, corresponding to spring, summer, and autumn spawning periods (Laptikhovsky et al., 2002; Hastie et al., 2009). This reproductive pattern produces two major recruitment events each year, one in spring and another in summer (Rodhouse et al., 1988). In the Irish Sea, spawning is generally bimodal, with peaks in spring and summer and a possible minor spawning pulse in autumn (Nyegaard, 2001). The eggs of *A. media* are small, measuring up to 0.19 mm in diameter, and are attached to solid substrates such as rocks, shells, or other firm materials (Nyegaard, 2001). The incubation period is temperature-dependent, lasting approximately two to three weeks at 15–18 °C (Lipinski, 1985), and is extended under cooler conditions. In Scottish waters, hatching occurs mainly around May. Reported potential fecundity varies widely, ranging from 1,200 to 19,000 eggs per female, reflecting the influence of environmental factors and female size.

A. media is a short-lived species, with an average lifespan of around twelve months. Individuals that hatch between January and May often complete their life cycle within six months (Arkhipkin & Nekludova, 1993). Males generally mature earlier than females, and all males larger than approximately 110 mm mantle length are typically mature (Rodhouse et al., 1988). Females reach sexual maturity at a maximum size of about 120 mm mantle length (Yau, 1994; Jereb et al., 2010). The youngest mature males and females have been observed at approximately 125 days old, although some individuals may remain immature at 145–160 days. Temperature strongly influences growth and maturation rates in *A. media*. In warmer waters, the species exhibits faster growth, shorter incubation times, and an extended spawning season, leading to more complex population structures with overlapping generations (Hastie et al., 2009). Such temperature-driven plasticity in life history traits allows *A. media* to adapt effectively to variable environmental conditions.

Ocean warming has significantly influenced the distribution and life history of *A. media* in northern waters. Over the past few decades, the species has transitioned from a seasonal immigrant to a more permanent component of the North Sea cephalopod fauna (Oesterwind et al., 2022). Rising sea temperatures have likely enabled overwintering and expanded the species' tolerable habitat range, facilitating its spread northward and westward (van der Kooij et al., 2016). Temperature not only affects geographic distribution but also drives developmental timing, spawning duration, and recruitment patterns. Warmer waters reduce embryonic development time and accelerate juvenile growth, while cooler temperatures delay maturation and restrict spawning to warmer months. These changes highlight *A. media*'s sensitivity to environmental variability and its potential as an indicator species for climate-driven ecosystem shifts.

A. media plays an important ecological role in coastal and shelf ecosystems. It serves as both predator and prey within the marine food web, feeding primarily on small fish and crustaceans while being consumed by larger fish, marine mammals, and seabirds (Hastie et al., 2013). Its abundance and rapid life cycle make it a key intermediary species linking lower and higher trophic levels. From a fisheries perspective, *A. media* is often caught as bycatch in mixed demersal trawl fisheries, particularly in the North Sea, English Channel, and Irish Sea. Although it is not a primary target species, it contributes to the overall squid biomass landed by European fleets. Changes in *A. media* abundance, distribution, or reproductive timing—driven by either environmental change or fishing pressure—may therefore have cascading effects on regional food-web dynamics and fisheries productivity. Continued monitoring using molecular identification is recommended to distinguish *A. media* from related species and to improve our understanding of its ecological responses to a warming ocean.

4.4.1.2 *Loligo vulgaris* (European squid)

The European squid, *Loligo vulgaris* (Lamarck, 1798), is one of the most common neritic cephalopods in the Greater North Sea and Mediterranean coasts (Salman & Karakulak 2009; Rosa et al., 2013). Historically, the species has been recorded across a broad latitudinal gradient – from the English Channel and southern North Sea to Denmark, southern Sweden, the Kattegat, Skagerrak, and the western Baltic Sea (Grimpe 1925; Tinbergen and Verwey, 1946; de Heij & Baayen, 2005; van der Kooij et al., 2016). Its distribution extends southward throughout the Mediterranean and along the eastern Atlantic coast to Morocco, Mauritania, and Senegal, while extending northward to the waters off Ireland and Scotland, and occasionally to the Kattegat and southern Norway (Jereb et al., 2015). *L. forbesii* extends slightly father north to the Orkney Islands and central Norway (Jereb et al., 2015; Laptikhovsky et al., 2022). *L. vulgaris* actively feeds on fish and crustaceans, and its diet has been documented through stomach-contents studies in multiple regions (e.g., Northeast Atlantic, Iberian waters). Larger individuals show increased piscivory and cannibalism has also been reported (Pierce et al., 1994b; Rocha et al., 1993).

Based on early observations of distribution and morphology, *L. vulgaris* was historically divided into two spawning forms: a spring-summer form (*L. vulgaris typica*) occurring in the southern North Sea, and an autumn form (*L. vulgaris breviceps*) prevalent in the Kattegat and the Danish Sounds (Grimpe, 1925). Grimpe proposed that mature individuals migrate northward each year, reaching the French coast in April before entering the North Sea via the English Channel around mid-May. Spawning occurred primarily in the southern North Sea, with egg masses most abundant off the Dutch coast between May and August (Tinbergen & Verwey 1946). In contrast, the autumn form was hypothesized to migrate northward along the Irish and western Scottish coasts before entering the North Sea via the Faeroe Channel and Norwegian Trench, arriving in the Kattegat between July and October. Grimpe attributed the morphological distinctions between forms to age-related variation. Subsequent work by Tinbergen and Verwey (1946) supported the general migratory pattern but rejected the two-form hypothesis, proposing that all individuals belong to a single species migrating northward along the coastline. Juveniles and paralarvae are typically confined to or near spawning grounds, as egg masses and nursery habitats overlap spatially. The eastward flow of Channel and coastal waters likely aids the transport of early life stages from spawning areas (Laptikhovsky et al., 2022).

Modern observations confirm that *L. vulgaris* undertakes long-distance seasonal migrations, often exceeding 500 km (Jereb et al., 2015). Earlier assumptions that hatchlings migrated southward due to the absence of juveniles in the North Sea have since been refined by new data indicating higher abundances in the western North Sea, particularly around the English Channel (van der Kooij et al., 2016). The previously recognized autumn stock (*L. vulgaris breviceps*) appears to have diminished markedly in recent decades. Similar declines in northern North Sea catches are reflected in BTS data since the 1990s (de Heij & Baayen, 2005). Contemporary assessments thus support the existence of a single, seasonally migrating population rather than two distinct spawning forms (Oesterwind et al., 2010).

L. vulgaris is an annual species with a maximum lifespan of around 15 months. Reproductive activity in *L. vulgaris* in the GNSE is concentrated in the English Channel and southern North Sea, and also occurs in parts of the Irish Sea, occurring mainly between November and April with a peak in February–March (Jereb et al., 2015; Laptikhovsky et al., 2022). Spawning begins in the western Channel and gradually progresses eastward with rising spring temperatures. Egg masses are deposited at depths of 2–120 m, predominantly in waters shallower than 50 m, where females attach egg strands to hard substrates such as rocks, shells, or gravel (Boyle & Rodhouse, 2005; Jereb et al., 2015). As temperatures rise through May–June, spawning extends toward the Dutch and German coasts. By late autumn, mature individuals return to the western Channel and adjacent Celtic and English coastal areas. Spatially, the spawning grounds of *L. vulgaris* are centered within the English Channel, while *L. forbesii* occupies a broader semicircular zone surrounding it, with overlap in transitional areas such as the Celtic Sea and southern North Sea (Laptikhovsky et al., 2022).

Paralarvae of *L. vulgaris* are reported in plankton samples from Galicia (Spain), Portugal and the English Channel (Moreno and Pereira, 1998; González et al., 2010; Collins et al, 2002). It is neither pelagic nor fully benthic; *L. vulgaris* is more or less restricted to the sea bottom during the spawning season and displays pelagic behavior at other times such as hunting (Worms, 1983). *L. vulgaris* is usually more abundant in the water column at depths less than 100m (Guerra et al., 1994; Sánchez et al., 1998; Tserpes et al., 1999); thus, it is described as nektobenthic and neritic.

Temperature strongly regulates the reproductive ecology of *L. vulgaris*. Embryonic development proceeds optimally between 12–24 °C but is inhibited or fails below approximately 10 °C (Laptikhovsky et al., 2022). Consequently, colder winter bottom temperatures in the eastern English Channel and northern North Sea (~10 °C from January to April) delay or restrict spawning in these regions until late spring. Rising sea-bottom and surface temperatures are expected to reshape *L. vulgaris*’s range. While warming may exceed optimal limits in southern areas, it creates new suitable conditions in northern waters (Schickele et al., 2021). Embryos and early life stages, however, remain sensitive to elevated temperature and ocean acidification, which can reduce survival and cause developmental abnormalities (Rosa et al., 2014). Observed trends indicate a northward and westward shift in the species' center of distribution, with more consistent year-round occurrence in parts of the North Sea (van der Kooij et al., 2016). These spatial and temporal changes are likely driven by climate warming and have implications for fisheries management (Schickele et al., 2021).

L. vulgaris is one of the most harvested and common cephalopod species in Europe with the main recruitment areas along southern Atlantic coasts from Galician through Portuguese waters (Jereb et al., 2015; Schickele et al., 2021). Historical and recent studies indicate that *L. vulgaris* occurs in the southern North Sea in low to moderate abundance, especially during late spring and summer (de Heij & Baayen, 2005). While the southern North Sea is not a core recruitment region compared to the Iberian Peninsula, it nonetheless contributes to the species' reproductive habitat.

Human activities could also cause some damage to the species. André et al. (2011) found exposure to low-frequency sounds results in permanent and substantial alterations of the sensory hair cells of the statocysts, the structures responsible for *L. vulgaris'* sense of balance and position. Thus, the acoustic impacts of artificial sound sources could potentially impact the migration, reproduction, and feeding of the species.

4.4.1.3 *Loligo forbesii* (veined squid)

The veined squid, *Loligo forbesii* (Steenstrup, 1856), is one of the most abundant neritic cephalopods in the northeastern Atlantic and is currently the second most common cephalopod recorded in the ICES North Sea International Bottom Trawl Surveys (IBTS) (Oesterwind et al., 2010). *L. forbesii* extends across temperate to subtropical waters (20–60° N) and is particularly common around the British Isles (Rosa et al., 2013; van der Kooij et al., 2016). Its eastern distribution is typically bounded by the Norwegian Trench, with variable abundances in the Skagerrak and Kattegat (de Heij & Baayen, 2005; Oesterwind et al., 2010). It occupies continental shelf seas and oceanic islands throughout the eastern Atlantic, including the Mediterranean and Azores. The species reaches its northern limit in Irish and British waters (Rosa et al., 2013). In European waters, it is one of two *Loligo* species of major commercial importance, dominating northern fisheries while *L. vulgaris* is more prevalent in southern regions. Populations in the Azores are considered to represent a separate subspecies (Rosa et al., 2013).

L. forbesii is present year-round in the North Sea, showing a central and northern distribution during winter and a patchy, widespread presence across the basin in summer. During winter, the species' distribution is closely associated with sea-bottom temperature (SBT), salinity, and depth (Pierce et al., 1998; Oesterwind et al., 2010). The species exhibits extensive seasonal movements, migrating between offshore spawning grounds and inshore nursery areas. Spawning activity begins in November–December on the outer shelf and shelf-edge waters of the Celtic Sea and west of Ireland, progressively expanding eastward into the North Sea during winter and spring, facilitated by the Shelf Edge Current and Atlantic inflows (Laptikhovsky et al., 2022).

Nursey grounds of *L. forbesii* follows the same seasonal migration pattern from west to east. It spawns primarily in deeper waters (10–150 m), and egg masses are attached to fixed substrates such as macrophytes, shells, rocks, ropes, or static fishing gear, often in shallow coastal zones (Holme, 1974; Lordan & Casey, 1999). In warmer southern regions, egg clusters have been observed as deep as 300–700 m offshore waters (Lordan & Casey, 1999; Salman & Laptikhovsky, 2002; Laptikhovsky et al., 2022). The limited number of deepwater egg records may also reflect sampling bias, as rocky substrates suitable for egg attachment are often inaccessible to trawling, and offshore observations are rarely reported (Holme, 1974; Lordan & Casey, 1999). Females are intermittent terminal spawners, producing up to approximately 23,000 eggs. Spawning begins in late autumn, advancing eastward and northward as temperatures rise, and typically ends by July, though residual egg masses may persist until November (Laptikhovsky et al., 2022). Egg clusters are variable in size and may include strings deposited by one or several females. Even within a single female's egg strings, multiple paternity may occur, since they can be fertilised by different males (Shaw & Boyle, 1997).

The species follows an annual life cycle, with individuals living up to 15–16 months. Two seasonal cohorts may occur: a dominant winter-spawning group and a smaller summer-spawning group, indicating flexible recruitment timing across years (Rosa et al., 2013). Males exhibit distinct growth strategies, with smaller "sneaker" males and larger "mate-guarders" coexisting on spawning grounds (Pierce et al., 1994a; Porteiro & Martins, 1994). Early life stages (paralarvae and juveniles) first appear in deeper northern waters between January and February, subsequently moving inshore and eastward during spring and summer before retracting toward northern waters in autumn. This pattern reflects a migratory life cycle synchronized with seasonal temperature fluctuations and oceanic circulation (Laptikhovsky et al., 2022).

Juvenile and paralarval distribution mirrors the seasonal expansion of spawning grounds. Early life stages occur north and west of Scotland and Ireland in winter (January–February), move inshore in spring (March–April), and expand eastward around Scotland into the North Sea during summer (May–August). In autumn, the population retracts toward northern and western areas (Laptikhovsky et al., 2022). This dynamic connectivity between spawning and nursery grounds is maintained by the Shelf Edge Current system, facilitating gene flow across regions and preventing strict population isolation (Laptikhovsky et al., 2022).

Growth in *L. forbesii* follows two main phases: an early rapid, exponential phase, and a subsequent slower, logarithmic phase (Forsythe & Van Heukelem, 1987; Forsythe & Hanlon, 1989). During the exponential phase, juvenile squid may grow at rates up to 8% of body mass per day, lasting for approximately two to four months (Jackson, 1994). Growth rates are highly variable and influenced by food availability, temperature, sex, season, maturity, and hatching time (Forsythe & Van Heukelem, 1987; Smith et al., 2005; Wangvoralak, 2012). As poikilotherms, their growth rate is positively correlated with temperature before sexual maturity, although the later logarithmic phase is less temperature-dependent (Forsythe, 1993; Grist & Des Clers, 1998). Squid exposed to colder conditions before hatching may mature at larger sizes and older ages (Wangvoralak, 2012).

Temperature has a major influence on embryonic development time (Boletzky, 1987). At 12.5 °C, development lasts around 75 days (Hanlon et al., 1989) but can vary significantly with temperature: approximately 140 days at 8 °C, 60 days at 12 °C, and 36 days at 16 °C (Gowland et al., 2002). In Scottish waters, viable egg masses have been observed to persist for up to six months at 8–10 °C, suggesting that development may be arrested over winter, potentially producing two cohorts from a single breeding population (Boyle et al., 1995). Size at hatching decreases with increasing temperature, and body shape varies accordingly—hatchlings reared at 12 °C have long, narrow mantles, while those reared at cooler or warmer temperatures have shorter, wider bodies (Paulij et al., 1990; Martins, 1997). Developmental abnormalities occur outside the optimal temperature range of approximately 10–13 °C. Gowland et al. (2002) reported an increased occurrence of deformities at higher temperatures, while Martins (1997) observed more deformities below 13 °C, indicating a narrow temperature window for normal embryonic development.

Over recent decades, *L. forbesii* has transitioned from a seasonal visitor to a permanent resident in the North Sea (Oesterwind et al., 2022). The species now exhibits an extended spawning season that includes both winter–spring and summer–autumn periods (van der Kooij et al., 2016). Warming sea-surface and bottom temperatures—estimated to have increased by about 1 °C over the past century—are thought to have reduced thermal barriers and facilitated this expansion northward and westward (van der Kooij et al., 2016). Climate-driven shifts in phenology and habitat use highlight *L. forbesii*'s adaptability to changing environmental conditions and may necessitate future adjustments in fisheries management strategies.

L. forbesii is important to European fisheries and one of the most commonly caught squid in the North East Atlantic (Pierce et al., 2013). Similar to *L. vulgaris*, it is an active predator, preying on a variety of crustaceans and small fish, with occasional cannibalism reported (Pierce et al., 1994b). It constitutes an important trophic link in the marine food web, serving as prey for a broad spectrum of fish, seabirds, and marine mammals (Rosa et al., 2013). Its abundance and ecological versatility underscore its significance in North Atlantic shelf ecosystems.

Human activities could also cause some damage to the species. Due to its similarity to *L. vulgaris* in both anatomy and ecology, it is likely that low-frequency artificial noise could potentially impact the migration, reproduction, and feeding of the species, similar to *L. vulgaris* (André et al., 2011), though little evidence specific to *L. forbesii* is currently available.

4.4.1.4 ***Loligo* spp.**

The genus *Loligo* (family Loliginidae) are typical short-lived, high metabolism coastal squids whose biology and ecology share many commonalities while also exhibiting species-specific differences. For example, adult squid in this genus consume very high proportions of their body mass in food each day, such as *Loligo opalescens*, consuming 15-18% of body weight, and hatchlings can be even more voracious. Due to the low metabolic reserves, a brief period without food supply will cause rapid mortality (Vidal et al., 2002).

Temperature and food availability together drive growth, development, and reproductive allocation in *Loligo* spp. (Pecl et al., 2004; Pecl & Jackson, 2008). *Loligo opalescens* survive for shorter periods without food at higher temperatures, consistent with elevated metabolic demand (Vidal et al., 2002; Pecl & Jackson, 2008). Growth responses to temperature are species- and population-specific. For instance, *L. gahi* and *L. pealei* exhibit faster growth in warmer water, whereas *L. noctiluca* show slower growth under warmer conditions due to physiological limits (Jackson & Moltschaniwskyj, 2001). In *Loligo* spp., the broad pattern holds that warmer temperatures reduce embryonic duration, decrease hatchling size, accelerate growth, shorten life span and lead to earlier maturation at smaller sizes. Because metabolic rate rises with temperature, smaller individuals often perform better in warmer conditions while larger conspecifics may be advantaged in cooler water (Pecl & Jackson, 2008; Rosa et al., 2025).

Early life stages (embryo and paralarvae) represent crucial bottlenecks for recruitment in *Loligo* spp. Many Loliginids invest a relatively large fraction of lifespan in embryogenesis. For instance, *L. vulgaris* may spend 1-2 months in the egg, and in *L. gahi* that may extend to 2-5 months (Barón, 2002; Oosthuizen et al., 2002). Because embryonic and juvenile phases are so important, factors that affect these early stages – temperature, salinity, food availability, and synchronization with prey production – will have strong impacts on year-class recruitment. For *Loligo reynaudii* (chokka squid) – mostly around the coast of South Africa (Pierce 2010, Pierce et al., 2013) – and other Loliginids, pelagic paralarval survival and food availability during the first two months are particular important predictors of subsequent catch (Cinti et al., 2004).

Loligo distributions have shown environmentally linked shifts in recent decades. In the North Sea, for example, *L. vulgaris* gradually extended its range from the north-western and southern parts of the basin to occupy nearly the whole sea between 1980 and 2014, suggesting that a change attributed to climate-driven environmental shifts (van der Kooij et al. 2016). Genetic work in other Loliginids (*Loligo reynaudii* and *Doryteuthis pealeii* – located mostly at coasts of South Africa and the eastern USA) has shown little evidence for discrete spawning populations despite locally dense aggregations — thereby suggesting high connectivity and perhaps resilience, but also potential vulnerability to wide-scale environmental change (Shaw et al. 2010). In summary, the genus *Loligo* exemplifies short-lived, high-metabolism cephalopods whose life history is tightly coupled to immediate environmental and trophic conditions.

4.4.2 Ommastrephidae

4.4.2.1 ***Illex coindetii* (broadtail shortfin squid)**

The broadtail shortfin squid, *Illex coindetii* (Vérany, 1839) is a widely distributed member of the family Ommastrephidae, and is the second most abundant Ommastrephid squid found in IBTS during 2007-2010 (Oesterwind et al., 2010; 2015), occurring in the central and northern North Sea. The range of *I. coindetii* includes the entire Mediterranean Sea and extends across the eastern Atlantic Ocean from the North Sea and the British Isles to the coasts of West Africa (60°N to 17°S and 30°W), and into the western Atlantic from the Gulf of Mexico to Venezuela (Roper et al., 1998, 2010; Sanchez et al., 1998). The increasing abundance in the North Sea implies a recent eastward expansion into the Kattegat and Belt Sea (Oesterwind & Schaber, 2020). *I. coindetii* is typically found on the continental shelf and upper slope at depths ranging from 100-800 m (Pierce et al. 2010; Jereb et al., 2015b). It has been recorded from surface waters to >1000 m, but concentrations peak between 100 and 400-600 m (Roper et al., 2010). In the North Sea, it has been observed increasingly in central and northern areas, and appears to show a preference for depths greater than ~62 m (Oesterwind et al., 2020).

I. coindetii inhabits muddy, sandy, and debris-rich substrates, typically in the middle and lower sublittoral and upper bathyal zones (Roper et al., 2010). These habitats are often characterized by the presence of *Funiculina* spp., which provide structural complexity to the seafloor. The species is commonly found in association with various demersal crustaceans and fish, particularly the deep-water rose shrimp (*Parapenaeus longirostris*), European hake (*Merluccius merluccius*), and blue whiting (*Micromesistius poutassou*) (Jereb & Ragonese, 1991; Rasero et al., 1996; Dawe & Brodziak, 1998). It frequently co-occurs with other cephalopods occupying similar ecological niches, including the lesser flying squid (*T. eblanae*), the horned octopus (*E. cirrhosa*), and the midsize squid (*A. media*) (Ciavaglia & Manfredi, 2009; Krstulović Šifner et al., 2005; Silva et al., 2011). These associations suggest that *I. coindetii* forms part of a complex benthic and neritic community structured around productive continental shelf and slope habitats.

In the Greater North Sea and adjacent waters, mated females bearing spermatangia bundles and egg masses were found in summer, indicating that *I. coindetii* is likely reproducing locally, with hatching at least from June to December (Oesterwind et al., 2020; Barrett et al., 2021; Ringvold et al., 2021). Seasonal size-structure data show large differences between winter and summer catches – in winter, the majority of individuals are juvenile (~69%) and mean mantle length (DML) is ~74 ± 32 mm, whereas in summer larger mature individuals predominate (mean DML ~134 ± 34 mm), and a maximum male DML of 312 mm and female 213 mm were recorded (Oesterwind et al., 2015). These data suggest a spawning season extending from spring through autumn, with maturation occurring at smaller sizes in some cohorts (Oesterwind et al., 2020). In winter, most *I. coindetii* were immature or maturing, while in summer almost exclusively larger individuals were fished, mostly matured and had spent (Oesterwind et al., 2020). Age and growth studies from the Mediterranean indicate a lifespan of less than nine months, with daily growth rates (mantle length) of ~1.00 mm per day in males and ~1.33 mm per day in females (Sanchez et al., 1998).

Adult *I. coindetii* exhibit diel vertical migrations, ascending from the seabed to upper water layers at night while generally remaining below the thermocline (Sánchez et al., 1998). These vertical movements are likely linked to foraging behaviour and predator avoidance, allowing the squid to exploit prey resources across depth gradients. Seasonal migrations have also been documented in the French Mediterranean and the Catalan Sea (Mangold-Wirz, 1963b; Sánchez et al., 1998). During spring, the majority of the population moves into shallower waters between 70 and 150 m, where they remain throughout summer for feeding and reproduction. In autumn and winter, individuals disperse across a wider bathymetric range, suggesting a dynamic use of habitats driven by both environmental conditions and life-cycle requirements (Pierce et al., 2010).

Water temperature affects the success and duration of embryonic development (Pierce et al., 2010). *I. coindetii* takes about 10-14 days at 15°C; this temperature corresponds to the median temperature value reported for Mediterranean Sea midwater (Villanueva et al., 2011). During summer, *I. coindetii* was recorded at depths between 25 and 94 m, in bottom-water temperatures ranging from 7.5 °C to 15.9 °C and salinities between 33.3 and 35.2 psu. In winter, individuals were found deeper, between 62 and 166 m (mostly 70–105 m), where bottom temperatures ranged from 5.5 °C to 9.4 °C and salinity from 34.8 to 35.4 psu (Oesterwind et al., 2015). Statistical analyses indicated a weak or non-significant relationship between abundance and bottom temperature or salinity, although an increase in depth showed a positive effect on occurrence ($p < 0.0001$). These patterns suggest that while *I. coindetii* tolerates a broad range of hydrographic conditions, its distribution in the North Sea may be primarily shaped by depth-related factors and water mass characteristics rather than temperature or salinity alone (Oesterwind et al., 2015).

I. coindetii has been found in the stomachs of various marine mammals (Pierce et al., 2010). In Europe, this species is predominantly caught as bycatch in demersal and pelagic trawl fisheries (Sánchez et al., 1998). Since 2018, the landings of *I. coindetii* reach 5000-7000 tonnes per year, mostly by Spanish Fisheries (Abad et al., 2023). Its growing presence in the North Sea, and evidence for local spawning, suggest that climatic and oceanographic changes may be facilitating its expansion eastward and northward (van der Kooij et al., 2016; Oesterwind et al., 2020).

4.4.2.2 *Todarodes sagittatus* (European flying squid)

The European flying squid, *Todarodes sagittatus* (Lamarck, 1798), is a widely distributed member of the family Ommastrephidae, occurring throughout the eastern Atlantic to approximately 62°W, where it is found associated with the Mid-Atlantic Ridge (Vecchione et al., 2010), and from Arctic waters to about 13°S (Nigmatullin et al., 2002; Pierce et al., 2010; Jereb et al., 2015a). Its range includes Icelandic waters, throughout Norwegian waters, and Skagerrak Kattegat and the Belt Sea. *T. sagittatus* has been found in the North Sea, focusing in the northern area – coasts of Belgium, the Netherlands, and southeast England (Oesterwind et al., 2010; Oesterwind et al., 2015), and it is widely distributed in the Mediterranean Sea, where the species inhabits open ocean and coastal environments, extending from the surface to near-bottom depths of up to 2500 m (Mangold-Wirz, 1963b; Nesis, 2003; Pierce et al., 2010).

T. sagittatus inhabits both the open ocean and waters near the coast. It undertakes pronounced diel vertical migrations, ascending toward the surface at night to feed and descending to deeper waters during the day (Jereb et al., 2015). Seasonal occurrences in the North Sea have been reported since the early 20th century (Grimpe, 1925), and recent surveys show that most individuals are concentrated in the northern North Sea, with occasional captures in central regions and near the Scottish coast (Oesterwind et al., 2015). In the North Atlantic, *T. sagittatus* exhibits extensive trophic and ontogenetic migrations, moving between oceanic spawning grounds and continental-shelf feeding areas (Pierce et al., 2010; Roper et al., 2010). The species spawns primarily in deeper offshore waters, notably along the Mid-Atlantic Ridge (Oesterwind et al., 2015), and potentially off the west coast of Ireland (Lordan et al., 2001a). Spawning likely occurs on the continental slope during late winter or early spring off northern Europe, in March–April off France, and from September to November in the western Mediterranean (Piatkowski et al., 1998; Quetglas et al., 1998; Arkhipkin et al., 1999; Lordan et al., 2001a). Females generally outnumber males, and ripe males are found year-round, whereas mature females occur predominantly during the spawning period (Pierce et al., 2010). Individuals attain relatively large body sizes compared with other Ommastrephids: in winter, females average 304 ± 59 mm DML and males 285 ± 23 mm DML, while in summer, lengths of up to 437 mm DML have been recorded (Oesterwind et al., 2015).

Historically, *T. sagittatus* has been associated with mass occurrences and episodic strandings along northern European coasts, including Yorkshire, the Scottish east coast, the Orkney and Shetland Islands, and along the Norwegian coast from Oslofjord to Varangerfjord (Grimpe, 1925; Wiborg & Beck, 1984; Sundet, 1985; Joy, 1990). These large aggregations occasionally supported a substantial commercial fishery in Norway between 1978 and 1984 (Sundet, 1985; Oesterwind et al., 2015). The recurrent high abundance in northern North Sea waters, particularly near the Shetland and Orkney Islands and along the Norwegian coast, is thought to be linked to the inflow of warm Atlantic water via the North Atlantic Drift, which facilitates long-distance transport from offshore spawning areas toward northern feeding grounds (Shimko, 1989; Joy, 1990; Roper et al., 2010). The North Atlantic population likely follows a cyclic migratory route between spawning areas on the Mid-Atlantic Ridge and the western continental slope of Europe, and feeding grounds further north, reaching Icelandic and Faroese waters in summer before moving into Shetland and Norwegian waters in autumn (Wiborg & Beck, 1984; Joy, 1990).

In the North Sea, *T. sagittatus* has been caught at depths ranging from 44 to 171 m, typically at bottom temperatures of 5.5–8.4 °C and salinities of 34.9–35.4 psu (Oesterwind et al., 2015). Statistical analyses indicated that abundance increased significantly with depth ($p < 0.001$; $\rho = 0.272$), suggesting that vertical distribution is influenced primarily by bathymetric conditions rather than by temperature or salinity alone. These patterns are consistent with the species' affinity for deeper, cooler, and more oceanic waters. Although the species' occurrence in the North Sea has historically been seasonal, recent studies indicate that its presence has become more regular in recent years (Oesterwind et al., 2022). This trend may reflect changes in oceanographic conditions, such as increased Atlantic inflow and rising sea temperatures, which could facilitate the northward and eastward expansion of suitable habitat for this highly migratory species.

4.4.2.3 *Todaropsis eblanae* (lesser flying squid)

The lesser flying squid, *Todaropsis eblanae* (Ball, 1841), is a neritic demersal species widely distributed in the eastern Atlantic from approximately 61°N to 36°S, including the entire Mediterranean Sea, and in the southwestern Indian Ocean, and the southwestern Pacific (Pierce et al., 2010; Roper et al., 2010; Agus et al., 2025). In the North Sea, *T. eblanae* dominated the Ommastrephid assemblage based on IBTS by-catch data from 2007–2010 (Oesterwind et al., 2015). Historically rare or absent, it is now permanently present in the North Sea, Skagerrak, and Kattegat, forming a developed summer spawning stock and showing more regular winter occurrences, likely related to warm Atlantic water inflows and its adaptability to increasing sea temperatures (van der Kooij et al., 2016; Oesterwind et al., 2022). Spatially, the species is more abundant in the central and northern North Sea than in the southern region, with larger catches in winter than in summer (Oesterwind et al., 2015).

Unlike other Ommastrephid species, *T. eblanae* does not have strong migration patterns, probably the least mobile of the Ommastrephid squids, and is more likely to behave like neritic Loliginid squid species (Lordan et al., 2001a; Roper et al., 2010; Jereb et al., 2015). It inhabits sandy and muddy substrates, typically inhabiting depths between 20 and 780 m, mainly over the lower sublittoral and upper bathyal zones (Roper et al., 2010; Oesterwind et al., 2015; Jereb et al., 2015). It spawns in the North Sea from summer to autumn (Oesterwind et al., 2015). This seasonal pattern is supported by observations of mature individuals in Scottish waters between June and November (Hastie et al., 1994) and in the northern North Sea during summer (Zumholz & Piatkowski, 2005). In the North Atlantic, females reach up to 290 mm mantle length (ML) and males up to 220 mm (Robin et al., 2002), with a lifespan of approximately 1–2 years. Size at maturity varies geographically, ranging from 120–130 mm ML in males to 140–200 mm ML in females (González et al., 1994). Fecundity varies widely, from 4,500–28,000 eggs in Scottish waters (Hastie et al., 1994) to 43,000–275,000 eggs off West Africa (Laptikhovsky & Nigmatullin, 1999). The species is an intermittent terminal spawner, with growth rates and size varying by hatching season (Robin et al., 2002).

In the North Sea, *T. eblanae* exhibits seasonal and depth-related variation in abundance and maturity. In summer, most specimens were fully mature (72%), while in winter the majority were maturing (68%), with juveniles contributing up to 31% of the total catch (Oesterwind et al., 2015). Females generally attain larger sizes than males (mean DML: 147 ± 29 mm vs. 117 ± 19 mm in summer), but males are relatively heavier for a given length, reflecting a mild morphometric sexual dimorphism characterized by more robust arms and head development in males (Robin et al., 2002; Oesterwind et al., 2015).

Regarding environmental preferences, in summer *T. eblanae* occurred at depths between 31–106 m, at temperatures ranging from 7.3–17.3°C and salinities of 34.1–35.4 psu, with highest abundance between 50–90 m depth. Abundance showed positive correlations with salinity ($p < 0.001$; $\rho = 0.200$) and depth ($p = 0.006$; $\rho = 0.172$), but decreased with increasing temperature ($p < 0.001$; $\rho = -0.169$). In winter, individuals were found between 34–169 m at temperatures of 4.6–8.5°C and salinities of 34.7–35.9 psu; abundance was positively influenced by both depth ($p < 0.001$; $\rho = 0.281$) and temperature ($p < 0.001$; $\rho = 0.215$) (Oesterwind et al., 2015). These findings indicate that *T. eblanae* tolerates a broad range of hydrographic conditions, but its occurrence is strongly shaped by depth and salinity gradients.

Commercially, *T. eblanae* is captured as bycatch throughout the year in otter trawl fisheries and, to a lesser extent, by gillnets, longlines, and jigging, mainly at depths around 100–400 m (Robin et al., 2002). It contributes notably to short-finned squid catches in Spain and Portugal but remains less important than *I. coindetii* in French fisheries. Its increased frequency in the North Sea has been linked to ongoing climate-driven warming trends and northward shifts in suitable habitat (van der Kooij et al., 2016; Oesterwind et al., 2022).

Recent observations suggest that *T. eblanae* is one of the Ommastrephid squids most responsive to ocean warming in the Northeast Atlantic. Historically rare in the North Sea, it is now regularly recorded throughout the region, reflecting a poleward range expansion facilitated by increasing sea temperatures and enhanced inflow of warm Atlantic water (van der Kooij et al., 2016; Oesterwind et al., 2022). The species' broad thermal tolerance and flexible reproductive strategy likely enable it to exploit newly suitable habitats in temperate and boreal waters. Continued warming may therefore favour the persistence and potential population increase of *T. eblanae* in northern areas, with possible ecological implications for local food webs and fishery bycatch composition.

4.4.3 Sepiidae

4.4.3.1 *Sepia officinalis* (common cuttlefish)

The common cuttlefish, *Sepia officinalis* (Linnaeus, 1758), is widely distributed throughout the Northeast Atlantic and Mediterranean Sea, extending from the Faroe Bank and Shetland Islands southwards to Northwest Africa, reaching the border between Mauritania and Senegal (Dunn 1999; Guerra et al., 2001; Jereb et al., 2015). In northern Europe, records include the Bay of Biscay, English Channel, and southern to central North Sea, with occasional occurrences along the Norwegian coast as far north as Trondheim during years of strong Atlantic inflow (Stephen, 1944; Jereb et al., 2015a). Although sporadically found in the Skagerrak and Kattegat, it is generally absent from the Baltic Sea except for rare incursions into its westernmost parts (Rexfort & Mutterlose, 2009). Populations from the Bay of Biscay, English Channel, and North Sea are thought to represent three semi-independent stocks with considerable gene flow between them (Wolfram et al., 2006; Bloor et al., 2013; Laptikhovsky et al., 2023).

S. officinalis inhabits shallow coastal and shelf waters, typically between 10 and 200 m depth, but most reproductive activity occurs around 10 m, where eggs are attached to hard substrates such as sea fans, tubeworms, plants, or artificial structures (Guerra et al., 2015; Guerra et al., 2016). Spawning begins in the western English Channel in March and progresses eastward following seasonal warming, reaching the southern North Sea and Dutch coast by May (Laptikhovsky et al., 2019; Laptikhovsky et al., 2023). Despite a thermal regime favourable for egg development existing around the UK and Ireland, spawning is normally restricted to the English Channel and southernmost North Sea with egg masses occasionally observed in Norfolk (Laptikhovsky et al., 2023). Peripheral spawning grounds extend northward to Norfolk and the Irish Sea during warm years. In southern Brittany and the western English Channel, breeding occurs between mid-March and June, with hatching from June to September, while in the southern North Sea reproduction occurs between late April/May and mid-September (Laptikhovsky et al., 2023). Instead of spawning continuously across the full season, females exhibit intermittent spawning, releasing eggs in bursts over a restricted thermal window (Laptikhovsky et al., 2019).

In the Netherlands, recruitment of cuttlefish is known to occur in the Eastern Scheldt, with adults migrating to the area to spawn in spring and juveniles appearing in late summer (Van der Loos & Gmelig Meyling, 2019). Strandings of cuttlebones along the Dutch coast – such as after storms off Katwijk (Jongbloed et al., 2016) or individual stranded specimens on Texel (Cadée, 2002) – suggest mortality, but analyses indicate these assemblages may reflect older or transported remains rather than recent local reproduction. Given the known high variability in *S. officinalis* recruitment due to environmental and maternal factors, there is a clear need for systematic, long-term monitoring in Dutch coastal waters to assess the extent and drivers of local recruitment.

Growth and maturation patterns are strongly temperature dependent. In the English Channel, individuals follow two main life-cycle strategies: Group I Breeders (GIB), which mature and spawn within one year, and Group II Breeders (GIIB), which reproduce at two years of age (Dunn, 1999; Gauvrit et al., 1998; Laptikhovsky et al., 2024). In warmer western areas, early-hatched individuals may grow rapidly and reproduce after one winter, while others spawn after two years (Goff & Daguzan, 1991). Growth is initially linear, slowing with size and approaching maturation, and differs between sexes, with females showing reduced growth as reproductive investment increases (Domingues et al., 2002; Domingues et al., 2003a). Daily growth rates in hatchlings range from 2–12% body weight per day depending on diet and temperature (Domingues et al., 2001; Domingues et al., 2003b). Young cuttlefish can adapt to very low food intake and remain alive with growth rates much lower than normal, allowing animals to survive under unfavorable conditions (Boletzky, 1983). Temperature exerts a major influence on growth rate and life span, with optimal performance between 15–22 °C and upper tolerance near 30 °C, above which oxygen limitation induces stress (Melzner et al., 2006; Melzner et al., 2007; Guerreiro et al., 2023). *S. officinalis* tolerates salinities as low as 18 ± 2, enabling survival in estuarine and lagoon environments (Boletzky, 1983; Guerra & Castro, 1988). It can survive in temperatures as low as 9.5 °C but becomes lethargic below 10 °C and stressed above 30 °C (Guerreiro et al., 2023).

Human activities impact *S. officinalis* both directly and indirectly. It is one of the most important cephalopods in Northeast Atlantic fisheries, with most catches taken by beam trawlers in the English Channel, where annual landings between 2015 and 2020 reached 8.9–12.6 thousand tons (ICES, in prep.; Laptikhovsky et al., 2023). Additionally, exposure to anthropogenic low-frequency noise can cause permanent damage to sensory hair cells within the statocysts, potentially impairing spatial orientation and balance (André et al., 2011).

Climate change is expected to alter the phenology and distribution of *S. officinalis* rather than cause major range contractions. Rising sea temperatures have already modified its reproductive strategy in the English Channel, where the historically biennial life cycle has partly shifted to an annual one, producing early-maturing individuals (Laptikhovsky et al., 2024). This plasticity allows populations to maintain reproductive output within a warming environment. The species' broad thermal tolerance (9–17 °C, with limits around 10–30 °C) confers resilience to moderate warming, enabling persistence across northern European waters while populations in overheated southern areas may gradually decline (Schickele et al., 2021; Guerreiro et al., 2023). Projections indicate only a slight reduction in overall habitat suitability (≈1–2%) under future warming scenarios, as losses in southern habitats are offset by expanded suitability in northern shelf seas (Guerreiro et al., 2023). Nonetheless, climate-driven shifts in spawning timing, temperature-dependent egg development, and oxygen limitation at higher temperatures may influence recruitment dynamics and the timing of fisheries targeting this species.

4.4.3.2 *Rhombosepion elegans* (elegant cuttlefish)

The elegant cuttlefish *Rhombosepion elegans* (Blainville, 1827) and historically placed in the genus *Sepia*, is the smallest Mediterranean member of the family Sepiidae (Sanjuan et al., 1996; Salman, 2015). It is widely distributed across the eastern Atlantic and the Mediterranean Sea (Ward & Boletzky, 1984; Jereb & Roper, 2005), occurring from western Scotland and Ireland southward along the West African coast to northern Namibia (Sánchez, 1988; Jereb & Roper, 2005). It is present in Celtic Sea (Lordan et al., 2001a) and the English Channel (Jereb et al., 2015). This species inhabits a broad range of continental shelf and upper-slope environments and is also recorded in semi-enclosed and brackish systems such as the Sea of Marmara and estuarine areas of northwestern Spain (Sánchez, 1988; Jereb & Roper 2005).

R. elegans is a sublittoral species typically found on sandy or sandy–muddy bottoms from shallow coastal waters to depths approaching 450 metres (Ward & Boletzky, 1984; Guerra & Castro, 1989; Jereb & Roper 2005; Jereb et al., 2015). Although occasional records extend to about 500 metres, the species is most abundant at depths shallower than 400 metres (Jereb et al., 2015; Gibson-Hall & Wilson, 2025). Its small and narrow cuttlebone, characterised by tightly packed septa, enables the species to inhabit greater depths than most other Sepiids (Jereb et al., 2015). However, depths beyond this range are likely unsuitable for survival. The species tolerates moderate fluctuations in salinity and has been found in brackish waters of 18 to 25 psu in the Sea of Marmara and the outer Ría de Vigo, suggesting some euryhalinity (Ünsal et al., 1999; FAO, 2010). Nonetheless, compared with *S. officinalis*, *R. elegans* is considered more sensitive to large variations in temperature and salinity (Jereb et al., 2015). Eggs are attached to firm surfaces such as alcyonarian sea fans, shells, or coral fragments on muddy bottoms. They are whitish, translucent, and small—about five millimetres in diameter (Guerra 1984; Jereb et al., 2015).

Migratory patterns of *R. elegans* vary across its range and can be related to reproduction (Salman, 2015). In the western Mediterranean, adults move toward shallow coastal spawning grounds at depths of 40 to 70 metres during spring and summer (Sánchez, 1988), whereas in regions such as the Ría de Vigo or the Sicilian Channel, such movements are limited or absent (Guerra & Castro, 1989). In the Aegean Sea and other parts of the Mediterranean, reproduction occurs throughout the year, peaking between July and October (Salman, 2015), followed by a recruitment pulse of juveniles in winter and spring. This variability suggests that local hydrography and habitat structure strongly influence seasonal migrations.

Reproduction in *R. elegans* is continuous rather than synchronous, with females spawning multiple batches of eggs over time. Female fecundity ranges from about 500 to 1,200 eggs, while mature males carry 150 to nearly 500 spermatophores (Salman, 2015). After hatching, juveniles adopt a benthic lifestyle immediately. Growth rates differ between regions but generally range from two to three millimetres per month, and individuals live for roughly one to one and a half years (Guerra & Castro, 1989; Jereb & Ragonese, 1991). The smallest mature males measure around 20 millimetres mantle length, while females reach maturity at about 30 millimetres. Most individuals, however, mature at larger sizes, typically after one year of growth (Guerra & Castro, 1989; Jereb & Ragonese, 1991).

The elegant cuttlefish feeds mainly on small crustaceans, fishes, and polychaete worms. Its diet remains relatively consistent throughout growth, with little evidence of ontogenetic shifts. In the food web, *R. elegans* occupies an intermediate trophic level and serves as prey for a range of larger predators, including sharks, rays, dolphinfish, and bottlenose dolphins (Guerra, 1985; Jereb & Roper, 2005).

This species is caught primarily as bycatch in trawl fisheries throughout the Mediterranean and along the West African coast (Jereb & Roper, 2005). Although it is rarely reported separately in official statistics, *R. elegans* can represent a significant portion of total cuttlefish landings in some regions, particularly in the Sicilian Channel and the Gulf of Cádiz. It is sold both fresh and frozen and represents a locally valuable resource. Estimated exploitation rates in certain Mediterranean areas suggest considerable fishing pressure on local populations (Pierce et al., 2010).

Owing to its broad geographic range and ability to occupy deeper habitats, *Rhombosepion elegans* appears relatively resilient to projected ocean warming compared with more shallow-living species (Guerreiro et al., 2023). Model projections indicate minimal reductions in habitat suitability under future climate scenarios. The species is expected to maintain, and in some cases expand, suitable habitats at higher latitudes and greater depths. Nevertheless, local population trends will continue to depend on regional temperature shifts, oxygen availability, and fishing intensity.

4.4.4 Sepiolidae

4.4.4.1 *Rossia macrosoma* (stout bobtail squid)

The stout bobtail squid, *R. macrosoma* (Delle Chiaje, 1829), is a demersal Sepiolid distributed across the eastern Atlantic and the Mediterranean Sea (Guerra, 1992). Its range extends from the Greenland and Norwegian Seas southwards along the Atlantic coasts of Europe and North Africa, encompassing the North Sea and most of the Mediterranean basin (Reid and Jereb, 2005; Drerup et al., 2021). The species typically inhabits sandy and muddy substrates from depths of about 30 to 600 m, although individuals have been recorded from 32 to 899 m and even near the surface at night (Roper et al., 1984; Rosa et al., 2006; Jereb et al., 2015). In the Mediterranean, *R. macrosoma* is most common between 200 and 400 m, occupying the broad transitional zone between the continental shelf and slope, where faunas of both regions overlap (Roper et al., 1984). It generally prefers deeper waters in winter but ascends to shallower habitats during the spawning season (Reid and Jereb, 2005).

Spawning behavior in *R. macrosoma* has been well documented. Females attach their eggs to hard substrates such as rock crevices or beneath overhangs, often within cryptic locations that reduce predation risk (Racovitza, 1894; Boletzky and Boletzky, 1973; Drerup et al., 2021). Freshly laid eggs are soft and black but gradually harden and take on a bluish tint. Egg masses are typically multilayered, and females frequently deposit new eggs onto existing batches, suggesting intermittent spawning behavior (Salman and Önsoy, 2010; Drerup et al., 2021). This spawning strategy, common among Sepiolids, allows females to release several batches over time, either returning to previously laid clusters or sharing deposition sites with conspecifics (Gabel-Deickert, 1995; Laptikhovsky et al., 2008). Observations in Scottish waters have revealed that females periodically detach from their egg clutches to rest nearby before resuming spawning activity (Drerup et al., 2021).

The spawning period of *R. macrosoma* varies geographically but generally extends from spring through autumn, with regional peaks reflecting temperature and depth gradients. In the Mediterranean, spawning occurs from March to November (Mangold-Wirz, 1963a; Rosa et al., 2006), whereas in western Scottish waters, reproductive activity primarily takes place between August and November (Drerup et al., 2021). Seasonal migrations accompany reproduction: larger adults move from deeper offshore zones into shallower coastal areas—typically between 9 and 30 m—to mate and spawn, followed by smaller individuals later in the season (Roper et al., 1984; Reid and Jereb, 2005). Survey data from the Joint Nature Conservation Committee (2018) and Seasearch (2020) confirm that around 90% of *R. macrosoma* individuals in West Scottish waters occur between June and November, with peak observations in September and October

(Drerup et al., 2021). These patterns suggest a strong seasonal component in reproductive ecology, closely linked to depth and temperature preferences.

R. macrosoma is an active predator feeding primarily on crustaceans, small fish, and molluscs (Mangold-Wirz, 1963a). Its diet, rich in protein and lipid content, underpins its fast growth and energy-demanding lifestyle typical of cephalopods inhabiting variable depth ranges. The species plays an important role in benthic food webs, acting both as predator and as prey for larger fishes and marine mammals.
Although *R. macrosoma* is commonly captured in scientific and commercial trawl surveys, it rarely appears in large numbers and is generally not a primary target species (Roper et al., 1984; Reid and Jereb, 2005). Its broad bathymetric distribution and capacity to inhabit deep-water refuges may afford some resilience to fishing pressure and warming-induced habitat shifts. However, in the North Sea and adjacent areas, increasing water temperatures may facilitate more stable year-round populations, altering seasonal dynamics historically observed in this species (Oesterwind et al., 2022).

Owing to its wide bathymetric range and capacity to occupy deeper, cooler habitats, *R. macrosoma* is expected to be less affected by ocean warming than more strictly shelf-dwelling cephalopods (Pierce et al., 2010). Early observations suggested a seasonal presence in the North Sea (Grimpe, 1925), but recent records of its permanent occurrence in the North Sea suggest that rising temperatures may have facilitated the northward expansion or stabilization of populations previously occurring only seasonally (Oesterwind et al., 2022). Nevertheless, the species' dependence on oxygen-rich benthic environments makes it potentially vulnerable to regional deoxygenation and bottom trawling impacts, particularly in semi-enclosed basins of the Mediterranean (Oesterwind et al., 2022). Overall, *R. macrosoma* appears moderately resilient to climate-driven changes due to its depth flexibility and opportunistic life history, but local population trends will likely depend on the interplay between thermal gradients, oxygen availability, and fishing pressure.

4.4.4.2 *Sepietta oweniana* (common bobtail squid)

The common bobtail squid, *Sepietta oweniana* (d'Orbigny, 1841), is a demersal Sepiolid species with a broad distribution in the eastern Atlantic, ranging from Norway southward to Mauritania, and throughout the Mediterranean Sea to the Sea of Marmara (Reid & Jereb, 2005; Guerra, 1992). It has been recorded from the west coast of Norway off Ålesund (Grieg, 1933) and occurs regularly in the Skagerrak and Kattegat regions between the eastern North Sea and the western Baltic Sea (Bergström & Summers, 1983). The species is also found along the coasts of Scotland, Ireland, the Celtic Sea, and the Porcupine Seabight (Collins et al., 2001; Lordan et al., 2001b), and extends south along the European and North African Atlantic coasts to 14°N (de Heij & Goud, 2010). In the Mediterranean, *S. oweniana* is widespread in both western and eastern basins, including the Adriatic, Ionian, Aegean, and Levantine Seas (Mangold-Wirz, 1963a; D'Onghia et al., 1996; Lefkaditou et al., 2003; Salman et al., 1998; Jereb et al., 2015). It has also been reported from the Sea of Marmara (Katağan et al., 1993; Ünsal et al., 1999). Historically recorded as a seasonal visitor to the North Sea, *S. oweniana* is now considered a permanent resident (Grimpe, 1925; Oesterwind et al., 2010).

S. oweniana inhabits sandy and muddy bottoms across a wide depth range from 20 m to more than 1000 m, although it is most commonly found between 50 and 300 m in the Northeast Atlantic (Bergström & Summers, 1983; Collins et al., 2001). In the Mediterranean, it typically occurs near the shelf break between 200 and 400 m, occasionally descending to 500 m (Bello, 2019; Quetglas et al., 2000; González & Sánchez, 2002). In the Gulf of Cádiz and southern Portuguese waters, it is also reported from 300–500 m (Silva et al., 2011; Czudaj et al., 2012). The species prefers soft, muddy substrates and is frequently associated with *Rondeletiola minor* and Norway lobster (*Nephrops norvegicus*) grounds (Naef, 1912; Lefkaditou & Kaspiris, 2005). Although present in brackish transition zones such as the Kattegat, its salinity tolerance is lower than that of other bobtail squids, and it is not found in true brackish waters (Katağan et al., 1993; Ünsal et al., 1999; Jereb et al., 2015).

Reproductive activity in *S. oweniana* is highly variable across regions, reflecting local hydrographic conditions. Spawning peaks occur in May–September in the Catalan Sea (Mangold-Wirz, 1963a; Deickert & Bello, 2016), in July in the northern Tyrrhenian Sea (Giordano et al., 2009), and in February–March in the Strait of Sicily (Jereb et al., 1997). In the Aegean Sea, two distinct peaks occur in March–April and

November (Salman, 1998; Lefkaditou & Kaspiris, 2005). Spawning typically takes place in relatively shallow waters but may occur as deep as 544 m (Cuccu et al., 2010). Females exhibit a small-size, multiple-spawning strategy, producing several batches of eggs over an extended period while continuing to feed and grow (Bello & Deickert, 2003; Cuccu et al., 2010). Eggs are deposited on various solid substrates, particularly ascidians (*Microcosmus* spp.) in the Catalan Sea (Mangold-Wirz, 1963a; Deickert & Bello, 2005), and the egg capsules range from thin and elastic to hard-shelled forms, especially at greater depths (Mangold-Wirz, 1963a; Cuccu et al., 2010). Incubation duration varies with temperature, lasting about 25 days at 23 °C, 30 days at 20 °C, 2–3 months at ≥10 °C, and up to 6 months at 6.8 °C (Bergström & Summers, 1983; Jereb et al., 2015).

After hatching, growth is rapid and largely independent of temperature, averaging 4–8 mm per month under laboratory conditions (Jereb et al., 2015). Individuals reach maturity within 6–7 months, and the life cycle is typically completed within 6–12 months, depending mainly on embryonic development duration. Seasonal and vertical migrations related to reproduction and feeding have been observed in several regions, including the Atlantic and Mediterranean (Mangold-Wirz, 1963a; Lefkaditou & Kaspiris, 2005; Giordano et al., 2009), though such movements appear limited or absent in areas with narrow continental shelves such as the Strait of Sicily and the northern Aegean Sea (D'Onghia et al., 1996; Jereb et al., 1997).

Sepietta oweniana is commonly taken as bycatch in demersal trawl fisheries targeting crustaceans and small fish throughout the Mediterranean and eastern Atlantic (Jereb et al., 2015). Although rarely reported separately in catch statistics, it is a valuable component of mixed cephalopod landings in many areas (Reid & Jereb, 2005). Its small size and high reproductive output allow it to maintain populations despite considerable fishing pressure in some regions (Jereb et al., 2015).

Owing to its wide distribution and bathymetric plasticity, *S. oweniana* shows moderate resilience to climate-driven ocean warming (Czudaj et al., 2012; Oesterwind et al., 2022). The expansion of stable populations in the North Sea and its persistence in both deep and shallow habitats indicate adaptability to environmental shifts. However, its relatively narrow salinity tolerance and reliance on oxygen-rich benthic habitats may limit its resilience in areas affected by deoxygenation or altered circulation (Oesterwind et al., 2022). Overall, the species is expected to maintain broad distribution under future climate scenarios, though regional populations may fluctuate according to depth-specific thermal and oxygen regimes.

4.4.4.3 *Sepiola atlantica* (Atlantic bobtail squid)

The Atlantic bobtail squid, *Sepiola atlantica* (d'Orbigny, 1842), is a neritic cephalopod distributed throughout the Northeast Atlantic, from approximately 65°N to 35°N (Reid & Jereb, 2005). It occurs from Iceland (de Heij et al., 2017) and the Faroe Islands (Yau & Boyle, 1996) to the Norwegian Sea and along the west coast of Norway (Grimpe, 1925; Grieg, 1933). The species is common in the North Sea (Grimpe, 1925; de Heij & Baayen, 2005; Oesterwind et al., 2010; Jones & Richardson, 2012; de Heij et al., 2017) and is recorded in the Skagerrak, Kattegat, and occasionally in the western Baltic Sea (Grimpe, 1925). Its distribution extends southward along the British Isles, including Scotland, Ireland, and the Celtic Sea (Stephen, 1944; Collins et al., 2001; de Heij et al., 2017), through the English Channel (Grimpe, 1925) and along the French and Spanish coasts to northwest Africa, reaching as far as off Casablanca, Morocco (de Heij et al., 2017). It is a permanent resident of the North Sea (Grimpe, 1925; Jereb et al., 2015).

Sepiola atlantica inhabits the continental shelf and extends to the upper slope, generally between 6 and 150 m depth (Jereb et al., 2015) and were mostly caught between 10 and 100 m (de Heij et al., 2017). In Scottish waters, it is most abundant between 50–120 m (Yau & Boyle, 1996), whereas in Iberian waters, it is commonly found between 6–50 m, including in the Galician Rías (Rodrigues et al., 2011a; Rodrigues et al., 2011b). It prefers clean sandy bottoms and is mainly epibenthic, though individuals have occasionally been collected in midwater both day and night (Collins et al., 2001). Around Iceland, specimens have been captured pelagically (Yau & Boyle, 1996), suggesting vertical mobility. The species is stenohaline, being absent from brackish or highly variable salinity environments (Guerra, 1992; Rodrigues et al., 2011a).

Seasonal inshore–offshore movements have been observed in the North Atlantic. Around Anglesey (north Wales), populations migrate inshore in July, reaching peak abundance between July and August, before returning offshore by late October (Jones & Richardson, 2012). This pattern is thought to be linked to feeding opportunities, particularly shrimp availability in shallow waters, and to environmental conditions favoring growth and reproduction. In Galician waters, abundance decreases during summer, likely due to migration into deeper, cooler waters (Rodrigues et al., 2011a; Jereb et al., 2015).

Reproductive activity in *S. atlantica* occurs between March and August, peaking in June (Yau & Boyle, 1996). Females produce between 42 and 126 mature ova, and juveniles are most frequently encountered in May, suggesting an extended spawning season (Yau & Boyle, 1996). In the Ría de Vigo, sexual maturity is reached at smaller sizes than in northern populations, with 50% maturity (ML_{m50}) at 8.9 mm in males and 9.8 mm in females (Rodrigues et al., 2012). *S. atlantica* is an intermittent terminal spawner with group-synchronous ovary maturation, capable of depositing multiple egg clutches across different sites (Rodrigues et al., 2011b; Jereb et al., 2015).

Eggs are laid singly but clustered together on hard substrates such as hydroids and bryozoans (e.g. Cellaria spp.) (Rees, 1957; Rodrigues et al., 2011b). The egg capsules are spherical, slightly pointed apically, and range from 1.75–4.92 mm in length (mean 2.75 ± 0.44 mm; Rodrigues et al., 2011b). Embryonic development is temperature-dependent, lasting approximately 61.8 ± 3.8 days at 13°C, 40.1 ± 4.8 days at 16.4°C, and 22.6 ± 1.7 days at 18°C (Rodrigues et al., 2011c; Jereb et al., 2015).

Growth follows two phases: a slow initial phase during the first 120 days (average 0.05 mm day^{-1}; 0.043 mm day^{-1} in males and 0.055 mm day^{-1} in females), followed by a slightly faster phase up to day 210, after which growth stabilizes (Jones & Richardson, 2010; Jereb et al., 2015). The lifespan of *S. atlantica* is estimated between 7 and 10 months, depending on water temperature and the duration of embryonic development (Jones & Richardson, 2010).

Water temperature and salinity are key factors influencing the species' life cycle. *S. atlantica* is sensitive to salinity fluctuations, which restrict its occurrence to fully marine environments (Guerra, 1992; Rodrigues et al., 2011a). Temperature affects both embryonic development rate and longevity, with faster development and shorter lifespans in warmer waters (Rodrigues et al., 2011c; Jereb et al., 2015). Seasonal migrations likely respond to changes in bottom temperature and prey distribution, as individuals move to deeper or shallower habitats to optimize foraging and reproductive success (Jones & Richardson, 2012; Rodrigues et al., 2011a).

Although *S. atlantica* is not directly targeted by fisheries, it frequently appears as bycatch in demersal trawl fisheries operating on sandy and muddy bottoms throughout its range (Collins et al., 2001; Jereb et al., 2015a). It was found alone or sometimes together with *Sepiola pfefferi* and occasionally with *Rondeletiola minor* (de Heij et al., 2017). In the North Sea and Northeast Atlantic, trawling may disturb its preferred benthic habitats and potentially impact egg clusters attached to sessile organisms such as hydroids or bryozoans. Additionally, bottom temperature increases linked to climate change may alter reproductive timing and spatial distribution, potentially pushing populations northward or to deeper waters (Jones & Richardson, 2012; Jereb et al., 2015a). Despite these pressures, *S. atlantica* remains widely distributed and locally abundant, indicating some resilience to moderate environmental and anthropogenic stressors.

4.4.5 Eledonidae

4.4.5.1 *Eledone cirrhosa* (horned octopus/curled octopus)

The horned octopus, *Eledone cirrhosa* (Lamarck, 1798), is a widely distributed benthic octopod inhabiting the Northeast Atlantic and Mediterranean Sea (Guerra, 1992; Belcari et al., 2002; Oesterwind et al., 2022). Its range extends from approximately 67°N in northern Norway and southern Iceland to the northwest African coast (Grieg, 1933; Guerra, 1992; Jereb et al., 2015a). The species is common throughout the North Sea (Grimpe, 1925; de Heij & Baayen, 2005; Oesterwind et al., 2010) and along the British Isles, including the Scottish coast, the Celtic Sea, and the English Channel (Stephen, 1944; Rees, 1956; Boyle, 1983; Lordan et al., 2001b; Barrett & Brazier, 2024). Southward, *E. cirrhosa* occurs along the Atlantic coasts of France, Spain, and Portugal, though its southern limit is uncertain and may extend to approximately 33°N (Guerra, 1992; Regueira, 2017; Regueira et al., 2018). In the Mediterranean, it is widespread and abundant, occurring in the western, central, and eastern basins, including the Adriatic, Ionian, Aegean, and Levant Seas, as well as in the Sea of Marmara (Ünsal et al., 1999; Belcari et al., 2002; Giordano et al., 2010; Jereb et al., 2015; Regueira, 2017; Quetglas et al., 2025). Occasional occurrences in the Kattegat and Skagerrak suggest sporadic penetration into brackish transition zones (Oesterwind et al., 2022; Øresland et al., 2024).

E. cirrhosa is a soft-bottom, eurybathic species, inhabiting continental shelf and slope regions at depths ranging from the shallow sublittoral down to 700–800 m (Belcari et al., 2002; Relini et al., 2006; Smith, 2023). Most populations, however, occur between 50 and 300 m, depending on local topography and substrate (Belcari et al., 2002; Jereb et al., 2015a). Depth distribution is often sex- and season-dependent: females predominate in shallower waters (30–80 m), a balanced sex ratio is found at intermediate depths (100–200 m), and males are more common below 200 m (Mangold-Wirz, 1963a; Tursf et al., 1995; Belcari et al., 2002; Relini et al., 2006). In the Mediterranean, seasonal migrations have been observed, with females moving inshore in spring for breeding (Tursf et al., 1995; Regueira, 2017). Conversely, other studies have suggested downward migrations during spawning, with females aggregating on hard substrates at deeper shelf or upper slope depths (ca. 200-400 m), where eggs can attach (Belcari & Sartor, 1999; Relini et al., 2006). Abundance and distribution patterns vary across fishing areas in relation to depth, shelf morphology, and regional hydrographic conditions (Lefkaditou et al., 2000; González & Sánchez, 2002; Jereb et al., 2015a).

Reproduction in *E. cirrhosa* exhibits marked seasonality and regional variation (Belcari et al., 2002; Pierce et al., 2010). In the North Sea, females mature mainly during July–September, with spawning occurring shortly thereafter (Boyle, 1983; Boyle & Knobloch, 1983). However, males show no clear seasonality in maturity (Boyle & Knobloch, 1984). Along the Iberian coast, spawning peaks in May–June (Fernández, 2017; Regueira et al., 2017), while in Portuguese waters, mature males are present from February–July and mature females from May–August (Jereb et al., 2015a). In the Mediterranean, spawning occurs earlier in the western basin (spring–summer) and later in the eastern basin (summer–autumn) (Belcari & Sartor, 1999; Belcari et al., 2002; Cuccu et al., 2003; Giordano et al., 2010; Jereb et al., 2015a).

Females reach a maximum of 190 mm mantle length (ML), while males attain up to 135 mm ML (Belcari & Sartor, 1999). Maturity occurs at smaller sizes in the Mediterranean than in the Atlantic, and males mature earlier than females (Belcari et al., 2002; Jereb et al., 2015a). The species has a flexible life cycle, typically 1–2 years, comprising both fast-growing, early-maturing individuals and slower-growing, late-maturing individuals (Boyle & Knobloch, 1982; Boyle et al., 1988). Mediterranean populations generally live for around two years, though less than 10% may survive up to three years (Lefkaditou & Papaconstantinou, 1995; Cuccu et al., 2003).

Fecundity varies widely, with averages of ~9000 eggs in the North Sea, ~5500 in the Catalan Sea, and ~5000 in the Tunisian Sea (Mangold-Wirz, 1963; Boyle et al., 1988; Boyle & Knobloch, 1983; Rjeibi et al., 2013). Eggs are attached to hard substrates, such as rocky outcrops or sessile invertebrates, and hatching occurs after 3–4 months, typically during April–July at 14–18°C (Mangold et al., 1971; Jereb et al., 2015a). Paralarval individuals of *E. cirrhosa* have been recorded at ~4–8 mm mantle length in plankton samples around the British Isles, indicating a brief pelagic phase before settling to the seabed (Collins et al., 2002). Growth and size-at-age studies (Boyle & Knobloch, 1982) suggest life histories vary regionally with environmental conditions.

E. cirrhosa supports commercial fisheries throughout much of its range, particularly in the western and central Mediterranean (Tursf et al., 1995; Belcari et al., 2002; Sánchez et al., 2004; Relini et al., 2006; Quetglas et al., 2025). It is captured mainly by bottom trawls, often alongside *Eledone moschata* and *Octopus vulgaris* (Pierce et al., 2010; Barrett & Brazier, 2024). *Octopus vulgaris* and *E. cirrhosa* share habitats, yet maintain distinct ecological niches, reducing direct competition. In the Mediterranean, it is marketed in two commercial categories, with smaller individuals (<50 mm ML) commanding higher prices (Belcari et al., 2002; Belcari & Sartor, 1999). In some areas, spring–summer trawl fisheries target recruits, coinciding with the species' recruitment period, although this practice was banned in the Catalan Sea due to concerns about overexploitation (Relini & Orsi Relini, 1984; Belcari et al., 2002; Sánchez et al., 2004). In the North Atlantic, it is mostly landed as bycatch, with limited economic importance in Scotland and northern Spain, where annual landings average around 700 tonnes (Jereb et al., 2015a).

Despite localized fishing pressure, *E. cirrhosa* remains abundant and resilient in many regions. However, bottom trawling may damage benthic habitats and disturb egg-laying sites, while rising sea temperatures could shift its distribution poleward and disrupt reproductive timing (Sánchez et al., 2004; Oesterwind et al., 2022). *O. vulgaris* was found overlapping with *E. cirrhosa* around UK shelf areas, though historically *E. cirrhosa* is more common in northern waters and *O. vulgaris* more southern (Barrett & Brazier, 2024). The changes in oceanographic conditions may influence the balance between these two species, potentially altering their coexistence dynamics in future.

5 Synthesis

In this study, we reviewed potential indicators to be used in the MSFD under Descriptors 1 and 3 to assess GES for cephalopods, identified species (groups) in the GNSE where MSFD assessment is possible and meaningful, and reviewed available data to calculate the proposed indicators for each species (group). Here, we summarise the recommendations made in order to assess GES for cephalopods in the coming cycle of the MSFD, per descriptor and criterion.

5.1 D1 - Biodiversity

Scientific trawl surveys are seen as the most important source of information on Descriptor 1, Biodiversity. In recent years, awareness on the diversity and taxonomy of cephalopods in the GNSE has increased among the scientific community and data from trawl surveys has become more reliable. However, taxonomic issues in survey data persist and more communication between cephalopod experts and survey coordinators may benefit data quality. For this, frequent contact between ICES groups WGCEPH and survey groups (WGBEAM, IBTSWG) is recommended. Specific issues to be addressed are the identification of *Loligo* species, identification of different species within the family Ommastrephidae, distinction between *R. macrosoma* and other Sepiolidae, and identification of *Alloteuthis* in the North Sea as *A. media* rather than *A. subulata.* Alternatively, *Alloteuthis* could be identified as *Alloteuthis* spp. given that the exact geographic range of different species is not entirely known.

5.1.1 D1C1 – Mortality rate per species from incidental bycatch

No indicators for D1C1 (Mortality rate from discards/bycatch) can be meaningfully computed due to low discard rates and assumed negligible impact on populations. Discard rates should continue to be monitored.

5.1.2 D1C2 – Population abundance

Relative abundance from survey CPUEs is recommended as the indicator for D1C2, where the multi-year average compared to the previous monitoring period or a long-term mean is proposed as a reference point. The most suitable survey differs per species (group). Table 11 gives the recommended surveys to be used for indicators of population abundance for each species (group). Modern methods of calculating indices of abundance through statistical modelling allow for the use of multiple surveys into one index. Small national surveys and citizen science platforms are largely unsuitable to systematically determine population abundance at the scale of the GNSE, though sampling by recreational divers may provide limited information at a small spatial scale.

Table 11 *Recommended survey per species (group) for D1C2 (Population abundance).*

Species	Recommended survey(s)	Comment
Alloteuthis media	IBTS Q1 (2000-present), IBTS Q3 (2000-present), DYFS (2000-present)	Data may be unreliable due to small sizes compared to mesh size. Both Q1 and Q3 IBTS may be used and possibly give contrasting signals. DYFS may provide complimentary information on very young individuals.
Loligo vulgaris	IBTS Q1 (2002-present), CGFS (2014-present)	Joint index for English Channel and North Sea recommended. Individuals assigned to *Loligo* spp. may be assigned to species based on parameters such as location, depth, temperature and season.
Loligo forbesii	IBTS Q3 (2000-present), CGFS (2016- present)	Possible misidentifications in southern North Sea IBTS Q1 (more likely to be *L. vulgaris)*. Population also extends to

Species	Recommended survey(s)	Comment
		West of Scotland and Celtic Seas and should be considered for indicator of abundance. Individuals assigned to Loligo spp. may be assigned to species based on parameters such as location, depth, temperature and season.
Illex coindetii	IBTS Q3 (2015-present)	Only from ~2015 onwards, when a spawning population established itself in the northern North Sea.
Todarodes sagittatus	IBTS Q1 (2008-present)	Population likely extends to West of Scotland and Celtic Seas and should be considered for indicator of abundance.
Todaropsis eblanae	IBTS Q1 (2015-present), IBTS Q3 (2015-present), CGFS (West; 2018-present)	Population likely extends to West of Scotland and Celtic Seas and should be considered for indicator of abundance.
Sepia officinalis	BTS (2006-present), CGFS (2014-present), DYFS (2020-present)	Indicators are best calculated separately for the English Channel and North Sea, as these are thought to represent semi-independent populations. For the North Sea population, the DYFS may provide complimentary information on younger individuals.
Rhombosepion elegans	BTS (2006-present)	Population likely extends to West of Scotland and Celtic Seas and should be considered for indicator of abundance.
Rossia macrosoma	IBTS Q1 (2012-present), IBTS Q3 (2012-present)	Data may be unreliable due to small sizes compared to mesh size.
Sepiolidae nei	IBTS Q1 (2004-present), CGFS (2014-present)	Data may be unreliable due to small sizes compared to mesh size.
Eledone cirrhosa	BTS (2003-present)	IBTS is also possibly informative.

For all species, population boundaries are a persistent issue, with a lack of knowledge on whether several distinct populations can be identified or if all individuals in the GNSE (or even Northeast Atlantic Ocean) belong to a single, mixing population. A research program on the genetics of cephalopods across the Northeast Atlantic may provide crucial insights into population structures. For *S. officinalis* for example, it's known from genetic analysis that three semi-distinct populations exist in the Bay of Biscay, English Channel and southern North Sea. For these, separate indicators of population abundance should be calculated.

Although the DYFS and SNS surveys are not suitable as standalone sources of abundance indices, both surveys may provide complimentary information for nearshore stages (mostly young individuals) for certain species. Combining this information with IBTS or BTS surveys which cover broader spatial distributions can be incorporated via Delta-GAM or Tweedie-GAM models to create multi-survey indices (Berg et al., 2016) and may strengthen recruitment signals for nearshore components of the index.

5.1.3 D1C3 – Demographic characteristics (size and age distribution)

Reviewed indicators under D1C3 (demographic characteristics) are not applicable to cephalopods and should not be computed to avoid erroneous interpretation of indicator trends.

5.1.4 D1C4 – Distributional range and pattern

The proposed indicator for distributional range and pattern is the change in spatial units occupied, e.g. at the level of ICES statistical rectangles, relative to the number of spatial units occupied in a reference period. Trawl surveys are most suitable to map the distribution of species across spatial units. For this, all surveys can be considered, not just those proposed in Table 11, as survey catchability is of limited importance to presence/absence.

An exploration of data from acoustic surveys in collaboration with the ICES group WGIPS is recommended to assess if this data may be used to study distribution ranges and patterns, especially for pelagic (Ommastrephid) squids.

5.1.5 D1C5 – Habitat requirements

No indicators for D1C5 (habitat requirements) are proposed. Knowledge on habitat requirements and response to human activities of cephalopods is limited and monitoring of the effects of e.g. offshore infrastructure and climate change is recommended. This may provide more knowledge on the future quality of cephalopod habitats under anthropogenic stressors.

5.1.6 D1C6 – Pelagic habitat requirements

No indicators specific to cephalopods are proposed for D1C6 (Pelagic habitat requirements). This indicator is mainly meant to assess the status of plankton communities. Studies on the links between plankton communities and cephalopods could help in our understanding of the links between these groups, as cephalopod abundance is known to be influenced by plankton productivity. Furthermore, the early, paralarval life stages of most cephalopods are planktonic (Roper, Nigmatullin & Jereb, 2010) and plankton monitoring should include these.

5.2 D2 – Non-indigenous species

Citizen science platforms may be used for Descriptor 2 (Non-indigenous species).

5.3 D3 – Commercially exploited fish and shellfish

For Descriptor 3 on commercially exploited fish and shellfish, we recommend a focus on the two main species of commercial interest in the Netherlands: *L. vulgaris* and *S. officinalis* in the southern North Sea and eastern English Channel. These species are caught in the only Dutch fisheries targeting cephalopods and represent the vast majority of Dutch cephalopod landings.

Assessing the status of commercially exploited cephalopod stocks is best conducted with stock assessment models, which are currently unavailable for cephalopod stocks in the GNSE. The most promising methods are (generalized) depletion models and surplus production models, where the former is more appropriate for cephalopods, but more data-intensive, than the latter. We recommend research into the development of such models for the main commercially interesting cephalopod stocks. Given the international nature of the fisheries for *L. vulgaris* and *S. officinalis*, coordination with France, the United Kingdom, Belgium and Germany is essential.

Until analytical stock assessments are available, alternative indicators from logbook data may be used for the D3 criteria.

To provide information on taxonomy of landings, we recommend increasing market sampling of *Loligo* (which is likely only *L. vulgaris* but may also be *L. forbesii*) and *S. officinalis* in the southern North Sea and eastern English Channel, both at Dutch and international fish auctions. For *Loligo*, sampling effort should be increased in central and western English Channel.

Commercial logbooks often do not provide (correct) information on the taxonomy of landings. Providing guidance to fishers on 3-alpha codes could increase data quality, especially for identifications that can be done visually. For example, Loliginid and Ommastrephid squids could be easily distinguished and reported at the appropriate taxonomic level, namely SQC or SQZ (*Loligo* spp. or Loliginidae) and OMZ (Ommastrephidae). Furthermore, providing guidance to fishers on consistent use of gear codes in the otter trawl fleet would be helpful for distinguishing fishing behaviour: OTB for single-rig otter trawls, OTT for twin-rig otter trawls, and QUA or OTP for quad-rig otter trawls. Lastly, we recommend that demersal seines register rope lengths consistently in logbooks.

For the D3 indicators, it is important that they are calculated at an appropriate spatial and temporal scale, meaning during the main fishing seasons for *L. vulgaris* (October-April) and *S. officinalis* (August-December) and combining data from all countries involved in the fisheries (United Kingdom, France, Belgium, The Netherlands and Germany).

Given the low occurrence and rates of discards, it is recommended that discards are not considered when calculating D3 indicators.

5.3.1 D3C1 – Harvest rate (fishing mortality)

We recommend two indicators for D3C1 derived from analytical stock assessment models. These are fishing mortality (F) from surplus production models, with F_{MSY} as a reference point, and catch compared to the mean latent productivity (minus uncertainty), from generalized depletion models. As an alternative when stock assessment models are not (yet) available, we recommend Y/CPUE.

5.3.2 D3C2 – Spawning stock biomass

We recommend two indicators for D3C3 derived from analytical stock assessment models. These are spawning stock biomass (SSB) from surplus production models, with MSY $B_{trigger}$ as a reference point, and biomass compared to escapement biomass, from generalized depletion models. As an alternative when stock assessment models are not (yet) available, we recommend CPUE of mature individuals.

To determine the share of mature individuals throughout the season, we recommend increased market sampling at both Dutch and international fish auctions.

5.3.3 D3C3 – Demographic characteristics (size and age distribution)

For D3C3, only the indicator proposed by ICES (2024a), Recruitment, is suggested, with multi-annual means compared to the long-term mean as reference point. This can be derived from trawl surveys at the start of the fishing season if the timing of the survey matches the timing of the season. Alternatively, the potential of egg and larvae surveys to be used for recruitment indices of certain (commercially interesting) cephalopods could be explored. Commercial landings data, including information on the size composition of landings, could be used to estimate the abundance of individuals recruiting to the fishery. Generalized depletion models may also provide recruitment indices.

5.4 Conclusion

Cephalopods provide a unique challenge to the assessment of Good Environmental Status under the MSFD given their short and semelparous life cycle and complex migratory behaviour. While their commercial importance is increasing, knowledge on their life cycle and ecology is lagging. Several indicators were found to be unsuitable to cephalopods in general. Nevertheless, both scientific surveys and commercial data may provide valuable insights into the status of cephalopods and an increase in sampling effort, harmonized taxonomic practices, and research may provide a wealth of information on this enigmatic group. This may lead to successful integration of cephalopods into the reassessment of the marine environment under the MSFD in 2030.

6 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

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Justification

Report: C108/25
Project Number: 4318100537

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: ir. R. van Hal
Researcher

Signature: [redacted]

Date: December 12, 2025

Approved: C.J. Wiebinga, PhD
Business Manager Projects

Signature: [redacted]

Date: December 12, 2025

Annex 1 Extended indicator table

Descriptor	Criterium	Indicator	Defined/accepted in MSFD?	Reference points	Suitability for cephalopods	Reasoning	Source
D1: Marine biodiversity	C1: Mortality rate per species from incidental bycatch	Fishing mortality due to incidental capture/discards (F)	Yes (for fish)	F_{msy}	Possibly suitable	Dependent on availability of methods that allow for the calculation of F (such as stock assessment models). Reference points to be based on sustainable levels of F.	
		Number and rate of individuals caught as by-catch per species per fishing metier/fleet-area	In development (for fish); Yes (for some marine mammals)	Not defined	Suitable	For non-commercial species, only developed for some marine mammals (not for fish, cephalopods, etc.)	
	C2: Population abundance	Presence, no decrease compared to previous period (OSPAR FC1)	Yes (for fish)	Relative to previous period	Suitable	Developed for sensitive fish species (OSPAR FC1) with long life cycles. Averaged abundances over the last 6 years compared to the 6 years before (short-term) and compared to the whole time-series (long-term). Sampling coverage is seen as adequate when a species is present in at least 6 samples.	Ontwerp Mariene Strategie (deel 1) OSPAR (2016)
		SSB > MSY $B_{trigger}$	Yes (for fish)	MSY $B_{trigger}$	Not suitable	A cat 2 stock assessment is required which is unavailable for most cephalopod species. Furthermore, it is unlikely that the MSY approach is valid for cephalopods (Roa-Utera, 2019).	Ontwerp Mariene Strategie (deel 1)
		Favourable Reference Population	Yes (for several fresh water fish under the Habitat Directive)	FRP	Not suitable	Likely not suitable due to the dynamic nature of cephalopod stocks and the lack of data on what constitutes a favourable population size.	Ontwerp Mariene Strategie (deel 1)

Descriptor	**Criterium**	**Indicator**	**Defined/accepted in MSFD?**	**Reference points**	**Suitability for cephalopods**	**Reasoning**	**Source**
	C3: Demographic characteristics (size and age distribution)	Large fish indicator	Yes (for fish)	30%	Likely unsuitable	This indicator could possibly be calculated at some point during the life cycle, but given the semelparity of cephalopods, a complete lack of large individuals is in no way an indication of a degraded population.	OSPAR
	C4: Distributional and range pattern	Favourable reference range	Yes (for several fresh water fish)	FRR	Not suitable	Probably not applicable to fully marine species where (man-made) barriers to distribution are not relevant and habitat size cannot be decreased. Only applicable to Habitat Directive species.	Ontwerp Mariene Strategie (deel 1)
		Distributional pattern and range	Yes	Distributional range in reference period	Suitable	Compares number of spatial units (ICES statistical rectangles) occupied to that occupied in a reference period.	Bobowski et al. (2023); OSPAR (2016)
	C5: Habitat requirements	-	Yes (for marine mammals and fish)	-	-	Only applicable to Habitat Directive species.	Ontwerp Mariene Strategie (deel 1)
	C6: Pelagic habitat requirements	-	Not yet defined	-	-	Based on plankton community, not specific to any (cephalopod) species	Ontwerp Mariene Strategie (deel 1)
D3: Commercially exploited fish and shellfish	C1: Harvest rate (fishing mortality)	$F < F_{MSY}$	Yes (for fish)	F_{MSY}	Not suitable	A cat 2 stock assessment is required which is unavailable for most cephalopod species. Furthermore, it is unlikely that the MSY approach is valid for cephalopods.	Ontwerp Mariene Strategie (deel 1)
		Harvest rate (Yield/Catch-Per-Unit-Effort)	No	Multi-year trends	Suitable	Commercial information at high taxonomic scale needed. Temporal scale needs to be considered due to short life cycle.	Bobowsi et al. (2023)
	C2: Spawning stock biomass	Spawning stock biomass	Yes (for fish)	MSY $B_{trigger}$	Not suitable	A cat 2 stock assessment is required which is unavailable for most cephalopod species. Furthermore, it is unlikely that	Ontwerp Mariene Strategie (deel 1)

Descriptor	Criterium	Indicator	Defined/accepted in MSFD?	Reference points	Suitability for cephalopods	Reasoning	Source
						the MSY approach is valid for cephalopods.	
		Catch-Per-Unit-Effort of mature individuals	No	Multi-year trends	Suitable	Commercial information at high taxonomic scale needed. Temporal scale needs to be considered due to short life cycle.	Bobowski et al. (2023)
	C3: Demographic characteristics (size and age distribution)	Proportion of older fish in a population (in a given year) relative to the proportion of older fish at equilibrium under constant fishing at FMSY	No	1	Not suitable	Due to the semelparous nature of most cephalopod stocks, any indicator assessing population structure by age is unsuitable. Category 2 stock assessment required.	ICES (2024a); Griffiths et al. (2024)
		Proportion of older spawners by biomass	No	Not defined	Not suitable	Due to the semelparous nature of most cephalopod stocks, any indicator assessing population structure by age is unsuitable.	ICES (2024a); van Deurs et al. (2023)
		Average spawner age, weghted by cohort biomass	No	Not defined	Not suitable	Due to the semelparous nature of most cephalopod stocks, any indicator assessing population structure by age is unsuitable.	ICES (2024a); van Deurs et al. (2023)
		SSB as a proportion of recruitment	No	Not defined	Possibly suitable	Dependent on estimates of both spawning stock and recruitment. Squid biomass is highly dynamic, so between-year changes should be interpreted with caution.	ICES (2024a); Probst (2023)
		Recruitment	No	Not defined (long-term geometric mean)	Suitable	ICES (2024) shows that for long-lived species, this is more suitable than other, more complex indicators, in predicting recruitment. Squid biomass is highly dynamic, so between-year changes should be interpreted with caution.	ICES (2024a)

Descriptor	Criterium	Indicator	Defined/accepted in MSFD?	Reference points	Suitability for cephalopods	Reasoning	Source
		90th percentile of length of individuals in the population	No	Not defined	Possibly	Informs on population reaching largest sizes and successfully reaching maturity. However, the link between size and maturity is weak for many cephalopod species. Temporal scale needs to be considered due to short life cycle.	ICES (2024a); ICES (2023)
		90th percentile of length of individuals in the population, excluding recruits	No	Not defined	Likely unsuitable	Informs on population reaching largest sizes and successfully reaching maturity. However, the link between size and maturity is weak for many cephalopod species. Temporal scale needs to be considered due to short life cycle.	ICES (2024a); ICES (2023)
		Average spawner weight, weighted for differences in weight at age of cohorts	No	Not defined	Likely unsuitable	the link between size and maturity is weak for many cephalopod species. Temporal scale needs to be considered due to short life cycle.	ICES (2024a); van Deurs et al. (2023)
		Small squid indicator	No	Not defined	Suitable	Could be a sign of fishing in recruitment or nursery areas, though is that a problem for a semelparous species?	Bobowsi et al. (2023)

Annex 2 Extended species table

Family/Order	**Genus**	**Species**	**Prevalence**	**Included?**
Brachioteuthidae	*Brachioteuthis*	spp.	Sporadic	No
Gonatidae	*Gonatus*	*fabricii*	Sporadic	No
		steenstrupi	Sporadic	No
		spp.	Sporadic	No
Loliginidae	***Alloteuthis***	***media***	Uncommon	Yes
		subulata	Common	Assumed to be A. media
		spp.	Common	Assumed to be A. media
	Loligo	***forbesii***	Common	Yes
		vulgaris	Common	Yes
		spp.	Common	Yes, explore data to see if these can be assigned to L. vulgaris and L. forbesii
	Lolliguncula	spp.	Sporadic	No, possible misidentification
	-	-	Common	Possibly. Surveys regularly determine only to family level, though less so in recent years. Explore data to see if determination can be done based on length and region.
Teuthida	-	-	Uncommon	No. Determined at Order level. Data cannot be meaningfully used in any assessment
Sepiolida	-	-	Uncommon	Yes. Determined at Order level. Can be assumed to belong to family Sepiolidae.
Ommastrephidae	***Illex***	***coindetii***	Common	Yes
		illecebrosus	Uncommon	Yes, as I. coindetii. Not commonly used.
		spp.	Uncommon	Yes, as I. coindetii. Not commonly used.
	-	-	Uncommon	No. Sometimes determined to family level, though not since 2020
	Sthenoteuthis	spp.	Sporadic	No
	Todarodes	*spp.*	Sporadic	Yes, as T. sagittatus (IBTS)

Family/Order	Genus	Species	Prevalence	Included?
		sagittatus	Uncommon	Yes. Little data available from IBTS, BTS data assumed to be misidentifications of T. eblanae.
	Todaropsis	spp.	Sporadic	Yes, as T. eblanae
		eblanae	Uncommon	Yes
Sepiidae	-	-	Sporadic	No, at family level. Can be ignored.
	Rhombosepion	spp.	Sporadic	No
		elegans	Sporadic	Yes. Previously S. elegans.
		orbignyanum	Sporadic	No
	Sepia	spp.	Uncommon	No. Not reported to genus level since 2022
		elegans	Uncommon	Yes, as R. elegans.
		officinalis	Common	Yes
Sepiolidae	*Adinaefiola*	*ligulata*	Sporadic	Yes, as Sepiolidae
		pfefferi	Sporadic	Yes, as Sepiolidae
	-	-	Uncommon	Yes, as Sepiolidae
	Rondeletiola	*minor*	Sporadic	Yes, as Sepiolidae
	Rossia	spp.	Sporadic	Yes, as Sepiolidae, or as R. macrosoma
		macrosoma	Uncommon	Yes. Would result in paraphyletic group 'other Sepiolidae'
		palpebrosa	Sporadic	Yes, as Sepiolidae
	Sepietta	spp.	Sporadic	Yes, as Sepiolidae
		neglecta	Sporadic	Yes, as Sepiolidae
		oweniana	Uncommon	Yes, as Sepiolidae
	Sepiola	spp.	Common	Yes, as Sepiolidae
		atlantica	Common	Yes, as Sepiolidae
		tridens	Sporadic	Yes, as Sepiolidae
Bathypolypodidae	*Bathypolypus*	spp.	Sporadic	No
Eledonidae	***Eledone***	***cirrhosa***	Common	Yes

Family/Order	Genus	Species	Prevalence	Included?
		spp.	Sporadic	Yes, as E. cirrhosa
Octopodidae	-	-	Sporadic	No, at family level
	Octopus	*vulgaris*	Sporadic	No

Annex 3 Supplementary Figures

Figure S1. *Annual species presence across surveys for selected cephalopod taxa from 2000–2024 (1/3).*

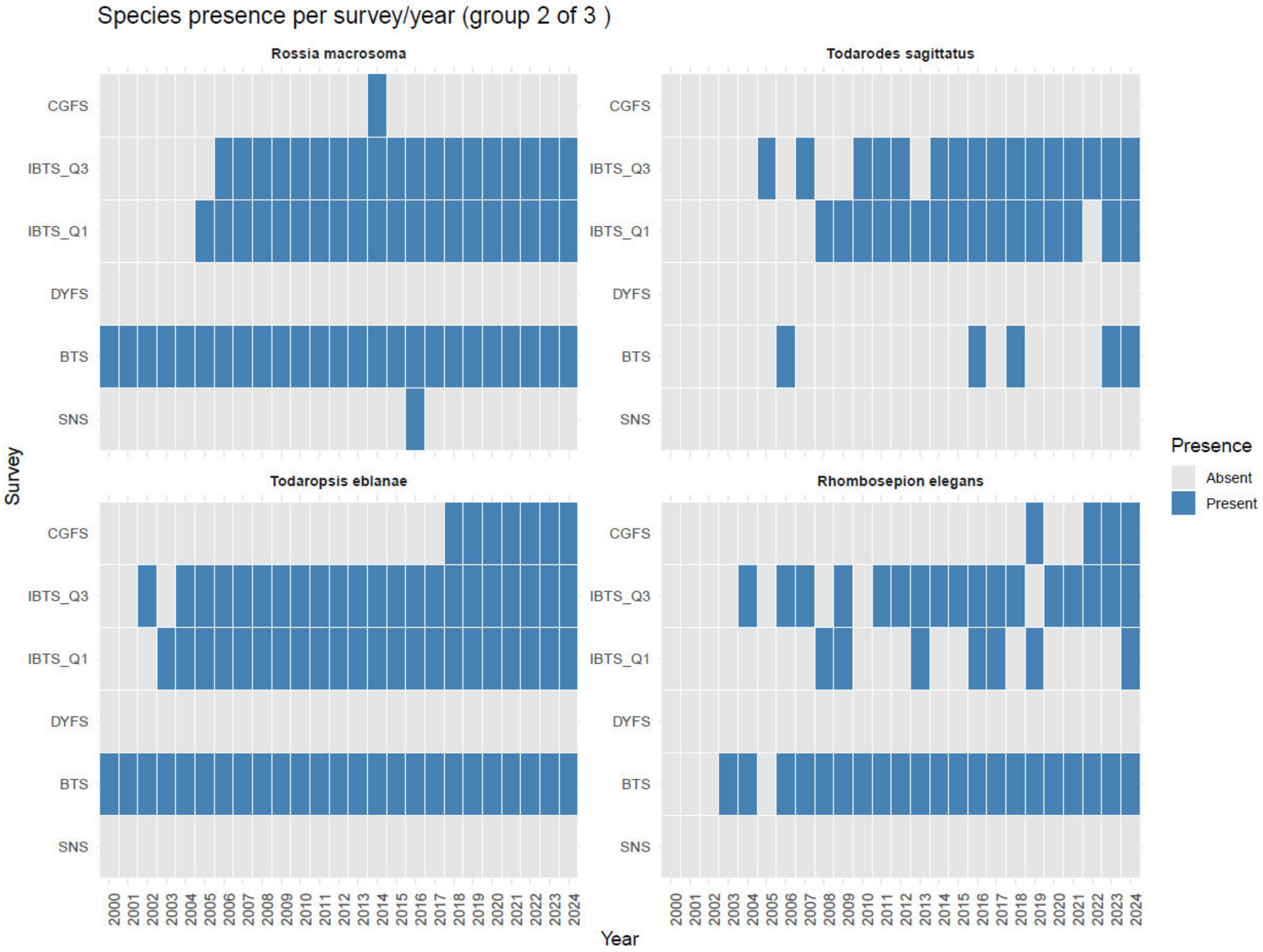

Figure S2. *Annual species presence across surveys for selected cephalopod taxa from 2000–2024 (2/3).*

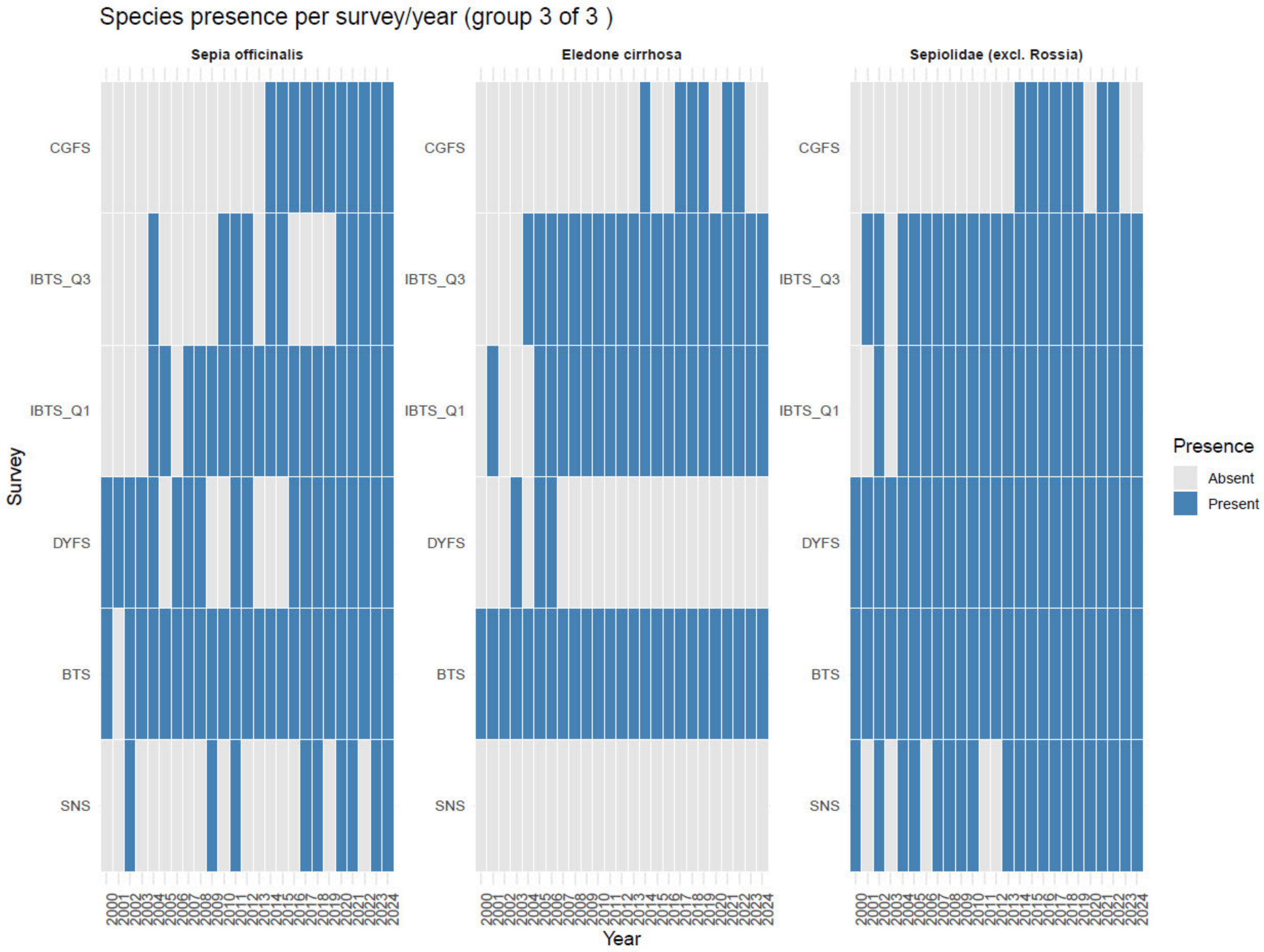

Figure S3. *Annual species presence across surveys for selected cephalopod taxa from 2000–2024 (3/3).*

Figure S4 *Annual total catches (sum of individuals) for priority cephalopod species by reporting country. Species are color-coded and each panel represents a national series. The figure highlights substantial cross-national variation in both catch magnitude and species composition: the Netherlands and Germany report predominantly A. media, France contributes most L. vulgaris and S. officinalis records, and Scotland (GB-SCT) and Norway show the strongest signals for I. coindetii and L. forbesii in offshore years.*

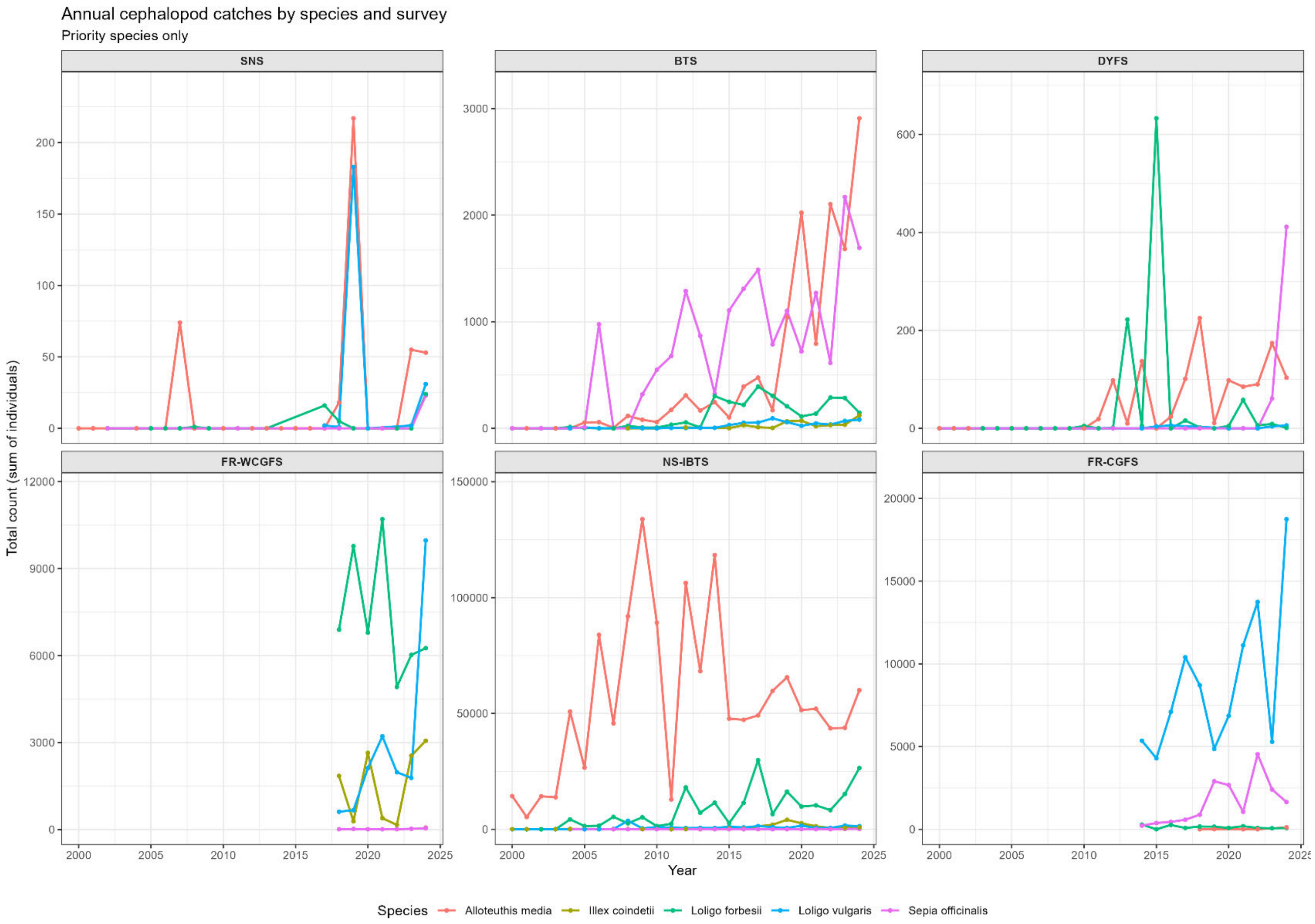

Figure S5. *Annual total catches (sum of individuals) for priority cephalopod species by reporting country. Species are color-coded and each panel represents a national series. The figure highlights substantial cross-national variation in both catch magnitude and species composition: the Netherlands and Germany report predominantly A. media, France contributes most L. vulgaris and S. officinalis records, and Scotland (GB-SCT) and Norway show the strongest signals for I. coindetii and L. forbesii in offshore years.*

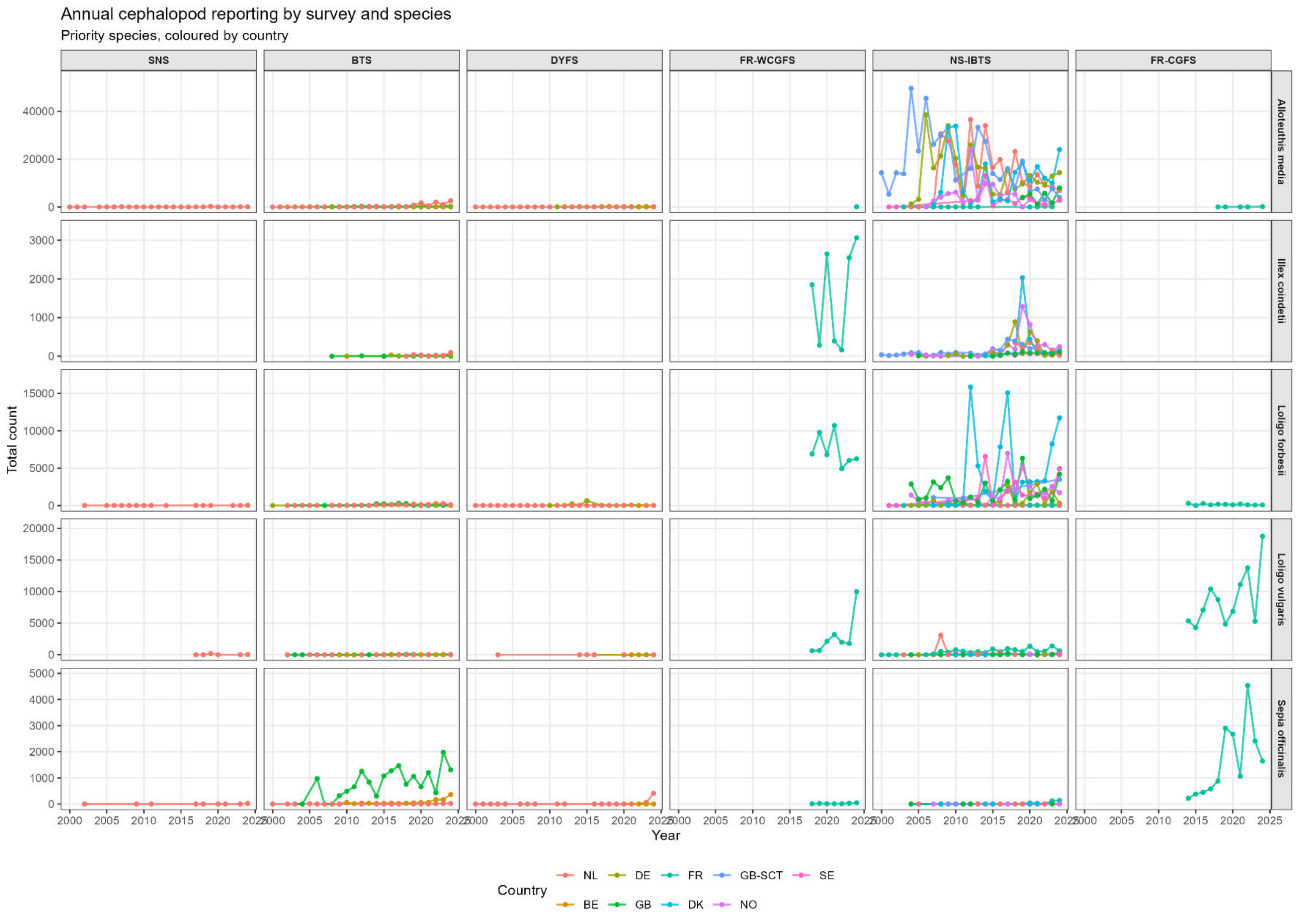

Figure S6 *Annual total counts for priority species, shown for each survey and colored by country. Rows represent species and columns represent surveys. The figure visualizes the interaction between survey coverage and national reporting effort, illustrating—for example—that L. vulgaris appears almost exclusively in French CGFS datasets, while A. media and L. forbesii are reported by multiple countries participating in IBTS. Differences in detection and reporting among countries are evident for all species.*

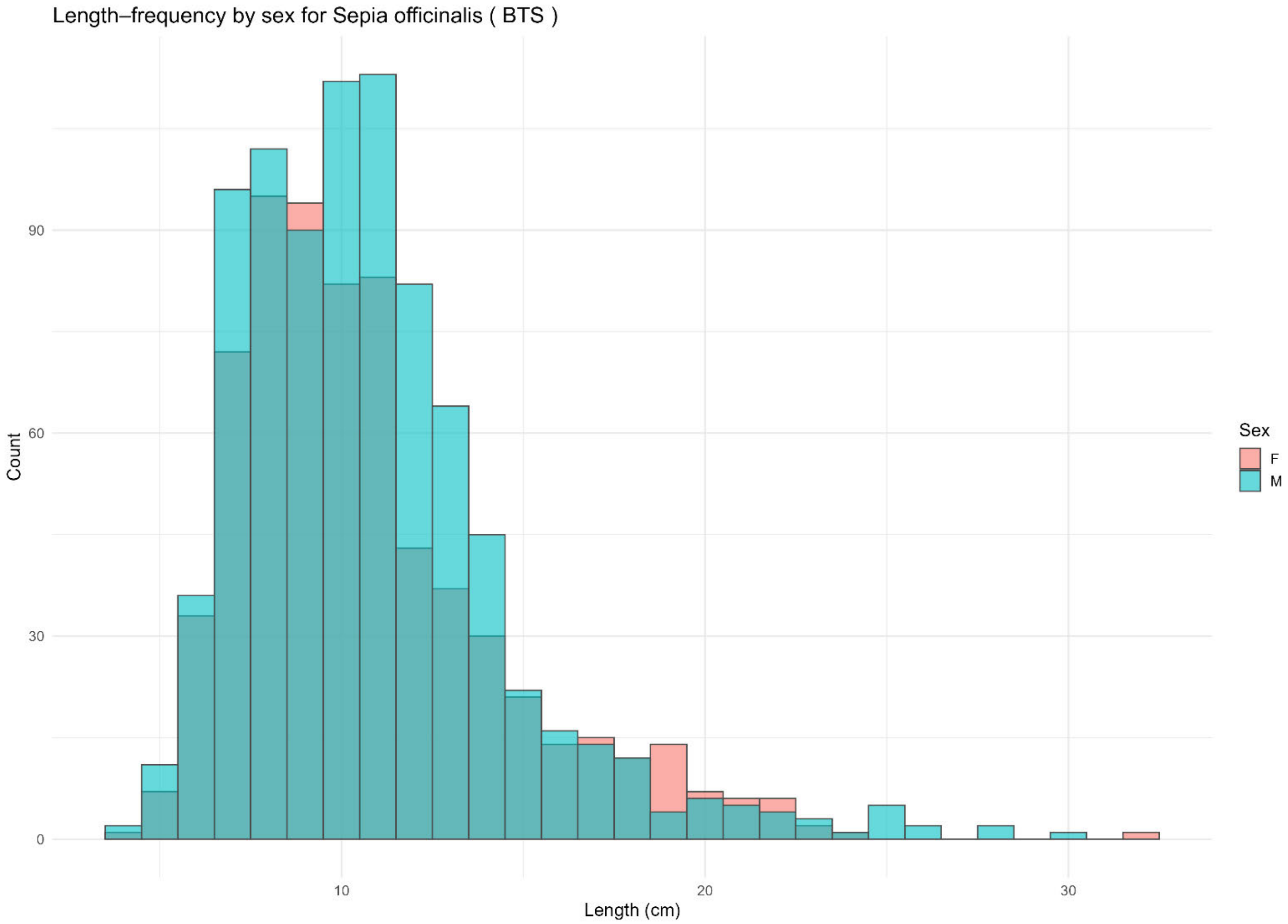

Figure S4. *Length-frequencies between male and female Sepia officinalis derived from BTS CA data.*

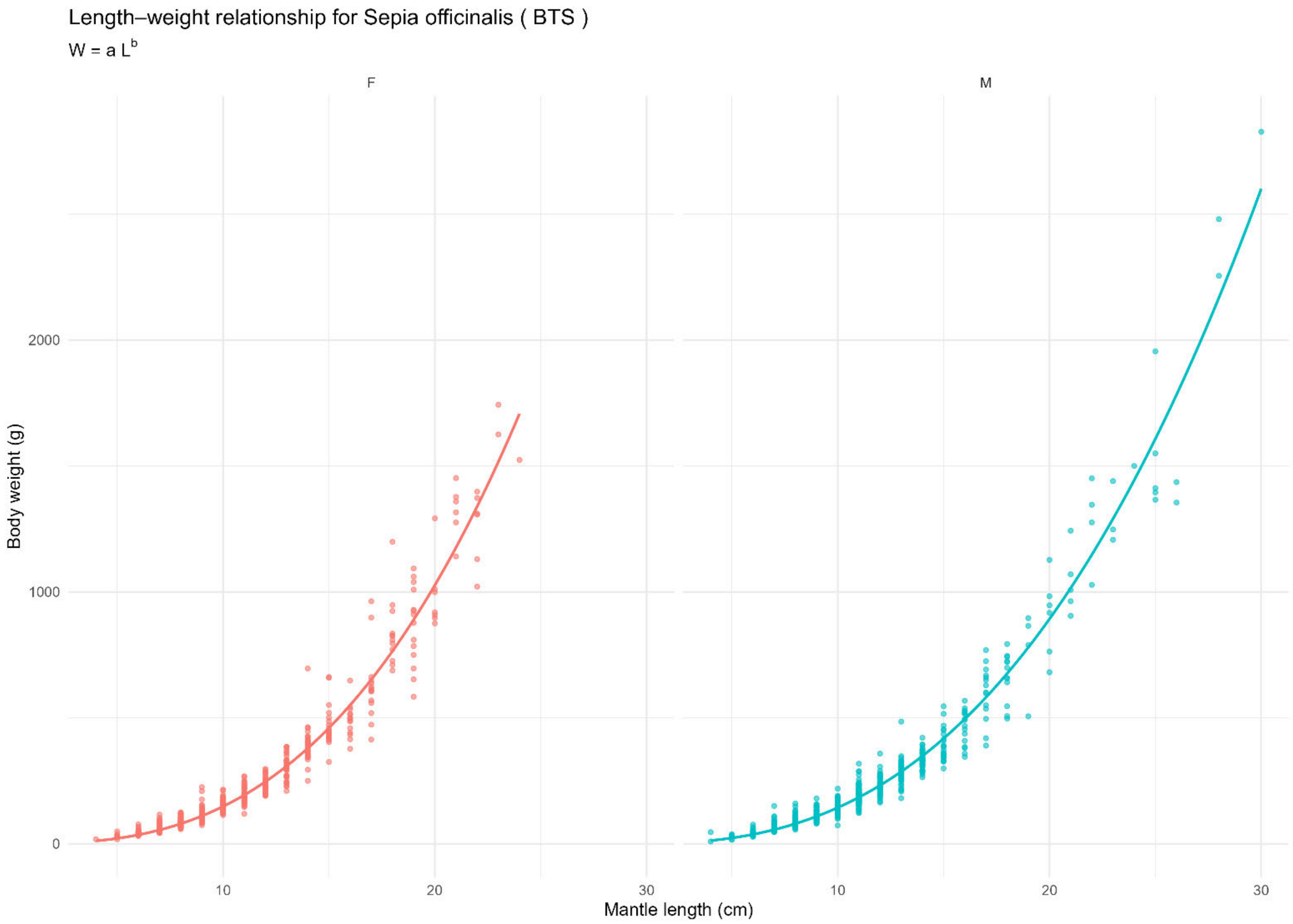

Figure S5. *Length-weight relationships between male and female Sepia officinalis derived from BTS CA data.*

Annex 4 Supplementary Tables

Table S1 *Full records, hauls and total counts table for taxonomic cephalopod groups caught in surveys broken down by country.*

Species	Country	Records	Hauls	Total count
Alloteuthis media	DE	14,759	1,821	9,342,693
	GB-SCT	5,805	1,054	5,034,583
	NL	8,687	3,293	1,758,113
	DK	4,206	800	1,663,992
	NO	1,403	337	1,030,253
	FR	880	809	416,271
	SE	1,799	524	409,708
	GB	3,040	1,395	224,277
	BE	369	369	4,363
Loligo forbesii	FR	4,069	838	1,194,349
	NO	5,780	775	587,181
	DK	2,603	509	572,412
	SE	1,488	327	393,646
	GB	3,663	1,160	331,177
	DE	2,660	621	237,772
	GB-SCT	523	116	81,060
	NL	1,676	685	22,750
	BE	29	29	292
Loligo vulgaris	FR	12,310	1,360	3,215,576
	NL	1,148	373	41,024
	DE	384	174	8,797
	GB	496	341	2,677
	DK	398	187	2,389
	BE	160	124	1,582
	NO	27	16	82
	SE	1	1	2
Sepia officinalis	FR	3,679	787	350,931
	GB	8,947	2,630	99,266
	BE	779	272	8,374
	NL	606	326	5,822
	DK	37	25	81
	DE	14	9	65
	GB-SCT	13	13	20
	NO	4	3	8
Illex coindetii	FR	763	151	151,068
	DE	1,095	367	43,059
	NO	1,569	470	32,319
	DK	799	242	21,885
	GB-SCT	1,819	937	13,252
	NL	770	236	11,522
	SE	352	157	3,491

Species	Country	Records	Hauls	Total count
	GB	625	323	2,222
Sepiolidae (excl. Rossia)	FR	643	643	62,864
	NL	1,433	1,219	9,842
	BE	200	200	8,107
	DE	726	514	4,393
	GB	596	594	1,650
	SE	110	109	422
	DK	19	12	326
	NO	79	70	232
Cephalopoda	DK	69	37	63,075
	DE	48	19	2,172
	NL	23	21	213
	NO	2	2	42
Todaropsis eblanae	FR	378	187	14,897
	NO	490	202	5,881
	DE	318	209	1,444
	GB	471	355	910
	DK	138	83	638
	GB-SCT	263	182	610
	NL	284	232	554
	SE	97	66	518
Eledone cirrhosa	GB	2,635	2,634	8,299
	NO	723	404	4,812
	NL	520	505	2,026
	DE	169	135	566
	GB-SCT	330	330	532
	BE	6	6	176
	DK	30	19	160
	FR	32	32	116
	SE	14	14	31
Rossia macrosoma	NO	225	152	1,040
	GB	439	439	865
	DE	106	70	761
	GB-SCT	104	104	240
	NL	80	65	231
	DK	17	10	55
	FR	7	7	26
	SE	2	2	7
Rhombosepion elegans	GB	907	643	2,418
	NO	19	16	66
	NL	15	10	35
	FR	5	4	19
	GB-SCT	9	9	9
	DE	4	4	8
Todarodes sagittatus	NO	149	80	1,264
	GB-SCT	118	64	729
	DE	72	49	339
	GB	46	35	101

Species	Country	Records	Hauls	Total count
	NL	20	14	66
	DK	7	4	52
Sepia	NL	158	157	589
	NO	9	8	22
	DE	3	3	6
	FR	2	2	6
Sepiolida	GB-SCT	12	12	119

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