



Oceanographic parameters associated with spatial occurrence of cephalopods in standardized demersal fishing trawls in the NE Atlantic

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Abstract

In this work, the environmental occurrence ranges of different European cephalopod species are described for the whole NE Atlantic shelf including the greater North Sea and Baltic Sea. This is done based on the environmental parameters collected in-situ during surveys that caught commercially important cephalopod species (1990–2022). Results are supplemented and compared with information available in the published literature and are discussed in relation to available habitat across the range, survey design, etc., and, in particular, which species are most likely to be affected by climate change. Our analyses illustrate that *Loligo forbesii* occupies a broader depth range than *Loligo vulgaris* and *Alloteuthis* spp. Because *L. forbesii* occurs further offshore and at greater depths, this species is likely more resilient to warming than the other loliginids in our study. *Octopus vulgaris* is documented in areas close to the coast with a more southerly distribution, whereas *Eledone cirrhosa* occurs further north and further away from the coast. *Eledone cirrhosa* occurs at lower temperatures and has a much broader depth range, which may provide resilience against warming. By contrast, both ommastrephid squid species (*Illex coindetii* and *Todaropsis eblanae*) showed a very similar tolerance to the three environmental variables (salinity, temperature, depth). This information should contribute to future species distribution modelling by allowing validation of realistic results against each species' range, habitat requirements, and environmental ranges, while appreciating the data limitations caused by the timing and gear used in the survey cruises that supply occurrence and density data.

Keywords Distribution · Physiological tolerances · Continental shelf · Temperature · Salinity · Depth

Introduction

Changing oceans impact the marine ecosystem in different ways. Rising ocean temperatures can affect the presence and absence of species e.g., when local environmental conditions exceed individual species' physiological tolerances (Worm and Lotze 2016), exacerbated by negative biotic interactions (Pearson and Dawson 2003), which may result in some species ('losers') being replaced by other species ('winners') in changing oceans (Wernberg et al. 2014). The

cephalopods appear to be amongst the 'winners' and have benefited from ocean changes as a number of studies in different areas of the world indicate (e.g., Doubleday et al. 2016). In addition, top-down effects of fishing on marine food webs, by reducing the abundance of some commercial predatory finfish species, might also support the increase of cephalopods (Pauly et al. 1998; Pauly and Palomares 2005). Evidence is mounting that climate change has caused shifts in distribution and expansions for various cephalopods, worldwide (e.g., Keller et al. 2016; Oesterwind et al. 2022;

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van der Kooij et al. 2016; Golikov et al. 2024; Huang et al. 2024). Consequently, fisheries have adapted to these new resource levels and cephalopod landings have increased or are increasing in many areas (e.g., Hastie et al. 2009a; Pinnegar et al. 2016; Doubleday et al. 2016; Arkhipkin et al. 2021; Sulanke et al. 2026a). However, in some areas, a stable or even a declining trend in cephalopod biomass is observed (e.g., declines of *Loligo forbesii* on the Iberian Coast; Chen et al. 2006), which might be linked to unfavourable living conditions (e.g., low salinities, high temperatures) and/or overfishing. Borges et al. (2023) also describe a potential overarching negative impact of ocean warming on cephalopods, which runs contrary to the ‘winners’ narrative.

Cephalopods play an important role in marine ecosystems by exerting top-down pressure on lower trophic levels, but also through a bottom-up effect caused by their role as major prey for some marine mammals and predatory fishes (Clark 1996a, 1996b; Rodhouse et al. 1996; Klages and Clarke. 1996; Oosterwind and Piatkowski 2023). Hence, changes in the distribution and abundance of cephalopods might both cause and explain changes in ecosystem functions and services, which highlights the importance of knowledge regarding their distribution and its drivers. To address the dynamic changes that we can expect in the future, information on distribution-associated environmental conditions will provide the opportunity to model future suitable habitats and occurrence of cephalopods, which is interesting from both fishery and ecological perspectives. Some model outcomes are already published and show realistic projections (Alabia et al. 2016; Borges et al. 2022; Guerreiro et al. 2023a; 2023b; Huang et al. 2024). The quality of the results depends not only on the modelling framework used (e.g., whether all relevant abiotic factors are included, consideration of spatial variability, etc.), but will also depend on the available species data and its quality. However, many statistically sound modelling studies have failed to consider the ecology of the species, resulting in implausible models (Fiorentino et al. 2025). For example, Schickele et al. (2021) showed an observed contemporary distribution for *Octopus vulgaris* based on a publicly available dataset (in this case, OBIS/GBIF), which very likely has errors in relation to the northern limits of distribution because this species does not normally occur in the North Sea (at least, in recent decades; Goud et al. 2019; Oosterwind et al. 2022) and which included very old records in the model (the oldest is from 1843). Also, the model’s omission of relevant ecological variables, such as salinity, resulted in a slightly positive environmental suitability index for this species in the Baltic Sea, where salinities are currently too low for most cephalopods and will probably decrease further in the future (Lehmann et al. 2022). Here, Schickele et al. (2021) failed to take account of the salinity tolerances of

O. vulgaris, although they considered this variable for two other cephalopod species (*Sepia officinalis* and *Loligo vulgaris*). The widespread use of public data and an increased urgency to understand and predict the distribution shifts attributable to global warming leads to more publications in this topic, which increases the risk of obtaining inappropriate models (Robinson et al. 2017).

Some information on the physiological tolerances of cephalopods is known from laboratory studies and aquaculture experience (e.g., Giménez & García 2002; Rosa et al. 2014), which under certain conditions (i.e. where sufficient temperature range is included) can provide information about the fundamental niche of the species (see below). Tolerance information for a species can be inferred from field observations about its realised niche (e.g., Pierce et al. 1998; Hastie et al. 2009a; Oosterwind et al. 2010, 2015; Ikica et al. 2019; Barrett et al. 2021). For example, environmental data are sometimes logged in-situ and are coincident with species sampling (e.g. on a research cruise), which provides a precise understanding of habitable conditions and which can also be a useful comparison against modelled environmental data. This is the empirical equivalent of a more experimental approach, where temperature-logging tags have been used to explore the thermal niche inside and outside of the breeding season in Atlantic cod, along with temperature-associated growth rates (Righton et al. 2010). Information from both field and laboratory has advantages and disadvantages, as discussed by Binning (2025). Laboratory data are constrained by the experimental design (e.g., often restricted to one or few temperature levels), while aquaculture experiments aim to provide information about optimal culturing conditions and hence present optimal temperature-metabolism-growth relationships, rather than replicating the real constraints presented by natural habitats, chiefly biotic interactions. Nevertheless, this physiological information from experiments can help to define basic tolerances and, depending on the experiment, might point towards the ‘fundamental niche’ (broad environmental tolerances in the absence of other constraints, particularly biotic interactions; Hutchinson 1957). The latter is generally wider than the ‘realised niche’ in a natural ecosystem, which instead reflects the species tolerance shaped by food availability as well as the pressures of biotic interactions from predators, competitors, symbioses and facultative interactions, etc. (Hutchinson 1957). Both fundamental and realised niche information can be used to construct models that predict future species distributions with the latter being more useful for estimating future distribution predictions (Pearson and Dawson 2003). Such information can be provided from field observation of where species occur in nature. A caveat with cephalopods (and other marine species) is that field data sources are limited by the spatial and

temporal scope of surveys, as well as the catchability of cephalopods in survey gears.

The International Council for Exploration of the Sea (ICES) co-ordinates and hosts a publicly available database, DATRAS (Database of Trawl Surveys), which is focused on commercially fished species in the NE Atlantic. This database hosts international fisheries survey sampling data presented in a standardised format, with good information on sampling effort and gear. Oceanographic conditions measured in situ during fishing operations are also provided for each fishing haul. Biases are, however, present due to sampling constraints (such as sampling gear, also very shallow or very deep areas are not sampled) and due to changes over time in taxonomic identification and resolution, specifically, early cephalopod records were identified to genus rather than species level and some species are difficult to identify morphologically. The present study was conducted by researchers who also contribute cephalopod data to DATRAS, with detailed knowledge about potential data biases. There are three purposes of this study. First, to use DATRAS to describe the current distribution of commercially important cephalopods in the NE Atlantic Shelf, providing remarks about any biases and issues in those data. Second, to advance our knowledge regarding the ‘realised niche’ of these cephalopods using a combination of occurrence and in-situ oceanographic data, i.e. ‘environmental occurrence’. This information provides a basis for assessing the ecological plausibility of distribution modelling exercises in the NE Atlantic under current and future climate change scenarios. Finally, the environmental occurrences and preferences of related species are compared to examine whether differences might help to predict any ‘winners’ or ‘losers’ from future climate changes in the NE Atlantic.

Material & methods

To obtain data on both the occurrence of cephalopod species in the NE Atlantic Shelf and associated oceanographic data, we accessed the ICES DATRAS, an online database including bottom trawl fish surveys. These fish surveys are coordinated by different ICES expert groups that have been developed for use in fish and shellfish stock assessments and community studies by the ICES community and public users. The spatial-temporal coverage of the different otter and beam trawl surveys (Supplementary Table S1) includes the following ICES ecoregions: Baltic Sea, Greater North Sea, Celtic Seas and the Bay of Biscay & Iberian Coast (for more information and fishing protocols: <https://www.ices.dk/data/data-portals/Pages/DATRAS.aspx>). For the present study, the available data from 1990 to 2022 were extracted and filtered by species and ICES fishing areas. Taxa recorded

at genus (except for *Alloteuthis* spp.), family, or higher taxonomic ranks were excluded. Species names were checked using the World Register of Marine Species (WoRMS) database. Some taxonomic issues were identified. For example, it is very likely that *Illex illecebrosus* records in the Irish Shelf and North Sea study regions refer to *I. coindetii* (Oesterwind et al. 2020; Sheerin et al. 2020; AMP pers. obs.), so these records were combined under *I. coindetii*. However, records of *Alloteuthis subulata* as well as some records of *O. vulgaris* in the northern part of the North Sea seem to be questionable and indicate some additional identification problems within the surveys (Sheerin et al. 2023; Oesterwind et al. 2022; Goud et al. 2019), which will be discussed in depth in the relevant sections below.

Information about the species occurrence and associated environmental ranges was obtained by cross-referencing the station information (i.e., haul meta-data - HH table) and length-based data (HL table) from DATRAS, using the shared fields survey, year, quarter (Q1 to Q4), ship, gear, station number and haul number. Oceanographic variables considered were bottom depth, sea bottom temperature (SBT) and sea bottom salinity (SBS), because these are demersal surveys and fished individuals are linked to the environmental conditions at the bottom. Only fishing hauls classified as valid and with information on the total number of animals caught or the catch weight were considered. To filter out implausible environmental values in the dataset, such as those caused by data entry errors, we removed, for each species, all data points that were outside the 1st and 99th percentile boundaries. For the most frequently observed species, we also calculated the mean abundance, standardized to 60 min haul duration, and the standard error using a bootstrapping procedure. Mean abundance estimates were determined using all valid hauls, including those with zero catch of the species, to cover the full extent of the sampled area. Hauls with invalid animal counts (e.g., negative values in the original dataset) were excluded.

The cleaning and processing of DATRAS datasets was partially conducted using modified versions of functions provided by the *tidyices* package (Hjorleifsson 2021) while the data visualization was performed using the *ggplot2* package (Wickham 2016), both developed for R (R Core Team 2019). We further conducted a literature review to supplement and compare our analysis.

Results

Survey coverage

The surveys cover the whole NE Atlantic shelf including the greater North Sea and Baltic Sea (Fig. 1). A total of 100

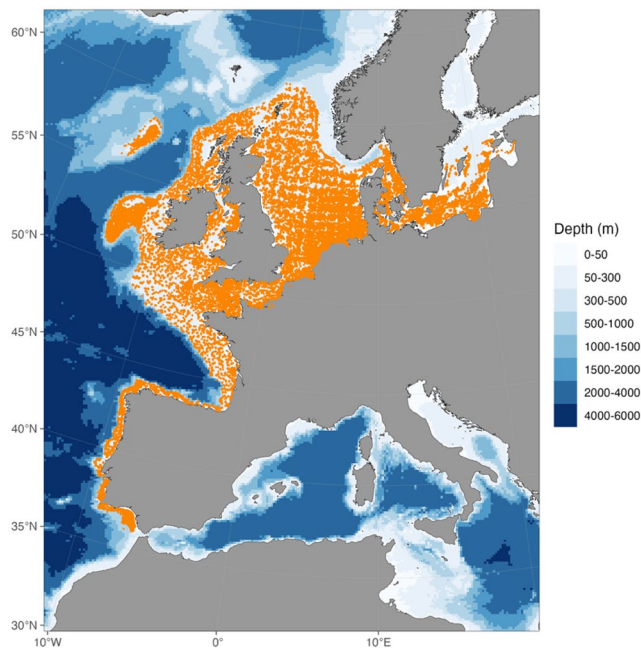


Fig. 1 Location of all valid hauls (orange dots) between 1990 and 2022 according to the DATRAS database and considering the shoot location for each haul. Each dot represents a fishing operation

736 valid hauls with plausible geographic information were analysed, including a depth range between 1 m and 787 m, SBS between 4.92 and 38 psu and SBT between -0.2 and 35.4 °C (Supplementary Figure S1). The most frequent species available were *Alloteuthis* spp., *Eledone cirrhosa*, *I. coindetii*, *L. forbesii*, *L. vulgaris*, *O. vulgaris* and *Todaropsis eblanae* (Fig. 2). Datapoints were also available for species such as *Todarodes sagittatus* and sepiolids but these were not analysed further on the basis that *T. sagittatus* is an oceanic squid and we assume that the area covered by surveys does not sufficiently cover its total distribution range; while for sepiolids, we assume that catchability was low due to the mesh sizes used.

Species distribution and environmental occurrence

Alloteuthis spp.

New genetic results indicate some taxonomic problems within the genus *Alloteuthis*, especially between *A. subulata* and *A. media* because their distribution overlaps in Iberia and the Mediterranean, although the North Sea and Irish Shelf currently contain only *A. media* (Olmos-Pérez et al. 2018; García-Mayoral et al. 2020; Alujević et al. 2022; Sheerin et al. 2023). Therefore, we have used the classification *Alloteuthis* spp. when referring to records from the entire range for this genus. Prior to recent genetic barcoding confirming North Sea and Irish Shelf records as *A. media*, species assignments were based on morphology and

Alloteuthis 'subulata' was reported as widely distributed in shallow coastal waters of the NE Atlantic and Mediterranean Sea (between 20 °N and 60 °N) (Hastie et al. 2009b, 2013). It is particularly abundant in Irish waters and the English Channel (Rodhouse et al. 1988; Lordan et al. 1995; Nyegaard 2001) and common in the North Sea (De Heij and Baayen 2005; Oosterwind et al. 2010). *Alloteuthis* spp. were also considered the dominant cephalopod in the southern North Sea (De Heij and Baayen 1999). These species extend southward along the coasts of France, Spain and Portugal (Hastie et al. 2009a; Olmos-Pérez et al. 2018; Moura et al. 2020; García-Mayoral et al. 2020) and the Mediterranean Sea (Mangold-Wirz 1963; Belcari and Sartor 1993; Relini et al. 2002; Cuccu et al. 2003; Kaspiris and Tsiambaos 1986; Lefkaditou et al. 2012) and it is clear that *A. subulata* and *A. media* are present throughout that range (Sheerin et al. 2023). Our analysis of DATRAS shows that *Alloteuthis* spp. are distributed all over the NE Atlantic Shelf area (Fig. 2), particularly in the central region of the North Sea and in the Irish Sea, which has also been shown by current literature (Oosterwind et al. 2010; de De Heij and Baayen 2005). However, *Alloteuthis* spp. are absent from some areas of deeper water to the west of Ireland (Fig. 2; Table 1).

Within our dataset, *Alloteuthis* spp. were fished between 7 and 154 m depth (Table 1). In terms of local abundance, DATRAS showed a peak between depths of 50 and 100 m (Fig. 3). Our data showed that *Alloteuthis* spp. occur at SBTs between 5.6 and 20.1 °C (Table 1). The analysis showed two temperature-related peaks in occurrence (Supplementary Figure S2). One was around 17 °C, and due mainly to records obtained during the third quarter of the year for the relatively shallow central and southern North Sea (ICES division 4b, 4c) and the English Channel (7d) (Supplementary Figure S5). This peak is comparable only with temperatures preferred by *A. 'subulata'* in Portuguese waters (15 – 18 °C; Hastie et al. 2009b). The second peak was approximately 7.5 °C, where high abundances were also recorded, mainly driven by samples obtained during the first quarter of the year, around the north and central North Sea (ICES divisions 4a, 4b) (Fig. 3, Supplementary Figure S5). In the past, most records of *Alloteuthis* spp. in divisions 4a, 4b and 4c coincided with progressively lower SBTs, a trend that has reversed in the past 10 years as temperatures are increasing in the North Sea (Supplementary Figure S5). Seasonal migrations performed by *Alloteuthis* spp. within the North Sea (Heij and Baayen 1999; Oosterwind et al. 2010) may also influence the observed SBT peaks in the central North Sea.

Concerning SBS, *Alloteuthis* spp. occurred between 30.1 and 36.2 psu (the broadest salinity tolerance of the three loliginids) but with most of the observations coincident with salinity values around 35 psu (Table 1, Supplementary

Fig. 2 Distribution of the presence records (i.e. with information on the total number of individuals caught or the total weight of the catch) for the seven taxa considered most well covered by the ICES DATRAS Surveys during 1990–2022

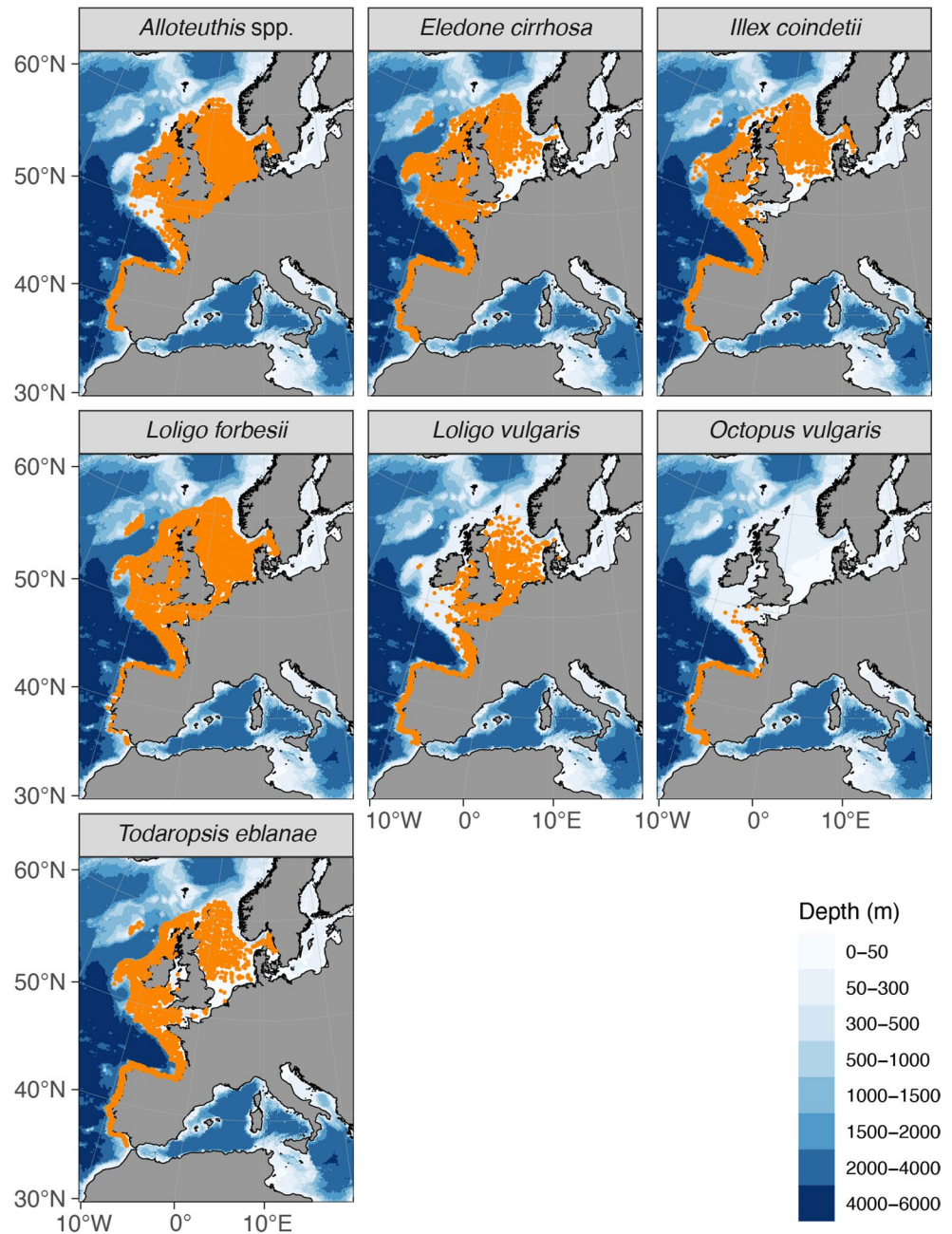


Figure S2). The peak in observations at SBSs around 35 psu also coincided with records of highest abundance (Fig. 3).

Loligo forbesii

The veined squid (*Loligo forbesii*) has a significant commercial value in Northeastern Atlantic waters (Jereb et al. 2015). It is a nektonbenthic species that can be found in coastal and continental shelf areas of the NE Atlantic, from the Faroe Islands (Gaard 1987) and Norway (Grieg 1933) to the west coast of Africa and around the Canary Islands, Azores and Madeira (Porteiro and Martins 1992; Clarke

and Lu 1995; Pham et al. 2009; Jereb et al. 2015) and it is also present in the Mediterranean Sea (Quetglas et al. 2000; Lefkatidou et al. 2003; Relini et al. 2009). *Loligo forbesii* is very common in the North and Central North Sea (Pierce et al. 1998; Bellido et al. 2001; Oesterwind et al. 2010; Smith et al. 2013), west of Ireland (Sheerin et al. 2023) and southwards to the French and Iberian coasts (Pereira et al. 1998; Relini et al. 2009).

Our analysis shows that the North and Central North Sea, as well as Irish and Scottish waters showed the highest *L. forbesii* occurrences (Fig. 2, Supplementary Figure S6). Especially in ICES area 4a, b and 6a, *L. forbesii* occurrences

Table 1 Environmental conditions summarised by species from survey fishing hauls, excluding invalid hauls and unlikely environmental values based on the 1st and 99th percentile boundaries. n – number of sampling stations; SD – standard deviation

Taxa	Depth (m)					Temperature (°C)					Bottom Salinity (psu)				
	Min	Max	mean	SD	Range	n	Min	Max	mean	SD	Min	Max	mean	SD	Range
<i>Alloteuthis</i> spp.	7	154	54	33	147	10,562	5.6	20.1	12.6	4.7	30.1	36.2	34.6	0.9	6.1
<i>E. cirrhosa</i>	23	524	142	94	501	7630	7	16.7	11.3	2.2	33	36.7	35.4	0.5	3.7
<i>I. coindetii</i>	40	488	150	74	448	7406	6.5	16.1	11.1	2.2	31.9	36.1	35.4	0.5	4.3
<i>L. forbesii</i>	23	349	104	54	326	13,445	6.3	19.3	10.8	3.2	32.3	36.1	35	0.5	3.8
<i>L. vulgaris</i>	15	174	57	31	159	3754	6.2	20.1	13.5	3.4	31.6	36.5	35.3	0.9	4.9
<i>O. vulgaris</i>	23	259	98	46	236	1200	11.8	20.2	14.2	1.7	35.3	36.5	35.9	0.3	1.2
<i>T. eblanae</i>	41	459	153	77	418	6187	6.7	15.1	11.1	1.8	34.2	36.3	35.5	0.3	2.1

have increased within the last 20 years (Supplementary Figure S6).

Of the loliginids, *L. forbesii* has the greatest depth range and can occur in deeper waters than *Alloteuthis* spp. and *L. vulgaris* (Table 1; Fig. 3). It also possesses a wide salinity (32.3–36.1 psu, Table 1) and temperature range (6.3–19.3 °C, Table 1). Most *L. forbesii* individuals from DATRAS were fished around a depth of 125 m, but a second abundance peak occurred around 90 m. In contrast, despite the comparatively small number of occurrences, the records of *L. forbesii* in the Cantabrian Sea were consistently found in the shallowest waters. Abundances in relation to salinity also show two peaks of equal magnitude, around 31 and 35 psu. Abundances linked with SBT illustrate only one peak around 12 °C and almost all individuals were fished between 8 and 13 °C (Fig. 3).

Loligo vulgaris

One of the most common squids in the coastal waters of the NE Atlantic and the Mediterranean (Worms 1983; Rosa et al. 2013), *L. vulgaris*, is a key cephalopod species for European fisheries (Malhomme et al. 2015; Palas and Pita 2015; Jereb et al. 2015; Sulanke et al. 2026b). It is a nekto-benthic and neritic species with its distribution ranging from Norway (Grieg 1933) to the west coast of Africa (off Senegal and Angola; Adam 1962). It is commonly present in the central and southern North Sea (De Heij and Baayen 2005; Oesterwind et al. 2010; Laptikhovsky et al. 2022), and abundant in the English Channel (Royer et al. 2002) and along the coasts of France, Spain and Portugal (Guerra 1992; Coelho et al. 1994; Moreno et al. 1994; Olmos-Pérez et al. 2018; Moura et al. 2020; García-Mayoral et al. 2020). *Loligo vulgaris* is also widely distributed in the Mediterranean Sea (Belcari and Sartor 1993; Relini et al. 2002; Lefkaditou et al. 2003; Piccinetti et al. 2012).

DATRAS data illustrated a wide distribution (Fig. 2) and showed highest concentration of occurrences in the Central North Sea and the English Channel (Supplementary Figure S7), and in the Cantabrian Sea and Atlantic Iberian waters. Within the last 20 years, the number of occurrences of *L. vulgaris* has increased considerably in the eastern English Channel, Atlantic Iberian waters and, to a lesser degree in the Central North Sea, although this trend seems to have been interrupted more recently (Supplementary Figure S7). *Loligo vulgaris* was absent in the northern parts of the North Sea and mainly absent to the north and west of Ireland and in Scottish waters (Fig. 2, Supplementary Figure S7), in contrast to the distribution of *L. forbesii*. In the Irish Sea and Bristol Channel, *L. vulgaris* is present but rare.

DATRAS data showed a depth distribution ranging between 15 and 174 m (Table 1) and occurrence in SBT

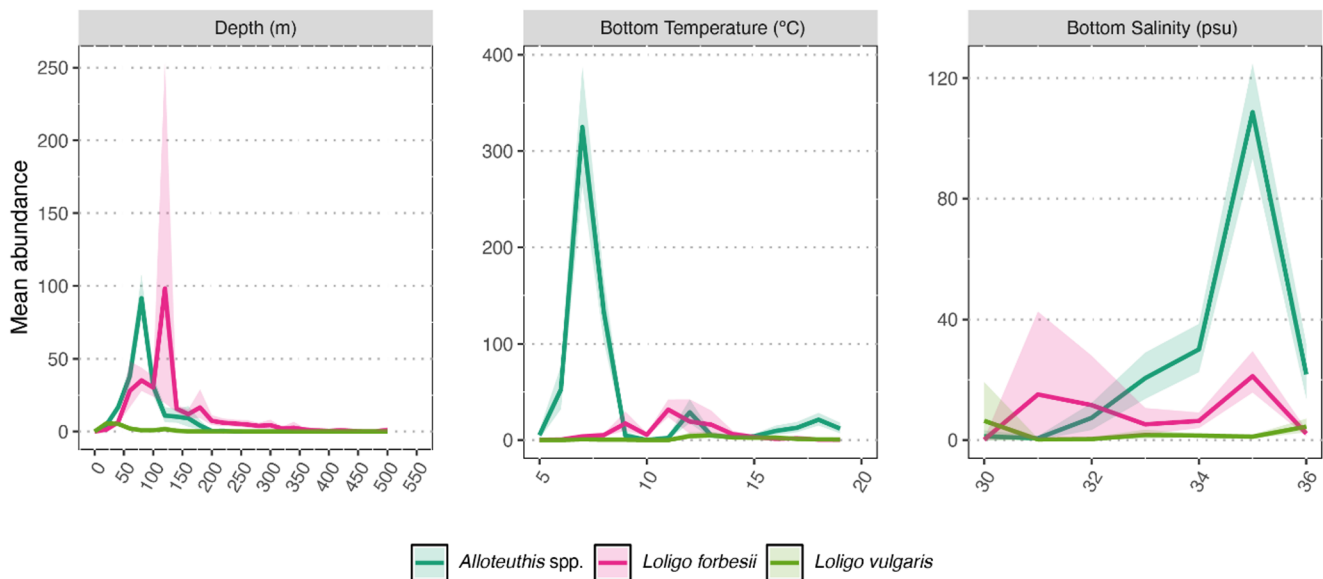


Fig. 3 Estimates of mean abundance (number of individuals per 60 min of haul duration, y-axis) for loliginids species considered in this study (*Alloteuthis* spp., *Loligo forbesii* and *L. vulgaris*) according

between 6.2 °C and 20.1 °C with two temperature-related occurrence peaks (Supplementary Figure S2). One of the peaks was around 15 °C and was mainly influenced by the southernmost occurrences around the Bay of Biscay and the Iberian Coasts (Supplementary Figure S8), which agrees with field observations reported in the literature (Villa et al. 1997; Pereira et al. 1998). The second record peak was around 7.5 °C and was mainly driven by the occurrences around the Central North Sea, in the first quarter of the year. It is noteworthy that in some northern ICES divisions, *L. vulgaris* was observed at relatively warmer temperatures in recent years (e.g., sub-area 4c, southern North Sea; and especially region 7d, the English Channel; Supplementary Figure S8). A recent study has shown that *L. vulgaris* habitat suitability has increased by 31% around the UK since 1985 due to ocean warming (Engelhard et al. 2018), which highlights the effects of global warming on species distribution. However, ocean warming may also lead to a decrease in embryo survival rate in *L. vulgaris* (Rosa et al. 2014), which could counteract this.

Regarding salinity, DATRAS data showed that *L. vulgaris* was present between 31.6 and 36.5 psu. Most records for the species were found at stations with SBSs above 34 psu, with two distinct peaks: one around 35 psu and the other around 36 psu (Supplementary Figure S2). These results show a narrower salinity range compared with other loliginids in DATRAS (particularly *Alloteuthis* spp.). This narrower range is probably explained by the absence of *L. vulgaris* from Skagerrak and Kattegat (in contrast with *L. forbesii*), which tend to have lower salinities than the rest of the study area.

to the depth, temperature and salinity gradients (x-axis). Depth values are binned by 20-metre intervals while temperature and salinity values are binned according to 1 intervals

Abundance begins to increase at SBT above 12 °C. Most *L. vulgaris* were fished at shallow depths, around 20 m.

Illex coindetii

An oceanic, benthopelagic species, *Illex coindetii* occurs in subtropical / temperate, offshore and coastal waters and continental slope areas (Hastie et al. 2009a). In the NE Atlantic, *I. coindetii* is widely distributed and has been reported from the Oslo Fjord in Norway (Lu 1973) and the Belt Sea of the Baltic Sea (Oesterwind and Schaber 2020) as far south as Namibia (Roeleveld 1998). While it seems that this species expanded further north into the North Sea around 10 years ago (2015 onwards, Supplementary Figure S9), probably due to ocean warming (Oesterwind et al. 2020), the results of the present study suggest that *I. coindetii* is almost absent in the southern part of the North Sea and the English Channel (Fig. 2), possibly due to the very shallow bathymetry. Within recent years, the highest frequency of occurrence of *I. coindetii* was in the northern and Central North Sea and southern Bay of Biscay.

The depth distribution within the DATRAS dataset ranged from around 40 m to 488 m (Table 1; Fig. 4, Supplementary Figure S3). The linked SBT ranged from around 6.5 °C to 16.1 °C and showed two peaks. The first peak was at around 12 °C (ranging from 10 °C to 14 °C) and was mainly driven by the stations in the Cantabrian Sea (division 8c) and in the Atlantic Iberian waters (division 9a) (Table 1; Fig. 4, Supplementary Figure S9). The second peak was in the northern and Central North Sea around 8 °C (ranging from 7 to 9 °C, Supplementary Figure S9). In relation to

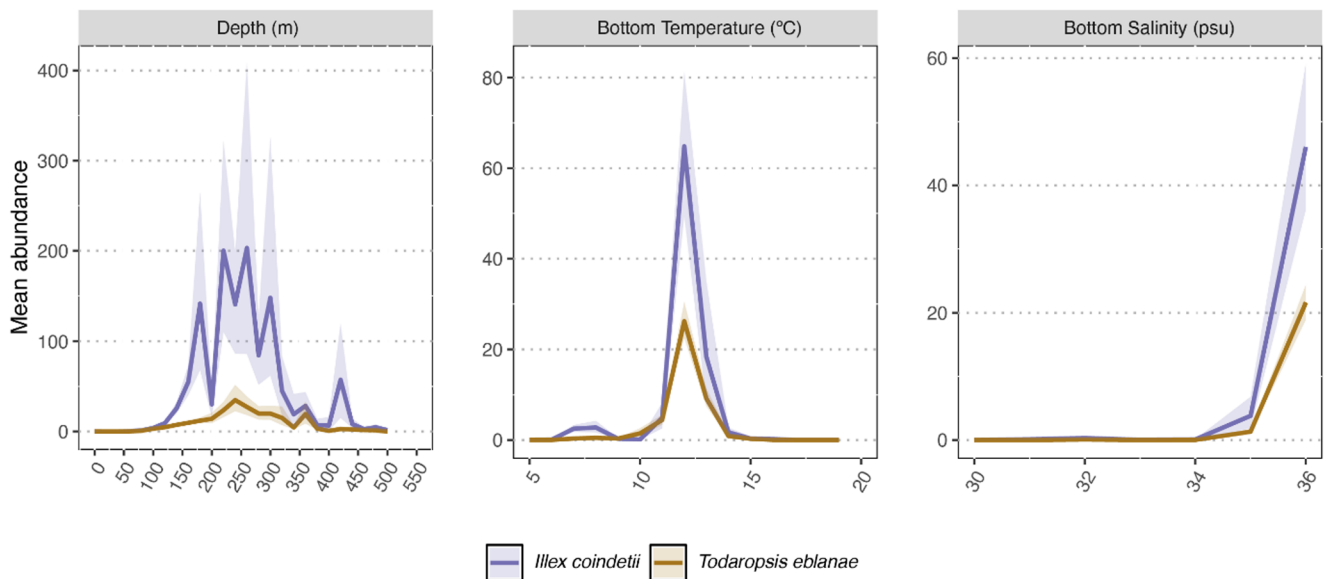


Fig. 4 Estimates of mean abundance (number of individuals per 60 min of haul duration, y-axis) for ommastrephid species considered in this study (*Illex coindetii* and *Todaropsis eblanae*) by depth, temperature

and salinity gradients (x-axis) across the study area. Depth values are binned by 20-meter intervals while temperature and salinity values are binned according to 1 intervals

salinity, highest abundances were at around 35 psu (Fig. 4), while the general salinity range was between 31.9 and 36.1 psu (Table 1; Fig. 4, Supplementary Figure S3). Regarding depth, peaks in abundance were observed around 250 m, 350 m, and 400 m but *I. coindetii* was most abundant at around 250 m. Abundance peaks in relation to SBT were seen at around 7.5 °C and around 12 °C, the latter being higher in magnitude (Fig. 4).

Todaropsis eblanae

A demersal mid-sized ommastrephid squid, *Todaropsis eblanae* has a worldwide distribution, including the NE Atlantic (Roper et al. 2010; Barrett et al. 2021), Mediterranean (Jereb et al. 2015), SE Atlantic (Roeleveld 1998; Kremer et al. 2025), SW Indian, and the SW Pacific Oceans (Nesis 1979), along with eastern and NW Australian waters (Jereb & Roper 2010). In recent years, *T. eblanae* has also been recorded in the Arctic (Sabirov et al. 2009). Similar to *I. coindetii*, *T. eblanae* is not present in the southern North Sea and in the English Channel, again most likely due to the shallow bathymetry (Fig. 2).

The DATRAS dataset showed occurrences in SBT between 6.7 and 15.1 °C (Table 1, Supplementary Figure S3). The observed depth ranged from 41 m to 459 m (Table 1, Supplementary Figure S3), while the salinity range was 34.2–36.3 psu (Table 1).

With regard to abundance, most individuals were fished at depths around 250 m, range 100–390 m; for SBT, abundance peaked around 12 °C, ranging between 10 °C and

14 °C; and highest abundance was at salinity values around 35 psu (Fig. 4).

Eledone cirrhosa

The horned octopus, *Eledone cirrhosa*, lives on rocky and muddy bottoms over the continental shelf and slope of the north-western Atlantic (Boyle 1983; Pierce et al. 2024). It is documented from the Greater North Sea, Celtic Sea, Bay of Biscay, Iberian Coast (Fig. 2) and Mediterranean Sea (Regueira et al. 2014; Jereb et al. 2015; Pierce et al. 2024), and western Africa to Senegal (Luna and Rocha 2025). This species appears as bycatch in commercial fisheries in the NE Atlantic except for UK waters where fisheries interest in it has increased in recent years (Barrett et al. 2023), and it is also one of the most commercially important cephalopod species in the Mediterranean Sea (Belcari et al. 2022b).

The distribution map shows gaps in *E. cirrhosa* occurrence in the southeastern North Sea (Fig. 2), but it was present between 23 m and 524 m in the NE Atlantic (Table 1, Supplementary Figure S4), with highest catches between 100 and 400 m depth (Fig. 5). Giordano et al. (2010) found the highest Density Index values ($N\ km^{-2}$) in Galician waters between 100 and 200 m depth, and similarly, in the central Mediterranean, the Density Index values were highest in the depth range 101–200 m, with the highest Biomass Index ($kg\ km^{-2}$) at 51–100 m. In the present study, most individuals were fished between 150 and 400 m depth with a maximum abundance around 200 m (Fig. 5).

Eledone cirrhosa tolerates a wide range of temperatures, and our analysed dataset showed occurrence between SBTs

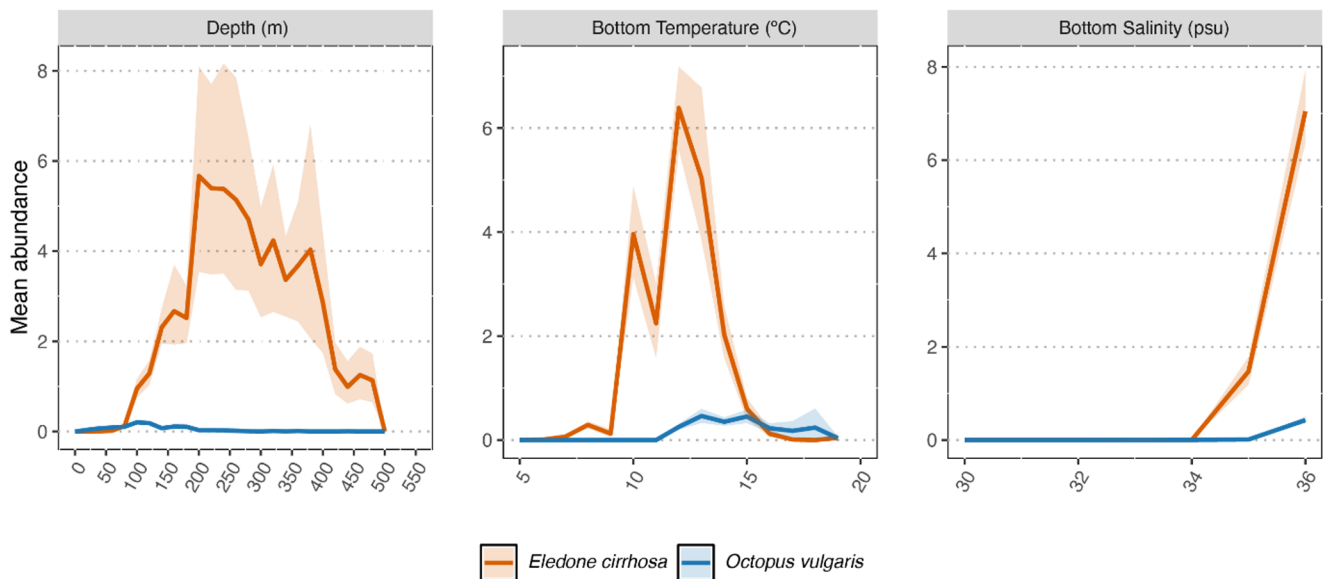


Fig. 5 Estimates of mean abundance (number of individuals per 60 min of haul duration, y-axis) of *Eledone cirrhosa* and *Octopus vulgaris* according to depth, temperature and salinity gradients (x-axis).

of 7 and 16.7 °C (Supplementary Figure S4), with highest abundances between 10 and 15 °C and a maximum abundance at 12 °C (Fig. 5). Its salinity range was between 33.0 and 36.7 psu (Table 1, Supplementary Figure S4), but highest abundances were at around 36 psu (Fig. 5).

Octopus vulgaris

Although widely distributed in the northern and central East Atlantic and Mediterranean Sea (Rosa et al. 2024), most *Octopus vulgaris* sampling stations are in a relatively small area: the Gulf of Biscay and along the Iberian Coast. This species is found in different biotopes: coral reefs, rocks, sandy or muddy bottoms, and seagrass (Katsanevakis and Verriopoulos 2004). Based on our dataset (Fig. 2), *O. vulgaris* very seldom occurs in northern waters, and is not present in the North Sea, Irish Sea, west of Ireland or Scottish waters. Its main distribution is along the southern Shelf including the Iberian Peninsula, with decreasing abundance in the Bay of Biscay (Fig. 2).

Octopus vulgaris is one of the most important commercial species with especially high economic value along the Iberian coast (ICES 2025). This octopus is commonly found in intertidal zones, inhabiting tide pools. However, our analysis illustrates a depth distribution between 23 and 259 m (Table 1, Supplementary Figure S4), but with highest abundances occurring at depths of less than 100 m (Fig. 5). This is consistent with information from the Mediterranean Sea, where Belcari et al. (2022a) mention that the species becomes rare below 200 m.

Depth values are binned by 20-meter intervals while temperature and salinity values are binned according to 1 intervals

Our SBT data showed occurrences between 11.8 and 20.2 °C (Table 1, Supplementary Figure S4), with most individuals caught between 12 and 14 °C in the Gulf of Biscay and between 14 and 16 °C on the Iberian Coast (Fig. 5). Mangold (1983) described temperature tolerances between 6 and 33 °C, with an optimum of about 21–22 °C for sub-adults (between 150 and 200 g) reported from aquaculture studies (Miliou et al. 2005), whereas Giménez & García 2002 reported in their experimental study, optimal economic performance (balance between growth and costs) to be from 16 to 21 °C. It is clear that *O. vulgaris* is a stenohaline species which cannot survive large changes in salinity (Iglesias et al. 2016). Our analysis reveals a salinity tolerance between 35.3 and 36.5 psu (Table 1, Supplementary Figure S4) with highest abundances at around 36 psu (Fig. 5). A salinity of 30 psu was considered the minimum tolerance after several laboratory experiments (Iglesias et al. 2016). However, some local adaptation may occur. For example, in the Ebro Delta, where Delgado et al. (2011) observed that salinity did not affect the survival rate or growth within a test range of 29.0–34.0 psu.

Discussion

A fisheries survey database was used here to describe the realised niche or ‘environmental occurrence’ ranges of several important cephalopod species in Europe to support future distribution predictions. Environmental ranges were obtained for three key environmental drivers of species distribution using species occurrence data and in-situ

oceanographic information collected during fish surveys. This analysis improves knowledge of distribution and the realised niche for various cephalopod species on the NE Atlantic shelf and highlights biases or pitfalls which can be avoided when carrying out species distribution modelling using DATRAS data.

Northward expansions and distribution shifts have been observed for various cephalopod and fish species in the North East Atlantic shelf waters (e.g. Perry et al. 2005; Engelhard et al. 2014; van der Kooij et al. 2016; Núñez-Riboni et al. 2019; Oesterwind et al. 2022). Shallower shelf areas and coastal waters may be more sensitive and respond faster to climate changes (Reusch et al. 2018), which may lead to an earlier impact on species distributions in these areas. Certain species may also be more sensitive, such as those with a narrow environmental tolerance range (if they cannot adapt), and may be among the first ‘losers’ from distribution shifts due to climate change. For example, it can be expected that neritic species with narrower depth ranges may be more vulnerable to global warming because they have limited access to cooler ‘refuge’ depths, hence they may be among the first to face local extinctions. In addition, spatial patterns in habitat availability (including accessibility of potential new habitats), which permit mobile species to move into more suitable habitats, will also play a role. For this reason, it may be an over-simplification to expect simple latitudinal shifts to take place at the relatively local scale of the European Seas (Rutterford et al. 2015). Though usually not considered in species distribution modelling, there may also be biotic constraints from predators, prey and competitors; constraints that are not explicitly addressed in this work.

DATRAS observations showed that *L. forbesii* has a much wider depth range than *L. vulgaris*, while *Alloteuthis* spp. are intermediate between the two *Loligo* species. Therefore, in terms of global warming adaptation, the more offshore and larger depth range of *L. forbesii* may render this species more resilient to change than *L. vulgaris* or *Alloteuthis* spp., especially since shallow coastal waters warm up more quickly (Reusch et al. 2018). For salinity, *Alloteuthis* spp. have more abundance modes at low salinity, followed by *L. forbesii*, then *L. vulgaris*, which was surprising, given the more coastal distribution and narrower depth profile of the latter in our survey data. However, this is likely to be explained by the current absence of *L. vulgaris* from Skagerrak and Kattegat, where it was observed in the past (Grimpe 1925; Tinbergen and Verwey 1945), which tend to have lower salinities than the rest of the study area. The temperature niche almost completely overlapped in both species of *Loligo*, but the preferred modes differed: *Loligo forbesii* had several modes of abundance at lower temperatures while modal frequencies were observed at

higher temperatures in *L. vulgaris*, demonstrating a more southerly distribution of observations in the latter. Again, *L. vulgaris* has not been observed in the Skagerrak and Kattegat in recent years, although it is much more widespread in the Mediterranean and more abundant in southern Europe than *L. forbesii*, which reflects the preference of *L. vulgaris* for warmer waters masses. Van der Kooij et al. (2016) described an increasing abundance of *L. vulgaris* in the north of its range and previous studies also have illustrated that *L. forbesii* appears to be declining in the southern parts of its range in the Iberian coast (Chen et al. 2006). Our analysis of DATRAS data shows that *L. vulgaris* is also absent from northern and western waters of the Irish and Scottish shelves, which contrasts markedly with the broadly similar distributions presented in the literature for both *Loligo* species (e.g., Jereb et al. 2005, 2015).

The distribution or migration pattern of *L. vulgaris* might have changed over time. In the early-to-mid 20th century, it was documented as migrating along the eastern North Sea northwards until the Danish coast and in some years into the Skagerrak and Kattegat (Grimpe 1925; Tinbergen and Verwey 1945; Otterlinde 1959) but, by the 1990s and beginning of 2000s it was very rare in the North Sea surveys. In recent years, numbers are increasing and a targeted fishery has developed for this species in the southern North Sea during Winter months (Sulanke et al. 2026a). Whether *L. vulgaris* was really absent in the northern area in 1990–2000 s or whether the observed absence was due to a mismatch between its presence and the timing of the survey is unknown. The present study also found that the recorded occurrence of *L. forbesii* has increased in the North and Central North Sea, as well as in Irish and Scottish waters. For *L. vulgaris*, the number of occurrences also increased in recent years (with high fluctuations) in the Greater North Sea and eastern English Channel, as well as further south in the Bay of Biscay and eastern Portuguese waters.

In *Alloteuthis* spp. the two temperature-related occurrence peaks may be related to the two species present in the fished range - *A. media* and *A. subulata* - with *A. media* being the northernmost of the two in distribution (Sheerin et al. 2023). In the north of the range, *A. media* tends to be coastal; absent in the deeper waters to the far west of Ireland.

By contrast with loliginid squid, both ommastrephid squids showed a very similar tolerance to all three environmental variables. While *I. coindetii* has been able to successfully reproduce in its northernmost distribution area, namely the North Sea, since around 2016 (Oesterwind et al. 2020), *T. eblanae* was established much earlier in the same area (also its northernmost distribution). It appears that *I. coindetii* required higher temperatures for its establishment than *T. eblanae*, because it started to successfully reproduce

in the North Sea in a year with very high temperatures (Oesterwind et al. 2022). However, this contrast is not reflected in the data of the present study, which shows similar tolerance ranges between adults of these species. With the high depth tolerances observed in this study, it seems that both ommastrephid species have the potential to migrate into deeper waters to avoid excessive temperatures.

The two octopods considered in this analysis have different abiotic tolerances, which are reflected in the distribution maps. While *O. vulgaris* is only documented in areas close to the coast and also appears to be restricted in its distribution, which skews towards the south of the study area, *E. cirrhosa* occurs much further north and farther from the coast. The data show that, of the two species, *E. cirrhosa* has a much broader depth range and can also cope with lower temperatures. This might help *E. cirrhosa* to avoid warmer coastal water temperatures. Indeed, Quetglas et al. (2025) observed an increasing mean depth of *E. cirrhosa* in the western Mediterranean (195.1 ± 5.0 m in 2001–2020 vs. 269.6 ± 12.3 m in 2021–2024), which may already represent an adaptation to the warming of coastal waters. *Octopus vulgaris* was once native to the North Sea, but its presence there is now very rare. It seems that the cold winter in 1962/1963 (Crisp 1969) caused local extinctions in *Octopus* populations in this part of the distributional range. However, sightings of *O. vulgaris* in the English Channel are becoming increasingly common and there are reports of ‘blooms’ or once-off peak abundance years in this area (Stewart et al. 2026). Temporary incursion of *O. vulgaris* in the English Channel has been documented in the distant past (Garstang 1900), while the warming of the North Sea and less bottom trawling could lead to recolonization of the northern area in the future (Hiemstra 2015). Overall, while *E. cirrhosa* tends to dominate the north, *O. vulgaris* appears to be dominant in the south.

Sampling cephalopods on fisheries surveys has limitations, though the present study mitigated some of these. These surveys are aimed at finfish and are limited to certain seasonal sampling while the mesh sizes involved mainly sample larger juveniles and adults (beginning from 20 mm dorsal mantle length; Oesterwind et al. 2010). This approach offers only a snapshot of particular parts of the short life-cycles that are typical of cephalopods and only covers a limited number of seasons. As mentioned above, it cannot be determined whether or not *L. vulgaris* has been failing to migrate as far north into the North Sea in the 1990s and 2000s, as assumed (Oesterwind et al. 2022), or whether the time window of its migration has shifted due to temperature changes and hence were not covered by the survey period. A second limitation is the importance of matching the fishing gear used on survey cruises with cephalopod habitat preferences; for example, the present analysis elected to focus

only on bottom or near-bottom-dwelling cephalopod species as these are more appropriate for bottom trawls data, as represented in DATRAS. A third limitation of fisheries survey data regards controlling for several important taxonomic biases: doubtful records in DATRAS were re-assigned in the present study (e.g. *I. illecebrosus* to *I. coindetii*). Also, it is likely that many *Alloteuthis* spp. were incorrectly reported as *Loligo* spp. in older records (and possibly vice-versa), so ‘*Loligo* spp.’ records were omitted entirely from the present analysis. For this reason, apparent increases observed in *Alloteuthis* spp. abundance (as seen in the present study) should be interpreted with caution. Also, since many records from the 1990s did not distinguish *L. forbesii* and *L. vulgaris*, even in areas where only one of those species is common (such as western waters of Ireland and Scotland), caution should be applied to reports of increases in either *Loligo* species from timeframes that draw on early ‘*Loligo*’ records.

Many records in DATRAS are at genus or family level. However, the very distinct preferences shown by congeners in the present study illustrates the importance of species-specific analyses and modelling. Carrying out an analysis with only genus information could lead to erroneous conclusions. For example, as shown in the present study, the fact that *Alloteuthis* spp. had two distinct abundance peaks, at < 10 °C and 20 °C, probably reflects the fact that there are two species in the sampled range, with *A. subulata* having the more southerly distribution, and the North Sea / Irish shelf confirmed to contain *A. media* only, although both species do occur throughout the rest of the range (Sheerin et al. 2023). Hence, the inclusion of taxonomic revisions of *Alloteuthis* spp. in the present analysis permitted improved interpretation of the apparently broad environmental tolerances seen across this genus.

Excluded from this analysis are pelagic species (e.g. *T. sagittatus*) that would not be captured in DATRAS sampling gear. Unsuitable depth preferences (*T. sagittatus*) and smaller-bodied species (sepiolids) for whom the mesh sizes used in trawls are too large were also omitted. The coverage of the analysed dataset includes the total NE Atlantic Shelf area and therefore a very wide spatial range, but does not include very shallow areas that are inaccessible to survey vessels, or areas beyond the shelf where at least some of the species occur (the deepest records obtained in DATRAS were ~700 m). The tolerances represented in the analysis are associated with adults, since eggs and paralarvae are inaccessible or too small to be retained in the sampling gear, but it should be borne in mind that early life stages often have narrower tolerances compared with adults and greater conservatism in their habitat requirements. Apart from ommastrephids, the cephalopods featured in this study breed inshore hence the entire lifecycle is otherwise captured.

Despite all these caveats, DATRAS data includes surveys from the coldest and warmest oceanographic seasons (Q1 and Q3) in the northern parts of the study area (for further information see Supplementary Table S1), and includes several decades worth of data. Both of these features are advantageous as including a large spatial and temporal scale is critical when investigating the distribution shifts arising from global warming (Pearson and Dawson 2003).

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Data availability The datasets analysed during the current study are available in the ICES DATRAS.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

Ethical approval Due to the use of a public dataset not necessary.

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References

- Adam W (1962) Cephalopodes de l'archipel du Cap-Vert, de l'Angola et du Mozambique. Memórias da Junta de Investigação do Ultramar (2ª Série). 1962;33:9–64
- Alabia ID, Saitoh SI, Igarashi H, Ishikawa Y, Usui N, Kamachi M, Awaji T, Seito M (2016) Future projected impacts of ocean warming to potential squid habitat in western and central North Pacific. ICES J Mar Sci 73(5):1343–1356. <https://doi.org/10.1093/icesjms/fsv203>
- Alujević K, Šegvić-Bubić T, Isajlović I, Trumbić Ž, Petrić M (2022) Distribution and differentiation patterns of sympatric squids *Alloteuthis media* and *Alloteuthis subulata* (Cephalopoda: Loliginidae) using morphological and molecular approaches. Front Mar Sci 9:856674. <https://doi.org/10.3389/fmars.2022.856674>
- Rosa R, Roura Á, Amor M, Gleadow IG, Guerra Á et al (2024) *Octopus vulgaris*, the common octopus. In: *Octopus Biology and Ecology*. pp. 187–216. Academic Press. <https://doi.org/10.1016/B978-0-12-820639-3.00020-0>
- Arkhipkin AI, Hendrickson LC, Payá I, Pierce GJ, Roa-Ureta RH, Robin JP, Winter A (2021) Stock assessment and management of cephalopods: advances and challenges for short-lived fishery resources. ICES J Mar Sci 78(2):714–730. <https://doi.org/10.1093/icesjms/fsaa038>
- Barrett CJ, MacLeod E, Oosterwind D, Laptikhovskiy V (2021) Ommastrephid squid spawning in the North Sea: oceanography, climate change and species range expansion. Scientia Mar 85(3):e065. <https://doi.org/10.3989/scimar.05065.005>
- Barrett CJ, Bradley K, Brazier A (2023) Common, curled or miscellaneous: the need for species-specific recordings of octopuses to inform stock assessments. Mar Policy 153:105632. <https://doi.org/10.1016/j.marpol.2023.105632>
- Belcari P, Sartor P (1993) Bottom trawling teuthofauna of the northern Tyrrhenian Sea. Scientia Mar 57(2):145–152
- Belcari P, Cuccu D, González M, Srairi ALI, Vidoris P (2022a) Distribution and abundance of *Octopus vulgaris* Cuvier, 1797 (Cephalopoda: Octopoda) in the Mediterranean Sea. Scientia Marina 66(Suppl 2):157–166. Available from: <https://scientiamarina.revistas.csic.es/index.php/scientiamarina/article/view/614>
- Belcari P, Tserpes G, González M, Lefkaditou E, Marceta B et al (2022b) Distribution and abundance of *Eledone cirrhosa* (Lamarck, 1798) and *Eledone moschata* (Lamarck, 1798) (Cephalopoda: Octopoda) in the Mediterranean Sea. Scientia Marina 66(Suppl 2):143–155. Available from: <https://scientiamarina.revistas.csic.es/index.php/scientiamarina/article/view/613>
- Bellido JM, Pierce GJ, Wang J (2001) Modelling intra-annual variation in abundance of squid *Loligo forbesi* in Scottish waters using generalized additive models. Fish Res 52(1–2):23–39. [https://doi.org/10.1016/S0165-7836\(01\)00228-4](https://doi.org/10.1016/S0165-7836(01)00228-4)
- Binning SA (2025) The lab-field continuum in conservation physiology research: leveraging multiple approaches to inform policy and practice. Conserv Physiol 13(1):coaf063. <https://doi.org/10.1093/conphys/coaf063>
- Borges FO, Guerreiro M, Santos CP, Paula JR, Rosa R (2022) Projecting future climate-change impacts on the distribution of the *Octopus vulgaris* species complex. Front Mar Sci 9:1018766. <https://doi.org/10.3389/fmars.2022.1018766>
- Borges FO, Sampaio E, Santos CP, Rosa R (2023) Climate-change impacts on cephalopods: a meta-analysis. Integr Comp Biol 63(6):1240–1265. <https://doi.org/10.1093/icb/icad102>
- Boyle PR (1983) Cephalopod Life Cycles, Vol I: Species Accounts. Academic
- Chen CS, Pierce GJ, Wang J, Robin JP, Poulard JC et al (2006) The apparent disappearance of *Loligo forbesi* from the south of its range in the 1990s: trends in *Loligo* spp. abundance in the

- northeast Atlantic and possible environmental influences. *Fish Res* 78(1):44–54. <https://doi.org/10.1016/j.fishres.2005.12.002>
- Clarke MR (1996b) Cephalopods as prey. III. Cetaceans. *Philos Trans R Soc B Biol Sci* 351(1343):1053–1065. <https://doi.org/10.1098/rstb.1996.0093>
- Clarke MR (1996a) The role of cephalopods in the world's oceans: an introduction. *Philos Trans R Soc B Biol Sci* 351(1343):979–983. <https://doi.org/10.1098/rstb.1996.0088>
- Clarke MR, Lu CC (1995) Cephalopoda of Madeiran waters. *Bol Mus Mun Funchal Sup* 4:181–200
- Coelho ML, Quintela J, Bettencourt V, Olavo G, Villa H (1994) Population structure, maturation patterns and fecundity of the squid *Loligo vulgaris* from southern Portugal. *Fish Res* 21(1–2):87–102. [https://doi.org/10.1016/0165-7836\(94\)90097-3](https://doi.org/10.1016/0165-7836(94)90097-3)
- Crisp DJ (1969) The effects of the winter of 1962/63 on the british marine fauna. *Helgolander Wiss Meeresunters* 10:313–327. <https://doi.org/10.1007/BF01626116>
- Cuccu D, Addis P, Damele F, Manfrin Piccinetti G (2003) Primo censimento della teutofauna dei mari circondanti la Sardegna. *Biol Mar Mediterr* 10(2):795–798
- De Heij A, Baayen RP (1999) Seasonal distribution of the cephalopod *Alloteuthis subulata* in the central and southern North Sea. *Basteria* 63:129–138
- De Heij A, Baayen RP (2005) Seasonal distribution of cephalopod species living in the central and southern North Sea. *Basteria* 69(1–2):91–119
- Delgado M, Gairín JI, Carbó R, Aguilera C (2011) Growth of *Octopus vulgaris* (Cuvier, 1797) in tanks in the Ebro Delta (NE Spain): effects of temperature, salinity and culture density. *Scientia Mar* 75(1):53–59. <https://doi.org/10.3989/scimar.2011.75n1053>
- Sulanke E, Döring R, Oesterwind D (2026b) First description of the emergence of targeted squid fisheries in the German North Sea demersal trawl fleet. *Re. Stud Mar Sci* 93: 104738
- Doubleday ZA, Prowse TA, Arkhipkin A, Pierce GJ, Semmens J, Steer M et al (2016) Global proliferation of cephalopods. *Curr Biol* 26(10):R406–R407. <https://doi.org/10.1016/j.cub.2016.04.002>
- Engelhard GH, Righton DA, Pinnegar JK (2014) Climate change and fishing: a century of shifting distribution in North Sea cod. *Glob Change Biol* 20:2473–2483. <https://doi.org/10.1111/gcb.12513>
- Engelhard GH, van der Kooij J, Righton DA, Jones MC, Pinnegar J (2018) Squid on the move in a marine climate-change hotspot and why it matters to fisheries and society. In: Book of abstracts of the 4th International symposium on the effects of climate change on the world's oceans. PICES Secretariat; p.108
- Fiorentino D, Núñez-Riboni I, Oesterwind D, Pierce M, Akimova A (2025) Improving species distribution models for climate change studies: ecological realism and performance metrics. *Ecol Model* 508:111207. <https://doi.org/10.1016/j.ecolmodel.2025.111207>
- Gaard E (1987) An investigation of the squid *Loligo forbesi* Steenstrup on Faroe Bank. *ICES CM*;1987:18
- García-Mayoral E, Roura Á, Ramilo A, González ÁF (2020) Spatial distribution and genetic structure of loliginid paralarvae along the Galician coast (NW Spain). *Fish Res* 222:105406. <https://doi.org/10.1016/j.fishres.2019.105406>
- Garstang W (1900) The plague of octopus on the south coast, and its effect on the crab and lobster fisheries. *J Mar Biol Association United Kingd* 6(2):260–273
- Giménez AF, García García B (2002) Growth and food-intake models in *Octopus vulgaris* Cuvier (1797): influence of body weight, temperature, sex and diet. *Aquac Int* 10(5):361–377. <https://doi.org/10.1023/A:1023335024053>
- Giordano D, Busalacchi B, Bottari T, Perdichizzi F, Profeta A et al (2010) Population dynamics and distribution of *Eledone cirrhosa* (Lamarck, 1798) in the Southern Tyrrhenian Sea (Central Mediterranean). *Cah Biol Mar* 51(2):213–227
- Golikov AV, Jørgensen LL, Sabirov RM, Zakharov DV, Hoving H-J (2024) Long-term annual trawl data show shifts in cephalopod community in the western Barents Sea during 18 years. *Front Mar Sci* 11:1392585. <https://doi.org/10.3389/fmars.2024.1392585>
- Goud J, De Heij A, Hiemstra AF (2019) Cephalopods in the North Sea. *Vita Malacologica* 18:34–67
- Grieg JA (1933) Cephalopods from the west coast of Norway. *Bergens Mus Årbok* 4:1–25
- Grimpe G (1925) Zur Kenntnis der Cephalopodenfauna der Nordsee. *Helgoländer Wiss Meeresunters* 16(3):1–124
- Guerra Á (1992) Mollusca, Cephalopoda. *Fauna Ibérica*, vol 1. Museo Nacional de Ciencias Naturales, pp 75–82
- Guerreiro MF, Borges FO, Santos CP et al (2023a) Impact of climate change on the distribution and habitat suitability of the world's main commercial squids. *Mar Biol* 170(1):129. <https://doi.org/10.1007/s00227-023-04261-w>
- Guerreiro Fernandes M, Oliveira Borges F, Pereira Santos C, Rosa R (2023b) Future distribution patterns of nine cuttlefish species under climate change. *Mar Biol* 170(1):159. <https://doi.org/10.1007/s00227-023-04310-4>
- Hastie LC, Pierce GJ, Wang J, Bruno I, Moreno A et al (2009a) Cephalopods in the north-eastern Atlantic: species, biogeography, ecology, exploitation and conservation. *Oceanogr Mar Biol Annu Rev* 47:111–190. <https://doi.org/10.1201/9781420094220.ch3>
- Hastie LC, Nyegaard M, Collins MA, Moreno A, Pereira JM, Piatkowski U, Pierce GJ (2009b) Reproductive biology of the loliginid squid *Alloteuthis subulata* in the north-east Atlantic and adjacent waters. *Aquat Living Resour* 22(1):35–44. <https://doi.org/10.1051/alr/2009002>
- Hastie LC, Allcock L, Jereb P, Lefkaditou E, Moreno A et al (2013) *Alloteuthis subulata*, European common squid. In: Rosa R, Pierce GJ, O'Dor R (eds) *Advances in Squid Biology, Ecology and Fisheries*. Nova Science, pp 109–122
- Hiemstra AF (2015) Recognizing cephalopod boreholes in shells and the northward spread of *Octopus vulgaris* Cuvier, 1797 (Cephalopoda, Octopodoidea). *Vita Malacologica* 13:53–56
- Hjörleifsson E (2021) Tidycies: Making working with various ICES data a little smoother (R package version 0.1.0)
- Huang H, Zhou Z, Peng D, Chu J (2024) Potential impacts of climate change on cephalopods in a highly productive region (Northwest Pacific): habitat suitability and management. *Sci Total Environ* 953:175794. <https://doi.org/10.1016/j.scitotenv.2024.175794>
- Hutchinson GE (1957) Concluding remarks. *Cold Spring Harb Symp Quant Biol* 22:415–457
- ICES (2025) Working Group on Cephalopod Fisheries and Life History (WGCEPH; outputs from 2024 meeting). *ICES Sci Rep*. <https://doi.org/10.17895/ices.pub.29390171.v2>
- Iglesias P, Picón P, Nande M, Lago MJ, Otero JJ et al (2016) Effect of low salinity on survival and ingested food of the common octopus, *Octopus vulgaris* Cuvier, 1797. *J Appl Aquac* 28(3):267–271. <https://doi.org/10.1080/10454438.2016.1190953>
- Ikica Z, Pesic A, Markovic O, Joksimovic A, Krstulovic Sifner S (2019) Distribution and abundance of Horned Octopus (*Eledone cirrhosa* Lamarck 1798) (Cephalopoda: Octopoda) in south-east Adriatic sea. *Studia Mar* 32(2):44–51. <https://doi.org/10.5281/zenodo.3584196>
- Jereb P, Roper CF (eds) (2005) *Cephalopods of the World: Chambered nautilus and sepioids (Nautilidae, Sepiidae, Sepiolidae, Sepiadariidae, Idiosepiidae, and Spirulidae)*, vol 1. FAO
- Jereb PF, Roper CF (eds) (2010) *FAO species catalogue for fishery purposes. Cephalopod of the World. An Annotated and Illustrated Catalogue of Cephalopod Species Known to Date. Vol 2*
- Jereb P, Allcock AL, Lefkaditou E, Piatkowski U, Hastie LC, Pierce GJ (2015) Cephalopod biology and fisheries in Europe: II. Species accounts. *ICES Coop Res Rep*. Copenhagen: ICES; pp. 1–360. <https://doi.org/10.17895/ices.pub.5493>

- Kaspiris P, Tsiambaos P (1986) A preliminary list of Cephalopoda from western Greece. *Biol gallo-hellenica: travaux des groupes franco-helléniques et de la Station Kéramou*. 1986;12:209–210
- Katsanevakis S, Verriopoulos G (2004) Den ecology of *Octopus vulgaris* Cuvier, 1797, on soft sediment: availability and types of shelter. *Scientia Mar* 68(2):147–157. <https://doi.org/10.3989/sci.mar.2004.68n1147>
- Keller S, Bartolino V, Hidalgo M, Bitetto I, Casciaro L et al (2016) Large-scale spatio-temporal patterns of Mediterranean cephalopod diversity. *PLoS ONE* 11(1):e0146469. <https://doi.org/10.1371/journal.pone.0146469>
- Klages NTW, Clarke MR (1996) Cephalopods as prey. II. Seals. *Philos Trans R Soc B Biol Sci* 351(1343):1045–1052. <https://doi.org/10.1098/rstb.1996.0092>
- Kremer KL, Hagen W, Oesterwind D et al (2025) Trophic ecology of squids in the Benguela Upwelling System elucidated by combining stomach-content, stable-isotope and fatty-acid analyses. *Mar Biol* 172:32. <https://doi.org/10.1007/s00227-024-04592-2>
- Laptikhovskiy V, Allcock L, Barnwall L, Barrett CJ et al (2022) Spatial and temporal variability of spawning and nursery grounds of *Loligo forbesii* and *Loligo vulgaris* squids in ecoregions of Celtic Seas and Greater North Sea. *ICES J Mar Sci* 79(6):1918–1930. <https://doi.org/10.1093/icesjms/fsac128>
- Lefkaditou E, Mytilineou C, Maiorano P, D'Onghia G (2003) Cephalopod species captured by deep-water exploratory trawling in the northeastern Ionian Sea. *J Northwest Atl Fish Sci* 31. <https://doi.org/10.2960/J.v31.a33>
- Lefkaditou E, Tsigenopoulos CS, Alidromiti C, Haralabous J (2012) On the occurrence of *Alloteuthis subulata* in the eastern Ionian Sea and its distinction from the sympatric *Alloteuthis media*. *J Biol Res-Thessaloniki* 17:169–175
- Lehmann A, Myrberg K, Post P, Chubarenko I, Dailidienė I et al (2022) Salinity dynamics of the Baltic Sea. *Earth Syst Dyn* 13(1):373–392. <https://doi.org/10.5194/esd-13-373-2022>
- Lordan C, Collins MA, Burnell GM, Cross TF (1995) The significance of squid in Irish fisheries. *ICES Doc CM* 1995/K 13:8
- Lu CC (1973) Systematics and zoogeography of the squid genus *Illex* (Oegopsida; Cephalopoda). PhD dissertation, Memorial University of Newfoundland
- Luna A, Rocha F (2025) Cephalopod distribution in the Canary Current: latitudinal and bathymetric patterns. *J Biogeogr* 52:e15112. <https://doi.org/10.1111/jbi.15112>
- Malhomme F, Porcher Z, Safi G, Robin JP (2015) English Channel Loliginid squid stocks and MSFD descriptors: surplus-production models used to estimate stock status and biomass and the role of squid resources in the trophic network
- Mangold K (1983) *Octopus vulgaris*. *Cephalopod Life Cycles*, vol I. Academic, pp 335–364
- Mangold-Wirz K (1963) Biologie des Céphalopodes benthiques et nectoniques de la Mer Catalane. *Vie et Milieu Suppl* 13:285
- Miliou H, Fintikaki M, Kountouris T, Verriopoulos G (2005) Combined effects of temperature and body weight on growth and protein utilization of the common octopus, *Octopus vulgaris*. *Aquac* 249(1–4):245–256. <https://doi.org/10.1016/j.aquaculture.2005.03.038>
- Moreno A, da Cunha MM, Pereira JM (1994) Population biology of veined squid (*Loligo forbesi*) and European squid (*Loligo vulgaris*) from the Portuguese coast. *Fish Res* 21(1–2):71–86. [https://doi.org/10.1016/0165-7836\(94\)90096-5](https://doi.org/10.1016/0165-7836(94)90096-5)
- Moura T, Chaves C, Figueiredo I, Mendes H, Moreno A et al (2020) Assessing spatio-temporal changes in marine communities along the Portuguese continental shelf and upper slope based on 25 years of bottom-trawl surveys. *Mar Environ Res* 160:105044. <https://doi.org/10.1016/j.marenvres.2020.105044>
- Nesis KN (1979) Squids of the family Ommastrephidae in the Australian-New Zealand region. In: *Nekton and Ichthyoplankton of the Australian-New Zealand Region*. Nauka:140–146
- Núñez-Riboni I, Taylor MH, Kempf A, Püts M, Mathis M (2019) Spatially resolved past and projected changes of the suitable thermal habitat of North Sea cod (*Gadus morhua*) under climate change. *ICES J Mar Sci* 76:2389–2403. <https://doi.org/10.1093/icesjms/fsz132>
- Nyegaard M (2001) An analysis of reproductive behaviour, demography, diet, and spatial distribution of the European common squid (*Alloteuthis subulata*) in the Irish Sea (Master's thesis). University of Tromsø
- Oesterwind D, Piatkowski U (2023) Stomach-content analysis of North Sea cephalopods: often-overlooked predators with direct impact on commercially used fish species? *Mar Biol* 170(1):101. <https://doi.org/10.1007/s00227-023-04236-x>
- Oesterwind D, Schaber M (2020) First evidence of *Illex coindetii* in the Baltic Sea and Kattegat. *Thalassas* 36(1):143–147. <https://doi.org/10.1007/s41208-019-00178-8>
- Oesterwind D, ter Hofstede R, Harley B, Brendelberger H, Piatkowski U (2010) Biology and meso-scale distribution patterns of North Sea cephalopods. *Fish Res* 106(1):141–150. <https://doi.org/10.1016/j.fishres.2010.06.003>
- Oesterwind D, Piatkowski U, Brendelberger H (2015) On distribution, size and maturity of short-fin squids (Cephalopoda, Ommastrephidae) in the North Sea. *Mar Biol Res* 11(2):188–196. <https://doi.org/10.1080/17451000.2014.894246>
- Oesterwind D, Bobowski BTC, Brunsch A, Laptikhovskiy V, van Hal R et al (2020) First evidence of a new spawning stock of *Illex coindetii* in North Sea (NE-Atlantic). *Fish Res* 221:105384. <https://doi.org/10.1016/j.fishres.2019.105384>
- Oesterwind D, Bobowski BT, Brunsch A, Laptikhovskiy V, Van Hal R, Sell AF, Pierce G J (2020). First evidence of a new spawning stock of *Illex coindetii* in the North Sea (NE-Atlantic). *Fish Res* 221: 105384. <https://doi.org/10.1016/j.fishres.2019.105384>
- Oesterwind D, Barrett CJ, Sell AF, Núñez-Riboni I, Kloppmann M et al (2022) Climate change-related changes in cephalopod biodiversity on the North East Atlantic Shelf. *Biodivers Conserv* 31(1):1–15. <https://doi.org/10.1007/s10531-022-02403-y>
- Olmos-Perez L, Pierce GJ, Roura Á, Gonzalez AF (2018) Barcoding and morphometry to identify and assess genetic population differentiation and size variability in loliginid squid paralarvae from NE Atlantic (Spain). *Mar Biol* 165(8):136. <https://doi.org/10.1007/s00227-018-3387-y>
- Otterlind G (1959) Bläckfiskar i Västerhavet. In: *Natur i Bohuslän*
- Palas S, Pita P (2015) La pesca recreativa de cefalópodos en la ría de vigo: aspectos ecológicos, sociales y económicos. In: Méndez M, editors. XVIII Foro Dos Recursos Marinos E Da Acuicultura Das Rías Galegas. pp 1–10
- Pauly D, Palomares ML (2005) Fishing down marine food web: it is far more pervasive than we thought. *Bull Mar Sci* 76(2):197–212
- Pauly D, Christensen V, Dalsgaard J, Froese R, Torres F Jr (1998) Fishing down marine food webs. *Science* 279(5352):860–863. <https://doi.org/10.1126/science.279.5352.860>
- Pearson RG, Dawson TP (2003) Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? *Glob Ecol Biogeogr* 12(5):361–371. <https://doi.org/10.1046/j.1466-822X.2003.00042.x>
- Pereira JMF, Moreno A, Cunha MM (1998) Western European Squid Distribution: A Review. *ICES CM* 1998/M(29–20). <https://doi.org/10.17895/ices.pub.26807230>
- Perry AL, Low PJ, Ellis JR, Reynolds JD (2005) Climate change and distribution shifts in marine fishes. *Science* 308:1912–1915. <https://doi.org/10.1126/science.1111322>
- Pham CK, Carreira GP, Porteiro FM, Gonçalves JM, Cardigos F et al (2009) First description of spawning in a deep water loliginid squid, *Loligo forbesi* (Cephalopoda: Myopsida). *J Mar Biol Assoc U K* 89(1):171–177. <https://doi.org/10.1017/S0025315408002415>

- Piccinetti C, Vrgoč N, Marčeta B, Manfredi C (2012) Recent state of demersal resources in the Adriatic Sea
- Pierce GJ, Bailey N, Stratoudakis Y, Newton A (1998) Distribution and abundance of the fished population *Loligo forbesii* in Scottish waters: analysis of research cruise data. *ICES J Mar Sci* 55(1):14–33. <https://doi.org/10.1006/jmsc.1997.0257>
- Pierce GJ, Ivaylova S, Matos FL et al (2024) *Eledone cirrhosa*, horned octopus. In: *Octopus Biology and Ecology*. pp. 311–357. Academic Press. <https://doi.org/10.1016/B978-0-12-820639-3.00021-2>
- Pinnegar JK, Engelhard GH, Jones MC, Cheung WWL, Peck MA et al (2016) Socio-economic impacts — fisheries. In: Quante M, Colijn F, editors. North Sea Region Climate Change Assessment. pp. 375–395. Springer. https://doi.org/10.1007/978-3-319-39745-0_12
- Porteiro FM, Martins HR (1992) First finding of natural laid eggs from *Loligo forbesi* Steenstrup, 1856 (Mollusca: Cephalopoda) in the Azores. *Arquipélago-Life Earth Sci* 10:119–120
- Quetglas A, Carbonell A, Sánchez P (2000) Demersal continental-shelf and upper-slope cephalopod assemblages from the Balearic Sea (north-western Mediterranean). *Biological Aspects of Some Deep-Sea Species. Estuar Coastal Shelf Sci* 50(6):739–749. <https://doi.org/10.1006/ecss.1999.0603>
- Quetglas A, de Mesa A, Guijarro B, Massuti E, Ordinas F et al (2025) Life history traits and fishery of the horned octopus (*Eledone cirrhosa*) in the western Mediterranean Sea. *Fish Res* 288:107446. <https://doi.org/10.1016/j.fishres.2025.107446>
- R Core Team (2019) R: A language and environment for statistical computing. R Foundation for Statistical Computing
- Regueira M, González AF, Guerra A (2014) Habitat selection and population spreading of the horned octopus *Eledone cirrhosa* (Lamarck, 1798) in Galician waters (NW Atlantic). *Fish Res* 152:66–73. <https://doi.org/10.1016/j.fishres.2013.09.003>
- Relini G, De Rossi C, Piano T, Zamboni A (2002) Osservazioni sui cefalopodi dei fondistrascibili liguri. *Biol Mar Mediterr* 9(2):792–795
- Relini LO, Mannini A, Lanteri L, Beccornia E (2009) First record of an egg mass of *Loligo forbesi* (Cephalopoda: Loliginidae) in the Ligurian Sea, with notes about egg-laying patterns in southern populations. *Boll Malacol* 45:27–33
- Reusch TBH et al (2018) The Baltic Sea as a time machine for the future coastal ocean. *Sci Adv* 4(5):eaar8195. <https://doi.org/10.1126/sciadv.aar8195>
- Righton DA, Andersen KH, Neat F, Thorsteinsson V, Steingrund P et al (2010) Thermal niche of Atlantic cod *Gadus morhua*: limits, tolerance and optima. *Mar Ecol Progr Ser* 420:1–13. <https://doi.org/10.3354/meps08889>
- Robinson NM, Nelson WA, Costello MJ, Sutherland JE, Lundquist CJ (2017) A Systematic Review of Marine-Based Species Distribution Models (SDMs) with Recommendations for Best Practice. *Front. Mar. Sci.* 4:421 <https://doi.org/10.3389/fmars.2017.00421>
- Rodhouse PG, Swinfen RC, Murray AWA (1988) Life cycle, demography and reproductive investment in the myopsid squid *Alloteuthis subulata*. *Mar Ecol Progr Ser* 45:245–253. <https://doi.org/10.3354/meps045245>
- Rodhouse PG, Nigmatullin CM, Clarke MR (1996) Role as consumers. *Philos Trans R Soc B Biol Sci* 351(1343):1003–1022. <https://doi.org/10.1098/rstb.1996.0090>
- Roeleveld M (1998) The status and importance of cephalopod systematics in southern Africa. *S Afr J Mar Sci* 20:1–16
- Roper CFE, Nigmatullin C, Jereb P (2010) Family Ommastrephidae. In: *Cephalopods of the World. An annotated and illustrated catalogue of species known to date* 2:269–347
- Rosa R, O'Dor R, Pierce GJ (2013) Advances in Squid Biology, Ecology and Fisheries. Nova Science
- Rosa R, Trubenbach K, Pimentel MS, Boavida-Portugal J, Faleiro F et al (2014) Differential impacts of ocean acidification and warming on winter and summer progeny of a coastal squid (*Loligo vulgaris*). *J Exp Biol* 217(4):518–525. <https://doi.org/10.1242/jeb.096081>
- Royer J, Périès P, Robin J-P (2002) Stock assessments of English Channel loliginid squids: updated depletion methods and new analytical methods. *ICES J Mar Sci* 59(3):445–457. <https://doi.org/10.1006/jmsc.2002.1203>
- Rutterford LA, Simpson SD, Jennings S, Johnson MP, Blanchard JL et al (2015) Future fish distributions constrained by depth in warming seas. *Nat Clim Change* 5(6):569–573. <https://doi.org/10.1038/nclimate2607>
- Sabirov RM, Lubin PA, Golikov AV (2009) Finding of the lesser flying squid (*Todaropsis eblanae*, Oegopsida, Ommastrephidae) from the Barents Sea. *Zool J* 88:1010–1012
- Schickele A, Francour P, Raybaud V (2021) European cephalopods distribution under climate-change scenarios. *Sci Rep* 11(1):3930. <https://doi.org/10.1038/s41598-021-83457-w>
- Sheerin E, Barnwall L, Oliveira L, Petroni M, Silva H et al (2020) Cephs and Chefs DNA Barcoding report INTERREG. <https://www.cephsandchefs.com/wp-content/uploads/2021/05/WP4.1-Barcoding-Report.pdf>
- Sheerin E, Power AM, Oesterwind D et al (2023) Evidence of phenotypic plasticity in *Alloteuthis media* (Linnaeus, 1758) from morphological analyses on North Sea specimens and DNA barcoding of the genus *Alloteuthis* Wülker, 1920 across its latitudinal range. *Mar Biol* 170(1):35. <https://doi.org/10.1007/s00227-023-04178-4>
- Smith JM, Macleod CD, Valavanis V, Hastie LC, Valinassab T et al (2013) Habitat and distribution of post-recruit life stages of the squid *Loligo forbesii*. *Deep Sea Res Part II Top Stud Oceanogr* 95:145–159. <https://doi.org/10.1016/j.dsr2.2013.03.039>
- Stewart BD, Thomas S, Smyth TJ, James MK, Sullivan E et al (2026) Common octopus (*Octopus vulgaris*) blooms off the Southwest of the UK: history, trends, causes and consequences. Report on Work Package 1. <https://plymse.ac.uk/id/eprint/10535/1/Octopus%20bloom%20-%20history%20causes%20-%20consequences%20%28Work%20Package%201%29%20FINAL.pdf>
- Sulanke E, Döring R, Oesterwind D (2026a) Value and volatility of squid as a fisheries resource in the North Sea and adjacent waters—starting point for a sustainable management. *Fish Manage Ecol* 1–4. <https://doi.org/10.1111/fme.70036>
- Tinbergen L, Verwey J (1945) Zur Biologie von *Loligo vulgaris* Lamarck. *Arch Néerlandaises Zool* 7(1):186–213
- Van der Kooij J, Engelhard GH, Righton DA (2016) Climate change and squid range expansion in the North Sea. *J Biogeogr* 43(11):2285–2298. <https://doi.org/10.1111/jbi.12847>
- Villa H, Quintela J, Coelho ML, Icely JD, Andrade JP (1997) Phytoplankton biomass and zooplankton abundance on the south coast of Portugal (Sagres), with special reference to spawning of *Loligo vulgaris*. *Scientia Mar* 61(2):123–129
- Wernberg T, Russell BD, Thomsen MS, Connell SD (2014) Marine biodiversity and climate change. In: Freedman B (ed) *Global Environmental Change*. Springer, pp 195–212. https://doi.org/10.1007/978-94-007-5784-4_80
- Wickham H (2016) ggplot2: Elegant graphics for data analysis. Springer, New York
- Worm B, Lotze HK (2016) Marine biodiversity and climate change. In: Letcher T, editor. *Climate and Global Change: Observed Impacts on Planet Earth* (2nd ed.). Elsevier, pp. 195–212. <https://doi.org/10.1016/B978-0-444-63524-2.00013-0>
- Worms J (1983) *Loligo vulgaris*. In: *Cephalopod life cycles*; 1:143–157

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