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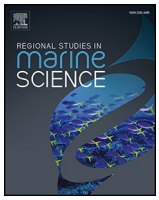

First description of the emergence of targeted squid fisheries in the German North Sea demersal trawl fleet

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ABSTRACT

As demersal fisheries in the southern North Sea are struggling for profitability, alternative high-value resources are in dire need. In the past few years, squid fishing has emerged as a profitable seasonal fishery. Due to the novelty of this fishery, detailed knowledge remains scarce, as no observer program has been facilitated yet, and catches are not reliably reported on the species level. Conclusions on the ecological and socio-economic implications of this novel strategy, therefore, remained speculative. We combined spatiotemporal hotspot data analysis and clustering techniques with onboard sampling to provide the first scientific description of this novel fishery. We identified a targeted fishery on the common squid *Loligo vulgaris*, taking place on highly localised fishing grounds, particularly four hotspots in the Southern North Sea and the Eastern English Channel, identified using Getis-Ord *G* statistics. Fishing activity followed a distinct seasonal trajectory shifting northwestwards from the beginning (October) towards the end (March) of the season. The economic relevance for the North Sea demersal fishing fleet is significant, as the share of overall revenues generated by squid rose from under 1 % in 2018–21 % in 2024. Targeted squid fishing requires considerable investments, but is, in terms of regulations, relatively open, as no quotas and only very few technical regulations apply under EU and UK law. Acknowledging the rapid increase of this fishery's economic importance, we highlight the need for commencing a strategic management process for emerging squid fisheries in the North Sea, ensuring long-term sustainability and avoiding ecological damage.

1. Introduction

North Sea demersal fisheries are currently in a serious crisis. These fishing fleets, which contribute significantly to the overall productivity of fisheries in the North Sea (STECF, 2023), are under a multitude of pressures, as both their target species and fishing operations are affected by larger-scale developments. A surge in fuel prices has led to a sharp increase in operational costs (Guillen et al., 2023), and this fishery is already particularly fuel-intensive (Tyedmers, 2001; Bastardie et al., 2022). At the same time, quotas for traditionally targeted high-value species such as cod (*Gadus morhua*) in the southern North Sea or sole (*Solea solea*) have steadily decreased, as complex combinations of climate-induced ontogenetic (Fincham et al., 2013; van de Wolfshaar et al., 2022) and distribution (Engelhard et al., 2011; Teal et al., 2012) shifts and decade-long fishing pressure (Mollet et al., 2016) led to local reductions of available biomass. With stocks shifting northwestwards to deeper, colder waters (Dutz et al., 2016; Støttrup et al., 2017), commercial-sized plaice (*Pleuronectes platessa*), which is another key target species of demersal fisheries, is increasingly hard to catch in a marketable size in the southern North Sea (ICES, 2024a) and has been at least partially substituted by Southern (*Lepidopsetta bilineata*) and Northern Rock Sole (*Lepidopsetta polyxystra*) from the Pacific on the European market (Neerlandia-Urk, 2022). This development has led to a continuous decline in quota utilization of plaice, and in 2024, the German fleet landed only 16 % of the plaice quota it was allocated in the North Sea, Skagerrak, and Kattegat (ICES, 2024a). The reliability of Norway lobster (*Nephrops norvegicus*), another high-value target species of demersal fisheries in the North Sea (Sulanke et al., 2025), has also abated, as quota to fish it is primarily obtained by trading it with the United Kingdom for cod quota, and this system is jeopardised by the turmoil Brexit has caused in the European fisheries landscape (Letschert et al., 2021). In addition, fisheries are facing increasing competition for space, as not only offshore industries are rapidly growing in the North Sea (Jentoft and Knol, 2014; Martins et al., 2023), but also ambitious

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conservation programs are put into place, and calls for the exclusion of mobile bottom-contacting gears from these protected areas have been repeatedly made (Seas At Risk, 2022; OceanCare, 2023; Bearzi et al., 2024). Identifying alternative fishing resources has become an urgent priority in light of these challenges.

Among the potential alternatives, squid fisheries have emerged as a valuable and accessible strategy. Recent shifts in the distribution of several commercially interesting squid species, which were induced by climate change, have led to increasing abundances of squid in the North Sea (Schickele et al., 2021; Laptikhovsky et al., 2022; Oesterwind et al., 2022), reaching levels that facilitate directed fisheries. While targeted squid fisheries in the eastern English Channel and the southern North Sea are a novelty, other cephalopod fisheries are well-established in the Greater North Sea area. Squid and cuttlefish fishing has been established in the western English Channel for over a decade, where catches have fluctuated immensely (Alemany et al., 2017), which is primarily attributable to the shifts in cuttlefish reproductive strategies. Climate change has most likely altered their life cycle, leading to the emergence of annual reproduction instead of the former biannual cycle (Laptikhovsky et al., 2024). Another well-established cephalopod fishery in the North Sea is the seasonal fishery in the Moray Firth, where *Loligo forbesii* are fished when they aggregate in autumn and winter for spawning (Young et al., 2006). A long-time economic pillar of local coastal trawl fisheries, its management is constrained by a lack of reliable data, and the targeted squid show signs of shifting northward (McBride, 2025c). On the contrary, demersal trawling and seining vessels have reported a steep increase in squid catches in the southern North Sea (27.4.c) and the western English Channel (27.7.d) over recent years, and a novel fishery has emerged, predominantly carried out by Dutch, Belgian, French, and UK fishing vessels (Sulanke, pers. communication). The German demersal trawl fleet of the North Sea (Sulanke et al., 2025), though comparably small in size (STECF et al., 2023), is also participating in this new fishery, yet the extent, commercial significance, and even the targeted squid species were unknown. Therefore, our research closes an important knowledge gap, addressing the socio-economic importance as well as ecological implications of this first documented fishery of the German fleet that is directly enabled by the consequences of climate change and management decisions.

Squid species are of high commercial interest and targeted by many directed fisheries around the world (Seto et al., 2023), yet the semelparous lifestyle and short lifespan make them difficult to manage using traditional stock assessment frameworks (Bobowski et al., 2023). Therefore, often ad-hoc or real-time assessments are applied (Arkhipkin et al., 2021; Moustahfid et al., 2021; ICES, 2024b; Peng et al., 2024), setting critical biomass thresholds or CPUE boundaries. Nonetheless, excessive fishing pressure has led to multiple examples of squid stocks being overfished, leading to economic hardship for associated fisheries (Seto et al., 2023; Science, 2024; Pierce et al., 2025). Cephalopods, especially squids, have high reproductive potential and are flexible, highly mobile, and very efficient predators, and most likely benefit from climate change on a global scale (Doubleday et al., 2016). Regionally, multiple squid species such as *Illex coindetii*, *Loligo vulgaris,* and *L. forbesii* have altered their distribution (Göpel et al., 2022; Oesterwind et al., 2022), abundance (Göpel et al., 2022) and phenology (Oesterwind and Schaber, 2020; Laptikhovsky et al., 2024) with most of these changes being attributed to climate change. Due to their high reproductive potential and adaptability, they are principally well-suited as a fisheries target species, yet their volatility and high degree of fluctuation require tailored management approaches and a degree of economic robustness in the fisheries targeting them (Arkhipkin et al., 2021). A detailed analysis such as the one presented is therefore crucial for profoundly assessing the socio-economic characteristics of this fishery and deriving conclusions about its potential long-term sustainability.

2. Material and methods

Data on landings, revenues, and vessel positions were retrieved from the German federal fishery data registry provided by the German Federal Office of Agriculture and Food (BLE), which are routinely collected annually. An alternative fleet segmentation approach described in detail in Sulanke et al. (2025) was used to identify the mixed demersal trawl fleet operating in the North Sea. Of this fleet, vessel-based catch, revenue, and position data were analyzed. To analyze the spatiotemporal dynamics of the squid fishery in the two seasons present in the data, 2023 and 2024, reported catches were aggregated to a 0.1° x 0.1° grid covering all ICES-areas of the ICES Greater North Sea Ecoregion (27.4.a, 27.4.b, 27.4.c, 27.7.d, and 27.3.a.20). From the catches aggregated in this manner, a contiguity-based spatial weights matrix was computed to calculate the Getis-Ord Global *G* statistic (Getis and Ord, 1992) to test overall spatial heterogeneity. Local spatial autocorrelation statistics (Ord and Getis, 1995) where applied to identify local hotspots and cold spots. Centroids of grid cells belonging to hotspots were clustered using hierarchical agglomerative clustering with the unweighted pair-group method with arithmetic mean (UPGMA) as the fusion algorithm (Sokal, 1958). The optimal number of clusters was determined by computing average silhouette widths for solutions between 0 and 30 clusters and choosing the number of clusters with the highest average silhouette width (Rousseeuw, 1987). To analyze relative temporal distribution of fishing activity in hotspots, Kernel density estimates of fishing activity distribution were computed using a Gaussian smoothing Kernel (Parzen, 1962), which is fully implemented in the *geom_density()* function of the *ggplot2* package (Wickham, 2016). For all data analysis and visualization, the R statistical software was applied (R Core Team, 2024), making extensive use of the packages and functions included in the *tidyverse* package (Wickham et al., 2019) family. Maps were created with the help of the *sf* package (Pebesma and Bivand, 2023), spatial statistics were computed applying the *sfdep* package (Josiah Parry, Locke, 2024), and oceanographic bathymetry data were retrieved and mapped using the *marmap* package (Pante et al., 2023).

To gather information on the socio-economic conditions and operational characteristics, a commercial squid fishing trawler was observed and sampled during a peak-season fishing trip from January 2nd to January 5^{th,} 2025, in the southern North Sea (see Fig. 1). For confidentiality reasons, the vessel's technical data are not given, as they would allow identification. All nine hauls conducted during the fishing campaign were sampled, the catch was identified to species level, and squid dorsal mantle lengths (DML) were measured in cm. ANOVA (Fisher, 1954) and Tukey's-HSD-test (Tukey et al., 1985) were used to test the significance of length differences between all size classes. All sorting of squid into four size classes (SQU1: >1000 g, SQU2: >500 g – 1000 g, SQU3: 300 – 500 g, SQU4: <300 g) was done by the crew members by hand, as auctions, which are the only feasible selling channel for freshly caught squid in the North Sea, demand pre-sorted catches. All additional catches were identified to species level. Additional interviews with stakeholders were held at fish auctions and in fishing ports to integrate the socio-economic characteristics of the fishery.

3. Results

3.1. Data analysis

Analysing the German North Sea mixed demersal trawl fleets' catch and logbook data revealed the remarkable emergence of the squid fishery. Before 2019, squid and other cephalopods accounted for minimal fractions of less than 1 % of the overall fleet revenues (see Fig. 1) and were bycatch. After 2019, squid catches surged, accounting for 10 % of the fleet revenues in 2023 and nearly 21 % in 2024, making them the second most valuable species caught. Other significantly important species are Norway lobster, sole, turbot, and plaice. Plaice was the

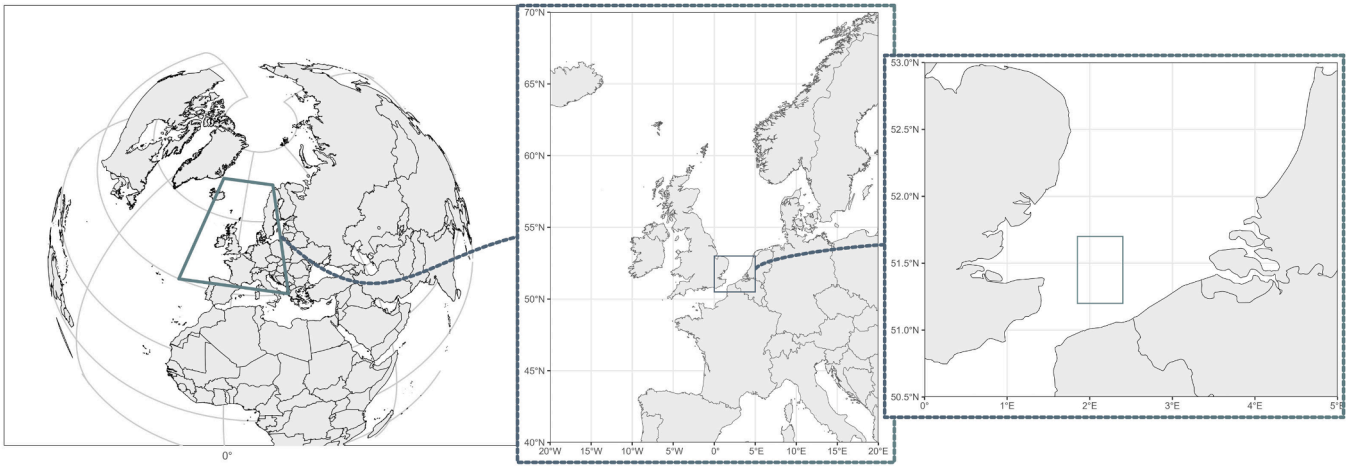

Fig. 1. Study area mapped on a global (left), regional (center), and local (right) scale.

commercially most important species of the fleet in 2013, accounting for nearly 45 % of its revenue. This value continuously decreased over the analysed period, falling to 16 % in 2024. Norway lobster, the overall most valuable target species of the fishery, showed remarkable fluctuations in the share in overall revenues, with 9 % in 2020 and 57.5 % in 2017 being the lowest and highest, respectively. With 26 %, the share of Norway lobster is within the range of the timeline average share of the species of 32.7 %. Sole, another high-value target species, showed strong fluctuations as well, as it fell from a very high share of 34.5 % in 2020 to just 1.2 % in 2024. The share of turbot, on the other hand, remained relatively stable at around 10–14 %.

Both species are high-value species, fetching high ex-vessel prices of over 12€/kg in recent years (see Fig. 2). Yet, these high prices are the result of a steady recovery, as prices for multiple high-value species notably fell in 2020. Sole prices dropped from 14.28 €/kg to 9.63 €/kg, and turbot prices from 9.10 €/kg to 7.15 €/kg. Norway lobster showed a similar price trajectory, as prices fell from 5.75 €/kg to 3.78 €/kg and recovered steadily afterwards, reaching their highest mark of 7.47 €/kg in 2024. Squid prices steadily increased after 2019 from 3.83 €/kg to 8.61 €/kg. Ex-vessel prices for plaice and cod remained relatively stable at approximately 2.50 €/kg and 3.50 €/kg, respectively. Cuttlefish only became relevant as a target species in 2020 and only account for roughly 1 % of the revenues (see Fig. 1) as they have comparably low prices in the range of plaice and cod of about 4€/kg (see Figs. 2 and 3).

Logbook analysis of 2023 and 2024, which were the first two years in which a considerable part of the trawl fleet participated in the fishery, revealed a distinct fishing season from October to May (see Fig. 4). Commercial squid and cuttlefish fishing of the German fleet started in 2019, yet catches during that time were obtained by a single vessel using Scottish seines, a fishing technique also called ‘fly-shooting’. It was not until 2023 that more vessels entered the fishery, using specifically made trawl nets. Following the establishment of this new fishing technique, peak-season monthly catches more than doubled, exceeding 50 tons in January 2024, which is the highest monthly catch ever recorded for squid in German fisheries.

While in most of the North Sea and the Skagerrak, catches of squid

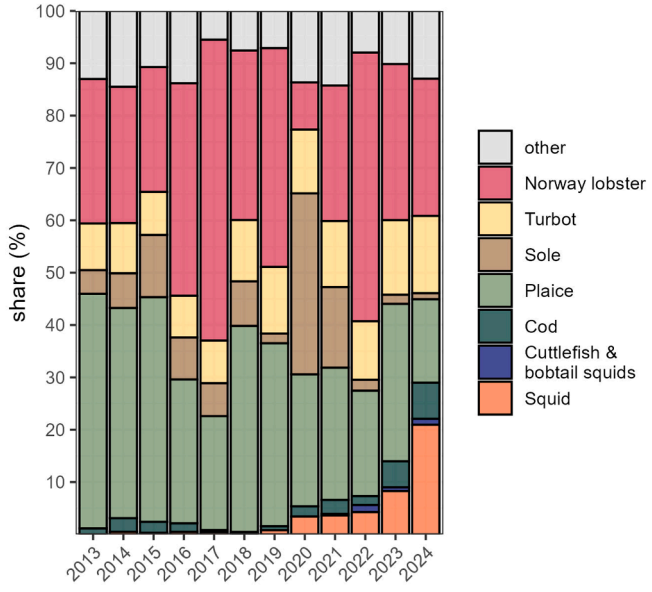

Fig. 2. Timeline of the share of the most important target species in the overall annual revenue of the German North Sea demersal fishing fleet from 2013 to 2024. The year is depicted on the X-axis, the share is depicted on the Y-axis. Target species or species groups are colour-coded. Revenue data was obtained from fisheries landing reports provided by the German Federal Office for Agriculture and Food (BLE).

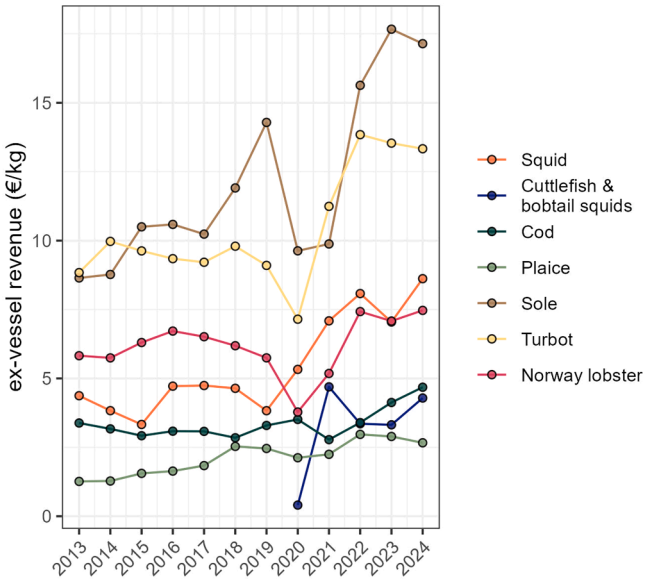

Fig. 3. Timeline of average ex-vessel revenues of selected target species of German North Sea mixed demersal fisheries. Average revenues are given in €/kg, the colour indicates the species or group of species. Revenue data was obtained from fisheries landing reports provided by the German Federal Office for Agriculture and Food (BLE).

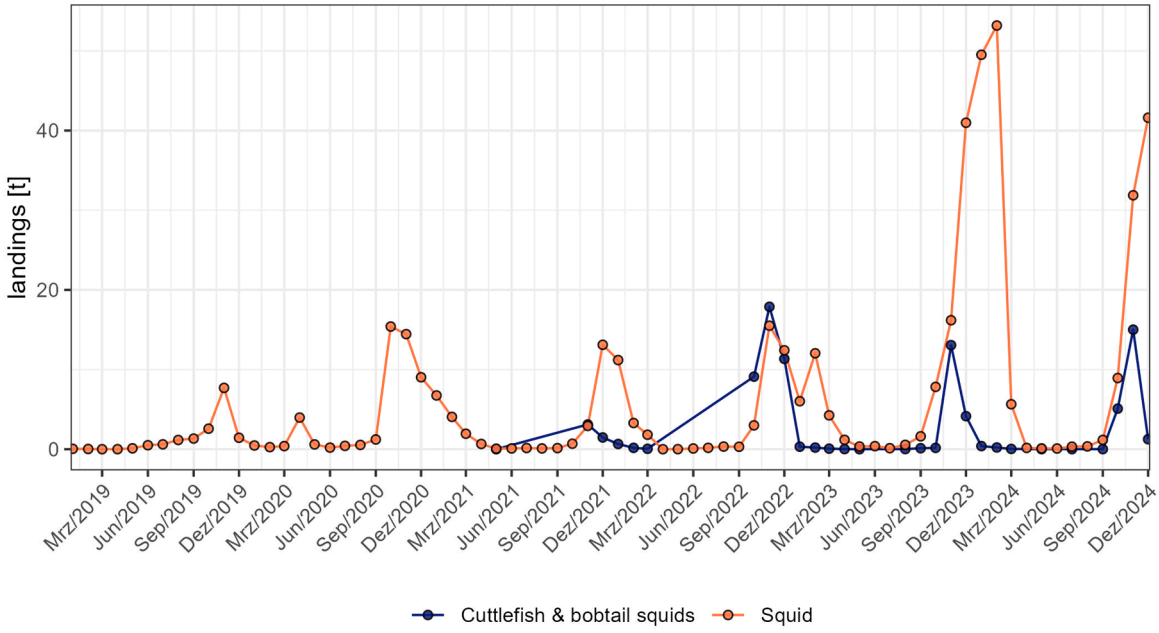

Fig. 4. Seasonal timeline of squid, cuttlefish, and bobtail squid catches of the German North Sea mixed demersal trawl fleet. Monthly catches between January 2019 and December 2024 in tons are displayed; the colour of the points and lines indicates the species group. Catch data was obtained from fisheries landing reports provided by the German Federal Office for Agriculture and Food (BLE).

were rather small at less than 100 kg/haul, although widespread and common, with only a few hauls of 100–500 kg per squid, big catches of more than 500 kg or more than 1000 kg of squid per haul were concentrated in the southern North Sea (see Fig. 5 - (A)). The Getis-Ord Global *G* statistic applied to the 0.1°-grid-aggregated dataset revealed significant difference from random spatial distribution (Global *G* $5.48*10^{-3}$, Expected *G* under random distribution $7.45*10^{-5}$, p-value < $2.2*10^{-16}$), indicating significant spatial clustering of hot spots in the data ($Z = 86.61$). Local Getis-Ord *G* statistic revealed hotspots (*G* greater than 0) of moderate (p-value <= 0.05 and >= 0.01) and high (p-value <= 0.01) significance, cold spots (*G* smaller than 0) of high (p-value <= 0.01) significance and insignificant spots. All cold spots showed high significance values. Mapping of local *G* test results (see Fig. 5 – (B)) indicated spatial clustering of highly significant hotspots in the southern North Sea and the Eastern English Channel, while in the central and northern North Sea, only hotspots of moderate significance were present. Hierarchical clustering of the Euclidean Distance matrix computed from hotspot grid cell centroids was performed, in which the optimal number of clusters was determined at 4, with the highest average silhouette width at 0.731. Plotting the four hotspot clusters revealed their spatial distribution: Cluster I was located the furthest west of all clusters, in the Eastern English Channel near the coast of France in the Baie de Seine, with a single outlier grid cell further towards the center of the Channel. Cluster II was also located in the Eastern English Channel, but further to the east and closer to the coast than Cluster I. Cluster III was located slightly north of the Straight of Dover, and Cluster IV in the southernmost part of the North Sea, the Southern Bight (see Fig. 5 - (C)). To assess temporal dynamics, the Kernel density estimate of monthly haul distributions in the four hotspot clusters was plotted. Cluster I had the highest relative density of hauls in December and March, Cluster II in November and December, Cluster III in November and December, with December being the most pronounced relative peak of the dataset, indicating a high spatiotemporal concentration of fishing activity, and Cluster IV in January and February (see Fig. 5 - (D). Overall, the combined application of spatial and temporal clustering and distribution analysis revealed a significant spatiotemporal concentration of the squid fishery and a pronounced northwestward trajectory of fishing activity concentration in the progression of the fishing season.

3.2. Commercial fishery sampling

The fishing trip of an anonymous commercial fishing vessel targeting squid at DS was sampled at the height of the squid season from January 2nd to January 5th, 2025. Squid were caught with a specifically manufactured squid trawl with an approximate opening width of 40 m between trawl doors and an approximate opening height of 8 m. Acquisition costs of the net were approximated at 35,000€ by the fishers, as the net was acquired by the fishing company owning the vessel and several others. Trawls were undertaken only during daylight hours, as squid aggregate close to the seabed during the day and disperse in the water column at night, presumably for feeding. All hauls were towed in a narrow seabed area approximately 25 NM long and 5 NM wide at depths between 37 m and 42 m, bounded by a rocky area with shallow (10 m to 15 m depth) dune ridges to the southeast and a basin of over 60 m depth to the northwest (see Fig. 5). A total of 9 hauls was conducted in two days of fishing. Trawls were towed for 1–3 h and distances between 4.8 NM and 13.4 NM, with an average duration of 1.9 h (SD: 0.82 h) and an average distance of 8.16 NM (SD: 3.73 NM). The fished area was located at the intersection of the EEZ borders of Belgium, France, and the UK, and multiple hauls were towed across multiple states' EEZs (see Fig. 5). As it was peak squid season, the fishing ground was densely populated by approximately 20 trawlers of different nationalities, towing northeast to southwest and vice versa.

A total of 1020 kg of squid specimens were caught in the two-day fishing campaign, which were all *Loligo vulgaris*. The largest size class accounted for the smallest share of the catch with only 1.28 % of the catch weight (see Fig. 6). All other size classes had comparable shares of the catch weight with 36.39 %, 35.24 %, and 27.1 % for SQU2, SQU3, and SQU4, respectively. As sorting was done by hand and therefore had a degree of subjectiveness, the mantle lengths of the four size classes showed considerable overlap, yet median mantle lengths reflected the size differences, nevertheless. SQU4 had a median mantle length of 16 cm (MW: 15.68 cm; SD: 2.71 cm), SQU3 had 21 cm (MW: 21.45 cm; SD: 1.89 cm), SQU2 had 30 cm (MW: 30.45 cm; SD: 4.00 cm), and SQU1 had the biggest median mantle length of 48 cm (MW: 48.36 cm, SD: 2.31 cm). The largest individual caught (54 cm DML) was in SQU1, which is the maximum reported DML of North East Atlantic *L. vulgaris*

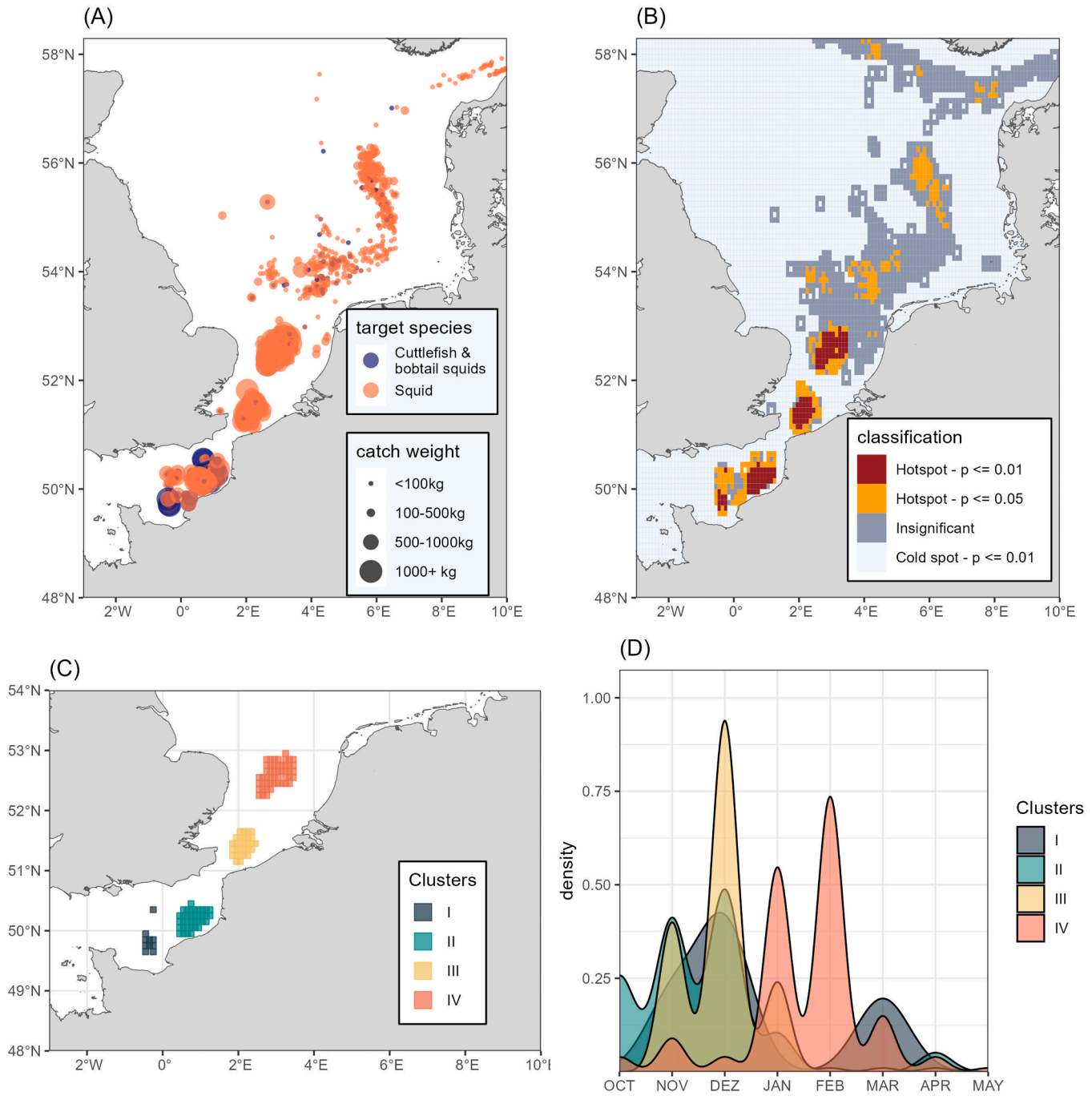

Fig. 5. Grid of figures displaying spatiotemporal dynamics of German squid fisheries for the years 2023 and 2024. A) Map of fishing positions of German North Sea demersal trawl fisheries catching cephalopods in the Greater North Sea Ecoregion. Positions were taken from the logbooks of 2023 and 2024. Point sizes correspond to the catch weight, the colour of the points indicates the species group caught. Haul sizes were categorized into minor (< 100 kg), small (100–500 kg), medium (500–1000 kg), and big (1000 + kg). Fishing locations were obtained from logbook reports provided by the German Federal Office for Agriculture and Food (BLE). B) Map of spatial hotspot analysis result. Hotspots with high ($p <= 0.01$) and medium ($p <= 0.05$) significance, insignificant spots, and high significance cold spots ($p <= 0.01$) are displayed. C) Map of hierarchically clustered hot spots of squid fishing. The four clusters are color-coded. D) Kernel density estimate of empirical haul distribution during the squid fishing season within the four identified squid fishing hot spots. The month is displayed on the x-axis, following the continuity of the winter fishing season from October to May, the Kernel density estimate is displayed on the y-axis.

(Moreno et al., 2007) and is only 10 cm below the maximum published mantle length of this species (Perales-Raya, 2013). Median mantle lengths of all size classes were significantly different from each other (ANOVA p-value: $2e^{-16}$, Tukey-HSD-test p-values of all parings approximating 0). All squid were kept chilled on ice and sold fresh at an auction, limiting the duration of the fishing trip to no longer than three days after obtaining the first catches. Whiting (*Merlgius merlangus*) was the most common bycatch, and the part of the catch exceeding the minimum conservation reference size (27 cm, EU 1998) was kept, which was approximately 200 kg in total. Undersized whiting was discarded, which is a legal exemption from the existing landing obligation for the species (EU, 2023). Many whiting individuals showed bitemarks from squid beaks, which most likely were sustained in the cod-end of the net during hauling. Other bycatch species, of which only a few individuals

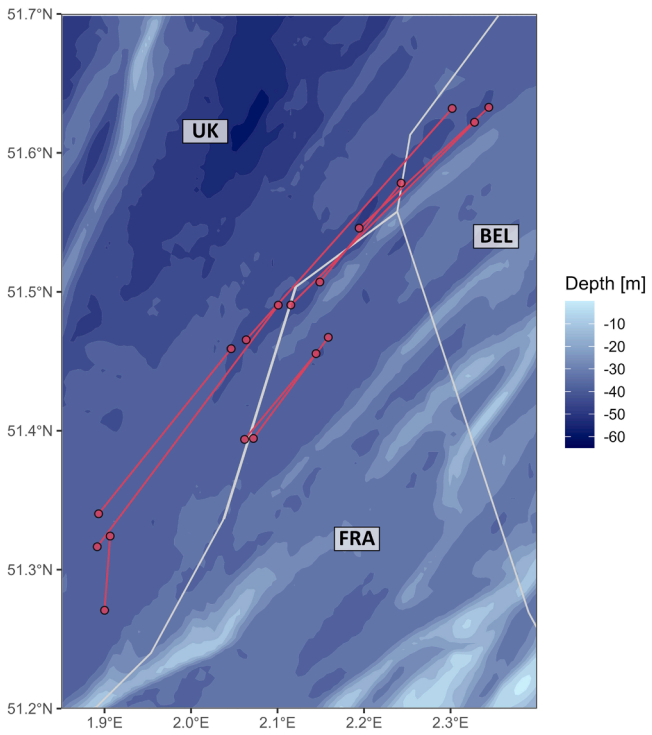

Fig. 6. Map of trawl tracks covered by the exemplary squid trawler during the sampled trip. Points mark deployment and retrieval positions; the colour scale depicts the depth. White lines mark EEZ borders, the governing nations are marked with the corresponding abbreviations (UK = United Kingdom; BEL = Belgium; FRA = France).

were caught and kept for their high market value, were: European seabass (*Dicentrarchus labrax*), Greater weever (*Trachinus draco*), John Dory (*Zeus faber*), Lemon sole (*Microstomus kitt*), Cuttlefish *(Sepia officinalis*), and tub gurnard (*Chelidonichthys lucerna*). Other very common, yet mostly discarded, bycatch species were dab (*Limanda limanda*) and striped red mullet (*Mullus surmuletus*) (Fig. 7).

3.3. Auctions & sales channels

Interviews on sales channels were held both on board and at the IJmuiden fish auction, which is one of the most important auction sites for squid, together with Vlissingen and Den Helder in Belgium, depending on the season and the fishing activity at the previously described fishing grounds. Fishermen and auction visitors unanimously reported that all squid size classes reach similar ex-vessel prices of around 10 €/kg, with fluctuations being driven by supply and demand in the main buying regions, which are Spain, Portugal, and France. The majority of the squid sold at auctions is processed in the Netherlands, primarily in Urk, and wholesalers buy large quantities to supply the processing sites. Yet, wholesalers and restaurants also buy smaller quantities for high prices, contributing to the overall revenue of the fishery.

4. Discussion

Our results revealed a unique and completely novel fishery that the German fleet had never undertaken before. News from the fishing sector and scientific reports (ICES, 2024b) suggested increased fishing activity on squid by Dutch, Belgian, British, French, and German vessels in the southern North Sea and the eastern English Channel, but a full scientific description was, to our best knowledge, missing. Identifying the fishery as a targeted fishery on *L. vulgaris*, which is only one of several squid species in the North Sea showing increasing abundances and widened distribution ranges, increases the ecological understanding of squid population dynamics in the area (van der Kooij et al., 2016; Schickele et al., 2021; Oesterwind et al., 2022), as squid species are usually not or not reliably reported to the species level in commercial catch statistics (ICES, 2024b) and are only insufficiently assessed in scientific surveys, because no delegated survey for squids exists. The very specific fishing areas identified, which are also used in seasonal succession, support the notion of the underrepresentation of squid in scientific surveys. The fished area sampled in the study was approximated at 25NM long and 5NM wide, equalling 125 square miles. For comparison, a rectangle of the International Bottom Trawl Survey in the area is around 37NM times 30NM, which is 1110 square miles. Given this size difference, the pronounced seasonality we described, and the low sampling frequency of scientific surveys, sampling this fishery without a specifically designed program is highly unlikely. We, therefore, urge not only including this

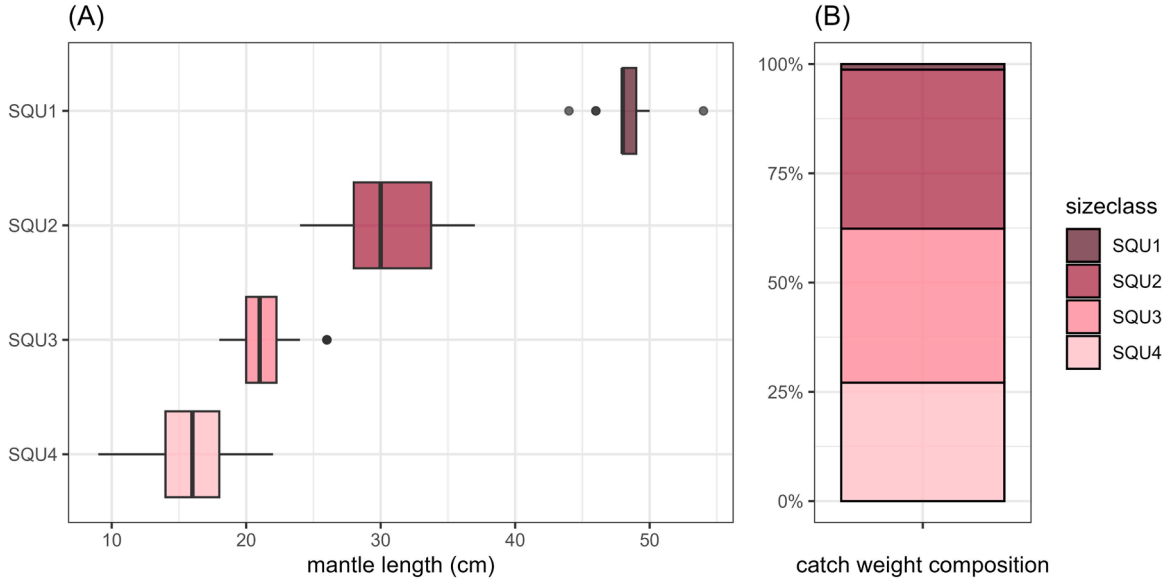

Fig. 7. Grid of catch characteristics measured during the sampled trip on Loligo vulgaris specimen. Boxplot (A) depicts the range of mantle lengths in cm of the four squid size classes. Plot (B) depicts the share of the four size classes in the total catch obtained during the sampled trip. The colour depicts the size class.

fishery in the respective on-board sampling and observer programs of the EU and UK, but also for a multilateral initiative to create a specifically designated, coordinated research survey.

Squid are highly efficient predators that play a significant role in marine ecosystems both as predators and prey (Bello, 1991; Clarke, 1996; Caddy and Rodhouse, 1998; Piatkowski et al., 2001; Oesterwind et al., 2022; Oesterwind and Piatkowski, 2023; Schäfer et al., 2024). The fishery we described makes use of aggregations of individuals that are highly specific in time and space, which most likely form because individuals are either spawning or feeding, or a combination of both. Many whiting individuals had visibly full stomachs, and sampling revealed that most of them were feeding on sandeel (*Ammodytes* sp.). The sandeel individuals found in whiting stomachs constitute a potentially suitable prey organism for squid (Pierce et al., 1994; Oesterwind and Piatkowski, 2023), and the fishing area is a suitable habitat for sandeel (ICES, 2025a). In addition, area and timing match the reproductive cycle of the Downs herring stock, and fishers interviewed linked the appearance of the squid to the spawning herring. Squid are capable, opportunistic predators and capable of preying on herring (Pierce et al., 1994; Oesterwind and Piatkowski, 2023), as herring spawning aggregations have been proven to attract predators, e.g., haddock and whiting (Toresen, 1991). Yet, the season also matches the reproductive cycle found for *L. vulgaris* in previous work (Oesterwind et al., 2010; Laptikhovsky et al., 2022) and the pronounced fishing season and strong seasonality align closely with the findings of Marcout et al. (2025). Their promising approach of a standardised index for spatiotemporal variability assessment should be followed up harnessing international fleet data sets and, preferably, catch data identified to the species level. The area documented in our study has been documented as a spawning site by the mentioned as well as earlier studies (Jereb et al., 2015), yet the abundances in which the squid were aggregating in the area are, according to the fishers participating in this novel fishery, unprecedented. The stock component spawning in the southern North Sea (*L. vulgaris typica*) might benefit from regional warming and milder winters, creating more favorable temperature conditions for egg development. Alternatively, the aggregation could be a feeding aggregation, potentially on sandeel, which has been documented as a prey item for *L. vulgaris* before (Jereb et al., 2015), in preparation for spawning in more western areas of the English Channel. The rapid end of the squid season in the southern North Sea in early to mid-March could be interpreted as an indication of the semelparous squid dying after spawning, yet only fecundity sampling of individuals caught in the southern North Sea can provide a definitive answer.

Regardless of the specific reason for *L. vulgaris* aggregating in the sampled area, climate change and the warming of the North Sea are likely to be at least an influencing factor in this distribution change. Especially in the shallow, semi-enclosed North Sea and the adjacent Baltic Sea, where climate change effects are comparably pronounced (Colijn and Quante, 2016; Meier et al., 2022), traditional key fisheries target species such as cod and herring are impaired by the effects of ocean warming. The subsequent economic damage to the German demersal fishing fleet has been immense, and vessel numbers are continuously declining (STECF, 2024). The *L. vulgaris* fishery is the first documented example of targeted cephalopod fishing by the German fishing fleet. It is a much-needed economic relief for the North Sea demersal trawl fleet, which suffers from the pressures described in the introduction of this article, and the unparalleled rapid growth of the economic importance of the fishery reflects that. *L. vulgaris* is not only a high-value target species fetching excellent auction prices, but it is also subject to very few regulations. As previously described, fishers need to follow only the minimum mesh size and bycatch regulations when engaging in the squid fishery. Yet, the bycatch regulations have become somewhat problematic, as patrol boats have found bycatch of undersized whiting exceeding allowed limits during controls, resulting in closures of the fishing area for up to three weeks (McBride, 2025b). Given the described short season and spatial limits of squid fishing in the southern North Sea, these closures have severe economic consequences for the vessels. Whiting in the North Sea is well within safe biological limits, and the quota is not fully utilized (ICES, 2025b). A feasible solution for the problem might be a temporary increase of the allowed percentage of undersized whiting bycatch and a simultaneous development program for specialized squid trawls, avoiding whiting bycatch. At the same time, and more importantly, the ecological and economic sustainability of this new resource needs to be safeguarded. The semelparous lifestyle of squid in combination with their short life span, makes it particularly hard to perform traditional stock assessments, which are the pillar of EU fisheries science and the subsequent management. Determining a total allowable catch of *L. vulgaris* before the season starts is extremely challenging and, if performed, most likely to come with a lot of uncertainties. Therefore, established management measures from other squid fisheries around the globe, such as pre-season biomass indices or live assessments during the fishing season, might have potential for managing the southern North Sea *L. vulgaris* fishery as well (Agnew et al., 2005).

Our analysis revealed that the southern North Sea *L. vulgaris* fishery takes, at least in part, place on the intersection of EEZ borders of EU member states and the UK, highlighting the urgent need for standardised management procedures for a fishery in which both EU and UK vessels participate. Technical and catch-related management measures can only be effective if they are multilaterally agreed upon and implemented by all relevant nations. This is especially challenging as the UK has left the EU and, therefore, also the European Common Fisheries Policy (CFP). The agreement on unchanged conditions for EU Fishing vessels following 2027 (including no change in the 2026 quota distribution key between the UK and the EU) could be a sign that both sides are interested in a common management of resources. Fisheries agreements between the two parties are currently set for fixed periods, which is not an ideal situation for fostering long-term sustainability and should be changed to longer-term objectives and measures.

Since leaving the CFP, the UK has implemented novel regulations such as mandatory VMS tracking for small coastal vessels (Marine Management Organisation, 2025) or a ban on sandeel reduction fisheries in protected areas, the latter being successfully contested by Danish sandeel fishers using the dispute settlement mechanism included in the BREXIT agreement (McBride, 2025a). To keep the southern North Sea squid fishery from becoming the next subject of contention in EU-UK fisheries relations, commonly agreed management strategies should be preferred to unilateral advances. This also applies to gear regulations, as the demersal trawls and seines currently used in squid fishing are opposed both in the UK and the EU (Seas At Risk, 2022; OceanCare, 2023), and campaigns for banning them have gained momentum in recent years. In other regions of the world, squid are commonly caught using jigs on a commercial scale (Chen et al., 2008), which have no contact with the seabed, use less fuel than trawls (Davie et al., 2015), and usually have very little bycatch as they are using specialised squid hooks without barbs. Yet, scientific trials of commercial-scale squid jigging in the North Sea have not been successful, and it is currently only applied on a recreational level (Marine Management Organisation, 2023). If a ban on mobile bottom-contacting gear should be implemented in the southern North Sea, it cannot be expected that fishers can make a rapid transition to jigging, as it requires considerable technical and operational adjustments. Therefore, a transitional phase would need to be facilitated, ideally including funding and support.

5. Conclusion

Combining data analysis and field sampling, we conducted the first scientific description of a novel regional squid fishery in the southern North Sea. As we highlighted, the economic importance of the fishery is significant, as the targeted high-value *L. vulgaris* constituted a fifth of the analysed fleet's annual revenues. A high level of specialisation in terms of gear and operational strategy is required by the participating vessels,

yet a high market demand and ex-vessel price, fueled by the struggles of other global squid fisheries, states a compelling incentive to join the fishery. Our analysis is largely restricted to the German fleets, and further research and onboard observer programs should be facilitated as soon as possible in the Netherlands, France, the UK, and Belgium to cover the other, often considerably larger, fleets participating in this fishery. Furthermore, a strategic, multilateral management process should be commenced, utilising existing research and creating a roadmap to safeguard the long-term sustainability of the resource. Southern North Sea squid fisheries are indubitably at least partly caused by the effects of climate change and can serve as a stress test for the European fisheries management landscape. Traditional target species can no longer sufficiently guarantee the long-term economic viability of North Sea fisheries, and fishers are in dire search for alternatives. As continuous warming of the ocean will cause accelerating changes in species distribution and ecology, the squid fishery will not be the last 'new' target fishery in the Northeast Atlantic. The rapid speed of the ongoing ecological change will continuously force fishers, managers, and researchers to adapt and develop feasible solutions, avoiding previous mistakes of unsustainable harvesting and overfishing of valuable resources.

CRediT authorship contribution statement

Daniel Oesterwind: Writing – review & editing, Writing – original draft, Visualization, Validation. **Ralf Döring:** Writing – review & editing, Conceptualization. **Erik Sulanke:** Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no competing interests or personal relations influencing the objectivity of the presented work.

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Data availability

The authors do not have permission to share data.

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