STUDY AND EVALUATION OF THE BIOLOGICAL PARAMETERS OF *Illex coindetii* (Vérany, 1839), IN THE CONTEXT OF BOTTOM TRAWLING ALONG THE CATALAN COAST

Name: Ivan Ruiz Pérez

Date: 02/09/2025

Universitat de Barcelona - ICATMAR

Directors: Alberto Javier Rico and Ferran Bustos

Internal tutor (UB): Luis Cardona

Acknowledgments

Firstly, I would like to express my gratitude to my directors, Alberto Javier Rico and Ferran Bustos, for their constant support, commitment and dedication. Without their guidance and work, this project would not have been possible. I would also like to thank the entire ICATMAR team for giving me the opportunity to carry out this work alongside them. In particular, I would like to thank each and every one of them for their encouragement, trust and for motivating me to always give my best in this project.

Finally, I am deeply grateful to my family and friends, who have accompanied me throughout this process, listening to me when I needed it and offering me their unconditional support at all times.

Index

Abstract

The Mediterranean Sea hosts a highly diverse fishing tradition. Along the Catalan coast, located in the northwestern Mediterranean, bottom trawling represents the most important fishing activity in terms of revenue. Because of this, the *Institut Català de Recerca per la Governança del Mar* (ICATMAR) conducts a monitoring program targeting the most commercially significant species in the region. *Illex coindetii* (Vérany, 1839) has become the most important cephalopod species in terms of both landed biomass and income. Belonging to the family *Ommastrephidae*, this species exhibits a high variability in biological and population parameters, due to its wide distribution. Thus, the objective of this study is to update the status of the species in the Catalan coast. The general length–frequency distribution ranged from 30 to 230 mm of dorsal mantle length (DML), with a modal value at 90 mm and a mean of 102 mm of DML. Annual data revealed slightly larger individuals in 2023–2024. Seasonal analysis revealed up to three cohorts, reflecting the species' reproductive cycle, which is characterized by continuous spawning with seasonal peaks. Spatially, the modal length was slightly higher in northern and southern zones. Regarding its bathymetric distribution, highest densities occurred between 100 and 200 m. The length–weight relationship showed a trend related to sexual dimorphism, with females being larger than males, showing negative and positive allometry, respectively. Reproductive biology analyses indicated that maturity is size-dependent in both sexes, with males reaching maturity at smaller sizes (L50) than females. During the sampling period, males showed a higher proportion of mature individuals. However, females exhibited two clear reproductive peaks: one in winter and another in early summer. The biological dynamics of the species show the complexity of the marine living resources, making evident the need for a continuous monitoring of life-history parameters, which can provide essential information for its sustainable management.

Key words: Mediterranean Sea, fisheries, *Illex coindetii*, population structure and reproductive biology.

Resum

El mar Mediterrani acull una tradició pesquera molt diversa. Al llarg de la costa catalana, situada al nord-est del Mediterrani, la pesca d'arrossegament de fons representa l'activitat pesquera més important en termes d'ingressos. Per això, l'*Institut Català de Recerca per la Governança del Mar* (ICATMAR) realitza un programa de seguiment dirigit a les espècies més rellevants comercialment de la regió. *Illex coindetii* (Vérany, 1839) s'ha convertit en l'espècie de cefalòpodes més important tant en termes de biomassa terrestre com d'ingressos. Pertanyent a la família *Ommastrephidae*, aquesta espècie presenta una gran variabilitat en els paràmetres biològics i poblacionals, a causa de la seva àmplia distribució. Així, l'objectiu d'aquest estudi és actualitzar l'estat de les espècies a la costa catalana. La distribució de talles general va variar de 30 a 230 mm de longitud del mantell dorsal (DML), amb un valor modal a 90 mm i una mitjana de 102 mm de DML. Les dades anuals van revelar individus lleugerament més grans en 2023-2024. L'anàlisi estacional va revelar fins a tres cohorts, reflectint el cicle reproductiu de l'espècie, que es caracteritza per la fresa contínua amb pics estacionals. En el pla espacial, la longitud modal era lleugerament més alta a les zones nord i sud. Pel que fa a la seva distribució batimètrica, les densitats més altes es van produir entre 100 i 200 m. La relació longitud-pes va mostrar una tendència relacionada amb el dimorfisme sexual, amb les femelles més grans que els mascles, mostrant al·lometria negativa i positiva, respectivament. Les anàlisis de biologia reproductiva indiquen que la maduresa depèn de la mida en ambdós sexes, amb els mascles arribant a la maduresa a mides més petites (L50) que les femelles. Durant el període de mostreig, els mascles van mostrar una major proporció d'individus madurs. No obstant això, les femelles van mostrar dos pics reproductius clars: un a l'hivern i un altre a principis d'estiu. La dinàmica biològica de l'espècie mostra la complexitat dels recursos marins vius, fent evident la necessitat d'un seguiment continu dels paràmetres de la història de la vida, que poden proporcionar informació essencial per a la seva gestió sostenible.

Paraules clau: Mar Mediterrani, pesqueries, Illex coindetii, estructura poblacional i biologia reproductiva.

1. Introduction

The Mediterranean Sea has a long history of ocean research and fishing, with marine resources exploited for thousands of years. Fishing has always been central to the region's development (Margalef, 1989). Zooming into the northwestern region, it is distinguished by an elevated biological productivity, a phenomenon that is predominantly influenced by river discharges into the sea (Piroddi *et al*., 2020). As a result, this area is characterized by a high diversity of species, which has led to the development of an intense fishing activity marked by the use of a wide array of fishing gears (Lucchetti *et al*., 2023).

Among its subregions, the Catalan coast, located in the northeast of the Iberian Peninsula, is an area where fishing has strong cultural roots and has long been an important source of income and identity for coastal communities (ICATMAR, 2025). On top of that, this region features a highly variable geomorphology. The north is dominated by submarine canyons (Clavel-Henry *et al*., 2021), the centre presents a more homogeneous seabed, with high anthropic pressure due to the presence of densely populated areas such as Barcelona (Blanco *et al*., 2023), and the south is defined by an extensive continental shelf conditioned by the sediment contribution from the Ebre river (Carreton *et al*., 2025).

Across the different fisheries operating in Catalonia, bottom trawling (figure 1) is the most productive in terms of income (ICATMAR, 2025). The process of bottom trawling entails the utilisation of a funnel-shaped net, which is dragged through a designated area of the ocean floor. This procedure is undertaken with the objective of capturing organisms in the final segment of the gear, named as the cod-end (Lucchetti *et al*., 2023). This fishing gear is a non-selective and multi-specific extractive activity that targets demersal species across a broad range of depths. In certain areas, regulations set a maximum depth at which this activity can be conducted to prevent overexploitation of species inhabiting the deep-sea ecosystem due to their life-history traits that make them particularly vulnerable (Clarke *et al*., 2015). This is the case of bottom trawling in Spanish waters, where the limit is set at 800 m depth (*APA/412/2024*). In the case of Catalonia, the variability of the sea bed, as mentioned before, affects to this activity allowing deep sea fishing in the north, and limiting it within a distance of three nautical miles from the coastline, as opposed to the standard 50 m depth limitation, in the south (EU 1967/2006; Clavel-Henry *et al*., 2021).

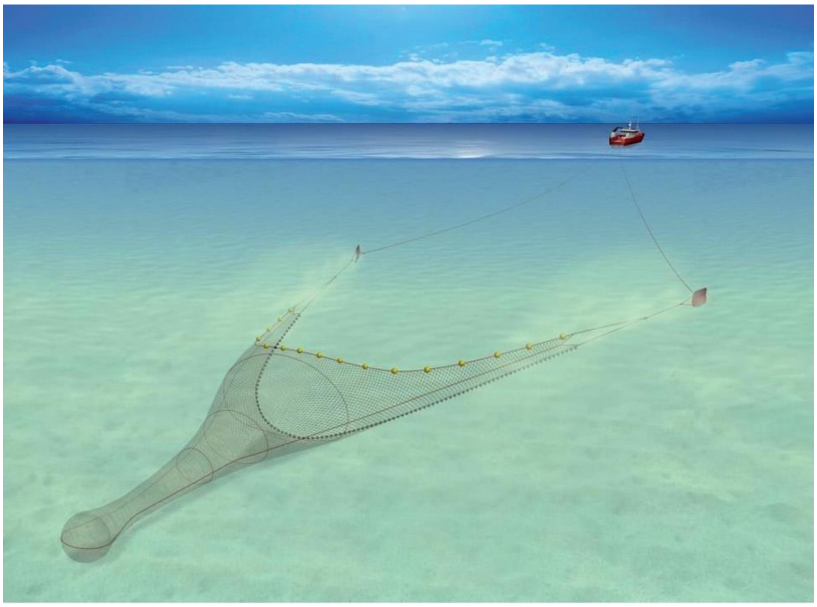


Figure 1. Graphical representation of a bottom trawl net dragging along the seabed. Source: Seafish. 2023.

The low selectivity of bottom trawling often results in the capture of a considerable amount of non-target species, referred to as bycatch (Alsayes *et al.*, 2009). In cases where regulatory frameworks allow it, these bycatch specimens may be subject to commercialisation. On the other hand, those that are deemed unsuitable (i.e., non-commercial species or commercial species that are damaged or do not reach the minimum legal size), are typically disposed of and referred to as the discarded fraction of the catch (Machias *et al.*, 2001; Zeller *et al.*, 2018).

In this context, the role of local scientific institutions that monitor fishery resources in the different Mediterranean subregions is essential. This is the case case of the *Institut Català de Recerca per la Governança del Mar* (ICATMAR), which is a collaboration body between the *Direcció General de Política Marítima* i *Pesca Sostenible* of the *Generalitat de Catalunya* and the *Institut de Ciències del Mar* (ICM – CSIC). The primary objective of ICATMAR is to provide scientific advice for the sustainable management of fisheries in the Catalan coast to different administrations from local to European level. Based on a rigorous biological data collection methodology, ICATMAR assesses the evolution of stock dynamics from the main marine commercial species along the Catalan coast, such as *Illex coindetii* (Vérany, 1839) (Carreton *et al.*, 2025).

The broadtail shortfinned squid, *Illex coindetii*, is considered an important target species for the bottom trawl fleets of the Mediterranean Sea (Sánchez *et al.*, 1998; Lucchetti *et al.*, 2021). In Catalonia, it has become the most important cephalopod species in terms of biomass and income for the bottom trawl fishery over the last decades. Actually, the species ranked the third in captured biomass and the seventh in terms of income for the entire Catalan bottom trawl fishery in 2024 (ICATMAR, 2025).

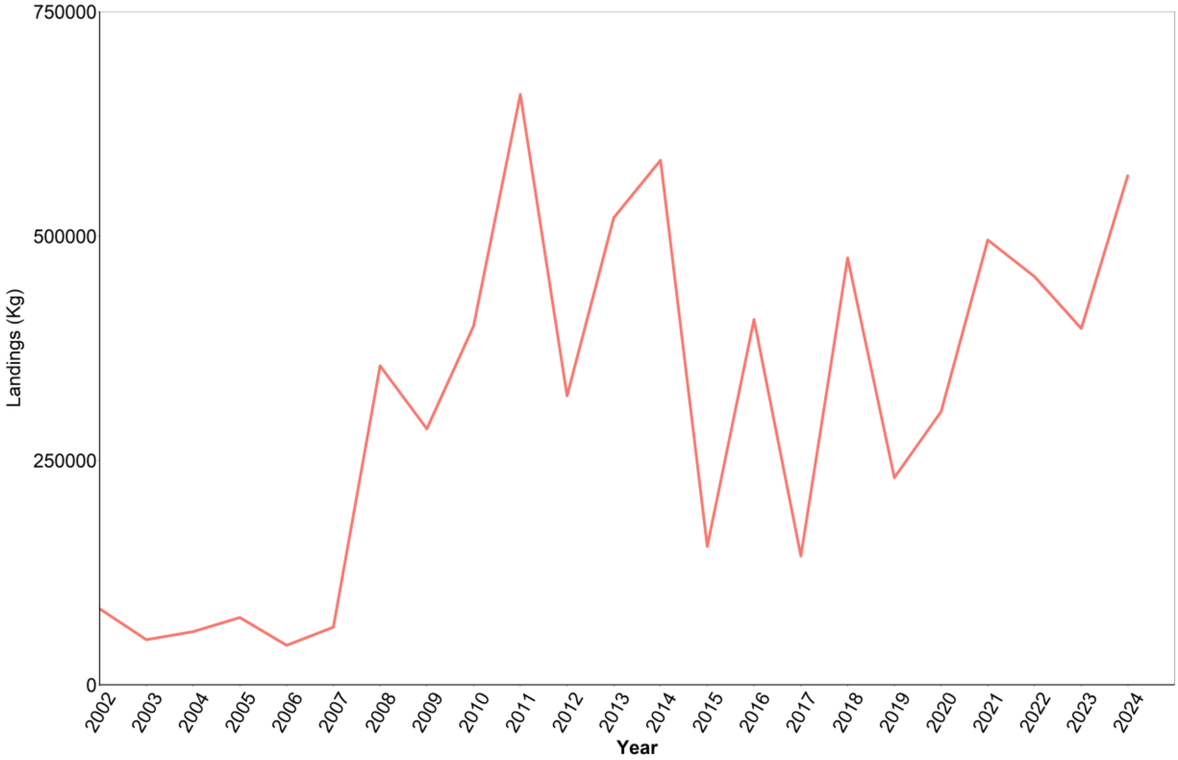


Figure 2. Historic series of total annual landings of *Illex coindetii* in Catalonia from 2002 to 2024. Source: *Generalitat de Catalunya*, 2024.

Illex coindetii (figure 4) is a cephalopod species that belongs to the group of oceanic squids, the *Ommastrephidae* family. It is widely distributed (figure 3), from the Mediterranean Sea to both the eastern and western Atlantic (Sánchez *et al.*, 1998; Jereb *et al.*, 2001). Furthermore, *Illex coindetii* plays an important ecological role in the trophic chain due to its high predatory activity and represents an important diet component for many important commercial species such as *Merluccius merluccius* (Linnaeus, 1758) or endangered megafauna (Jereb *et al.*, 2001; Arvanitidis *et al.*, 2002; Luna *et al.*, 2021).

Its life cycle is complex: the paralarval and juvenile stages of the species generally exhibit nektonic behaviour, while the adult stage is demersal and performs vertical migrations associated with the day-night cycle (Sánchez *et al.*, 1998; Lefkaditou *et al.*, 2008). This species inhabits a wide bathymetric range from 50 to 1110 m depth. Nevertheless, the usual depth range covers part of the continental shelf and the upper slope from 50 to 500 m (Lefkaditou *et al.*, 2008; Rosas-Luis *et al.*, 2014), while maximum abundances are usually concentrated between 100 and 200 m (Jereb & Ragonese, 1995; Ceriola *et al.*, 2006).

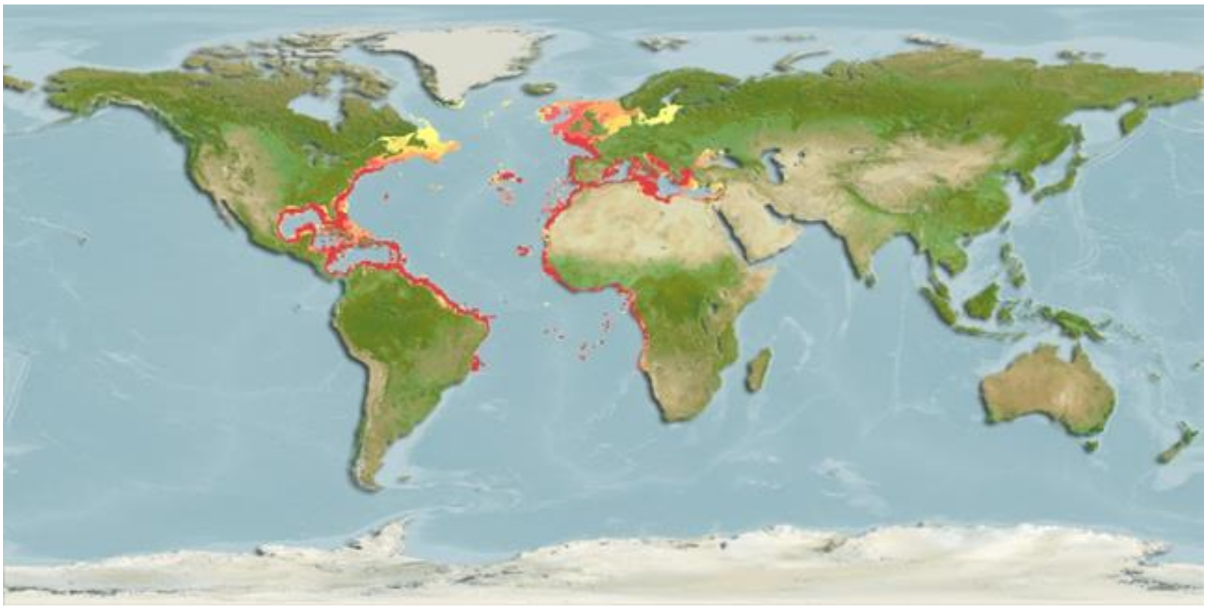


Figure 3. Geographical distribution of *Illex coindetii*. The colors indicate relative probabilities of ocurrence of the species, being yellow the lowest values and red the highest. Source: AquaMaps, 2019.

The principal diagnostic features of *Illex coindetii* are the moderate longitude and narrowness of the mantle, the rhomboidal form of the fins, which reach the posterior axis of the mantle, and the orange/brownish colouring of the body in juvenile and adult individuals (Sánchez *et al*., 1982; Jereb *et al*., 2001; Martínez *et al*., 2002).

Figure 4. Adult specimen of *Illex coindetii*. Source: © CALOCEAN

Like other cephalopods, *Illex coindetii* is a gonochoric species with sexual dimorphism. Males exhibit hectocotylization in one of the fourth pair of arms, which consists in a modified arm used during mating to transfer spermatophores (Zecchini *et al*., 2012). On the other hand, females reach larger sizes than males, with maximum mantle lengths of 250–270 mm and 180–

200 mm, respectively (Sánchez *et al*., 1998; Salman, 2017). Due to its relatively brief lifespan (7 to 18 months), this species is considered as an r-strategist, which is featured by a rapid growth and high mortality rate (Lefkaditou *et al*., 2008). Consequently, reproductive cycle shows a continuous recruitment and spawning marked with seasonal peaks that can fluctuate annually and geographically (Sánchez *et al*., 1998; Arvanitidis *et al*., 2002; Lefkaditou *et al*., 2008).

Given its ecological role and importance as a marine resource, *Illex coindetii* has been the focus of scientific research since the beginning of the 20th century (Sánchez *et al*., 1998). For this reason, to support the sustainability of its exploitation and to understand how environmental changes and anthropic pressure can affect its dynamics, the estimation of biological and population parameters is crucial (Blanco *et al*., 2023). Therefore, the objective of this Master's thesis is to provide an updated overview of the biological and population parameters of *Illex coindetii* in the context of bottom trawling along Catalan coast.

2. Methodology

This study has been conducted within the framework of the continuous monitoring program of the marine living resources along the Catalan coast that the ICATMAR carries out since 2018.

2.1 Study area

The sampling area covers the adjacent waters of the 580 km of Catalonia's coastline, Spain (from 42°26'06"N – 3°10'28"E to 40°31'23"N – 0°30'52"E), located in the northwestern Mediterranean Sea (figure 5). This area belongs to the geographical sub-area (GSA) 6, a group of geographical units established in the Mediterranean Sea by the General Fisheries Commission for the Mediterranean (GFCM) with the objective of having a better management of marine living resources (*GFCM/33/2009/2*).

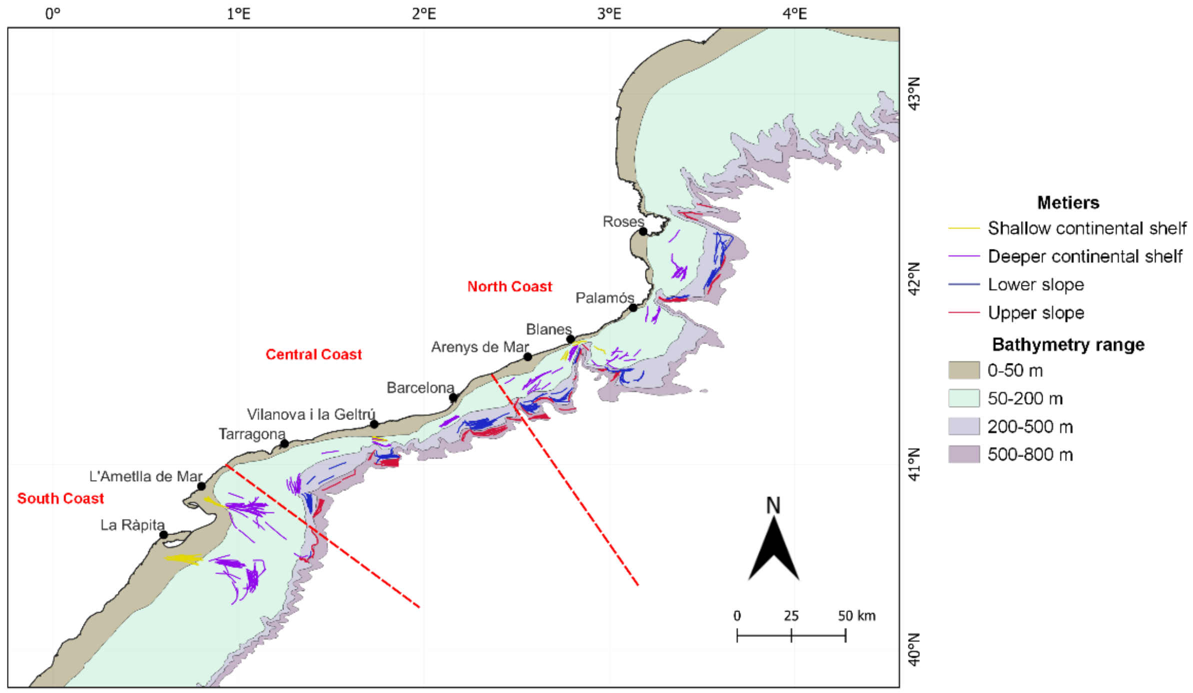


Figure 5. Map of the study area. Coloured lines show sampling tracks from ICATMAR's bottom trawl monitoring program. Carreton *et al*, 2025

Sampling was carried out at nine ports selected by their commercial importance and location along the Catalan's coast. These ports were grouped in 3 zones depending on their location along the coast:

- **North**: includes Roses, Palamós, Blanes, and Arenys de Mar.
- **Centre**: includes Barcelona, Vilanova i la Geltrú, and Tarragona.
- **South**: includes L'Ametlla de Mar and La Ràpita.

To cover the bathymetric range in which *Illex coindetii* occurs, four depth strata were considered in the sampling:

- **Shallow continental shelf:** includes the depth range situated above 75 m.
- **Deeper continental shelf:** includes the depth range from 75 to 200 m.
- **Upper slope:** includes the depth range from 200 to 500 m.
- **Lower slope:** includes the depth range from 500 to 800 m.

2.2 Sample collection

Specimens of *Illex coindetii* were obtained on board commercial vessels from the Catalan bottom trawl fleet. Based on depth strata, a total of three experimental hauls were carried out during each trip. In order to analyse temporal variations on the population, each port was sampled quarterly. The design of this sampling methodology allows the comparison of data annually but also geographically and by season which were defined by quarter.

During sampling trips, each haul was tracked with a GPS, starting at the moment when the fishing gear reaches the sea bed, and ending when the fishing gear returns to the vessel's deck. Other parameters like mean depth (m), fishing time (h), speed (kn) and gear characteristics, such as width (m) of the net mouth, allowed to estimate the total swept area during the haul. Thus, it was possible to standardize the abundance (ind/km2) and biomass (kg/km2) data. The mesh of nets used by bottom trawlers during all hauls was 40 mm, with the exception of Palamós lower slope samplings, which was 50 mm, as these vessels are included in the Working Group for blue and red shrimp, *Aristeus antennatus* (Risso, 1816), Management Plan, which entails the implementation of specific measures (Ordre APM/532/2018, de 25 de maig).

On board, fishermen sorted the catch according to the categories that are commercialized at the fish market (commercial, small, medium or large) or as discard. As *Illex coindetii* is not subject to minimum size regulations, discards are attributable to the other factors such as insufficient catch. Depending on the size of the catch, different subsamples were made for each category: if only one commercial category was sorted, 30 individuals were selected. On the contrary, 20 individuals were selected from each category. The remaining specimens of each category, were measured on board to the nearest mm of DML using an ichthyometer. The samples were transported to the laboratory and stored in cooler at 4-6ºC for further analysis the following day. Regarding the discarded fraction of the catch, either the total or a sample was also taken to the laboratory where, along with other species, *Illex coindetii* individuals, were stored frozen at -20ºC for posterior analyses.

2.3 Biological processing of samples

At the laboratory, the DML of each individual was measured to the nearest mm. Then, each individual was weighed (nearest 0.1 g) using a precision scale. Finally, each commercial specimen was dissected by the ventral mantle in order to determine the sex and macroscopic maturity stage (figure 6). Individuals were classified as male, female or indeterminate if it was not possible to determine their sex. Following Follesa & Carbonara (2019), the maturity stage of individuals was assessed and classified. For males, five stages were considered (1-immature, 2-developing, 3-maturing, 4-mature, 5-spent), while four stages were considered for females (1-immature, 2-developing, 3-maturing, 4-mature). Males exhibit an additional maturity stage compared to females due to differences in the reproductive cycle (Sánchez *et al*., 1984)

Figure 6. Female specimen of *Illex coindetii* dissected ventrally during biological processing of samples to expose the internal structures of the mantle cavity.

2.4 Data analyses

All the data gathered on board and in the laboratory was introduced in ICATMAR'S data base (Ribera-Altimir *et al.*, 2023). Regarding the nature of the data used for this study, it is necessary to distinguish between two datasets. Firstly, population structure data, which comprises the period from 2018 to 2025 consisting on information of size and abundance by zone, season and depth. Secondly, biological data collected from January to July of the current year (2025), including data on weight, sex and reproductive stage by zone, season and depth as well.

2.4.1 Preliminary analyses

In order to identify the most relevant variables for subsequent analyses and obtaining an overview of the data structure, a preliminary analysis with Microsoft Excel was conducted, which consisted in an examination of the fluctuation in the relations between the number of individuals and the size classes across zone, season and depth.

2.4.2 Life-history analyses

All the analyses in the present study were carried out by using several packages of Rstudio. The packages used for the development of graphs were *ggplot2* and *sizeMat* (only for L_{50}). The package *dplyr* was utilised to facilitate the management of all data sets, their subsequent reorganization, and the creation of new variables derived from existing ones. Finally, the packages *philentropy* and *TropFishR* were used to perform various statistical tests, including Kolmogorov-Smirnov and Bhattacharya.

To perform the analyses, individuals' DML values were grouped by 0.5 cm rounded to the lowest bound. The abundance values for each size class represent the mean value of all hauls made during the entire sampling period, as well as for each year.

An analysis of variance (ANOVA) was performed to assess potential differences in mean values across depth strata, zones, and seasons. On the other hand, the Kolmogorov-Smirnov test (*philentropy*) was employed to identify significant differences between length-frequency distributions in each factor. Additionally, in the case of seasonal variation, the Bhattacharya method (*TropFishR*) was applied to detect different cohorts within the length-frequency distributions.

Length-weight relation was calculated by sex with the formula $W = a*ML^b$, where "W" is the weight of the organism, "L" is the length, "a" the intercept (a scaling constant) and "b" the slope (growth component which indicates the type of growth). The growth pattern of the species was determined by the "b" parameter: isometry when $b = 3$, positive allometry when $b > 3$ and negative when $b < 3$. To test the significance of deviations from isometry, a Student's t-test was performed.

Sex ratio was calculated by determining the proportion of each sex in the total number of individuals by size class. Subsequently, for each sex separately, the proportion of individuals at each sexual stage of maturity, was also determined in each size class. Chi-square test of independence was performed to determine relation between size, and sex ratio, and the same for sexual-stage distribution. Following the previously mentioned analysis, minimum size at maturity (size where appears the first mature individuals) was calculated (Follesa & Carbonara, 2019). In addition, L_{50} (size at which 50% of the individuals are mature) was estimated for each sex based on a sigmoidal relationship between size and the proportion of mature individuals.

Finally, to identify possible spawning peaks and determine the reproductive period of the species between January and July, the monthly distribution of maturity stages was analysed separately for each sex.

3. Results

3.1 Population structure

A total of 13024 *Illex coindetii* individuals were used for the analyses. Figure 7 shows that DML of individuals ranged from 30 to 230 mm with the mode at 90 mm and the mean at 102 mm.

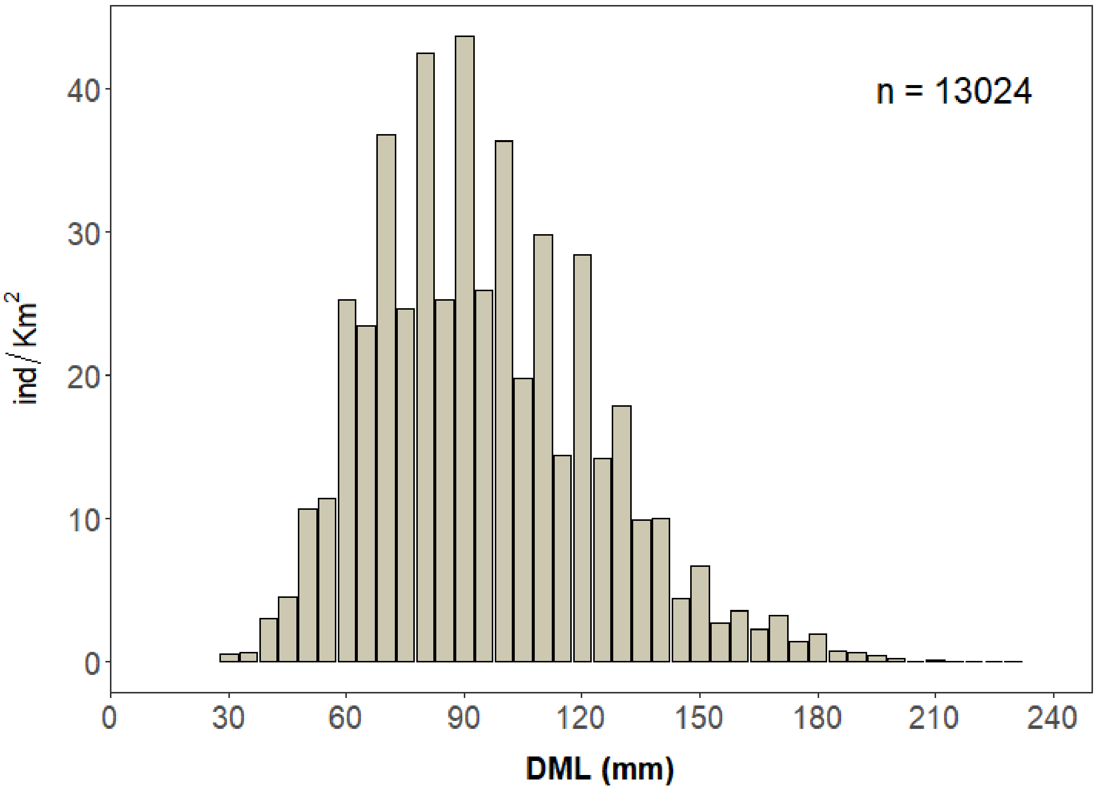


Figure 7. Length-frequency distribution of *Illex coindetii* based on individuals sampled between 2018 and 2025. Abundance is represented as individuals per unit of area (km^2).

3.1.1 Annual population distribution

Figure 8 shows the length-frequency distribution of the species by year. Data from 2018 and 2025 were excluded because complete annual datasets were unavailable. A predominance of individuals between the size range from 60 to 120 mm is observed every year with a peak around 80 mm of ML. It is worth noting the differences in abundance between years, being 2019, 2020, and 2022 those with lower values. A Kolmogorov-Smirnov test to detect interannual variation revealed significant disparities when comparing 2019 with 2023 ($D = 0.41463$, $p\text{-value} < 0.01$) and 2024 ($D = 0.34146$, $p\text{-value} < 0.05$).

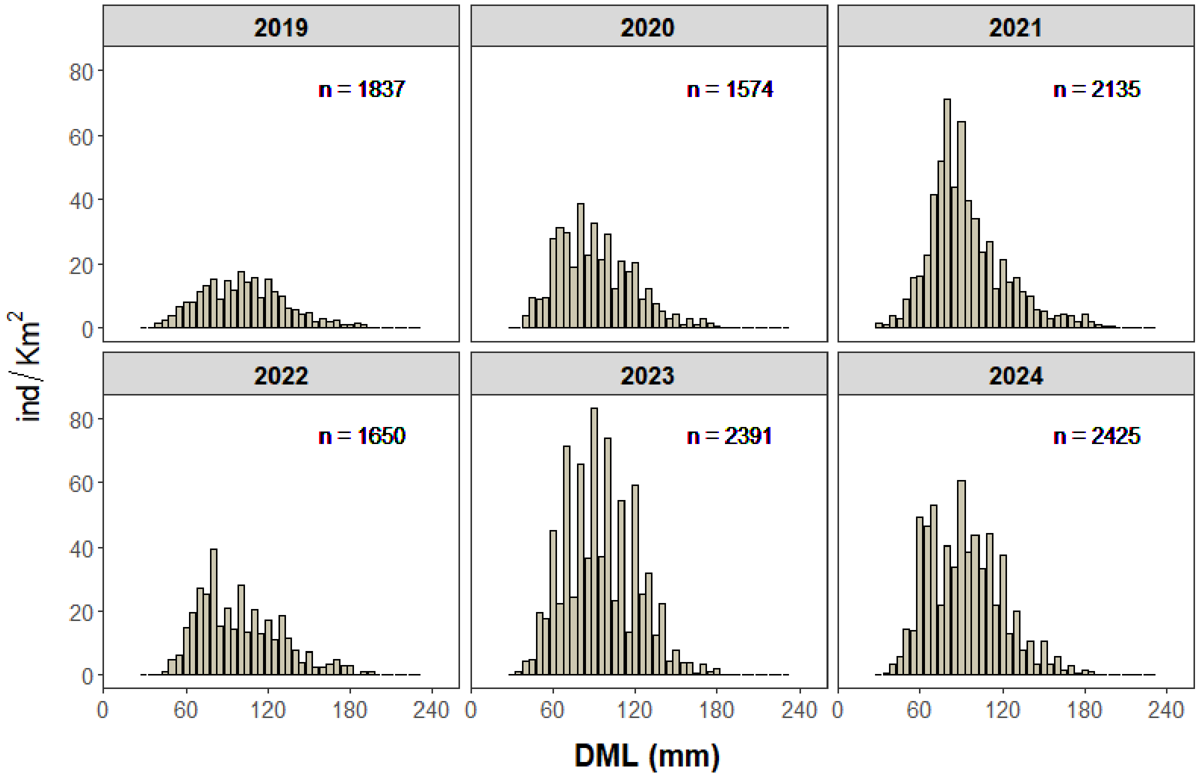


Figure 8. Annual length-frequency distribution of *Illex coindetii*.

3.1.2 Seasonal population distribution

When comparing length-frequency distributions by season (figure 9) it can be noticed that, although slight, spring shows a high abundance of individuals with sizes over 130 mm. In summer, the highest abundances are observed in individuals between size-range from 55 to 90 mm. Finally, winter and autumn were characterised by low abundances values across the whole size range. However, differences were observed in the predominant sizes, having winter the mode slightly shifted towards the left (i.e., smaller individuals). The Kolmogorov-Smirnov test revealed significant differences between all seasons (p-value < 0.001).

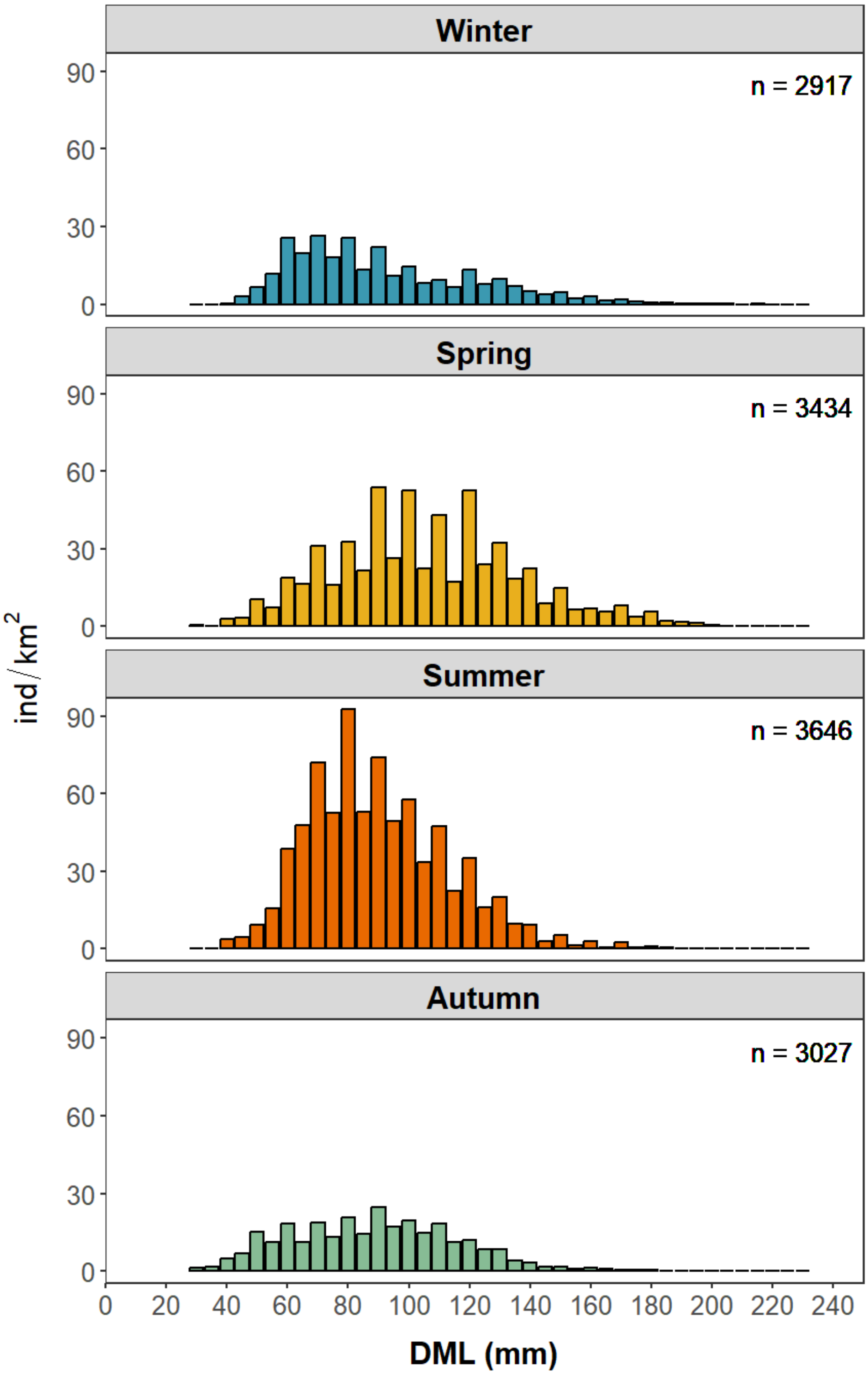


Figure 9. Length-frequency distribution of *Illex coindetii* by season.

Moreover, when comparing means (figure 10), ANOVA test showed significant differences, with a higher DML mean value in spring (F-value = 282.94, p-value < 0.001). No other significant differences were observed between seasons.

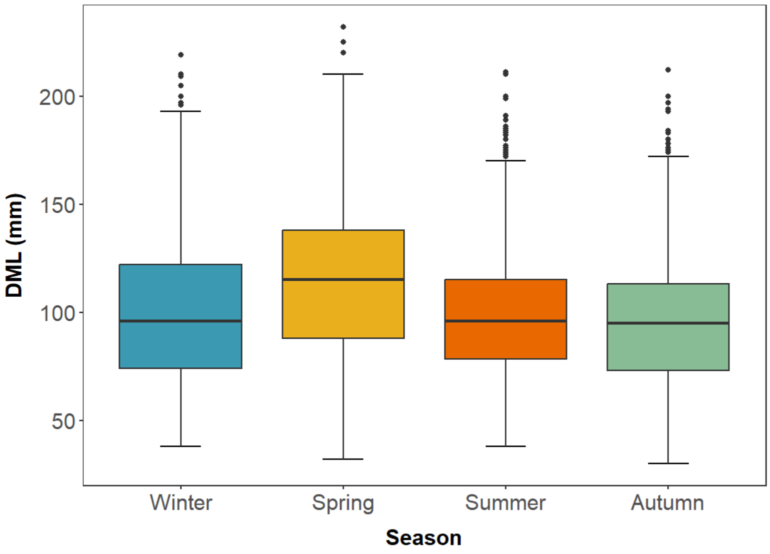


Figure 10, Box-plot comparing DML values of sampled individuals across seasons. Lines inside de box show the median DML value for each category. Extremes of the boxes indicate the first and third quartile. Whiskers indicate the maximum and minimum values. Points indicate values outside this range.

The Bhattacharya test applied to length-frequency distributions by season showed the presence of, at least, 2 different cohorts in winter, summer and autumn, while in spring a minimum of 3 cohorts were detected. Results of the test are shown in table 1, indicating the size range of each cohort, the mean size value and its standard deviation (SD), the separation index (SI, which indicates how separate are the groups) and the number of individuals in each group.

Table 1. Results of the Bhattacharya test performed on seasonal length-frequency distribution.

Season	Cohort	Mean	SD	Interval	SI	%	N
Winter	1	70.56396	12.025	60 - 85	4.044	32.09	936
	2	127.93141	16.348	120 - 155	NA	24.07	702
Spring	1	91.636	11.92670	80 - 105	3.722	22.98	789
	2	130.97185	9.209	130 - 145	2.719968	18.04	632
	3	165.98438	16.536	170 - 200	NA	7.34	252
Summer	1	75.622	11.100	70 - 85	3.392	24.74	902
	2	119.48826	14.768	120 - 155	NA	20.08	732
Autumn	1	63.912	13.210	40 - 75	2.830	29.47	892
	2	105.690	16.320	90 - 135	NA	53.52	1620

3.1.3 Spatial population distribution

An examination of the length-frequency data by zone (figure 11) revealed differences in size-class distributions as corroborated by the results of the Kolmogorov–Smirnov test (p-value < 0.001). Similarities in size-classes with major abundance values (60-80 mm) between the centre and south were notable. However, a distinct trend is evident in the northern region, where higher abundance values were associated with larger sizes (100-120 mm), contrasting with the patterns observed in the other two zones.

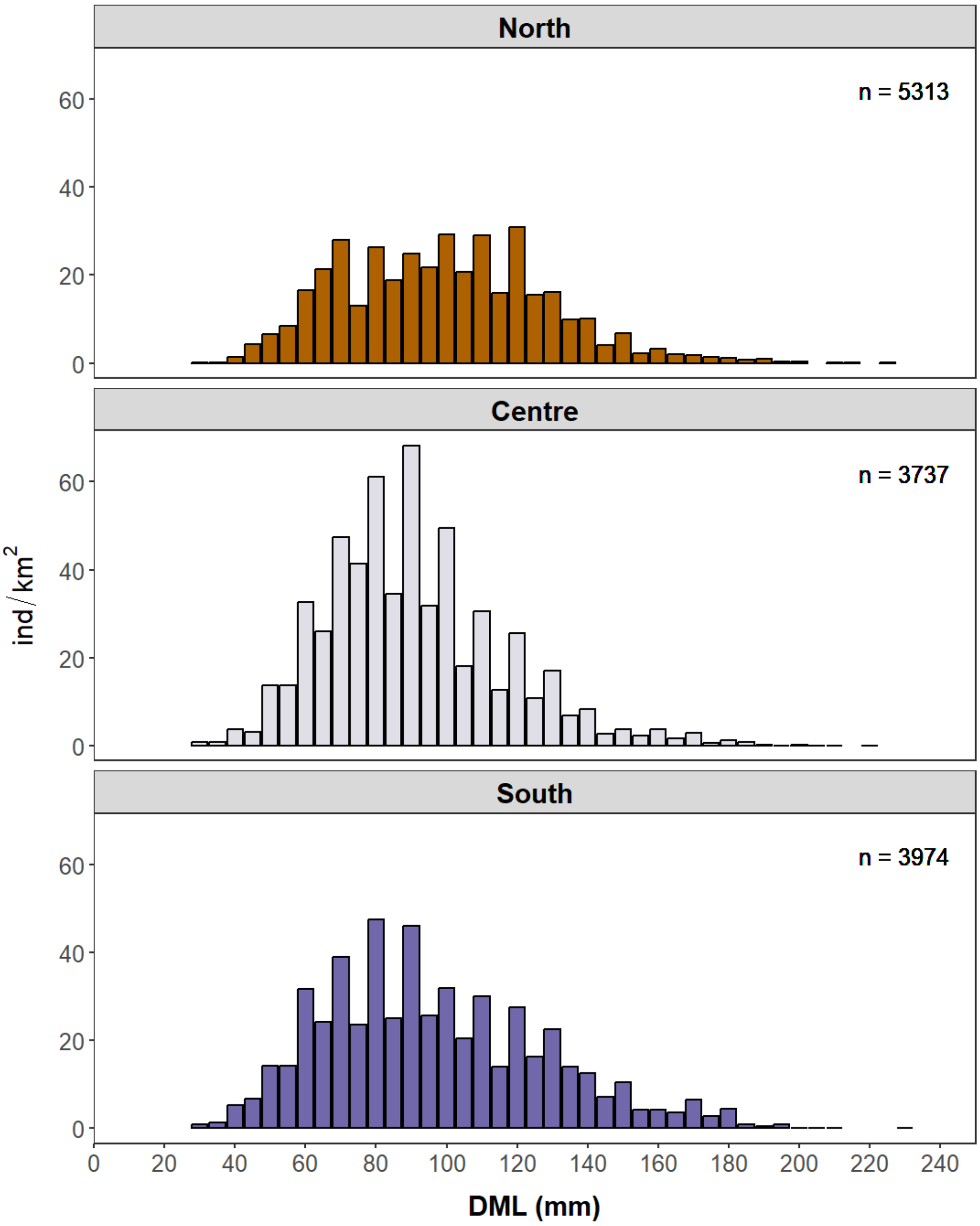


Figure 11. Length-frequency distribution of *Illex coindetii* by zone of the Catalan coast. All individuals sampled during the period from 2018 and 2025 were considered.

3.1.4 Bathymetric population distribution

The length-frequency distribution of the species across the different depth strata (figure 12) revealed notable differences in the captured individuals, being the deeper continental shelf the one hosting the highest value (n=8379). The Kolmogorov–Smirnov test showed significant differences between all depth strata (p-value < 0.001), except between the deeper continental shelf and the lower slope, for which the test did not provide sufficient evidence to reject the null hypothesis. It should be noted that both the deeper shelf and the upper slope showed individuals from practically all of the size classes which have been sampled.

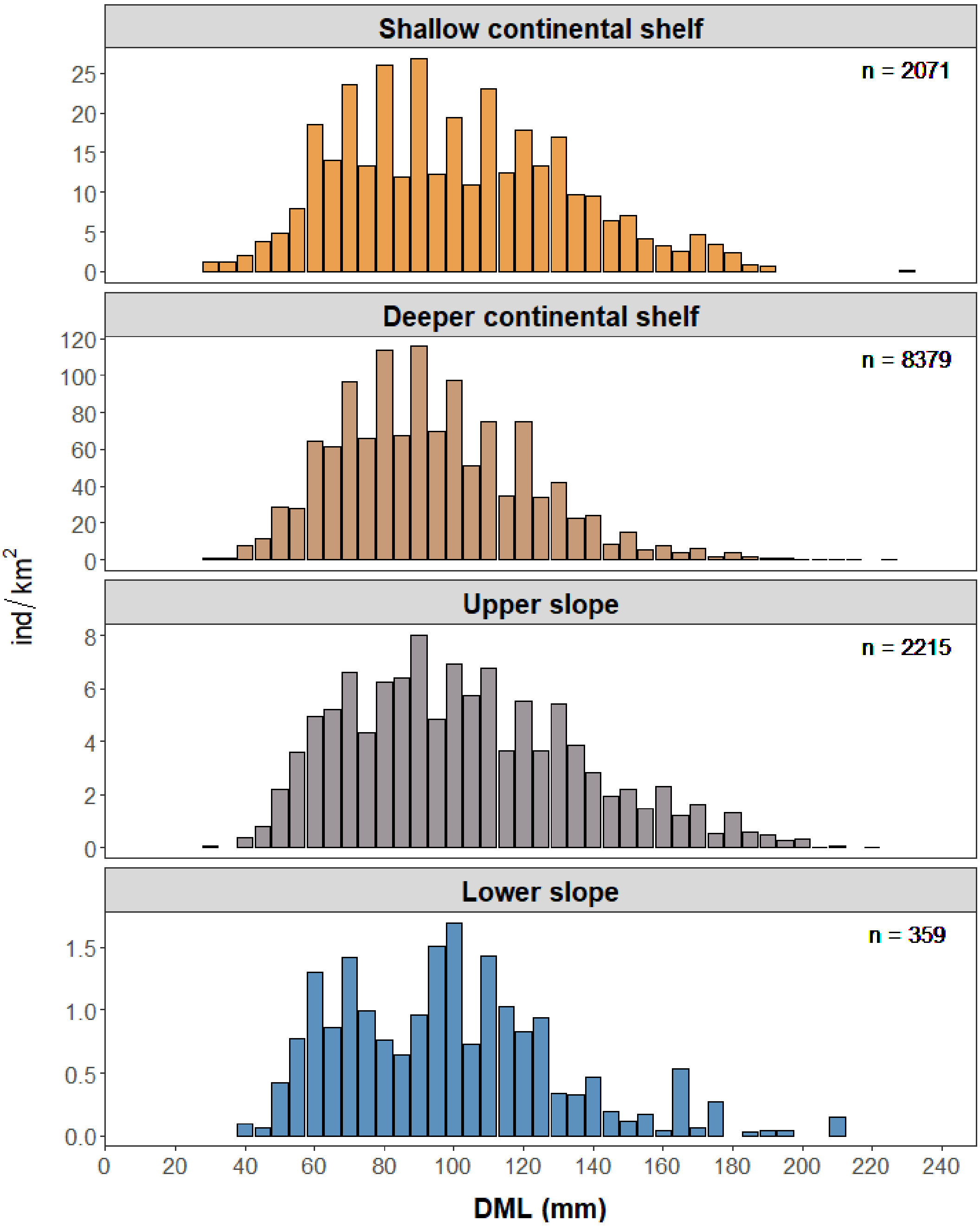


Figure 12. Length-frequency distribution of *Illex coindetii* by depth strata.

3.2 Length-weight relationship

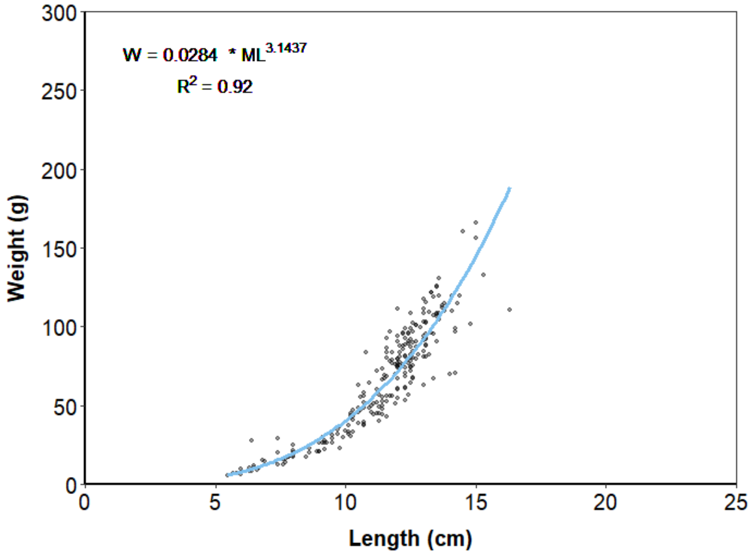


Figure 13. Length-weight relationship for *Illex coindetii* males.

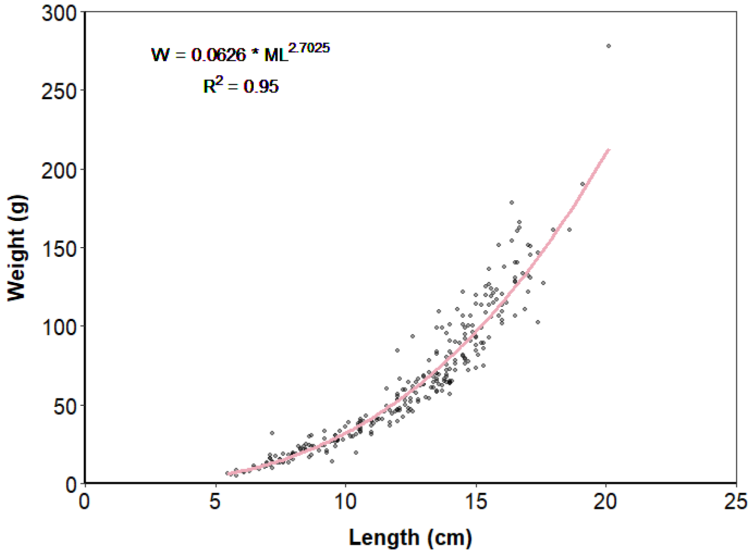


Figure 14. Length-weight relation for *Illex coindetii* females.

A total of 547 specimens were used to determine the length-weight relationship of the species (figures 13 and 14). When comparing by sex, males exhibited a positive allometric growth (b = 3.1437, t = 2.4961, p-value < 0.05) whereas females showed a negative allometric growth (b = 2.7052, t = -8.227, p-value < 0.001) (table 2).

Table 2. Length-weight relationship of *Illex coindetii* individuals of the Catalan coast.

	a	b	R^2	Length-weight relationship	Nº of individuals
Male	0.0284	3.1437	0.92	$W = 0.0284 * DML^{3.1437}$	240
Female	0.0626	2.7052	0.95	$W = 0.0626 * DML^{2.7025}$	289

3.3 Sex ratio

To calculate the sex ratio of *Illex coindetii* (figure 15) a total of 547 individuals were sampled: 240 were males (43.9 %) and 289 were females (52.8 %), while the remaining 18 correspond to indeterminate individuals (3.3 %). Analyses revealed dependence between the sex ratio and size ($\chi^2 = 111.36$, df = 28, p-value < 0.001). It can be observed that in the range of 60-70 mm of DML, sex ratio was near 1:3, with a clear predominance of males. Later on, within the 70-110 mm of DML, the trend shifted towards a predominance of females with a sex ratio of 3:1. Following, between 110 to 135 mm of DML, males predominated again (1:3). Then, as the DML increases from 140 mm onwards, there is a notable predominance of females.

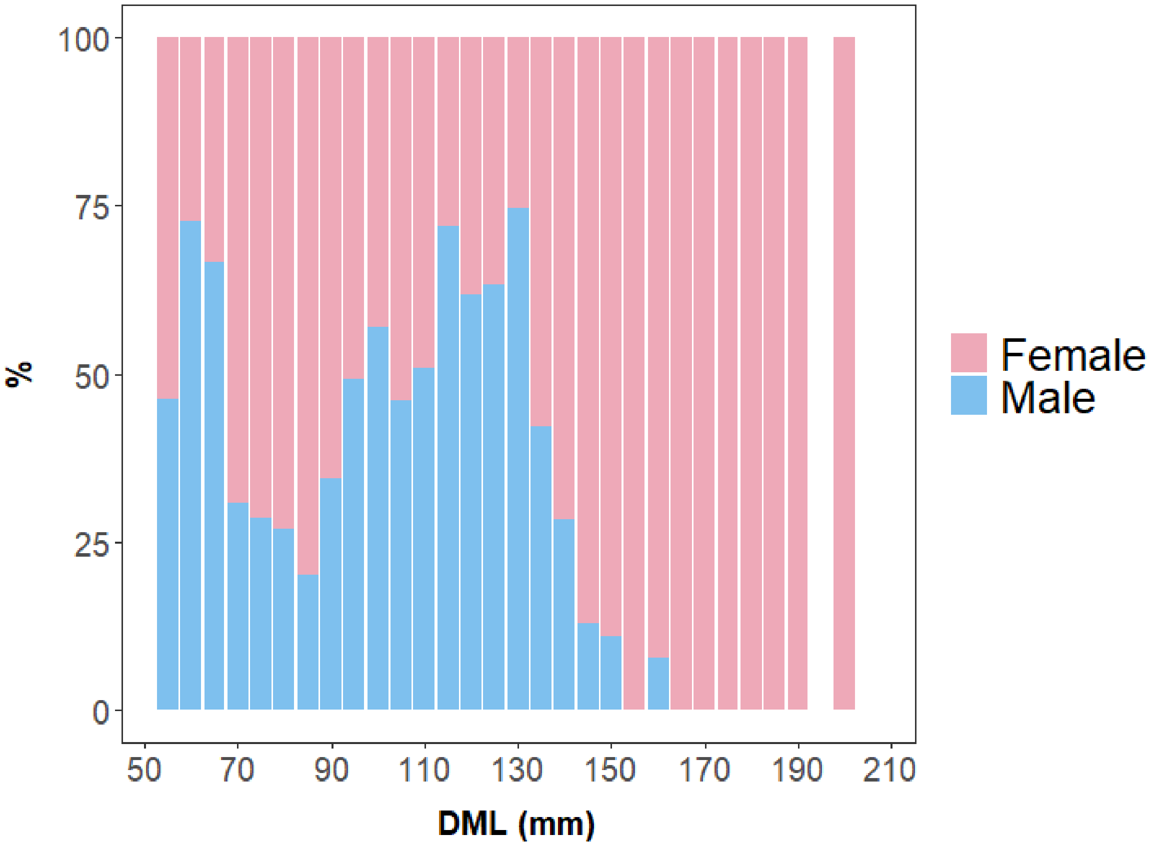


Figure 15. Sex ratio for *Illex coindetii* by DML.

3.4 Reproductive biology

3.4.1 Population maturity composition

A total of 529 specimens were used in this analysis. The composition of reproductive stages by size class of *Illex coindetii* shows that mature specimens (stage 3 or higher) were found within a wide DML range in both sexes: from 95 to 160 mm on males, and from 105 to 200 mm on females (figures 16 and 17, and table 3). As size increases, so does the proportion of more advanced stages of maturity, which suggests a relation between size and maturity stages (χ^2 = 287.88, df = 80, p-value < 0.001 for males and χ^2 = 291.27, df = 84, p-value < 0.001 for females). When comparing both sexes, a lower minimum size at maturity for males is observed. It must be noted that the gaps in the data at sizes of 155 mm of DML for males and 195 mm of DML for females are caused by the absence of individuals with these DML categories captured during the sampling period.

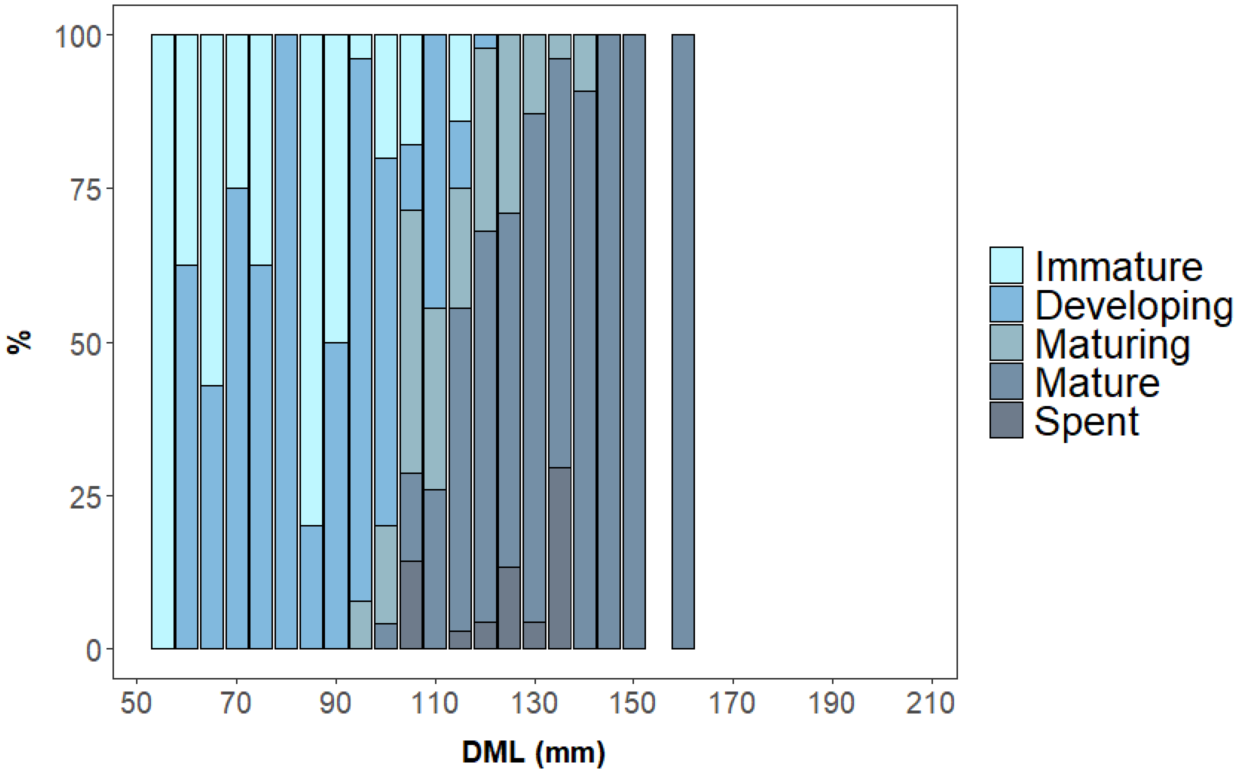


Figure 16. Distribution of maturity stages by DML for males of *Illex coindetii.* Each colour represents a maturity stage as described by Follesa & Carbonara (2019): 1-immature, 2-developing, 3-maturing, 4-mature, 5-spent.

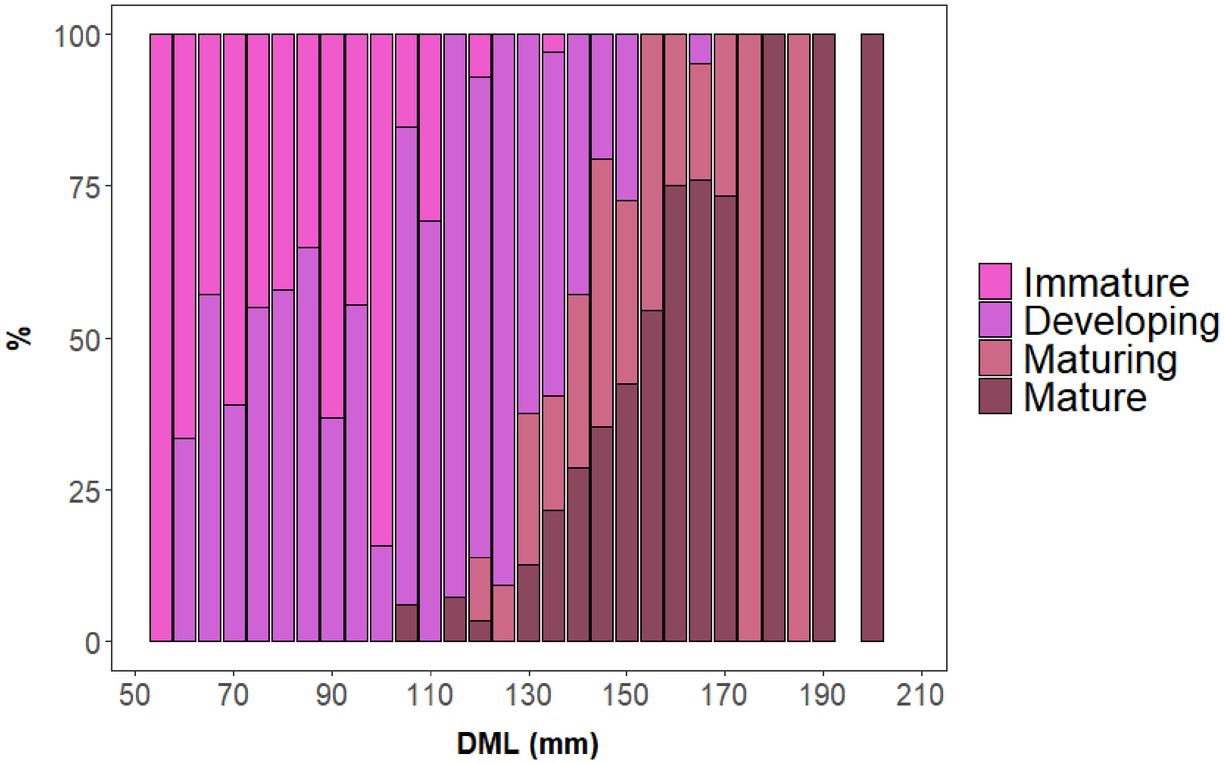


Figure 17. Distribution of maturity stages by DML for females of *Illex coindetii*. Each colour represents a maturity stage as described by Follesa & Carbonara (2019): 1-immature, 2-developing, 3-maturing, 4-mature.

3.4.2 Size at first maturity

Regarding the L_{50} (length at which 50% of individuals are sexually mature), a total of 240 male and 289 female individuals were used for the analysis. Males showed values around 3 cm lower than females, with 106.4 mm and 137.7 mm of DML for males and females respectively (figures 18 and 19, and table 3).

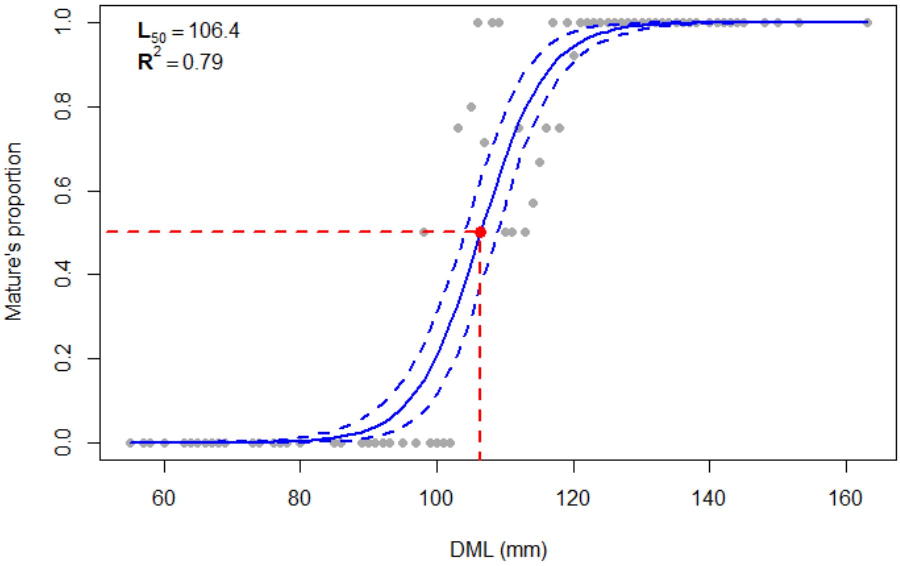


Figure 18. Size at first maturity (L_{50}) for males of *Illex coindetii*.

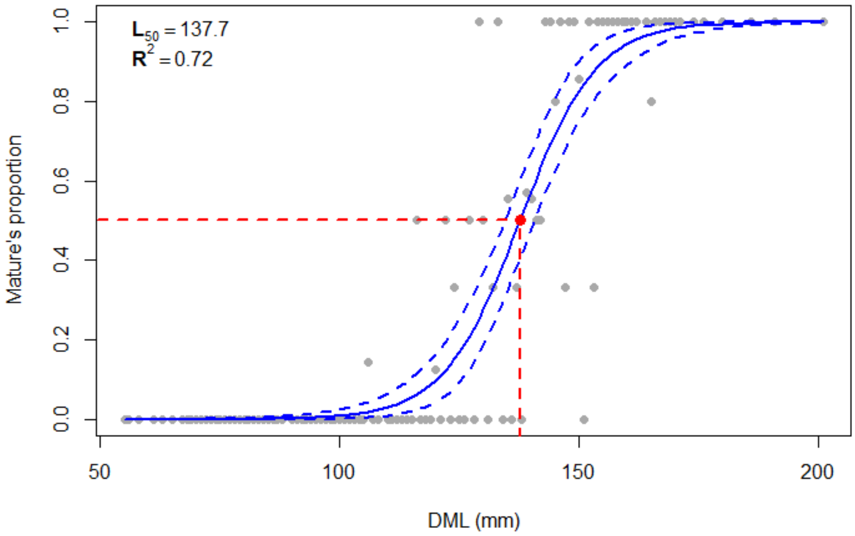


Figure 19. Size at first maturity (L_{50}) for females of *Illex coindetii*.

Table 3. Values for mínimum size at maturity and size at first maturity (L_{50}) parameters of *Illex coindetii*. CI, representens the confidence interval of the obtained results.

Sex	Min - Max	L50	CI
Male	95 - 125	106.4	104.1 - 108.8
Female	105 - 170	137.7	134.5 - 140.7

3.4.3 Reproductive cycle

To determine the reproductive cycle of the species between January and July of 2025, a total of 240 male and 289 female individuals were used (figures 20 and 21). Regarding males, it can be observed that January, April, May and June have a high proportion of mature individuals, while in February and March it dropped to around 50% and the highest proportion of immature individuals was found. Highlight that March, April and May are the only month having spent males. Females, showed a similar pattern, with the highest proportion of mature individuals in January, May, and especially June, where 100% of the sampled females were mature. However, in February and March most individuals were developing or immature.

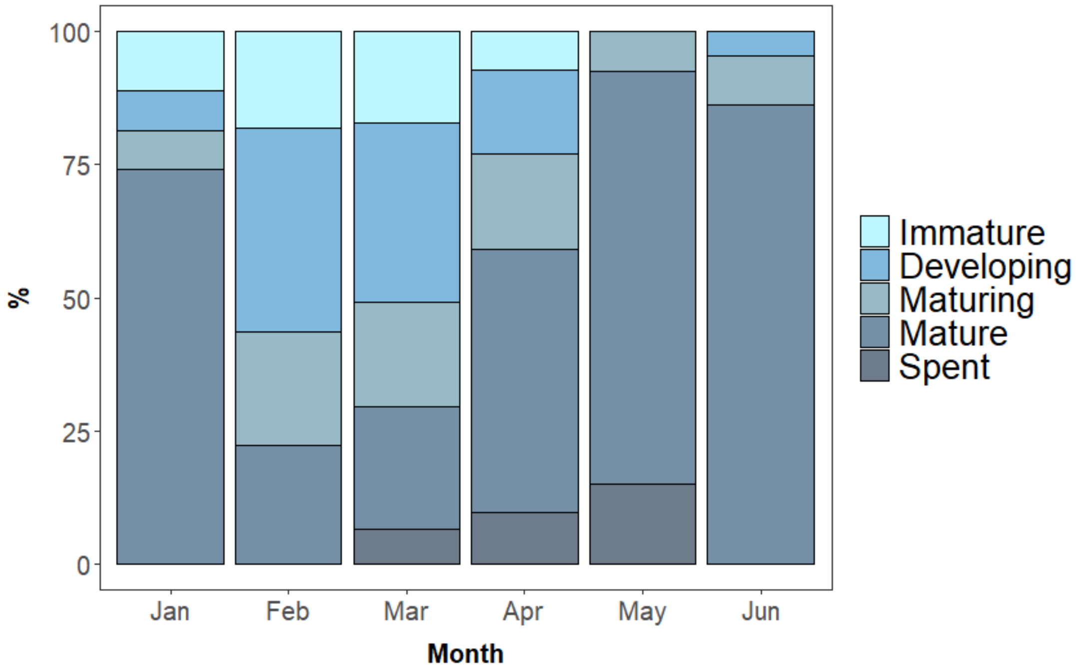


Figure 20: Reproductive cycle of *Illex coindetii* males collected between January and June 2025.

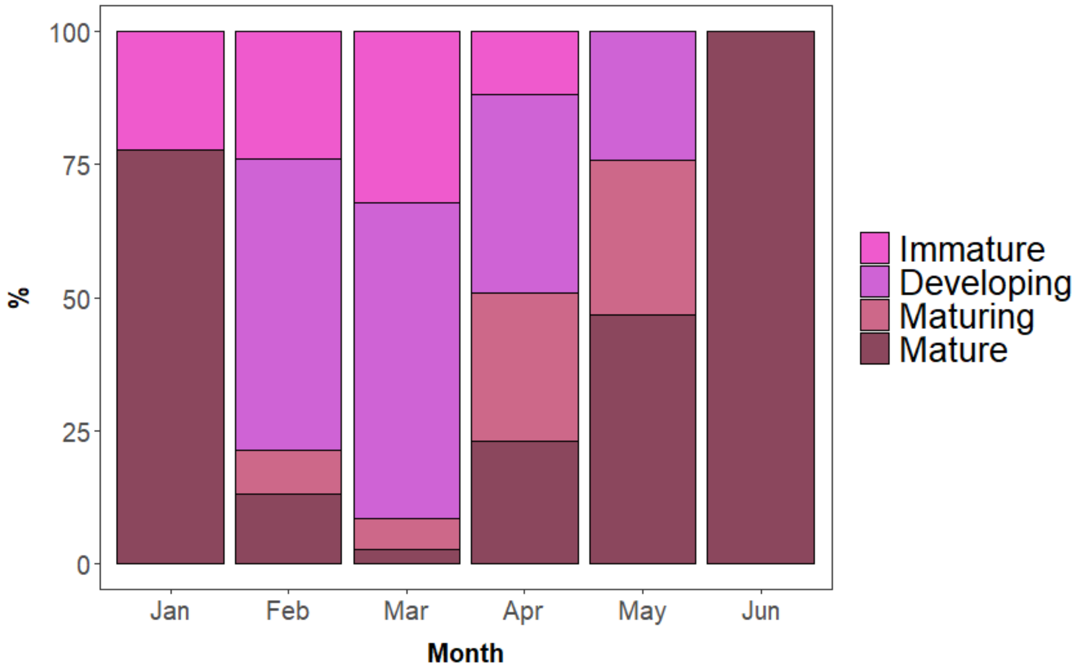


Figure 21: Reproductive cycle of *Illex coindetii* females collected between January and June 2025.

4. Discussion

The overall length–frequency distribution of the species shows that the most abundant size classes in the sampled area correspond to individuals with a DML between 60 and 130 mm, representing small to medium-sized organisms. Analysis of the annual distributions reveals a similar pattern, with slight differences in peak abundance among years. For instance, in 2023 and 2024 the modal class shifted towards larger sizes compared with previous years, although in all cases values remained within the general size range observed. It can be noted that the size range of *Illex coindetii* obtained in the present study coincides with that reported in previous studies, not only from the Catalan coast, but also from other Mediterranean areas such as the eastern basin and the Sicilian Channel (Sánchez *et al*., 1998; Salman, 2017). The low abundance of both small and large individuals is likely due to gear selectivity (mesh size) and biological characteristics of the species, respectively (Sánchez *et al*., 1984). In this regard, the species' semelparity or possible migrations to deeper waters during the reproductive period could explain the absence of larger individuals in the catches (Arkhipkin *et al*., 2000). When comparing the length–frequency distribution of the studied area with other populations, noticeable differences were observed with the Atlantic, which exhibit larger individuals (e.g., in Arvanitidis, (2002) the maximum recorded DML for males and females in the Celtic Sea is 240 mm and 320 mm, respectively). This might be due to the productivity levels between both areas, being the Mediterranean more oligotrophic than the Atlantic Ocean (Turley, 1999).

The length–frequency analysis by zone indicated a shift in modal size towards larger individuals in both the northern and southern areas. While no other studies compare the differences in the size classes of *Illex coindetii* among areas, these results suggest that this pattern may be related to a higher productivity in those areas. In the north driven by sediment transport and organic matter flux to deeper areas through submarine canyon morphology, while in the south by the input of nutrients and sediments from the Ebre River (López *et al*., 2015; Puerta *et al*., 2015; Lauria *et al*., 2016). Regarding the bathymetric distribution of the species, the trend observed matches those found in other studies, which report the species' typical bathymetric range between 50 and 500 m, with the highest concentrations in the deeper continental shelf (Jereb & Ragonese, 1995; Ceriola *et al*., 2006). The occasional presence of the species at the lower bond of its distribution may be associated with migrations based on reproductive behaviour. As previously described in Sánchez *et al*. (1998), Jereb *et al*. (2001) and Lefkaditou *et al*. (2008), individuals in an advanced maturity stage, tend to be distributed at lower depths.

On the other hand, seasonal patterns were also found. Spring was characterized by the presence of larger individuals compared to the other seasons, while he occurrence of a polymodal length–frequency distribution across all seasons suggested a cohort-based population structure (Arkhipkin *et al*., 2000). As reported in previous studies, the population of this species is structured into several cohorts, whose morphometric traits are influenced by the environmental conditions at the time of hatch: spring–summer individuals exhibit higher growth rates and therefore reach maturity at larger sizes, whereas autumn–winter individuals have lower growth rates, thus achieving maturity at smaller sizes (Arkhipkin *et al*., 2000; Bobowski *et al*., 2024). These differences in cohort growth characteristics are primarily attributable to water temperature, which has a direct effect on juvenile development (Lefkaditou *et al*., 2008).

Sex ratio showed a clear deviation from the expected 1:1, with males predominating in smaller size classes and females in larger ones. However, these findings do not fully correspond with previous studies conducted in the area, where the overall sex ratio tended to be closer to 1:1, despite the predominance of one sex at opposite ends of the length–frequency distribution (Sánchez *et al*., 1998; Ceriola *et al*., 2006). The discrepancies observed in the present study are most likely attributable to biases caused by gear features of the bottom trawl nets, since Sánchez *et al*. (1998) indicated that sex ratio is not affected by either seasonality or bathymetry.

Regarding length-weight relationship, a deviation from isometry is observed in both sexes, being consistent with previous studies on the species, not only in the northwestern Mediterranean Sea but also in other Mediterranean regions and even in the Atlantic (Hernández-García & Castro, 1998; Sánchez *et al*., 1998; Ceriola *et al*., 2006). However, the values of the growth parameter *b* appear to vary among areas, which may be explained by differences in environmental conditions and food availability (Ricker, 1979).

When interpreting the results of the reproductive biology, it should be noted that the data available only cover the months from January to June and therefore do not represent a complete annual cycle. For the maturity analyses, individuals were classified as mature when they had reached stage 3 or higher, i.e., when reproductive elements were observable in the gonads, suggesting reproductive viability (Follesa & Carbonara, 2019). Clear differences between sexes were detected, with males reaching maturity earlier than females, reflected in their lower minimum size at maturity and length at first maturity. Similar trends have been documented in other studies along the Catalan coast and across different regions of the Mediterranean Sea, showing marked sexual dimorphism, although with some variation in parameter values: e.g., Jereb & Ragonese (1995) reported L_{50} values of 120 mm and 150 mm of DML for males and females, respectively, in the Sicilian Channel, while Arvanitidis *et al*. (2002) found values of 113 mm and 179 mm in the Greek Seas (eastern Mediterranean).

Regarding the reproductive cycle, mature individuals were recorded throughout all sampled months, with distinct peaks of maturation. This aligns with previous studies that describe continuous spawning throughout the year (Sánchez *et al*., 1998; Arvanitidis *et al*., 2002;

Lefkaditou *et al*., 2008). However, a slight difference from Sánchez *et al*. (1998) was observed, as results from the present study suggest the possible occurrence of a second reproductive peak in the early part of the year (winter/spring). This could indicate a shift towards a bimodal reproductive cycle, potentially influenced by ongoing environmental changes in the context of global change (García Molinos, 2020). In addition, differences in the reproductive cycle within other populations of the species were also observed: for instance, the period of maximum spawning activity in the Sicilian Channel and the northern Spanish Atlantic occurs during the summer and autumn months. While in the African Atlantic, during summer (Salman, 2017).

5. Conclusion

Continuous monitoring of fisheries-related species is essential, particularly when they have emerged as important marine resources in recent years, as is the case for *Illex coindetii*. The last available data on the status of this species along the Catalan coast was published more than 20 years ago (Sánchez *et al*., 1998).

In the present study, changes in some biological and population parameters – specifically sex ratio and reproductive cycle – were observed. These shifts may be related to environmental changes, such as the rise in ocean temperature and salinity. This also highlights the challenges of research on cephalopods, a taxonomic group characterized by high spatio-temporal variability and complex biological traits, hindering their assessment (Boyle & Boletzky, 1996; Arkhipkin *et al*., 2021).

Overall, this study provides an updated overview of the main biological and population characteristics of *Illex coindetii* in the northwestern Mediterranean Sea. Furthermore, the information collected offers a valuable baseline for the monitoring and management of this species and highlights changes in fishery resources dynamics in the context of global change.

6. Developed tasks

The next tasks were performed by the student in order to develop the present study:

- Shipment on commercial vessels of the Catalan bottom trawl fleet to collect data and samples.
- Design of a macroscopic maturity identification key, based on the literature.
- Biological analyses of the samples, including measuring dorsal mantle length, weight, and dissection of the individuals, in order to identify sex and maturity stage.

- Digitalization of all biological data collected, into the ICATMAR database.
- Preparation of an R script, used for the statistical analyses and for the development of the figures included in this study.

7. Bibliography

Alsayes, A., Fattouh, S., & Abu-Enin, S. (2009). By-Catch and discarding of trawl fisheries at the Mediterranean coast of Egypt. *World Journal of Fish and Marine Sciences*, 1(3), 199-205.

Arkhipkin, A. (2000). Growth and maturation in two successive seasonal groups of the short-finned squid, *Illex coindetii* from the Strait of Sicily (central Mediterranean). *ICES Journal of Marine Science*, *57*(1), 31–41. https://doi.org/10.1006/jmsc.1999.0488

Arkhipkin, Alexander I., *et al*. "Stock assessment and management of cephalopods: advances and challenges for short-lived fishery resources." *ICES Journal of Marine Science* 78.2 (2021): 714-730. https://doi.org/10.1093/icesjms/fsaa038

Arvanitidis, C., Koutsoubas, D., Robin, J. P., Pereira, J., Moreno, A., da Cunha, M. M., ... & Eleftheriou, A. (2002). A comparison of the fishery biology of three Illex coindetii Verany, 1839 (Cephalopoda: Ommastrephidae) populations from the European Atlantic and Mediterranean waters. *Bulletin of marine science*, *71*(1), 129-146.

Balcells, M., Blanco, M., Colmenero, A. I., Barría, C., Santos-Bethencourt, R., Nos, D., López-Pérez, C., Ribera-Altimir, J., Sala-Coromina, J., Garriga-Panisello, M., Rojas, A., & Galimany, E. (2023). Fishing for litter, accidental catch in bottom trawl nets along the Catalan coast, Northwestern Mediterranean. *Waste Management*, *166*, 360–367. https://doi.org/10.1016/j.wasman.2023.05.021

Bhattacharya, C. G. (1967). A Simple Method of Resolution of a Distribution into Gaussian Components. *Biometrics*, *23*(1), 115. https://doi.org/10.2307/2528285

Boyle P. R. and Boletzky S. V. (1996) Cephalopod populations: definition and dynamics. *Phil. Trans. R. Soc. Lond. B* 351: 985 - 1002. https://doi.org/10.1098/rstb.1996.0089

Carreton, M., Galimany, E., Blanco, M., Garriga-Panisello, M., Colmenero, A. I., Balcells, M., ... & Company, J. B. (2025). Understanding the spatio-temporal variability of fisheries data for better bottom trawling management practices in the Catalan margin (NW Mediterranean Sea). *Marine Policy*, *172*, 106512. https://doi.org/10.1016/j.marpol.2024.106512

Ceriola, L., Ungaro, N., & Toteda, F. (2006). Some information on the biology of *Illex coindetii* Verany, 1839 (Cephalopoda, Ommastrephidae) in the South-Western Adriatic Sea (Central Mediterranean). *Fisheries Research*, *82*(1–3), 41–49. https://doi.org/10.1016/j.fishres.2006.08.024

Clarke, J., Milligan, R., Bailey, D., & Neat, F. (2015). A Scientific Basis for Regulating Deep-Sea Fishing by Depth. *Current Biology*, 25, 2425-2429. https://doi.org/10.1016/j.cub.2015.07.070

Clavel-Henry, M., Solé, J., Bahamon, N., Carretón, M., & Company, J. B. (2021). Larval transport of aristeus antennatus shrimp (crustacea: Decapoda: Dendrobranchiata: Aristeidae) near the Palamós submarine canyon (NW Mediterranean Sea) linked to the north balearic front. *Progress in Oceanography, 192*, 102515. https://doi.org/10.1016/j.pocean.2021.102515

European Union. (2006). *Council Regulation (EC) No 1967/2006 of 21 December 2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, amending Regulation (EEC) No 2847/93 and repealing Regulation (EC) No 1626/94*. *Official Journal of the European Union*, L 409, 11–85.

Follesa, M. C., & Carbonara, P. (2019). Atlas of the maturity stages of Mediterranean fishery resources. *General Fisheries Commission for the Mediterranean. Studies and Reviews*, (99), I-259. https://www.proquest.com/scholarly-journals/atlas-maturity-stages-mediterranean-fishery/docview/2266347679/se-2

Food and Agriculture Organization of the United Nations, General Fisheries Commission for the Mediterranean. (2009). *Resolution GFCM/33/2009/2 on the establishment of geographical sub-areas in the GFCM area of application, amending Resolution GFCM/31/2007/2*. GFCM.

García Molinos, J. Global marine warming in a new dimension. *Nat Ecol Evol* 4, 16–17 (2020). https://doi.org/10.1038/s41559-019-1037-5

Generalitat de Catalunya. (2018, 25 de maig). *Ordre APM/532/2018, de 25 de maig, per la qual es regula la pesca de gamba rosada (Aristeus antennatus) amb art d'aramall de fons en determinades zones marítimes properes a Palamós. Diari Oficial de la Generalitat de Catalunya* (DOGC).

Hernández-García, V., & Castro, J. J. (1998). Morphological Variability in *Illex Coindetii* (*Cephalopoda: Ommastrephidae*) Along the North-West Coast of Africa. *Journal of the Marine Biological Association of the United Kingdom*, *78*(4), 1259–1268. https://doi:10.1017/S0025315400044477

Institut Català de Recerca per a la Governança del Mar (ICATMAR). 2025. Commercial fisheries advisory report for the Northern GSA 6 2025 (ICATMAR, 25-07), 20 pp., Barcelona. https://doi.org/10.20350/DIGITALCSIC/17433

Institut Català de Recerca per a la Governança del Mar (ICATMAR). Evolució econòmica de les captures del sector pesquer a Catalunya 2024 (ICATMAR, 25-04) 209 pp, Barcelona. https://doi.org/10.20350/digitalCSIC/17287

Institut Català de Recerca per a la Governança del Mar (ICATMAR). State of fisheries in Catalonia 2024, Part 1: report on the monitoring of the commercial fishing fleet (ICATMAR, 25-05) 222 pp, Barcelona. https://doi.org/10.20350/DIGITALCSIC/17393

Jereb, P., Ragonese, S., 1995. *An outline on the biology of the squid Illex coindetii in the Sicilian Channel (Central Mediterranean)*. J. Mar. Biol. Assoc. UK 75, 373–390.

Jereb, P., Massi, D., Norrito, G., & Fiorentino, F. (2001). Preliminary observations of environmental effects on spatial distribution and abundance of *Eledone cirrhosa* and *Illex coindetii* in the Strait of Sicily (Central Mediterranean Sea) (Version 1). *ASC 2001* - K - Theme session. https://doi.org/10.17895/ices.pub.25635834.v1

Lauria, V., Garofalo, G., Gristina, M., & Fiorentino, F. (2016). Contrasting habitat selection amongst cephalopods in the Mediterranean Sea: When the environment makes the difference. *Marine Environmental Research*, *119*, 252-266. https://doi.org/10.1016/j.marenvres.2016.06.011

Lefkaditou, E., Politou, C.-Y., Palialexis, A., Dokos, J., Cosmopoulos, P., & Valavanis, V. D. (2008). Influences of environmental variability on the population structure and distribution patterns of the short-fin squid *Illex coindetii* (*Cephalopoda: Ommastrephidae*) in the Eastern Ionian Sea. *Hydrobiologia*, *612*(1), 71–90. https://doi.org/10.1007/s10750-008-9490-1

López Fernández, P. (2015). Flujos de partículas y biodisponibilidad de la materia orgánica en ecosistemas profundos: el cañón submarino de Blanes.

Lucchetti, A., Virgili, M., Vasapollo, C., Petetta, A., Bargione, G., Li Veli, D., Brĉic, J., & SALA, A. (2021). An overview of bottom trawl selectivity in the Mediterranean Sea. *Mediterranean Marine Science*, *22*(3), 566–585. https://doi.org/10.12681/mms.26969

Lucchetti, A., Petetta, A., Bdioui, M., Gökçe, G., Saber, M., Sacchi, J., ... & Carpentieri, P. (2023). *Catalogue of fishing gear in the Mediterranean and Black Sea region* (Vol. 695). Food & Agriculture Org. https://doi.org/10.4060/cc7260en

Luna, A., Sánchez, P., Chicote, C., & Gazo, M. (2022). Cephalopods in the diet of Risso's dolphin (Grampus griseus) from the Mediterranean Sea: A review. *Marine Mammal Science*, *38*(2), 725-741. https://doi.org/10.1111/mms.12869

Machias, A., Vassilopoulou, V., Vatsos, D., Bekas, P., Kallianiotis, A., Papaconstantinou, C., & Tsimenides, N. (2001). Bottom trawl discards in the northeastern Mediterranean Sea. *Fisheries Research*, *53*(2), 181–195. https://doi.org/10.1016/S0165-7836(00)00298-8

Margalef, R., 1989. *On diversity and connectivity, as historical expressions of ecosystems*. Coenoses 4, 121–126.

Martínez, P., Sanjuan, A., & Guerra, A. (2002). Identification of *Illex coindetii*, *I. illecebrosus* and *I. argentinus* (Cephalopoda: Ommastrephidae) throughout the Atlantic Ocean; by body and beak characters. *Marine Biology*, *141*(1), 131-143. https://doi.org/10.1007/s00227-002-0796-7

Ministerio de Agricultura, Pesca y Alimentación. (2024, 5 de mayo). *Orden APA/412/2024, de 5 de mayo, por la que se modifica el anexo III de la Orden APA/423/2020, de 18 de* *mayo, por la que se establece un plan de gestión para la conservación de los recursos pesqueros demersales en el mar Mediterráneo* (BOE núm. 109, de 7 de mayo de 2024). Boletín Oficial del Estado. https://www.boe.es

Piroddi, C., Colloca, F., & Tsikliras, A. C. (2020). The living marine resources in the Mediterranean Sea Large Marine Ecosystem. *Environmental Development*, *36*, 100555. https://doi.org/10.1016/j.envdev.2020.100555

Puerta, P., Hunsicker, M. E., Quetglas, A., Alvarez-Berastegui, D., Esteban, A., González, M., & Hidalgo, M. (2015). Spatially explicit modeling reveals cephalopod distributions match contrasting trophic pathways in the western Mediterranean Sea. *PLoS One*, *10*(7), e0133439. https://doi:10.1371/journal. pone.0133439

Ribera-Altimir, J., Llorach-Tó, G., Sala-Coromina, J., Company, J. B., & Galimany, E. (2023). Fisheries data management systems in the NW Mediterranean: From data collection to web visualization. *Database*, *2023*, baad067. https://doi.org/10.1093/database/baad067

Ricker, W. E. (1975). Computation and interpretation of biological statistics of fish populations. *Fish. Res. Board Can. Bull.*, *191*, 1-382.

Rosas-Luis, R., Villanueva, R., & Sánchez, P. (2014). Trophic habits of the Ommastrephid squid *Illex coindetii* and Todarodes sagittatus in the northwestern Mediterranean Sea. *Fisheries Research*, *152*, 21–28. https://doi.org/10.1016/j.fishres.2013.10.009

Salman, A. (2017). Fecundity and spawning strategy of shortfin squid *Illex coindetii* (*Oegopsida: Ommastrephidae*), in the eastern Mediterranean. *Turkish Journal of Fisheries and Aquatic Sciences*, *17*(4). https://doi.org/10.4194/1303-2712-v17_4_20

Sánchez Zalacaín, P. (1982). Características bioecológicas de *Illex coindetii* (Verany, 1837) en el Mar Catalán. http://hdl.handle.net/10261/155483

Sánchez, P., González, A. F., Jereb, P., Laptikhovsky, V. V., Mangold, K. M., Nigmatullin, C. M., & Ragonese, S. (1998). *Illex coindeti*i. *FAO Fisheries Technical Paper*, 59-76.

Turley, C. M. (1999). The changing Mediterranean Sea—a sensitive ecosystem?. *Progress in Oceanography*, *44*(1-3), 387-400. https://doi.org/10.1016/S0079-6611(99)00033-6

Zecchini, F., Vecchione, M., Belcari, P., & Roper, C. F. E. (2012). Development of the hectocotylus in *Illex coindetii* (Verany 1837) (Cephalopoda: Ommastrephidae). *Scientia Marina*, *76*(3), 463–472. https://doi.org/10.3989/scimar.03305.07D

Zeller, D., Cashion, T., Palomares, M., & Pauly, D. (2018). Global marine fisheries discards: A synthesis of reconstructed data. *Fish and Fisheries*, *19*(1), 30–39. https://doi.org/10.1111/faf.12233

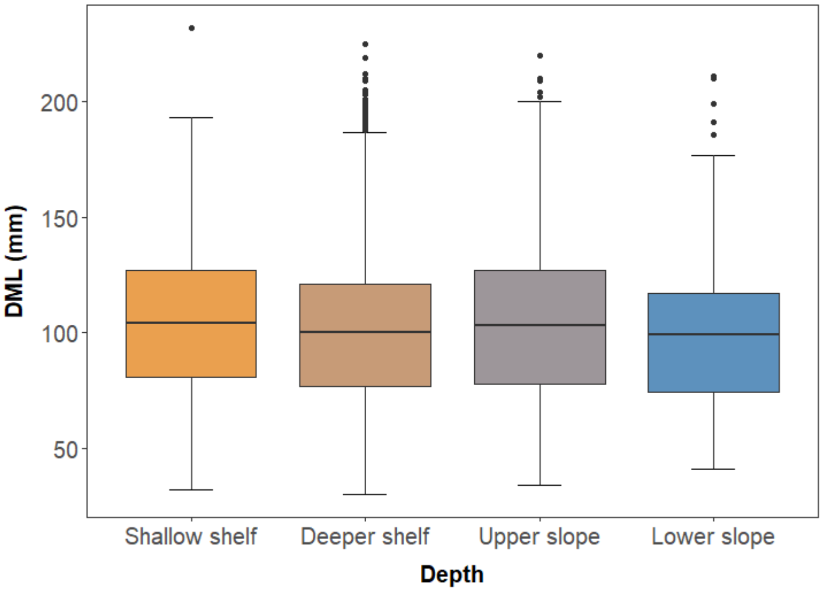
Annexes

1. Results of the Kolmogorov – Smirnov test

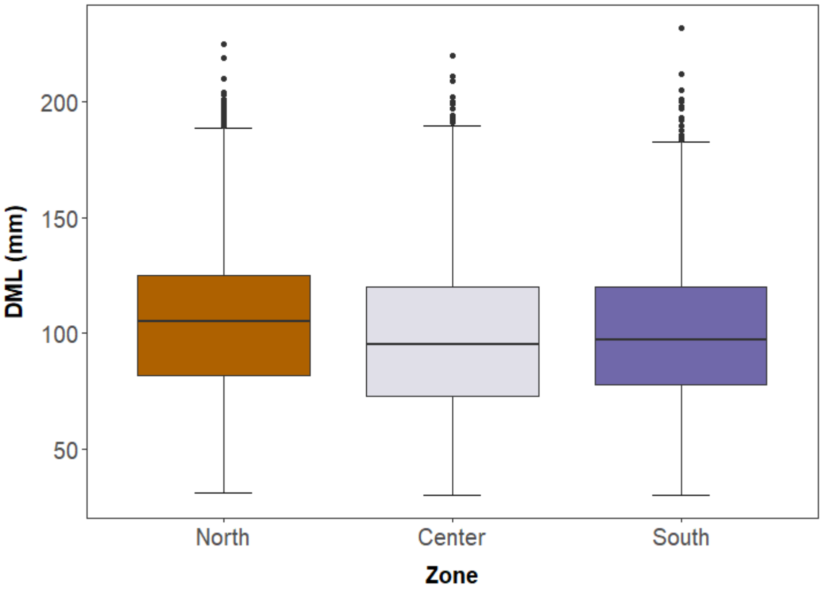
Annex table 1. Results of the Kolmogorov – Smirnov test by season, zone and depth.

		D	**p-value**
Season	Winter - Spring	0.19224	2.20E-16
	Winter - Summer	0.075811	1.21E-08
	Winter - Autumn	0.10236	3.86E-14
	Spring - Summer	0.24823	2.20E-16
	Spring - Autumn	0.2759	2.20E-16
	Summer - Autumn	0.08874	9.74E-12
Zone	North - Centre	0.1249	2.20E-16
	North - South	0.09578	2.20E-16
	Centre - South	0.055754	1.02E-05
Depth	Shallow continental shelf - Deeper continental shelf	0.081175	2.80E-10
	Shallow continental shelf - Upper slope	0.04102	0.04842
	Shallow continental shelf - Lower slope	0.11557	0.0005361
	Deeper continental shelf - Upper slope	0.062804	1.55E-06
	Deeper continental shelf - Lower slope	0.051183	0.3278
	Upper slope - Lower slope	0.11116	0.0009451

2. Box-plots by depth and zone

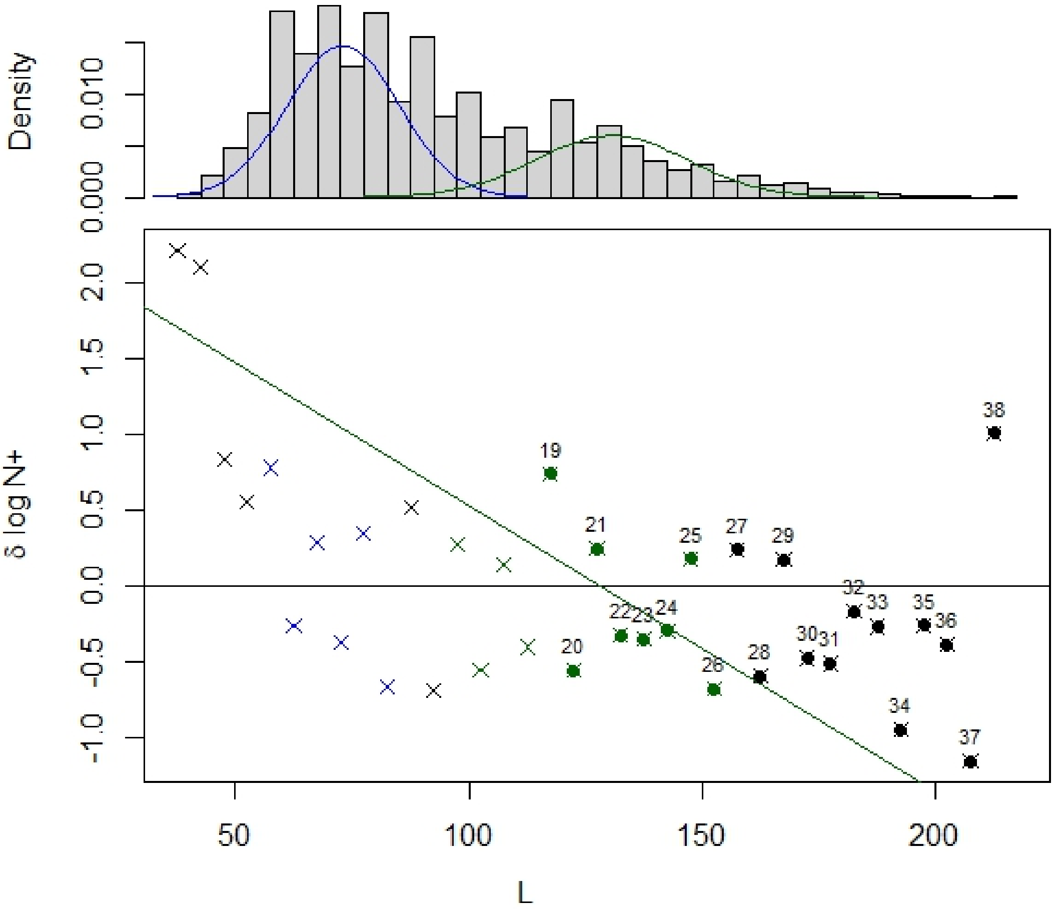


Annex figure 1. Box-plot comparing DML values of sampled individuals, categorised in the 4 different depth strata studied: shallow shelf, deeper shelf, upper slope and lower slope. Lines inside de box show the median ML value for each category. Extremes of the boxes indicate the first and third quartile. Whiskers indicate the maximum and minimum values, in order to identify possible outliers. Finally, points indicate values outside this range.

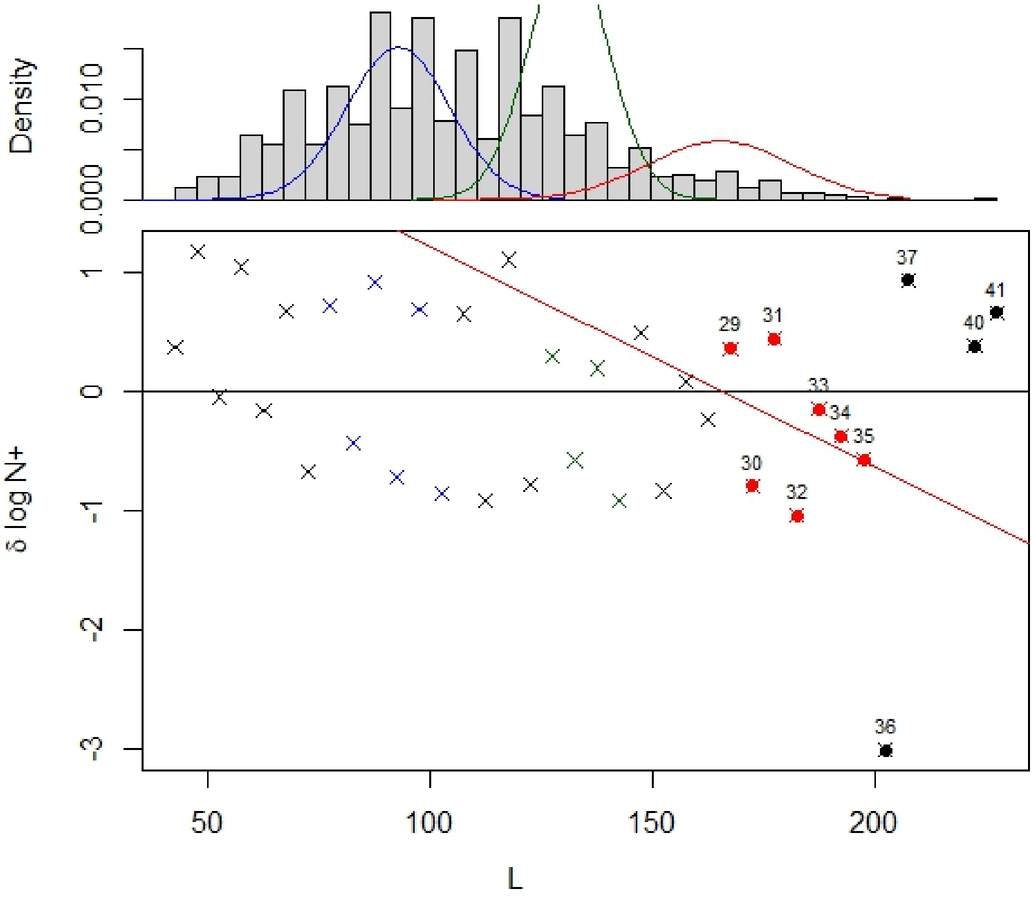


Annex figure 2. Box-plot comparing DML values of sampled individuals, categorised in the 3 different zones studied: north, centre and south. Lines inside de box show the median ML value for each category. Whiskers indicate the maximum and minimum values, in order to identify possible outliers. Extremes of the boxes indicate the first and third quartile. Finally, points indicate values outside this range.

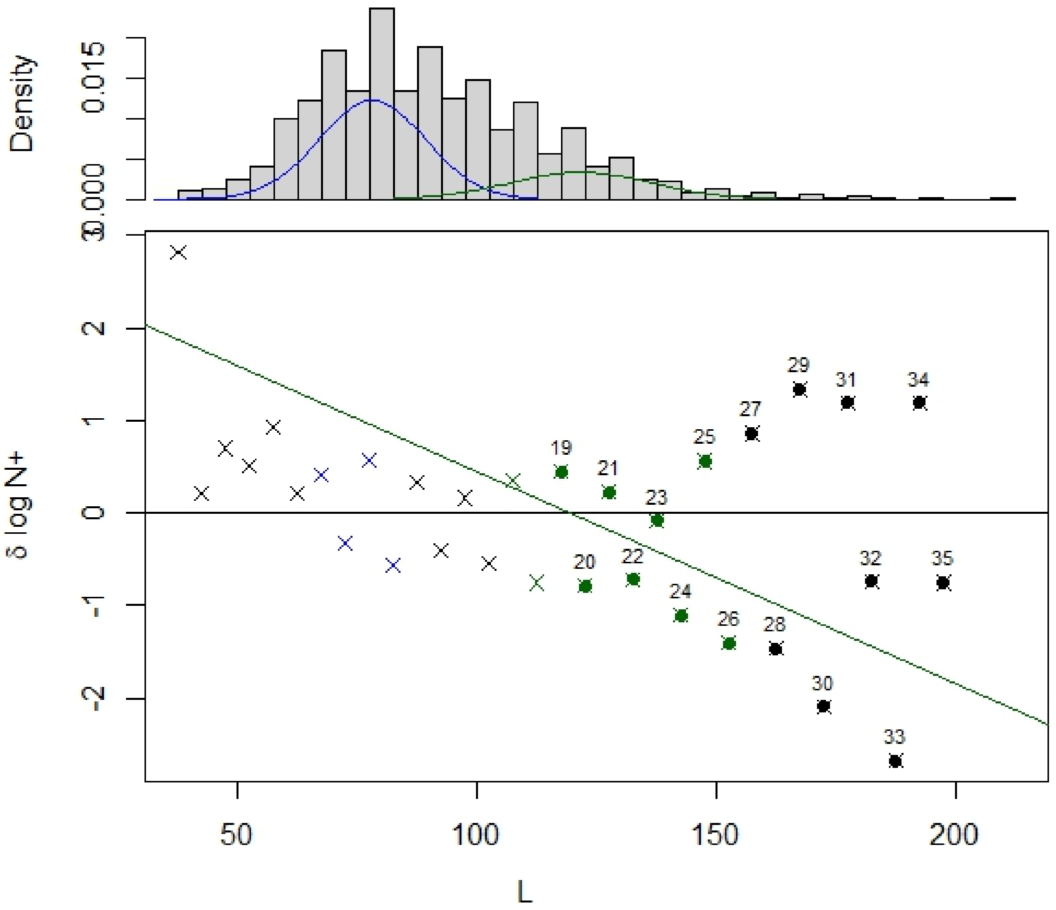
3. Bhattacharya results



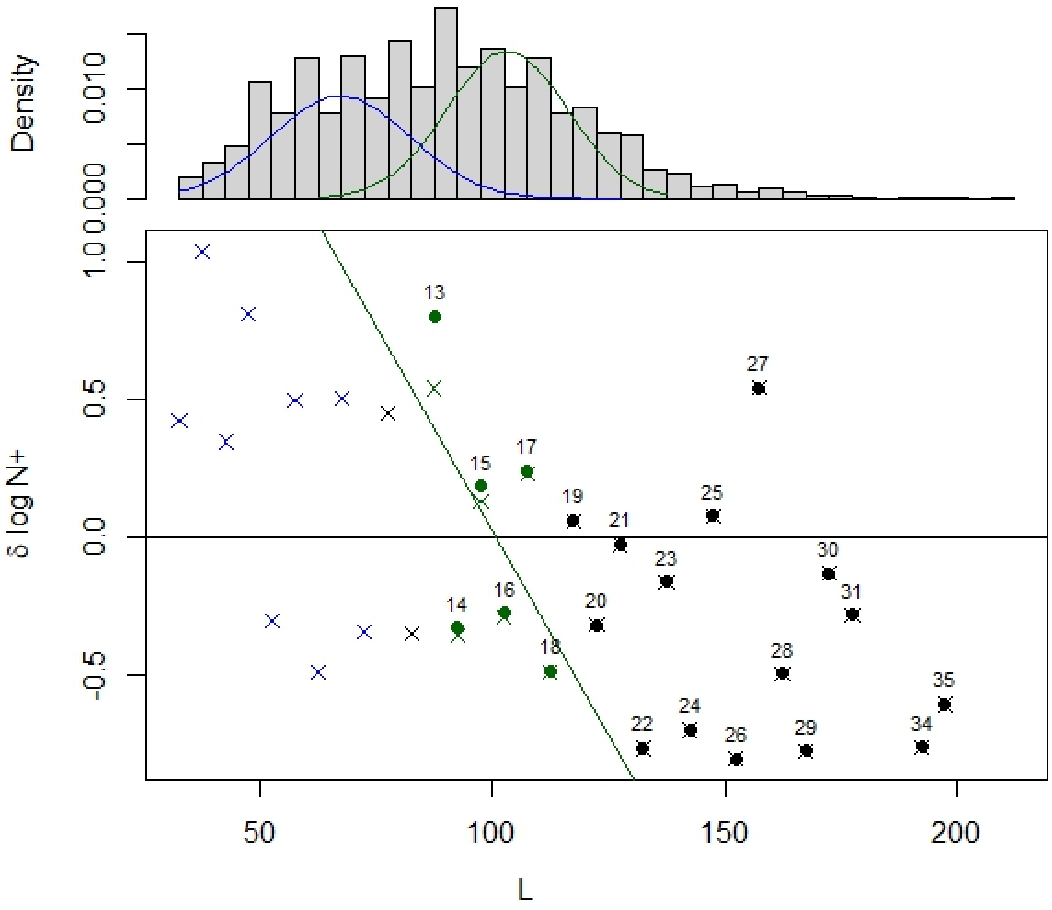
Annex figure 3. Output from the Bhattacharya method in RStudio (*TropFishR* package) for the length–frequency distribution of *Illex coindetii* during the winter season. The x-axis represents the size classes, while the y-axis shows the difference between the logarithm of the number of individuals in a given size class and that in the subsequent class. The horizontal line at zero indicates the median of the distribution. A minimum of two modes were found.



Annex figure 4. Output from the Bhattacharya method in RStudio (*TropFishR* package) for the length–frequency distribution of *Illex coindetii* during the spring season. The x-axis represents the size classes, while the y-axis shows the difference between the logarithm of the number of individuals in a given size class and that in the subsequent class. The horizontal line at zero indicates the median of the distribution. A minimum of three modes were found.



Annex figure 5. Output from the Bhattacharya method in RStudio (*TropFishR* package) for the length–frequency distribution of *Illex coindetii* during the summer season. The x-axis represents the size classes, while the y-axis shows the difference between the logarithm of the number of individuals in a given size class and that in the subsequent class. The horizontal line at zero indicates the median of the distribution. A minimum of two modes were found.



Annex figure 6: Output from the Bhattacharya method in RStudio (*TropFishR* package) for the length–frequency distribution of *Illex coindetii* during the autumn season. The x-axis represents the size classes, while the y-axis shows the difference between the logarithm of the number of individuals in a given size class and that in the subsequent class. The horizontal line at zero indicates the median of the distribution. A minimum of two modes were found.