Institut Català de Recerca per a la Governança del Mar (ICATMAR)

Scientific Report Supporting the Management Plan for Boat Seine (MPBS) (ICATMAR, 20-04)

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- Estudio científico para el plan de gestión de la sonsera (Codi: 201223321-201330394). Federació Territorial de Confraries de Pescadors de Barcelona i Girona (01/08/2012-31/12/2013).
- Seguimiento del plan de gestión de la sonsera. Federació Territorial de Confraries de Pescadors de Barcelona i Girona (01/01/2014-31/12/2014)-(01/01/2015-31/12/2015).
- Trabajo técnico para el Seguimiento del plan de gestión de la sonsera AG-2016-494. Departament d'Agricultura, Ramaderia, Pesca i Alimentació de la Generalitat de Catalunya (01/06/2016-31/12/2016)
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SUMMARY

Fishes with short lifespan are difficult customers for fisheries management. For years scientists are trying to point out that the biggest spanner(s) which is (are) thrown into the stock-recruitment relationship, are predator-prey relationships which cause huge B-P fluctuations in a myriad of permutations. Granted, environmental factors play a huge role. Therefore, investigations of both important topics are the key.

The present document is the report of five years of implementation of the monitoring plan established in management plan for artisanal fishing with boat seines, locally calls “sonsera”, of Catalonia. We add the dates of the scientific study (2012-2013) in order to present a complete study of the “sonsera” fishery.

The boat seine fishery is carried out by 26 artisanal boats based in 6 fishing ports in the central and northern coast of Catalonia (NW Mediterranean). Fishing boats operate on a daily basis and landings are entirely used for direct human consumption, as the targeted species are highly appreciated in the region.

This document refers to the “sonsera” gear and provided information on the evolution of landings and fishing effort (the unit of effort being fishing days), different aspects of target species biology, boat seine fishing activity and impact on the ecosystem and population dynamics.

The “sonsera” is a net gear based on two long lateral wings and a bag between of the wings including the codend. The dimensions of the gear follow the accorded to the management plan adopted on 27 March 2014 (ORDRE AAM/87/2014).

The "sonsera" is used exclusively for fishing sandeel and gobid species. The sandeel fishing grounds are located very close to the coast (depending on the zone, within 400-600 m from the coast), in shallow waters (6-16 m depth) and with coarse sand sediment. Gobid species are fished in muddy or sandy-muddy bottoms, at 7-12 m depths transparent goby (*Aphia minuta*) in the southern fishing grounds, and at 30-50 m depth crystal goby (*Crystallogobius linearis*) in the northern fishing grounds.

In the case of sandeel information is available for *Gymnammodytes cicerelus* and *Gymnammodytes semisquamatus* (the last only includes the 2% of the total catches). As for the gobid species, information is available for *Aphia minuta*, *Crystallogobius linearis* (landings of this last species are very low). Ferrer’s goby (*Pseudaphya ferreri*) has reported very low catches along the catch series (2002-2012) and no catches in the period April 2012 to December 2019.

Three different sources of data over the study period were considered: Official statistics from Fisheries Department of the Generalitat de Catalunya; daily information from fishermen; monthly sampling on board “sonsera” boats.

Length-weight relationships show a weak positive allometry for *G. cicerelus*, and a quasi-isometry for *G. semisquamatus*. In any case the allometry, when present, although statistically significant in many cases is not strong enough to induce big errors in weight calculations.

Gymnammodytes cicerelus reproduction period in the area extends from November to February and at the end of the fishing season in mid-December the population consists of individuals that have attaint the size at first maturity. The size at first maturity of *G. cicerelus* is 8.6 cm TL. *G. semisquamatus* reproduction period extended from December to March-April. Therefore, it is advisable to maintain the timing of the currently implemented closed season, from mid-December to the end of February. The size at first maturity of *G. semisquamatus* is 7.6 cm TL.

The fishery of both of sandeel species covers the northern part of Catalonia, from El Masnou (15 km north of Barcelona) to cape of Creus (near the border with France). However, the effort is not evenly distributed. In the southern part the fishing effort shows an almost uninterrupted continuous, particularly between Mataró and Blanes, being the ports of Arenys de Mar and Blanes the most active ports. The maximum effort appears to be concentrated between these two ports, in front of the small town of Calella de la Costa. In the northern part, the activity is much lower and distributed in patches with large zones without activity.

The results of multi-annual generalized depletion (MAGD) model show that catch and effort data at high temporal frequency (month), complemented with biological information on mean body weight and initial estimates of natural mortality and time of recruitment to the fishery, can be used to produce assessment results of interest to fisheries management. The estimates of fishing mortality obtained for the Mediterranean sandeel in this fishery are very low compared to natural mortality estimates (less than 10%) and the important fluctuations in recruitment strength suggest that denso-dependent effects in the population dynamics of the species mainly drive the dynamics of this fishery. Given the high rate of natural mortality estimated (of the order of $M = 2\ yr^{-1}$), its short life-span (1-2 years) and that exploitation is based on age 0 individuals, it is recommended to keep exploitation rates at current levels (<4%), which can be adapted on a short time basis, subject to the perceived availability of the stock, in the framework of a co-management model that permits to modulate the daily effort and maximum catch limits.

The analysis of the boat seine catch when targeting sandeel evidenced a high selectivity of the “sonsera”, as the presence of by-catch species can be detected by the echo-sounder, which allows performing selective fishing operations resulting in catches without or with very few non- target species. From the general information of the by-catch study, it should be taken into account that a high % of by-catch species is recorded when the catch of the sonso is low and vice versa, a high capture of sonso shows a low % of by-catch.

From the information collected, it is known that fleet complies with the conditions requested in the MP regarding the prohibition of fishing over Posidonia meadows and the amount of by-catch. Therefore, the same strategy will be maintained in the remaining two year of MP implementation.

Regarding gobids fishery, a very limited number of boats targeted gobids (four to six) and for transparent goby only 1 or 2. In the last years, from 2012 to now, only the TAC proposed for transparent goby has been reached, being catches of crystal goby residual.

1. INTRODUCTION AND OBJECTIVES

This document is the report of eight years of implementation of the monitoring plan established in management plan for artisanal fishing with boat seines (“sonsera”) of Catalonia. The boat seine fishery is carried out by 26 artisanal boats based in 6 fishing ports in the central and northern coast of Catalonia (NW Mediterranean). Fishing boats operate on a daily basis and landings are entirely used for direct human consumption, as the targeted species are highly appreciated in the region.

The “sonsera” is used to catch mainly *Gymnammodytes cicerelus* and some very small amounts of *G. semisquamatus* (known both as “sonso” in Catalan) as well as some small gobids (transparent goby *Aphia minuta*, crystal goby *Crystallogobius linearis*) and occasionally very low quantities of Ferrer's goby (*Pseudoaphia ferreri*).

Unlike the North Sea industrial sandeel fishery harvesting hundreds of thousands of tons extensively used in the fish oil and fishmeal industry, the Catalan fishery is based on small-scale boat seiners yielding some hundred tons per fishing season (March to mid-December) and sandeel is sold at the auctions for fresh consumption. The highest landings over 2000-2019 were around 800 tons in 2012-2013, period that coincided with the elaboration of the scientific study that was the basis for the definition of the "sonsera" MP. This value was taken as reference to fix the annual TAC for sandeel. The catches of small gobids *Aphia minuta* and *Crystallogbius linearis* were much low, slightly above 1000 kg per year in the case of *Aphia minuta* in the most recent fishing seasons. Crystal goby catches were very variable, from a maximum of 12407 kg in 2003-2004 to a minimum of 63 kg in 2011-2012. After March 2014 fishermen didn’t catch any Crystal goby. In the 2016-17 season, there is a residual catch of 16 kg in total. In 2017-2018 2700 kg were landing.

This report is based on the historical data of the fishery over 2000-2019, and on the data collected during the eight years of monitoring of the implementation of the boat seine management plan, 2012-2019. Data collected during this period include:

1) Close monitoring of the daily catch per boat under a special fishing plan based on a precautionary approach (each haul is geo-referenced, and includes data on depth, time and by-catch; information provided by the fishermen through log books specially designed to this aim).
2) A sampling campaign carried out on board boat seiners (monthly, two-three fishing days), to obtain data on the specific composition of the total catch, length frequency distributions of target and by-catch species, length-weight measurements, and when possible, target species sex and maturity.

The data collected has dealt with different aspects of target species biology, boat seine fishing activity, impact on the ecosystem and population dynamics. The results include the following topics:

- Target species identification
- Biological parameters for target species: length-weight relationships, growth, maturity stages
- Size distributions at the monthly scale and for the fishing season
- Stock assessment of target species
- Fleet composition and characteristics of the gear
- Geographical distribution of hauls
- Selective activity of the “sonsera”
- By-catch composition, species identification, sizes, amounts and release of alive specimens

The present document refers to the “sonsera” gear, however since this gear has two different strategies targeting sandeels and small gobids, it is organized in two parts, Part I deals with the boat seine fishery targeting sandeel; and Part II regards the boat seine fishery targeting gobid species. In this report, you can find information already reflected in the preliminary reports (Sanchez *et al* 2013 and Sanchez *et al* 2017). We have found it more useful to gather all the information in a single final report.

2. DATA COLLECTION

Different sources of data were used for the scientific study

1) Official statistics. Fishing statistics from Fisheries Department of the Generalitat de Catalunya, over the period 2000-2019. Data are available on a daily basis, and include the catch and income from the sale at the auction, by species and vessel, and the fishing port where the catch was landed. These data provided information on the evolution of landings and fishing effort, the unit of effort being fishing days. In the case of sandeel, information is available for the category *Gymnammodytes cicerelus* (which includes 2% of the *Gymnammodytes semisquamatus*). As for the gobid species, information is available for *Aphia minuta* and *Crystallogobius linearis* although the landings of this last species are very low.

2) Statistics specific of the monitoring. Every day fishermen must fill in a form with the position of the hauls, depth, catch and by-catch species and time at sea. This information allowed us to know the daily catches, effort and fishing ground as well as composition of the by-catch. The fishing grounds were mapped.

3) Sandeel sampling. Monthly sampling on board “sonsera” boats from August 2012 to December 2019 was carried out off the five ports with "sonsera" fleet (Barcelona, Arenys de Mar, Blanes, Sant Feliu de Guíxols, Palamós and L’Estartit) (Table 2.1). Twice a month one observer on board recorded the information on specific composition of the catches and by-catch, data on the fishing grounds where the boat seine operated (Table 2.2). In the closed season (January and February) only one sampling per month in two ports (Arenys de Mar and Blanes) was carried out in order to obtain samples for the biological study.

Samples of each haul were taken and examined at the ICM laboratory to identify the species and collect data on length frequency distributions, individual length-weight, sex, and maturation, in order to study the life cycle of the target species (determination of growth parameters, duration of the reproduction period, size at first maturity, gonadosomatic index) (Table 2.3). All by-catch was also examined at the laboratory, including species identification, lengths and weights. Specimens were measured (total length TL) to the nearest half centimetre (cm), and weighed (total weight TW) to the nearest 0.1 g. Gonads were weighed with a precision of 0.01 g (GNW). To establish the length-weight relationship specimens were measured to the nearest mm and weighed to the nearest 0.01 g.

Table 2.1. Number of vessels of the ”sonsera” fleet and corresponding crew, by port.

Port	Number of vessels	Number of crew
L’Estartit	3	7
Palamós	3	8
Sant Feliu de Guíxols	3	9
Blanes	7	21
Arenys de Mar	8	22
Barcelona	2	4
TOTAL	**26**	**71**

Table 2.2. Summary of the sandeel sampling with scientific observer on board sonsera boat by month and port during the monitoring of the management plan (fishing days, and in brackets, number of hauls).

Port	2012-2013	2014	2015	2016	2017	2018	2019
Arenys de Mar	21 (61)	10 (25)	8 (18)	11 (22)	10 (15)	8 (13)	10 (17)
Blanes	12 (23)	10 (31)	7 (11)	8 (14)	6 (8)	9 (10)	6 (11)
SF+Pal+L'Es*	10 (28)	9 (21)	5 (11)	1 (1)		2 (4)	5 (10)
TOTAL	**43 (112)**	**29 (77)**	**20 (40)**	**20 (37)**	**16 (23)**	**19 (27)**	**21 (38)**

*SF+Pal+L'Es = Sant Feliu de Guíxols + Palamós + L'Estartit

Table 2.3. Number of individuals of *Gymnammodytes cicerelus* and *G. semisquamatus* measured during the monitoring period. *G. cicerelus* were subsampled for measurement when necessary, while all specimens of *G. semisquamatus* were measured.

Year	*G. cicerelus*	*G. semisquamatus*
2012-2013	34164	4305
2014	11718	1017
2015	6014	291
2016	5204	1114
2017	11718	1017
2018	4770	901
2019	6131	534
TOTAL	**79719**	**9179**

4) Gobids sampling was carried out off the 3 ports with sonsera fleet (Barcelona for *A. minuta*, Arenys de Mar and Blanes for *C. linearis*). Twice a month one observer on board collected information on specific composition of the catches and by-catch, data on the fishing grounds where the boat seine operates, vessel and the fishing operation. Samples from each haul were taken and examined at the laboratory to identify the species and collect data on length frequency distributions, individual length-weight and when possible sex, and maturation, in order to study the life cycle of the target species and spatial distribution of the target species. Specimens were measured (total length TL) to the nearest half centimetre (cm), and weighed (total weight TW) to the nearest

0.1 g. To establish the length-weight relationship specimens were measured to the nearest mm and weighed to the nearest 0.01 g.

All by catch was also examined in the laboratory, including species identification, lengths and weights.

During all the monitored period, from the fishing season 2012-2013 to 2018-2019 (from mid-December to the end of April) transparent goby (*Aphia minuta*) was captured, while crystal goby *Crystallogobius linearis* was fished only in the fishing seasons 2012-2013, 2013-2014, 2016-2017 and 2017-2018 (Tables 2.4 and 2.5).

Table 2.4. Summary of gobids (*Aphia minuta* and *Crystallogobius linearis)* sampled with scientific observer carried out on board sonsera boat during the monitoring of the management plan (fishing days, and in brackets, number of hauls). Number on bracket = number of hauls.

Fishing season	*A. minuta*	*C. linearis*
2012-2013	5 (10)	6 (15)
2013-2014	3 (8)	4 (12)
2014-2015	3 (9)	
2015-2016	4 (16)	
2016-2017	4 (14)	1 (1)
2017-2018	3 (8)	2 (4)
2018-2019	2 (7)	
TOTAL	**24 (72)**	**13 (32)**

Table 2.5. Number of individuals of *Aphia minuta* and *Crystallogobius linearis* measured during the study period (December 2012 - April 2019).

Fishing season	*A. minuta*	*C. linearis*
2012-2013	1408	1434
2013-2014	813	1231
2014-2015	1267	
2015-2016	653	
2016-2017	996	106
2017-2018	1008	304
2018-2019	659	
TOTAL	**6804**	**3075**

3. BIOLOGY OF SANDEEL

3.1. Taxonomy

Gymnammodytes cicerelus (Rafinesque-Schmaltz, 1810)

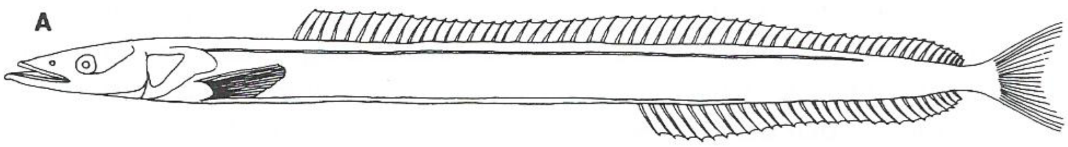


Figure 3.1.1. Adult of *Gymnammodytes cicerelus* from the Catalan coast (from Sabatés *et al*. 1990).

Diagnosis: ventro-lateral skin-folds extending well beyond pectoral fins to anus. Dorsal rays 56-59; anal rays 27-31; pectoral fin ray 12-15. Lateral line branched. Vertebrae 66-67 (mode 66).

Colour: iridescent silver, while the back is bluish-grey and the flanks and belly whitish. In this species it is possible to observe a strip of quit marked dark pigmentation along the top part of the flanks and over the head (Sabatés *et al*. 1990).

Size: to 17 cm SL.

Habitat: inshore to 15 m depth.

Food: probably plankton.

Reproduction: winter spawner.

Distribution: Mediterranean and Black Sea, overlapping with *G. semisquamatus* in the western Mediterranean.

Larvae: Sabatés *et al*. (2003) working on the North of the study area found larvae of *G. cicerelus* in winter (January-March).

Gymnammodytes semisquamatus (Jourdain, 1879)

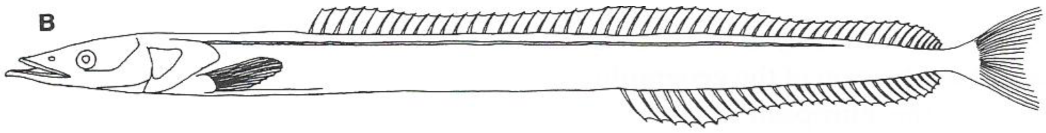


Figure 3.1.2. Adult of *Gymnammodytes semisquamatus* from the Catalan coast (from Sabatés *et al*. 1990).

Diagnosis: ventro-lateral skin folds extend from the base of the pectoral fin to just beyond the rear end of the fin. Dorsal rays 53-59; anal rays 26-32; pectoral fin ray 12-15. Lateral line branched. Vertebrae 64-72.

Colour: Body silver, while the back is dark brown and the flanks and belly whitish. The strip of pigmentation on the flanks is brownish and barely appreciable, though it does exist (Sabatés *et al*. 1990).

Size: to 28 cm SL (Atlantic).

Habitat: typically offshore over shell-gravel, also inshore where shell-gravel beaches occur.

Food: plankton.

Reproduction: summer batch spawner, ripe fish occurring from March to September in North Atlantic, but probably with more restricted spawning periods for each population (Reay 1986) and winter/spring spawner in the Mediterranean (present study).

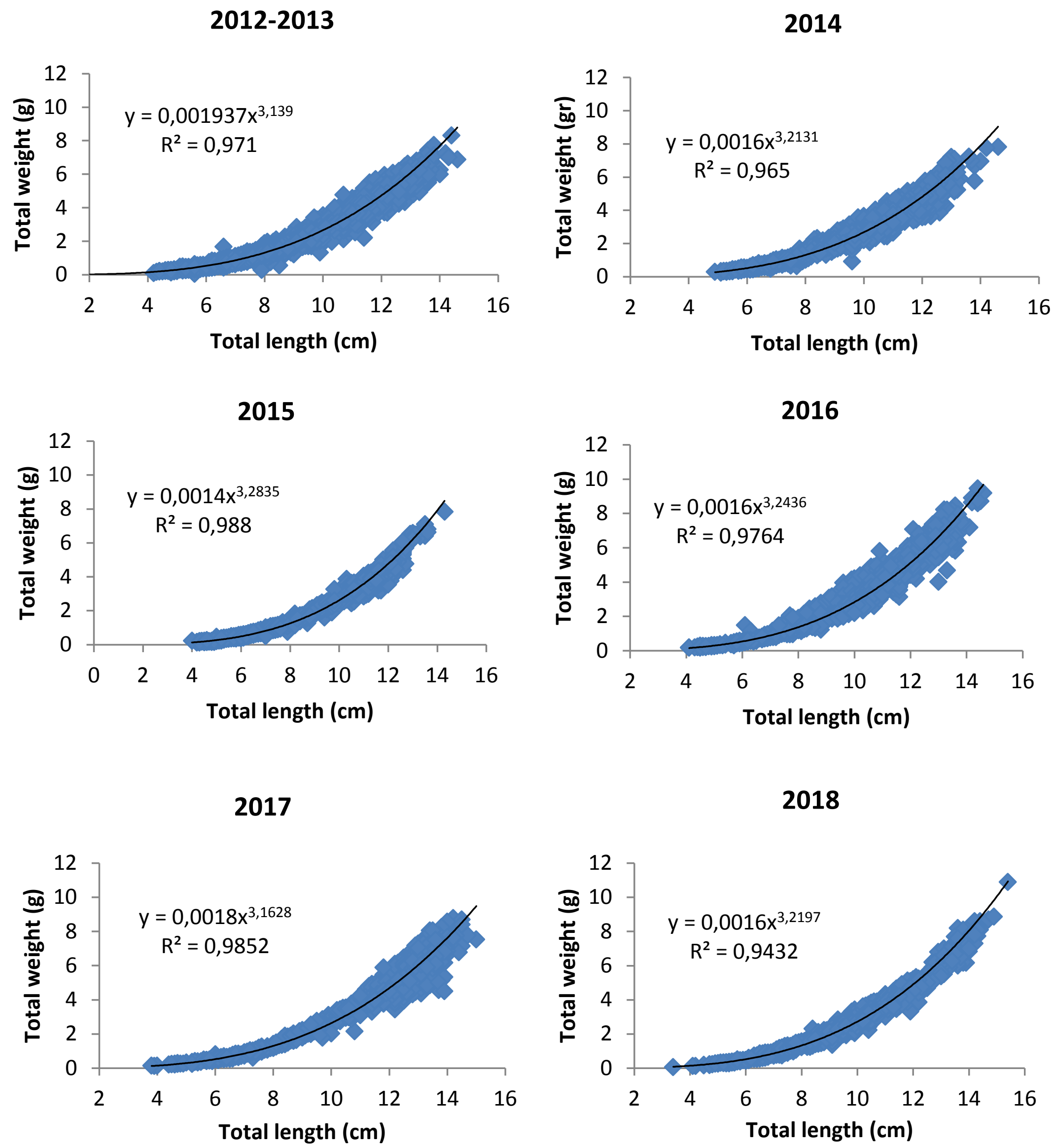
Distribution: eastern North Atlantic from the southern coast of Norway and the Shetlands (61° N) to Spain (36° N) including all coasts of the British Isles and the North Sea, but not the Baltic, and extending along northern Mediterranean coasts to at least 3° E (Reay 1986; Sabatés *et al*. 1990; Sabatés *et al*. 2003).

Larvae: Sabatés *et al*. (2003) working on the North of the study area found larvae of *G. semisquamatus* in winter (January-March) and few specimens in a 24-h sampling cycle carried out in July.

3.2. Length-weight relationship

Gymnammodytes cicerelus

The length-weight relationships for the entire *Gymnammodytes cicerelus* population are represented in Figure 3.2.1. Positive allometric growth was observed in this species.



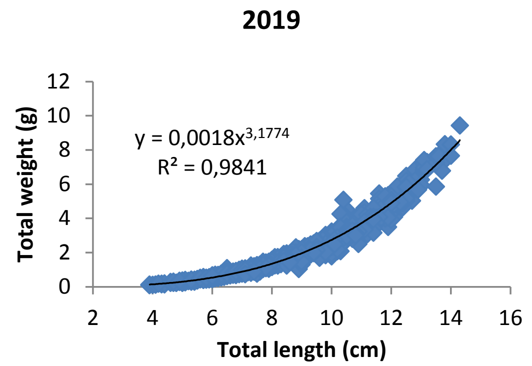
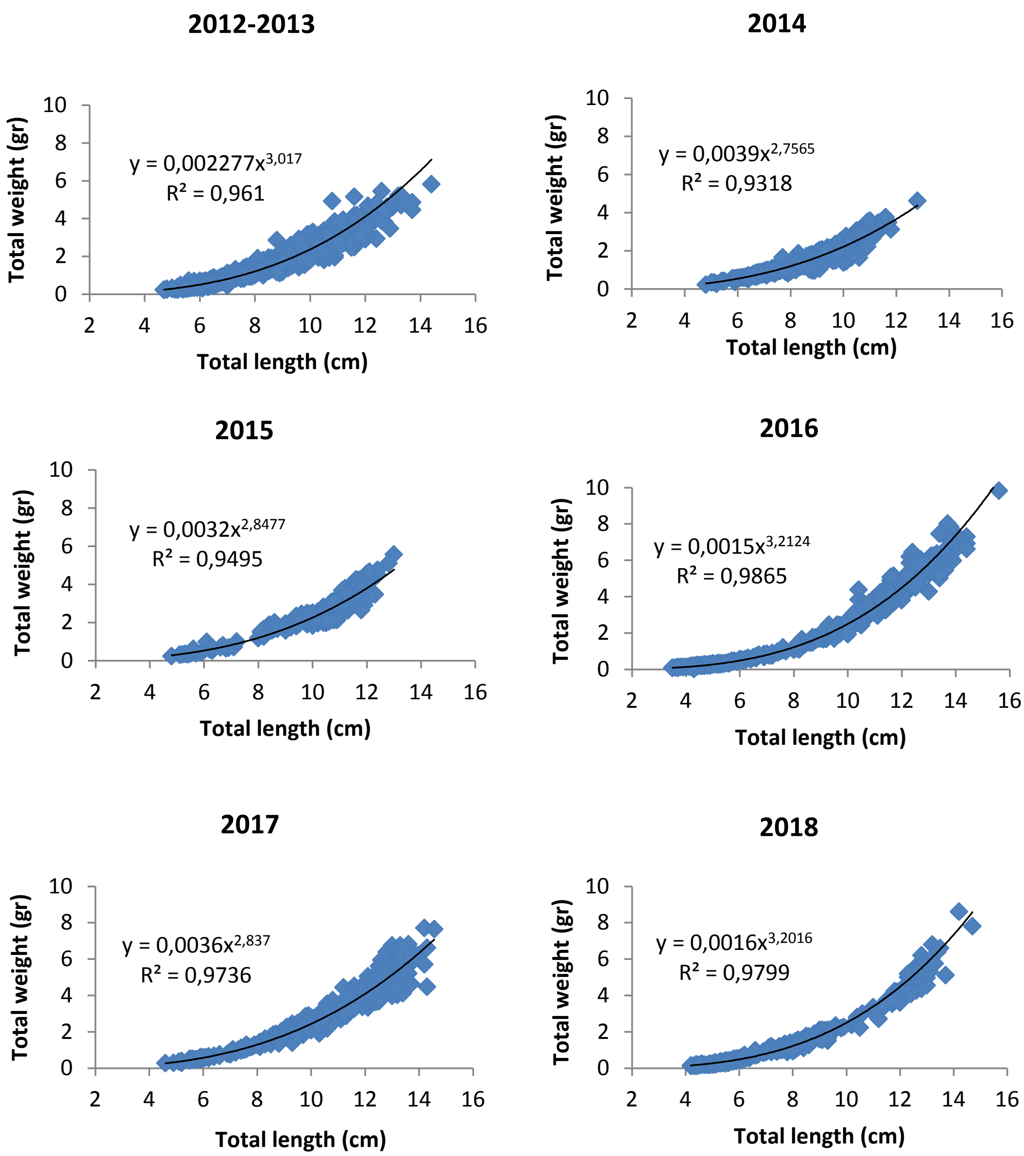


Figure 3.2.1. *Gymnammodytes cicerelus* length-weight relationship (a and b parameters) obtained for the study period (2012-2019).

Gymnammodytes semisquamatus

The length-weight relationships for the entire *Gymnammodytes semisquamatus* population are presented in Figure 3.2.2. Relative growth appears to be positive or negative allometric depending on the year.



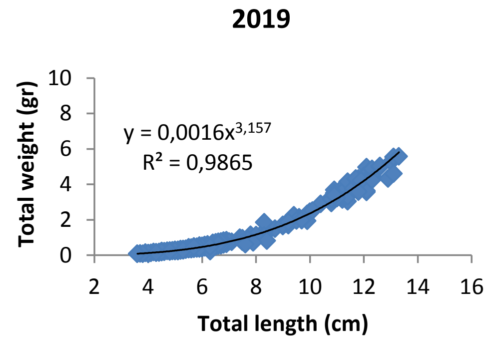


Figure 3.2.2. *Gymnammodytes. semisquamatus* length-weight relationship (a and b parameters) obtained for the study period (2012-2019).

3.3. Length frequency

Gymnammodytes cicerelus

The monthly length-frequency distribution in the catches of *Gymnammodytes cicerelus* ranged between 3 and 15 cm (Figure 3.3.1). A total of 79719 individuals were measured during the sampling period.

Specimens of the entire size range (small, medium and large) were caught during 2014. In 2015, the size frequency distribution consisted of small specimens and the presence of medium ones, while the absence of large individuals reflects the closure of the fishing season from July to December due to the very low abundance of sandeel. Exploratory samples were carried out during the ban of the fishery. In 2016, the scarcity of small specimens and the presence of medium and large specimens, reflects the delay in the beginning of the fishing season in April**.** In 2017, the season started on time but catches decreased during summer, reason why the fishery was closed during August and September, and it was opened again in October with a low quota. The following years, 2018 and 2019, were years of recovery but quotas were kept low as a precautionary measure.

Table 3.3.1 shows the monthly average size of *G. cicerelus*. It can be observed that mean size increases throughout the fishing season from February-April (when the first shoals appeared) to January-February of the following year.

Table 3.3.1. Monthly average size of *Gymnammodytes cicerelus*.

Month	2012	2013	2014	2015	2016	2017	2018	2019
January		10,32		11,56		12,30	12,42	10,67
February		5,56		6,29	8,60	12,14		11,07
March		5,82	9,48	5,42	6,86	8,01	7,09	7,53
April		5,98	7,59	6,64	7,24	6,17	6,17	6,35
May		6,81	7,51	7,22	7,36	8,20	7,21	7,05
June		7,45	7,53	8,94	8,75	9,88	8,80	6,37
July		7,33	8,22	8,32	10,01	10,74	8,92	8,53
August	7,77		8,59	10,07	10,95		10,05	7,39
September	8,05		8,64		11,75		9,55	8,09
October	8,72		9,88	11,52	11,43		10,25	8,96
November	9,86		11,29		12,17	12,81	10,70	9,80
December	8,37		10,89		12,20	12,33	11,00	8,77

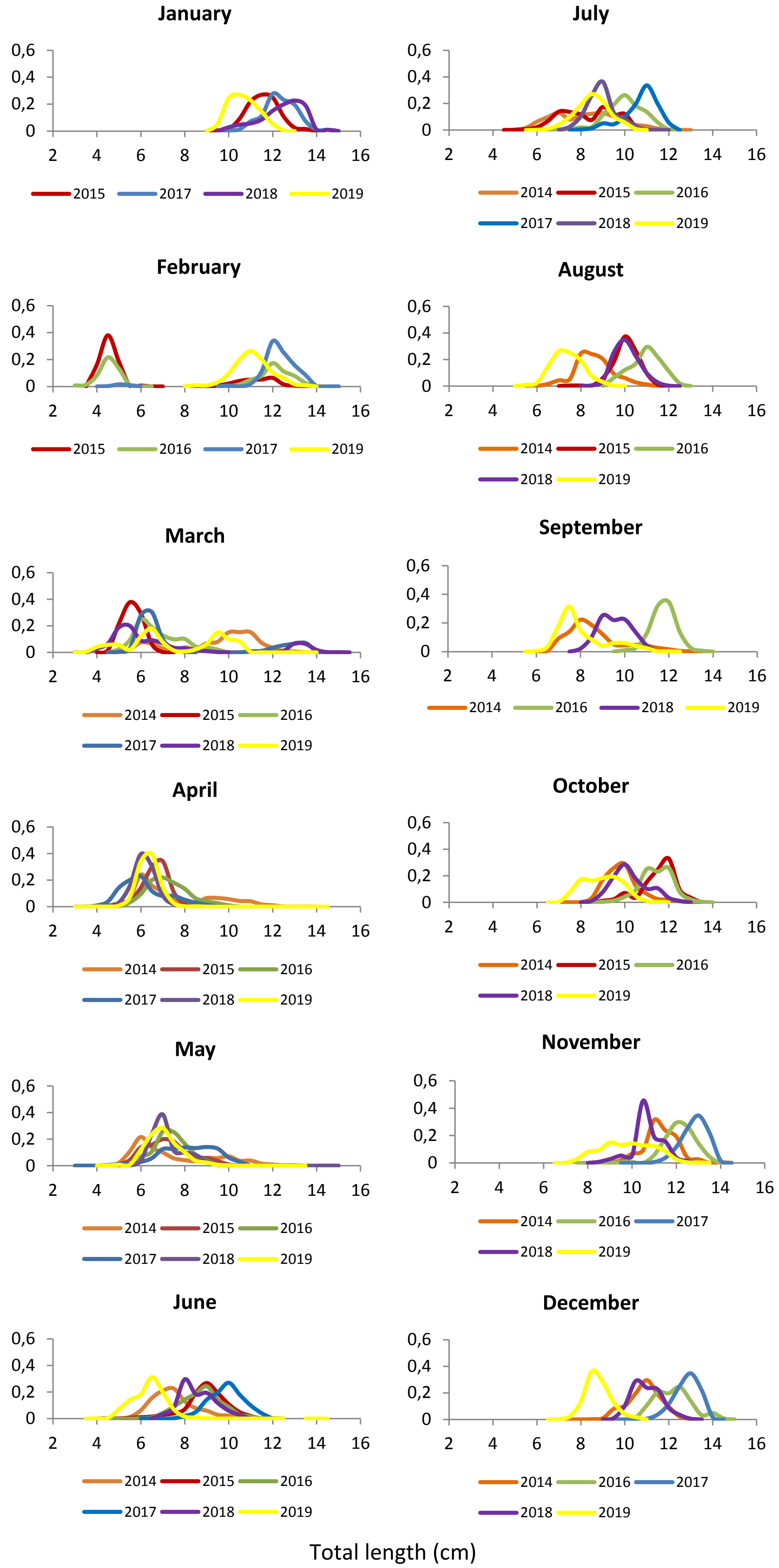


Figure 3.3.1. Monthly length-frequency distribution of *Gymnammodytes cicerelus* during 2014-2019 expressed as a percentage.

Gymnammodytes semisquamatus

The monthly length-frequency distributions of the catches of *Gymnammodytes semisquamatus* ranged between 3 and 15.5 cm (Figure 3.3.2). A total of 9179 individuals were measured during the sampling period.

The size distribution was very different in the five years sampled. In 2014 and 2017, the presence of small and large individuals in a similar proportion was detected. In 2015 most of the individuals were large and there were few small. In 2016 the situation was the opposite, with more small individuals than large. In 2018 and 2019, the sizes were smaller than previous years.

Table 3.3.2 shows the monthly average size of *G. semisquamatus*. It can be observed that mean size increases throughout the fishing season from March-April (when the first shoals appeared) to February of the following year.

Table 3.3.2. Monthly average size of *Gymnammodytes semisquamatus*.

Month	2012	2013	2014	2015	2016	2017	2018	2019
January		10,32		10,85		12,30	11,74	
February		5,56		10,69	12,73	12,14		9,05
March		5,82	10,08	11,17	4,82	8,01	12,66	6,08
April		5,98	9,69	6,05	5,38	6,17	5,63	5,73
May		6,81	9,14	7,25	7,26	9,18		5,96
June		7,45	7,55	8,34	8,34	9,12	8,25	5,25
July		7,33		9,54	7,67		7,53	6,50
August	8,55		8,02		8,50		8,51	5,25
September	7,04		7,39		10,00			
October	7,83		7,70	11,94	10,03		8,46	
November	8,89		9,45		10,95	11,44	8,61	7,21
December	9,39		9,47	11,83	12,20	11,98	9,33	

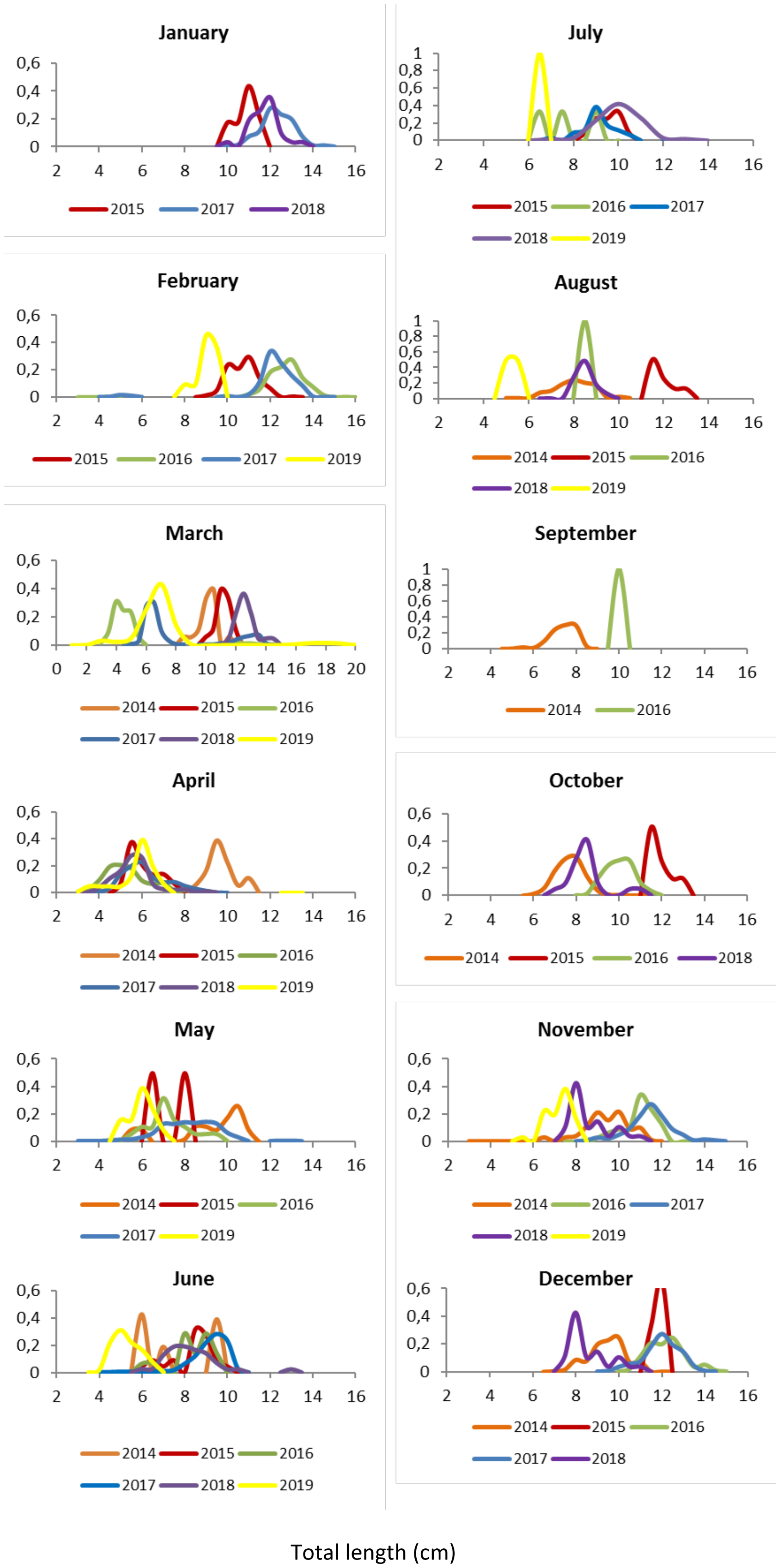


Figure 3.3.2. Monthly length-frequency distribution of *Gymnammodytes semisquamatus* during 2014-2019 expressed as a percentage.

3.4. Maturity and reproduction

Of the total specimens, 7502 gonads were removed (4525 *G. cicerelus*; 2976 *G. semisquamatus*), the sex determined, and macroscopically assigned to a gonadal stage based on the six maturity phases scale (I=Immature; II=Resting; III=Developing IV=Advanced maturation; V=Spawning; VI=Post spawning) (Figure 3.4.1 and Figure 3.4.2). Sex was easily assessed macroscopically in mature individuals. However, gonads from small individuals were indistinguishable macroscopically because ovaries and testes were a small and translucent filament. Fish that were too small to determine their sex or assign a gonadal phase were classified as indeterminate.

Gonads were fixed in 10% buffered formalin solution, dehydrated in ascending solutions of alcohols and embedded in a methacrylate polymer resin, sectioned at a thickness of 4 μm with a manual microtome, stained with Lee's stain (methylene blue and basic fuchsin), and mounted in a synthetic resin of dibutyl phthalate xylene on microscope slides to observe them macroscopically (Figure 3.4.3 to Figure 3.4.6).

Macroscopic gonadal stage

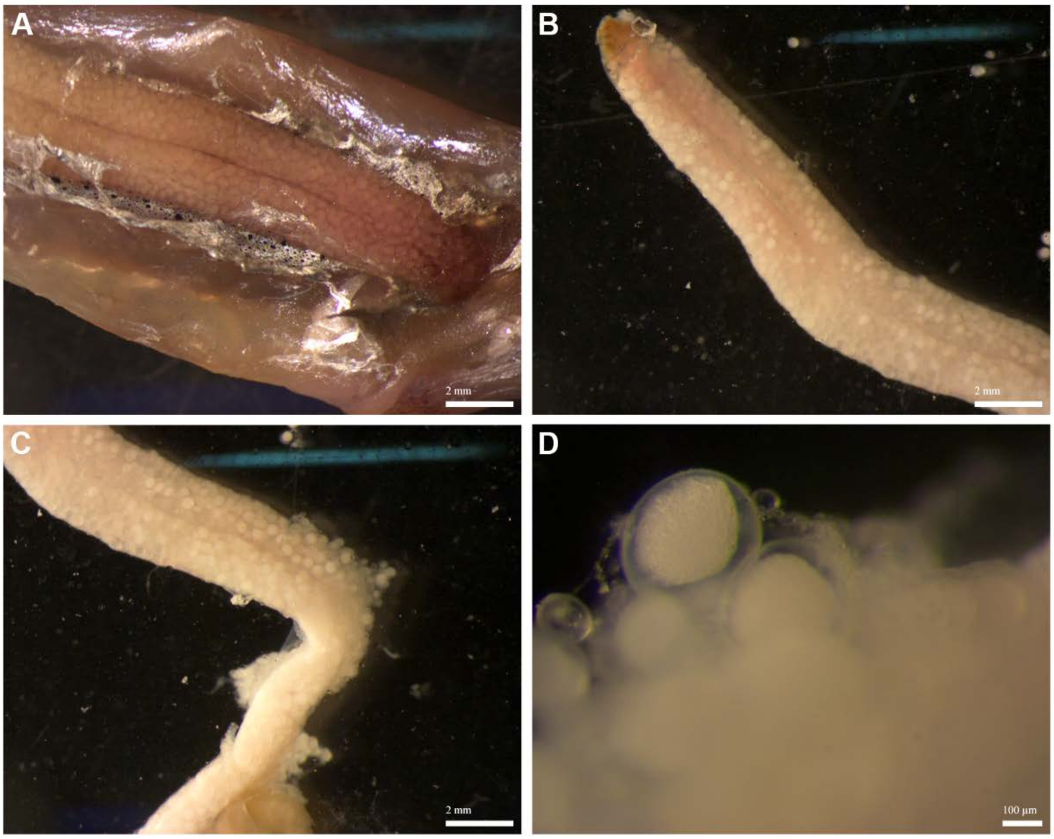


Figure 3.4.1. Macroscopic images of ovaries of females *G. cicerelus* showing different maturity phases: (A) Phase III; (B) Phase IV; (C) Phase V; (D) Phase V with detail of the oocytes.

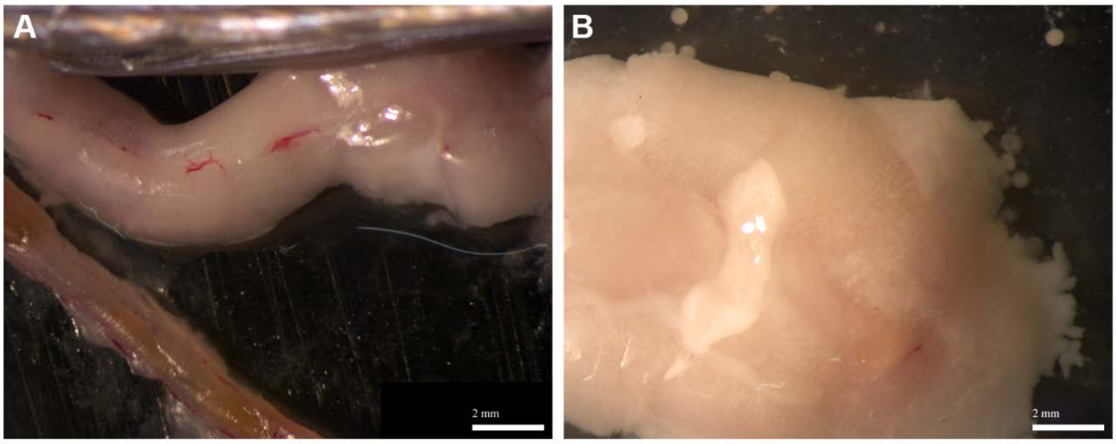


Figure 3.4.2. Macroscopic images of testis of male *G. cicerelus* at maturity Phase V: (A) General view of the gonad; (B) Detail of the testis.

Histological sections

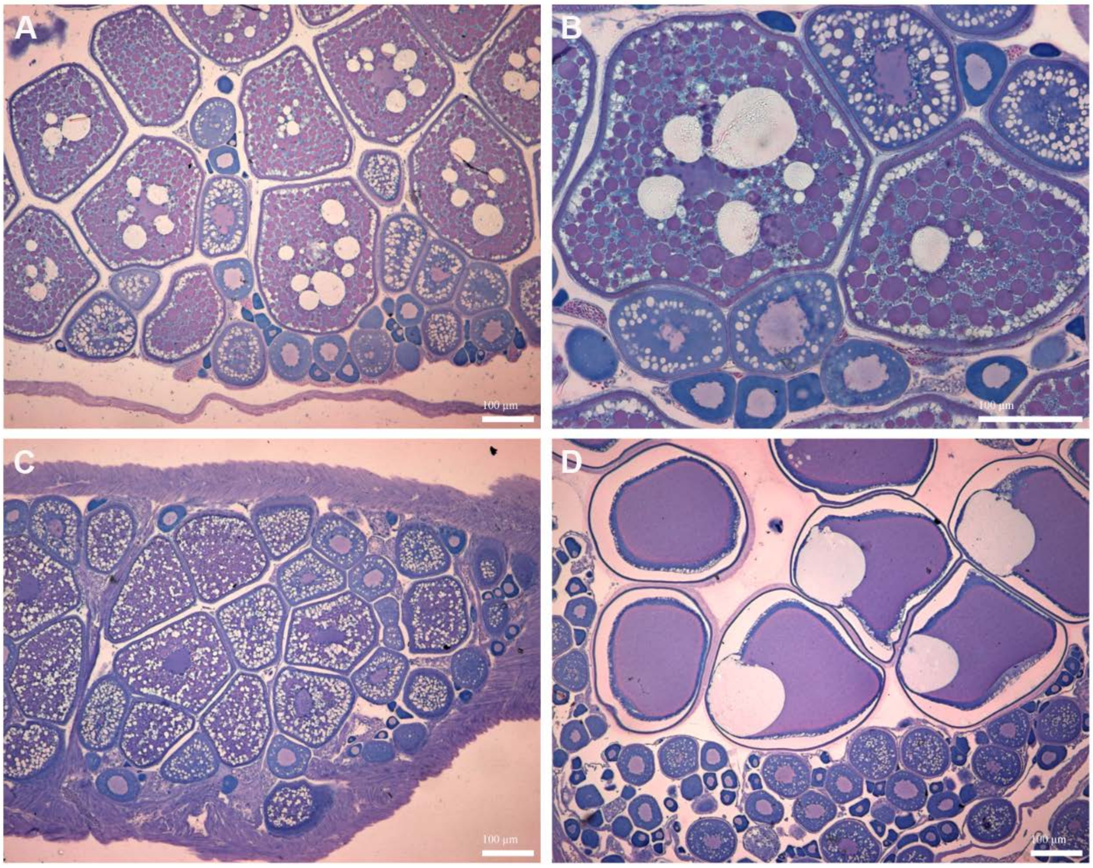


Figure 3.4.3. Histological sections from ovaries of female *G. cicerelus* in mature phases: (A) Advanced Phase IV showing oocytes in different stages of growth; (B) closed-up of a gonad in Phase IV; (C) Initial Phase IV; (D) Phase V showing hydrated oocytes.

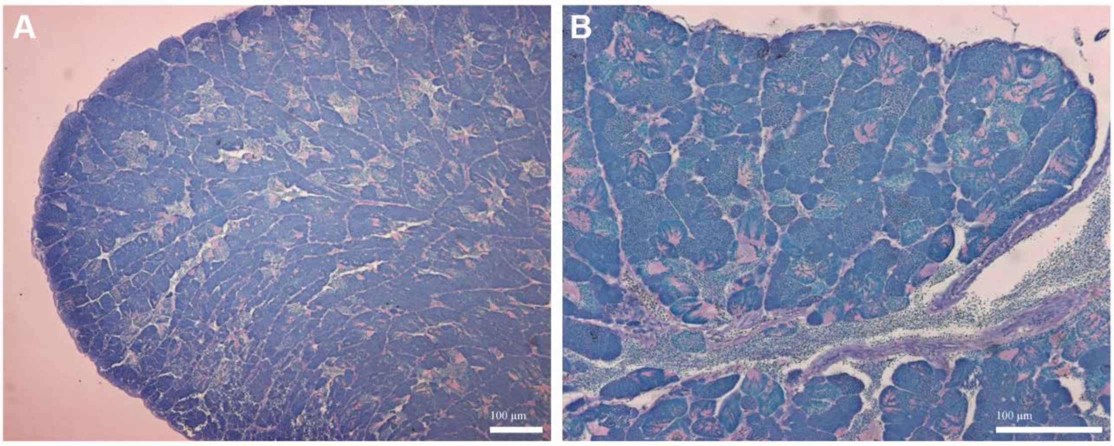


Figure 3.4.4. Transverse section of testes of *G. cicerelus* showing (A) lobular organization; (B) spermatozoa in the lumen of the seminal lobules and in the sperm duct.

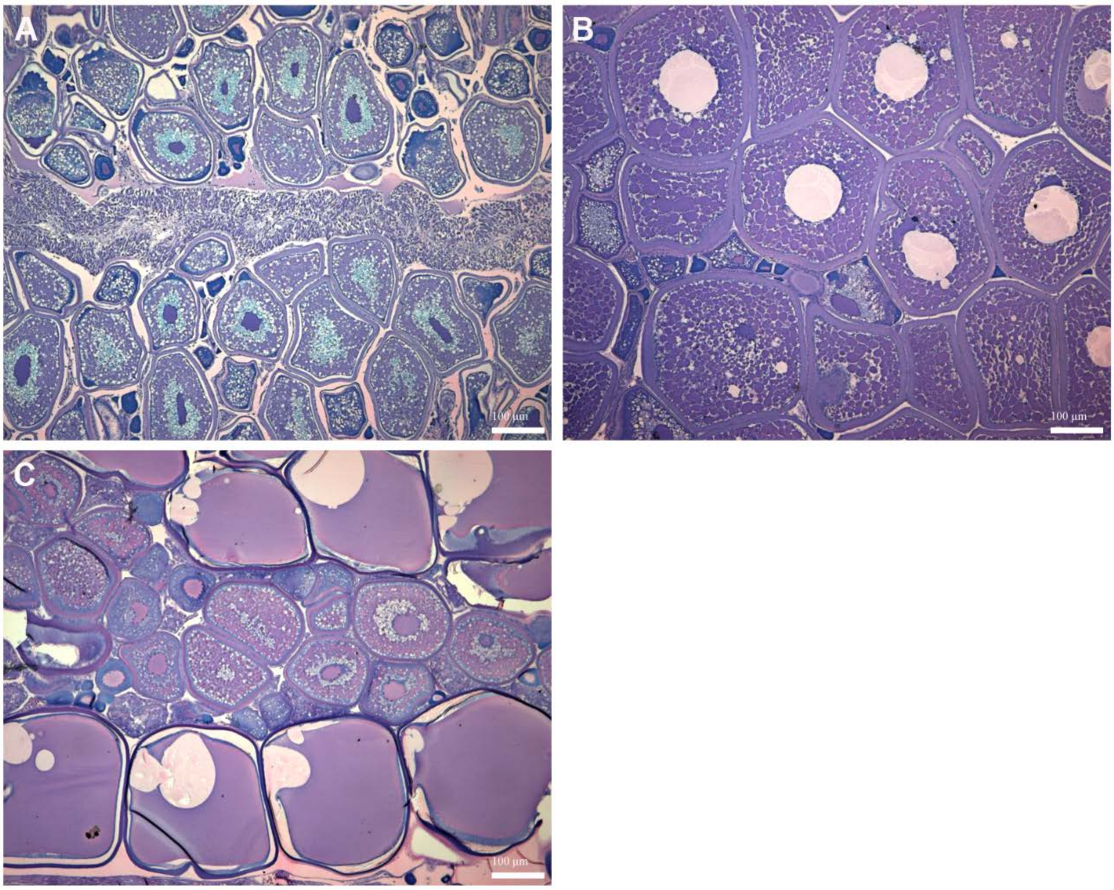


Figure 3.4.5. Histological sections from ovaries of female *G. semisquamatus* in mature phases: (A) Phase III showing the lobular separation and oocytes in different stages of growth; (B) Phase IV with vitellogenic oocytes; (C) Phase V showing hydrated oocytes.

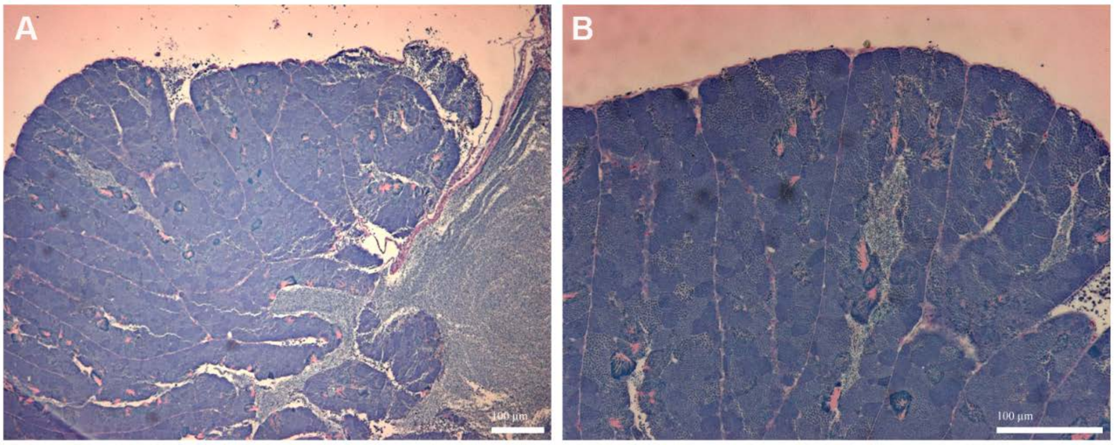


Figure 3.4.6. Transverse section of testes of *G. semisquamatus* showing (A) spermatozoa in the lumen of the seminal lobules and in the sperm duct; (B) lobular organization.

The spawning season was established from the analysis of the monthly variation of the maturity phases and the changes in gonadosomatic (GSI) index for each sex, which was calculated as:

$$GSI = (GNW / TW) \times 100$$

where TW is total weight and GNW gonad weight.

Gymnammodytes cicerelus

Spawning season and size at first maturity

The monthly distribution of the macroscopic classification of the maturity phases (Figures 3.4.7 and 3.4.8) revealed the maximum occurrence of advanced maturation females (Phase IV) from November to March. The presence of spawning females (Phase V) was also observed from November to March, with a maximum peak in January. Females in immature and resting Phases (I + II) were found all the year round except in January. Males showed the same pattern as females, with a maximum peak of individuals in Phase V in January and February.

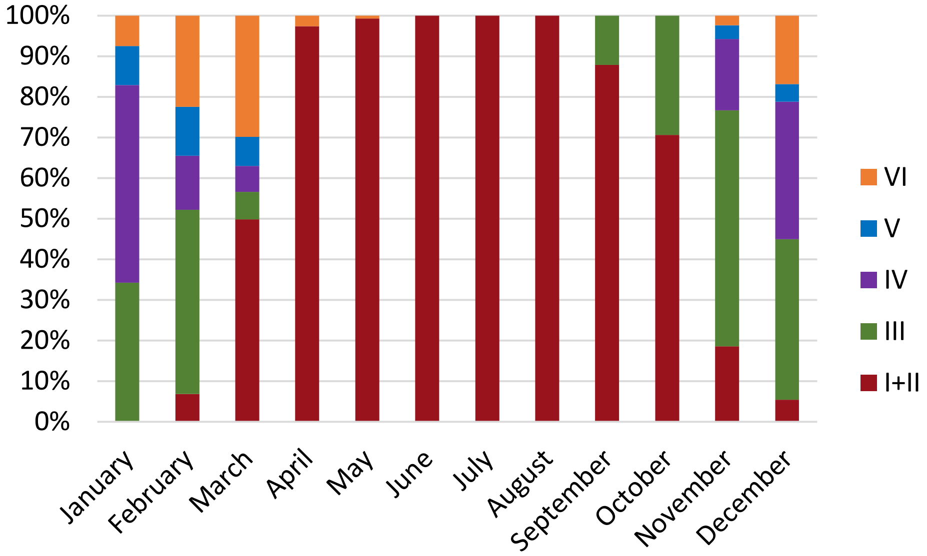


Figure 3.4.7. Monthly distribution of maturity phases for females of *G. cicerelus* (n=2564).

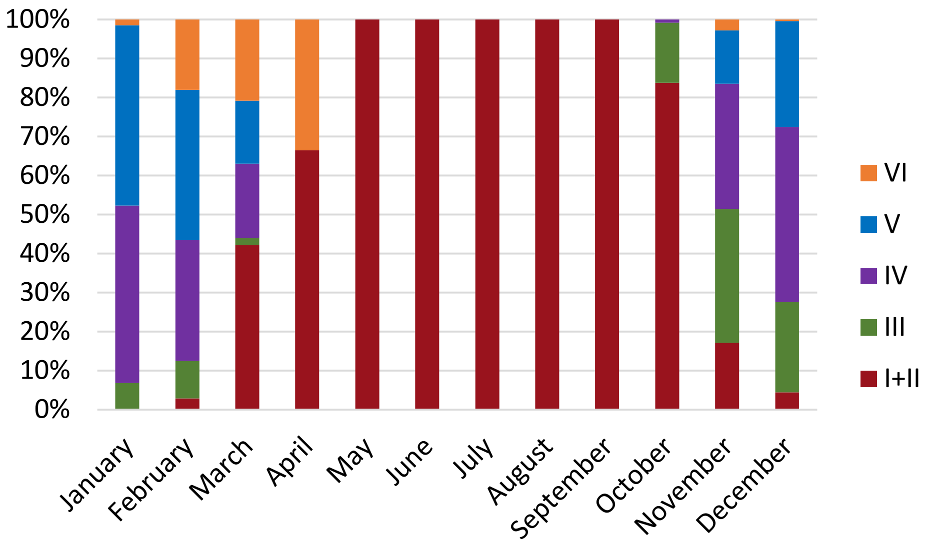


Figure 3.4.8. Monthly distribution of maturity phases for males of *G. cicerelus* (n=1963).

Gonadosomatic index (GSI) was calculated for males and females during the period 2012-2019. The highest mean GSI, for both females and males, was found from November to March, with a peak of maximum activity from December to February (Figure 3.4.9).

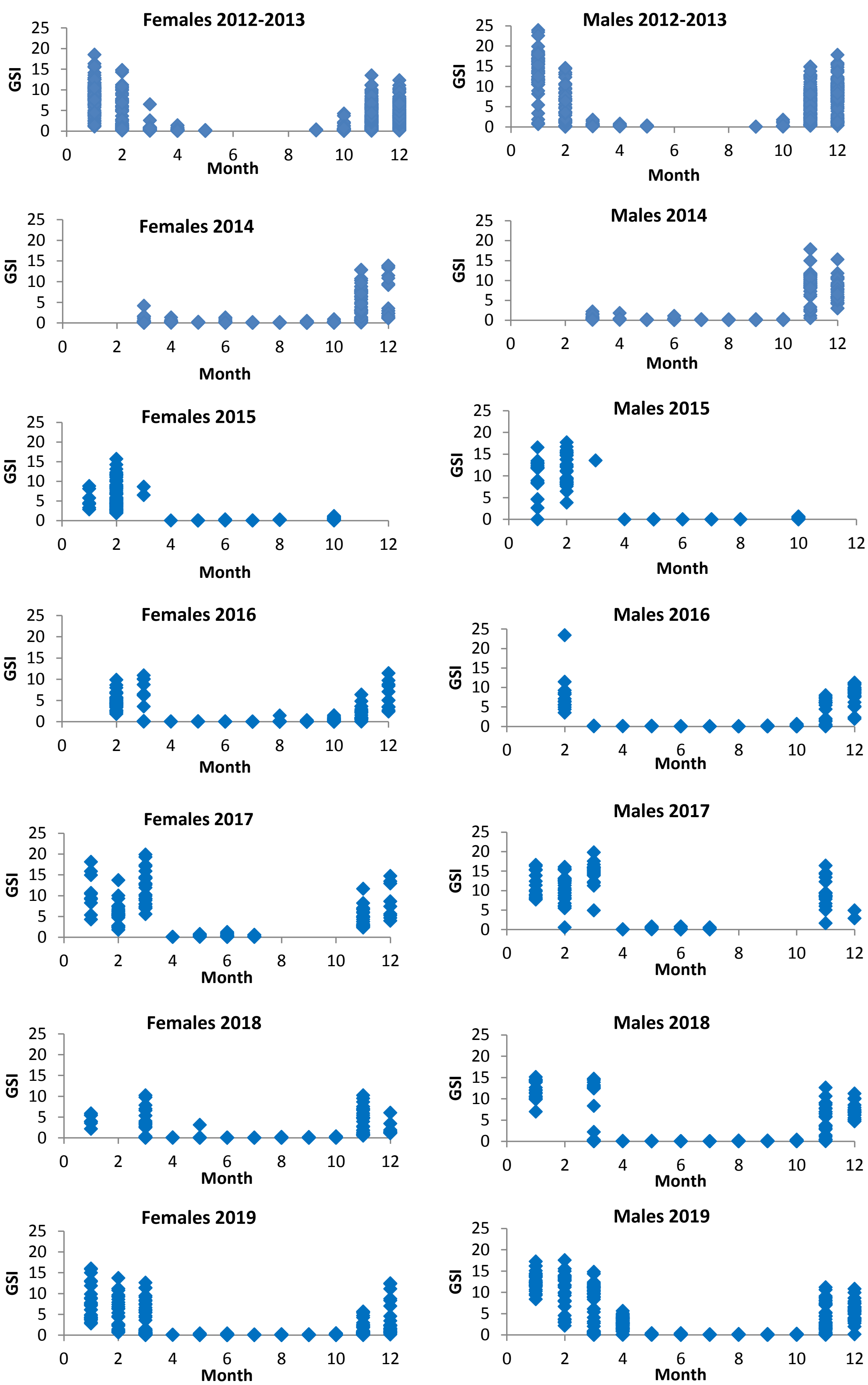


Figure 3.4.9. Monthly changes in the gonadosomatic index for females and males of *G. cicerelus.*

The size at first maturity (size at which 50% of individuals are mature, usually known as L_{50}) was estimated by fitting the percentage of maturity per length class of 0.5 cm to a log-normal accumulated curve with translation. The adjustment was weighted with the number of observations in each length class from a total of 3746 lectures (Figure 3.4.10).

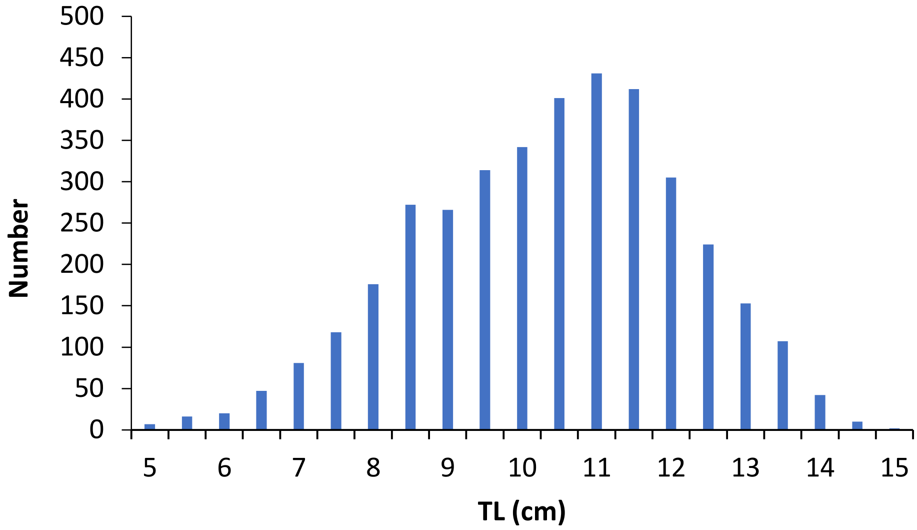


Figure 3.4.10. Maturity sampling for *G. cicerelus*. Number of individuals per 0.5 cm length class.

The results show a size at first maturity (L_{50}) of 8.6 cm TL. Sizes at which 25% and 75% of individuals are mature were also calculated: L_{25}=7.7 cm TL and L_{75}=9.7 cm TL (Figure 3.4.11).

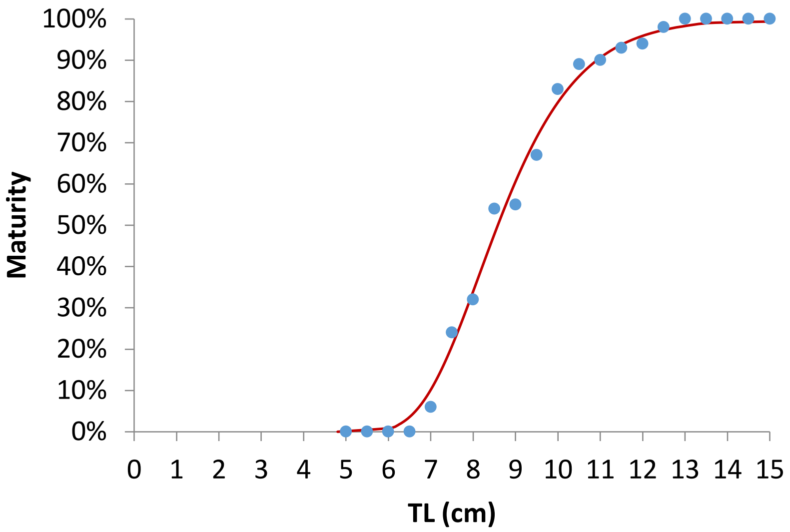


Figure 3.4.11. Maturity ogive for sex combined of *G. cicerelus*.

Gymnammodytes semisquamatus

Spawning season and size at first maturity

The monthly distribution of the macroscopic classification of the maturity phases (Figures 3.4.12 and 3.4.13) showed the maximum occurrence of advanced maturation females (Phase IV) from November to April. The presence of spawning females (Phase V) was also observed from November to April. Females in immature and resting Phases (I and II) were found all year round. Males showed a similar pattern as females, with a peak of individuals in phase V in January and February.

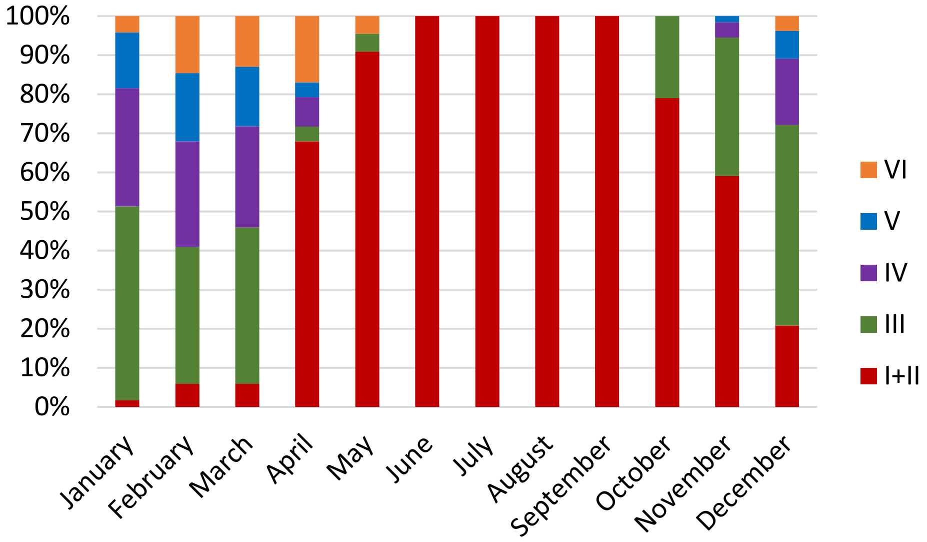


Figure 3.4.12. Monthly distribution of maturity phases for females of *G. semisquamatus* (n=1164).

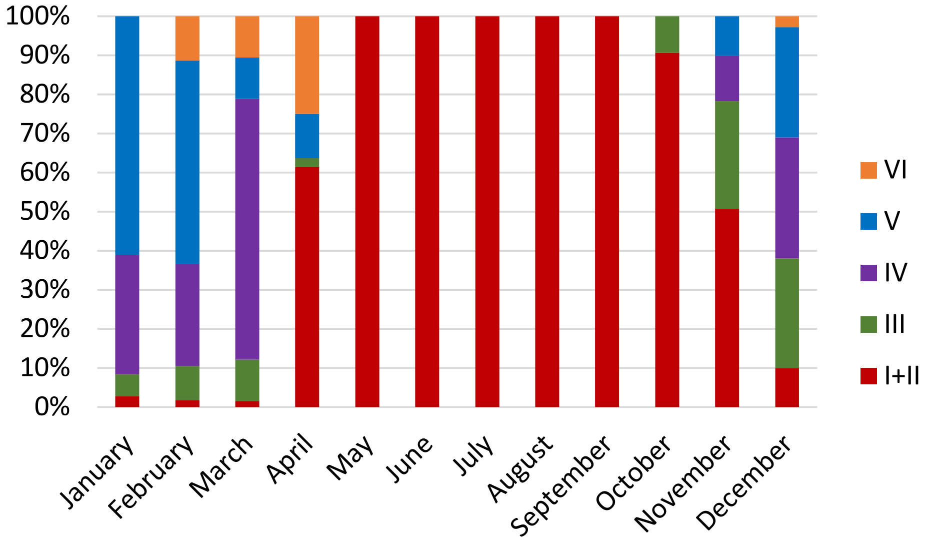


Figure 3.4.13. Monthly distribution of maturity phases for males of *G. semisquamatus* (n=917).

Gonadosomatic index (GSI) was calculated for males and females from 2012 to 2019. The mean GSI for females was highest from December to March, (Figure 3.4.14). Males showed a similar pattern than females.

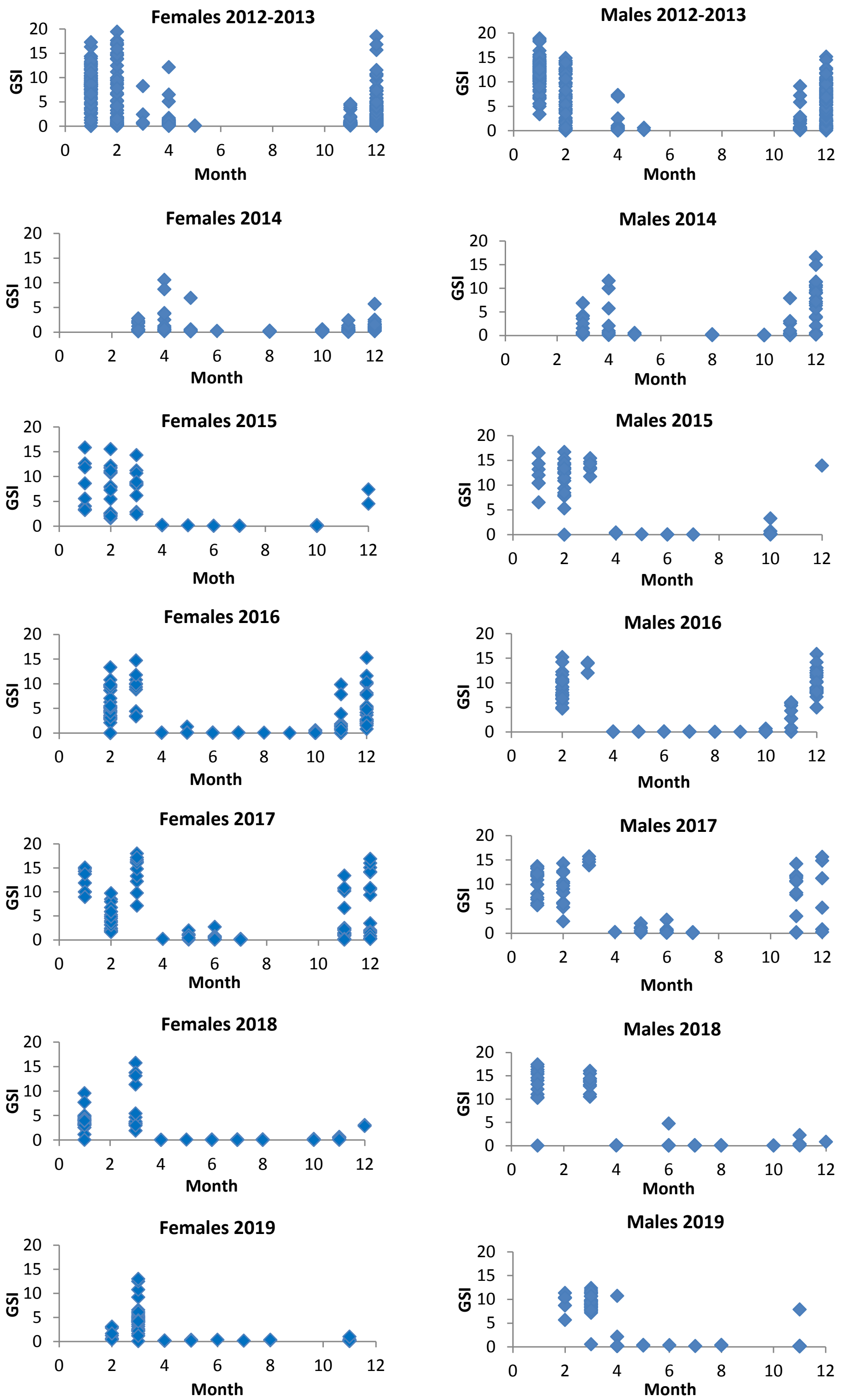


Figure 3.4.14. Monthly changes in the mean gonadosomatic index for females and males of *G. semisquamatus.*

The size at first maturity (size at which 50% of individuals are mature, usually known as L_{50}) was estimated by fitting the percentage of maturity per length class of 0.5 cm to a log-normal accumulated curve with translation. The adjustment was weighted with the number of observations in each length class from a total of 1515 lectures (Figure 3.4.15).

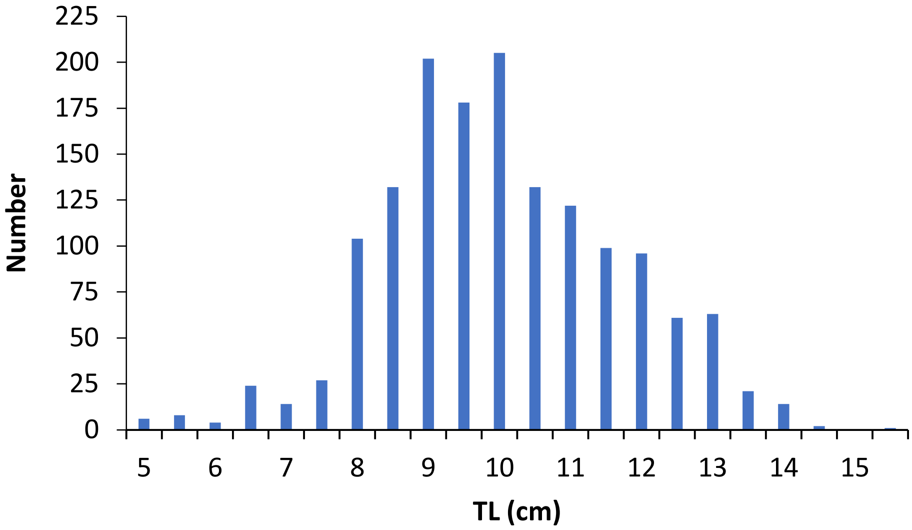


Figure 3.4.15. Maturity sampling for *G. semisquamatus*. Number of individuals per 0.5 cm length class.

The results show a size at first maturity (L_{50}) of 7.6 cm TL. Sizes at which 25% and 75% of individuals are mature were also calculated: L_{25}=6.8 cm TL and L_{75}=8.6 cm TL (Figure 3.4.16).

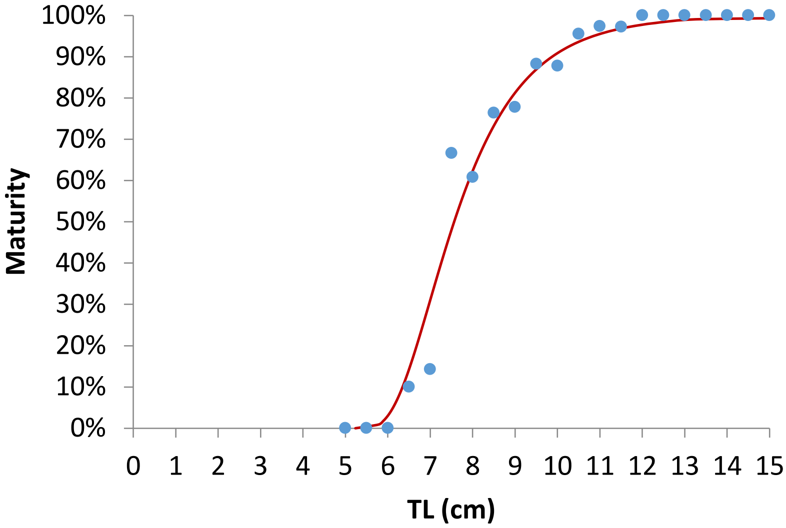


Figure 3.4.16. Maturity ogive for sex combined of *G. semisquamatus*.

4. SANDEEL FISHERY

4.1. Structure of the gear

The “sonsera” is a fishing gear that belongs to the group of boat seine and it is used for both the sandeel and the “llengüeta” fisheries.

The “sonera” is a net gear based on two long lateral wings and a bag between of the wings including the codend. According to the management plan adopted on 27 March 2014 (ORDRE AAM/87/2014) the dimensions of the gear are:

- Maximum length of wings: 125 m.
- Maximum height of wings: 35 m.
- Maximum length of codend: 30 m.

A rope no longer than 100 m is attached at the end of each wing.

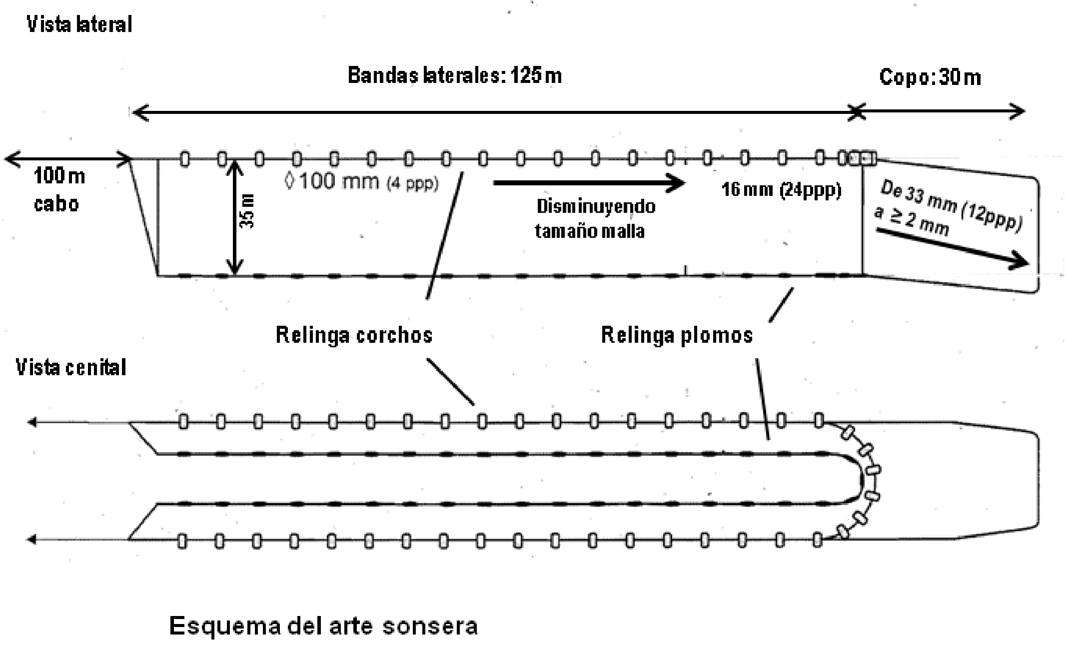


Figure 4.1.1. Drawing of the boat seine “sonsera” characteristics.

The mesh size decreases from the end of the wing (100 mm; 4 Ppp) to the net mouth (16 mm; 24 Ppp). The mesh size of the codend decreases from the mouth (33 mm; 12 Ppp), to its lower white portion of the mesh of the codend (no less than 2 mm; 200 Ppp). A cylindrical net extension is found at one end of the codend and sometimes another extension can be found at the other end. The catch is removed from these extensions. The above sizes are the minimum ones for the ends of each gear section. However, the wings and the codend constructive characteristics as well as the mesh size configuration may vary according to the habits and customs of each fishermen and net builders.

The wings have a leadline with large number of weights along the net bottom (a maximum of 6 weights per m; maximum 250 g each weight), and a floatline along the top of the net to provide flotation in order to achieve a positive buoyancy during the dropping operation.

Certain variability in the dimension of the “sonsera” previously described is permitted due to the geographic and bathymetric features of the northern sandeel distribution area. In this area, between Blanes and L’Estartit, the usual fishing grounds are located between 13 and 16 m, no deeper than 30 m. Therefore, a maximum wing height of 60m and a maximum rope length of 200 m are allowed. Regarding the crystal goby (*Crystalogobius linearis*) fisheries in the northern fishing grounds, a length of 200 m of the rope is also allowed.

4.2. Geographical distribution of effort

From 2012 to 2019 a total of 15458 hauls were recorded from the logbooks. The distribution among years and landing ports is presented in the following Table 4.2.1. This table shows Arenys de Mar as the landing port accounting for the half of hauls.

Table 4.2.1. Number of hauls recorded from longbooks from 2012 to 2019 by ports.

	2012	2013	2014	2015	2016	2017	2018	2019	TOTAL
Barcelona				6			4	33	**43**
Badalona				6	29	30	45	24	**134**
Arenys de Mar	1170	1370	1563	503	903	587	940	604	**7640**
Blanes	360	482	721	395	624	334	465	378	**3759**
Sant Feliu de Guíxols	257	346	456	212	303	148	228	188	**2138**
Palamós	111	224	106	162	269	41	115	125	**1153**
L’ Estartit	81	107	91	8	7	116	114	67	**591**
TOTAL	**1979**	**2529**	**2937**	**1292**	**2135**	**1256**	**1911**	**1419**	**15458**

In the logbooks, each haul is provided with the geographical coordinates; hence, hauls can be represented on the chart. However, a number of errors (impossible locations) were detected and corrected (when possible) or removed. In a previous report (Sánchez *et al*. 2017), maps with data from 2012 to 2016 were presented. In the present study, maps with data from 2016 to 2019 are presented (Figure 4.2.1 to 4.2.5).

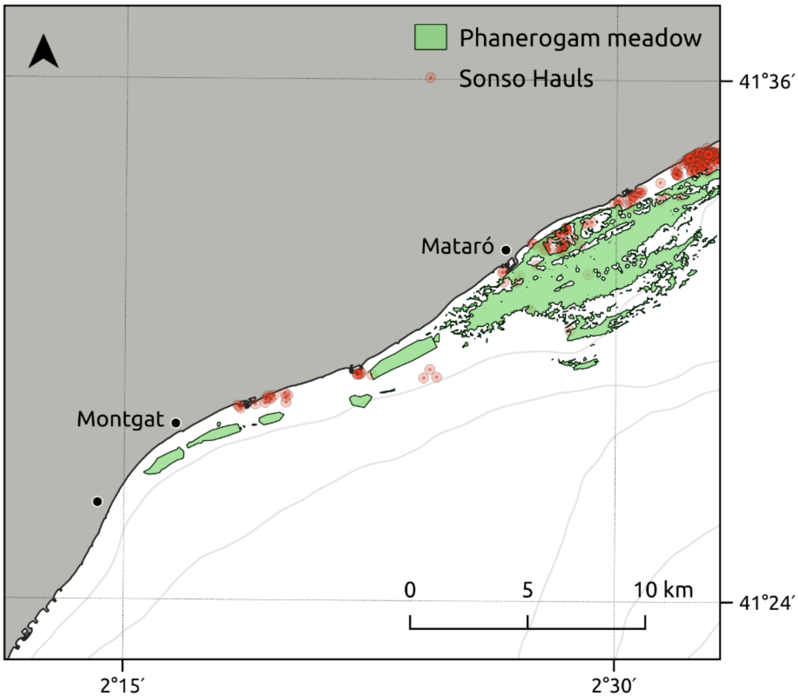


Figure 4.2.1. Detail of the geographical distribution of hauls in the southern extreme of the fishing area distribution (From Mataró to Arenys de Mar) (Southern positions).

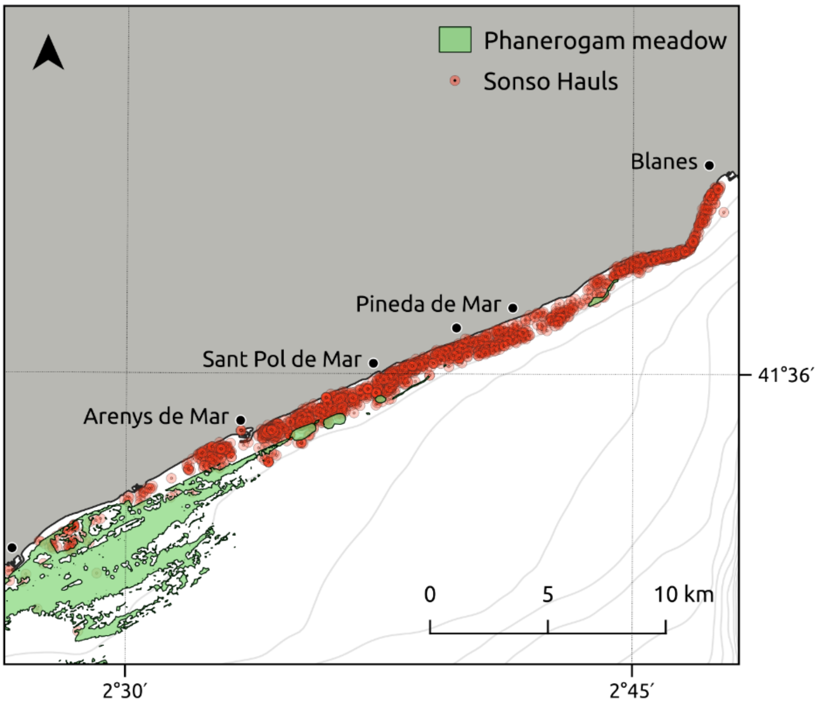


Figure 4.2.2. Detail of the geographical distribution of between Arenys de Mar and Blanes. This zone contains the maximum concentration of hauls.

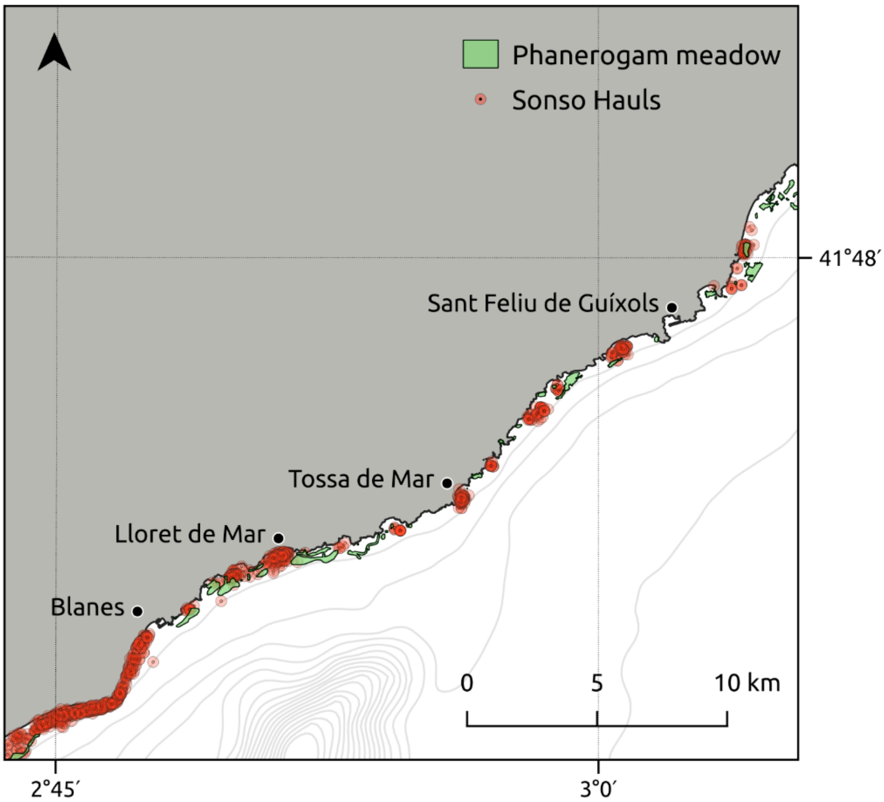


Figure 4.2.3. Detail of the geographical distribution of between Blanes and Sant Feliu de Guíxols.

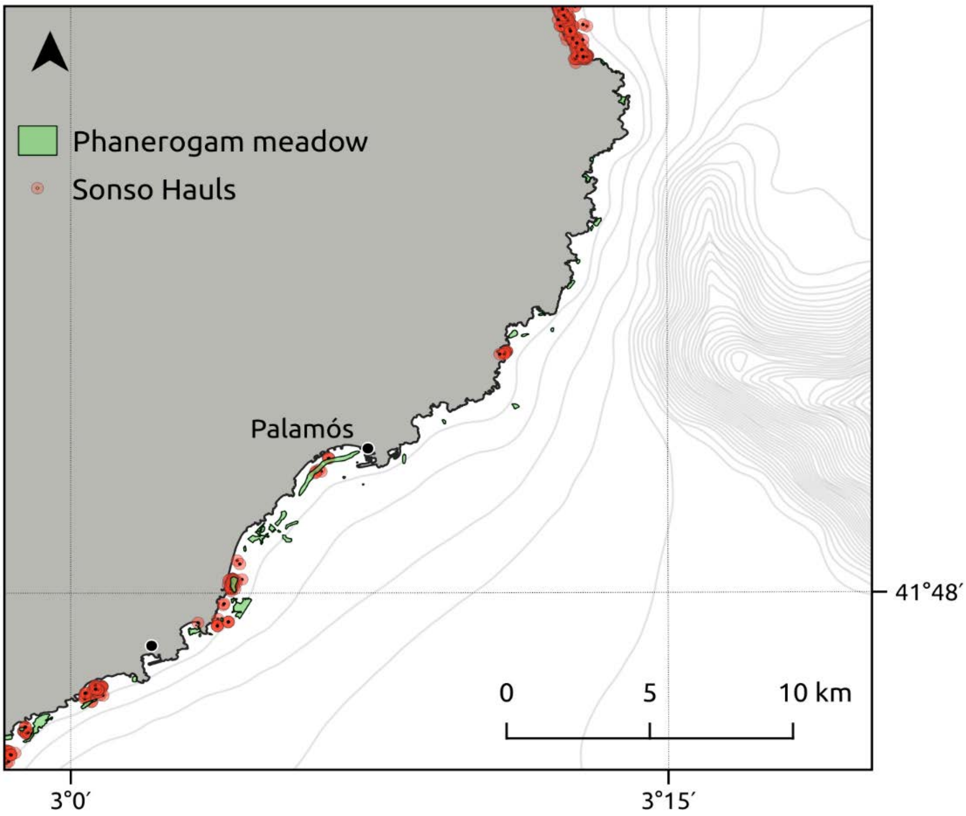


Figure 4.2.4. Detail of the geographical distribution in Palamós.

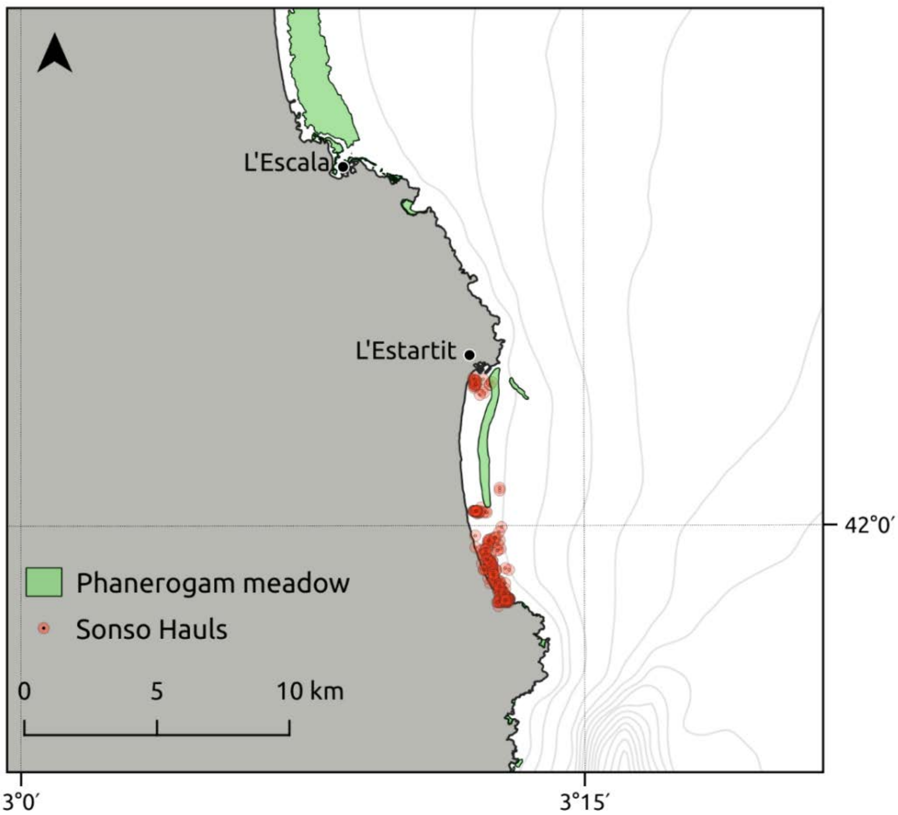


Figure 4.2.5. Detail of the geographical distribution in the beach of Pals (Northern position).

The maps show the position of the hauls during the studied period. Even when the fishing took place in the area corresponding to base port of the fishing boats, the fleet of Arenysde Mar overlapped their fishing ground with the Blanes fleet on fishing grounds between the two ports. Boats from Sant Feliu de Guíxols, Palamós and L’Estartit are those that displayed highest mobility. The depths where the fishing operations took place ranged from 4 m to 15 m for the fleet of Arenys de Mar and Blanes, and from 5.5 m to 30 m for the boats of Sant Feliu de Guíxols, Palamós and L’Estartit.

As shown by the maps, the "sonsera" is not used on sea bottoms characterized by the presence of sea grass meadows, in particular *Posidonia oceanica.* The fishing activity can have been carried out close to, but not directly on Posidonia meadows.

4.3. Sandeel (*Gymnammodytes cicerelus*) fishery in the Catalan Coast: landings, income and fishing activity

Sandeel displayed large variations over 2000-2019 (Figure 4.3.1, upper left panel). The data of the years before 2010 were heavily underestimated, as recognized by both, administrators and fishers**.** The increase of landings since 2010 can be partially explained by an improvement in the control of landings. Nevertheless, landings trend change in 2012, to such an extent that the fishery was closed in July 2015 due to very low catches (Figure 4.3.1, lower left panel). In 2016, landings slightly increased but in 2017 it is again a year of low catches. In the last two years of the study 2018-2019 the sandeel landings increased again. Catches are not very high as low quotas were maintained as a precautionary measure.

It is worth noting that since August 2012 a close monitoring of the fishery was implemented, linked to the Management Plan (MP). The overall landings trend seems to point to natural variations in abundance, as fishermen with long experience suggest. At present, as it was historically done, a closed season is implemented from mid-December to March 1st, in coincidence with the species reproduction period.

The total annual income trend was similar to that of the annual landings (Figure 4.3.1, right upper panel). It is worth noting the very low activity of the fleet in 2015, which resulted in a rather low income per vessel from the sale of the sandeel catch at the auction. In 2016, although landings remained low, the income per vessel substantially increased (Table 4.3.1). In 2017, the decrease of the landings was reflected in a decrease of the income. The upward trend can be observed in the following years 2018 and 2019.

Landings and income by month during the five years of the study, 2015-2019, are presented in Table 4.3.2. In 2015 the fishery was closed because of the very low landings and according the control proposed for the MP. The low yield of experimental hauls performed in March 2016 led the fishermen to propose the postponement the opening of the fishing season to April. In August 2017 catches were almost nil with very few boats fishing. In September, the fishery was closed as a preventive measure and in October-December only a few vessels fished with very low quotas.

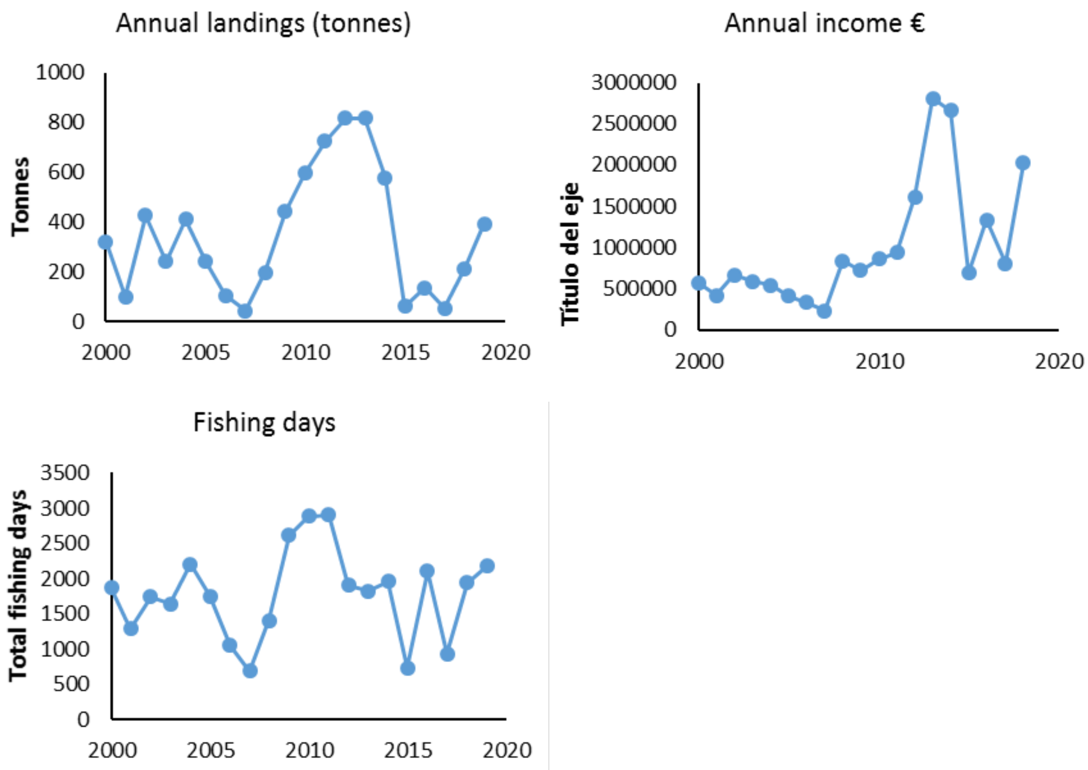


Figure 4.3.1. Sandeel annual landings, income and fishing days (total and by vessel). Input data in Table 4.3.1. Data source: Fisheries statistics of the Generalitat de Catalonia.

Table 4.3.1. Sandeel landings, income, fishing days, CPUE (kg/day/vessel) and VPUE (euros/day/vessel). Data source: Fisheries statistics of the Generalitat de Catalonia.

Year	Catches (tn)	Fishing days	Annual income €	CPUE	VPUE
2000	321,67	1873	576156	171,7	307,6
2001	100,48	1287	414853	78,1	322,3
2002	428,33	1743	667469	245,7	382,9
2003	243,65	1645	586637	148,1	356,6
2004	411,35	2208	541256	186,3	245,1
2005	241,47	1755	407336	137,6	232,1
2006	105,05	1056	333818	99,5	316,1
2007	43,41	688	233578	63,1	339,5
2008	199,18	1406	836682	141,7	595,1
2009	443,88	2611	721579	170,0	276,4
2010	596,71	2890	861149	206,5	298,0
2011	725,07	2906	935609	249,5	322,0
2012	818,90	1905	1613474	429,9	847,0
2013	818,61	1829	2809299	447,6	1536,0
2014	578,52	1961	2659132	295,0	1356,0
2015	61,37	738	691936	83,2	937,6
2016	136,25	2103	1334008	64,8	634,3
2017	54,18	938	805049	57,8	858,3
2018	217,72	1944	1844610	112,0	948,9
2019	393,85	2178	2747156	180,8	1261,3

Table 4.3.2. Sandeel fishery. Landings and income by month during the period 2012-2019. Data source: Fisheries statistics of the Generalitat de Catalonia.

Sandeel monthly landings (tonnes)

	3	4	5	6	7	8	9	10	11	12
2012	80	80	21	115	131	112	83	87	84	29
2013	48	116	115	83	106	95	91	78	36	15
2014	67	65	89	83	127	60	25	36	25	2
2015	7	15	21	16	2					
2016	0	9	20	18	20	24	17	13	12	4
2017	4	8	16	14	8	0	0	1	2	1
2018	6	16	19	20	27	27	26	32	28	12
2019	32	32	28	31	58	46	57	45	48	17

Sandeel monthly income (thousand €)

	3	4	5	6	7	8	9	10	11	12
2012	167,9	171,5	44,47	198	260,6	337,2	182	150,8	141,3	49,63
2013	170	365,2	368,5	286,9	404,1	389,9	283,3	204,1	159,6	64,32
2014	309,8	342,8	423,7	342,3	441,3	340,9	181,5	155,8	106,5	15,1
2015	68,6	183,2	230,6	178,6	30,8					
2016		143,3	294,0	212,7	203,7	207,1	122,1	73,3	56,1	21,7
2017	49,4	168,5	280,1	175,2	98,6	0,3	0,0	9,3	16,5	6,5
2018	136,3	322,3	332,2	240,2	227,0	197,3	155,3	170,6	122,6	122,6
2019	304,5	341,9	312,4	282,6	387,6	367,4	282,2	221,0	180,1	67,5

4.4. Assessment

Catch and CPUE 2012-2019

In a fishery as that of sandeel in the Catalan Coast, basically based on the exploitation of one cohort along the fishing season, it would be to be expected high landings and CPUE at the start of the fishing season, gradually decreasing as the season advances.

It is interesting observing the effect of the management measures applied from July 2012. The fishing effort was reduced, as demanded by the EC, to only 10 vessels allowed to go fishing daily. To this aim a calendar of activity was established for the 20 beach seiners participating in the scientific study from August 2012 to July 2013, in such a way that each vessel active one week remained in port the following week. From 2014, when the management plan was implemented, only half of the 26 vessels allowed to go fishing every week. In all, it is worth noting two results, regarding catches (in this period, with strict control of the fishing activity, landings correspond to catches) and CPUE. In 2012, the activity of the fleet was low from March to May (Table 4.3.2, Figure 4.4.1). The effect of this low activity in the first months of the fishing season was reflected in high landings from June, higher than in the previous seasons, with a much lower fishing effort. In 2013, CPUE expressed as daily catch by vessel in number was the highest of the whole data series 2012-2019.

Landings in 2014-2016 underwent marked changes. In these 2014 were still high, reached the minimum in 2015 and displayed a light recovery in 2016 (Figure 4.4.1). The pattern of monthly CPUE evidenced this change in the resource abundance. In July 2015 the fishery was closed and in the following year the start of the fishing season was delayed until April. This change in abundance took place despite the control of the fishing effort and landings in force in the frame of the management plan implementation. Landings and CPUE in 2018 and 2019 showed a recovery of the population.

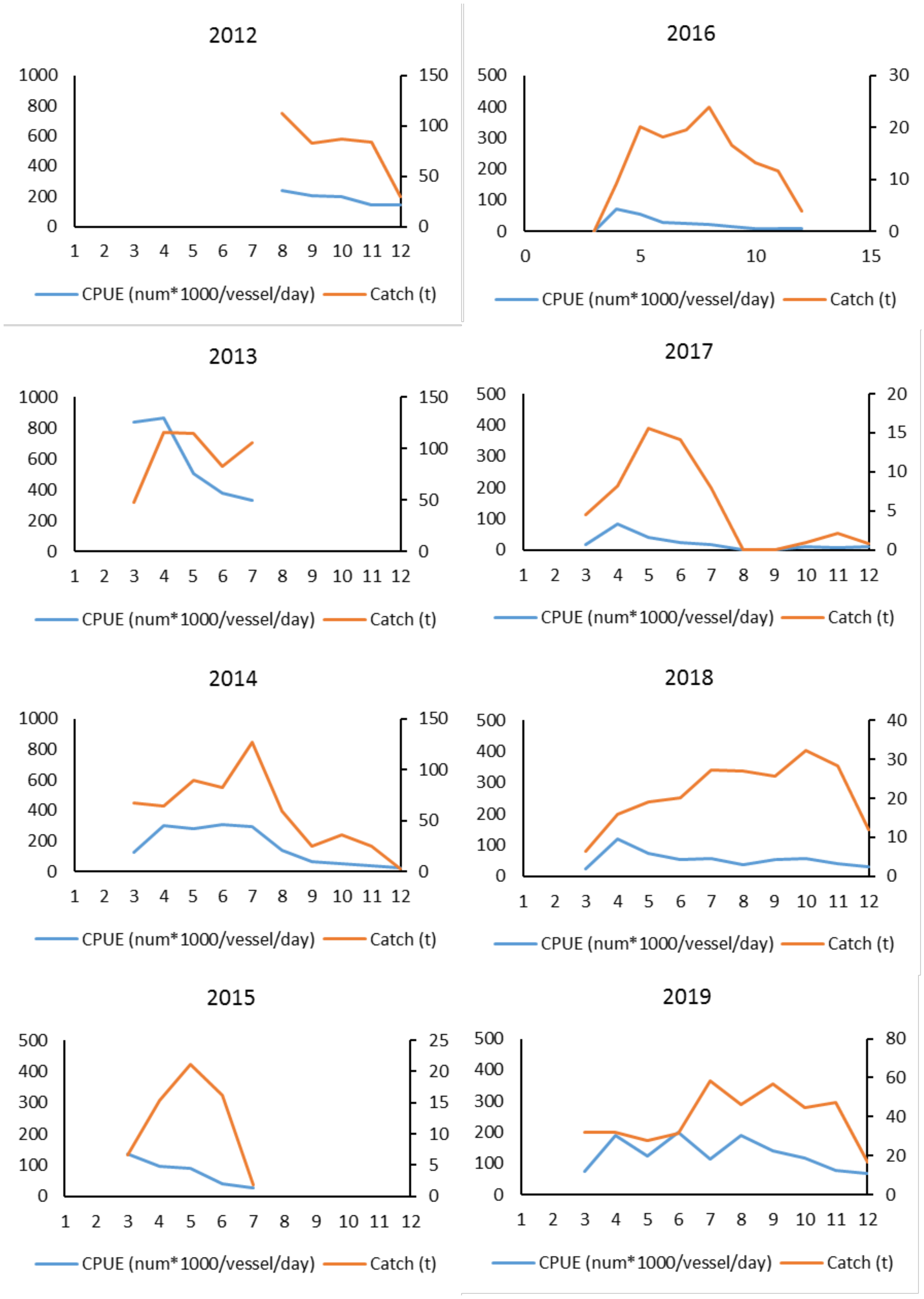


Figure 4.4.1. Monthly CPUE (number of individuals*1000/day per vessel; left axis; and landings (in t; right axis) over the fishing seasons 2014-2016.

Multiannual General Depletion model

Generalized depletion models keep track of fishery removals to estimate vulnerable biomass. In addition to fishing, natural mortality (M) contributes to deplete the population of each species (Chapman, 1974). For one species and one fleet, Chapman's depletion model is:

$$C_t = q\, E_t \left(N_0 e^{-Mt} - e^{-M/2} \left(\sum_{i=0}^{i=t-1} C_i e^{-M(t-i-1)} \right) \right) e^{-M/2} \qquad [1]$$

where C_t is catch in numbers at time $t=1...T$ (T=204 in our application), q is a coefficient of catchability, E_t is fishing effort at time t (in number of vessels x days in our application), N_0 is the initial number of fish in the population, and M is the natural mortality. The sum over i cumulates the catches over the study period, assuming C_0 = 0. The quantity between the outer brackets models the depletion of the initial number (N_0) as a result of natural mortality and catch.

In the multi-annual generalized depletion (MAGD) model (Roa-Ureta 2012, 2014), annual pulses of recruitment in an age-structured population are interpreted as perturbations that reset the depletion process. For a MAGD model running at monthly scale, the set of perturbations $\{R_j\}$ can happen in month p_j, where j is the number of perturbations (j=1, …, 8 in our application, corresponding to the annual recruitment of sandeel as if happening in a single month per year). Additionally, the MAGD model assumes that catchability q is possibly non-linearly related to fish abundance N:

$$q(N) = kN^{1-\beta} \qquad [2]$$

where k is a catchability factor, and β measures the response of catch-per-unit effort to fish abundance: β is 1 when catchability is proportional to abundance, β <1 when catchability varies less than population numbers (hyperstability) and β >1 when catchability varies more than population numbers (hyperdepletion) (Hilborn and Walters 1992, Hatley et al. 2001). Furthermore, catches may be non-linearly related to fishing effort:

$$C_t(N, E) = q(N) E_t^{\alpha} N_t^{\beta} \qquad [3]$$

where α is a proportionality parameter between fishing effort and catches that can account for nonlinear effects (Roa-Ureta 2014). Finally, the complete formulation of the MAGD model for one species and one fleet is (Roa-Ureta 2014):

$$C_t = k\, E_t^{\alpha} \left(N_0 e^{-Mt} - e^{-M/2} \left(\sum_{i=0}^{i=t-1} C_i e^{-M(t-i-1)} \right) + \sum_{j=1}^{j=J} R_j e^{-M(t-p_j)} \right)^{\beta} e^{-M/2} \qquad [4]$$

The number of parameters to estimate by the model is 14 in our application to *sonsera*: 8 parameters corresponding to the perturbations, plus natural mortality (M), plus N_0 , the 3 parameters related to catchability (α, β and *k*) and the ᴪ parameter of the error distribution function (normal or lognormal). Initial values for the 8 parameters p_j corresponding to the timing of the perturbations were estimated from peaks in recruitment to the fishery identified in the observed catch series as spikes not explained by concurrent spikes in effort. Roa-Ureta (2014) proposed a statistic for graphical display of the perturbations of catch spike S_t:

$$S_t = 10\left(\frac{X_t}{\max(X_t)} - \frac{E_t}{\max(E_t)}\right) \qquad [5]$$

where X_t is the observed catch in numbers.

For sandeel and knowing that recruitment to the fishery occurs in spring, the perturbations in the catch spike were established visually *a priori* corresponding to the month of April of each year (i.e. months 4, 16, 28, etc.). These values were entered in the estimation algorithm as starting values of perturbation timings.

The remaining model parameters were estimated by minimizing the likelihood function of the difference between the observed catch series and the predicted catch series $\boldsymbol{L}(\theta, \{X_t, C_t\})$, assuming that catch in number at time step (month) is a random variable with random errors modelled as normal or lognormal distribution functions:

$$L(\theta;\, \{X_t, E_t\} = \begin{cases} \left(\frac{1}{2\pi\sigma^2}\right)^T e^{\left(\frac{\sum_1^T (X_t - C_t)^2}{\sigma^2}\right)} & Normal \\ \left(\frac{1}{2\pi\sigma^2}\right)^T e^{\left(\frac{\sum_t^T (\log(X_t) - \log(C_t))^2}{\sigma^2}\right)} \prod_1^T 1/C_t & Lognormal \end{cases} \qquad [6]$$

where θ is a vector of parameters, and π^2 is the variance of the distribution, assumed to be constant in time. The model estimation was performed with the R package CatDyn v. 1.1-1 (Roa-Ureta 2012, 2014), with the options CG (conjugate gradient optimization) and spg (spectral projected gradient), as recommended in Roa-Ureta (2014). The function CatDynExp was used to graphically fine tune the initial values of certain parameters (N_0, R_j, p_j). The starting values for R_j were set to 10^6 – 10^7 thousand individuals, based on the magnitude of sandeel annually recruiting to the fishery estimated by trial and error with the CatDynExp function. N_0 was set of the order of 10^7 thousand individuals. The parameter space explored for *k*, α, and β was wide, with *k* varying from 1e-3 to 1e-6, and *α* and *β* = 0.5 to 2.5 (with 1 as neutral value) and examining the fit produced by CatDynExp using the criterion that predicted and observed catch in numbers should match as close as possible and estimation errors should be Gaussian-shaped with a mean of 0.

The general depletion model parameters were estimated under a range of values of natural mortality (M) from 1 to 3 yr^{-1} at 0.1 time steps, based on initial estimates of M derived from the tmass and Pauly models in FISAT II, that yielded M = 1.36 yr^{-1} and M = 1.42 yr^{-1} respectively, as well as the Hoenig model implemented in the CatDyn library that yielded M = 2.16 yr^{-1}. Each scenario was run in 4 modalities: options CG and spg for the optimization algorithm, and lognormal and normal error distributions. The model fit with lowest AIC was selected among all the model runs.

In addition to the model parameters the CatDyn package provides also an estimate of population number (*N*), biomass vulnerable to the fishing gear (*B*), exploitation rate (%) and fishing mortality (F).

The model configuration with lowest AIC = 1513.674 was spg optimization with lognormal error (the CG optimization algorithm produced an AIC only slightly larger 1513.694, while assuming normal error distribution produced still larger AIC values and failed to converge in some cases). The observed and predicted catch by the selected model (lognormal distributed errors with spg optimization, Figure 4.4.2 top) fit reasonably well, especially in the last five years when landings were lower. The deviance residuals were approximately normal and clustered around 0 (Figure 4.4.2 bottom left). There was no appreciable trend in the deviance residuals (Figure 4.4.2 bottom centre). The observed vs predicted catch (Figure 4.4.2 bottom right) plot shows that the model presents a certain bias for very high values, of 0.040 billion individuals and more. These values correspond to the recruitment peaks of the first three years in the series 2012-2014 (Figure 4.4.2 top) that are not well captured by the model.

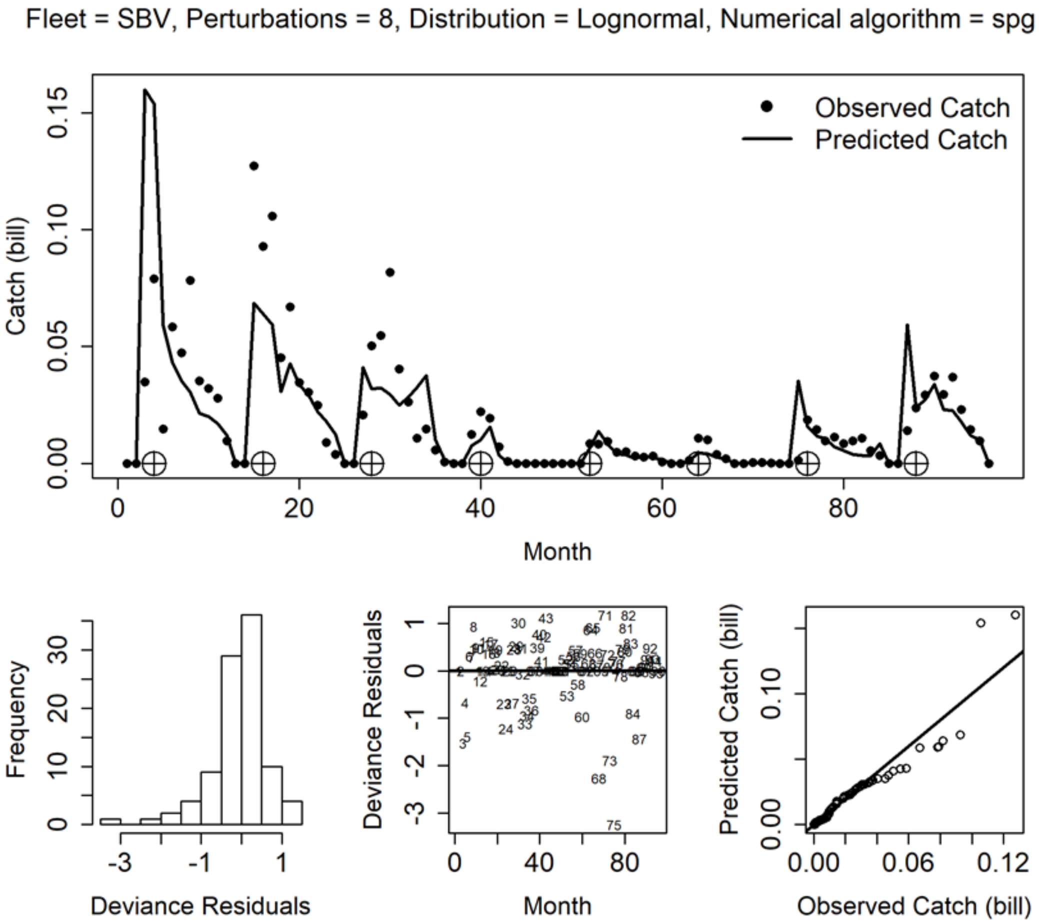


Figure 4.4.2. Diagnostic plots for the application of the Multi-Annual General Depletion Model to the Mediterranean sandeel fishery. The selected configuration was a model with spg optimization and lognormal error. Top: observed and predicted catch (in 109 individuals). Target symbols along the x-axis represent the timing of recruitment peaks. Bottom left: Histogram of deviance residuals; Bottom middle: deviance residuals long time; Bottom right: observed vs predicted plot with 1:1 line shown.

The parameter estimates of the model given in Table 4.4.1 indicate a high value of natural mortality for this species, equivalent to 2.625 yr^{-1}. The amount of individuals recruited to the fishery (perturbations R_j) varied by two orders of magnitude, from high recruitment in years 2012-2015 to very low recruitment in 2016 and 2017. In the last two years of the series recruitment levels are similar to those observed at the beginning of the series. The parameter α that links catches to effort produced a value much larger than 1, suggesting that catches increase more than proportionally with increasing effort. Conversely, β is smaller than 1 suggesting hyperstability. These parameter values can be interpreted in the sense that relatively small increases of fishing effort (i.e. increase in the number of fishing days or the number of boats licensed to operate) would rapidly increase the rate of removals from the fishery (α>1) but the corresponding decrease in population numbers would be difficult to appreciate from catch per unit effort statistics due to hyperstability (β<1).

Table 4.4.1. Final parameter estimates for the Multi-Annual General Depletion model applied to the Mediterranean sandeel (Gymnammodytes cicerelus) Catalonia fishery. The selected configuration was a model with spg optimization and lognormal error. Rj, annual perturbation (number of recruits, with month of estimated peak recruitment).

Model parameter	Value	CV (%)
M	0.219 month^{-1} (2.625 yr^{-1})	54.2%
N0	58.88 x 10^9 individuals	464.7%
R_1 (2012 April)	6.74 x 10^9 individuals	511.1%
R_2 (2013 March)	53.77 x 10^9 individuals	453.5%
R_3 (2014 April)	18.14 x 10^9 individuals	435.3%
R_4 (2015 April)	4.60 x 10^9 individuals	295.5%
R_5 (2016 March)	1.44 x 10^9 individuals	319.5%
R_6 (2017 March)	0.98 x 10^9 individuals	242.4%
R_7 (2018 March)	4.46 x 10^9 individuals	319.4%
R_8 (2019 March)	19.31 x 10^9 individuals	397.3%
α	1.74	14.9%
β	0.74	38.2%
k	9.92 x 10^{-5} / vessel	142.8%
ψ	0.37	20.2%

The estimates of annual recruitment are plotted in Figure 4.4.3A. Although the uncertainty in the parameter estimates is high, the figure shows that years 2013 and 214 produced high recruitment compared with the following 4 years. In the last year of the series 2019, recruitment increased again. The harvest rates at the end of the season were high for the first three years of the series (final escapement between 42 and 51%, Figure.4.4.3B). In 2015 the very low recruitment compared to the previous two years translated in low catch rates right at the beginning of the season (Table 4.3.2), leading to precautionary fishery closure and, consequently, very high escapement (83% at the end of the season). Note however that this high escapement did not result in high recruitment in 2016. Catch rates in 2016 were very low (Table

4.3.2) but the co-management committee could not agree on fisheries closure, resulting in a very high proportion of removals and a very low escapement rates (36% at the end of the season). In 2017 with low recruitment (Figure 3A) and low catch rates (Table 4.3.2) management action was taken to close the fishery at mid-season and reopen it with very low effort towards the end of the season (Figure 4.3.1), which resulted in a high escapement rate (75%, Fig. 4.4.3B). In the last two years of the series with increasing recruitment (Figure 4.4.3A), effort and catch rates have been kept high with relatively low escapement (20% in 2018 and 44% in 2019).

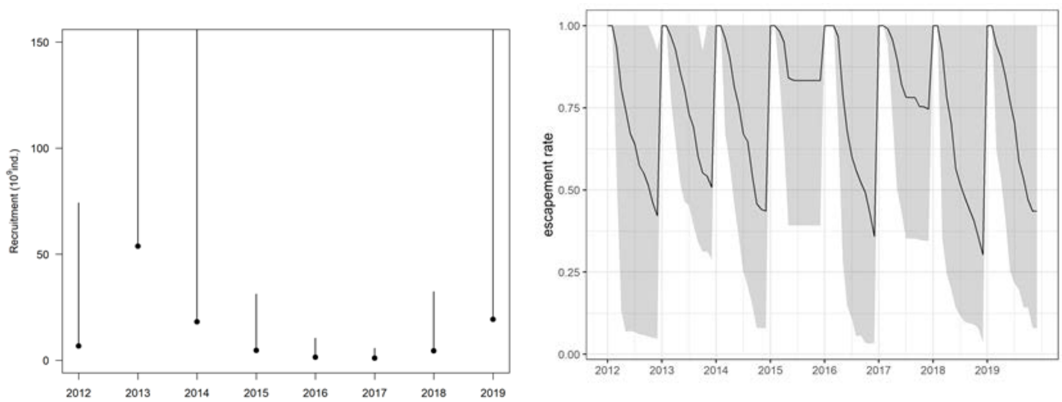


Figure 4.4.3. A: Annual recruitment estimated by the Multi-Annual General Depletion model for the Mediterranean sandeel fishery with upper 95% confidence interval. B: Escapement rates (cumulative proportion of removals from fishing, eq. 9). The escapement at the end of the season is estimated (eq. 8) at 42%, 51%, 44%, 83%, 35%, 75%, 30% and 44% for the years 2012-2019.

Conclusions

The results of our “minimal stock assessment” (*sensu* Roa-Ureta, 2014) show that the exploitation of the Mediterranean sandeel (*Gymnamodytes cicerelus*) could continue to be carried out sustainably under the condition of keeping fishing mortality at very low levels (exploitation rate <0.04) because natural mortality in this species is very high (estimated here at M=2.6 yr^{-1}). The fluctuating population dynamics of the Mediterranean sandeel (Figure 4.4.3A) imply periods of 2-3 years of high abundance (e.g. 2012-2104), followed by similar periods of very low abundance (2015-2017), when fishing mortality should be kept to a minimum. Retrospectively, the long fishery closure adopted during the second half of 2015 was probably an appropriate management measure, at a moment when the standing stock was lower than in the first two years of the study (Figure 4.4.3A). However, the fishery resumed in 2016 with high effort, which contributed to keep the stock at very low levels, forcing additional restrictions to fishing during the second half of 2017. The management measures envisaged in the co-management plan (from its inception), implementing an obligatory 2.5-month winter closure during spawning and closure of the fishery at any other time when perceived abundance is low, are good instruments to limit harvesting capacity.

An important result of our model application to management of this fishery is the non-linear response of catches with stock abundance or fishing effort. The abundance response coefficient (α) was much higher than 1 (estimated at 1.74), showing the disproportionately large effects of small increases in fishing effort (combination of number of days per month x number of vessels). On the other hand, the estimated effort response (β) was lower than 1 (0.74), suggesting hyperstability of landings per unit effort, i.e. catches can be maintained at high levels despite shrinking stock (Harley et al. 2001). That is, relatively small increases of fishing effort (i.e. fishing days or high increase of catches) would rapidly increase the rate of removals from the fishery ($\alpha>1$) but the corresponding decrease in population numbers would be difficult to detect from catch per unit effort statistics due to hyperstability ($\beta<1$). All in all, the harvesting capacity of this small scale fleet is high and the management of this fishery must continue to control tightly the effort and the catches.

4.5. By-catch composition

The analysis of the boat seine catch developed during the scientific study has evidenced the high selectivity of the “sonsera”, as the presence of by-catch species can be detected by the echo-sounder, which allows performing selective fishing operations resulting in catches without or with very few non- target species.

The percentage in weight of by-catch species regarding the total sandeel’s catch was very low over the study period average 2.25%.

The by-catch composition from the fishing grounds where the "sonsera" boat seine fleet operated was analysed through scientific cruises from August 2012 to June 2013. Samples were obtained monthly on board from five ports in the Catalan coast (Arenys de Mar, Blanes, Sant Feliu de Guíxols, Palamós and L’Estartit). Even during the closed season, from 15 December to 28 February, samples of non-target species were collected to complete the information on their presence along an annual cycle.

Later, in the laboratory, species were identified and length and weight were obtained for each specimen.

Results

Table 4.5.1 evidences the low biomass of by-catch species by comparing the total catch of sandeel and the total catch of by-catch species.

The period 2012-13 with the maximum catches of sandeel showed the minimum biomass of the by-catch species. On the contrary the year 2015 with the minimum catches of sandeel showed the maximum biomass of the by-catch species (Table 4.5.1).

It is also important taking into account that the number of species captured per haul (Figure 4.5.1) are mainly, between 0 and 3, being 0 species captured the most abundant option this means no by-catch option. These results showed that the "sonsera" fishery is a very specific fishing gear, so not many unwanted species per haul are captures.

Table 4.5.1. Summary of number of hauls and species during the period 2012-2019. Total sandeel per haul and percentage of by-catch biomass per sandeel haul.

Years	Nº hauls	Nº species	Kg sandeel/haul	% bycatch/haul
2012-13	76	33	218,88	0,26
2014	31	27	48,48	2,37
2015	16	19	26,49	6,54
2016	11	20	42,79	4,51
2017	6	13	45,29	0,55
2018	13	12	105,70	0,69
2019	16	25	104,05	0,83

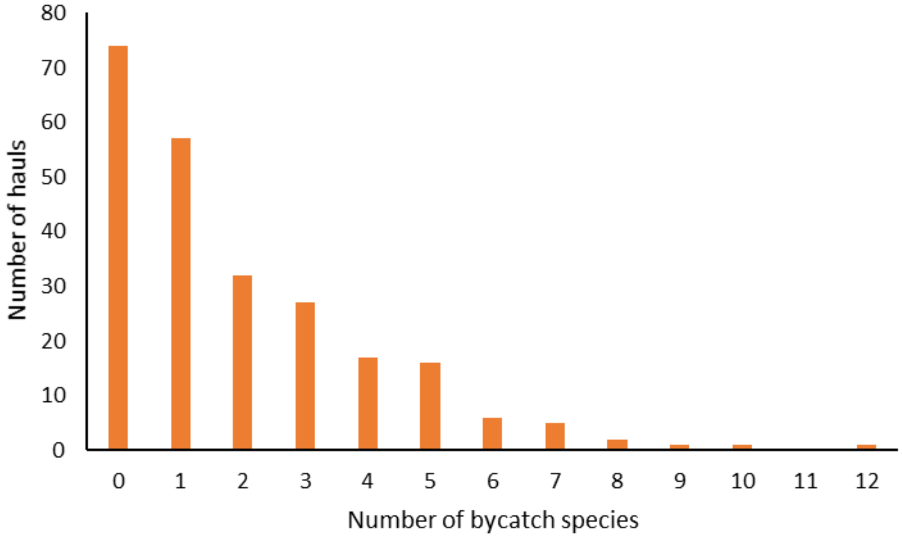


Figure 4.5.1. Number of species captured per haul during 2012-2019.

More detailed information regarding the biomass of the by-catch species is presented on the Table 4.5.2 as a summary of the biomass of the commercial and not commercial species that are by-catch of this fishery. Even with not an important biomass in catches, it is important to note that of the assemblage of the by-catch species a lot of them are regulated commercial species with a minimum legal size (MLS).

Table 4.5.2. By-catch relative weight (Kg species/kg "sonso") per year. Highlighted the most abundant species annually.

	2012	2013	2014	2015	2016	2017	2018	2019
Arnoglossus spp.	8,82E-07	0	0	0	0	0,0000053	0	0
Atherina hepsetus	0	0	0	0	0	0,01105833	0	0
Belone belone	2,85E-05	0,00054872	0,00031524	0,003	4,62E-05	0	0	4,07565E-05
Boops boops	0	2,83E-05	8,73E-06	0	0	0,00035	0	0
Bothus podas	0,00065088	0,00011362	0,0012794	0,00062143	0,00208923	0,00091667	0,00145098	0,001076484
Callionymus maculatus	0	0	4,67E-07	0	0	0	0	0
Callionymus risso	0	0	0	0	2,52E-06	0	0	0
Caranx rhonchus	0	3,43E-05	0,00060159	0	0	0	0	0
Chelidonichthys cuculus	0	1,07E-05	0	0	0	0	0	0
Dactylopterus volitans	0	0	7,41E-06	0	0	0,00126667	0	0

Dasyatis pastinaca	0	0	0	0,00108444	0	0	0	0,000114001
Diplodus annularis	0	0	0	0	0	4,17E-05	0	0
Echiichthys vipera	4,88E-07	1,61E-06	0	0	3,22E-06	0	0	0
Engraulis encrasicolus	2,98E-08	1,02E-05	0,00173567	0,00040707	0,00058195	0,0000754	2,09E-05	0
Gobidae	8,70E-08	0	0	0,00047	0,00046154	0	0,00016395	6,60629E-07
Lithognathus mormyrus	0	6,55E-05	0	0	0	0	0	
Liza aurata	0	0	0,00147778	0	0	0	0	
Loligo vulgaris	9,10E-06	6,64E-05	0	0	0,00070253	0	1,41E-05	3,78263E-06
Mullus spp.	4,06E-07	0	0	0,001120565	0	0	0	0,000214459
Muraena helena	0	0	4,27E-05	0	0	0	0	
Myliobatis aquila	5,78E-05	0	0	0	0	0	0	
Octopus vulgaris	3,12E-05	0	0,0015	0	0	0	0	0,000139499
Pagellus acarne	0	9,62E-07	0	0,01907143	0	0	0	1,86468E-05
Pagellus erythrinus	0,00076057	0,00257676	0,00170277	0,01551141	0,01320513	0,0014019	0,00068335	0,000761119
Pagellus spp.	0	0	0,00333333	0	0	0	0	
Pomatoschistus marmoratus	0	0	0	0	2,88E-07	0	0	0
Pomatoschistus pictus	0	0	2,12E-05	0	0	0	0	
Pseudaphia ferreri	0	0	6,83E-05	0	4,00E-05	0,00000109	1,19E-06	0
Raja asterias	0,00013462	0	0,00716667	0	0	0	0	0
Sarda sarda	8,25E-05	0,0001239	0	0	0	0	0	
Sardina pilchardus	0	0,00106814	0,00011183	0	3,17E-05	0	0	0
Sardinella aurita	4,33E-05	7,34E-06	0	0	0	0,0000382	0	1,691E-05
Scomber japonicus	0	0,00013049	0,0005642	0	0	0	0	0
Scomber scombrus	0	0,00010476	0,0001446	0	0	0	0	0,000993873
Sepia officinalis	3,62E-06	4,23E-05	0	0	0	0	5,56E-07	0,000108684
Sepietta oweniana	0	0	0	0	0	0	0,00010492	0
Sepiola spp.	0	0	0,0000035	0	0	4,83E-06	0,00045889	7,67182E-06
Seriola dumerili	9,18E-05	0	0	0	0	0	0	
Sparidae	0	0	0,0000985	0	0	0	0,00075758	
Sparus aurata	0	1,56E-05	0	0	0	0	0	
Spicara spp.	6,98E-05	0,0003287	0,00016589	0	0	0,00370417	0	0

Synodus saurus	0,00229714	0,00304945	0,00033959	0,000143	0,02494745	0,0002289	0,00068403	0,000460988
Trachinus araneus	0	0	0	0	0	0	0,00088889	0
Trachinus draco	6,83E-05	0,00044395	0,00040291	0	0	0	0	0,000173394
Trachinus evacuens	0	7,20E-06	0	0	0	0	0	
Trachinus radiatus	1,87E-05	0	2,58E-06	0	9,14E-06	0	0	0
Trachurus spp.	3,73E-06	0,0012676	0,0000055	0,00833333	7,34E-05	5,67E-06	0,00063134	0,000464736
Uranoscopus scaber	6,17E-06	4,15E-05	0	0	0	0	0	5,46723E-05
Xyrichthys novacula	0,0001762	3,28E-05	0,00027754	0,00442856	0,00117809	0	0,00044566	0,000608652

Cephalopods were represented by three species *Loligo vulgaris* (0.48%), *Octopus vulgaris (*1%) and *Sepia officinalis* (0.9%) and some species of Sepiolidae family (0,08%), any of them did not present important percentages into the by-catch.

The analysis of the average of percentages of the biomass of the by-catch species of the 8 years (Figure 4.5.2) analysed showed that the higher biomass percentage was for the commercial species *Pagellus erythrinus* (22%) the second was the non-comercial species *Synodus saurus* (20%) and the third other commercial species *Pagellus acarne* (12%).

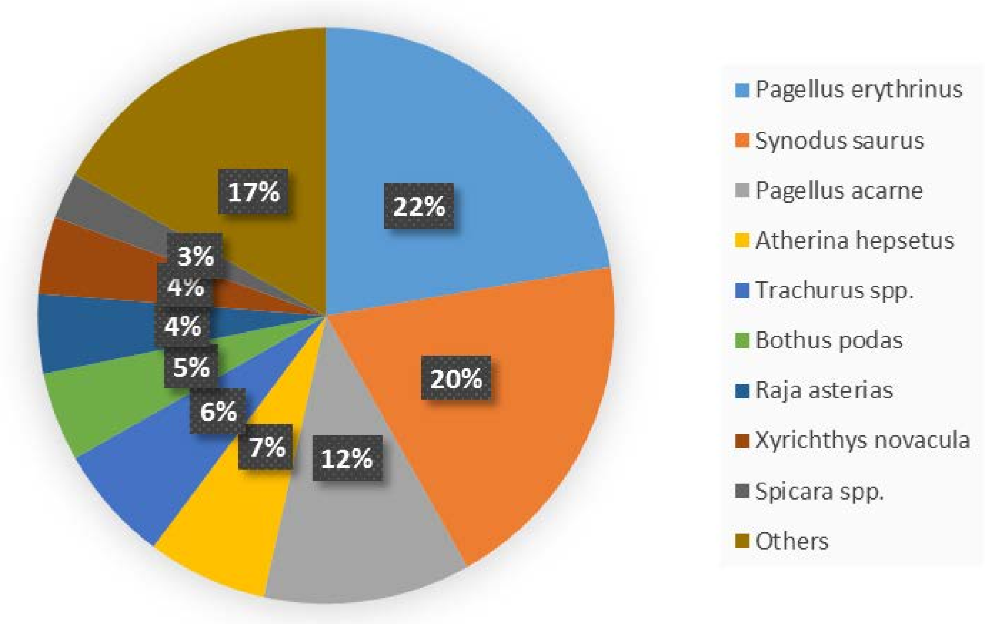


Figure 4.5.2. Average percentage of biomass of by-catch species per haul of sandeel considering all analysed years (2012-2019).

Seasonal analysis of the regulated species is presented on Figure 4.5.3 and shows the sizes of these species related to the monthly catches and with their MLS on the 8 studied years. In this figure, it is noted that individuals below the MLS were not captured for *Belone belone* or *Scomber* sp.. Only one species, *Pagellus acarne*, were always captured below the MLS, in the months of March and May. However, for *Pagellus erythrinus, Trachurus* sp*., Mullus* sp. *Engraulis encrasicolus* and *Sardina pilchardus* captured individuals were both below and above of the MLS. In the case of *Pagellus erythrinus* juveniles were caught between the months of February and November. Juveniles of *Engraulis encrasicolus* were caught in the months of October to December and *Mullus* spp. the small individuals were captured in July.

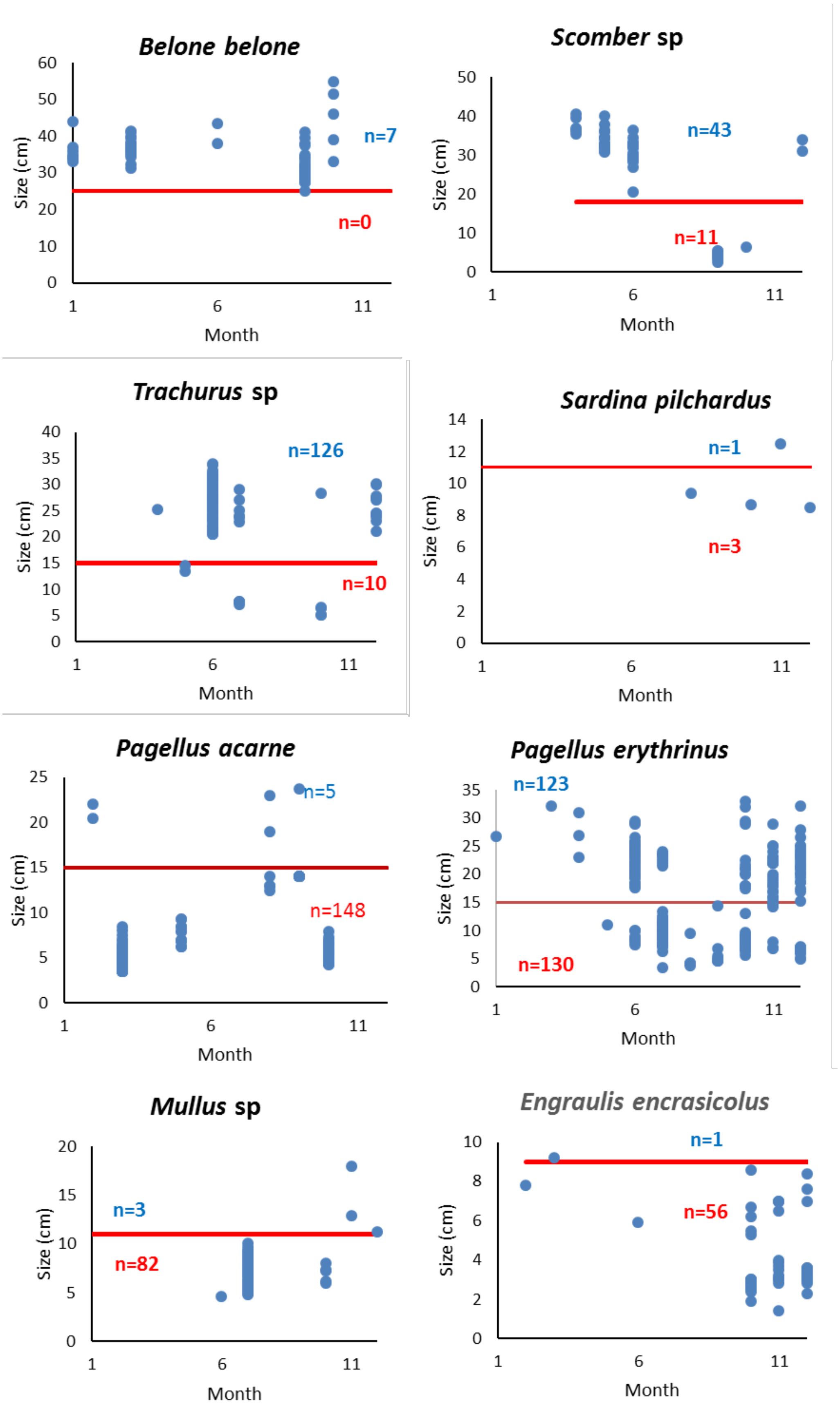


Figure 4.5.3. Size of regulated by-catch species by months, MLS (red line), number of animals above MLS (blue letter) and number of animals below MLS (red letter).

5. BIOLOGY OF GOBIDS

5.1. Taxonomy

Aphia minuta (Risso, 1810)

Diagnosis: Dorsal spines (total): 4-6; Dorsal soft rays (total): 113; Anal spines: 1; Anal soft rays: 11-15. Vertebrae: 26-28 (Whitehead *et al*. 1986). *Aphia minuta* is a small species no more than 6 cm long (Tortonese 1975) with a short lifecycle and rapid maturation of the gonads. The specimens present a long body flattened laterally. The scales are cycloid and easily lost. There are no scales on the nape of the neck or the first dorsal fin. The swim bladder is evident and persistent and the food canal is straight and short. The adults are white, yellowish or pink; the body is transparent with a few black chromatophores. In proximity to the opercules, a red spot can be observed due to the blood of the gills, visible because of the animal's transparency. This species presents sexual dimorphism: the males have a larger head, uneven teeth, a higher caudal peduncle and the fins are more developed, especially the ventral ones.

Distribution: *Aphia minuta* is spread throughout the Atlantic Ocean from Gibraltar to the Norwegian coasts, the North Sea and the western Baltic Sea. It is also present all over the Mediterranean basin including the Black Sea (Miller 1986).

Biology: It is a coastal species, pelagic in the larval and young stage. During sexual maturity the organisms acquire demersal-benthic habits.

Crystallogobius linearis (Düben, 1845)

Diagnosis: Dorsal spines (total): 2-3; Dorsal soft rays (total): 18-20; Anal spines: 1; Anal soft rays: 20-21. Patterns of sensory papillae require detailed description. This species present a pronounced sexual dimorphism. Anterior nostril is in the form of a short tube. Pectoral fin uppermost rays are within a membrane. Males have a prominent front canine teeth; pelvic disc complete and deep; 1st dorsal with only 2 with rays. Females have a pelvic disc reduced or lacking; 1st dorsal absent or rudimentary. Vertebrae: 30 (29-31) (Miller 1986).

Distribution: Eastern Atlantic: Lofotens, Norway, to Gibraltar. It is also known from the Mediterranean Sea. Eastern Central Atlantic: Madeira Island (Wirtz *et al*. 2008).

Biology: This occasionally territorial species occurs in coastal waters, over shell, sand, or mud bottoms; males bottom-living during breeding season. Feed on zooplankton (Wheeler 1992). Spawning takes place at age of 1 year old. Adults die afterwards. Eggs are laid in the empty tube-worms and are guarded by the male (Muus and Nielsen 1999). Eggs are pear-shaped (Miller 1986).

Pseudaphya ferreri (O De Buen & Fage, 1908)

Diagnosis: Teeth size does not differ markedly between sexes. Dl V, D2 I + 7-10, A I + 9-10, P 15-16. Scales in lateral series: 25-30. Vertebrae: 30. Colour: body transparent, with rosy stippling on sides, head and bases of median fins; caudal fin base with large triangular dark spot. Size: up to 3.5 cm (Miller 1986).

Distribution: It is found in the Mediterranean Sea in the western basin and the Adriatic Sea. Habitat: nektonic, over sandy beaches.

Biology: The females mature at 26-27 mm. Reproduction takes place in June.

5.2. Length-weight relationship and length frequency

Aphia minuta

Length-weight relationship

Figure 5.2.1 and Table 5.2.1 gives the length-weight relationship for *Aphia minuta* whole population. Positive allometric growth was observed in the species.

Table 5.2.1. Length/weight parameters for *Aphia minuta* obtained for the study period (2012-2019).

Year	a	b	R^2
2012-2013	0,0028	3,49	0,959
2014	0,0019	3,66	0,951
2015	0,0023	3,65	0,967
2016	0,0027	3,50	0,865
2017	0,0010	4,25	0,881
2018	0,0028	3,43	0,956
2019	0,0019	3,78	0,894
Mean	**0,0022**	**3,65**	**0,934**

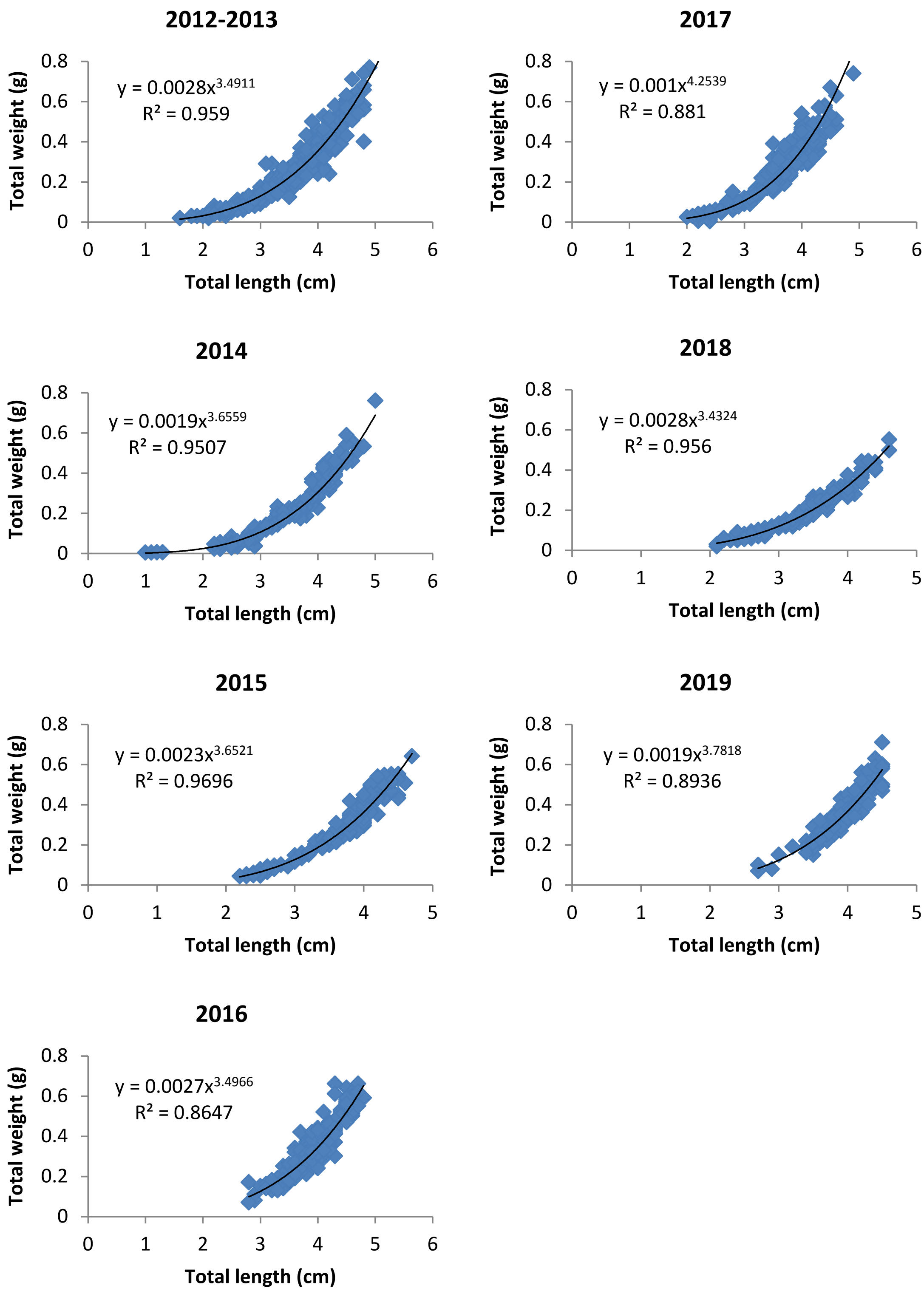


Figure 5.2.1. *Aphia minuta* length-weight relationship (a and b parameters) obtained for the study period (2012-2019).

Length frequency

The monthly length-frequency distribution in the catches of *Aphia minuta* ranged between 1 and 5 cm, with no clear mean size trend throughout the fishing season from December to May (Table 5.2.2). No clear growth pattern can be observed on length frequency distribution but, the average monthly size, in 2018, was smaller compared to other years of the study period. There is a remarkable interannual variability (Figure 5.2.2).

Table 5.2.2. Summary of the mean length by month of *Aphia minuta*.

Month	2012-2013	2014	2015	2016	2017	2018	2019
December	2,80	-	-	-	-	-	-
January	-	2,91	3,20	3,47	3,19	2,90	-
February	3,44	3,63	3,10	3,42	3,36	2,74	-
March	3,50	3,59	3,68	3,82	3,29	2,95	3,75
April	3,54	-	-	3,95	3,02	-	3,69
May	3,83	-	-	-	-	-	-

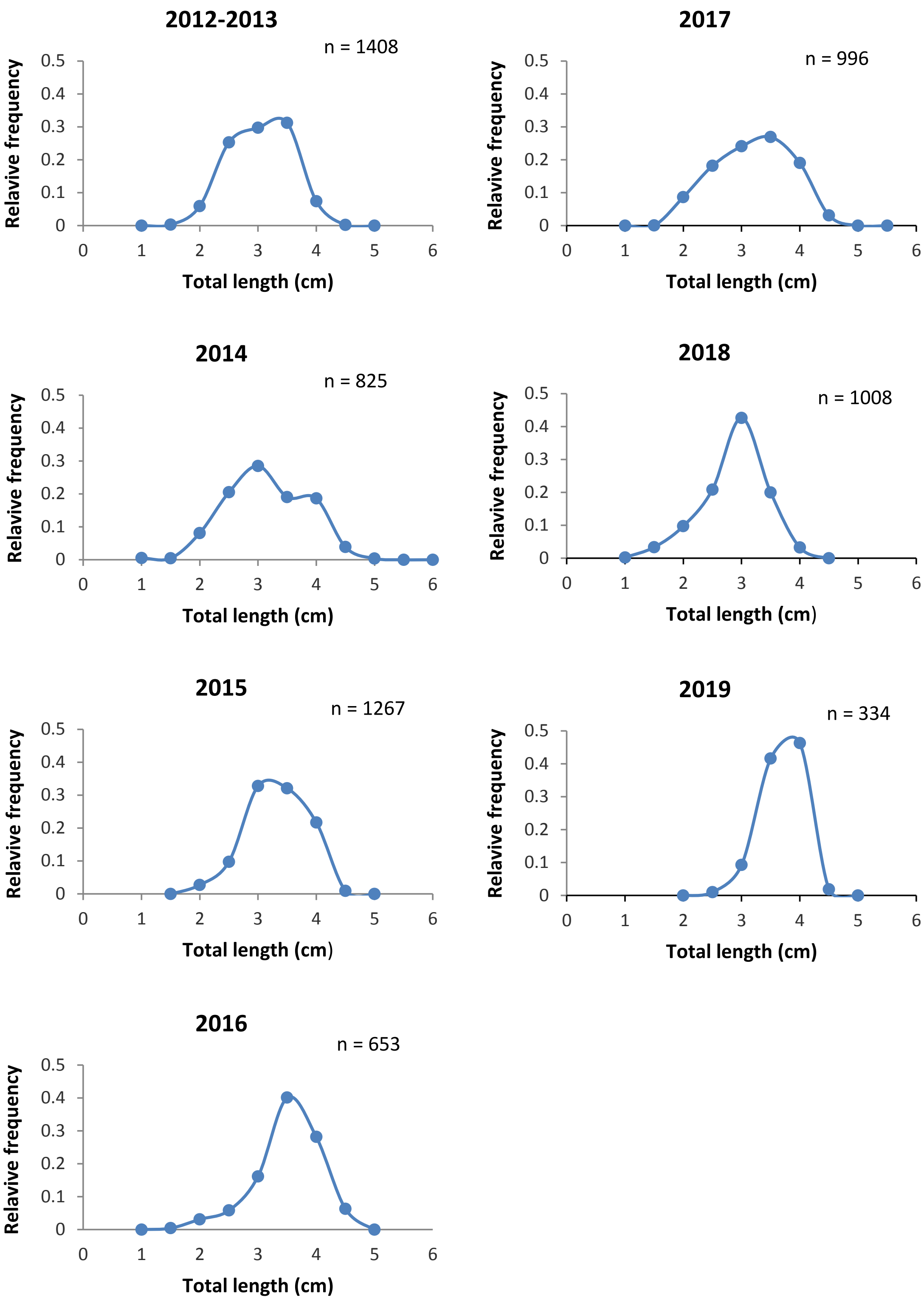


Figure 5.2.2. Annual length-frequency distribution (January 2015 to April 2019) of *Aphia minuta* (n = number of individuals sampled).

Crystallogobius linearis

Length-weight relationship

Figure 5.2.3 shows the length-weight relationship for *Crystallogobius linearis* whole population. Positive allometric growth was observed in the species.

Table 5.2.3. Length/weight parameters for *Crystallogobius linearis* obtained for the study period (2012-2019).

Year	a	b	R^2
2012-2013	0,0043	2,86	0,8468
2014	0,0025	3,22	0,7548
2015	-	-	-
2016	-	-	-
2017	0,0052	2,65	0,5223
2018	0,0023	3,31	0,8535
2019	-	-	-
Mean	0,0038	2,94	0,819

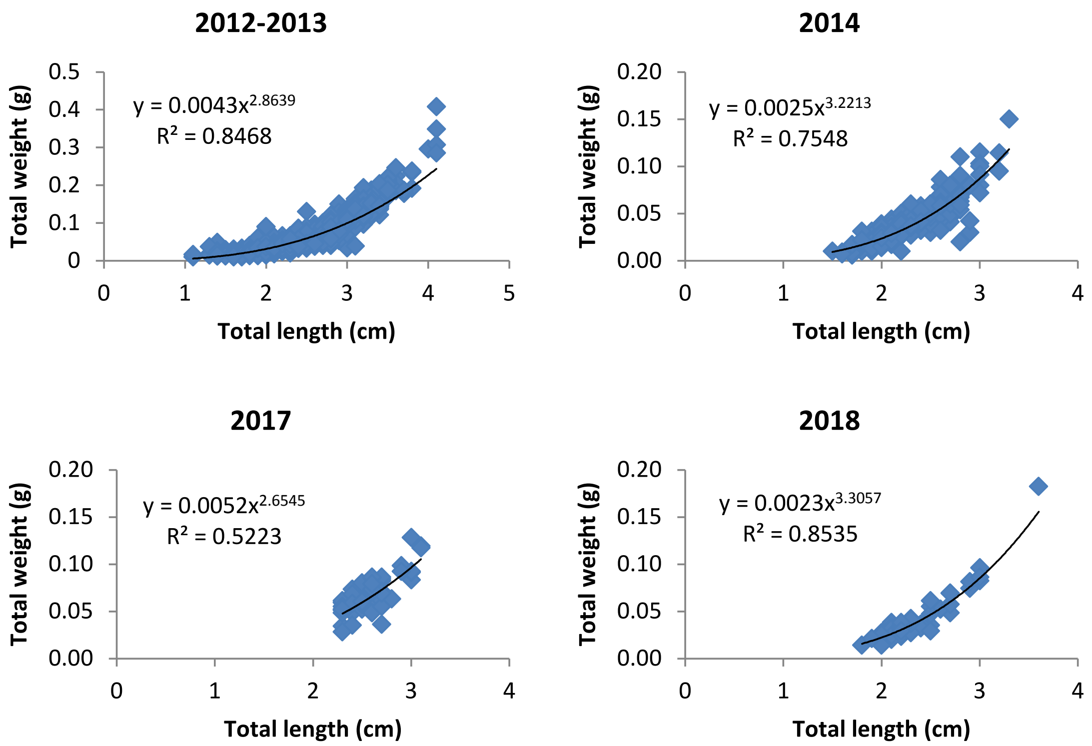


Figure 5.2.3. *Crystallogobius linearis* length-weight relationship (a and b parameters) obtained for the whole study period (2012-2019).

Length frequency

The monthly length-frequency distribution in the catches of *Crystallogobius linearis* ranged between 1 and 4 cm. Mean size shows same values in 2017 than in 2012-2013 and the mean size of 2018 is similar that in 2014 (Table 5.2.2). Not defined growth pattern can be observed on the length frequency distributions obtained (Figure 5.2.4).

Table 5.2.2. Summary of the mean length by month of *Crystallogobius linearis*.

Month	2012-2013	2014	2017	2018
January	2,18	1,96	-	-
February	2,61	2,10	2,33	1,83
March	2,16	-	-	1,97
April	2,53	-	-	-
May	2,55	-	-	-

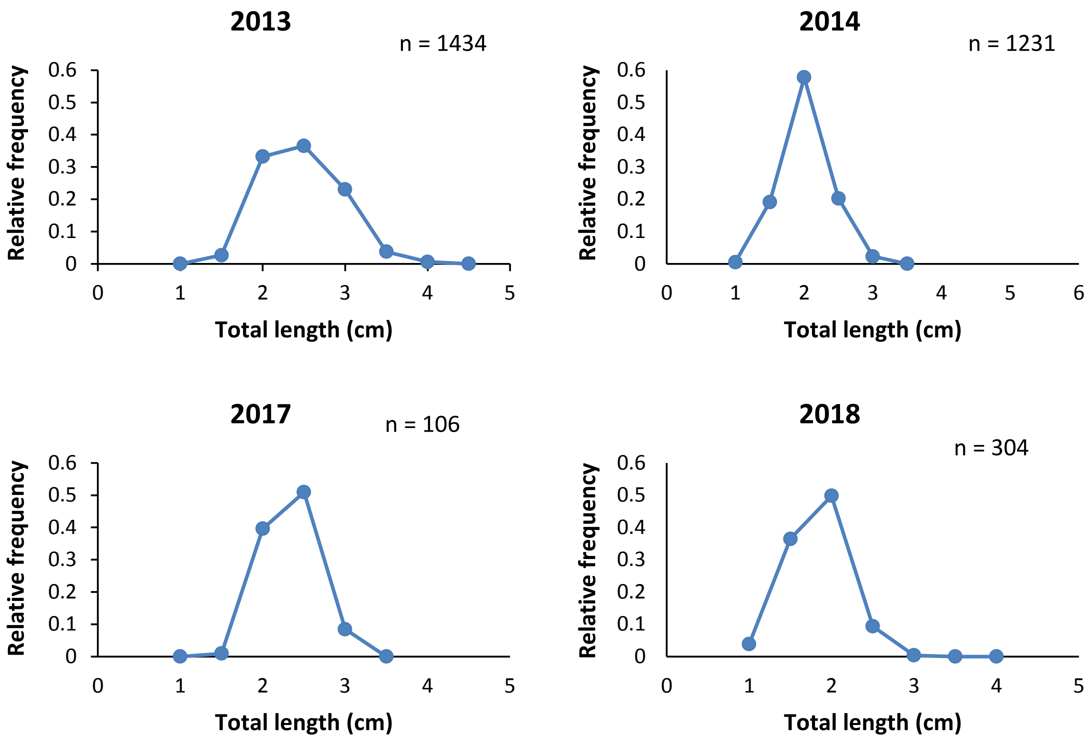


Figure 5.2.4. Monthly length-frequency distribution (2012-2018) of *Crystallogobius linearis* (n = number of individuals sampled).

Pseudaphia ferreri

In March 2018, a sample of *Pseudaphia ferreri* was obtained during an experimental fishing to establish the biomass of sandeel and allow the opening of the season. Few specimens were measured to establish a significant length-weight relationship. Sizes were similar to those obtained for *A. minuta* and *C. linearis*; individuals ranged from 2 cm the smallest to 3.5 cm the largest (Figure 5.2.5).

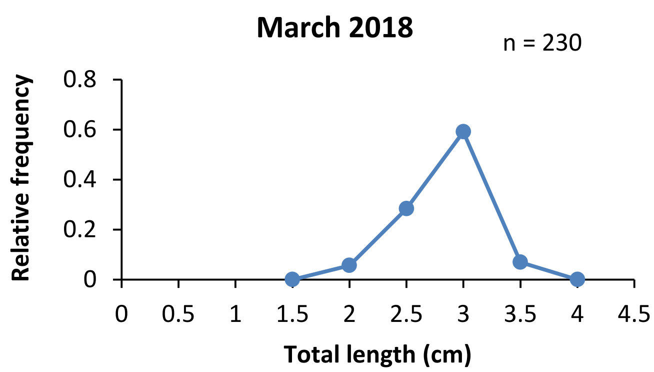


Figure 5.2.5. Monthly length-frequency distribution (March 2018,) of *Pseudaphia ferreri* (n = number of individuals sampled).

5.3. Reproduction

Aphia minuta

In the studied period (2012-2019) some mature females were found in March and April but there is no enough information to stablish well defined reproductive parameters.

Crystallogobius linearis

From a total of 310 individuals examined, some individuals with visible oocytes have been observed in February sampled months, but the majority of the population is in a resting phase. Due to the scarce information obtained about reproductive phases, it is not possible to define reproductive parameters.

6. GOBIDS FISHERY

6.1. Boat seine fleet and landings

Historically, goby fishery was carried out throughout the year, with a slight decrease activity in summer. From 2012 until present, the gobids fishing season was shortened, from mid-December to the end of April and the main targeted species was transparent goby (*Aphia minuta*). Landings and activity (fishing days) for transparent goby from 2011-2012 until now, corresponds to two boats and all landings are registered in Barcelona and Badalona ports.

There are registered landings for crystal goby (*Crystallogobius linearis*) only during the period of January-February 2013; January-February 2014, February-March 2017 and February-April 2018 corresponding to Arenys de Mar and Blanes ports. There are not landings registered for *Pseudaphia ferreri* species in the period studied but we are aware of the presence of this species in the area.

Landings

Data on transparent goby (*Aphia minuta*) and crystal goby (*Crystallogobius linearis*) landings and activity of the boat seine fleet were obtained from the daily slips from the sale at the auction that takes place upon the arrival of the vessels at port (data source: fishing statistics elaborated by the Fisheries Department of the Generalitat de Catalunya). Data were available on daily landings, separated by each species, by vessel, for the period 2000 to May 2019.

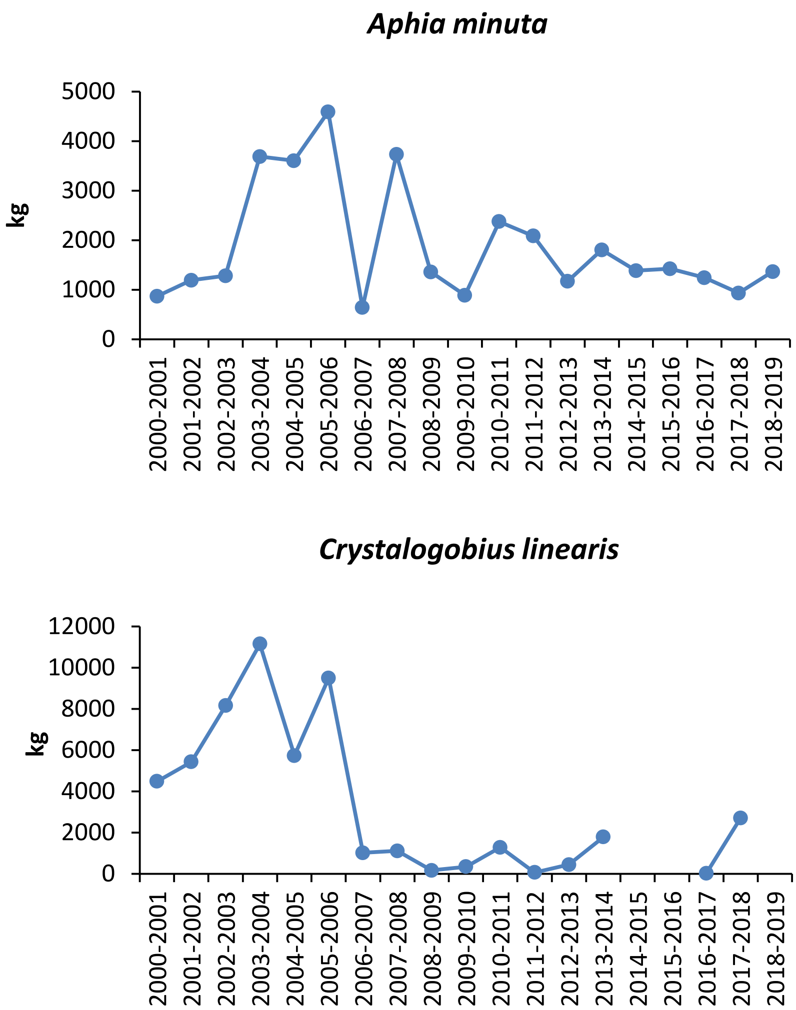


Figure 6.1.1. Transparent goby (left) and crystal goby (right) landings (kg) in the Catalan Coast over the fishing seasons 2000-2001 to 2018-2019.

The boat seine fleet operates in the central and northern Catalan Coast (i.e. from Barcelona to the north). Nevertheless, transparent goby is fished in the southern study area, near Barcelona, close to the mouth of River Llobregat; and crystal goby is fished a little northwards, close to the fishing port of Blanes. Over the studied period, the annual landings of both species fluctuated markedly. Transparent goby landings varied between 0.6 t in 2006-2007 and 4 t in 2005-2006; and crystal goby between 12.4 t in 2003-2004 with landings practically nil since 2006-2007. No landings were registered since mid-2014 to 2016; and in 2017 only testimonial landings were reported corresponding to 2 days fishing of one boat (16 kg). In 2017-2018 2.7 t were landing. Since 2013 a quota for gobids fisheries has been stablished. These quotas are 1800 kg for transparent goby and 3800 kg for crystal goby. For transparent goby the quota has been regularly reached. In the case of crystal goby the last years (end 2014-2017) fishermen have not practically fished this species and consequently quota has not been reached.

Some years the amount of *C. linearis* detected with the echo-sounder was small and fishermen prefer not to fish them; this occurred in years 2015, 2016 and 2019.

No landings are registered for *Pseudoaphia ferreri* since March 2012 to now. The explanation the fishermen offered for the absence of Ferrer's goby in the catches was that this species is jointly fished with sandeel in certain fishing grounds. Since the target species of the sampling was sandeel, the fishing grounds that were visited where those with presence only of sandeel.

Fishing days, per fishing season

Historically, the fishing season extended from November to May, which is, partly overlapping with the sandeel fishing season (March to mid-December). The unit of effort considered in this study is the number of fishing days (i.e. the sum of the number of days each boat seiner sold gobids at the auction upon arrival to port). Transparent goby fishing days and CPUE kg/day per vessel) trends (Figure 6.1.2 and 6.1.3) have been stabilized after the quota establishment. In the case of crystal goby, fishing days and CPUE follow the same trend as landings.

The gobids fishery represents a small part of the overall boat seine fleet landings and activity.

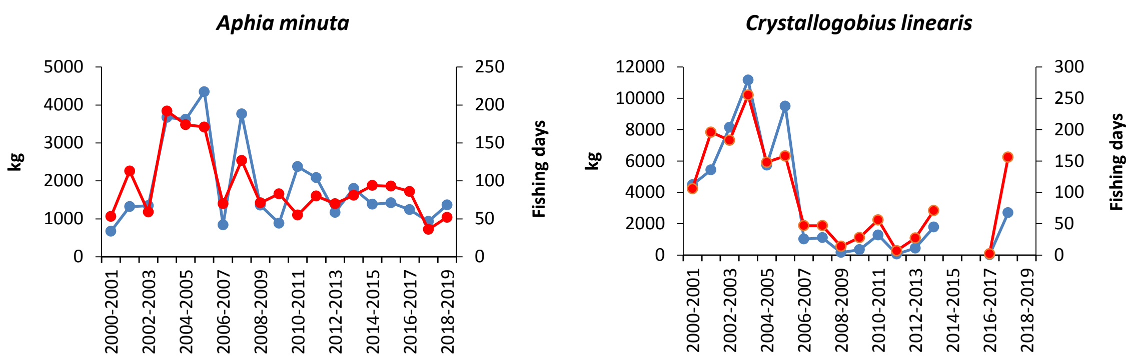


Figure 6.1.2. Landings (kg; in blue, left axis) and fishing days (in red, right axis) trend of transparent goby and crystal goby in the Catalan Coast over the fishing seasons 2000-2001 to 2018-2019.

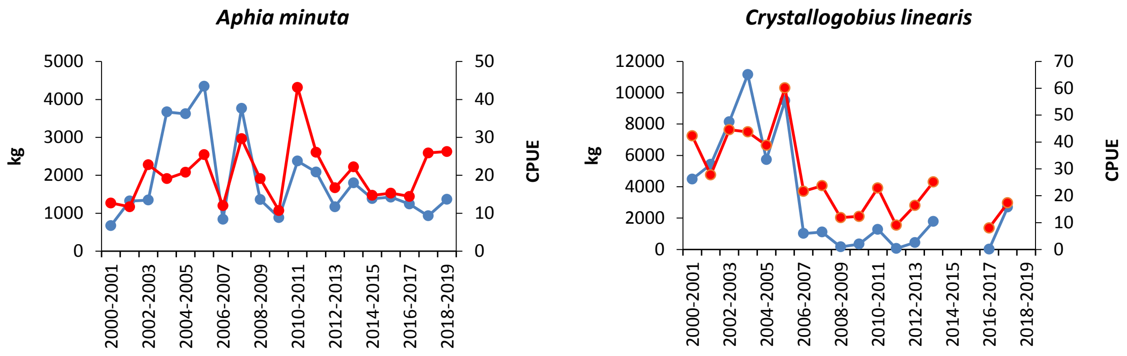


Figure 6.1.3. Landings (kg; in blue, left axis) and fishing season CPUE (kg/day per vessel; in red, right axis) trend of transparent goby and crystal goby in the Catalan Coast over the fishing seasons 2000-2001 to 2018-2019.

6.2. Assessment

During the studied period (2012-2013 to 2018-2019) in the study area the boat seine fleet targets one goby species: transparent goby (*Aphia minuta*) and secondarily crystal goby (*Crystallogobius linearis*) (2013-2014, 2016-2017 and 2017-2018).

Historical Series

The data source on landings and fishing effort is the same used in section 6.1. Data are presented at annual and monthly scales. The unit of effort considered is the number of fishing days (i.e. the sum of the number of days each boat seiner sold transparent goby and crystal goby at the auction upon arrival to port). Monthly catch per unit of effort (CPUE) was calculated as kg per day and vessel. Data are presented by fishing season i.e. from December to April.

Catch and CPUE

Over the fishing seasons 2000-2001 to 2012-2013, landings of the two species displayed marked fluctuations, as shown in section 6.1 (Figure 6.1.1). In the case of the transparent goby, the landings fluctuations were inter-seasonal, and ranged between 0.5 t in 2006-2007 and 4 t in 2005-2006. In crystal goby landings, though, two period are distinguished, from 2001-2002 to 2005-2006 fishing seasons, with landings >5 t per season and a peak in 2003-2004 (12.4 t), and from 2006-2007 onwards, with landings negligible. No explanation is available on whether the very low landings of crystal goby in this period are due to under-reporting or to a change in the fishermen's strategy.

The monthly landings, fishing days and CPUE (kg/day per vessel) trends over 2001-2002 to 2012-2013 are presented in Figures 6.2.1, 6.2.2 and in Figures 6.2.3, 6.2.4 for the period 2013-2014 to 2018-2019 for transparent goby and crystal goby respectively. These figures show and suggest some questions regarding the boat seining gobids fishery, based on annual species with very short life cycle.

1) In transparent goby species, highest landings did not occur at the beginning of the fishing season, which suggests that the onset of the fishing season was not coincidental with the massive incorporation of recruits. In recent years, March was the month with more landings peaks, but these were also observed in April. Regarding crystal goby, the high variability in the timing of occurrence of highest landings and the scarcity of catches in recent years, don't allow drawing any conclusion about this fishery.

2) Generally, landings, fishing days and CPUE trends are variable, with a decreasing trend at the end of the season in some years.

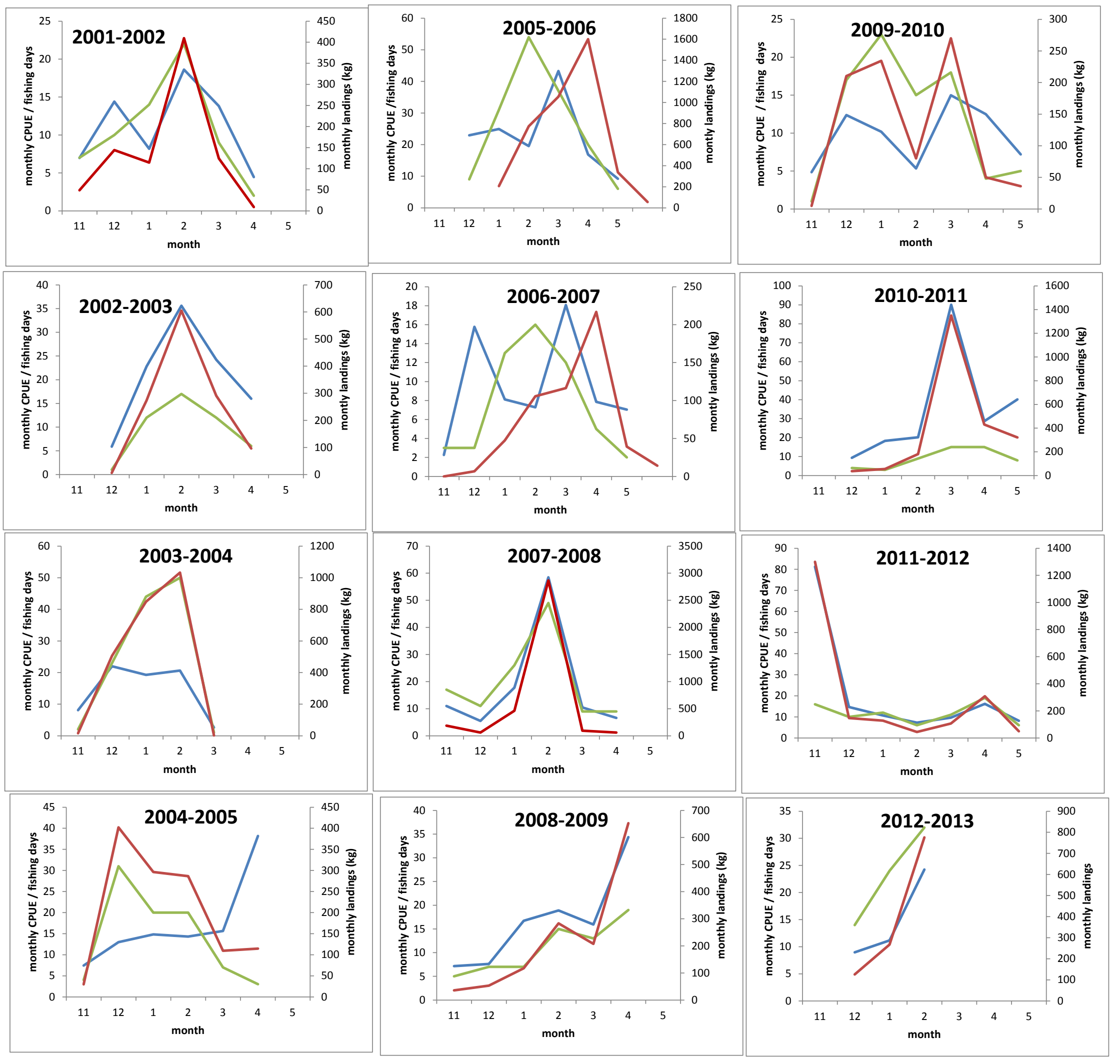


Figure 6.2.1. Transparent goby (*Aphia minuta*). Monthly CPUE (kg/day per vessel; blue; left axis), fishing days (green; left axis), and landings (in kg; red; right axis). (Sánchez *et. al* 2013).

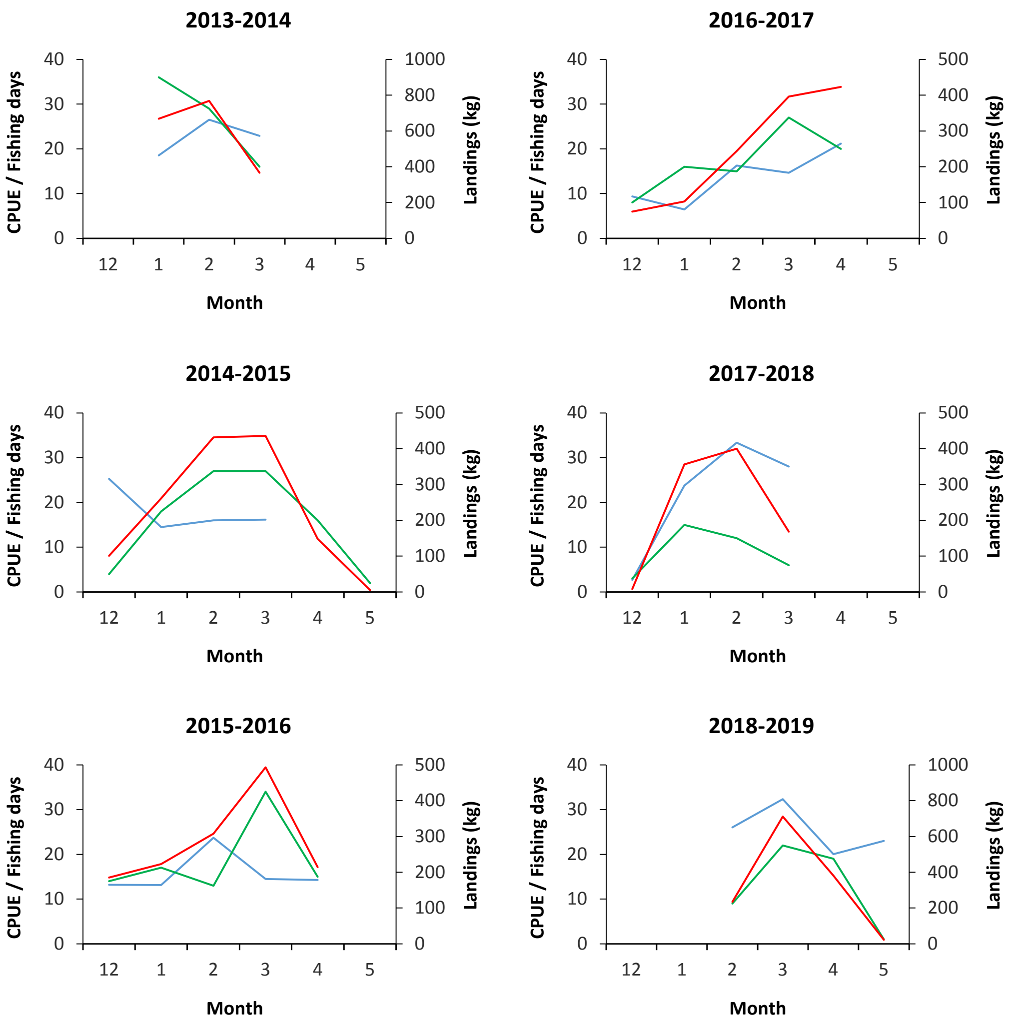


Figure 6.2.2 Transparent goby (*Aphia minuta*). Monthly CPUE (kg/day per vessel; blue; left axis), fishing days (green; left axis), and landings (in kg; red; right axis). From 2013-2014 to 2018-2019.

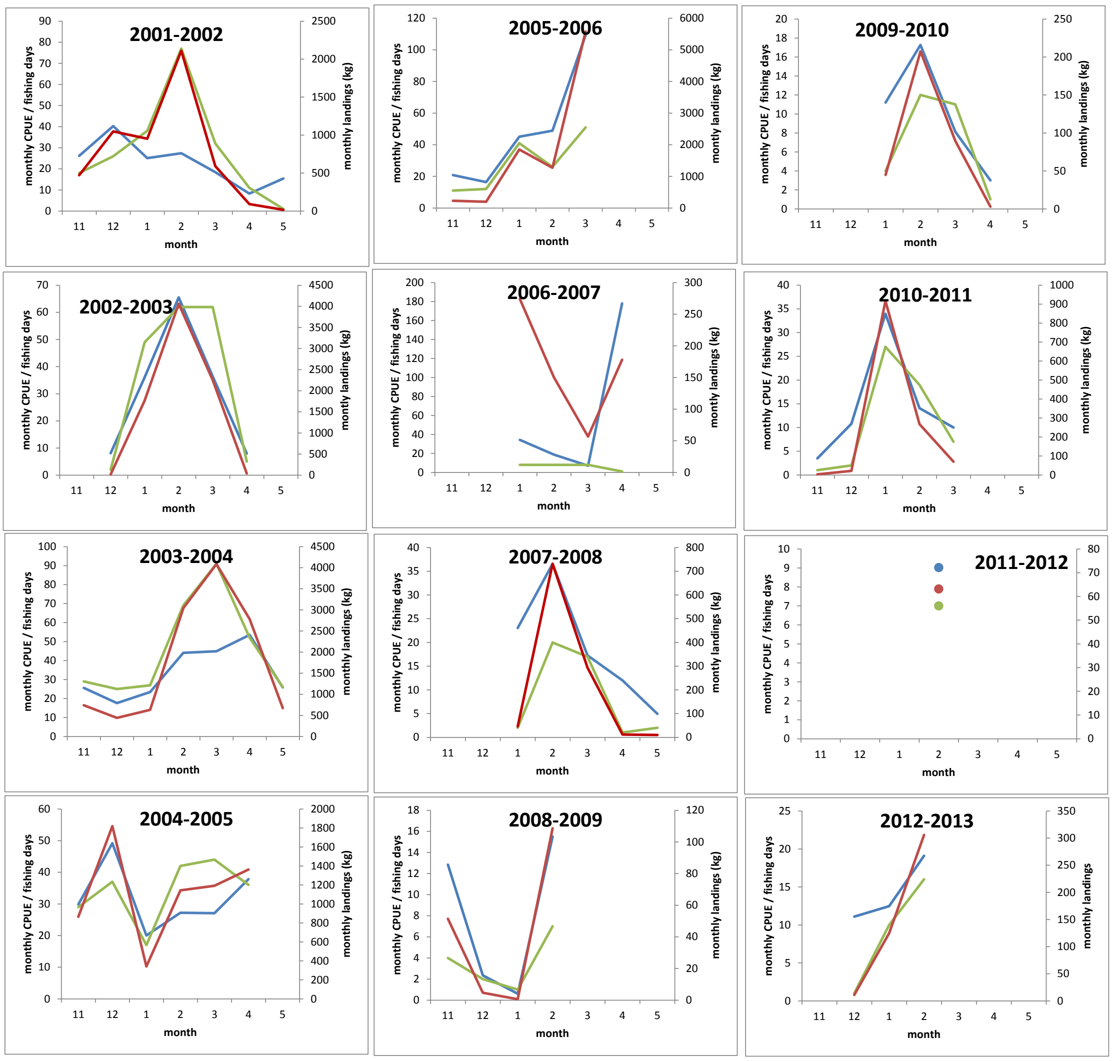


Figure 6.2.3. Crystal goby (*Crystallogobius linearis*). Monthly CPUE (kg/day per vessel; blue; left axis), fishing days (green; left axis), and landings (in kg; red; right axis). (Sánchez *et. al* 2013).

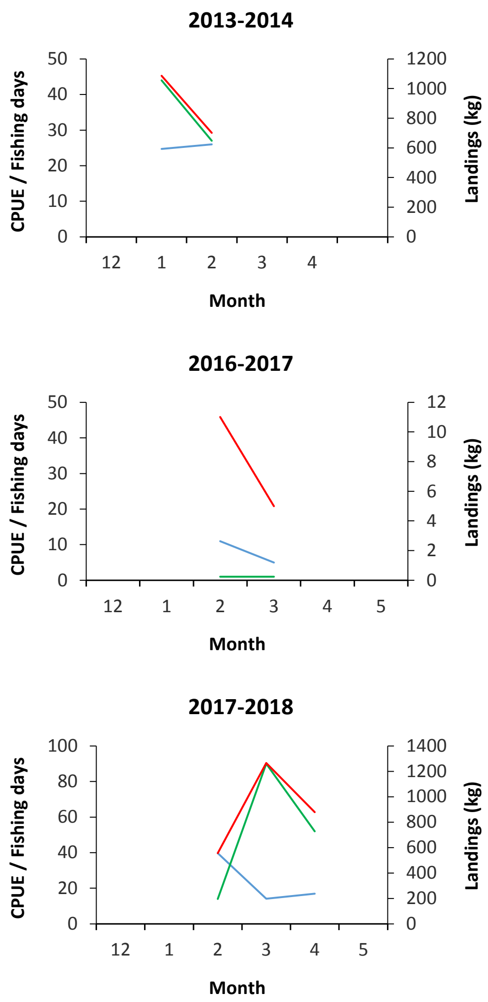


Figure 6.2.4. Crystal goby (*Crystallogobius linearis*). Monthly CPUE (kg/day per vessel; blue; left axis), fishing days (green; left axis), and landings (in kg; red; right axis). Present study.

The *Aphia minuta* life cycle is short, usually lasting only one year and ends shortly after reproduction. The breeding season is quite long and spawning takes place at least twice during its short life span. The existence of two different annual cohorts has been proposed (La Mesa *et al*. 2005, and references therein). However, in our study area, there is a lot of annual variability and in some years two peaks are clearly seen and in others only one as shown in Figures 6.2.5 and 6.2.6.

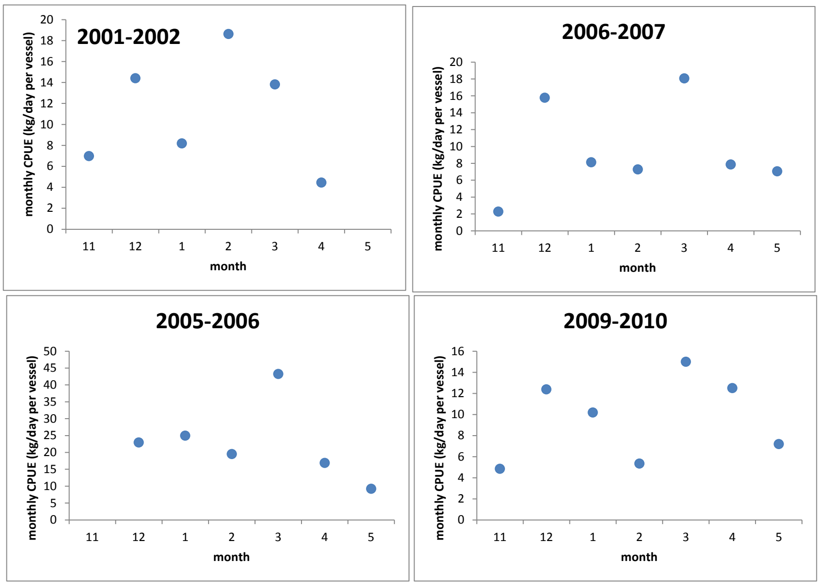


Figure 6.2.5. Transparent goby (*Aphia minuta*). Monthly CPUE (kg/day per vessel) trend in fishing seasons displaying more than one peak.

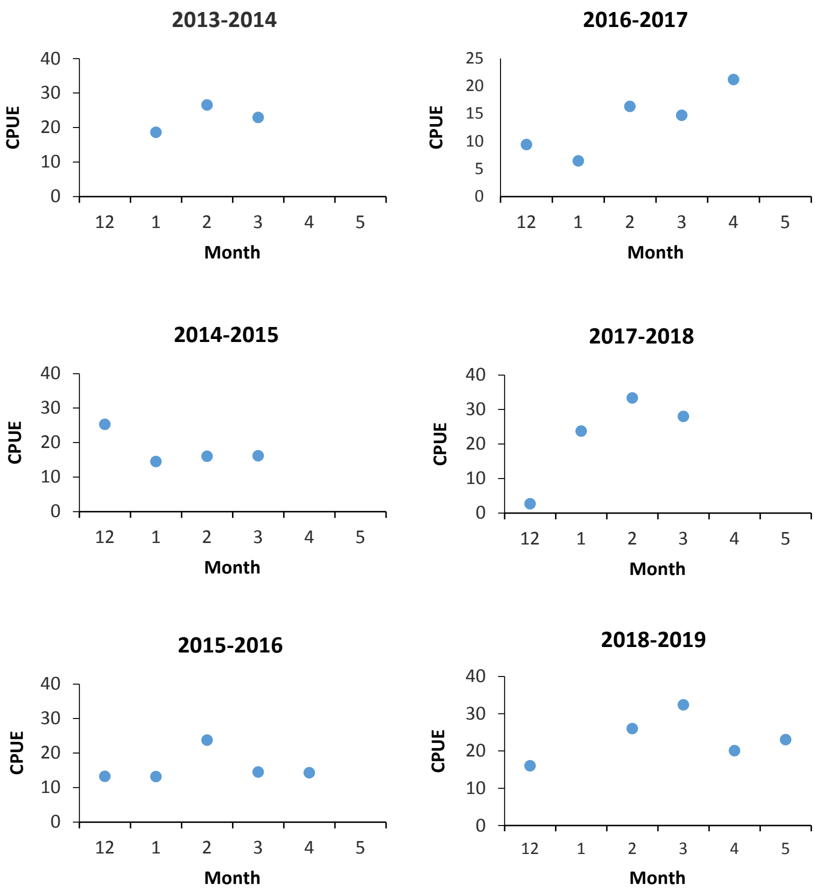


Figure 6.2.6. Transparent goby (*Aphia minuta*). Monthly CPUE (kg/day per vessel) trend in recent fishing seasons.

Biomass estimation. Depletion methods

Depletion methods are based on the principle that a decrease in the CPUE as the population is reduced or depleted is directly related to the extent of population decrease. This is not the case in the boat seine gobids fishery and this is why this methodology has not been applied. As shown in Figures 6.2.1 to 6.2.3, the highest CPUE are not obtained at the beginning of the fishing season, which suggest that the onset of the fishing season is not coincidental with the massive incorporation of recruits; the CPUE trend may display more than one peak along the fishing season; and, also, CPUE trend in the last months of the fishing season is increasing in some years, suggesting increasing abundance by the end of the season.

6.3. By-catch composition

The by-catch composition from the fishing grounds where the “sonsera” boat seine fleet operates was studied by scientific cruises from January 2015 to April 2019. Samples were monthly obtained on board from Barcelona port. The objective species is the transparent goby, *Aphia minuta*. Later, in the laboratory, species of by-catch were identified and length and weight were obtained for each specimen.

The weight ratio between transparent goby and the by-catch species presented a different picture from that presented in the case of the sandeel.

In this case, the study of the selectivity had only information from the sampling on board and all by-catch species retained in the gear were analysed, that is, including the species that otherwise would have been returned at sea alive. Information from fishermen log-books did not exist. The analysis of percentage in weight of target species versus non-target species pointed out the selectivity of this kind of fishery.

It is important to notice that the by-catch species analysed would have been released at sea alive if it had not been studied. It is characteristic of this fishery the very coastal and shorter hauls. This implies that the majority of organisms caught are alive when are on board and consequently can be returned alive on the sea.

Transparent goby, *Aphia minuta*

The by-catch species percentage in weight in *Aphia minuta* catches showed a 4.66%. More than 20 species can be caught regularly throughout the study and, although the number of individuals is low, the percentage is high due to relationship of weights.

For instance, the percentage by number of annular seabream *Diplodus annularis*, and European anchovy *Engraulis encrasicolus* represents 0.00008% and 0.00007% respectively of *Aphia minuta* individuals' number. These two species are the most abundant in number in the by-catch.

More detailed information regarding the biomass of the by-catch species is presented on the Figure 6.3.1. The analysis of the average of percentages of the biomass of the by-catch species of the 8 years analysed showed that the higher biomass percentage was for the commercial species *Diplodus annularis* (17%), *Trachurus* spp. (16%) *Pagellus acarne* (12%) and *Pagellus erythrinus* (11%).

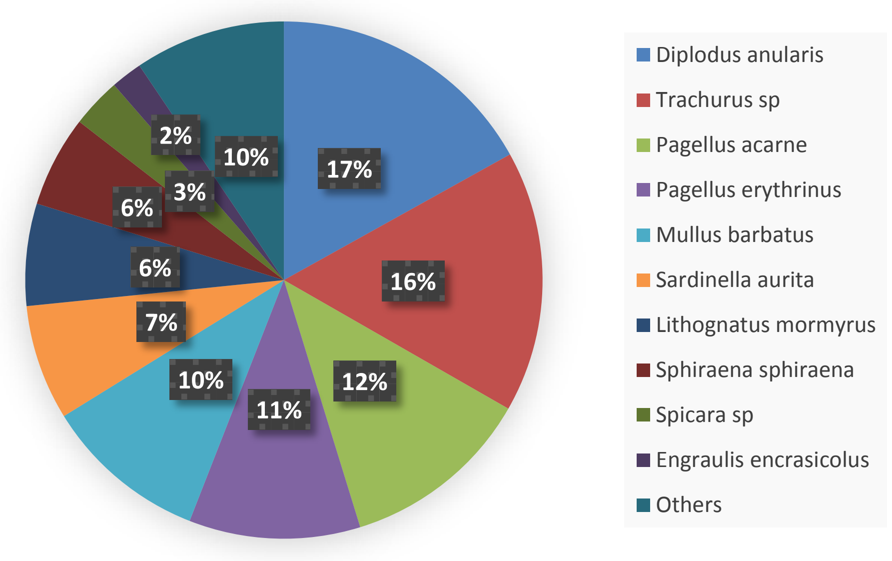


Figure 6.3.1. Average percentage of biomass of by-catch species per haul of *Aphia minuta* considering the five analysed period 2012-2019.

By-catch species length frequency distribution

The commercial species more abundant in number were analysed and their length frequency distribution presented. Figure 6.3.2 shows the frequency distributions of by-catch species in the period 2012-2019.

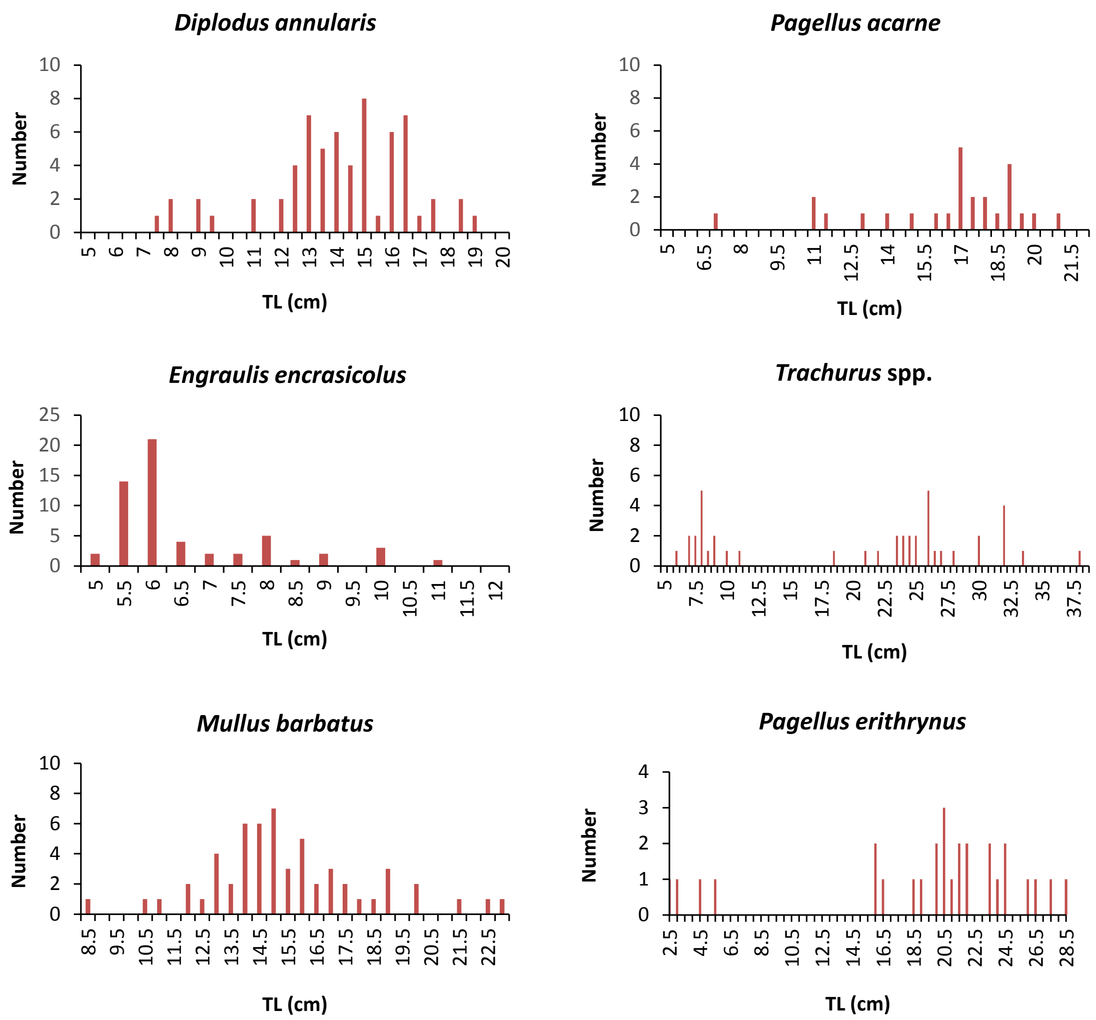


Figure 6.3.2. Length frequency distribution of *Pagellus acarne, Diplodus annularis, Engraulis encrasicolus*, *Trachurus* spp, *Mullus barbatu*s and *P. erythrinus* retained as by-catch of transparent goby (period 2012-2019).

Pagellus acarne, *P. erythinus* and *Diplodus annularis* appeared as by-catch from January to April, 26, 28 and 64 individuals respectively. *P. acarne* the smallest individuals (<11 cm) have been caught in January and the biggest ones in March and April. In the present study, only 4 *P. erythrinus* and 6 *D. annularis* recruits (<10 cm) have been captured as by-catch.

Catches of the small pelagic *Engraulis encrasicolus* consisted of a total of 67 individuals, mainly recruits (<9 cm). Horse mackerel (*Trachurus* spp.) 42 individuals caught with a wide length range (7-32 cm) and they were caught from January to April. A total of 56 *Mullus barbatus'* individuals were caught as by-catch, only 2 of them were <11 cm.

Crystal goby, *Crystalogobius linearis*

Crystallogobius linearis fishery behaves similarly to *Aphia minuta*, with a high number of by-catch species which, being heavier, show high weight percentages of the total catch.

Throughout the study period, 113.5 kg of crystal goby against 119.9 kg of by-catch species were analysed. Based on this relationship the percentage of most frequent species among all the by-catch is presented. The percentage in number of *Mullus barbatus*, *Pagellus erythrinus* and *Spicara* spp. was 12.3%, 23.5% and 40.4%. Regarding cephalopods, *Octopus vulgaris*, *Eledone cirrhosa*, *E. moschata*, and *Loligo vulgaris*, represented all together 1.6% also in number. Pelagic species both adults and juveniles are practically absent over the complete study period.

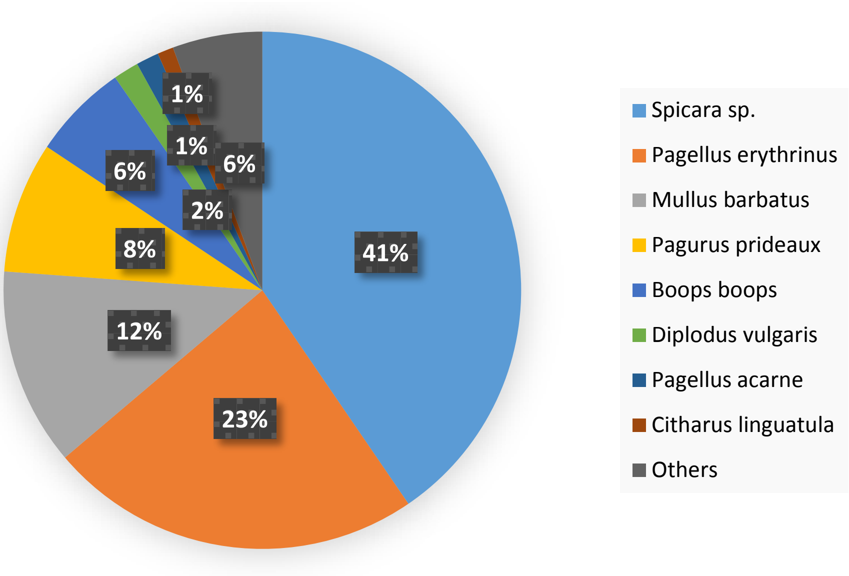


Figure 6.3.3. Average percentage of number of individuals of by-catch species per haul of *Crystalogobius linearis* considering the analysed period 2012-2019.

By-catch species length frequency distribution

Taking into account the species that have a legal minimum size, a certain number of *Pagellus erythrinus* had been caught, with size under the authorized <15 cm, representing 60% of the total individuals analysed. *Mullus barbatus* showed few individuals with sizes <11 cm, representing 8.4% of the total individuals caught. Into the small number of *P. acarne* the majority were undersized specimens (<17 cm) (Figure 6.3.3). The most abundant species in the captures is *Spicara* spp., most of the captured specimens presented sizes >13 cm. As mentioned in the case of sandeel and transparent goby, these by-catch species, retained for analysis, would have been returned at sea alive.

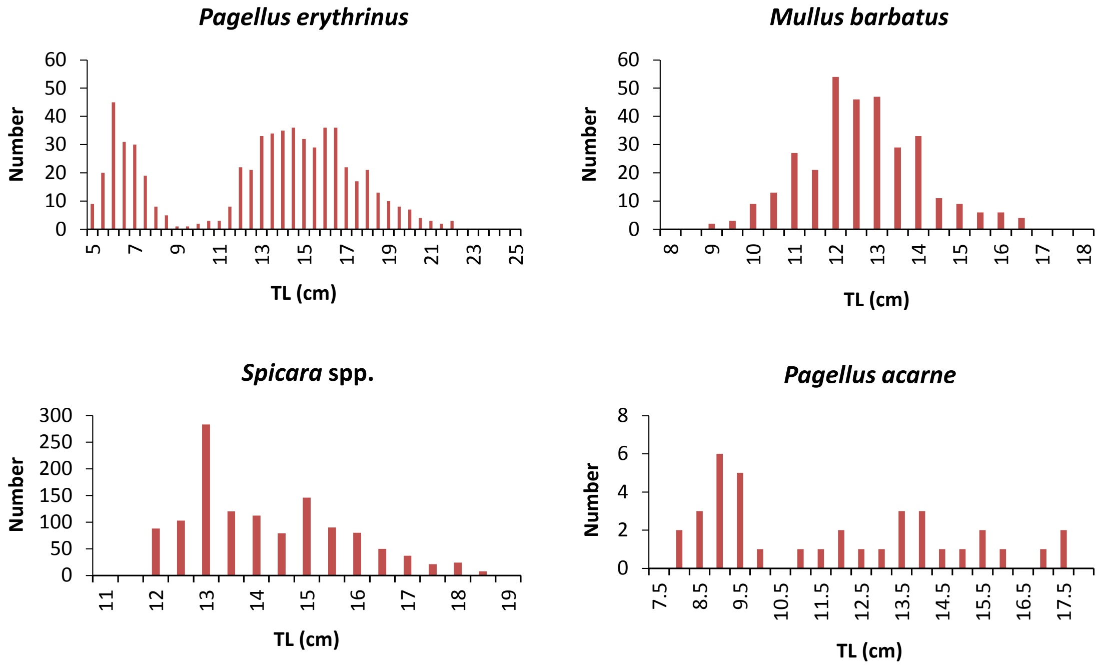


Figure 6.3.4. Length frequency distribution of *Pagellus erytrhinus, Pagellus acarne, Mullus barbatus* and *Spicara* spp. from by-catch of crystal goby fishery.

CONCLUSIONS

Sandeel

The boat seine fishing gear (sonsera) is used exclusively for fishing sandeel and gobid species. The sandeel fishing grounds are located very close to the coast (depending on the zone, within 400-600 m from the coast), in shallow waters (6-16 m depth). Gobid species are fished in muddy or sandy-muddy bottoms, at 7-2 m depths transparent goby in the southern fishing grounds, and at 30-50 m depth crystal goby in the northern fishing grounds.

From plotting haul positions against phanerogams distribution maps, it can be concluded that the "sonsera" is not used on sea bottoms characterized by the presence of sea grass meadows, in particular *Posidonia oceanica.*

The analysis of the boat seine catch when targeting sandeel evidenced the high selectivity of the “sonsera”, as the presence of by-catch species can be detected by the echo-sounder, which allows performing selective fishing operations resulting in catches without or with very few non- target species. The percentage in weight of by-catch species regarding the total sandeel’s catch was very low over the study period, around 2-8%. Only juveniles of *Pagellus acarne* need more control effort to avoid to be captured from this fishing activity.

This study has allowed knowing the main biological traits of sandeel (distribution, growth, reproduction period, size-at-first maturity, and timing of recruitment). The biology of *G. cicerelus* and *G. semisquamatus* in the study area were unknown, except scattered information reporting the presence of larvae at certain time of the year.

Gonadosomatic index (GSI) was calculated for mature males and females during the period 2012-2019. The mean GSI for females was highest from December to February, with a peak of maximum activity in January and February. Male showed the same pattern as females with a peak of maximum activity in January.

The results of a multi-annual generalized depletion (MAGD) model show that catch and effort data at high temporal frequency (month), complemented with biological information on mean body weight and initial estimates of natural mortality and time of recruitment to the fishery, can be used to produce assessment results of interest to fisheries management. The estimates of fishing mortality obtained for the Mediterranean sandeel in this fishery are very low compared to natural mortality estimates (less than 10%) and the important fluctuations in recruitment strength suggest that the dynamics of this fishery are mainly driven by denso-dependent effects in the population dynamics of the species. Given the high rate of natural mortality estimated (of the order of M = 2 yr^{-1}), its short life-span (1-2 years) and that exploitation is based on age 0 individuals, it is recommended to keep exploitation rates at current levels (<4%), which can be adapted on a short time basis, subject to the perceived availability of the stock, in the framework of a co-management model that permits to modulate the daily effort and maximum catch limits.

Gobids

Regarding gobids fishery, 2001-2013 historical average catch is proposed as TAC, which provides an estimate of 1.8 tons of *Aphia minuta* and 3.8 tons of *Crystallogobius linearis*. In fact, in the last years, crystal goby has not been captured and consequently the TAC has not been reached.

The fact that the landings pattern within each fishing season is very variable; landings peak fluctuating in a variable way, with increase after decreasing and vice versa, prevents the use of depletion methods.

In any case, it is the sandeel that drive the boat seining activity; both landings and fishing days resulting from targeting gobids are very low regarding those of sandeel. Regarding gobids fishery TAC proposed for transparent goby would be considered as adequate and for crystal goby, TAC would be maintained as a maximum, being in mind that this fishery could be restored in the future.

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