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# SPATIAL BASED APPROACH TO FISHERIES MANAGEMENT. AN APPLICATION TO BOTTOM TRAWLING IN THE STRAIT OF SICILY

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**Esame finale anno 2022**

This thesis is dedicated to
my mother, my grandfather and my grandmother…
people who taught me the most important values of my life…

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# 1. INTRODUCTION

## 1.1 Spatial Based Approach to Fishery Management

In 2002, during the World Summit on Sustainable Development of Johannesburg, the European Union (EU) highlighted the importance of reducing the overexploitation of many fish stocks and, in this contest, the Common Fisheries Policy (CFP) worked to guarantee the conservation of the marine living resource and a sustainable use of fishery (EU, 2013). The main goal of the CFP is the adaptation of fishing activities to exploitation rates that maintain or restore the population of harvested stocks above levels that can produce the Maximum Sustainable Yield (MSY) and, to reach this aim, different strategies have been identified, including the effective implementation of an Ecosystem Approach to Fishery Management (EAFM) and the progressive reduction of discard (Russo *et al.*, 2017).

Another important step toward more sustainable management of fisheries was done during the United Nations Sustainable Development Summit in 2015, in which the General Fisheries Commission for the Mediterranean Sea (GFCM) approved the resolution on the mid-term strategy (2017-2020) toward the sustainability of Mediterranean and Black Sea fisheries (Resolution GFCM/40/2016/2). This resolution aims to reverse the alarming trend of the status of exploited stocks, while supporting livelihoods for coastal communities and mitigating the negative effects of fisheries on the ecosystem, by 2020 (Russo *et al.*, 2017).

In this contest of achieving more sustainable resource exploitation of fisheries, in recent years there has been increasing interest in the Ecosystem-based Approach to Fisheries (EAF) and, during the reform of the EU Common Fishery Policy in 2013, the need to adopt this approach was highlighted (EU, 2013). In particular, implementing the ecosystem approach to fisheries management is an important step in the process of establishing a sound basis for the sustainable harvest of marine living resources (Bianchi & Skjoldal, 2008). According to FAO (2003), the aims of EAF are "to balance diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries". The approach thus intends to foster the use of existing management frameworks, improving their implementation and reinforcing their ecological relevance, and it will contribute significantly to achieving sustainable development (Garcia, 2003).

Nevertheless, the application of an ecosystem-based approach is strongly limited by appropriate management and policy measures (Cowan *et al.*, 2012). In fact, there are relatively few case studies of successful implementation (Arkema *et al.*, 2006) and often the original goals of sustainability and biodiversity conservation are not achieved due to conflicting political interests. Although ecosystem models (Stecken & Failler, 2016) are used to provide insights into the long term effects of fishing on the ecosystem, short-term advice on the status of stocks is still largely based on single species models (Hilborn, 2011; Fogarty, 2014). Despite the spatial dimension of ecological and capture processes are traditionally not considered either in assessment or in management, in the last decades space entered progressively fishery sciences. Protecting the Essential Fish Habitats (EFHs), i.e. habitats where commercial species pass their life cycles, mainly spawning and nursery, has become a relevant aspect of stock conservation within the framework of the EAF (Garofalo *et al.*, 2011; Colloca *et al.*, 2015). In this context, EAF considers the spatial dimension in assessing and managing fisheries that allow fishers to make a living while also targeting the conservation of marine resources (Bastardie *et al.*, 2014; McGilliard *et al.*, 2015; Khoukh & Maynou, 2018; Russo *et al.*, 2019). Regarding the importance of the spatial scale, in the recent review on the effects of Marine Managed Areas (MMAs) on fisheries, Hilborn (2014) recalled the importance of assessing how much the benefits of closing a fishery area are reflected outside the protected area and how the source-sink dynamics is of crucial importance for the correct understanding of the potential of MMAs. The positive effects of the spill-over from MMAs to adjacent areas, which is one of the cornerstones of the spatial management of fishing resources, have recently been confirmed in different areas of the central-western Mediterranean (Pipitone *et al.*, 2014).

## 1.2 The Strait of Sicily

Sicily is the largest island in the central Mediterranean Sea and includes the seven Aeolian Islands and the island of Ustica to the north, the three Aegadian Islands to the west and the Pelagian Islands to the south. In particular, the Strait of Sicily (SoS) represents the main link between the Western and Eastern Mediterranean basins. It has a minimum width of about 150 km (between Cape Bon and Mazara del Vallo), a length of about 600 km and a mean sill of about 400 m depth (Astraldi *et al.*, 2001). It has a highly irregular bottom bathymetry, characterized in the southwest by the wide Tunisian continental shelf and the northeast by the Sicilian shelf. These two shelves are separated by deep water areas from which arises the volcanic island of Pantelleria (Omrani *et al.*, 2016).

According to the definition by the General Fisheries Commission for the Mediterranean (GFCM) of Geographical Sub-Areas (GSAs) (GFCM, 2009), the SoS encompasses different fisheries areas: 12 GSA, 13 GSA, 15 GSA and 16 GSA (Fig. 1).

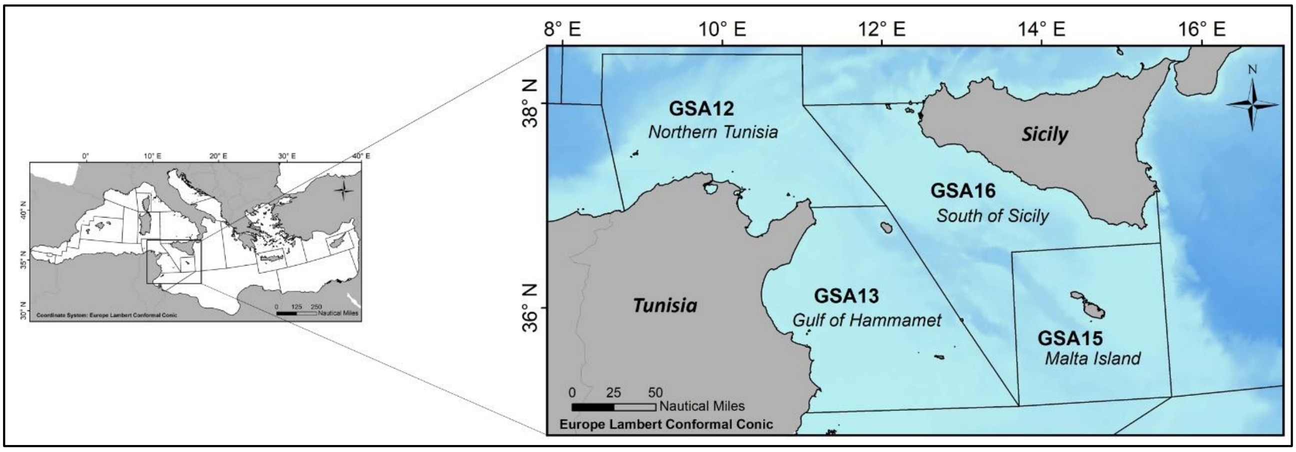


Figure 1. The geographical subareas (GSAs) representing the SoS.

The bottom of the SoS is scattered by several submarine elevations (topographically indicated as banks) made up of sedimentary or volcanic rocks (Civile *et al.*, 2016), that can reach up to 1000 m in height. This complex topography influences the circulation scheme of the SoS characterized by filaments, meanders and eddies, that along the shelf edge of the banks can produce upwelling, locally increasing the biological productivity (Lermusiaux & Robinson, 2001; Béranger *et al.*, 2004) and making this area an important hotspot of biodiversity within the Mediterranean (Deidun *et al.*, 2015; Garofalo *et al.*, 2007). Furthermore, several authors highlighted the presence of important nursery and spawning areas for main fishery resources (Fiorentino *et al.*, 2003; Garofalo *et al.*, 2004; Abella *et al.*, 2008; Garofalo *et al.*, 2008; Fortibuoni *et al.*, 2010; Garofalo *et al.*, 2011; Colloca *et al.*, 2015) in the SoS, mainly where banks are present. The protection of essential fish habitats is one of the most important issues for fishery management in the SoS (Russo *et al.*, 2014; Colloca *et al.*, 2015) During the 40th meeting of the General Fisheries Commission for the Mediterranean Sea (30 May 2016 - 03 June 2016), a MultiAnnual Plan (MAP) for the fisheries exploiting European hake (HKE) and deep-water rose shrimp (DPS) in the SoS was adopted. This MAP includes, *inter alia*, the implementation of three special MMAs, called Fishery Restricted Areas (FRAs) to protect juveniles of HKE and DPS.

Moreover, the whole SoS was recognized at the international level as an Ecologically or Biologically Significant Area (EBSA) by the contracting parties of the Convention on Biological Diversity (CBD) in 2014 (COP12, October 2014, Pyeongchang, Republic of Korea). In addition, in 2015 during the second RAC/SPA (Regional Activity Centre for Specially Protected Areas), experts started the review of the existing literature on the SoS (Fiorentino *et al.*, 2004; Gristina *et al.*, 2006; Garofalo *et al.*, 2008; Fortibuoni *et al.*, 2010; Bo *et al.*, 2014; Canese & Bava, 2014; Battaglia *et al.*, 2015; Deidun *et al.*, 2015) to assess the possibility of creating one or more Specifically Protected Areas of Mediterranean Importance (SPAMIs) including these banks. Overall, these environments are poorly investigated owing to difficulties in carrying out scientific surveys and investigations in areas characterized by a rough topography, offshore location and a strong hydrodynamic regime (Bo *et al.*, 2011).

## 1.3 Main Characteristics of Fishery in the Strait of Sicily

The SoS represents one of the highest productive areas for demersal fisheries of the basin (Gristina *et al*; 2006; Di Lorenzo *et al.*, 2017). In 2016, the active fishing fleet operating in the SoS comprises 1157 vessels for a total of about 32,000 tons (in terms of Gross Tonnage - GT) and 134,000 kW (in terms of engine power). The majority are small-scale vessels (667 vessels) and bottom trawlers (395 vessels), followed by long-liners (33 vessels), polyvalent fishing boats (24 vessels), purse-seiners (22 vessels) and fishing steering wheels (16 vessels) (Maiorano *et al.*, 2019). In particular, bottom trawling in Sicily has a very important role in the national panorama both for what concerns the vessels with Length Overall (LOA) > 24 m operating in the SoS and in other areas of the southern and eastern Mediterranean, and for the more traditional trawler fishing active in fishing areas near the coast (Maiorano *et al.*, 2019). The GSA 16 vessels have a significantly higher average size (68 GT) than the national fleet (41 GT) and the Sicilian fishing activity was of about 162,000 fishing days with an annual mean of 139 fishing days by vessel.

In 2016, the production of the fishing fleet in GSA 16 amounted to about 20,000 tons of catches equivalent to about €154 million and the trawling fishing was the most productive fishing type for a total of about 13,300 tons catches species and an economic value of €114 million, followed by purse-seine fishing with about 2500 tons catches for a total economic value of about €7 million (Maiorano *et al.*, 2019). In general, the 5 most abundant commercial species are the following: the deep-water rose shrimp (*Parapenaeus longirostris*, DPS – Lucas, 1846) (5293 tons), the European anchovy (*Engraulis encrasicolus*, ANE – Linneaus, 1758) (2282 tons), the giant red shrimp (*Aristaeomorpha foliacea*, ARS – Risso, 1827) (1490 tons), the European hake (*Merluccius merluccius*, HKE – Linnaeus, 1758) (1373 tons) and the European pilchard (*Sardina pilchardus*, PIL – Walbaum, 1792) (1290 tons) (Maiorano *et al.*, 2019). These 5 species represent 58% of the total production and 54% of the turnover achieved by the Sicilian fleet. In particular, from an economic point of view, ARS and DPS represent about 50% of the total revenue with a revenue of about €33.4 million (mean market price of about €/Kg 22.4) and about €32.2 million (mean market price of about €/Kg 6.1) in 2016, respectively.

From the production point of view, bottom trawling is the most important fishing activity in the SoS and includes three main segments: small vessel trawlers, with LOA between 12 – 18 m, medium vessels between 18 and 24 m and vessel trawlers larger than 24 m in LOA. The first and the second segment operate mainly in Sicilian territorial waters (within 12 miles from the coast, fishing from 1 to 2 days); while the third operate far from the Sicilian coast both on the continental shelf and the slope down to 700 – 800 m depth with long fishing trips until 1 – 2 months and every 20 – 30 days the catch frozen on board was landed in the near port, then skipped to the home port in refrigerated trucks and, finally, marketed throughout Italy. According to De Angelis *et al.* (2020), these "distant" trawlers adopt 4 different fishing strategies: African shelf and Sardinia shelf targeting to shallow waters species (mainly fish and cephalopods), wide deep water, operating from the Sardinia Channel to the coast off Libya, and Eastern deep water, operating in the Aegean and in the Levant Sea, targeting to deep water crustaceans.

## 1.4 Structure and Fleet Capacity of the Bottom Trawler Fleets in the Strait of Sicily

Bottom trawling fleets predominate in many Mediterranean fisheries, being responsible for a high share of total catches and, in many cases, yielding the highest earnings among all the fishing sub-sectors (FAO, 2020). In this contest, the SoS constitutes an important fishing area for demersal resources in the central Mediterranean Sea and host several important marine fisheries (Fig. 2). Among them, Mazara del Vallo is the main port for demersal fisheries; its fleet represents the main commercial fleet of trawlers in the SoS and one of the most important fleet in the Mediterranean Sea (Milisenda *et al.*, 2017).

The main demersal *target* species of this fishery are 4 species of high commercial value: the deep-water rose shrimp (DPS, *Parapenaeus longirostris* – Lucas, 1846), the European hake (HKE, *Merluccius merluccius* – Linnaeus, 1758), the giant red shrimp (ARS, *Aristaeomorpha foliacea* – Risso, 1827) and the red mullet (MUT, *Mullus barbatus* – Linneaus, 1758). In particular, DPS is the main *target* species of trawling amounting to about 50% of the total landings by Italian bottom trawlers (Knittweis *et al.*, 2013). According to the most recent stock assessment (GFCM, 2019), both DPS and HKE are in overfishing with a high fraction of undersized catches. To improve the exploitation pattern (reducing the amount of undersized specimens in the catch) of these species, 3 Fisheries Restricted Areas (FRAs), corresponding to stable nurseries of European hake and deep-water rose shrimp (FAO, 2016) (Fig. 2), were established by GFCM in 2016 and adopted by the Italian Government in the July of 2019. In these FRAs, located East of Adventure Bank, West of Gela Basin and East of Malta Bank, bottom trawling is prohibited throughout the year (http://www.fao.org/gfcm/data/maps/fras). Situated in the northern sector of the SoS, the FRAs occupy a total area of 1711 km$^2$: 621 km$^2$ (mean depth = 175 m; depth range = 73 – 720 m) for the FRA to the east of Adventure Bank, 621 km$^2$ (mean depth = 315 m; depth range = 20 – 662 m) for the FRA to the west of Gela Bank and 469 km$^2$ (mean depth = 249 m; depth range = 60 – 1195 m) for the FRA to the east of Malta Bank (Garofalo & Fiorentino, 2022).

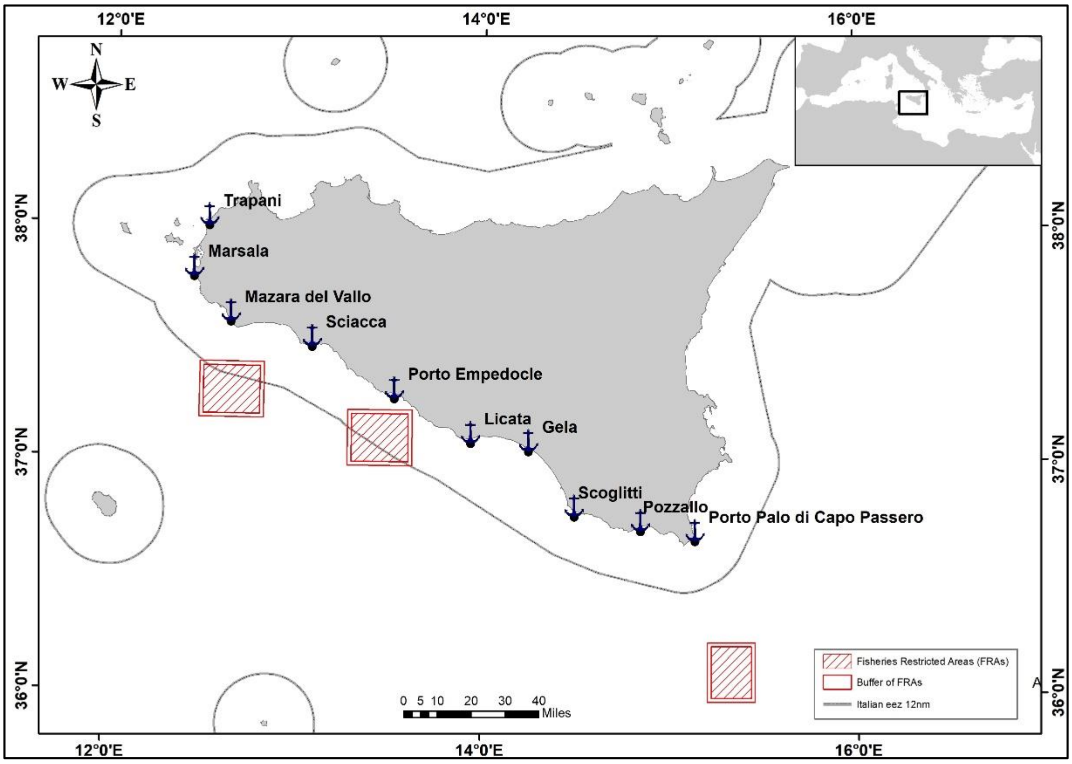


Figure 2. Main trawl fleets situated along the south coast of Sicily and the FRAs situated in the SoS.

According to the EU Community Fishing Fleet Register (https://data.europa.eu/euodp/it/data/dataset/the-community-fishing-fleet-register), 351 trawling fishing vessels with LOA > 12 m for a combined gross tonnage (GT) of about 24,800 tons and engine power of about 88,000 kilowatts (kW) are registered along the southern coast of Sicily.

Mazara del Vallo constitutes the fleet with the greatest number of vessels (100 vessels equivalent to 28.5% of the total vessels) (Appendix 4), followed by Sciacca and Porto Palo di Capo Passero fleets with 80 (22.8% of the total vessels) (Appendix 8) and 44 vessels (12.5% of the total vessels) (Appendix 6), respectively (Fig. 3). On the other hand, Gela, Pozzallo and Marsala fleets showed the lowest number with 1 (0.3% of the total vessels) (Appendix 1), 9 vessels (2.6% of the total vessels) (Appendix 7) and 9 vessels (2.6% of the total vessels) (Appendix 3), respectively (Fig. 3). The other fleets show the following results: 39 vessels (11.1% of the total vessels) for Licata fleet (Appendix 2), 30 vessels (8.5% of the total vessels) for Trapani fleet (Appendix 10), 24 vessels (6.8% of the total vessels) for Porto Empedocle fleet (Appendix 5) and 15 vessels (4.3% of the total vessels) for Scoglitti fleet (Appendix 9) (Fig. 3).

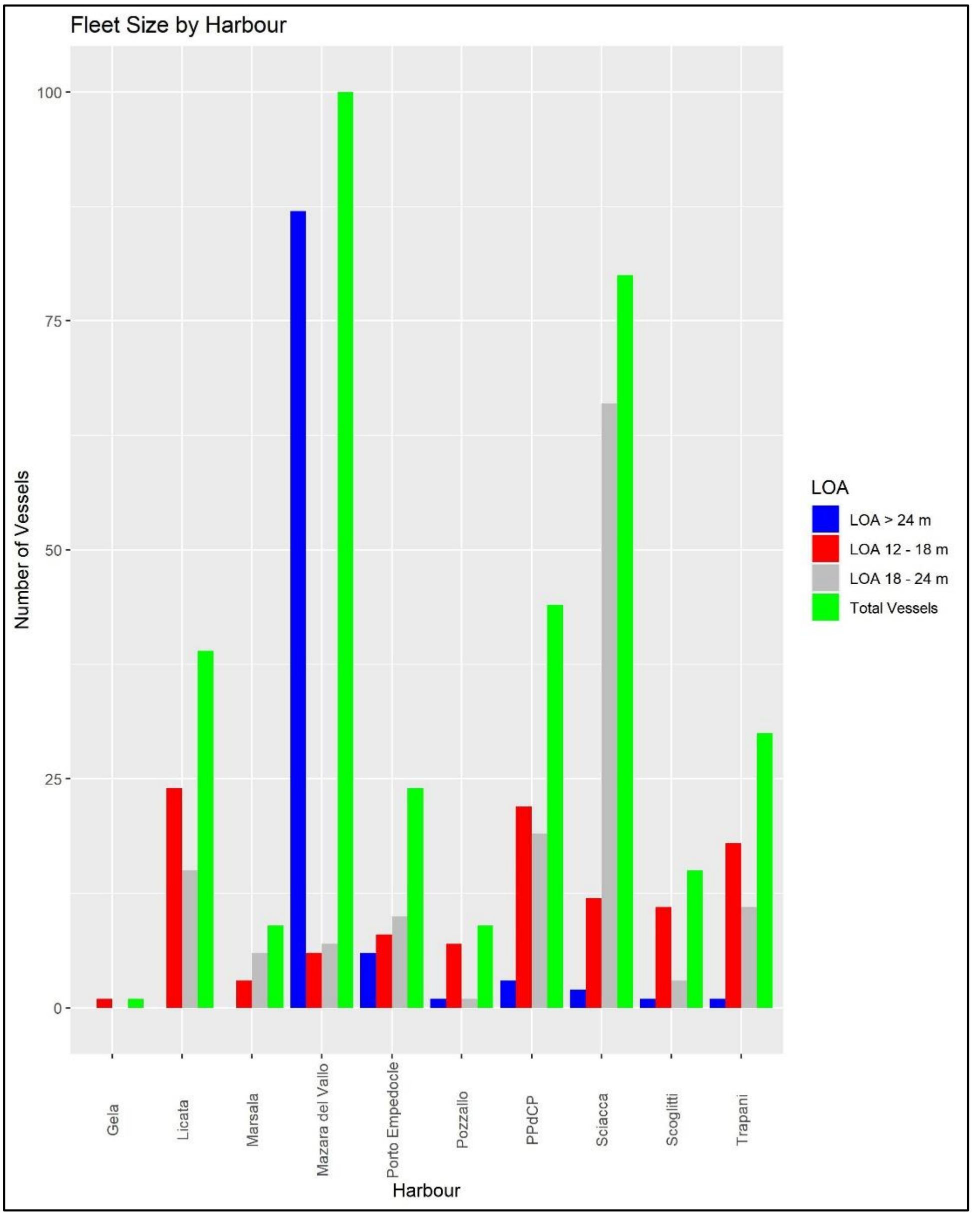


Figure 3. Composition of the Italian fleets situated in the SoS divided by LOA: 12 – 18 m, 18 – 24 m and > 24 m.

In terms of LOA, GT and kW, the fleet of Mazara del Vallo showed the higher mean values for the segment > 24 m (Tab. 1; Fig. 4).

Table 1. Number of vessels divided by LOA, mean LOA value and standard deviation, mean GT value and standard deviation, mean kW value and standard deviation calculated using the fleet capacity of each harbour situated in the SoS.

| Harbour | LOA (m) | N° of Vessels | Mean LOA value ± St. d. | Mean GT value ± St. d. | Mean kW value ± St. d. |
|---|---|---|---|---|---|
| Gela | 12 – 18 m | 1 | 15.2 ± 0 | 24 ± 0 | 206 ± 0 |
| | 18 – 24 m | 0 | 0 | 0 | 0 |
| | > 24 m | 0 | 0 | 0 | 0 |
| Licata | 12 – 18 m | 24 | 15.3 ± 1.5 | 17.1 ± 7.2 | 128.5 ± 38.9 |
| | 18 – 24 m | 15 | 20.4 ± 1.4 | 44.9 ± 10 | 208 ± 84.8 |
| | > 24 m | 0 | 0 | 0 | 0 |
| Marsala | 12 – 18 m | 3 | 15.2 ± 2.2 | 20 ± 8.9 | 131.3 ± 33.9 |
| | 18 – 24 m | 6 | 21.9 ± 0.7 | 67.2 ± 7.4 | 278 ± 25.4 |
| | > 24 m | 0 | 0 | 0 | 0 |
| Mazara del Vallo | 12 – 18 m | 6 | 15.8 ± 1.8 | 21.5 ± 5.9 | 148.8 ± 38.8 |
| | 18 – 24 m | 7 | 21.8 ± 1.5 | 72.9 ± 25.5 | 306 ± 124.3 |
| | > 24 m | 87 | 29.7 ± 3.4 | 162. 9 ± 62.5 | 417.1 ± 227.1 |
| Porto Empedocle | 12 – 18 m | 8 | 14.1 ± 1.4 | 22 ± 22.5 | 121.5 ± 36 |
| | 18 – 24 m | 10 | 21.9 ± 1.2 | 65.3 ± 12.7 | 288 ± 81.1 |
| | > 24 m | 6 | 25.6 ± 1.3 | 113.2 ± 28.7 | 320.6 ± 150.4 |
| Porto Palo di Capo Passero | 12 – 18 m | 22 | 16.1 ± 1.4 | 20.6 ± 9.2 | 158.4 ± 42.1 |
| | 18 – 24 m | 19 | 21.2 ± 1.8 | 52.8 ± 13 | 276.5 ± 103.6 |
| | > 24 m | 3 | 25.4 ± 0.7 | 84.7 ± 5.7 | 301 ± 142.6 |
| Pozzallo | 12 – 18 m | 7 | 14.3 ± 0.8 | 13.3 ± 6.1 | 130.6 ± 50.6 |
| | 18 – 24 m | 1 | 22.7 ± 0 | 99 ± 0 | 308.8 ± 0 |
| | > 24 m | 1 | 26.2 ± 0 | 82 ± 0 | 457 ± 0 |
| Sciacca | 12 – 18 m | 12 | 16.2 ± 1.3 | 28.6 ± 9.6 | 175.6 ± 38.7 |
| | 18 – 24 m | 66 | 20.7 ± 1.5 | 55.4 ± 16.2 | 213.6 ± 79.4 |
| | > 24 m | 2 | 25.2 ± 0.1 | 104 ± 11.3 | 249.1 ± 90.3 |
| Scoglitti | 12 – 18 m | 11 | 15.5 ± 1.3 | 18.5 ± 5.5 | 135.7 ± 34 |
| | 18 – 24 m | 3 | 21.2 ± 2.3 | 62.3 ± 21.4 | 264.7 ± 61.8 |
| | > 24 m | 1 | 25.7 ± 0 | 61 ± 0 | 324 ± 0 |
| Trapani | 12 – 18 m | 18 | 14.4 ± 1.7 | 16.7 ± 9.8 | 109.2 ± 42.2 |
| | 18 – 24 m | 11 | 20.3 ± 1.9 | 53.5 ± 14.4 | 200.1 ± 33.6 |
| | > 24 m | 1 | 27.3 ± 0 | 93 ± 0 | 385 ± 0 |

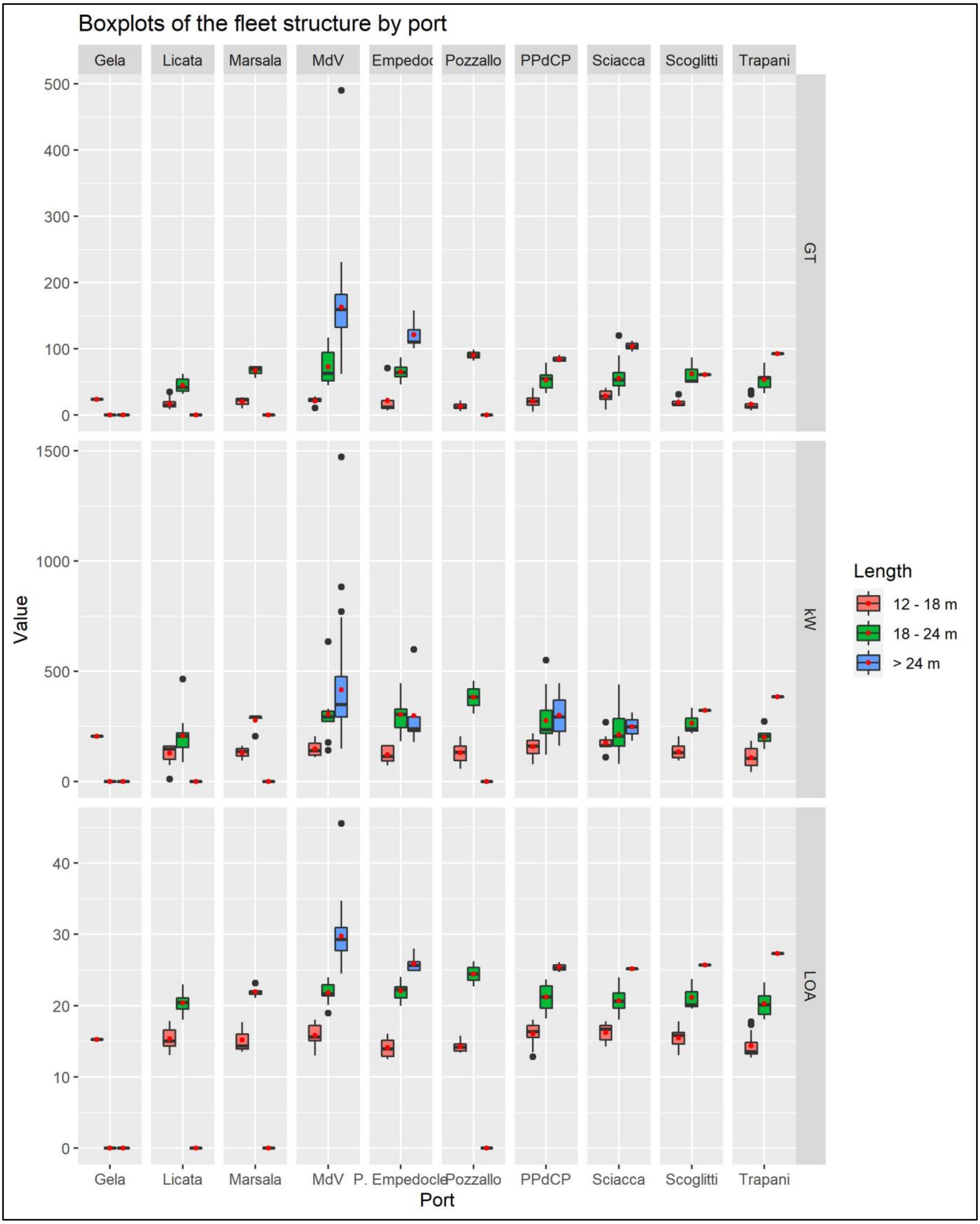


Figure 4. Boxplots of fleet capacity indicators in terms of gross tonnage (GT), engine power (kW) and Length OverAll (LOA) of the different fleets situated in the SoS. Red point: mean; black line: median.

## 1.5 Biology of the Main *Target* Species of Trawling Fishery in the Strait of Sicily

### 1.5.1 The deep-water rose shrimp (*Parapenaeus longirostris* – Lucas, 1846)

DPS is a decapod crustacean belonging to the *Penaeidae* family characterized by the presence of a long furrow beginning near the eyes and the carapace is pink-orange with a reddish rostrum. The rostrum is well developed and slightly curved upward, it is smooth on the ventral edge and shows 7 equidistant teeth on the dorsal edge, followed by an epigastric tooth (Fig. 5).

Usually, this demersal species inhabits sandy-muddy bottoms between 70 and 400 m (Carlucci & Gancitano, 2017); but, in the Mediterranean Sea, the greatest abundance of DPS is recorded between 100 and 300 m depth (Audouin, 1965; Holthuis, 1980; Nouar, 1985; Abellò *et al.*, 2002). Moreover, DPS has a size-related bathymetric distribution, linked to the ontogenetic migration of juveniles from the continental shelf to the slope (Fortibuoni *et al.*, 2010). The SoS, together with the seas around Greece, is the Mediterranean region with the greatest abundance of this species (Levi *et al.*, 1995; Abellò *et al.*, 2002).

DPS is a partial asynchronous spawner with reproductive pattern varying according to location, salinity, water temperature and size of the specimens (Bianchini *et al.*, 2010). Extended breeding periods were identified in Italian seas, with maximum spawning peaks coinciding with several seasons. In particular, although the mature females are present throughout the year in the SoS (Mori *et al.*, 2000), according to Levi *et al.* (1995) this species showed an evident reproductive peak from November to February and another peak in April; while the lowest percentage of mature females was observed in June-July.

In the Mediterranean Sea, sexual maturity of this species is reached for both sexes during the first year of life (Ardizzone *et al.*, 1990; Ben Meriem *et al.*, 2001) and the size at first maturity in females range between 20.1 – 24.0 mm Carapace Length (CL) in the GSA 16 (Ben Meriem *et al.*, 2001; Gancitano *et al.*, 2008; Bianchini *et al.*, 2010).

Concerning the recruitment period, it was observed throughout the year confirming a quite extended breeding season with maximum peaks coinciding with different periods Recruits are distributed above all between 100 – 200 m depth (Carlucci *et al.*, 2009). In particular, in the SoS were localized some stable nursery areas at 200 m depth; these areas are located both along the central Sicilian coast and on the eastern side of Adventure Bank and Malta Bank, next to a spawning area, which could feed two different local stock sub-unit (Fortibuoni *et al.*, 2010; Garofalo *et al.*, 2011).

*P. longirostris* growth varies between the two sexes, females reaching larger sizes than males. Growth parameters of deep water pink shrimp in the SoS are similar to those estimated in other areas of the Mediterranean and the Atlantic Ocean, and indicate a fast and short life cycle of 3 – 4 years, with typically higher growth rates in males (Fiorentino *et al.*, 2013a).

DPS is a euryphagous species and has a wide diet. In different areas of the Mediterranean Sea, it is reported that larger/older DPS specimens switch between opportunistic predation, during which they catch small fishes, cephalopods and, above all, crustaceans (amphipods, copepods and ostracods) and sedentary preys in seabed sediment, such as polychaetes, bivalves, gastropods, foraminifera and radiolarian (Sobrino *et al.*, 2005; Nouar *et al.*, 2011).

In general, DPS represents an important economical resource for the bottom trawl fishery in many areas of the Mediterranean. In particular, in the SoS, this species is caught throughout the year by average size vessels having a LOA between 12 – 24 m, which operate according to fishing trips lasting 1 – 2 days; furthermore, DPS is a species targeted by the fleet fishing on the high seas of Mazara del Vallo, which operates with larger size vessels (LOA > 24 m) in national and international waters with fishing trips lasting 3 – 4 weeks (Di Lorenzo *et al.*, 2017; Milisenda *et al.*, 2017;).

According to the Reg. (EC) 1967/2006, the minimum landing size for this specie is 20 mm CL.

Figure 5. Examples of *Parapenaeus longirostris*.

### 1.5.2 The European hake (*Merluccius merluccius* – Linneaus, 1758)

HKE is a bony fish belonging to the *Merlucciidae* family and it represents one of the most important commercial resources for trawl and small scale fisheries using gillnets and bottom longlines (Martin *et al.*, 1999). This species is characterized by an elongated body with two dorsal fins and one anal fin. The colorations are slate-grey on the back and lighter on the sides; the belly is whitish (Fig. 6).

HKE occurs in the Mediterranean Sea and it is distributed in all the Italian biogeographical sectors (Relini & Lanteri, 2010). The European hake is a necto-benthic fish with a wide bathymetric distribution between 10 and 1000 m depth, although it is mainly found between 70 and 400 m (Orsi Relini *et al.*, 2002). The bathymetric distribution of these species is referred to the size: usually, the smallest specimens are caught more frequently on the external surface of the continental shelf (50 – 200 m depth), while the larger ones are distributed mainly along the continental slope (Colloca *et al.*, 2017). These specie prefers bottom muddy, but also lives in other substrate types (muddy-sandy and sandy).

The European hake growth in the Mediterranean Sea is still subject to debate, but it is generally agreed that growth may vary between cohorts, seasons and years, probably due to environmental factors such as temperature (Bănaru *et al.*, 2013).

HKE is a partial spawner: a female usually spawns 4 or 5 times before ovaries stop producing oocytes. In the SoS, the reproduction of HKE happens all the year round (Ragonese *et al.*, 2004). Recruitment and settlement occurs at a size of 2 – 8 cm Total Length (TL) (Orsi Relini *et al.*, 1989). In particular, in the northern side of the SoS are present 2 nursery areas situated in the eastern side of Adventure Bank and of Malta Bank between 100 and 200 m depth (Fiorentino *et al.*, 2006; Garofalo *et al.*, 2011).

Concerning the diet, the European hake feeding habits show ontogenetic changes. Juveniles feed mostly on euphausiids and mysids (Sartor *et al.*, 2003; Carpentieri *et al.*, 2008). The main changes in the diet occur when juveniles migrate from nurseries toward the coast and after achieving sexual maturity (Flamigni, 1984). As observed in the GSA 16, Decapod crustaceans are the main prey of specimens between 13 and 24 cm TL, whereas fish are the preferred food for specimens exceeding 25 cm TL (Andaloro & Arena, 1985). Moreover, Sinopoli *et al.* (2012) reported a diet change not only as a function of size, but also associated with the exploitation of fishing grounds in northern Sicily. According to Carrozzi *et al.* (2019), Euphausiids and mysids dominated the diet of hake smaller than 14 cm TL and crustacean decapods and fish were the main prey of hake between 14.5 cm to 17.5 cm TL. A shift toward pelagic and necto-benthic fish occurred over 18 cm TL: hake between 18 and 32 cm TL prey mostly upon Atlantic horse mackerel (*Trachurus trachurus*) whilst the silver scabbardfish (*Lepidopus caudatus*) was an important prey for hake over 32 cm TL.

As determined by the Reg. (EC) 1967/2006, the minimum landing size for this specie is of 20 cm TL and, in the GSA 16, the maximum length observed for females and males is of 92 cm and 58.5 cm, respectively.

Figure 6. Example of *Merluccius merluccius*.

### 1.5.3 The giant red shrimp (*Aristeomorpha foliacea* – Risso, 1827)

ARS is a large-sized decapod crustacean belonging to the *Aristaeidae* family with a scarlet red color firm though flexible and light exoskeleton and black eyes (Fig. 7). Adults show a secondary sexual dimorphism: the rostrum is short in males, whilst it extends beyond the antennal scale in females. Juveniles and sub-adults, not yet sexually mature, do not show such characteristics since males too have a long rostrum (Cau *et al.*, 1982; Ragonese & Bianchini, 1995).

ARS is considered a deep-water benthopelagic shrimp with a reported depth distribution of 120 – 1300 m, generally on muddy bottoms (Fischer *et al.*, 1987), but it lives mainly at depths comprised between 400 – 700 m (Cau *et al.*, 2002; Kapiris *et al.*, 2002). In particular, in Italian water, the geographical distribution of this species has a quite irregular trend: it is absent in northern and central Adriatic, while it is quite abundant in central and central-southern Tyrrhenian, in the SoS, the Ionian Sea and Sardinian Sea (Spedicato *et al.*, 1998; Belcari *et al.*, 2003; Carlucci *et al.*, 2006).

The length-frequency distribution of this species shows a discrete distribution by age classes and a polymodal trend, which highlights a clear sexual dimorphism, with females reaching bigger sizes than males (Cau *et al.*, 2002; Papaconstantinou & Kapiris, 2003). According to FAO species identification guides, the maximum body length of females is 225 mm (59 mm carapace length) and that of males 170 mm (45 mm carapace length). Females commonly measure 170 – 200 mm body length and males 130 – 140 mm (Fischer *et al.*, 1987; Carpenter & Niem, 1998). For the SoS, a length range of 16 – 74 mm and a median carapace length of 36 mm has been reported (Cau *et al.*, 2002; Ragonese *et al.*, 2004).

The giant red shrimp has a slow growth and a long life cycle, estimated in 7 – 9 years for females and 4 – 5 years for males (Cau *et al*., 2002; Papaconstantinou & Kapiris, 2003; Ragonese *et al*., 2012). Such differences are probably due to a different growth pattern between the two sex. Males reach sexual maturity earlier and this slow down their growth and life cycle duration (Ragonese *et al*., 2012).

Concerning the spawning period, it shows a clear seasonality, similar throughout the different Mediterranean areas, which extends between spring and summer. Females show a spawning peak between June and September whilst mature males can be found all year round (Ragonese & Bianchini, 1995; Belcari *et al*., 2003; Papaconstantinou & Kapiris, 2003). In particular, in the Central Mediterranean Sea, the recruitment of juvenile takes place in spring (Ragonese *et al*., 2004) when individuals have reached a size of 25 – 31 mm carapace length (Garofalo *et al*., 2011).

ARS shows a highly diversified diet (Cartes, 1995) and it is an active predator of big size and mobile organism (Cartes, 1995; Bello & Pipitone, 2002). The most abundant categories of prey include both organism typical of muddy bottoms and pelagic organisms; their diet includes crustaceans (e.g. *Plesionika* spp.), fishes (e.g. *Myctophidae* and *Macruridae*) and cephalopods (e.g. *Sepiolidae* and *Teuthoidea*) (Kapiris *et al*., 2010).

The length-frequency structure of the giant red shrimp catches shows a polimodal distribution and a clear sexual dimorphism, with females reaching bigger sizes than males (Ragonese *et al*., 1994; Cau *et al*., 2002; Papaconstantinou & Kapiris, 2003). Generally, the length-frequency distribution analysis can identify 4 – 5 modal classes for females and 3 – 4 for males (Leonardi & Ardizzone, 1994; Ragonese *et al*., 1994; D’Onghia *et al*., 1998; Ragonese *et al*., 2012). Literature on growth of ARS according to the Von Bertalanffy growth model was reviewed by Fiorentino *et al*. (2013a).

ARS constitutes an important economic resource from trawl fisheries in many areas of Mediterranean (Ragonese *et al*., 1994; Cau *et al*., 2002; Belcari *et al*., 2003; Mytilineou *et al*., 2006). According to the Ministry of Agriculture Food and Forestry Policies (Mipaaf), the southernSicily is the area with the highest catches accounting more than 1400 average tons per year and an increasing trend in the years 2003 – 2013.

Concerning the management measures, no specific management plans for this species currently exist neither for the Mediterranean basin nor for individual Italian GSAs. At the present, no minimum landing size is in force in the Reg. (EC) 1967/2006.

Figure 7. Examples of *Aristeomorpha foliacea*.

### 1.5.4 The red mullet (*Mullus barbatus* – Linneaus, 1758)

MUT is a bony fish belonging to the *Mullidae* family and it represents one of the most important commercial species in Italy; even though it is not always the main *target* of fishery, it is an important component of the landing both of the bottom trawl and small-scale fisheries (Fiorentini *et al.*, 1997; Tserpes *et al.*, 2002). The red mullet is characterized by a slightly laterally compressed body, a short snout with an almost vertical anterior profile, an opercule without spines and 2 barbels under the mandibular symphysis. Its colour is pinkish and not uniform, sometimes with barely visible yellow bands (Fig. 8).

MUT is widespread in all the Mediterranean Sea; it is a benthic fish living on sandy and muddy bottoms, showing a marked preference for shelf bottoms (5 – 250 m), although a wider bathymetric range has been reported in some Mediterranean areas (Voliani, 1999). In this contest, the bathymetric distribution pattern of this species is characterized by a massive coastal recruitment during summer, followed by a gradual dispersion towards deeper waters (Voliani *et al.*, 1991; Abella *et al.*, 1996).

The species is fast growing and reaches more than half of its total size during its first year of life. Growth varies between sexes: females are characterised by a faster growth rate and larger size, reaching 28 – 29 cm TL, while males grow more slowly and seldom exceed 20 cm TL (Voliani, 1999).

Red mullet reproduction is almost exclusively from May to July (Menini *et al.*, 2001; Pesci, 2006; Fiorentino *et al.*, 2008). Almost the entire population spawns within the first year of life and the size at first maturity ranging from 10 to 13 cm TL for males and from 10.5 to 14 cm TL for females (Pesci, 2006; Fiorentino *et al.*, 2008).

MUT mainly feeds on small benthic invertebrates (crustaceans, polychaets, echinoderms, bivalve mollusks) (Lipari *et al.*, 1998). In particular, among small crustaceans, anphipods, mysids and isopods are frequently found; more occasional findings regard cephalopods (Lipari *et al.*, 1998). The diet of the red mullet is size-related, with an increase in polychaetes and shrimps consumption and a decrease in the consumption of small crustaceans in specimens of larger sizes (Bautista-Vega *et al.*, 2008). Differences in diet between males and females may be found, probably related to differences in their growth rates (Vassilopoulou & Papaconstantinou, 1993).

The Reg. (EC) 1967/2006 fixed the minimum legal size for *Mullus spp.* for European countries in the Mediterranean at 11 cm TL.

Figure 8. Example of *Mullus barbatus*.

### 1.5.5 The horse mackerel (*Trachurus trachurus* – Linneaus, 1758)

The horse mackerel (HOM, *Trachurus trachurus* – Linnaeaus, 1758) is a bony fish belonging to the *Carangidae* family and it represents the main discarded by-catch of the DPS fishery. It has an accessory lateral line along the whole back provided with very large bone scutes whose length represents the most striking feature distinguishing the three species of horse mackerel (*T. trachurus*, *T. mediterraneaus* and *T. picturatus*). In particular, in HOM, the line is longer than in the other species and extends beyond the soft rays of the second dorsal fin (23 – 31), being the bony scutes larger than the other two species.

A distinctive feature of *T. trachurus* coloration is represented by a small black spot on the edge of the *operculum*, in the upper corner. The upper part of the body and head, range from black to gray and to bluish-green, the lower part of the body and the head are generally lighter, whitish or silvery (Fig. 9).

This species can reach a maximum size of 60 cm TL, although it is commonly found between 15 and 30 cm TL (Relini *et al.*, 1999).

As regards geographical distribution, HOM can be found throughout the Mediterranean Sea. *T. trachurus* is frequented found a depth between 10 and 500 m; generally, in winter it moves significantly away from the coast and down to a deep exceeding 500 m. In the SoS, this species was caught also in deep waters (down to 600 m or more), but generally it shows a preference for a depth range comprised between 100 – 200 m (Ragonese *et al.*, 2004).

Concerning the diet, HOM feeds on different prey species belonging to Crustacea (Euphausiacea, Mysidacea, Decapoda), Cephalopoda and Teleosts. In particular, euphausiids (essentially the species *Nyctiphanes couchii* and *Euphausia krohni*) represent the most important prey in all seasons, both in small and medium-size classes (Šantić *et al.*, 2005).

According to the EC Reg. No. 1967/2006, the minimum landing size fot *T. trachurus* is 15 cm TL.

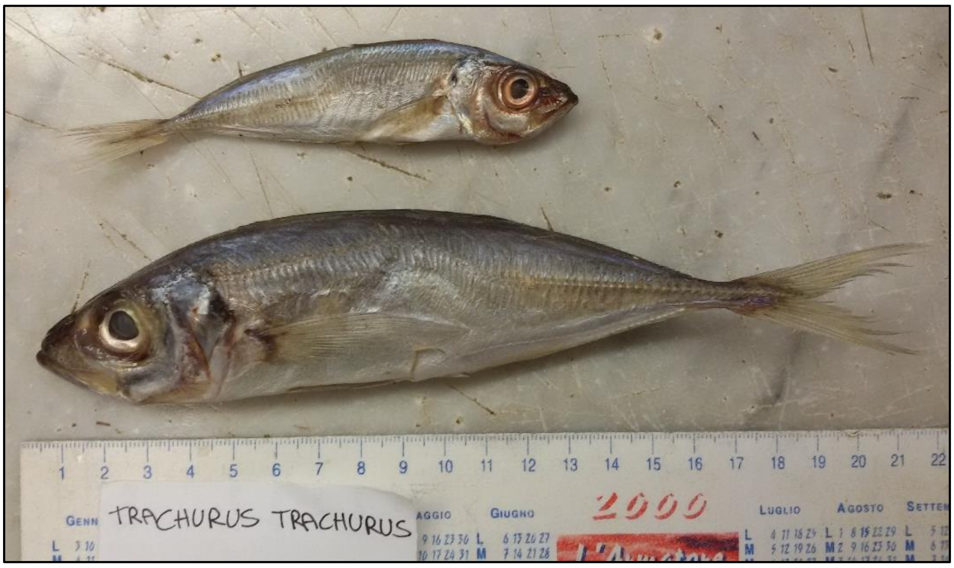


Figure 9. Examples of *Trachurus trachurus*.

## 1.6 The Use of Spatial Bio-Economic Models in Fishery Assessment

Fishery systems, in terms of fish stocks, fleets that exploit them and the stakeholders involved in the processing, storage and marketing process, represent complex systems that need to be managed in order to ensure a sustainable and efficient exploitation of marine resources (Garcia *et al.*, 2015). In the last years, driven by the EAF management (Curtin & Prellezo, 2010), the need to incorporate the economic and social dimensions into the management process has more and more been recognized. In particular, biological evaluation of management measures is usually conducted by a Management

Strategy Evaluation (MSE) approach (Punt *et al.*, 2016) consisting of simulation of the fish stocks and the fleets that exploit them together with the management process (Garcia *et al.*, 2015).

In this contest, there is growing use and interest in Bio-Economic Models (BEM) as tools for understanding pathways of development and fishery behaviour, in order to assess the impact of different management strategies on the natural resource and human welfare (Lleonart & Maynou, 2003; Mattos *et al.*, 2006; Maynou *et al.*, 2006; Prellezo *et al.*, 2012). These tools quantify the effects arising from the application of specific management measures to particular stocks, to simulate different scenarios and to obtain an evaluation of risks associated with different levels of resource exploitation (Silvestri & Maynou, 2009).

With reference to its original definition, the "sustainability" is a multidisciplinary concept comprising the environment (and the natural capital), the economics and the society. Considering only one of these pillars is wrong and lead to ineffective measure. For this reason, bioeconomic models are nowadays the best tool to explore potential management actions (Imperatives, 1987). Consequently, the bio-economic models are essential tools for the administrators and decision-makers because they offer a way to simulate and evaluate the economic and biological effects of different management measures (technical, economic or both) in short and mid time; this could be very useful in the design of policies for mid-term objectives and for exploring different ways to attain them. Moreover, models offer fishermen and managers a new perspective on the behaviour of the system, including its temporal scale. In particular, the bio-economic models could contribute to an increased comprehension of the usefulness or uselessness of certain management measures and establish the difference between short and mid-term regarding gains and losses (Lleonart & Maynou, 2003).

Actually, there are different bio-economic models existing in fisheries science that enable to simulate and to evaluate the impact of management measures. Different available models are characterised by differences in data requirement, modelled processes and assumptions. Some of these bio-economic models and their main characteristics are shown in Table 2.

The added value of smartR is that it allows to model both mixed fisheries and trophic relationships among exploited species. Modelling of fleet behaviour is performed at the vessel-level and prediction of effort displacement is performed through an individual-based model, similar to the approach used in the DISPLACE, the most similar available software. Notably, however, smartR is entirely realized in R. Therefore, it can be customized or further developed by users and all intermediate objects and metadata are fully accessible.

For my thesis project, I decided to use a spatial bio-economic model called SMART (Spatial MAnagement of demersal Resources for Trawl fisheries) (Russo *et al.*, 2014, 2019). This model was developed specifically to evaluate spatial and temporal regulation of trawling effort in the

Mediterranean fisheries. Furthermore, SMART is a multi-species and multi-fleet bio-economic model that assess the potential effects of different trawl fisheries management scenarios on the demersal resources, while assessing the economic performances of fleets. For these reasons, it was chosen as the appropriate tool to evaluate the effects of the implementation of the three GFCM FRAs on the Italian coastal trawlers operating in the SoS which could be affected by the spatial closures. The characteristics and the structure of this model are shown in the next paragraph.

Table 2. Some of the bio-economic models present in literature and their main characteristics.

| **Model** | **SMART** | **DISPLACE** | **InVest** | **ISIS-Fish** | **SIMFISH** | **TI-FishRent** |
|---|---|---|---|---|---|---|
| Age structure | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Length structure |  | ✓ | ✓ | ✓ |  |  |
| Multiple gears |  | ✓ | ✓ | ✓ | ✓ | ✓ |
| Multispecies/mixed fisheries | ✓ | ✓ |  | ✓ | ✓ |  |
| Connectivity (larval dispersal/adult migration) | ✓ |  | ✓ | ✓ |  | ✓ |
| Prediction of effort displacement | ✓ | ✓ |  |  | ✓ | ✓ |
| Simulation of scenario (including temporal and/or spatial closure) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Modelling of trophic relationship among species | ✓ |  |  |  |  |  |
| Agent-based modelling (IBM of fishers) | ✓ | ✓ |  |  | ✓ |  |
| **References** | D'Andrea *et al.*, 2020a | Bastardie *et al.*, 2014 | Sharp *et al.*, 2016 | Mahèvas & Pelletier, 2004 | Bartelings *et al.*, 2015 | Simons *et al.*, 2014 |

## 1.7 The SMART Model

SMART (Spatial MAnagement of demersal Resources for Trawl fisheries) is a spatially explicit bio-economic model aimed to assess the state of demersal resources and to evaluate certain aspects of bio-economic performance of different trawl fisheries management scenarios on the demersal resources (Russo *et al.*, 2014, 2019). Initially, this model was applied to assess behaviour of demersal fisheries in the Strait of Sicily and some aspects of bio-economic performance under different management scenario. The species used as proxies for these aims are three of the main *target* species of trawl fisheries in the SoS: the deep water rose shrimp (*Parapenaeus longirostris*, Lucas 1847), the European hake (*Merluccius merluccius*, Linneaus 1758) and the red mullet (*Mullus barbatus*, Linneaus 1758).

According to Russo *et al.* (2014), SMART was developed by setting up and combining the following 4 tools:

1) a spatial analysis approach which models the distribution of demersal resources, fishing effort and abiotic factors in order to produce matrices of geo-referenced data in the investigated area for the years 2006 – 2010;
2) an Artificial Neural Network (ANN) which captures the relationships between resources, fishing effort and abiotic factors on the basis of the time series of matrices obtained from the previous step, and then predicts resources abundance and distribution in the near future;
3) a deterministic model that computes the specific size structure of catches corresponding to a given combination of resources distribution and fishing effort using classic fishery science equations. These catches are then converted into revenues on the basis of market prices by species/size, while a simple model is used to compute the fuel costs associated to the fishing effort pattern. Finally, revenues and costs are used to obtain gains;
4) a simulation approach using the previous tools to explore the effects of different management scenarios of fishing effort on resources abundance in the near future. This component of the model works by iteratively generating patterns of fishing effort for different scenarios and then applying tools 2 and 3 to predict the bio-economic effects.

In 2019, inside the project "Marine protected Areas Network Toward Sustainable fisheries in the Central Mediterranean" (MANTIS), SMART was updated and improved and distributed as an R package (smartR) (Russo *et al.*, 2019). In this new version, the innovative aspect of SMART is represented by the bi-directional connectivity between spawning and nurseries areas of *target* species in terms of both larval dispersal and adult migration, embedding the outcomes of a larvae transport Lagrangian model and of an empirical model of fish migration. This aspect is essential to understand how closing a given area (or a set of areas) is reflected outside and how the spillover effect from

FRAs to adjacent area could contribute to improve both fisheries and status of the stocks in the whole system (Pincin & Wilberg, 2012; McGilliard *et al.*, 2015).

In particular, SMART was applied in the Central Mediterranean Sea to assess the potential effects of different trawl fisheries management scenarios on 4 demersal species of high commercial value: the deep water rose shrimp, the European hake, the giant red shrimp and the red mullet. These approach combines multiple modeling components, integrating the best available sets of spatial data about catches and stocks, fishing footprint from Vessel Monitoring Systems (VMS) and economic parameters in order to describe the relationships between fishing effort pattern and impacts on resources and socio-economic consequences.

The final workflow of the SMART approach is described in Figure 10 and summarized as follows:

1. processing landings data, combined with VMS data, to estimate the spatial/temporal productivity of each cell, in terms of aggregated Landings Per Unit of Effort (LPUE) by species, according to the method described and applied in Russo *et al.* (2018);
2. processing biological data to estimate LPUE by age and by species, for each cell/time;
3. analysing VMS data to access the fishing effort by vessel/cell/time;
4. combining LPUE by age with VMS data to model the landings by vessel/species/length class/time/cell;
5. estimating the cost by vessel/time associated with a given effort pattern and the related revenues, as a function of the landings by vessel/species/length class/time (step 4);
6. combining costs and revenues by vessel, at the early scale, to obtain the profit, which is the proxy of the vessel performance. Profit could be aggregated at the fleet level to estimate the overall performance;
7. using estimated landings by species/age, together with survey data, to run mice model for the selected case of study in order to obtain a biological evaluation of the fisheries.

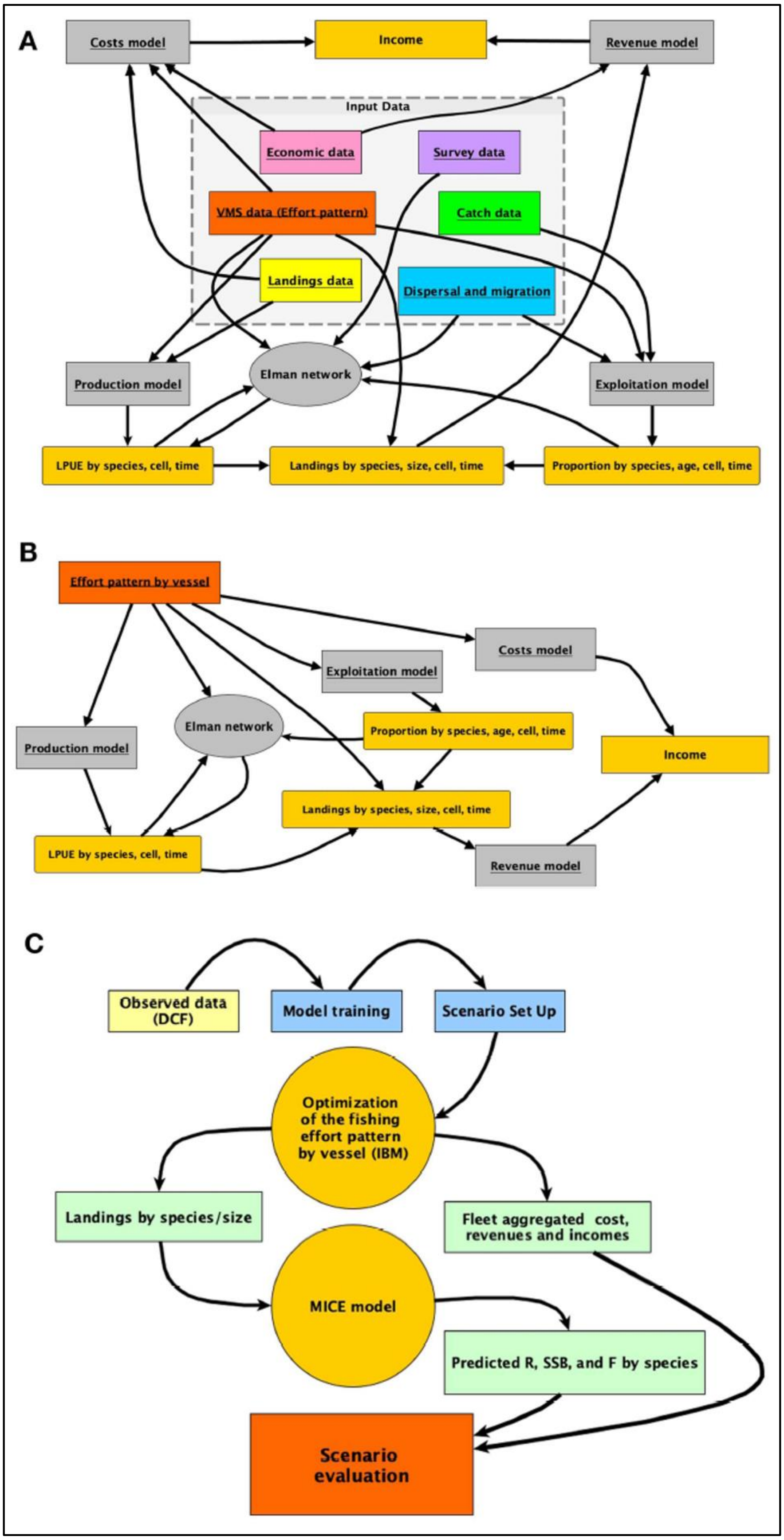


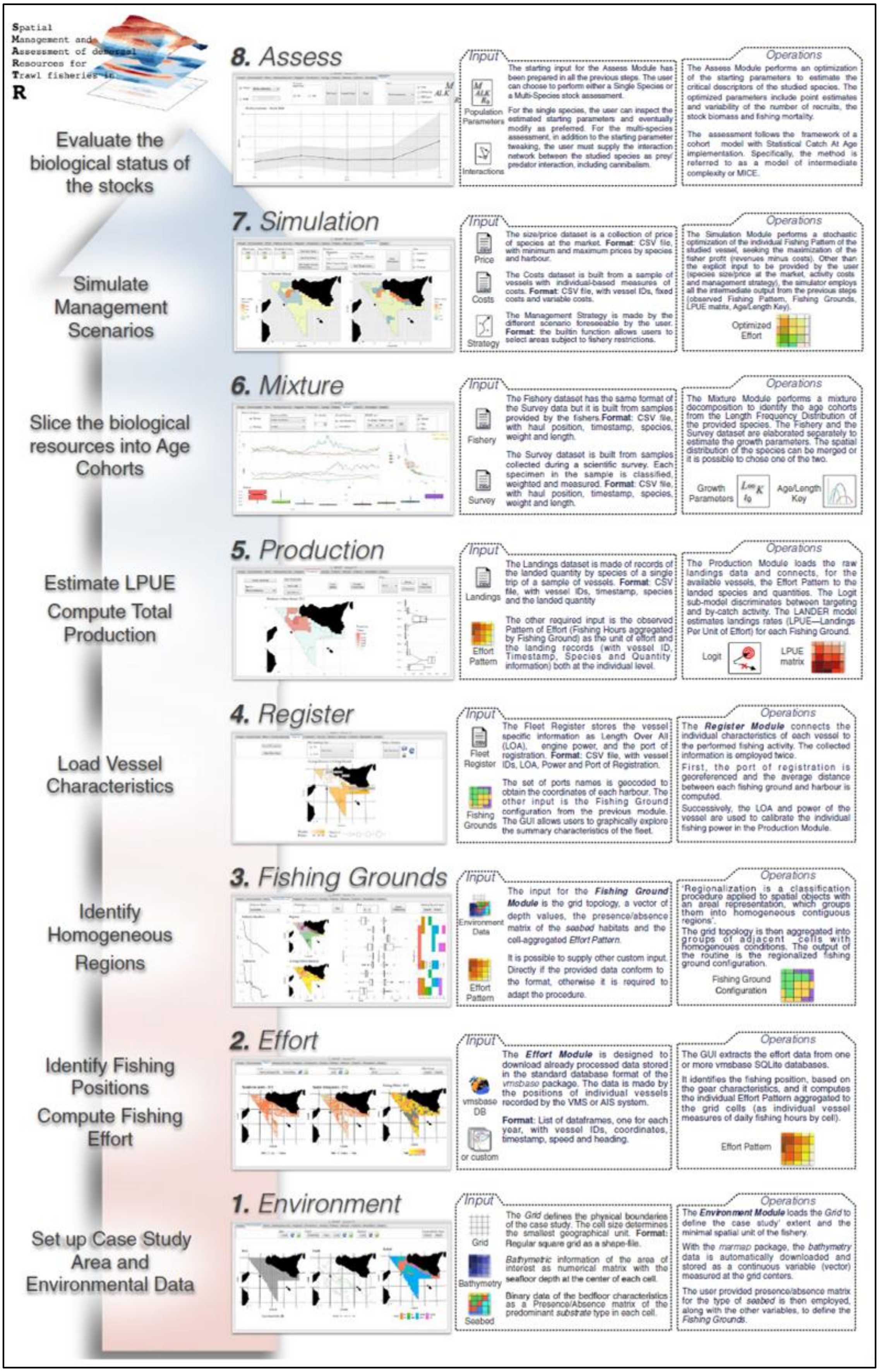
Figure 10. Representation of (A) the architecture of the SMART model, showing as the different input data are processed by different modules; (B) summary of the IBM implemented to obtain the economic quantities to be optimized in relation to the effort pattern of each vessel; (C) the typical workflow, from DCF data to the final MSE evaluation. Picture taken by Russo *et al.* (2019).

SMART is distributed and can be used as an R package (smartR). Within this package it is possible to achieve the complete set of analyses required by the SMART approach: from the editing and formatting of the raw data; the construction and maintenance of coherent datasets; the numerical and visual inspection of the generated metadata; to the final simulation of management scenarios and the forecast of their effects (D'Andrea *et al.*, 2020b). The smartR package is built adopting the object-oriented framework through the functionalities provided by the R6 package (Chang, 2017).

In particular, the smartR package processes and combines the data derived from three fundamental points of the fishery system: the environment, the working fleet and the biological resource. These three distinct components can be further subdivided and systematized as follows:

1. Environment:
    - grid topology;
    - bathymetry;
    - seabed categories.
2. Fleet:
    - Vessel Monitoring System/Automatic Identification System
    - fleet register;
    - economy (costs and gains);
    - production.
3. Resource:
    - spatial/temporal distribution;
    - demographic distribution.

Overall, according to D'Andrea *et al.* (2020a) the smartR workflow comprises 8 main (and one accessory) Graphical User Interfaces (GUI), or modules (Fig. 11): (1) environment configures the case study area with three environmental layers (grid, bathymetry and seabed); (2) effort loads the fishing effort database, assigns fishing locations and aggregates the data to the grid (as fishing hours); (3) fishing grounds subdivides the study area into homogeneous regions; (4) register loads fleet register data (vessel IDs, length, power and registration port); (5) production reconstructs the spatial origin of the catches and estimates the Landings (or catches) per Unit of Effort (i.e. LPUE as Kgs × fishing hours × vessel length) for each fishing ground; (6) mixture and cohorts (cohorts is the accessory GUI) loads Length Frequency Distributions (LFD) from survey and fishery datasets, determines growth parameters, subdivides the studied stocks into cohorts and visualizes the spatial distribution of the cohorts; (7) simulation estimates costs and revenues, and simulates different management scenarios; (8) assess evaluates the biological status of the studied stocks. smartR adopts the object-oriented framework provided by the R6 package (Chang, 2017).



The starting input for the Assess Module has been prepared in all the previous steps. The user can choose to perform either a Single Species or a Multi-Species stock assessment.

For the single species, the user can inspect the estimated starting parameters and eventually modify as preferred. For the multi-species assessment, in addition to the starting parameter tweaking, the user must supply the interaction network between the studied species as prey/predator interaction, including cannibalism.

The Assess Module performs an optimization of the starting parameters to estimate the critical descriptors of the studied species. The optimized parameters include point estimates and variability of the number of recruits, the stock biomass and fishing mortality.

The assessment follows the framework of a cohort model with Statistical Catch At Age implementation. Specifically, the method is referred to as a model of intermediate complexity or MICE.

The size/price dataset is a collection of price of species at the market. **Format**: CSV file, with minimum and maximum prices by species and harbour.

The Costs dataset is built from a sample of vessels with individual-based measures of costs. **Format**: CSV file, with vessel IDs, fixed costs and variable costs.

The Management Strategy is made by the different scenario foreseeable by the user. **Format**: the builtin function allows users to select areas subject to fishery restrictions.

The Simulation Module performs a stochastic optimization of the individual Fishing Pattern of the studied vessel, seeking the maximization of the fisher profit (revenues minus costs). Other than the explicit input to be provided by the user (species size/price at the market, activity costs and management strategy), the simulator employs all the intermediate output from the previous steps (observed Fishing Pattern, Fishing Grounds, LPUE matrix, Age/Length Key).

The Fishery dataset has the same format of the Survey data but it is built from samples provided by the fishers. **Format**: CSV file, with haul position, timestamp, species, weight and length.

The Survey dataset is built from samples collected during a scientific survey. Each specimen in the sample is classified, weighted and measured. **Format**: CSV file, with haul position, timestamp, species, weight and length.

The Mixture Module performs a mixture decomposition to identify the age cohorts from the Length Frequency Distribution of the provided species. The Fishery and the Survey dataset are elaborated separately to estimate the growth parameters. The spatial distribution of the species can be merged or it is possible to chose one of the two.

The Landings dataset is made of records of the landed quantity by species of a single trip of a sample of vessels. **Format**: CSV file, with vessel IDs, timestamp, species and the landed quantity

The other required input is the observed Pattern of Effort (Fishing Hours aggregated by Fishing Ground) as the unit of effort and the landing records (with vessel ID, Timestamp, Species and Quantity information) both at the individual level.

The Production Module loads the raw landings data and connects, for the available vessels, the Effort Pattern to the landed species and quantities. The Logit sub-model discriminates between targeting and by-catch activity. The LANDER model estimates landings rates (LPUE—Landings Per Unit of Effort) for each Fishing Ground.

The Fleet Register stores the vessel specific information as Length Over All (LOA), engine power, and the port of registration. **Format**: CSV file, with vessel IDs, LOA, Power and Port of Registration.

The set of ports names is geocoded to obtain the coordinates of each harbour. The other input is the Fishing Ground configuration from the previous module. The GUI allows users to graphically explore the summary characteristics of the fleet.

The ***Register Module*** connects the individual characteristics of each vessel to the performed fishing activity. The collected information is employed twice.

First, the port of registration is georeferenced and the average distance between each fishing ground and harbour is computed.

Successively, the LOA and power of the vessel are used to calibrate the individual fishing power in the Production Module.

The input for the ***Fishing Ground Module*** is the grid topology, a vector of depth values, the presence/absence matrix of the *seabed* habitats and the cell-aggregated *Effort Pattern*.

It is possible to supply other custom input. Directly if the provided data conform to the format, otherwise it is required to adapt the procedure.

'Regionalization is a classification procedure applied to spatial objects with an areal representation, which groups them into homogeneous contiguous regions'.

The grid topology is then aggregated into groups of adjacent cells with homogenoues conditions. The output of the routine is the regionalized fishing ground configuration.

The ***Effort Module*** is designed to download already processed data stored in the standard database format of the *vmsbase* package. The data is made by the positions of individual vessels recorded by the VMS or AIS system.

**Format**: List of dataframes, one for each year, with vessel IDs, coordinates, timestamp, speed and heading.

The GUI extracts the effort data from one or more vmsbase SQLite databases.

It identifies the fishing position, based on the gear characteristics, and it computes the individual Effort Pattern aggregated to the grid cells (as individual vessel measures of daily fishing hours by cell).

The *Grid* defines the physical boundaries of the case study. The cell size determines the smallest geographical unit. **Format**: Regular square grid as a shape-file.

*Bathymetric* information of the area of interest as numerical matrix with the seafloor depth at the center of each cell.

Binary data of the bedfloor characteristics as a Presence/Absence matrix of the predominant *substrate* type in each cell.

The ***Environment Module*** loads the *Grid* to define the case study' extent and the minimal spatial unit of the fishery.

With the *marmap* package, the *bathymetry* data is automatically downloaded and stored as a continuous variable (vector) measured at the grid centers.

The user provided presence/absence matrix for the type of *seabed* is then employed, along with the other variables, to define the *Fishing Grounds*.

Figure 11. Architecture and workflow of the smartR package. Picture taken by D'Andrea *et al*. (2020a).

In particular, the environmental data is assembled from 3 main input: a grid topology, a bathymetry matrix and seabed classification (Tab. 3; Fig. 11).

Table 3. Environment panel description.

| **COMPONENT** | **FUNCTIONALITY** |
|---|---|
| Grid - Load | Opens a file selection window to choose a shapefile and set up the graphical output |
| Depth – Download | Downloads the bathymetry of the area of interest |
| Depth – Save | Stores the bathimetric data as an XYZ matrix |
| Depth - Load | Loads an XYZ matrix as bathimetric data |
| Seabed - Load | Opens a file selection window to choose a seabed shapefile and set up the graphical output |
| Asset – Export | Stores grid, depth and seabed data as an RDS object |
| Asset - Import | Loads the environmental RDS object with grid, depth and seabed data |

The fleet dataset is the second main descriptive data required to use the smartR package. It integrates the actual fishing effort allocated in the area of interest (of VMS/AIS equipped vessels) and the general characteristics of each vessel (from the fleet register) within the working fleet (Tab. 4; Fig. 11).

Table 4. Effort panel description.

| **COMPONENT** | **FUNCTIONALITY** |
|---|---|
| Load – from vmsbase DB | Opens a file selection window to choose a proper vmsbase DB |
| Load – from rData | Opens a file selection window to choose an already exported rData file with vms data |
| Fishing Point - Set | Opens a new window to set the speed and depth parameters to filter the fishing points |
| Maps - Droplist | Draws the raw points, fishing points and gridded data for the selected temporal frame |
| Asset – Export | Stores raw points, fishing points and gridded data as an RDS object |
| Asset - Import | Loads the effort RDS object with raw points, fishing points and gridded data |

The vessel register dataset is loaded and cross-linked, by the common field carrying the vessel identification number information, to the already loaded tracking device dataset (Tab. 5; Fig. 11).

Table 5. Fleet register panel description.

| COMPONENT | FUNCTIONALITY |
|---|---|
| Load EU register<br>View Raw Data | Opens a file selection window to choose a csv file with the standard output provided by the FRONT (2018) portal<br>Opens a new window to show the loaded raw data |
| Plot Summary Data | Shows summary statistics for all the loaded register data or for only the vms equipped vessels |
| Get Harbour<br>Folder Icon<br>Save Icon | Retrieves the geographical coordinates for the harbours in the fleet register field<br>Opens a file selection window to choose the RDS file of harbours' coordinates<br>Stores the harbours' coordinates as an RDS file |

To analyse the patterns of effort, catches and production at the higher level of the fishing ground, the data at the cell level is spatially aggregated (Tab. 6; Fig. 11).

Table 6. Fishing ground panel description.

| COMPONENT | FUNCTIONALITY |
|---|---|
| Distance Metric | Droplist to select different distance or similarity measures |
| Clustering | Slider to select the maximum number of cluster to test |
| Run | Button to start the SKATER clustering routine |
| Plot | Droplist to show the output of the slicing with different number of clusters |
| Select Partitioning | Button to select the current number of clusters |
| Asset – Export<br>Asset - Import | Stores the regionalisation result as an RDS object<br>Loads the previously saved regionalisation result from an RDS object |

The information collected, from both scientific surveys and commercial fisheries datasets, is subject to an analogous, but still separated, processing routine. The data is loaded, the distinct years and specie observed are stored, and then, if more than one specie is considered, the data is separated in different sub-classes, one for each of the reported specie, and the subsequent operations are carried out on the distinct specie. Finally, using the geo-referenced information, each Length Frequency Distribution (LFD) record of the resource data is allocated to the geographically corresponding cell of the grid (Tab. 7; Fig. 11).

Table 7. Mixture panel description.

| **COMPONENT** | **FUNCTIONALITY** |
|---|---|
| Mixture Analysis - Radio | Radio buttons to select the input data between the survey or the fishery dataset |
| Specie – Droplist | Droplist to select the specie to analyse in the chosen dataset |
| Sex - Droplist | Droplist to select the sex to analyse for chosen specie/dataset |
| N. Cohorts | Droplist to select the maximum number of cohort to test in the mixture analysis |
| Growth Curve | Radio buttons to select a growth curve to employ in the analysis between "von Bertalanffy" and "Gompertz" |
| MCMC sim – N. Adapt | Number of adaptation steps in the MCMC simulation |
| MCMC sim – Sample size | Number of samples to employ in the MCMC simulation |
| GO | Button to start the MCMC simulation |
| View | Radio buttons to show the main graphical output between the MCMC diagnostics, Age/Length key and the Birth graph |

The raw production data is loaded (Tab. 8; Fig. 11) and the first operation stores the unique identifiers of the fishing vessels and cross-matches the vessels with the same identifiers in the fleet dataset.

Table 8. Production panel description.

| **COMPONENT** | **FUNCTIONALITY** |
|---|---|
| Load Landings | Opens a file selection window to choose a proper file of landings data |
| Specie | Droplist to select the current specie to analyse |
| Set Threshold | Opens a new window with a GUI to select a weight threshold as input for the Logit |
| Get Logit | Opens a new window with a GUI to setup the input parameters for the Logit model |
| Get NNLS | Opens a new window with a GUI to setup the input parameters for the NNLS model |
| Tune Betas | Opens a new window to filter the results of the NNLS model |
| Predict Production | Predicts the landings of the current specie |
| View – Year | Droplist to select the time frame of the statistical summary |
| View – Betas | Shows the spatial pattern of the beta values for the selected Year |
| View – Production | Shows the spatial pattern of the production values for the selected Year |
| View – Total Production | Shows the summary statistics of total production and beta values |

The economic performance of the fleet results from the balance between total cost and revenues of every vessel actively involved in the fishery. Thus, to gauge the economic performance of the fishing fleet at the individual level, it is necessary to relate the operational cost to the fishing activity and, concurrently, obtain a measure of the revenues of the same fishing activity. Practically, the magnitude of the economic performance is given by the outcome of the deployed strategy, as gains, which results from the subtraction of the cost from the revenues. The first step is the computation of a set of three economic indicators (spatial index, number of days at sea and production index) (Tab. 9; Fig. 11). The second step is the estimate of the costs relative to each one of the three indicators. The third step is the computation of the revenues from the total landed quantity for each specie and, lastly, the subtraction of the costs from the revenue to get the gains.

Table 9. Simulation panel description.

| **COMPONENT** | **FUNCTIONALITY** |
|---|---|
| Effort Index - Get | Button to start the computation of the values for the Effort Index |
| Days at Sea - Get | Button to start the computation of the Days At Sea |
| Production Index - Get | Button to start the computation of the values for the Production Index |
| Set Cost Data | Opens a new GUI window to load the economic data and setup the regression models for the economic performance |
| Set Size Class | Opens a new GUI window to setup the size/price class for each specie |
| Set length/weight relationship | Opens a new GUI window to compute the Length/Weight relationship for each specie |
| Scenario – Threshold | Slider to setup the optimization threshold for the scenario Simulation |
| Scenario – Time scale | Radio button to select the time scale of the scenario simulation between yearly or seasonal |
| Scenario – Set Closed Area | Opens a new GUI windows to select the closed areas for the spatial restriction in the scenario simulation |
| Scenario – Start Simulation | Button to begin the scenario simulation |
| View | Radio button to show the output of the simulation between the summary statistics, absolute or relative values of effort' change |

The Stock Assessment procedure implemented in smartR (Tab. 10; Fig. 11) is a MICE model (Punt *et al.*, 2016). The chosen framework models a simple Statistical Catch At Age (SCAA) with a basic population dynamic which follows the classical approach of Doubleday 1976 where the catch-at-age datasets are fitted for multiple cohorts simultaneously and the fishing mortality is split into age and year components.

Table 10. Stock assessment panel description.

| **COMPONENT** | **FUNCTIONALITY** |
|---|---|
| Single – Specie<br>Multi – Set Interaction | Radio button and droplist to select a specie to analyse with a single specie approach<br>Opens a new GUI window to setup the interaction between specie with a multi-specie approach |
| Forecast Next Year | Radio button to specify if the forecast of the year+1 should be done or not |
| Set Input | Button to setup the initial parameters for the stock assessment |
| Inspect Input | Opens a new GUI window to show the input parameter computed and to be used in the stock assessment |
| Start | Button to begin the computation |
| View | Droplist and radio button to show the results of the stock assessment, for the selected, specie between SSB, Observed/Predicted values for the survey/catch data or the Total Catch values |

# 2. PAPER 1: Evaluation of the Economic Performance of Coastal Trawling off the Southern Coast of Sicily (Central Mediterranean Sea)

## 2.1 ABSTRACT

The economic performances of four trawling fleets (those of the Sicilian cities of Trapani, Sciacca, Licata and Porto Palo di Capo Passero) operating in the coastal waters along the southern coast of Sicily (Geographical SubArea 16), and potentially affected by the establishment of the Fisheries Restricted Areas (FRAs), were analysed. The main economic performance results (revenues, costs and profits) of 37 trawlers were calculated prior to the implementation of FRAs and compared with those estimated by the spatial bio-economic model SMART after the FRAs' establishment. Results showed that the fleets of Sciacca and Licata, located in the central part of the southern Sicilian coast, had a short-term reduction of profits as a result of the implementation of the FRAs; conversely, a short-term increase in the economic performances of Trapani and Porto Palo di Capo Passero fleets was expected. Although the FRAs represent a good tool for rebuilding overexploited stocks, the different socio-economic impacts of the single fleets should be assessed before adopting them and the implementation of specific compensative measures should be planned for the impacted fleet until a more productive state of the stock is reached.

**Keywords:** bottom trawling, catch composition, bio-economic model, SMART, Strait of Sicily.

## 2.2 INTRODUCTION

Fisheries play a key role in providing food, income and employment in many parts of the world (Jennings *et al.*, 2009). In particular, marine capture fisheries have a significant role in reaching the nutritional requirements of the population, providing food security, particularly for the coastal population of developing countries, and achieving the Sustainable Development Goals (SDGs) (Hák *et al.*, 2016).

Despite these important roles in the world food system, too often fisheries have been determined as undertaking the unsustainable exploitation of resources (the so-called overfishing) and fish stocks are in decline worldwide (Branch *et al.*, 2011; Gascuel *et al.*, 2012; Prellezo *et al.*, 2012; Hilborn *et al.*, 2020; Pauly *et al.*, 2022).

Within this context, the socio-economic dimensions assume a fundamental role, encompassing both the basic bio-economic aspects of fisheries and the different effects of fishery policies on stakeholders and their potential social consequences (Garcia *et al.*, 2018). Comparative scenario analyses of different potential remedial actions examine the economic costs and benefits of stock rebuilding policies when stocks are overfished or depleted (Garcia *et al.*, 2018) and economic indicators provide powerful instruments in assessing and supporting fishery management (Pinello & Dimech, 2013; Sreekanth *et al.*, 2017).

The Strait of Sicily (SoS hereafter), situated in the central Mediterranean Sea, represents one of the highest productive areas for demersal fisheries of the basin (Gristina *et al.*, 2006; Fiorentino *et al.*, 2013a; Di Lorenzo *et al.*, 2017; Russo *et al.*, 2019; Geraci *et al.*, 2021). In 2016, the 395 Italian bottom trawlers operating in this area landed approximately 13,300 tons with an economic value of EUR 114 million (Maiorano *et al.*, 2019). The deep-water rose shrimp (DPS, *Parapenaeus longirostris*–Lucas, 1846), the European hake (HKE, *Merluccius merluccius*–Linnaeus, 1758), and the giant red shrimp (ARS, *Aristaeomorpha foliacea*–Risso, 1827) represent the main demersal targeted species with a yield of about 5290, 1490 and 1370 tons, respectively, and total revenue of approximately EUR 75.6 million in 2016 (Maiorano *et al.*, 2019). According to the most recent stock assessment (GFCM, 2016), both HKE and DPS are overfished with a high proportion of undersized catches.

To help reduce overfishing, the General Fisheries Commission for the Mediterranean (GFCM) established three Fisheries Restricted Areas (FRAs) in the SoS, corresponding to areas where juveniles of European hake and deep-water rose shrimp aggregate annually (stable nurseries), aimed at improving the exploitation pattern of both HKE and DPS (FAO, 2016). In these FRAs, located close to the Sicilian coast to the east of Adventure Bank, west of Gela Basin and east of Malta Bank (http://www.fao.org/gfcm/data/maps/fras), trawling activities are prohibited. By using the spatially explicit bio-economic model SMART (Spatial MAnagement of demersal Resources for Trawl fisheries), Russo *et al.* (2019) demonstrated that the three FRAs improved both the state of HKE and DPS stocks and the overall fishery economic performance of the whole Italian trawler fleet operating in the SoS. However, since these closures can affect different fleets according to the spatial position of their traditional fishing grounds, further studies to assess the possible negative economic effects of management measures at local level are advisable.

In the present study, the economic performances of the trawling fleet operating in the SoS were analysed in order to (i) provide more detailed information on the structure of the different Italian trawling fleets operating in the SoS, in terms of capacity indicators and (ii) apply the spatial bio-economic model SMART to estimate the different effects in terms of short economic performances on single fleets operating close to the Italian territorial waters which are assumed to be more strongly affected by the FRAs.

## 2.3 MATERIALS AND METHODS

### 2.3.1 Study Area

The study area is located in the central Mediterranean Sea and comprises the Italian side of the SoS (Fig. 12). According to the definition by the GFCM of geographical subareas (GSAs), this area corresponds to the GSA16 (southern Sicily) and extends for about 34,000 km$^2$ (GFCM, 2007). Situated in the northern sector of the SoS, the FRAs occupy a total area of 1711 km$^2$: 621 km$^2$ (mean depth = 175 m; depth range = 73 – 720 m) for the FRA to the east of Adventure Bank, 621 km$^2$ (mean depth = 315 m; depth range = 20 – 662 m) for the FRA to the west of Gela Bank and 469 km$^2$ (mean depth = 249 m; depth range = 60 – 1195 m) for the FRA to the east of Malta Bank (Garofalo & Fiorentino, 2022).

Finally, the study area is characterised by complex seafloor morphology and hydrodynamic process (Bèranger *et al.*, 2004) with a wide range of water depths including two shallow banks (< 100 m depth) on the western (Adventure Bank) and eastern (Malta Bank) side, respectively, separated by a narrow shelf in the middle.

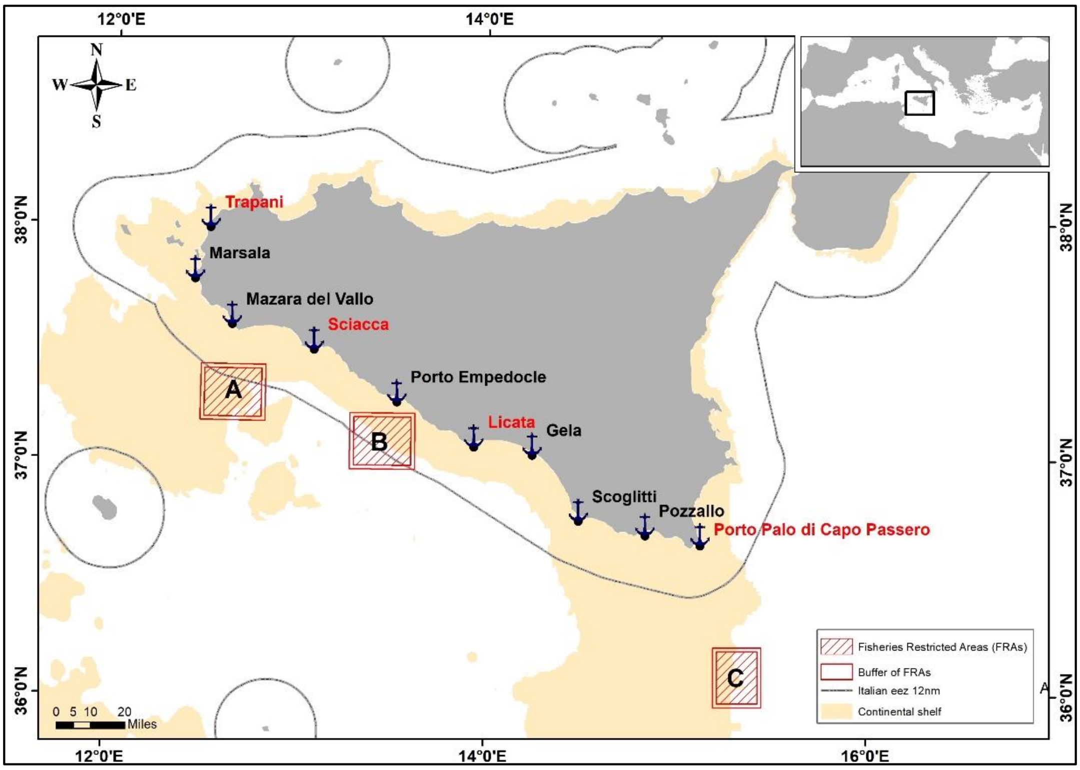


Figure 12. Main trawl fleets based along the south coast of Sicily and the Fisheries Restricted Areas (FRAs) situated in the Strait of Sicily (SoS). In red, the investigated fleets in this work. A: the FRA situated to the east of Adventure Bank; B: the FRA situated to the west of Gela Basin; C: the FRA situated to the east of Malta Bank.

The SoS constitutes an important fishing area for demersal resources and hosts several important marine fisheries (Fig. 12). Among them, Mazara del Vallo is the main port for demersal fisheries; its fleet represents the main commercial fleet of trawlers in the SoS and one of the most important fleets in the Mediterranean Sea (Gristina *et al.*, 2006; Pinello *et al.*, 2018; Falsone *et al.*, 2020). Bottom trawling is the most important fishing activity and includes three main segments: small vessel trawlers, with a length overall (LOA) between 12 and 18 m, medium vessels between 18 and 24 m and vessel trawlers larger than 24 m LOA. The first and the second segment ("domestic fleet") operate mainly within or close to the Sicilian territorial waters (within 12 miles from the coast, fishing from 1 to 2 days); while the third one ("distant fleet") operates some distance from the Sicilian coast both on the continental shelf and the slope down to 700 – 800 m depth with fishing trips lasting between 1 – 2 months. Every 20 – 30 days the catch, which is frozen on board, was landed in the closest port and then skipped to the home port in refrigerated trucks and, finally, distributed throughout Italy for consumption. According to De Angelis *et al.* (2020), these "distant" trawlers adopt 4 different fishing strategies: (i) fishing on the African shelf and (ii) on the Sardinia shelf, both strategies being targeted at shallow waters species (mainly fish and cephalopods), (iii) wide deep water, operating from the Sardinia Channel to the coast of Libya and (iv) Eastern deep water, operating in the Aegean and in the Levant Sea, targeting deep water crustaceans.

Since the objective of the work is to evaluate the short-term expected effects of the FRAs on the fleets which are more strongly affected by the reduction of fishing grounds, we selected only the vessels with LOA comprised between 12 and 24 m, which operate almost exclusively within the territorial waters (hereafter "domestic" trawlers (De Angelis *et al.* (2020)).

### 2.3.2 Data

A set of 186 trawlers, equipped with vessel monitoring systems (VMS) and with an LOA between 12 and 24 m, representing 51% of the total trawlers based in GSA 16, was initially considered for this study. In order to identify how domestic fleets are affected by the FRAs, we decided to consider only the vessels that during the year, for at least 8 months, use the same port both as home and landing port. Thus, the initial set was reduced to a subset of 37 trawlers as shown in Table 11. The economic results of the fishing activities of these fleets were therefore interpreted according to their proximities to the adopted FRAs (Fig. 12).

Table 11. Selected trawlers to calculate the economic performance by fleet.

| Port | Length OverAll (m) | N° of Vessels |
|---|---|---|
| Licata | 12 - 18 | 5 |
|  | 18 - 24 | 0 |
| Porto Palo di Capo Passero | 12 - 18 | 8 |
|  | 18 - 24 | 4 |
| Sciacca | 12 - 18 | 4 |
|  | 18 - 24 | 13 |
| Trapani | 12 - 18 | 0 |
|  | 18 - 24 | 3 |
| Total | 12 -24 | 37 |

Landings data by vessel and species were collected within the Italian National Program under the European Data Collection Framework (Reg. EU 199/08) during 2016. Price by species (EUR/kg) during 2016 year was taken from Maiorano *et al.* (2019).

### 2.3.3 Economics Performance: Revenues, Costs and Profits

We used SMART, a spatial model to assess the state of the demersal resources and some aspects of bio-economic performance under different management scenarios (Russo *et al.*, 2014, 2019; D'Andrea *et al.*, 2020a). In particular, this model combines multiple modeling components, integrating the best available sets of spatial data about catches and stocks, fishing footprint from VMS and economic parameters to describe the relationships between fishing effort pattern and impacts on resources and socio-economic performances. The structure of the SMART model can be summarised as follows:

(1) Processing of landings data, combined with VMS data, to estimate the spatial/temporal productivity of each cell, in terms of aggregated landings per unit of effort (LPUE) by species, according to the method described and applied in Russo *et al.* (2019);
(2) Processing biological data to estimate LPUE by age and by species, for each cell/time;
(3) Analysing VMS data to access the fishing effort by vessel/cell/time;
(4) Combining LPUE by age with VMS data to model the landings by vessel/species/length class/time/cell;
(5) Estimating the cost by vessel/time associated with a given effort pattern and the related revenues, as a function of the landings by vessel/species/length class/time (step 4);
(6) Combining costs and revenues by vessel, at the early scale, to obtain the profit, which is the proxy of the vessel performance. Profit could be aggregated at the fleet level to estimate the overall performance;

(7) Using estimated landings by species/age, together with survey data, to run a mouse model for the selected case of study in order to obtain a biological evaluation of the fisheries.

In this work, the fishing activity of each trawler before (2016) and after the FRAs adoption (2017–2019) was simulated and compared at the level of each single "domestic" fleet. Although the FRAs were implemented in 2016, they became effective only in July 2019 and, consequently, empirical data of the economic performance of the fleets/trawlers considered in this study were not available in the period examined. For this reason, we decided to use a simulation approach to compare the effects pre and post-FRAs in terms of economic performance.

To evaluate the positive or negative variation in profit of each fleet, the three "classical" indicators of economic performance by fleet were used: revenue (R), cost (C) and profit (P) [10]. According to Tietze *et al*. (2005), R depends on species and quantities caught and prices which mainly vary according to markets and seasonal fluctuations. The main C factors are the operation costs (e.g., fuel and crew salaries) and the vessel costs (repair/maintenance of the vessel). Operation costs are principally composed of labour costs and fuel costs; other cost items include: cost of selling fish, port duties, cost of ice, food and supplies for the crew. The major components of labour cost are wages and other labour charges such as insurance and employer contributions to pension funds. Moreover, the major elements of vessel costs are vessel and gear repair and maintenance expenses and vessel insurance (Effiong *et al*., 2016). Finally, the economic performance in terms of P of each fleet was calculated according to a step-by-step procedure, considering the balance between costs and revenues of the vessels monitored in the fisheries.

Concerning the revenue before the FRAs' adoption, the mean monthly revenue ($R_m$) of a single vessel $v$ during the year 2016 ($y$) was firstly calculated as follows:

$$R_{m,v} = \left(\sum_{s=1}^{S}(q_{s,y} \times p_{s,y})\right)/12 \tag{1}$$

where $q_{s,y}$ is the number of landings (expressed in Kg) for the species $s$ during the year $y$ by the respective mean price at the market ($p_{s,y}$) in EUR.

Secondly, the mean monthly revenue ($R_M$) by fleet $f$, considering all the vessels $v$ using the same landing port during the year $y$, was calculated as follows:

$$R_{M,f} = \left(\sum_{v=1}^{v} R_{m,v}\right)/\mathrm{n} \tag{2}$$

where n is the total number of vessels ($v$) that, in the same month, show the same landing port.

The simulated revenues ($R$) after the FRAs' adoption for the vessel $v$ during the period $t$ were calculated as follows:

$$R_{v,t} = \sum_{s=1}^{S} \sum_{l}^{L} (q_{s,l,t} \times p_{s,l,t}) \tag{3}$$

where $q_{s,l,t}$ is the number of landings for the species *s* and size class *l* during the period *t* by the respective price at the market ($p_{s,l,t}$).

Accordingly, the simulated mean monthly revenue (*RR*) for fleet (*f*) during the period *t* was calculated as follows:

$$RR_{f,t} = (\textstyle\sum_{v=1}^{v} R_{v,t})/\mathrm{n} \tag{4}$$

where n is the total number of vessels (*v*) that, in the same month, show the same landing port.

Concerning costs, SMART distinguishes them into "spatial-based", "effort-based" and "production-based" components. The spatial-based costs (*SC*) are a function of spatial locations of fishing operations being mainly related to fuel consumption and they were estimated starting from real values related to a subset of vessels. The effort-based costs (*EC*) regarding the number of days at sea spent by each vessel and include the labor costs (e.g., salaries) and the other expenses (repair/maintenance of the vessel) directly linked to the temporal duration of fishing activities. Finally, the production-based costs (*PC*) are linked to the number of landings (e.g., commercialisation costs) (Russo *et al.*, 2019). The *EC* and the *PC* were based on official aggregated data for the study area in the same period (source: Carvalho *et al.*, 2019). The total costs (*TC*) before (2016) and after (2017–2019) the implementation of the FRAs were both simulated in the same way using the Smart model.

The spatial domain of the SMART model for the SoS was defined as a grid with 500 square cells *c* (15 × 15 nautical miles) and the spatial (for each cells *c*) and temporal (for each time *t*) distribution of the effort for each vessel *v* was reconstructed using VMS data. In particular, for the spatial-based costs, a spatial index (*SI*) was computed, for each vessel *v* and time *t* (month) as:

$$SI_{v,t} = \textstyle\sum_{c=1}^{C} (d_{v,c} \times E_{c,v,t}) \tag{5}$$

where $d_{v,c}$ is the distance between cell *c* and the harbour of departure (computed as the linear distance between the center of each cell and the position of the harbour) for the vessel *v* and $E_{c,v,t}$ is the amount of effort (in hours of fishing) deployed by vessel *v* in the cell *c* during the time period *t*.

The relationship for spatial-based costs is defined as:

$$SC_{v,t} = \alpha \times LOA_v \times SI_{v,t} \tag{6}$$

where $SC_{v,t}$ are the spatial-based costs (in EUR) borne by vessel *v* during the time period *t*; $SI_{v,t}$ is the spatial index defined above; $LOA_v$ is the length overall of the vessel *v* and $\alpha$ is the parameter to be estimated.

Instead, the effort-based costs were calculated as follows:

$$EC_{v,t} = \gamma \times LOA_v \times DS_{v,t} \tag{7}$$

where $EC_{v,t}$ are the effort-based costs (in EUR) borne by vessel *v* during the time period *t* and $\gamma$ is the parameter to be estimated.

The production-based costs were defined as:

$$PC_{v,t} = \mu \times LV_{v,t} \tag{8}$$

where $PC_{v,t}$ are the production-based costs (in EUR) by vessel *v* during the time period *t*; $\mu$ is the parameter to be estimated and $LV_{v,t}$ is the landing value, which is the product of landings by species and size times the respective prices.

Consequently, the mean total costs (*TC*) for fleet (*f*) during the period *t* were obtained as follows:

$$TC_{f,t} = (\textstyle\sum_{v=1}^{v} SC_{v,t} + EC_{v,t} + PC_{v,t})/\mathrm{n} \tag{9}$$

where n is the total number of vessels (*v*) that, in the same month, show the same landing port.

Thus, the mean monthly landings profit ($P_m$) for a fleet *f* during the period *t* is:

$$P_{m,f,t} = R_{M,f} - TC_{f,t} \tag{10}$$

while the simulated mean monthly profit ($PS_m$) for a fleet *f* during the period *t* is:

$$PS_{m,f,t} = RR_{f,t} - TC_{f,t} \tag{11}$$

## 2.4 RESULTS

### 2.4.1 Structure and Fleet Capacity of the Marine Fisheries in the SoS

In 2016, according to the EU Community Fishing Fleet Register (https://data.europa.eu/euodp/it/data/dataset/the-communityfishing-fleet-register), 186 trawlers with LOA between 12 and 24 m were registered and operated in the investigated area with a total gross tonnage (GT) of about 7000 tons and engine power (kW) of about 35,000 kilowatts. Overall, vessel trawlers with LOA between 18 and 24 m are the most abundant (111 trawling vessels corresponding to 59.7% of the total). Sciacca constituted the fleet with the greatest number of vessels (78 vessels corresponding to 41.9% of the total), followed by Porto Palo di Capo Passero and Licata fleets with 40 (21.5%) and 39 vessels (21%), respectively. Trapani fleet showed the lowest number with 29 vessels (equivalent to 15.6% of the total) (Tab. 12).

No differences were evident in the capacity indicators between the fleets, with the exception of Trapani’s vessels in the segment 12 – 18 m which showed LOA, GT and kW lesser than the other fleets fleets (Fig. 13).

Table 12. The number of trawlers by Length OverAll (LOA) of each port in 2016.

| Port | LOA (m) | N° of Vessels |
|---|---|---|
| Licata | 12 - 18 | 24 |
| | 18 - 24 | 15 |
| Porto Palo di Capo Passero | 12 - 18 | 21 |
| | 18 - 24 | 19 |
| Sciacca | 12 - 18 | 12 |
| | 18 - 24 | 66 |
| Trapani | 12 - 18 | 18 |
| | 18 - 24 | 11 |

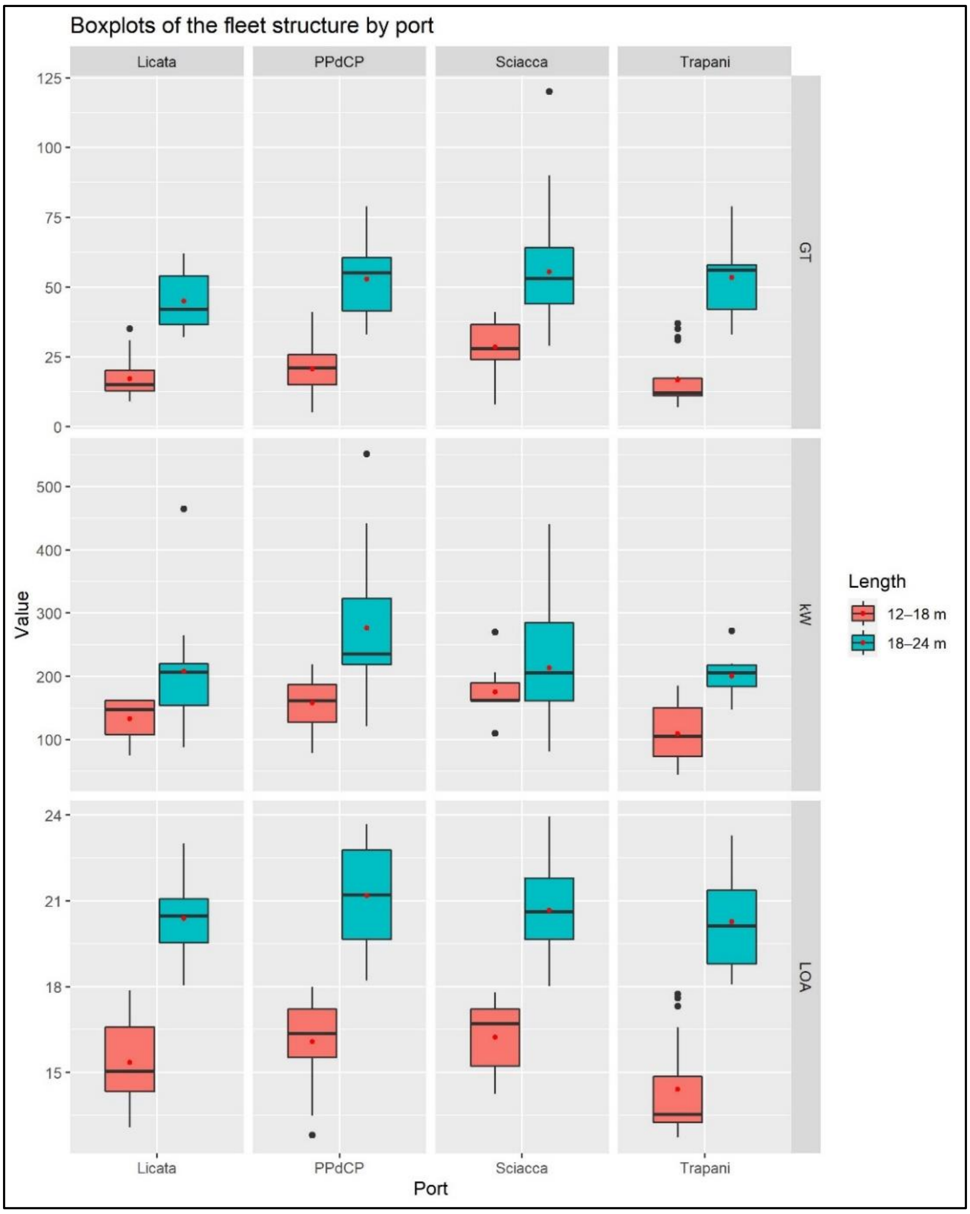


Figure 13. Boxplots of fleet capacity indicators in terms of gross tonnage (GT), engine power (kW) and Length OverAll (LOA) of the different fleets considered in this study. Red point: mean; black line: median, boxplot: 25–75% quartiles.

### 2.4.2 Catch Composition and Economic Performance

Approximately 1300 tons was landed by the 37 selected "domestic" trawlers (belonging to 89 species) in 2016. The landings consisted mainly of Crustacea (580 tons; 42.9% total landing), Osteichthyes (520 tons; 38.5%), Cephalopoda (about 230 tons; 17.2%) and Chondrichthyes (18 tons; 1.3%) commercial. The most abundant species was *Parapenaeus longirostris* which represent the 38.9% (about 520 tons) of the total landings; while *Lepidopus caudatus*, followed by *Merluccius merluccius*, constitute the second and the third most relevant fraction in terms of landings values with the 13% (about 175 tons) and the 9.5% (about 127 tons), respectively (Tab. 13).

Table 13. Landings by species of investigated "domestics" trawlers in 2016 (Source: Reg. EU 199/08).

| **Species** | **Taxonomic Group** | **Total landings (Tons)** | **Percentage (%)** | **Cumulative Percentage (%)** |
|---|---|---|---|---|
| *Parapenaeus longirostris* | Crustacea | 523.3 | 38.9 | 38.9 |
| *Lepidopus caudatus* | Osteichthyes | 175.1 | 13.0 | 51.9 |
| *Merluccius merluccius* | Osteichthyes | 127.6 | 9.5 | 61.4 |
| *Eledone moschata* | Cephalopoda | 62.1 | 4.6 | 66.0 |
| *Mullus surmuletus* | Osteichthyes | 62.0 | 4.6 | 70.6 |
| *Illex coindetii* | Cephalopoda | 40.8 | 3.0 | 73.6 |
| *Sepia officinalis* | Cephalopoda | 32.6 | 2.4 | 76.0 |
| *Trachurus trachurus* | Osteichthyes | 25.1 | 1.9 | 77.9 |
| *Loligo vulgaris* | Cephalopoda | 23.7 | 1.8 | 79.7 |
| *Octopus vulgaris* | Cephalopoda | 23.6 | 1.8 | 81.5 |
| Other | Osteichthyes | 128.3 | 9.5 | 91.0 |
| Other | Crustacea | 55.2 | 4.1 | 95.1 |
| Other | Cephalopoda | 49.4 | 3.7 | 98.8 |
| Other | Chondrichthyes | 18.1 | 1.2 | 100 |

Approximately 1200 tons of landings were simulated by the SMART model for the 37 selected "domestic" trawlers after the establishment of the FRAs (2017–2019). The simulated landings consisted mainly of Osteichthyes (557 tons; 45.9% total simulated landing), Crustacea (about 442 tons; 36.5%), Cephalopoda (about 201 tons; 16.6%) and Chondrichthyes (about 11 tons; 0.9%)

commercial. Furthermore, during the simulations, the three most abundant species were *Parapenaeus longirostris* (about 276 tons; 22.8%), *Lepidopus caudatus* (about 266 tons; 22%) and *Merluccius merluccius* (about 91 tons; 7.5%) (Tab. 14).

Table 14. Simulated landings by species of investigated "domestic" trawlers after the establishment of the FRAs (2017–2019).

| **Species** | **Taxonomic Group** | **Total landings (Tons)** | **Percentage (%)** | **Cumulative Percentage (%)** |
|---|---|---|---|---|
| *Parapenaeus longirostris* | Crustacea | 276.8 | 22.8 | 22.8 |
| *Lepidopus caudatus* | Osteichthyes | 266.7 | 22.0 | 44.8 |
| *Merluccius merluccius* | Osteichthyes | 91.5 | 7.5 | 52.3 |
| *Eledone moschata* | Cephalopoda | 48.9 | 4.0 | 56.3 |
| *Mullus surmuletus* | Osteichthyes | 48.3 | 4.0 | 60.3 |
| *Illex coindetii* | Cephalopoda | 35.8 | 3.0 | 63.3 |
| *Sepia officinalis* | Cephalopoda | 33.0 | 2.7 | 66.0 |
| *Trachurus trachurus* | Osteichthyes | 21.9 | 1.8 | 67.8 |
| *Loligo vulgaris* | Cephalopoda | 25.3 | 2.1 | 69.9 |
| *Octopus vulgaris* | Cephalopoda | 28.5 | 2.4 | 72.3 |
| Other | Osteichthyes | 128.6 | 10.6 | 82.9 |
| Other | Crustacea | 165.9 | 13.7 | 96.6 |
| Other | Cephalopoda | 29.8 | 2.5 | 99.1 |
| Other | Chondrichthyes | 11.2 | 0.9 | 100 |

The selected "domestic" trawlers of Sciacca, Porto Palo di Capo Passero and Licata showed the most abundant annual landings with about 770 tons (57.3%), about 340 tons (25.1%) and about 190 tons (14%), respectively; while Trapani represented the fleet with the lowest landings in the SoS with about 50 tons (3.6%).

*Parapenaeus longirostris* was the most caught species with landings amounting to: about 86 tons (46%) of the Licata fleet, about 149 tons (44%) of the Porto Palo di Capo Passero fleet, about 280 tons (36%) of the Sciacca fleet and about 8 tons (16%) of the Trapani fleet (Fig. 14).

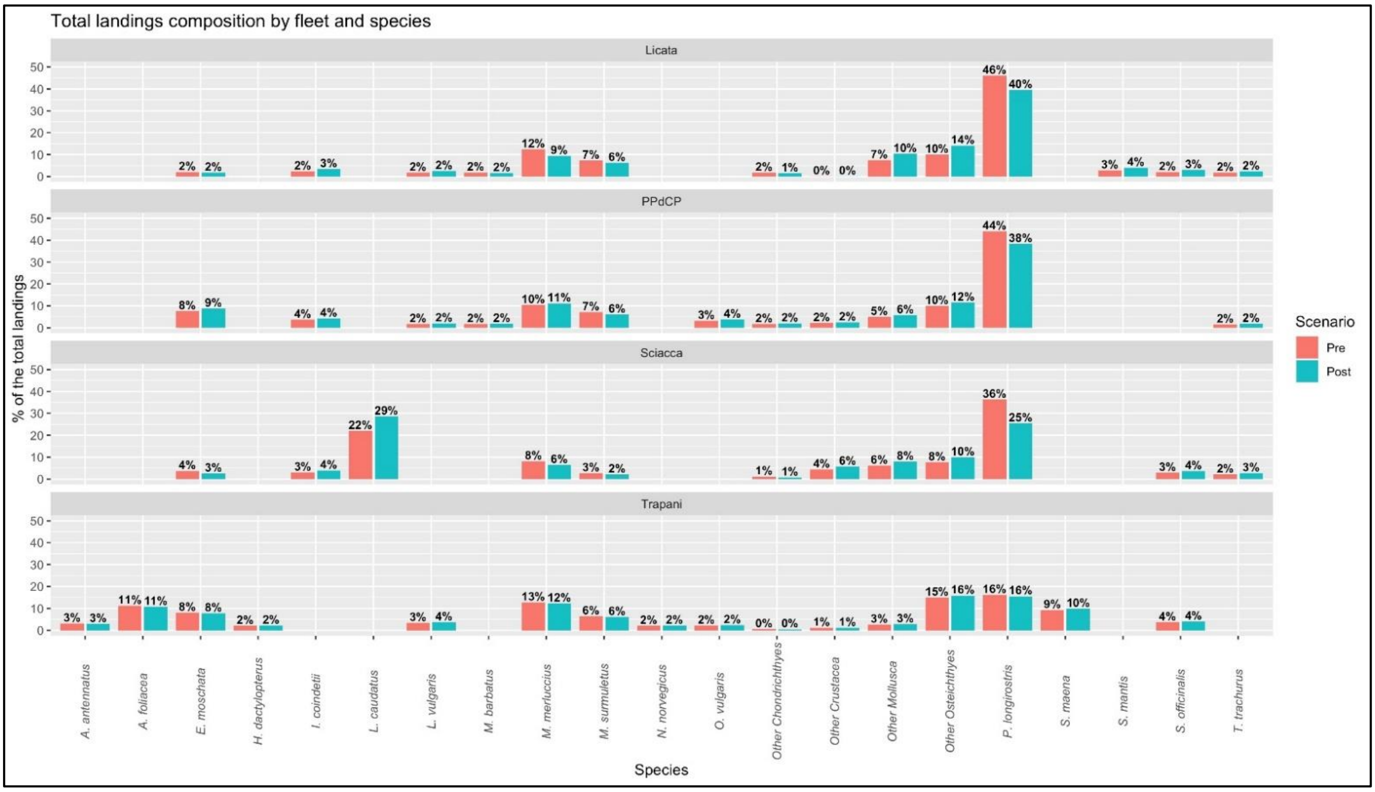


Figure 14. Comparison between the total landings composition of the selected “domestic” trawlers by fleet and species in 2016 and the simulated total landings composition of the same trawlers by fleet and species after the establishment of the FRAs (2017–2019) in 2016.

Except for the Sciacca fleet, the second most important catch is represented by *Merluccius merluccius* for all the fleets considered, with the Porto Palo di Capo Passero fleet showing the highest value (about 35 tons, 10.5%), followed by the Licata fleet with a landing value of about 23.5 tons (12.5%). Conversely, the most abundant species of Sciacca trawlers, after *Parapenaeus longirostris*, were *Lepidopus caudatus* and *Merluccius merluccius* with, respectively, landing values of about 169 tons (22%) and 62 tons (8.1%) (Fig. 14).

Excluding the Sciacca fleet, the composition of the simulated landings confirmed that DPS is always the most caught species, even if it shows a general decrease in all the considered fleets: 40% for the Licata fleet, 38% for the Porto Palo di Capo Passero fleet, 25% for the Sciacca fleet and 16% for the Trapani fleet. *L. caudatus* was the most caught species of the fleet of Sciacca (Fig. 14).

In this context, SMART returned estimates of the expected fishing effort pattern by vessels, and then at the aggregated level of the fleet, including the fishing effort displacement. Indeed, the establishment of the three FRAs is associated with an increase of the fishing effort around the FRAs, and in the south and southeast region of the SoS (for more details see Russo *et al.*, 2019).

The comparison between the mean monthly economic performances and the corresponding standard deviation before the establishment of the FRAs (2016) and the simulated one after the FRAs establishment (2017–2019) for each fleet is shown in Figure 15.

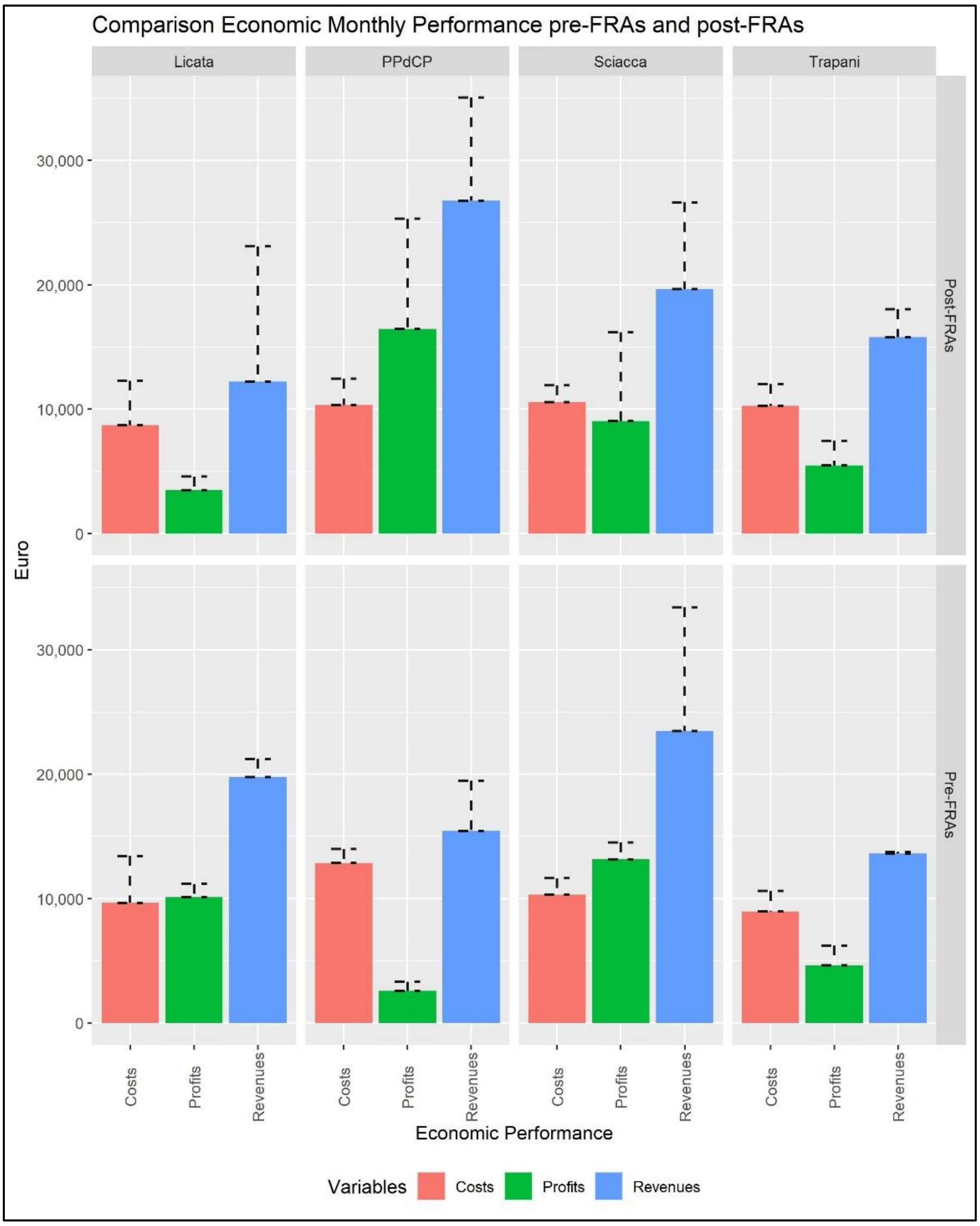


Figure 15. Mean monthly revenues (mean + standard deviation), mean monthly total costs (mean + standard deviation) and corresponding profits (mean + standard deviation) by fleet, before (2016) and after the establishment of the FRAs (2017-2019).

Considering the landings economic performances before the FRAs adoption, the monthly revenues and profits of Sciacca and Licata fleet were the highest with the value of about EUR 23,500 ± 9900 and EUR 19,500 ± 1500 (revenues) and about EUR 13,000 ± 1300 and EUR 10,000 ± 1000 (profits), respectively. Trapani is the fleet providing the lowest revenues with about EUR 13,500 ± 140 per month. On the other hand, Porto Palo di Capo Passero showed the lowest monthly profits with a value of about EUR 2500 ± 750 (Fig. 15).

The monthly costs are lower for the marine fisheries of Trapani and Licata (about EUR 9000 ± 1600 and EUR 9600 ± 3700, respectively); while they are slightly higher in the other marine fisheries: about EUR 12,800 ± 1100 for the Porto Palo di Capo Passero fleet and about EUR 10,300 ± 1300 for the Sciacca fleet (Fig. 15).

Simulation of the economic performance after the adoption of the FRAs suggested strong short-term variation. In particular, the Porto Palo di Capo Passero fleet obtained the highest values both for revenues and profits with about EUR 26,000 ± 8000 and EUR 16,500 ± 8500, respectively. While, Sciacca and Trapani represent the second and the third marine fisheries in terms of revenues and profits with values of about EUR 19,500 ± 7000 and EUR 15,500 ± 2300 (revenues) and about of EUR 9000 ± 7000 and EUR 5500 ± 2000 (profits), respectively. Finally, Licata fleets show the lowest values both for revenues (about EUR 12,200 ± 10,500) and profits (about EUR 3500 ± 1000) (Fig. 15).

As simulated the monthly costs concerns, Licata fleet obtained the lowest value with about EUR 8700 ± 3500. Conversely, the other fleets show very similar values being about EUR 10,300 ± 2100 for Porto Palo di Capo Passero, EUR 10,600 ± 1300 for Sciacca and EUR 10,200 ± 1700 for Trapani (Fig. 15).

## 2.5 DISCUSSION

In recent years, bio-economic models have been increasingly used to evaluate the impact of fishery policies before they are put in place (Whitmarsh *et al.*, 2000, Pascoe *et al.*, 2016; Garcia *et al.*, 2018). In this study, the short-term effects of the FRAs' implementation were evaluated by using the SMART bio-economic model on four trawler fleets distributed along the southern coast of Sicily and fishing within the territorial waters.

In the SoS, bottom trawling provides considerable revenue for marine fisheries. Considering the bottom trawlers with LOA > 24 m, the three shrimp species represented by DPS, ARS and ARA accounted for 65% of total landings for a value of about EUR 74,500 in 2016 (Pinello *et al.*, 2018). Our results showed that DPS represents the most widely caught species also for the bottom trawlers with LOA < 24 m operating close to the territorial waters ("domestic" fleet), ranging from 17 to 45% of the total landings in the investigated fleets. These findings confirm the important role of this species in SoS fisheries and also in smaller vessels as reported by Knittweis *et al.* (2016). However, it is worth noting that the landings of smaller trawlers of the “domestic” fleet comprise a higher number of species than the yield of larger trawlers forming the distant fleet.

Prior to the implementation of the FRAs, results showed that the fleets operating in the central area of the southern coast of Sicily had the highest revenues and profits; this result could probably be due to the proximity of these marine fisheries to the Adventure Bank and the Malta bank, that are known as spawning and nursery areas for many demersal species of commercial interest, such as the deep-water rose shrimp, the European hake and the red mullet (Fiorentino *et al*., 2003; Levi *et al*., 2003; de Juan & Lleonart, 2010; Fortibuoni *et al*., 2010).

In particular, the Sciacca trawlers showed the greater value of DPS landing and the highest revenues before the adoption of the FRAs. This result could be explained by the favourable position of this fleet, situated in the middle of Adventure Bank and Gela basin, that would favour fishing activities in this area. Moreover, the high amount of *Lepidopus caudatus* landing, a species increasingly appreciated by Sicilian consumers (Falsone *et al*., 2021), contributed to increasing fleet profits.

In terms of fleet capacity, Porto Palo di Capo Passero and Sciacca showed the highest mean values of LOA, GT and kW for the investigated vessel segments. In this context, in terms of costs and especially considering the price and consumption of fuel, it is interesting to note the relatively high costs for the Porto Palo di Capo Passero fleet. This result could mean that the Porto Palo di Capo Passero fishermen decided to fish in areas away from the coast where the main demersal target species are not overexploited and where they are more abundant or to fish near the Malta Bank, a fishing area located very far from the coast, but these operations mean greater fuel consumption and, also, an increase in the number of days at sea with a consequent increase of salaries. Probably, these increased costs are the main reasons why the Porto Palo di Capo Passero fleet has the lowest profits compared to the other marine fisheries distributed along the SoS.

Comparing the economic performance in the short-term before and after FRA establishment during this “transition period” from 2017 to 2019 and considering this period representative of the short-term changes caused by the closure of the FRAs, Porto Palo di Capo Passero represents the fleet with the highest benefits from the FRA implementation, obtaining the best simulated profits in absolute with an increase of about EUR 13,500. This pattern is likely due to the fact that, as the Malta Bank FRA is situated far from the coast, the fishermen of Porto Palo di Capo Passero are not as affected by the closure of this area in terms of reduction of fishing grounds but they can benefit from the positive effects of the northward spill-over from the FRA along the permanent front bordering the outer shelf of the Malta Bank (Bèranger *et al*., 2004).

On the other hand, the Trapani fleet showed a modest increase of about EUR 850 in terms of profits if compared to the Porto Palo di Capo Passero fleet. Due to its position in the southwest along the Sicilian coast, this fleet seems to not be negatively affected by the establishment of the FRAs and the slight increase in profits could likely be due to the increase in catches linked to the spill-over effect concerning the species that tend to migrate northward from Adventure Bank FRA.

As was to be expected, the fleets showing in the short-term the greatest disadvantages as a consequence of the establishment of the FRAs in terms of profits, were the ones located in the central part of the southern Sicilian coast, namely the Sciacca and Licata fleets, from which the FRAs subtracted traditional fishing grounds. These two marine fisheries reduced their monthly profits by about EUR 4000 and EUR 6500, respectively. Due to the closure of a part of their fishing areas, these two fleets are expected to be negatively affected by the FRAs because fishermen must necessarily lengthen their fishing trips with a consequent increase in costs, especially in terms of fuel consumption.

Even if the primary target of the FRAs is improving the status of fish stocks and enhancing fisheries (Petza *et al.*, 2017; Dimarchopoulou *et al.*, 2018), they can also contribute to biodiversity conservation (Rodríguez-Rodríguez *et al.*, 2016; Fraschetti *et al.*, 2018). Of course, these closures need to be ecologically coherent (Hiddink *et al.*, 2006) and potential effects at different spatial scales must be considered (Dinmore *et al.*, 2003).

Although the FRAs are a very important tool for the rebuilding of overexploited stocks and socio-economic performance at the whole-fleet level in the SoS (Russo *et al.*, 2014, 2019), the short term profits of fleet fishing closer to the FRAs has resulted in them being negatively affected by the closures. Considering the different socio-economic impacts at the single-fleet level, specific compensative measures to help the impacted fleets could be planned till a more productive state of the stocks is reached.

In particular, since the management of Mediterranean fisheries is characterised by a large variety of complex and interdependent parameters (e.g., the predominance of multi-species stocks, a wide variety of fishing grounds, the high adaptability and techniques for ecological and economic market niches, the long-term coexistence of different production processes) for which the economic and social dimensions are often predominant (Bonzon, 2000), the evaluation of the socio-economic effects for each fleet involved in the management plan to rebuild overexploited stocks should be considered. Moreover, to support a spatially based approach to fishery management, the climate and environmental changes should be considered since they strongly affect the productivity of stocks through changes in terms of recruitment and other demographic parameters, causing a change in the sustainable yields of stock (Moullec *et al.*, 2019; Travers-Trolet *et al.*, 2020; Fiorentino & Vitale, 2021). Consequently, in the long period, the real situation could be very different from the current one.

Although our analyses were based on a limited set of vessels, the results obtained seem to be relevant in assessing the short-term effect of closures of critical habitats, such as the nurseries, at the level of a single fleet. However, due to the growing importance of the use of the FRAs in the Mediterranean, the results from the simulation should be confirmed by the specific monitoring of stock within and close to the closures in order to clarify the spill-over pattern of the juveniles from the FRAs to the adjacent areas, and of trawlers operating close to the FRA to understand the variation in their economic performances in the short and long term.

# 3. PAPER 2: How is artificial lighting affecting the catches in deep water rose shrimp trawl fishery of the Central Mediterranean Sea?

## 3.1 ABSTRACT

The effect of artificial lights mounted on the headrope trawl net on the catch of deep water rose shrimp (*Parapenaeus longirostris*), European hake (*Merluccius merluccius*), and Atlantic horse mackerel (*Trachurus trachurus*) was tested in a survey carried out on-board a commercial trawler off the SW Sicilian coast. A total of 18 repeated nocturnal hauls, alternating without (control) and with (test) LED lights (10 green and 10 white) according to the fishers' setup, were conducted. Overall, the test net catch rates were not significantly higher than those of the control net (Kruskal-Wallis test, $p > 0.05$), except for *P. longirostris* ($p < 0.05$). Conversely, the two-tailed Kolmogorov–Smirnov test revealed statistical differences in the size structure of *P. longirostris*, *M. merluccius*, and *T. trachurus* between the test and control nets ($p < 0.05$). Using generalised linear mixed models, the test net was found to yield higher catches of undersized individuals of the three species and adults of *P. longirostris* than the control net. Our study results are discussed in the context of the exploitation and management of Mediterranean trawl fisheries.

**Keywords:** LED lights, gear selectivity, fisheries management, undersized catch, catch comparison.

## 3.2 INTRODUCTION

Evidence of the use of light for fishing purposes is very ancient and can be traced back to the book "*De historia animalium*" written by Claudius Aelianus, a Roman philosopher that lived between the second and third centuries after Christ. Traditionally, light is used to attract and aggregate commercial fisheries species, such as pelagic fish and cephalopods, near fishing boats (e.g., Arakawa *et al.*, 1998; Parrish 1999; Kim & Wardle 2003; Arimoto *et al.*, 2010; Okpala *et al.*, 2017). In recent years, lights directly mounted on different types of active and passive fishing gear have been increasingly used to improve their catchability and/or reduce by-catch (e.g., Nguyen & Winger, 2019). Essentially, the main difference between underwater and surface lights is the inability of surface lights to affect different components of the marine community as surface lights cannot reach the depths of underwater lights mounted directly on the fishing gear.

The increasing use of underwater lights in recent years is linked with the rapid development of new lighting technology. In fact, very low amounts of energy are required, and they have a longer lifespan than the previous lighting technology (Matsushita *et al.,* 2012; ICES, 2012, 2013; Nguyen & Winger, 2019).

There is a growing scientific interest in understanding the effect of artificial light on animal catches (e.g., Cuende *et al.,* 2019; Field *et al.,* 2019; Bielli *et al.,* 2020; Cuende *et al*., 2020; Lomeli & Wakefield, 2020; Southworth *et al.,* 2020; Lomeli *et al.,* 2021; Karlsen *et al.*, 2021). Experimental surveys carried out in oceanic waters have revealed that the effect of artificial lights on trawl catch depends on several factors, including technical (e.g., placement of lights, light intensity, light spectrum) or external (e.g., water turbidity, depth, moon phase) factors (Melli *et al.*, 2018; Cuende *et al.*, 2019; O'Neill & Summerbell 2019; Southworth *et al.,* 2020). Based on evidence gathered during trawl surveys, the effect of light on fish is species-specific (e.g., Lomeli & Wakefield 2012; Grimaldo *et al.,* 2018) and size-dependent (e.g., Lomeli *et al.,* 2018a; Melli *et al.*, 2018).

Knowledge on the reactions of crustaceans and cephalopods to artificial lights during trawling remains limited and highlights a weak or nil attractive effect (e.g., Lomeli *et al.*, 2018b; Sbrana *et al.,* 2018; Lomeli *et al.,* 2020).

In the Mediterranean Sea, artificial fixed lights mounted on boats are traditionally used by purse seiners to attract anchovies and sardines during the night (Vidoris *et al.*, 2001; Tsagarakis *et al.*, 2012; Kraljević *et al.,* 2014). Artificial lights are also used in hand line fishing for deep-water squids in southern Italy, where fishers use a hand-jig line (called "totanara") consisting of a crown of hooks mounted on a stainless-steel cylinder, baited in its centre, and enhanced by the addition of a small blinking light (Battaglia *et al.,* 2010). In trawl fisheries, the use of artificial lights is recent and mostly limited to vessels exploiting deep-water crustaceans, such as *P. longirostris*. A recent study based on a scientific survey revealed no significant difference in *P. longirostris* catch rates (Sbrana *et al.,* 2018) whereas another study based on interviews with fishermen reported higher *P. longirostris* catch rates during night hauls (Pinello *et al.,* 2018).

In the Strait of Sicily, where the largest Mediterranean bottom trawl fleet targeting *P. longirostris* and the giant red shrimp, *Aristaeomorpha foliacea*, is found (the Mazara del Vallo harbour) (Vitale *et al.,* 2014; Milisenda *et al.,* 2017), artificial lights mounted on the trawl head rope are increasingly used to enhance the Catch Per Unit Effort (CPUE) of these species during night hauls (Pinello *et al.,* 2018; Geraci *et al.,* in press). Accordingly, in the Strait of Sicily, Geraci *et al.* (in press) during an unplanned and preliminary trial recorded an overall increase in gross catch, including *P. longirostris* and *M. merluccius*.

Given the importance of the crustacean trawl fishery in the Strait of Sicily (Levi *et al.,* 1995; Fiorentino *et al.,* 2013b; Di Lorenzo *et al.,* 2017), it is important to better understand the impact of such new technological improvements on demersal resources and fisheries ecological sustainability.

These aspects are particularly important as the use of artificial light in commercial fisheries carried out in EU Mediterranean waters is not regulated by specific measures. Therefore, it is necessary to accelerate discussions and adopt specific strategies and regulations on the use of underwater light at local, national and international scales to avoid any possible negative effects of their use on the exploited stocks (Nguyen & Winger, 2019).

In this study, the artificial lights used by Mazara del Vallo trawlers were tested for the first time during an *ad-hoc* trawl survey in the GSA16 (Geographical Subarea 16), South of Sicily, according to the General Fisheries Commission for the Mediterranean classification. The main aim of this study was to determine the effects of light on both catch composition and catch rate of the deep-water rose shrimp, *P. longirostris*, the European hake, *M. merluccius*, and Atlantic horse mackerel, *T. trachurus*. *P. longirostris* is the main *target* species of the fishery, while *M. merluccius* and *T. trachurus* are the main commercial bycatch and the main unwanted by-catch, *sensu* ICES (2020), respectively (Milisenda *et al.,* 2017). The results of this study have important implications for the long-term sustainability of trawl fisheries discussed in the context of the management goals of the EU Common Fisheries Policy, CFP (reg. EC 1380/2013).

## 3.3 MATERIAL AND METHODS

### 3.3.1 Study Area and Experimental Setup

The study area is located off the southwestern coast of Sicily within GSA16 (Fig. 16).

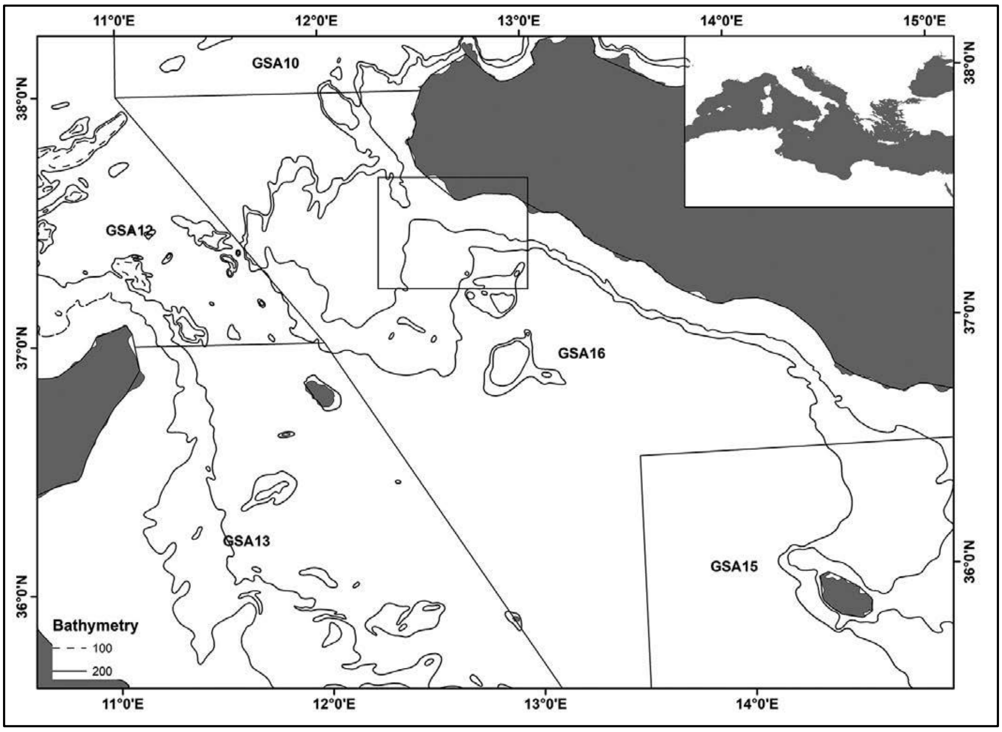


Figure 16. The study area highlighted using a black square box (from Vitale *et al.,* 2018a, 2018b).

In December 2018, a three-day survey was conducted by a commercial bottom trawler (20.95 m length overall and 294 kW engine power) of the Mazara del Vallo fleet. The trawler was equipped with a polyamide "volantina" trawl net, with a nominal mesh cod-end size of 40 mm square mesh. A total of 18 nightly hauls lasting one hour each (six repeated in each of the three nights) were carried out at speeds ranging from 2.6 and 2.8 knots, alternating the trawl net with (hereinafter referred to as test) and without light (hereinafter referred to as control) (Tab. 15).

Table 15. Main characteristics of the repeated hauls carried out at night throughout the 3-day experiment.

| Haul | Time (start) | Time (end) | Lat. (start) | Long. (start) | Mean depth (m) |
|---|---|---|---|---|---|
| 1 | 19: 00 | 20:00 | 37.560° N | 12.403° E | 134 |
| 2 | 21:00 | 22:00 | 37.506° N | 12.421° E | 142 |
| 3 | 23:00 | 24:00 | 37.483° N | 12.456° E | 143 |
| 4 | 01:00 | 02:00 | 37.503° N | 12.425° E | 136 |
| 5 | 03:00 | 04:00 | 37.537° N | 12.395° E | 128 |
| 6 | 05:00 | 06:00 | 37.519° N | 12.406° E | 131 |

The head rope of the net was equipped with a total of 20 LED underwater lights, 10 green and 10 white (Acquasport Sud ® S.A.S. Di Garzia Giovanni & C.) (Fig. 17).

Figure 17. LED lights mounted on the headrope of the trawl net used during the survey.

The choice to simultaneously use green and white LED lights is based on local ecological knowledge (fishers have declared this custom), on-board personal observations, and the monitoring activity of the landings in the context of the EU Data Collection Framework (DCF). In the same area, Geraci *et al.* (in press) carried out an unplanned preliminary trial using exactly the same configuration, colour of lights, and brand adopted by local fishers. In particular, the green and white LEDs were placed alternately and symmetrically along the head rope, with green and white LEDs alternating at a distance of approximately 50 cm from each other. The green and white LEDs peaked at wavelengths of 520 and 460 nm, respectively, with an intensity of 3.5 cd (data from manufacturer).

Environmental data that may affect the catch rate were collected for each haul, including sea state, sea water temperature, and moon phase. The moon phase was obtained from the tides4fishing.com website; obviously, this phase did not markedly differ during the survey. However, the third day was very cloudy, and the moon was completely covered; therefore, its effect was included in the analyses as moon presence/absence. Temperature data along the water column were recorded using a CTD probe (STAR-ODDI https://www.star-oddi.com/) mounted on a trawl.

On-board scientific observers were involved throughout the survey to monitor all fishing operations, collect biological samples, and collect data on fishing operations (e.g., speed, coordinates, depth). The catch of each haul was sorted on board in commercial and non-commercial fractions, according to local fishers' habits. All biological samples were transported to the National Research Council (CNR) laboratory, weighed (0.1-gram accuracy), and measured (to the nearest 5 mm Total Length – TL and 1 mm Carapace Length – CL) individually, while the benthic organisms were identified, numbered, and weighed as total by species.

## 3.3.2 Statistical Analysis

### 3.3.2.1 Catch Per Unit Effort (CPUE)

The CPUE expressed as kg/h was used to compare the control and test nets for the following categories: (i) ALL, (ii) *P. longirostris*, (iii) *M. merluccius*, and (iv) *T. trachurus* specimens. The first category included all species pooled by haul, except for benthic organisms which were excluded from the data analysis; this is because these organisms were assumed to be caught passively and therefore, independent of the use of artificial light. Local fishers, Pinello *et al.* (2018) and Geraci *et al.* (in press), previously reported an increase in catch rates. This background information allowed us to hypothesise that the use of artificial lights determines an increase in CPUE; therefore, a one-tailed Kruskal-Wallis H test ($\chi^2$) was applied to test the differences between the test and control nets.

#### 3.3.2.2 Size Structure Analyses

The size structures were expressed in terms of the number of specimens for each length class (i.e., Length Frequency Distributions (LFDs)). The general differences in the LFDs for *P. longirostris*, *M. merluccius*, and *T. trachurus* between the control and test nets were assessed using a two-sample Kolmogorov-Smirnov test (KS test).

As two fishing vessels could not be hired and a paired haul design could not be adopted, we assumed the same catch probability for control and test net hauls carried out at the same time of day, depth, and geographical position. The probability of retaining a fish at length in the test net related to the total catch in the control net was assessed according to the method proposed by Fryer *et al.* (2003). The comparison was made between nine hauls (i.e., nine in the test and nine in the control nets) and the length classes were set at 2 mm CL, 20 mm, and 10 mm TL for *P. longirostris*, *M. merluccius*, and *T. trachurus*. Undersized specimens were identified as fish whose length was below the minimum conservation reference size (MCRS) established by the EC Reg. 1967/2006 and Reg. 1380/2013 (20 mm CL for *P. longirostris*, 200 mm TL for *M. merluccius* and 150 mm TL for *T. trachurus*).

The experimental average catch comparison for each length class ($CC_l$) is given by the following expression:

$$CC_l = \frac{\sum_{i=1}^{9} nt_{li}}{\sum_{i=1}^{9} nc_{li} + \sum_{i=1}^{9} nt_{li}} \tag{1}$$

where $n_c$ and $n_t$ are the number of fish caught in each length class *l* in the control and test nets, respectively (e.g., Sola & Maynou, 2018; Vitale *et al.*, 2018a). A value of 0.5 for $CC_l$ indicates that the probability in capturing a fish of length *l* is the same between the test and control. Instead, a value above 0.5 indicates a higher probability of catching a fish of length *l* in the test than the control, and *vice versa* for a value below 0.5.

The observed $CC_l$ values of the test and control net of each selected species were modelled using generalised linear mixed models (GLMMs) with binomial distribution, where hauls were included as random effects to remove the variance linked to the expected change in abundance/catchability of the three species during the days and timeframes (Holst & Revill, 2009). The models were fitted with splines with different degrees of freedom. The selection of the best model was based on choosing the model with the lowest Bayesian information criterion (BIC) using the BICtab function (Brooks *et al.*, 2020).

The initial probability model was defined as follows:

$$\begin{aligned} &P\ [logit(test/test + ctrl)] \\ &= \alpha + f(size\ class) + \beta_1 moon\ presence/absence + \beta_2 day + \beta_3 timeframe + Uhaul + \varepsilon_i \end{aligned}$$

where α is the model intercept, *f* is the spline function, *β* is the regression coefficient, *U* is the random factor, and ε is the error term in the model.

Temperature and sea state were not included in the model as they did not vary during the survey. Variables were first checked for collinearity with a scatterplot of each pair of variables and Pearson's correlation matrix plots. In addition, the homoscedasticity assumption was assessed purely based on a scatter plot of the residuals (Zuur *et al.*, 2009). To directly quantify the relative effect of using the test *versus* control net on the length-dependent gear catch efficiency, the so-called catch ratio was estimated (e.g., Sistiaga *et al.*, 2015; Melli *et al.*, 2020; Lomeli *et al.*, 2021). The ratio between the catch efficiency of the control and test trawl nets of a given length, *l*, was computed using the following expression for the experimental data:

$$CR_l = \frac{\sum_{i=1}^{9} nt_{li}}{\sum_{i=1}^{9} nc_{li}} \qquad (2)$$

Simple mathematical manipulation yields the following general relationship between catch ratio and catch comparison:

$$CR_l = \frac{\sum_{i=1}^{9} CC_l}{\sum_{i=1}^{9} 1-CC_l} \qquad (3)$$

$CC_l$ is the predicted value of the catch comparison model (based on Eq. 1). A value of 1.0 for $CR_l$ indicates no difference in catch efficiency between the test and control groups. On the other hand, a value of 0.60 or 1.45 indicates that the probability of fish caught for a given length, with the test net is 40% less or 45% more than that sampled with the control net. In addition, to provide an overall idea for the effect of mounting LED lights on the trawl net, the mean $CR_l$ was provided. A double bootstrap approach with 1000 repetitions was applied to estimate the 95% confidence limits (Efron 1982; Millar, 1993). We removed the random effect of haul from the most parsimonious model before bootstrapping as it already accounted for variation/uncertainty through resampling, among hauls (i.e., among the nine haul pairs, with replacement) and within-haul (i.e., on the size structures, with replacement) (Brooks *et al.*, 2020).

Lastly, the probability of the test *versus* control net to catch undersized specimens ($P_u$) was calculated for *P. longirostris*, *M. merluccius*, and *T. trachurus*, as follows:

$$P_u = \frac{\sum_{i=1}^{9} nt_u}{\sum_{i=1}^{9} nc_u + \sum_{i=1}^{9} nt_u} \qquad (4)$$

where $nc_u$ and $nt_u$ represent the number of specimens in each length class up to the MCRS, respectively, in the control and test nets. To provide an overall idea of the light effect on juveniles,

$P_u$ was provided as the mean value. All analyses were carried out with R version 3.6.3 using the package, *selfisher* (Brooks, 2019).

## 3.4 RESULTS

### 3.4.1 Catch For Unit Effort (CPUE)

The main descriptive statistics of *P. longirostris, M. merluccius*, and *T. trachurus* specimens are shown in Table 16. In terms of absolute numbers, the test net caught more *P. longirostris*, *M. merluccius*, and *T. trachurus* specimens than the control net. For *M. merluccius* and *T. trachurus*, the number and percentage of undersized specimens were higher in the test than in the control, whereas the percentage of undersized specimens was higher in the control (Tab. 16).

Table 16. Main descriptive statistics of *Parapenaeus longirostris, Merluccius merluccius* and *Trachurus trachurus* caught during the survey.

| **Net** | **Species** | **Total number** | **Range (mm)** | **Mean (mm) ± sd** | **Nr. Undersized** | **%Undersized** |
|---|---|---|---|---|---|---|
| **TEST** | *P. longirostris* | 10519 | 9-33 | 19±3 | 6975 | 66 |
| | *M. merluccius* | 320 | 75-595 | 178±84 | 219 | 68 |
| | *T. trachurus* | 572 | 75-245 | 135±20 | 463 | 81 |
| **CONTROL** | *P. longirostris* | 7253 | 8-31 | 18±3 | 5475 | 75 |
| | *M. merluccius* | 243 | 60-595 | 196±89 | 137 | 56 |
| | *T. trachurus* | 243 | 90-235 | 144±31 | 159 | 65 |

Comparisons of CPUE between the test and control nets are shown in Figure 18. In particular, the median CPUE was slightly higher for the test in all categories, except for *M. merluccius*. However, the Kruskal-Wallis test did not highlight significant CPUE differences between the test and control net for ALL ($\chi2 = 1.335$, $p = 0.124$), *M. merluccius* ($\chi2 = 0.276$, $p = 0.300$), and *T. trachurus* ($\chi2 = 1.335$, $p = 0.124$), whereas for *P. longirostris*, a significant increase in the test net was found ($\chi2 = 2.823$, $p = 0.043$).

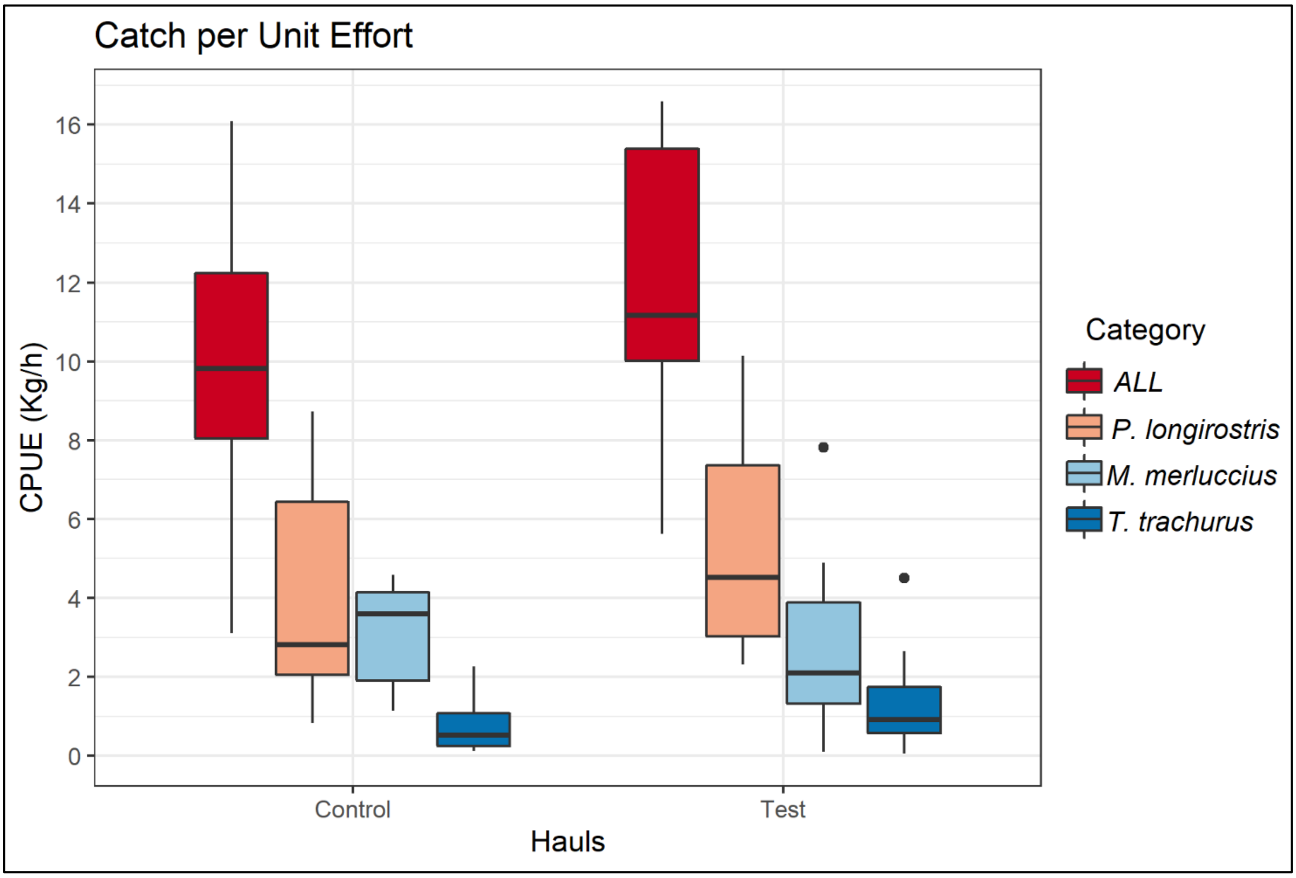


Figure 18. Catch per Unit Effort (CPUE) expressed as kg/h for: ALL (all catch pooled by haul), *Parapenaeus longirostris*, *Merluccius merluccius* and *Trachurus trachurus*.

### 3.4.2 Size Structure Analyses

Overall, LFDs expressed as absolute frequency for *P. longirostris*, *M. merluccius*, and *T. trachurus* revealed that the main component of the catch was composed of undersized specimens according to Reg. EU 1967/2006 in both test and control net configurations (Fig. 19). In particular, the modal class lengths for *P. longirostris* were 18 mm CL for both the test and control nets, whereas those for *M. merluccius* were 140 mm and 200 mm TL, respectively. The modal class length for *T. trachurus* was 135 mm TL in the test and 145 mm TL in the control net (Fig. 19). The KS test highlighted significant differences in the shape of the LFDs for the three species, namely *P. longirostris* ($D = 0.114$, $p < 2.2^{-16}$), *M. merluccius* ($D = 0.156$, $p = 0.002$), and *T. trachurus* ($D = 0.167$, $p < 0.0001$).

The final GLMMs by species are presented in Table 17.

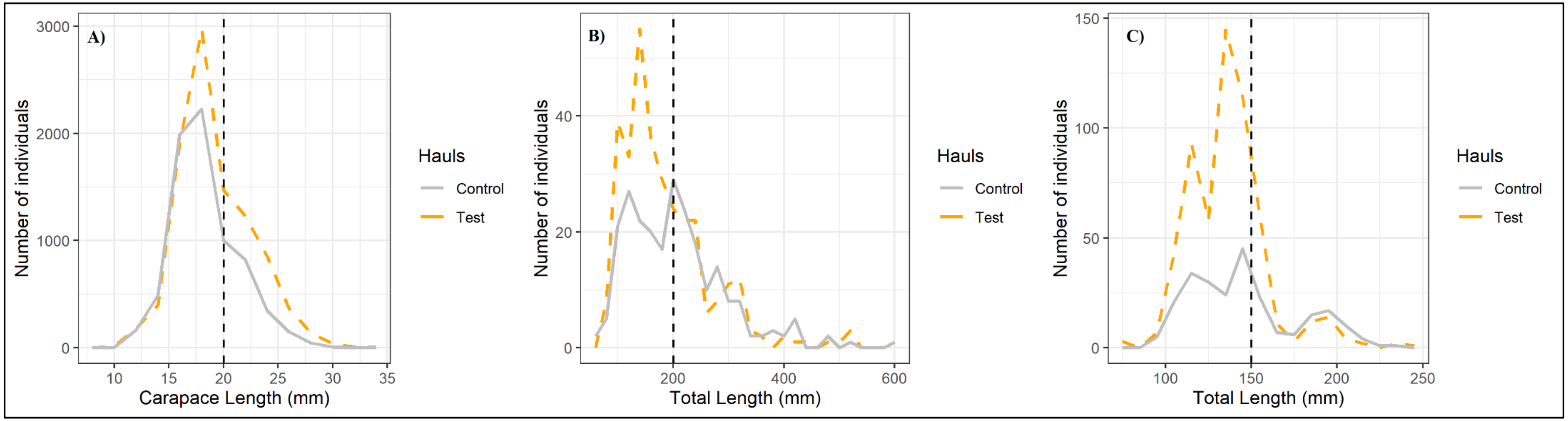


Figure 19. Absolute length frequency distribution of A) *Parapenaeus longirostris*, B) *Merluccius merluccius*, and C) *Trachurus trachurus*. Black dashed lines indicate the minimum conservation reference size (MCRS).

Table 17. Selected GLMM models with parameters and fit for the catch comparison curves (test vs control net) of *Parapenaeus longirostris*, *Merluccius merluccius* and *Trachurus trachurus*. In bold, significant terms.

| Stock | Model | | | | |
|---|---|---|---|---|---|
| | ~ *f*(size class, df = 3)*moon presence/absence + *U*(Haul) | Estimate | Std. Error | z value | p-value |
| | (Intercept) | -0.116 | 0.442 | -0.263 | 0.793 |
| | ***f*(size class, df = 3)1** | **-1.700** | **0.814** | **-2.089** | **0.037** |
| | ***f*(size class, df = 3)2** | **2.297** | **0.361** | **6.357** | **$2.06^{-10}$** |
| *P. longirostris* | *f*(size class, df = 3)3 | 0.927 | 0.766 | 1.211 | 0.226 |
| | moon presence/absence | -0.192 | 0.612 | -0.311 | 0.756 |
| | ***f*(size class, df = 3)1:moonpresence** | **4.210** | **1.214** | **3.468** | **$5.2^{-04}$** |
| | ***f*(size class, df = 3)2:moonpresence** | **-2.624** | **0.599** | **-4.378** | **$1.20^{-05}$** |
| | *f*(size class, df = 3)3:moonpresence | 1.042 | 1.227 | 0.850 | 0.396 |
| | ~ *f*(size class, df = 5) + *U*(Haul) | Estimate | Std. Error | z value | p-value |
| | (Intercept) | -0.710 | 0.474 | -1.496 | 0.134 |
| | ***f*(size class, df = 5)1** | **2.569** | **0.783** | **3.281** | **0.001** |
| *M. merluccius* | *f*(size class, df = 5)2 | -0.659 | 0.517 | -1.276 | 0.202 |
| | *f*(size class, df = 5)3 | 1.350 | 0.831 | 1.625 | 0.104 |
| | *f*(size class, df = 5)4 | 0.480 | 0.678 | 0.708 | 0.479 |
| | *f*(size class, df = 5)5 | 0.796 | 0.648 | 1.227 | 0.220 |
| *T. trachurus* | ~ *f*(size class, df = 3) + *U*(Haul) | Estimate | Std. Error | z value | p-value |
| | (Intercept) | 0.410 | 0.643 | 0.638 | 0.524 |

| | | | | |
|---|---|---|---|---|
| **_f_(size class, df = 3)1** | **2.541** | **1.244** | **2.043** | **0.041** |
| **_f_(size class, df = 3)2** | **-3.104** | **0.765** | **-4.059** | **$4.93^{-05}$** |
| _f_(size class, df = 3)3 | -0.236 | 0.796 | -0.296 | 0.767 |

Among the selected predictive variables, only the size class significantly affected the catch rates of all species, whereas the moon light affected significantly per size class only the *P. longirostris* ones.

The $CC_l$ and $CR_l$ values for *P. longirostris* were lower than the no-level effect up to 14 mm CL ($CC_l = 0.48$, $CR_l = 0.92$). Thereafter, the trend increased constantly up to 32 mm CL ($CC_l = 0.76$, $CR_l = 3.21$) and slightly decreased up to 34 mm CL ($CC_l = 0.75$, $CR_l = 3.11$), showing that the test had a higher catch probability than the control (Fig. 20A, B).

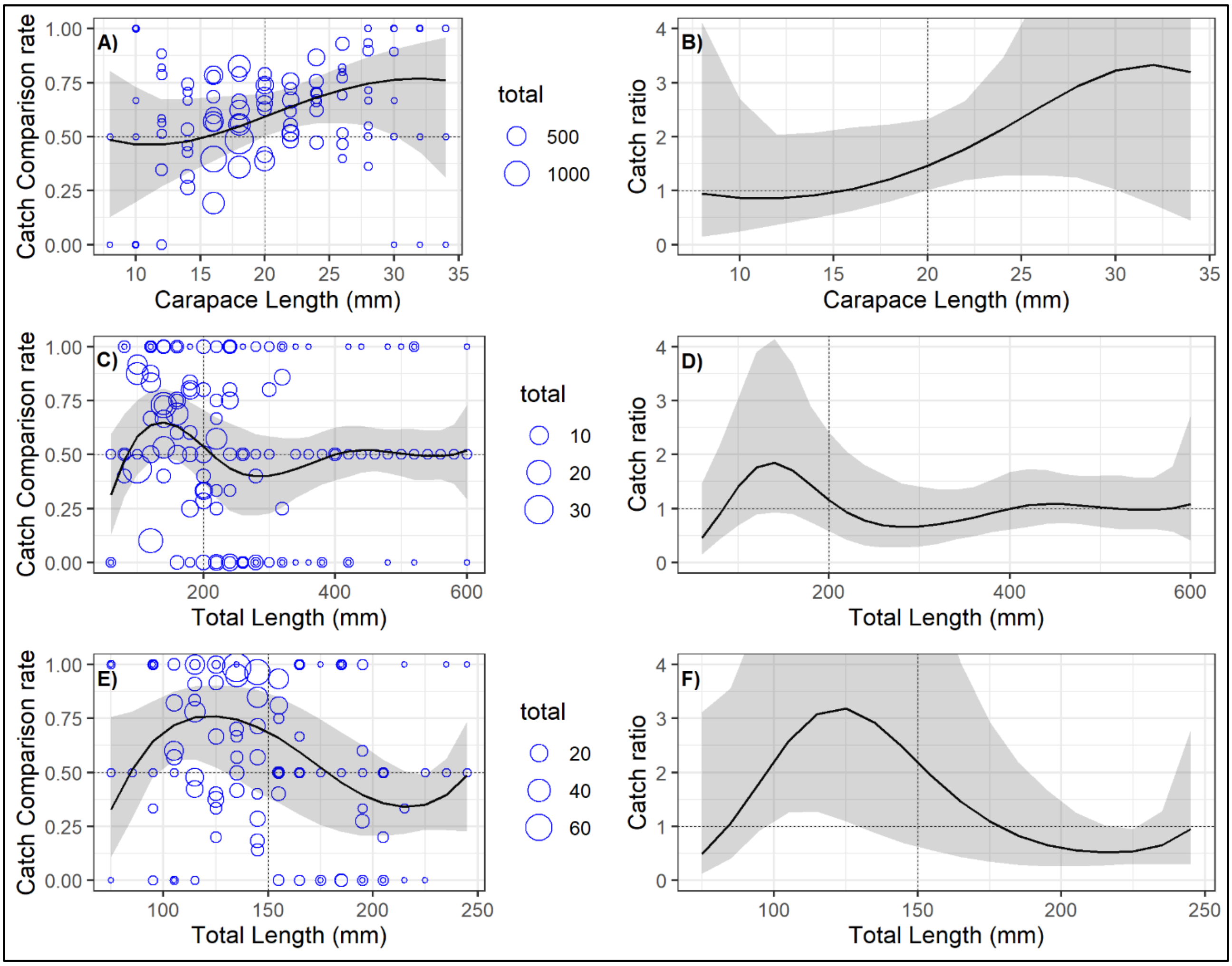


Figure 20. Catch comparison curves (left) and Catch Ratio curves (right) for (A, B) *Parapenaeus longirostris*, (C, D) *Merluccius merluccius*, and (E, F) *Trachurus trachurus*. (Left) blue circles are observed proportions, black dashed lines represent the model prediction, the grey band indicates the 95% confidence limit. The level of no effect (CCl = 0.5) is depicted by horizontal black dashed lines while the MCRS is indicated by black vertical dashed lines. (Right) solid black lines represent mean $CR_l$, the grey band indicates the 95% confidence limit. The level of no effect ($CR_l = 1.0$) is depicted by horizontal black dashed lines.

The mean $CR_l$ across all size classes highlighted as the catch by test net was approximately 86% more than that of the control (Fig. 21).

The $CC_l$ and $CR_l$ values for *M. merluccius* showed a higher efficiency of the test net in catching specimens from 100 to 200 mm TL ($CC_l = 0.61$; $CR_l = 1.56$; $CC_l = 0.56$; $CR_l = 1.26$). In contrast, for specimens between 220 mm and 380 mm TL ($CC_l = 0.49$, $CR_l = 0.97$; $CC_l = 0.48$, $CR_l = 0.94$), a slight decrease in the efficiency of the test was estimated. For the largest specimens, the $CC_l$ and $CR_l$ remained slightly above or equal to the level of no effect. For example, at 600 mm TL, $CC_l = 0.52$ and $CR_l = 1.10$ (Fig. 20C, D). The mean $CR_l$ across all size classes highlighted as the test catch was more or less equal to the control (8% more) (Fig. 21). The $CC_l$ and $CR_l$ of *T. trachurus* indicated a greater efficiency of the test up to 175 mm TL ($CC_l = 0.52$; $CR_l = 1.07$), except for 85 mm TL ($CC_l = 0.36$; $CR_l = 0.57$). Conversely, for larger specimens, from 185 ($CC_l = 0.45$; $CR_l = 0.82$) to 235 mm TL ($CC_l = 0.41$ and $CR_l = 0.70$), the test was less efficient (Fig. 20E, F). The mean $CR_l$ across all size classes was more for the test catch than the control (50%) (Fig. 21).

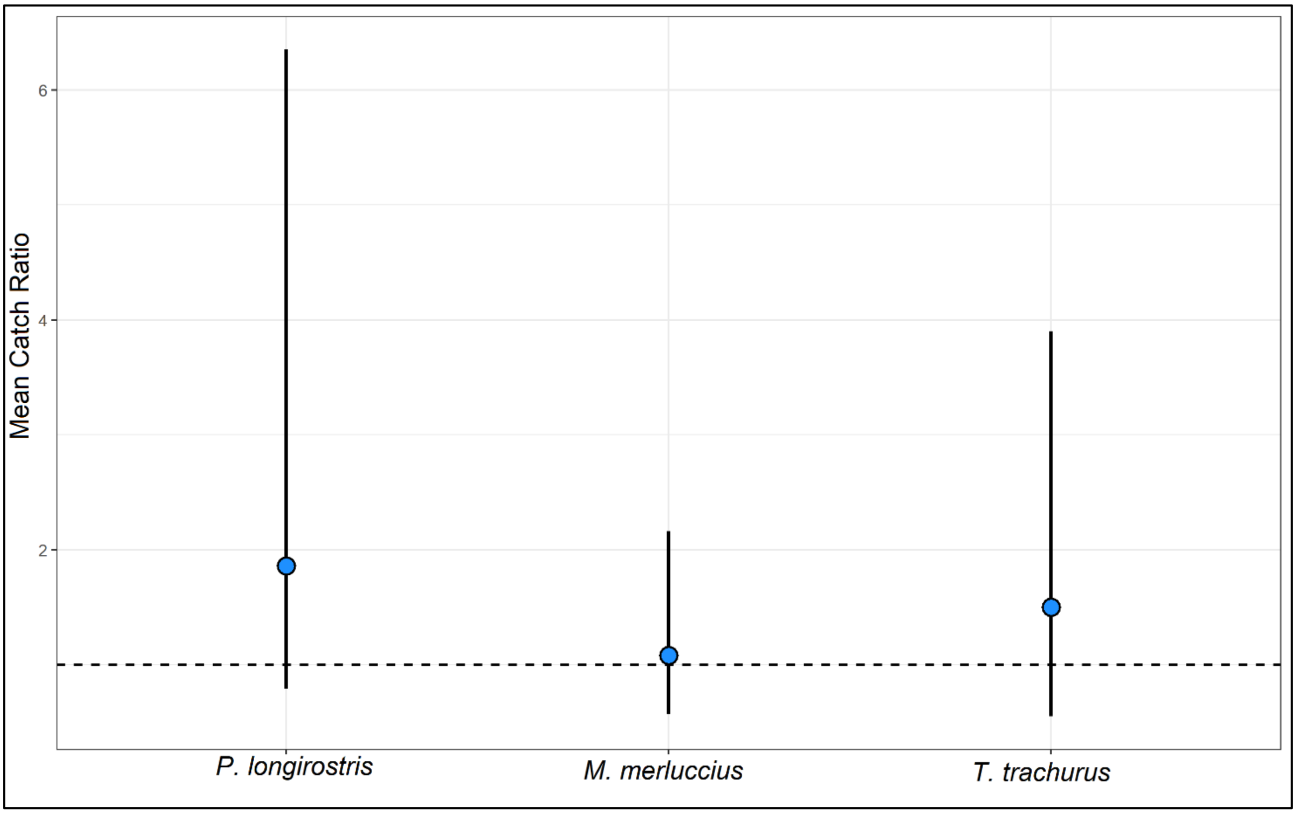


Figure 21. Mean Catch Ratio for *Parapenaeus longirostris*, *Merluccius merluccius*, and *Trachurus trachurus* between test and control nets is depicted by blue dots; bars indicate the 95% confidence limit. The level of no effect (mean CRl = 1.0) is depicted by the horizontal black dashed lines.

The mean probability to catch undersized specimens ($P_u$ ± sd) was higher for all species in the test than the control net, despite the similarity of $P_u$ for *P. longirostris* between both configurations (i.e.: *P. longirostris*: 0.56 ± 0.20; *M. merluccius*: 0.62 ± 0.20; *T. trachurus*: 0.74 ± 0.15).

## 3.5 DISCUSSION

The results of the present study indicate that bottom trawl nets equipped with 20 (10 green and 10 white) LED lights increase the overall catch rates during the night, even if they only significantly affected *P. longirostris*. In particular, catches of this species increased across almost all size classes. Importantly, the efficiency of the artificial illumination increased for *P. longirostris* specimens ranging from 20 to 30 mm CL, which is above the MCRS according to Reg. EC 1967/2006. This finding could be reflected in a higher profit for fishers owing to the larger size of the *P. longirostris* specimens caught using light. Conversely, for *M. merluccius* and *T. trachurus*, the test net caught more undersized species than the control, which might undermine the goal of the CFP to minimise unwanted catch (Reg. EC 1380/2013).

Although light is increasingly used in many Mediterranean fisheries, their impact on catch is still poorly understood, and the results of the few studies carried out are controversial (see Tab. 18).

Table 18. Synopsis of the studies conducted to test the effect of artificial lights during trawling. *Target*/bycatch is here intended to as for fisheries.

| **Area** | **Trawl type** | **Species** | ***Target*/by-catch** | **Light type** | **Colour/wavelength** | **Power/ Flux/intensity** | **Number of lights** | **Placement** | **Effect on size** | **Catch rates** | **Author** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bay of Biscay/Madeira | Midwater | Cephalopods | E | Electric (filament) | NA | 70 W | 1/2 | Top bar | NA | + | Clarke & Pascoe, 1985 |
| | | Fish | | | | | | | NA | + | |
| | | Crustaceans | | | | | | | NA | - | |
| Plymouth | Bottom | *Trachurus trachurus* | E | Electric (filament) | NA | 70 W | 2 | 3 m from each other from the headline centre | NA | + | Clarke *et al*., 1986 |
| | | *Merlangius merlangus* | | | | | | | NA | | |
| | | *Trisopterus minutus* | | | | | | | NA | | |
| | | *Eutrigla gurnardus* | | | | | | | NA | | |
| | | *Micromesitius potassou* | | | | | | | NA | | |
| | | *Merluccius merluccius* | | | | | | | NA | | |
| | | *Limanda limanda* | | | | | | | NA | | |
| | | Other 13 fish | | | | | | | NA | +/- | |
| Bay of Biscay | Midwater | Deep-Sea fish (12 species) | E | Electric (filament) | NA | 70 W | 1/2 | Top bar | Y* | + | Swinney *et al*., 1986 |
| | | *Gonostoma elongatum* | | | | | | | N | - | |
| | | Deep-Sea fish (20 species) | | | | | | | N | +/- | |
| Bering Sea | Bottom | *Theragra chalcogramma* | E | Electric (quartz halogen) | NA | 50 W | 1 | Footrope 3 m starboard of centre | N | +/- | Weinberg & Munro, 1999 |
| | | *Atheresthes stomias* | | | | | | | N | +/- | |
| | | *Pleuronectes asper* | | | | | | | N | +/- | |
| | | *Lepidopsetta bilineata* | | | | | | | N | +/- | |
| | | *Gadus macrocephalus* | | | | | | | N | +/- | |
| | | *Hippoglossoides elassodon* | | | | | | | N | - | |
| Rockal Trough | Bottom | *Alocephalus bairdii* | E | Electric (filament) | NA | 70 W | 2 | 3 m from each other from the headline centre | Y | + | Gordon *et al*., 2002 |
| | | *Centroscymnus coelolepis* | | | | | | | Y | + | |
| | | *Centroscymnus crepidater* | | | | | | | Y | + | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Coelorinchus labiatus* | | | | | | | Y | - | |
| | | *Coryphaenoides rupestris* | | | | | | | Y | + | |
| | | *Halargyreus johnsonni* | | | | | | | Y | + | |
| | | *Notacanthus bonapartei* | | | | | | | Y | + | |
| | | *Xenodermichthys copei* | | | | | | | Y | + | |
| | | Other fish | | | | | | | N | +/- | |
| Gulf of Mexico** | Bottom | Shrimp | T | Light sticks | NA | NA | 8 | 35 cm downstream of a BRD | N | +/- | Parsons *et al.*, 2012 |
| | | *Lutjanus campechanus* | B | | | | | | Y | - | |
| | | Other fish | B | | | | | | N | +/- | |
| U.S. Pacific coast** | Midwater | *Merluccius productus* | T | LED | White | 2600 lm+850 lm (from camera) | 2 | Top panel of an escape window (BRD) | NA | +/- | Lomeli & Wakefield, 2012 |
| | | *Oncorhynchus tshawytscha* | B | | | | | | | - | |
| | | *Sebastes entomelas* | B | | | | | | | +/- | |
| U.S. Pacific coast** | Midwater | *Merluccius productus* | T | LED | White | 2600 lm+850 lm (from camera) | 2 | Top panel of an escape window (BRD) | NA | +/- | Lomeli & Wakefield, 2014 |
| | | *Oncorhynchus tshawytscha* | B | | | | | | | + | |
| | | *Sebastes entomelas* | B | | | | | | | +/- | |
| Newport, Oregon** | Bottom | *Pandalus jordani* | T | LED | Green (540 nm); Blue (460 nm) | ≥0.5-2.0 lx | 1[#],3[#], 4[#], 10[##] | Near a sorting grids[#], centre of the footrope (1.2 m each other)[##] | NA[#] | +/-[#], +/-[##] | Hannah *et al.*, 2015 |
| | | *Thaleichthys pacificus* | B | | | | | | N[#] | +[#], -[##] | |
| | | *Lyopsetta exilis* | B | | | | | | NA[#] | +[#], | |
| | | *Sebastes crameri* | B | | | | | | NA[#] | +/-[#], -[##] | |
| | | *Sebastes* spp | B | | | | | | NA[#] | +/-[#], -[##] | |
| Barents Sea** | Bottom | *Pandalus borealis* | T | LED | Green (540 nm) | ≥0.5-2.0 lx | 5 | Around the escape exit of a sorting grids | Y | +/- | Larsen *et al.*, 2017 |
| | | *Sebastes spp.* | B | | | | | | N | + | |
| | | *Melanogrammus aeglefinus* | B | | | | | | Y | + | |
| | | *Gadus morhua* | B | | | | | | Y | + | |
| | | *Hippoglossoides platessoides* | B | | | | | | N | + | |
| Finnmark, Barents Sea*** | Bottom | *Melanogrammus aeglefinus* | T | LED | Green (540 nm) | ≥0.5-2.0 lx | 8 | In the centre of a square mesh | Y | + | Grimaldo *et al.*, 2018 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Gadus morhua* | T | | | | | panel by means floats | Y | +/- | |
| Barents Sea** | Bottom | *Pandalus borealis* | T | LED | Green (540 nm) | ≥0.5-2.0 lx | 4 | lower part of a Nordmøre grid | N | +/- | Larsen *et al.*, 2018 |
| | | *Hippoglossoides platessoides* | B | | | | | | N | +/- | |
| | | *Gadus morhua* | B | | | | | | N | +/- | |
| | | *Melanogrammus aeglefinus* | B | | | | | | N | +/- | |
| | | *Sebastes spp* | B | | | | | | N | +/- | |
| Newport, Oregon*** | Bottom | *Hippoglossus stenolepis* | T | LED | Green (540 nm) | ≥0.5-2.0 lx | 87 | Headrope (clusters of three ~1.3 m apart starting from the headrope centre) | N | - | Lomeli *et al.*, 2018a |
| | | *Parophrys vetulus* | T | | | | | | N | + | |
| | | *Glyptocephalus zachirus* | T | | | | | | N | - | |
| | | *Atheresthes stomias* | T | | | | | | N | - | |
| | | *Microstomus pacificus* | T | | | | | | Y | - | |
| | | *Eopsetta jordani* | T | | | | | | N | + | |
| | | *Sebastes crameri* | B | | | | | | N | + | |
| | | *Sebastes elongatus* | B | | | | | | N | + | |
| | | *Sebastes pinniger* | B | | | | | | N | + | |
| | | Other rockfishes | B | | | | | | N | + | |
| | | *Anoplopoma fimbria* | B | | | | | | Y | - | |
| | | *Ophiodon elongatus* | B | | | | | | N | - | |
| U.S. Pacific coast** | Bottom | *Pandalus jordani* | T | LED | Green (519 nm) | ≥0.5-2.0 lx | 5$^{\#}$, 10$^{\#}$, 20$^{\#\#\#}$ | Footrope (5$^{\#}$, 10$^{\#}$ lights 1.2 m apart from the centre; 20$^{\#\#\#}$ lights 0.6 m apart from the centre) | Y$^{\#}$,<br>Y$^{\#\#}$,<br>Y$^{\#\#\#}$ | +/-$^{\#}$,<br>+/-$^{\#\#}$,<br>+/-$^{\#\#\#}$ | Lomeli *et al.*, 2018b |
| | | *Thaleichthys pacificus* | B | | | | | | Y$^{\#}$,<br>Y$^{\#\#}$,<br>Y$^{\#\#\#}$ | -$^{\#}$,<br>-$^{\#\#}$,<br>-$^{\#\#\#}$ | |
| | | *Allosmerus elongatus* | B | | | | | | Y$^{\#}$,<br>Y$^{\#\#}$,<br>Y$^{\#\#\#}$ | -$^{\#}$,<br>-$^{\#\#}$,<br>-$^{\#\#\#}$ | |
| | | *Merluccius productus* | B | | | | | | Y$^{\#}$,<br>Y$^{\#\#}$,<br>Y$^{\#\#\#}$ | +/-$^{\#}$,<br>+$^{\#\#}$,<br>+/-$^{\#\#\#}$ | |
| | | Rockfish | B | | | | | | Y$^{\#}$,<br>Y$^{\#\#}$,<br>Y$^{\#\#\#}$ | -$^{\#}$,<br>-$^{\#\#}$,<br>-$^{\#\#\#}$ | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Citharichthys sordidus* | B | | | | | | Y$^{\#}$,<br>Y$^{\#\#}$,<br>Y$^{\#\#\#}$ | -$^{\#}$,<br>-$^{\#\#}$,<br>-$^{\#\#\#}$ | |
| | | *Glyptocephalus zachirus* | B | | | | | | Y$^{\#}$,<br>Y$^{\#\#}$,<br>Y$^{\#\#\#}$ | -$^{\#}$,<br>-$^{\#\#}$,<br>-$^{\#\#\#}$ | |
| | | *Lyopsetta exilis* | B | | | | | | Y$^{\#}$,<br>Y$^{\#\#}$,<br>Y$^{\#\#\#}$ | -$^{\#}$,<br>-$^{\#\#}$,<br>-$^{\#\#\#}$ | |
| Skagerrak, Denmark** | Bottom (horizontally separated) | *Nephrops norvegicus* | T | LED | Green (540 nm) | ≥0.5-2.0 lx | 10 | Before lower netting panel$^{\#}$, before upper netting panel$^{\#\#}$ | Y$^{\#}$, Y$^{\#\#}$ | +$^{\#}$ | Melli *et al.*, 2018 |
| | | *Gadus morhua* | B | | | | | | Y$^{\#}$, N$^{\#\#}$ | NA | |
| | | *Melanogrammus aeglefinus* | B | | | | | | N$^{\#}$, Y$^{\#\#}$ | NA | |
| | | *Merlangius merlangus* | B | | | | | | N$^{\#}$, Y$^{\#\#}$ | NA | |
| | | *Pleuronectes platessa* | B | | | | | | Y$^{\#}$, N$^{\#\#}$ | NA | |
| | | *Microstomus kitt* | B | | | | | | N$^{\#}$, Y$^{\#\#}$ | NA | |
| Tyrrhenian Sea, Italy**** | Bottom | *Parapenaeus longirostris* | T | LED | NA | NA | NA | Headrope | NA | +/- | Sbrana *et al.*, 2018 |
| | | *Merluccius merluccius* | T | | | | | | Y | NA | |
| Bay of Biscay*** | Bottom | *Merluccius merluccius* | T | LED | Blue | NA | 10 | Close to a square mesh panel just before the codend | N | +/- | Cuende *et al.*, 2019 |
| | | *Trachurus trachurus* | B | | | | | | N | +/- | |
| | | *Micromesistius poutassou* | T | | | | | | Y | + | |
| Oregon, N Pacific** | Midwater | *Oncorhynchus tshawytscha* | B | LED | Blue (464 nm)+ white light from video camera | ≥0.5-2.0 lx + 700 lm | 28 (in cluster of two)$^{\#}$<br>24 (in cluster of two)$^{\#\#}$ | About 61 cm apart over the distance of two escape windows | NA$^{\#}$, N$^{\#\#}$ | -$^{\#}$, -$^{\#\#}$ | Lomeli & Wakefield, 2019 |
| | | Other rockfishes | B | | | | | | NA$^{\#\#}$ | +/- | |
| Orkney Islands, Scotland***** | Bottom (horizontally separated) | *Limanda limanda* | B | LED (fibre optic cable) | Green (530 nm) | NA | 1 (30 m long but doubled up on itself) | Footrope#, leading edge of the separator panel## | Y$^{\#}$ and $^{\#\#}$ | + | O'Neill & Summerbell, 2019 |
| | | *Melanogrammus aeglefinus* | B | | | | | | N | - | |
| | | *Merlangius merlangus* | B | | | | | | Y$^{\#}$ and $^{\#\#}$ | - | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Pleuronectes platessa* | B | | | | | | N | - | |
| | | *Eutrigla gurnardus* | B | | | | | | Y# and ## | - | |
| | | *Chelidonichthys cuculus* | B | | | | | | N | - | |
| | | *Microstomus kitt* | B | | | | | | Y# and ## | NA | |
| Bay of Biscay** | Bottom | *Merluccius merluccius* | T | LED | White | NA | 10 | Upper part of the extension piece, over a square mesh panel# | N#, N## | +/-#, +/-## | Cuende *et al.*, 2020 |
| | | *Micromesistius poutassou* | T | | | | | Lower part of the extension piece, in front a square mesh panel## | N#, N## | +/-#, +/-## | |
| Oregon, N Pacific** | Midwater | *Merluccius productus* | T | LED | Blue (464 nm) | ≥0.5-2.0 lx | 16#, 32# | Along the escape area of a BRD 1.25 m apart each other | N | - | Lomeli & Wakefield, 2020 |
| | | *Oncorhynchus tshawytscha* | B | | | | | | N | - | |
| Oregon, N Pacific** | Bottom | *Pandalus jordani* | T | LED | Green (519 nm) | ≥0.5-2.0 lx | 5 | Headrope centre, about 1 m apart each other | N | +/- | Lomeli *et al.*, 2020 |
| | | *Thaleichthys pacificus* | B | | | | | | Y | - | |
| | | *Sebastes flavidus* | B | | | | | | Y | - | |
| | | *Sebastes saxicola* | B | | | | | | Y | + | |
| | | Other rockfishes | B | | | | | | Y | + | |
| | | *Atheresthes stomias* | B | | | | | | N | + | |
| | | *Lyopsetta exilis* | B | | | | | | Y | + | |
| | | Other flatfishes | B | | | | | | Y | + | |
| Irish Sea** | Bottom | *Aequipecten opercularis* | T | LED | White | 33 cd | 6 | Over a square mesh panel inserted 1.8 m aft of the centre of the headrope | NA | +/- | Southworth *et al.*, 2020 |
| | | *Merlangius merlangus* | B | | | | | | N | - | |
| | | *Melanogrammus aeglefinus* | B | | | | | | N | - | |
| | | *Gadus morhua* | B | | | | | | NA | +/- | |
| | | flatfish | B | | | | | | N | - | |
| Skagerrak, Denmark******* | Bottom (horizontally | *Nephrops norvegicus* | T | Luminous net | Green (520 nm) | NA | A v-shape ascending | Just before the codend | N | NA | Karlsen *et al.*, 2021 |
| | | *Gadus morhua* | B | | | | | | Y | NA | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | separated ) | *Melanogrammus aeglefinus*<br>*Merlangius merlangus* | B | | | | stripe of net | | Y | NA | |
| | | flatfishes | B<br>B | | | | | | Y<br>N | NA<br>NA | |
| Oregon, N Pacific** | Bottom | *Hippoglossus stenolepis* | B | LED | Green (519 nm) | 18 (attached in clusters of three) | ≥0.5-2.0 lx | Upper bridles and wing tips | Y | - | Lomeli *et al.*, 2021 |
| | | *Microstomus pacificus* | T | | | | | | Y | - | |
| | | *Eopsetta jordani* | T | | | | | | Y | - | |
| | | *Anoplopoma fimbria* | T | | | | | | Y | - | |
| | | *Ophiodon elongatus* | T | | | | | | N | - | |
| Strait of Sicily, Italy**** | Bottom | *Parapenaeus longirostris* | T | LED | Green (520 nm), white (460 nm) | 20 (10 green + ten white) | 3.5 cd | Headrope, 50 cm apart each other | Y | + | Geraci *et al.*, in press |
| | | *Merluccius merluccius* | B | | | | | | N | + | |
| | | All groundfishes combined | B | | | | | | NA | + | |
| Strait of Sicily, Italy**** | Bottom | *Parapenaeus longirostris* | T | LED | Green (520 nm), white (460 nm) | 20 (10 green + ten white) | 3.5 cd | Headrope, 50 cm apart each other | Y | + | Present study |
| | | *Merluccius merluccius* | B | | | | | | Y | +/- | |
| | | *Trachurus trachurus* | B | | | | | | Y | +/- | |
| | | All groundfishes combined | B | | | | | | NA | +/- | |

**E:** explorative; **T:** *target*; **B:** bycatch; **NA:** not available; **+:** increase, **-:** decrease, **+/-:** unaffected; **Y:** Yes, **N:** No; **Lampanyctus crocodilus, Sagamichthys schnakenbecki*; **the aim of the study was to reduce the catch of the bycatch species (intended as undersized individuals); ***the aim of the study was to reduce the catch of undersized *target* and bycatch species; ****the aim of the study was to assess the effect of lights (increase/decrease of catch rates) on both *target* and bycatch species (intended as accessory commercial catch) and discard (i.e. undersized individuals); ****** the aim of the study was to alter the height at which fish enter a trawl gear and reduce bycatch species (intended as undersized individuals); ******* the aim of the study was to increase the fish capture in the upper compartment; #: configuration of light.

Previously, in the Strait of Sicily, an unplanned and preliminary trial suggested a general attractive effect of artificial lights. In fact, a significant increase was recorded for the catch rates in weight during night in hauls with light for *P. longirostris*, *M. merluccius*, and gross catch (Geraci *et al.*, in press). Conversely, in the northern Tyrrhenian Sea, the use of light did not affect the catch rates in weight of *P. longirostris*, but caused a decrease in *M. merluccius* specimens below the MCRS (Sbrana *et al.*, 2018). On the other hand, Sardo *et al.* (2020) recently found that *T. trachurus* juveniles were repelled by white light in a laboratory study. In oceanic water, artificial lights have been evaluated as a potential tool to reduce the bycatch of fish in several fisheries, such as bottom trawls targeting shrimp and *Nephrops norvegicus* (Hannah *et al.*, 2015; Larsen *et al.*, 2017, 2018; Melli *et al.*, 2018; Lomeli *et al.*, 2018a, 2018b, 2020; Karlsen *et al*., 2021); midwater trawl for Pacific hake *(Merluccius productus*) (Lomeli & Wakefield, 2012, 2014, 2019, 2020); mixed bottom trawl fishery (Cuende *et al.*, 2019, 2020; Lomeli *et al.*, 2021); and trawl fishery for Queen scallops (*Aequipecten opercularis*) (Southworth *et al.,* 2020). These studies have revealed that the effects of artificial light on catch are highly variable, as they are dependent on many factors. Larsen *et al.* (2018), who worked with a rigid Nordmøre grid mounted on a shrimp trawl net targeting *Pandalus jordani*, noted that the addition of green LEDs around the escape exit was ineffective at reducing juvenile fish bycatch. Previously, in Pacific waters, Hannah *et al.* (2015) demonstrated that the CPUE of *P. jordani* did not change using blue-green lights in different portions of the trawl net; however, the bycatch amount was variable and dependent on the proper placement/location of lights within the fishing gear. Specifically, adding artificial light around a sorting grid caused an increase in bycatch, which was reduced when lights were mounted on the fishing line (Hannah *et al.*, 2015). Lomeli *et al.* (2018b) compared the CPUE obtained with a trawl net equipped with different configurations of 5, 10, and 20 LED lamps with those of an unilluminated trawl net; however, these researchers did not find any differences in *P. jordani* catch rates. On the contrary, they found a significant reduction in the bycatch for most of the species, except for *M. productus* using a ten LED-configuration. In Basque mixed bottom trawl fisheries, Cuende *et al.* (2019) tested a square mesh panel (SMP) together with different types of stimulators (i.e., ropes, floats, blue LED lights), and reported that blue LED light did not enhance the escape probability of *M. merluccius* and *T. trachurus*. More recently, no significant improvement in the release efficiency for either *M. merluccius* or *Micromesisitius poutassou* was confirmed in the same area by testing white LED lights with an SMP (Cuende *et al.*, 2020). The bulk of global discards from fisheries is derived from trawling (Perez-Roda *et al.*, 2019) and the recent implementation of the EC Reg. 1241/2019 aims to minimise the impact of fishing on marine ecosystems. The application of artificial light in trawl fisheries to reduce unwanted by-catch could be very fruitful, but needs to be further assessed (ICES, 2020). For this purpose, a shared protocol or "paper guidelines", summarising all information from scientific surveys, personal experience, and other disciplines (e.g., physics, physiology, ethology), could be very useful for both fishery biologists and fishers.

Our results confirmed the general positive effects of artificial lights on *P. longirostris* catch rates during the night reported by local fishers, who are increasingly using green and white (simultaneously) artificial lights on the headrope of trawl nets. Moreover, the use of 20 LED lights mounted symmetrically to the centre of the head rope in the crustacean trawl net might have an important effect on the size selectivity of the trawl, particularly for legal-sized *P. longirostris* and undersized individuals of *M. merluccius* and *T. trachurus*. As the estimated annual costs of approximately €500 Euro are associated with the use/maintenance of light (Pinello *et al.*, 2018) as well as the work for managing these lights on board, it is reasonable to suppose that the cost-benefit ratio should be positive. Traditionally, crustacean trawl fisheries are mainly carried out during the day owing to the higher catchability of the gear than the night. Indeed, during the daytime, *P. longirostris* stays on or relatively close to the bottom to avoid predators (Aguzzi *et al.*, 2009); however, at night, they migrate from the seafloor to prey on water columns (Rodríguez-Climent *et al.*, 2016). In the last few years, the use of artificial lights has enabled shrimp fishing activity during the night, abandoning the traditional alternation between deep-water trawling during the day, targeted to shrimp, and shallow water trawling during the night, targeted to fish and cephalopods. Owing to such recent widespread use of artificial light in deep-water crustacean fisheries, a further evaluation of its impact on the catch is needed to avoid the fact that an increase in CPUE can lead to a depletion of the exploited stocks. Fishing fleets using artificial lights should be carefully considered because of their expected effect in improving the catchability of *target* and non-*target* species. In the well-known situation of high overexploitation of stocks in the Mediterranean (e.g., Colloca *et al.*, 2017), including *P. longirostris* and *M. merluccius* in the Strait of Sicily (GFCM, 2019), lights and other technological tools may be increasingly used by fishing vessels to "buffer" the reduction in catch rate of traditional fishing gear. An expected consequence of the use of light in trawling could be an increase in fishing mortality that eliminates the reduction of the fishing effort implemented by the European CFP and contributing to a deterioration of the stocks status. Although more quantitative data should be gathered to generalise the results obtained, this study shows clear trade-offs between gains due to higher CPUE of commercial *P. longirostris* specimens and risks linked to higher unwanted by-catch of juveniles below the MCRS of *M. merluccius* and *T. trachurus*.

## 3.6 CONCLUSION

The present study indicates that the use of underwater lights in Mediterranean trawl fisheries should be carefully regulated through ad hoc measures that are currently lacking. The meta-synthesis of the effect of artificial lights during trawling highlights that, similar to the next years, scientists will face a new challenge in enhancing knowledge on the impact of artificial lighting on marine ecosystems during fishing activities, which are only now beginning to be examined in detail, at least in the Mediterranean. In the absence of sound scientific understanding, precautionary management measures should be taken to minimise the potential impacts of artificial light on some already overexploited stocks, where possible. Thus, more studies are needed to explore trade-offs in mixed trawl fisheries using different experimental artificial light settings (number location, intensity, and wavelengths) on different fishing grounds and species assemblages. Lastly, the different behaviour of species when approaching the gear should be considered. The aim would be to establish rules for the use of underwater lights in trawl fisheries, and to identify more suitable settings to improve fishery selectivity, thereby avoiding unwanted increases in both fishing mortality and unwanted by-catch. The construction of a solid baseline of knowledge on the impacts of artificial lighting in fishing practices will enable the potential design of realistic and effective management strategies that can benefit both marine ecology and society.

# 4. PAPER 3: Age structure of spawners of the axillary seabream, *Pagellus acarne* (Risso, 1827), in the central Mediterranean Sea (Strait of Sicily)

## 4.1 ABSTRACT

An unusual catch of mature specimens *of Pagellus acarne* (Risso, 1827) off the south coast of Sicily (Quadro Bank, central Mediterranean Sea) on October 2016 allowed to improve the ongoing knowledge on the age structure of spawners and other reproductive aspects of the species. A sample of 104 (32 female and 72 male) specimens was examined. Females showed size (range TL[1] = 20.5 to 25.5 cm; mean length = 22.3 ± 1.2 cm) longer than males (range TL = 16.5 – 23.5 cm; mean length = 20.0 ± 1.8 cm). About 94% of females and 88% of males were mature. The pooled sex LWR[2] was W[3] (g) = 0.003 $TL^{3.5207}$. The age structure estimated by *sagittae* readings ranged from age class III to VII in females and II to VI in males with a prevalence of age class VI and IV for females and males, respectively. The precision of age estimates was tested by applying both the APE[4] and the mean CV[5].

Our record suggests that the Quadro Bank is an EFH[6] for *P. acarne*. Knowing when and where adults aggregate for reproduction, is a prerequisite to develop effective management measures to preserve the replacement capability of exploited stocks and pursue sustainable fisheries strategies.

**Keywords:** Spawning aggregation; sexual inversion; hermaphroditism; protandric species; maturity at age

## 4.2 INTRODUCTION

Overall, species belonging to the family of *Sparidae* constitute an important fishery resources in warm temperate marine areas such as the Mediterranean Sea (e.g. Gordoa & Molì, 1997; Monteiro *et al.*, 2010; Marengo *et al.*, 2016) in terms of species diversity, total landing and high commercial value of the landings (Mouine *et al.*, 2012). Among the Sparidae, the genus *Pagellus* includes several species targeted by Mediterranean demersal fisheries, being the most important the axillary seabream, *P. acarne* (Risso, 1827), the blackspot seabream, *P. bogaraveo* (Brünnich, 1756) and the common pandora, *P. erythrinus* (Linnaeus, 1758).

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[1] Total Length

[2] Length-Weight Relationship

[3] Weight

[4] Average Percent Error

[5] Coefficient of Variation

[6] Essential Fish Habitat

In particular, *P. acarne* shows a wide geographical distribution along the northern and eastern Atlantic coasts from Norway to Senegal and around the Macaronesia Island, as well as the Mediterranean Sea (Russell *et al.*, 2014). The species inhabits mainly areas with sandy and muddy soft bottoms down to 500 m depth, although it is more common between 40 and 100 m with juveniles often frequently found on *Posidonia oceanica* (Delile, 1813) beds near the shore (Bauchot & Hureau, 1986; Coelho *et al.*, 2005; Parenti & Poly, 2004).

Axillary seabream is one of the main target species of small-scale commercial fisheries in the northern Atlantic Algarve (Erzini *et al.*, 2001), Azores (Morato *et al.*, 2001) and Canary Islands (Pajuelo and Lorenzo, 1994, 2000). In the Mediterranean Sea it is mostly a by-catch of both artisanal vessels and trawlers. The status of the stocks in the region is almost unknown with the exception of the Alboran Sea where it was identified an overfishing status of the axillary seabream stock with declining biomass (Baro, 2000). Currently, the only specific management measure applied for the species in the Mediterranean Sea is the minimum landing size (MLS) fixed at 17 cm total length (EC Regulation 1967/2006).

It is well known that the axillary sea bream exhibits protandric hermaphroditism where individuals first mature as males with the immature ovarian zone adjoins, then they undergo testicular regression and the ovarian zone becomes functionally female (Le-Trong & Kompowski, 1972; Lamrini, 1986; Reinboth *et al.*, 1986; Pajuelo & Lorenzo, 1994, 2000; Arculeo *et al.*, 2000).

The biology of *P. acarne* has been studied in several areas of the Mediterranean, including the western (Velasco *et al.*, 2010; Bensahla Talet *et al.*, 2013; Boufersaoui & Harchouche, 2015; Bensahla Talet *et al.*, 2017), the central (Andaloro, 1982; Arculeo *et al.*, 2000; Mokrani *et al.*, 2007) and the eastern basin (Mytilineou, 2000; Soikan *et al.*, 2015).

Available information concerns spawning period, sex-ratio, length at sexual inversion and at first maturity and Length-Weight Relationship (LWR), but very few is known about age structure of spawners. Studies on reproductive biology of fish are important and a basic requirement for an effective fishery resources management and conservation (Trippel, 1999). Furthermore, age structure of spawners is more and more recognized as a main factor in success of reproduction since a more age-diverse spawning stock tends to spawn earlier and over a longer period than a stock with few old individuals (Caddy & Seijo, 2002; Longhurst, 2002; Birkeland & Dayton, 2005; Fromentin, 2006; Fiorentino *et al.*, 2008; Brunel, 2010).

The objective of this study is to provide new data on the sex ratio, LWR and age structure of the spawning fraction of *P. acarne* population in the central Mediterranean Sea.

## 4.3 MATERIALS AND METHODS

### 4.3.1 Study Area and Sampling

A spawning aggregation of the axillary seabream was caught during a trawl haul carried out by a Sicilian commercial trawler in the international waters of the Quadro Bank (off Tunisian coast) (37°25,92 N – 10°37,63 E; 37°28,30 N – 10°40,59 E; mean depth 85 m) on October 1st 2016 at sunset (from 18:30 to 19:40, solar time). The catch, composed by 312 adults weighting 38 kg, was recorded by observers on board in the frame of the monitoring activities of commercial catch (CampBiol) within the European Data Collection Framework (DCF) (Fig. 22).

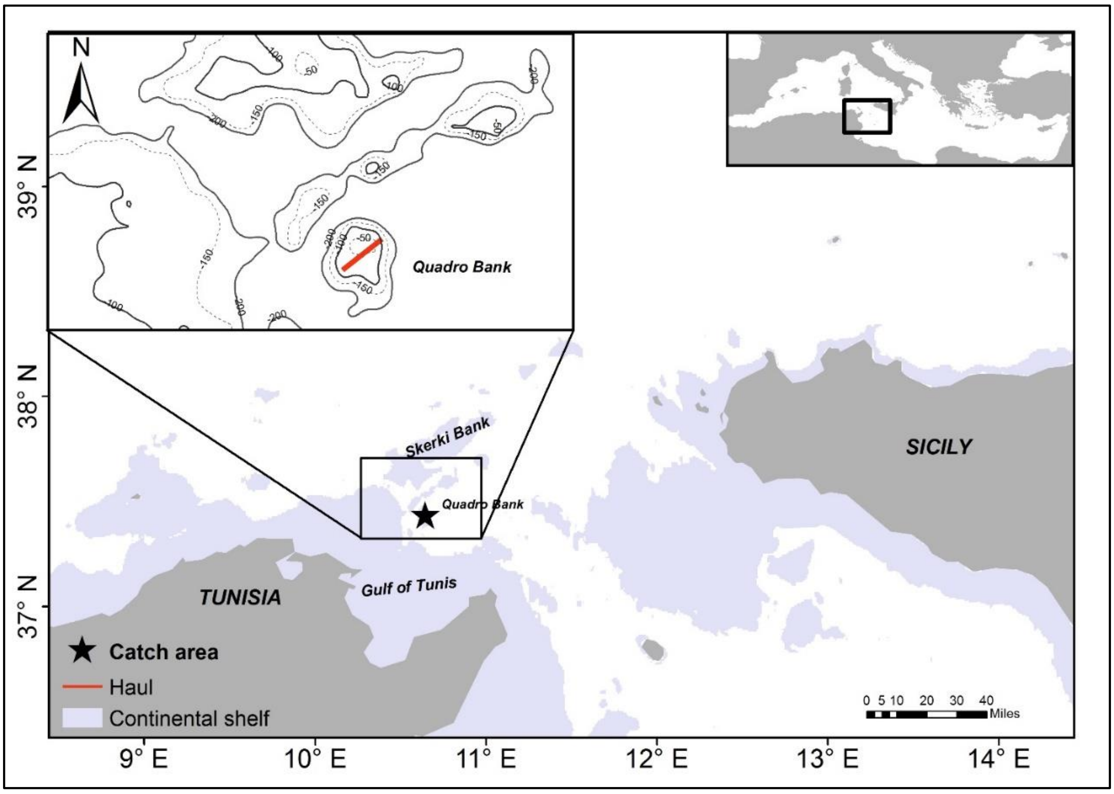

Figure 22. Map showing the position of the trawl haul (red line) where the spawning aggregation of *P. acarne* was found.

### 4.3.2 Laboratory Processing

One third of the catch was randomly sampled and frozen on board. Fish were then processed in laboratory where both Total Length (TL, to the nearest 0.5 cm) and Weight (W, to the nearest 0.1 g) were measured. Sex was evaluated macroscopically by inspection of gonads. Individuals presenting both male and female gonads were considered males if testis were predominant; otherwise females.

### 4.3.3 Reproductive Aspects

Maturity stages were assessed according to the MEDITS (International Bottom Trawl Survey in the Mediterranean) scale (Anonymous, 2016) based on eight distinct maturity stages: (0) undetermined, (1) immature = virgin, (2a) virgin-developing, (2b) recovering, (2c) maturing, (3) mature/spawner, (4a) spent and (4b) resting.

Sex-ratio (SR) was expressed in the overall sample and by length as:

$$SR = F/(F+M)$$

where F = number of females and M = number of males.

Due to the well know protrandic hermaphroditism of the species (Arculeo *et al.*, 2000), the sex-ratio by TL was described by using the logistic function:

$$SR_{(l)} = 1/[1+exp^{-r(TL-L_{50})}]$$

where $L_{50}$ is length where 50% of specimens are female, as proxy of the sexual inversion length, and r is a constant (Jennings *et al.*, 2001).

### 4.3.4 Length and Age Methodology of Estimates

The LWR was calculated combining sexes and using the classical allometric power function:

$$W = aTL^b$$

where W is the total body weight (g) and *a* and *b* constants (Jennings *et al.*, 2001). Since specimens were frozen in plastic bags to reduce the moisture loss, the variation in weight between fresh and thawed fish was considered negligible.

Otoliths were collected from each individual for ageing. In particular, *sagittae* were extracted, cleaned in distilled water and stored dry. Successively, otoliths were read in water under reflecting light by two readers for three times. The incremental growth pattern formed by one opaque and one translucent rings was assumed having annual value (*annulus*). The readers did not have access to information on size, sex or date of capture while they were counting growth increments. To assess ageing precision between readers, the index of Average Percent Error (APE) (Beamish & Fournier, 1981) and the mean Coefficient of Variation (CV) (Chang, 1982) were calculated.

Considering the mature status of the fish sampled confirming knowledge on the species spawning periods in the area (i.e. September-December with a peak in October, Mokrani *et al.*, 2007), the first of November was assumed as birthday for aging the sampled fish. The first translucent ring was considered the demersal check laid down during bottom settlement after the pelagic life stage (Rizzo *et al.*, 2005; Sieli *et al.*, 2011; Bottari *et al.*, 2016). The ages at length of specimens were finally organized in a classic Age-Length Key (ALK) to give the demographic structure of catch (Morales-Nin & Panfili, 2002).

## 4.4 RESULTS

### 4.4.1 Length and Reproductive Analysis

The sample was dominated by males (69.2%) being the sex ratio 0.31 with females (range TL = 20.5 – 25.5 cm; mean TL = 22.3 ± 1.2 cm) larger than males (range TL = 16.5 – 23.5 cm; mean TL= 20.0 ± 1.8 cm) ($p < 0.05$). The modal progression analysis (Bhattacharya test) showed a bimodal length frequency distribution for males, with evident modes at 18 and 21 cm TL, while the females appeared unimodal (22 cm TL) (Fig. 23).

Individual weight ranged from 109 to 266 g and 56 to 171 g for females and males respectively ($p < 0.05$).

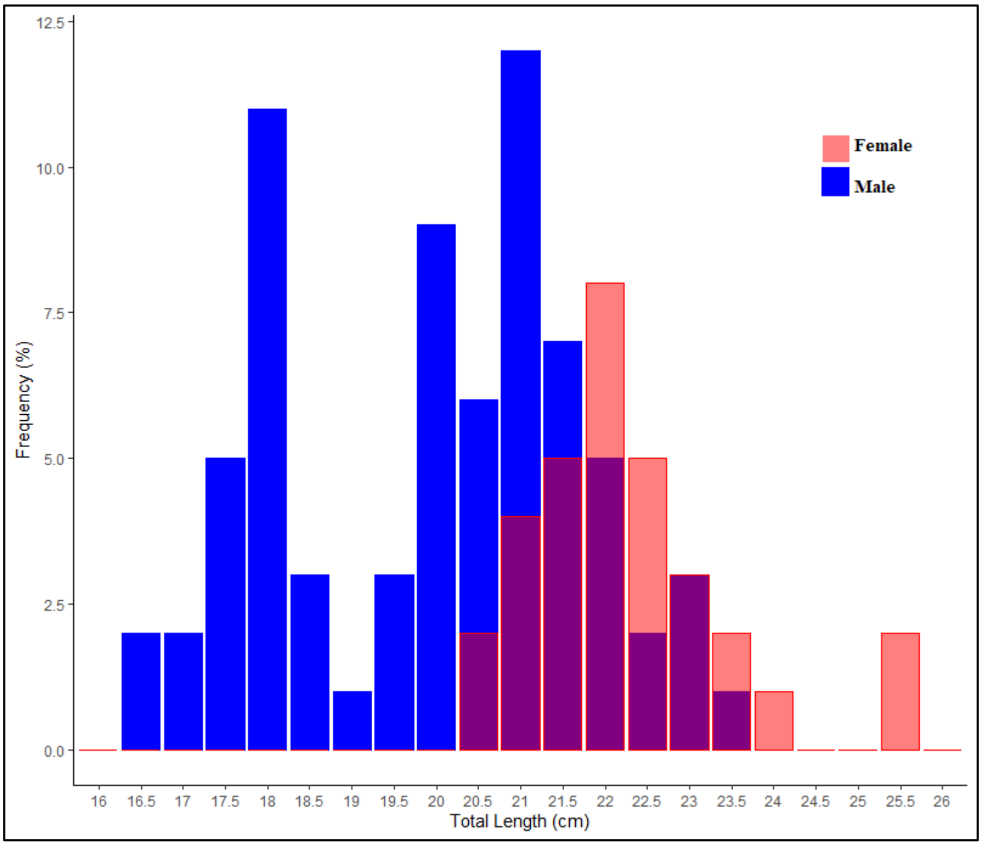

Figure 23. Length frequency distribution (LFD) by sex of *P. acarne*. Length frequency distribution of males was bimodal, with evident modes at 18 and 21 cm TL, while the females appeared unimodal (22 cm TL).

The estimated length at sexual inversion ($LSI_{50}$) was 22 cm TL (Fig. 24) (Intercept = -24.72, SE = 5.63; Slope = 1.12, SE = 0.26).

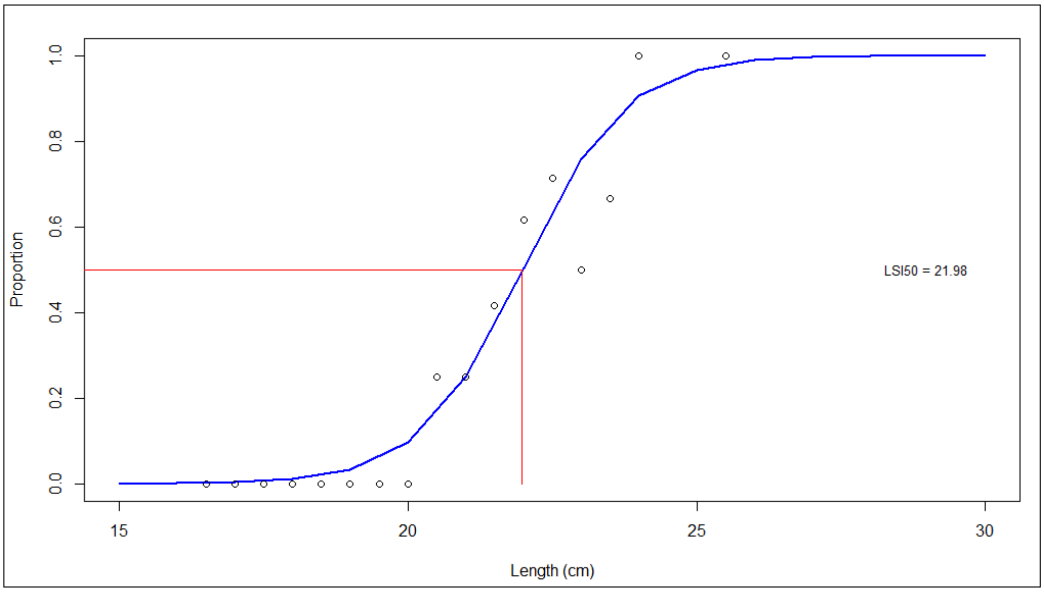

Figure 24. Logistic curve describing the sex ratio a proportion of F/(F+M) by size of *P. acarne*. An estimated of size sexual inversion ($LSI_{50}$ = 22.0 cm TL) with parameter (Intercept = -24.72, SE = 5.63; Slope = 1.12, SE = 0.26) are given.

The LWR corresponds to a positive allometric growth and the pooled parameters were a = 0.003 and b = 3.5207 (Tab. 20; Fig. 25).

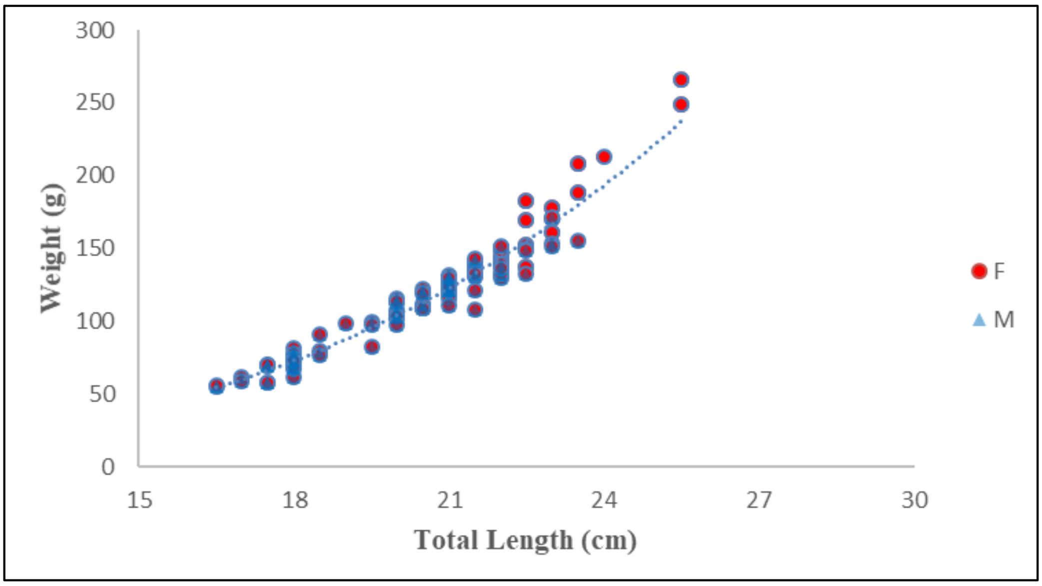

Figure 25. The length-weight relationship of *P. acarne* (sex pooled). Individual data were reported by sex.

All the females were mature with ovaries highly vascularized and with ripe and fluent eggs (stage 3, n = 31) or very close to stage 2c (n = 1). A total of 62 (59.6%) males were mature with fluent gonads (stage 3) while 7 (6.7%) were between recovering (stage 2b) and maturing (stage 2c) phases.

Only 1 specimen was virgin-developing (stage 2a), with a TL of 16.5 cm and 2 were spent (stage 4a). The mean (± s.d.) size of mature males (stage 2c and 3) was 20.0 ± 1.8 cm TL.

### 4.4.2 Age Analysis

All the examined specimens were successfully aged. Indices of ageing precision APE and CV were very low (10.38 and 13.12, respectively), showing a good consistency or reproducibility among readings. The age class composition was between II and VI and III and VII for males and females respectively (Fig. 26).

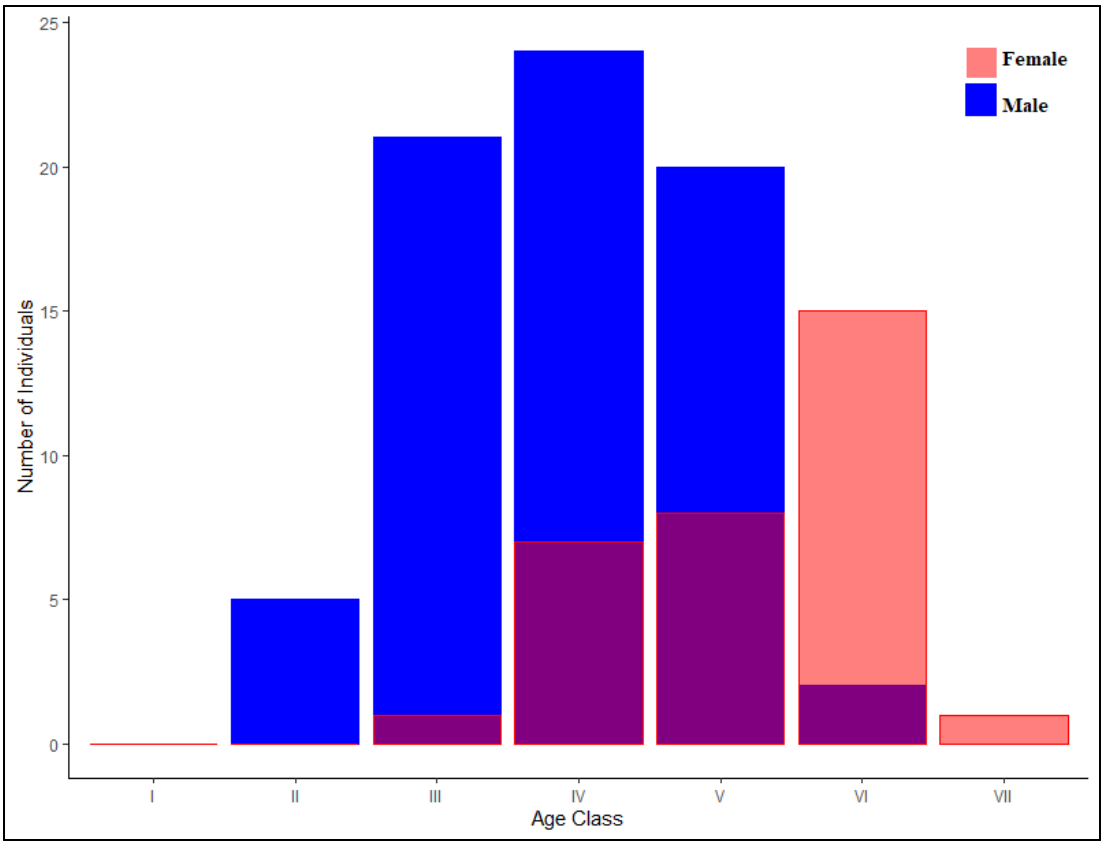

Figure 26. Age frequency distribution by sex of the *P. acarne* sample.

Due to the species' hermaphroditism, the ALK was prepared pooling sex (Tab. 19).

Table 19. Age-Length key by pooled sex of the *P. acarne* sample. Years expressed as “Age class”.

| Total Length (cm) | Pooled sex | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | Age class | | | | | | | |
| | I | II | III | IV | V | VI | VII | |
| 16.5 | | 1 | 1 | | | | | 2 |
| 17 | | 1 | 1 | | | | | 2 |
| 17.5 | | 2 | 3 | | | | | 5 |
| 18 | | 1 | 9 | 1 | | | | 11 |
| 18.5 | | | 3 | | | | | 3 |
| 19 | | | | 1 | | | | 1 |
| 19.5 | | | 1 | 2 | | | | 3 |
| 20 | | | 3 | 5 | 1 | | | 9 |
| 20.5 | | | 1 | 6 | 1 | | | 8 |
| 21 | | | | 8 | 7 | 1 | | 16 |
| 21.5 | | | | 4 | 5 | 3 | | 12 |
| 22 | | | | 3 | 7 | 3 | | 13 |
| 22.5 | | | | 1 | 1 | 5 | | 7 |
| 23 | | | | | 4 | 2 | | 6 |
| 23.5 | | | | | 1 | 2 | | 3 |
| 24 | | | | | | 1 | | 1 |
| 24.5 | | | | | | | | 0 |
| 25 | | | | | | | | 0 |
| 25.5 | | | | | 1 | | 1 | 2 |
| Total | 0 | 5 | 22 | 31 | 28 | 17 | 1 | 104 |
| Mean Total Length | 0 | 17.3 | 18.3 | 20.7 | 21.9 | 22.4 | 25.5 | |
| Standard Deviation | 0 | 0.6 | 1.0 | 1.0 | 1.1 | 0.8 | 0 | |

## 4.5 DISCUSSION

According to the literature axillary seabream’s reproduction in the Mediterranean Sea occurs between April and December (Tab. 20). Considering the Strait of Sicily, the spawning season is shorter extending from September to December with a peak in October in the Gulf of Tunis (Mokrani *et al.*, 2007). Our record of a species spawning aggregation in October supports the observation of an autumnal spawning period of the axillary seabream in the Strait of Sicily.

In our sample the overall sex ratio was significantly in favor of males (SR = 0.31), being the lowest value reported in literature (Tab. 20). No females smaller than 20.5 cm TL and no males larger than 23.5 cm TL were found confirming the protandric characteristic of this species.

Data on sex inversion, occurring between 20.5 and 23.5 cm TL, generally agreed with literature in Mediterranean (Boufersaoui & Harchouche, 2015; Dragicevic *et al.*, 2015) and in Atlantic (Coelho *et al.*, 2005). Moreover, the Length of Sexual Inversion ($LSI_{50}$) calculated in this work (22 cm TL) is similar to that estimated by Velasco *et al.* (2010) in Alboran Sea (21.5 cm TL), but differs from the $LSI_{50}$ value reported by the same authors in the Gulf of Cadiz (23.5 cm TL) (Tab. 20). It's very interesting to note that, in several studies performed in the Mediterranean Sea, the value of $L_{50}$ for females results lower than the value of the $LSI_{50}$. We suppose that this phenomenon could be due to the occurrence of primary females in the population, as commonly reported for Sparidae (Buxton & Garratt, 1990).

The minimum landing size regulation set at 17 cm TL, adopted within the European Union Common Fisheries Policy (EC Regulation 1967/2006) for the axillary seabream, seems insufficient to ensure stock renewal and should be increased as already proposed by Bensahla Talet *et al.* (2017). In particular, considering the medium size of sexual inversion present in literature, it should be very important to increase the MLS at 20 cm in order to reduce the catch of immature individuals.

Table 20. Biological comparison of data collected by different authors on *P. acarne*. M: males; F: females; P: pooled sex; NA: not available.

| **Region** | **Sex Ratio F/(F+M)** | **L min – L max (cm)** | **Size of sexual inversion ($LSI_{50}$) (cm)** | **Size of first maturity ($L_{50}$) (cm)** | **Spawning period** | **Source** |
|---|---|---|---|---|---|---|
| Tyrrhenian and Ionian Sea | NA | 8 – 28 (P) | NA | 16.5 (P) | July→September | Andaloro, 1982 |
| Strait of Messina | 0.32 | 18 – 22 (P) | NA | NA | August | Arculeo *et al.*, 2000 |
| Algarve | 0.66 | 12.4 - 36.5 (P) | 20 - 24 | 18.1 (M)<br>17.6 (F) | May→September<br>May→November | Coelho *et al.*, 2005 |
| Gulf of Cadiz | 0.49 | 11.3 - 30.9 (P) | 23.5 | 18.04 (M)<br>21.7 (F) | April→June<br>April→June | Velasco *et al.*, 2010 |
| Alboran Sea | 0.50 | 10.7 - 29.4 (P) | 21.5 | 17.7 (M)<br>20.1 (F) | May→October<br>May→October | |
| Algerian Sea | NA | 11.3 - 24.3 (M)<br>10.8 - 28.1 (F) | 19 - 24 | 16.8 (M)<br>16.5 (F) | NA | Boufersaoui and Harchouche, 2015 |
| Gulf of Tunis | 0.38 | 11.4 - 25.5 (P) | NA | 15.68 (M)<br>16.27 (F) | September→December | Mokrani *et al.*, 2007 |
| Adriatic Sea | NA | 9.3 – 29.5 (P) | 16.1 - 25.5 | 16.1 (M)<br>17.7 (F) | September→October | Dragicevic *et al.*, 2015 |
| Izmir Bay | 0.78 | 8.5 - 20.2 (P) | NA | 13.91 (M)<br>14.45 (F) | June→September | Soykan *et al.*, 2015 |
| Alboran Sea | NA | NA | 20.5 - 20.9 | 19 (P) | May→October | Baro, 2000 |
| Algerian Sea | 0.56 | 11.9 – 26.3 (P) | NA | 15.99 (M) | May→December | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | 12.75 (F) | | Bensahla Talet *et al.*, 2013 |
| Quadro Bank | 0.31 | 16.5 - 23.5 (M)<br>20.5 - 25.5 (F) | 22 | NA | October | Present study |

The LWR of the specimens caught in the Quadro Bank showed strong positive allometry probably as an effect of their maturity condition. Compared to our study, a less strong positive allometry was obtained for both sex around Gulf of Cadiz (Velasco *et al.*, 2010), in the Ionian Sea (Lembo *et al.*, 2012), in the Tyrrhenian Sea (De Ranieri, 2011; Spedicato *et al.*, 2012) and in the Balearic Island (Morey *et al.*, 2003). On the contrary, negative allometric growth was found in the south Adriatic Sea (Carbonara *et al.*, 2012) and in the Aegean Sea (Moutopoulos and Stergiou, 2002) (Tab. 21). Compared to other studies, the b parameter value of the Quadro Bank individuals was higher, this may be due either to the absence of juveniles in the catch or to the presence of adults with ripe gonads. Both these aspects undoubtedly may influence the fit of the LWR.

Table 21. Parameters of the LWR of *P. acarne* in different areas. NA: not available.

| **Area** | **Sex** | **N** | **a** | **b** | **$r^2$** | **Reference** |
|---|---|---|---|---|---|---|
| Quadro Bank | Pooled | 312 | 0.003 | 3.5207 | 0.95 | Present study |
| Gulf of Cadiz | Pooled | 461 | 0.0048 | 3.3207 | 0.98 | Velasco *et al.* (2010) |
| Alboran Sea | Pooled | 406 | 0.0093 | 3.1132 | 0.94 | |
| Izmir Bay | Pooled | 842 | 0.009 | 3.138 | 0.97 | Soykan *et al.* (2015) |
| Mersin Bay | Pooled | 901 | 0.0075 | 3.146 | 0.94 | Cicek *et al.* (2006) |
| Algarve | Pooled | 370 | 0.012 | 3.048 | 0.98 | Coelho *et al.* (2005) |
| Baie d'Oran | Pooled | 844 | 0.0089 | 3.1006 | 0.96 | Bensahla Talet *et al.* (2013) |
| Ligurian and North Tyrrhenian Sea | Pooled | NA | 0.0062 | 3.26 | NA | De Ranieri (2011) |
| South Tyrrhenian Sea | Pooled | NA | 0.0068 | 3.22 | NA | Spedicato *et al.* (2012) |
| South Adriatic Sea | Pooled | NA | 0.0288 | 2.71 | NA | Carbonara *et al.* (2012) |
| Ionian Sea | Pooled | NA | 0.0057 | 3.28 | NA | Lembo *et al.* (2012) |
| Aegean Sea | Pooled | NA | 0.0150 | 2.93 | 0.97 | Moutopoulos and Stergiou (2002) |
| Balearic Island and Iberian Coast | Pooled | 140 | 0.0660 | 3.21 | 0.995 | Morey *et al.* (2003) |
| Aegean Sea | Pooled | 334 | 0.0104 | 3.06 | 0.933 | Ilkyaz *et al.* (2008) |
| South Tyrrhenian Sea and North Ionian Sea | Pooled | NA | 0.0096 | 3.02 | NA | Andaloro (1982) |

The age structure of the spawners ranged between age class II and VII, with a prevalence of age class IV and VI for males and females, respectively. Comparison with von Bertalanffy curves available in literature suggests that our specimens show a similar growth pattern to others, excepting that reported by Soykan *et al.* (2015) for the Izmir Bay (Fig. 27).

Since the age corresponding to the size at first maturity reported by Mokrani *et al.* (2007) for the Gulf of Tunis (Tab. 20) should be the age class II, it is worth noting that most of the fish caught on the Quadro Bank on October 2016 were old spawners after their first reproduction.

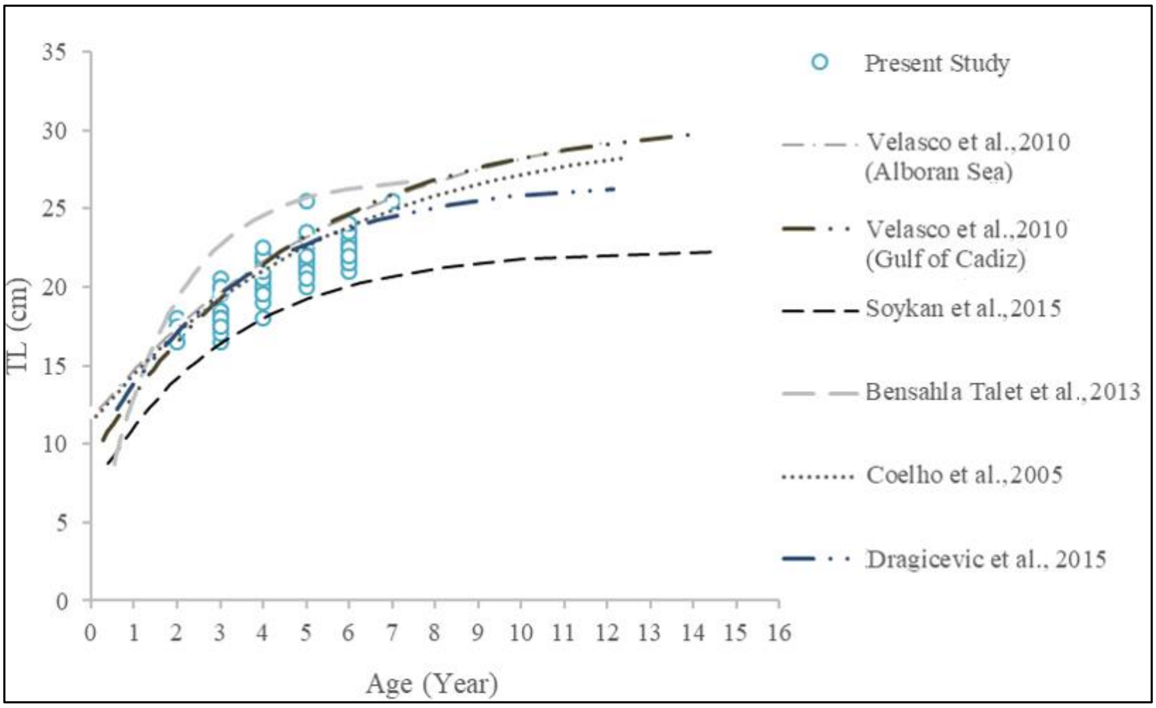

Figure 27. Length-at-age of *P. acarne* recorded off the Quadro Bank plotted with published von Bertalanffy growth.

## 4.6 CONCLUSION

The current consensus is that age structure of spawning stock is a main factor in increasing the success of recruitment in fish (Scott *et al.*, 2006). First-time and young spawners breed for a shorter period, produce fewer egg batches, exhibit lesser fecundity, and produce smaller eggs, with lower fertilization and hatching rates than the older and more fecund females. In the case of protrandic hermaphrodite species, such as *P. acarne*, excessive catch of the older fraction of spawning stock, i.e. the females producing highest quantity of eggs which develop more vital larvae, reduce the success of the recruitment and consequently the sustainability of exploited population.

Finally, the unusual high catch rate of mature big-sized specimens of axillary seabream, captured during a single haul carried out in 1 hour of bottom trawling on October 1st 2016 (n = 312; weight = 37.8 Kg), indicates that the area of Quadro Bank is a spawning area for this species as already verified for several fish species in the Gulf of Tunis (Hattour, 1991; Zarrad *et al.*, 2003).

A very significant phase of the reproductive activity is the spawning aggregation (Sadovy & Domeier, 2005) which is defined as a group of conspecific fish, gathered at a specific site and time for the purposes of spawning, with fish densities significantly higher than densities found during the non-reproductive period (Domeier & Colin, 1997). Given the biological importance of these sites, developing conservation strategies aimed at protecting the functions of those areas is very important to maintaining the sustainability of marine fisheries (Sadovy & Domeier, 2005; Sadovy de Mitcheson & Colin, 2012; Boucek *et al*., 2017).

Although there is growing interest in studies focused on the spawning aggregation of fish (e.g. Boucek *et al*., 2017; Roff *et al*., 2017; Stump *et al*., 2017) worldwide, in the Mediterranean Sea the ongoing knowledge is scarce (Aronov & Goren, 2008; Ganias, 2008). Fiorentino *et al*. (2001) described the age structure of a spawning aggregation of brown meagre *Sciaena umbra* (Linnaeus, 1758) caught in the Strait of Sicily (Maltese waters) during a single fishing operation. Also if limited in space and time, our record suggests the importance of the Quadro Bank as Essential Fish Habitat for completing the life cycle of *P. acarne*. Accumulating this kind of information is essential to develop management measures aimed to preserve the replacement capability of exploited stocks and pursue sustainable fisheries strategies.

# 5. GENERAL DISCUSSION

In the first paper, we used the spatial bio-economic model called SMART (Spatial MAnagement of demersal Resources for Trawl fisheries), a spatially explicit model to simulate the potential effects of different trawl fisheries management scenarios on the demersal resources and evaluate the potential benefits of different management approaches of the trawl fisheries targeting demersal stocks. By using SMART, Russo *et al.* (2014; 2019) showed that the 3 Fisheries Restricted Areas (FRAs) improve both the state of HKE and DPS stocks and the overall fishery economic performance of the whole Italian trawler fleet operating in the Strait of Sicily (SoS). However, since these closures can affect different fleets according to the spatial position of their traditional fishing grounds, further studies to assess the possible negative economic effects of management measures at local level are advisable.

The use of economic indicators and the application of SMART to the different trawl fleets fishing in the SoS allowed us to better understand the different short term economic performances of coastal bottom trawlers affected by the closure of FRAs. In particular, analyzing the costs, revenues and profits, we showed that the fleets having the greatest disadvantages by the establishment of the FRAs and the consequent subtraction of fishing grounds, are the those located close to the FRAs in the central part of the southern Sicilian coast (Sciacca and Licata); while the fleets situated away from the FRAs (Trapani and Porto Palo di Capo Passero) have an increase of the profits or are not particularly affected. These results confirmed that the use of spatial based bio-economic models can be very useful for fishery managers while formulating the management decisions, considering not only the biological aspects but also the economic ones. In particular, the compensative measures, adopted by the governments to mitigate the short term losses of gains consequent to the FRAs adoption, should involve exclusively the fleets that are expected to be negatively affected by the closures and not all fleets operating in the area.

Regarding the second paper, our results confirm that the use of underwater lights in trawl fishing is a good device to attract and aggregate fish and increase the catch rates. On the other hand, fishing with light device can encourage overfishing which can lead to the depletion of the fisheries resources in the region characterised by open access to fisheries and poor management regimens (Mills *et al.*, 2014; Solomon & Ahmed, 2016). For example, in Ghana, the use of light fishing has been completely banned in coastal water (Solomon & Ahmed, 2016); while, in Norway, the total light power of each fishing vessel must no exceed 15 kW (Solomon & Ahmed, 2016; Nguyen & Winger, 2019).

In particular, our results showed that the use of artificial lights increased the catch rates of DPS, the *target* species of the fishery, regardless their body length. On the other hand, the use of artificial lights increased also the catches of undersized hake and horse mackerel, arising concerns about the unregulated introduction of this fishing device in deep water shrimp fisheries. Since in the EU Mediterranean water there is not yet a specific management measure regulating the use of artificial light in commercial fisheries, it should be necessary to adopt specific strategies and regulation on the use of underwater lights at local, national and international scales to avoid or to minimise the potential impacts of artificial light on already over-exploited demersal stock.

In this contest, the unregulated use of lights could increase the capture of juveniles in nursery areas not falling within the FRAs, reducing their positive effect in bettering the exploitation pattern and reducing discards (Russo *et al*, 2014, 2019).

Finally, in the third paper, due to the importance of identification of Essential Fish Habitat in adopting spatial based measures in fishery management to protect critical phases in resources life cycles, we investigated in deep a very abundant catch of large sized specimens of the axillary seabream, *Pagellus acarne* (Risso, 1827), in the area of Quadro Bank (off Tunisian coast).

In particular, the results of this study showed that the Quadro Bank represents an area of spawning aggregation. There is a consensus that age structure of spawning stock is a main factor in increasing the success of recruitment in fish (Scott *et al.*, 2006). First-time and young spawners breed for a shorter period, produce fewer egg batches, exhibit lesser fecundity, and produce smaller eggs, with lower fertilization and hatching rates than the older and more fecund females. In the case of protrandic hermaphrodite species, such as *P. acarne,* excessive catch of the older fraction of spawning stock, i.e. the females producing highest quantity of eggs which develop more vital larvae, reduce the success of the recruitment and consequently the sustainability of exploited population. Although there is growing interest in studies focused on the spawning aggregation of fish (e.g. Boucek *et al.*, 2017; Roff *et al.*, 2017; Stump *et al.*, 2017) worldwide, in the Mediterranean Sea the knowledge is still scarce (Fiorentino *et al.*, 2001; Aronov & Goren, 2008; Ganias, 2008). Our results suggest that the Quadro Bank should be protected during the spawning season, occurring in the Strait of Sicily in Autumn, to preserve the replacement capability of the exploited stocks and pursue a more sustainable fisheries strategy.

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Appendix 1. Structure and composition of the Gela trawl fleet. LOA indicates the length overall expressed in metres; GT indicates the gross tonnage expressed in tons; kW indicates the engine power expressed in kilowatts.

| SERIAL NUMBER | NAME OF VESSEL | LOA | GT | kW | GEAR |
|---|---|---|---|---|---|
| GELA444 | Montevideo | 15.24 | 24 | 206 | Trawling fishing, long-line fishing, gill-net fishing |

Appendix 2. Structure and composition of the Licata trawl fleet. LOA indicates the length overall expressed in metres; GT indicates the gross tonnage expressed in tons; kW indicates the engine power expressed in kilowatts.

| SERIAL NUMBER | NAME OF VESSEL | LOA | GT | kW | GEAR |
|---|---|---|---|---|---|
| 1PE0703 | Nuovo S. Calogero | 13.07 | 9 | 95 | Trawling fishing |
| 1PE0962 | Mariana | 13.2 | 10 | 162 | Trawling fishing, purse-seine fishing |
| 1PE0763 | Angelo Padre | 13.4 | 10 | 89.71 | Trawling fishing |
| 1PE0932 | Odissea | 13.55 | 10 | 154 | Trawling fishing |
| 1PE0903 | Grecale | 13.74 | 16 | 147.06 | Trawling fishing |
| 1PE0859 | Stella del Mare | 13.95 | 13 | 96 | Trawling fishing |
| 1PE0638 | Aldebaran | 14.45 | 13 | 161.76 | Trawling fishing |
| 1PE0967 | Asia | 14.65 | 12 | 162 | Trawling fishing |
| 1PE0902 | Giovanni Casano | 14.7 | 19 | 147.06 | Trawling fishing |
| 1PE0709 | Daino | 14.82 | 14 | 161.76 | Trawling fishing |
| 1PE0889 | Padre Pio da Pietralcina | 14.85 | 15 | 118.38 | Trawling fishing |
| 1PE0919 | Maria Grazia | 14.92 | 13 | 161.76 | Trawling fishing, purse-seine fishing |
| 1PE0941 | Luna Rossa | 15.14 | 17 | 118 | Trawling fishing |
| 1PE0918 | Santa Rosa | 15.37 | 15 | 88 | Trawling fishing, purse-seine fishing, gill-net fishing |
| 1PE0738 | Luigi C. | 15.72 | 20 | 147.06 | Trawling fishing |
| 1PE0654 | Freccia Nera Seconda | 16 | 23 | 109 | Trawling fishing |
| 1PE0592 | Giuseppe Risorge | 16.03 | 21 | 161.76 | Trawling fishing |
| 1PE0940 | Jose | 16.5 | 11 | 129 | Trawling fishing, long-line fishing |
| 1PE0913 | Graziano | 16.85 | 26 | 161.76 | Trawling fishing |
| 1PE0945 | Nuovo San Liborio Pio | 17.23 | 13 | 75 | Trawling fishing |
| 1PE0824 | Maria Stella del Mare | 17.24 | 30 | 162 | Trawling fishing |
| 1PE0923 | Marcantonio | 17.39 | 31 | 104 | Trawling fishing |
| 1PE0956 | Santa Barbara | 17.62 | 15 | 11 | Trawling fishing, long-line fishing, gill-net fishing |
| 1PE0856 | Gaetano C. | 17.86 | 35 | 161.76 | Trawling fishing |
| 1PE0762 | S. Antonio | 18.05 | 35 | 206 | Trawling fishing |
| 1PE0761 | Tommaso D. | 18.07 | 34 | 220 | Trawling fishing |

| | | | | | |
|---|---|---|---|---|---|
| 1PE0826 | Canguro | 19 | 42 | 147 | Trawling fishing, long-line fishing, purse-seine fishing |
| 1PE0928 | Santo Padre | 19.52 | 32 | 198 | Trawling fishing, purse-seine fishing |
| 1PE0858 | Folgore | 19.53 | 44 | 205.88 | Trawling fishing |
| 1PE0931 | Mariano Padre | 20 | 38 | 162 | Trawling fishing |
| 1PE0721 | Nuovo Santissimo Crocifisso | 20.4 | 33 | 142.65 | Trawling fishing |
| 1PE0972 | Destriero I | 20.47 | 55 | 220 | Trawling fishing |
| 1PE0974 | L’Aurora | 20.66 | 40 | 220 | Trawling fishing |
| 1PE0713 | Ghibli | 20.7 | 42 | 88 | Trawling fishing |
| 1PE0927 | Giuseppe Pio | 20.88 | 50 | 132 | Trawling fishing |
| 1PE0728 | N.va Primula Rossa | 21.25 | 56 | 220 | Trawling fishing |
| 1PE0852 | Antonio Padre | 21.55 | 58 | 465 | Trawling fishing |
| 1PE0968 | Perla del Gargano | 22.64 | 53 | 265 | Trawling fishing |
| 1PE0966 | Destriero | 23 | 62 | 228 | Trawling fishing |

Appendix 3. Structure and composition of the Marsala trawl fleet. LOA indicates the length overall expressed in metres; GT indicates the gross tonnage expressed in tons; kW indicates the engine power expressed in kilowatts.

| SERIAL NUMBER | NAME OF VESSEL | LOA | GT | kW | GEAR |
|---|---|---|---|---|---|
| 1TP1181 | Mario padre | 13.5 | 10 | 95 | Trawling fishing, long-line fishing, gill-net fishing, purse-seine fishing |
| 1TP1293 | Cometa | 14.35 | 23 | 137 | Trawling fishing |
| 1TP1255 | Sara Jessica | 17.65 | 27 | 162 | Trawling fishing, long-line fishing |
| 1TP1169 | Vita Antonina | 21.1 | 56 | 206 | Trawling fishing, long-line fishing, gill-net fishing, purse-seine fishing |
| 1TP1075 | Marco Antonia | 21.6 | 73 | 294 | Trawling fishing, long-line fishing, gill-net fishing |
| 1TP0787 | Enza Paola | 21.69 | 65 | 294 | Trawling fishing, long-line fishing, gill-net fishing |
| 1TP1069 | Briglia D’Oro | 21.98 | 62 | 294 | Trawling fishing, long-line fishing, gill-net fishing |
| 1TP1087 | I Tredici | 22.1 | 73 | 286 | Trawling fishing, long-line fishing, gill-net fishing |
| 1TP0961 | Principe Rinaldo | 23.13 | 74 | 294 | Trawling fishing, long-line fishing, gill-net fishing |

Appendix 4. Structure and composition of the Mazara del Vallo trawl fleet. LOA indicates the length overall expressed in metres; GT indicates the gross tonnage expressed in tons; kW indicates the engine power expressed in kilowatts.

| SERIAL NUMBER | NAME OF VESSEL | LOA | GT | kW | GEAR |
|---|---|---|---|---|---|
| MV1349 | Capriccio | 13 | 11 | 110 | Trawling fishing, gill-net fishing |
| MV1320 | Nuova Stella del Mare | 15.03 | 22 | 177 | Trawling fishing, long-line fishing, gill-net fishing |
| MV1239 | Sara II° | 15.32 | 20 | 206 | Trawling fishing, purse-seine fishing |
| MV1343 | Nuovo Luciano C. | 15.83 | 22 | 119 | Trawling fishing, purse-seine fishing, gill-net fishing |
| MV1339 | Delfino Azzurro | 17.65 | 26 | 162 | Trawling fishing |
| MV1322 | Santa Elisabetta | 18 | 28 | 119 | Trawling fishing, purse-seine fishing, long-line fishing |
| MV1274 | San Marco | 18.95 | 45 | 324 | Trawling fishing, purse-seine fishing, gill-net fishing |
| MV1340 | Nuovo Andrea Primo | 20.1 | 47 | 294 | Trawling fishing, long-line fishing, gill-net fishing |
| MV1300 | Nuova Cristina | 21.35 | 53 | 177 | Trawling fishing |
| MV1301 | Nuovo Euripide | 21.4 | 63 | 272 | Trawling fishing, long-line fishing, gill-net fishing |
| MV1321 | Celestino B. | 21.6 | 51 | 294 | Trawling fishing |
| MV1258 | Katiuscia | 21.64 | 62 | 316 | Trawling fishing |
| MV1293 | Prassitele | 21.75 | 70 | 309 | Trawling fishing |
| MV1249 | Lucia Sannino I | 22.7 | 89 | 331 | Trawling fishing |
| MV1218 | Flavia G. | 23.14 | 105 | 272 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| MV1360 | San Marco | 23.64 | 100 | 143 | Trawling fishing |
| MV1352 | Gemma | 23.95 | 117 | 634 | Trawling fishing |
| MV1229 | Città di Alghero | 24.47 | 82 | 221 | Trawling fishing, long-line fishing, gill-net fishing |
| MV1205 | Framari | 24.5 | 120 | 185 | Trawling fishing |
| MV1341 | Nereide | 24.75 | 96 | 350 | Trawling fishing |
| MV1015 | Gennaro Padre | 24.92 | 62 | 149 | Trawling fishing, long-line fishing |
| MV0400 | Vega Prima | 25.07 | 130 | 338 | Trawling fishing, long-line fishing |
| MV1287 | Vega | 25.07 | 130 | 338 | Trawling fishing |
| MV0398 | Marpesca Due | 25.8 | 117 | 441 | Trawling fishing |
| MV1207 | Faro | 26.2 | 110 | 257 | Trawling fishing |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| MV1209 | Nuovo Eteocle | 26.65 | 107 | 302 | Trawling fishing |
| MV0356 | Giuseppe Salvatore Silaco | 26.7 | 121 | 442 | Trawling fishing |
| MV1142 | Callore | 26.85 | 101 | 195 | Trawling fishing |
| MV0387 | Francesco Moretti | 27 | 124 | 490 | Trawling fishing |
| MV0327 | Sirio | 27.05 |  | 316 | Trawling fishing |
| MV0949 | Fortunata Vita | 27.05 | 120 | 360 | Trawling fishing, long-line fishing |
| MV1203 | Achille Salvucci | 27.05 | 92 | 331 | Trawling fishing |
| MV0394 | Nuova Alcapa | 27.15 | 99 | 312 | Trawling fishing |
| MV1230 | N.vo Giacomo I° | 27.2 | 150 | 339 | Trawling fishing |
| MV1317 | Danish | 27.3 | 100 | 294 | Trawling fishing |
| MV1270 | Amaltea | 27.4 | 155 | 371 | Trawling fishing |
| MV0380 | Vincenza Giacalone | 27.5 | 153 | 368 | Trawling fishing |
| MV0393 | Maria Pina Seconda | 27.72 | 158 | 250 | Trawling fishing |
| MV1211 | San Giorgio | 27.73 | 138 | 403 | Trawling fishing |
| MV0388 | Afrodite Pesca | 28 | 140 | 176 | Trawling fishing |
| MV0369 | Nuova Aretusa | 28.1 | 119 | 250 | Trawling fishing |
| MV0371 | Bartolomeo Asaro | 28.1 | 159 | 412 | Trawling fishing |
| MV0985 | Maria Grazia | 28.29 | 114 | 261 | Trawling fishing |
| MV0397 | Antonino Maria | 28.4 | 161 | 214 | Trawling fishing |
| MV1266 | Pasquale Carriola | 28.58 | 133 | 346 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| MV1235 | Silvia C. | 28.94 | 103 | 294 | Trawling fishing |
| MV1283 | N.vo Lorenzo | 29 | 161 | 331 | Trawling fishing |
| MV0944 | Nazario Sauro | 29.01 | 111 | 349 | Trawling fishing |
| MV0401 | Speranza | 29.03 | 170 | 463 | Trawling fishing, long-line fishing |
| MV0366 | Grecale | 29.04 | 140 | 220 | Trawling fishing |
| MV0339 | Aristeus | 29.15 | 159 | 333 | Trawling fishing |
| MV0368 | Boccia V.M. | 29.16 | 188 | 293 | Trawling fishing |
| MV0399 | Gisteroda | 29.16 | 180 | 670 | Trawling fishing, long-line fishing |
| MV1346 | Gisteroda Madre | 29.16 | 172 | 662 | Trawling fishing, long-line fishing |
| MV1182 | Agostino Padre Secondo | 29.23 | 132 | 331 | Trawling fishing, purse-seine fishing |

| | | | | | |
|---|---|---|---|---|---|
| MV1241 | Seleuco | 29.27 | 174 | 662 | Trawling fishing |
| MV0373 | Antonino Genovese | 29.3 | 168 | 515 | Trawling fishing |
| MV0374 | Elisabetta Genovese | 29.3 | 168 | 515 | Trawling fishing |
| MV1353 | Padre Pio | 29.3 | 168 | 331 | Trawling fishing |
| MV0370 | Filippo Adamo | 29.49 | 139 | 287 | Trawling fishing |
| MV0334 | Sicula Pesca | 29.5 | 147 | 402 | Trawling fishing |
| MV0381 | Gladius | 29.5 | 165 | 250 | Trawling fishing |
| MV0382 | Medinea | 29.5 | 158 | 250 | Trawling fishing |
| MV0383 | Naucrates | 29.5 | 165 | 250 | Trawling fishing |
| MV0305 | Pietro Giacalone | 29.57 | 158 | 405 | Trawling fishing |
| MV0307 | Famavia | 29.57 | 158 | 405 | Trawling fishing |
| MV0322 | Priamo | 29.57 | 165 | 309 | Trawling fishing |
| MV0390 | Giovanni Vincenzo | 29.6 | 140 | 250 | Trawling fishing |
| MV1246 | Domenico Aiello | 29.62 | 185 | 480 | Trawling fishing |
| MV0317 | Eros B. | 29.81 | 140 | 485 | Trawling fishing |
| MV1202 | Baldassare | 29.81 | 144 | 330 | Trawling fishing |
| MV0343 | Antonino Sirrato | 29.9 | 184 | 305 | Trawling fishing |
| MV0367 | Boccia Secondo | 30 | 191 | 257 | Trawling fishing |
| MV0372 | Francesco Padre | 30 | 133 | 250 | Trawling fishing |
| MV0375 | Regina | 30 | 133 | 257 | Trawling fishing |
| MV0361 | Luna Rossa | 30.7 | 202 | 367 | Trawling fishing |
| MV0363 | Filippo Maria | 30.7 | 199 | 485 | Trawling fishing |
| MV1311 | Giuseppe Alessandro Aiello | 30.8 | 154 | 294 | Trawling fishing, purse-seine fishing, long-line fishing |
| MV0349 | Leovito | 30.92 | 173 | 338 | Trawling fishing |
| MV0377 | Matteo Mazzarino | 31 | 197 | 400 | Trawling fishing |
| MV0385 | Flori | 31 | 197 | 400 | Trawling fishing |
| MV0396 | San Cosma e Damiano Secondo | 31.06 | 179 | 485 | Trawling fishing |
| MV0379 | Giuseppe Schiavone | 31.2 | 161 | 257 | Trawling fishing |
| MV0292 | S. Anna | 32.3 | 182 | 744 | Trawling fishing |
| MV0311 | Kleos | 32.31 | 186 | 386 | Trawling fishing |
| MV0378 | Giulia P.G. | 32.31 | 189 | 441 | Trawling fishing |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| MV0338 | Gemma Prima | 32.6 | 215 | 743 | Trawling fishing |
| MV0314 | Teseo Primo | 32.79 | 186 | 735 | Trawling fishing |
| MV0365 | Francesco Saverio Pomposo | 32.79 | 186 | 485 | Trawling fishing |
| MV0309 | Dayton Prima | 32.8 | 198 | 441 | Trawling fishing |
| MV0240 | Ghibli Primo | 32.96 | 212 | 588 | Trawling fishing |
| MV0321 | Artemide | 32.97 | 196 | 441 | Trawling fishing |
| MV0312 | Bucefalo | 33.14 | 177 | 405 | Trawling fishing |
| MV0347 | Olympia | 33.15 | 231 | 883 | Trawling fishing |
| MV0299 | Pegaso S.B. | 33.3 | 182 |  | Trawling fishing |
| MV0303 | Altomare | 33.3 | 177 | 588 | Trawling fishing |
| MV0333 | Mediterraneo Primo | 34.1 | 181 | 728 | Trawling fishing |
| MV0246 | Aliseo | 34.69 | 230 | 770 | Trawling fishing |
| MV0350 | Orione Q. | 45.55 | 490 | 1472 | Trawling fishing |
| MV0351 | Pegaso Q. | 45.55 | 490 | 1472 | Trawling fishing |

Appendix 5. Structure and composition of the Porto Empedocle trawl fleet. LOA indicates the length overall expressed in metres; GT indicates the gross tonnage expressed in tons; kW indicates the engine power expressed in kilowatts.

| SERIAL NUMBER | NAME OF VESSEL | LOA | GT | kW | GEAR |
|---|---|---|---|---|---|
| PE1294 | Ammiraglio | 12.5 | 9 | 74 | Trawling fishing |
| PE1279 | Roberta | 12.8 | 11 | 118 | Trawling fishing |
| PE1221 | Rosa dei Venti | 12.9 |  | 88 | Trawling fishing |
| PE1274 | Nuova Virginia Madre | 13.54 | 7 | 96 | Trawling fishing |
| PE1263 | Barbara II | 14.32 | 12 | 162 | Trawling fishing |
| PE1281 | Concetta | 15 | 18 | 162 | Trawling fishing, gill-net fishing, long-line fishing |
| PE1265 | Riccardo Volpe | 15.51 | 71 | 110 | Trawling fishing |
| PE1132 | Perla del Mediterraneao | 16.08 | 26 | 162 | Trawling fishing |
| PE1248 | Gaspare Padre | 19.96 | 46 | 294 | Trawling fishing, long-line fishing |
| PE1291 | Mamma Pina | 20.72 | 52 | 333 | Trawling fishing |
| PE1215 | Carlotta | 20.76 | 59 | 294 | Trawling fishing |
| PE1259 | Sofia Fabio | 22 | 58 | 317 | Trawling fishing |
| PE1296 | Queen | 22.12 | 72 | 442 | Trawling fishing |
| PE1127 | Arcangelo Gabriele | 22.38 | 79 | 184 | Trawling fishing |
| PE1266 | Francesco S. | 22.5 | 87 | 228 | Trawling fishing |
| PE1267 | Pietro Andrea | 22.69 | 59 | 184 | Trawling fishing |
| PE1238 | Calogero Vasile | 23.74 | 69 | 316 | Trawling fishing |
| PE1268 | Italia II | 24 | 72 | 447 | Trawling fishing |
| PE1256 | Angelo Sacco II | 24.83 |  | 180 | Trawling fishing |
| PE1273 | Agostino Padre | 24.86 | 109 | 309 | Trawling fishing, long-line fishing |
| PE1231 | Buon Oriente | 25.1 | 101 | 228 | Trawling fishing |
| PE1302 | O’Scià | 26.15 | 110 | 230 | Trawling fishing, long-line fishing |
| PE1243 | Carmela e Salvatore C. | 26.2 | 129 | 250 | Trawling fishing |
| PE1295 | Edera Falzone | 28 | 158 | 600 | Trawling fishing, long-line fishing |

Appendix 6. Structure and composition of the Porto Palo di Capo Passero trawl fleet. LOA indicates the length overall expressed in metres; GT indicates the gross tonnage expressed in tons; kW indicates the engine power expressed in kilowatts.

| SERIAL NUMBER | NAME OF VESSEL | LOA | GT | kW | GEAR |
|---|---|---|---|---|---|
| 3SR0850 | San Giuseppe | 12.8 | 13 | 123 | Trawling fishing |
| 3SR0946 | Saetta | 13.48 | 5 | 78.68 | Trawling fishing |
| 3SR1018 | Lucia | 14 | 9 | 110 | Trawling fishing, long-line fishing |
| 3SR1030 | Piccolo Corrado II° | 14.03 | 6 | 96 | Trawling fishing |
| 3SR0818 | Giuseppe Alberti | 15.15 | 15 | 147.06 | Trawling fishing, long-line fishing, purse-seine fishing, gill-net fishing |
| 3SR1013 |  | 15.5 | 10 | 85 | Trawling fishing, long-line fishing, gill-net fishing |
| 3SR0957 | S. Vito Maria di Porto Salvo | 15.58 | 21 | 158 | Trawling fishing |
| 3SR0758 | Margherita | 15.82 | 18 | 205.88 | Trawling fishing |
| 3SR0835 | Apollo XI | 15.95 | 18 | 161 | Trawling fishing |
| 3SR0821 | Andromeda | 16.05 | 22 | 159 | Trawling fishing, long-line fishing, gill-net fishing |
| 3SR0947 | S. Marco | 16.3 | 25 | 205.88 | Trawling fishing |
| 3SR1056 | Romanella | 16.42 | 17 | 162 | Trawling fishing |
| 3SR0849 | Natalina Madre | 16.44 | 25 | 206 | Trawling fishing |
| 3SR1077 | Enzo C. | 16.5 | 25 | 206 | Trawling fishing, gill-net fishing |
| 3SR0838 | Giuseppe Burgaretta | 16.76 | 31 | 185 | Trawling fishing |
| 3SR0833 | Vittorio Taccone | 17.09 | 26 | 161.03 | Trawling fishing, gill-net fishing |
| 3SR1048 | Bescira | 17.25 | 15 | 140 | Trawling fishing, long-line fishing, purse-seine fishing, gill-net fishing |
| 3SR0971 | Carolina | 17.35 | 26 | 116.91 | Trawling fishing |
| 3SR0624 | Tempesta II° | 17.46 | 30 | 186.76 | Trawling fishing |
| 3SR0841 | Maria Salvatrice | 17.8 | 35 | 187 | Trawling fishing |
| 3SR1012 | Orchidea I | 17.8 | 41 | 219 | Trawling fishing |
| 3SR0783 | Sacro Cuore | 18 | 21 | 184.56 | Trawling fishing |
| 3SR1027 | Angiulina | 18.21 | 42 | 221 | Trawling fishing |
| 3SR1096 | La Lupa 2 | 19 | 36 | 216 | Trawling fishing, long-line fishing, purse-seine fishing |
| 3SR1094 | La Ninfa | 19.06 | 33 | 221 | Trawling fishing, long-line fishing |
| 3SR0888 | Maria Elena | 19.1 | 49 | 220 | Trawling fishing, long-line fishing |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 3SR0869 | F.lli Litrico | 19.41 | 38 | 324 | Trawling fishing, long-line fishing, purse-seine fishing, gill-net fishing |
| 3SR1019 | Beatrice 1 e 2 | 19.9 | 51 | 235 | Trawling fishing |
| 3SR0710 | Salvatore Padre | 20 | 46 | 206 | Trawling fishing, long-line fishing, purse-seine fishing |
| 3SR1085 | Città D’Anzio | 20.95 | 38 | 250 | Trawling fishing, long-line fishing |
| 3SR0844 | Orsa Maggiore 2 | 21.1 | 55 | 309 | Trawling fishing |
| 3SR1015 | Marinella Prima | 21.2 | 58 | 121.2 | Trawling fishing |
| 3SR0881 | Delfino | 21.25 | 59 | 404 | Trawling fishing |
| 3SR1029 | Nuovo Cico | 21.43 | 41 | 217 | Trawling fishing |
| 3SR0822 | Mare Chiaro | 22.1 | 55 | 220 | Trawling fishing, purse-seine fishing, gill-net fishing |
| 3SR0964 | Orchidea II° | 22.7 | 75 | 551.47 | Trawling fishing |
| 3SR0692 | Mauro Figlip | 22.85 | 62 | 158 | Trawling fishing |
| 3SR0937 | San Giorgio | 23.1 | 64 | 283.09 | Trawling fishing, long-line fishing, gill-net fishing |
| 3SR0999 | Annunziata II° | 23.62 | 59 | 331 | Trawling fishing, long-line fishing |
| 3SR0998 | Vincenzo Moscuzza | 23.66 | 63 | 323 | Trawling fishing, gill-net fishing |
| 3SR1022 | Ghibli | 23.68 | 79 | 442 | Trawling fishing |
| 3SR0958 | Europa | 24.73 | 80 | 294 | Trawling fishing, long-line fishing, purse-seine fishing, gill-net fishing |
| 3SR1081 | Aldo Padre | 25.3 | 83 | 447 | Trawling fishing |
| 3SR1020 | Oriente | 26.12 | 91 | 162 | Trawling fishing |

Appendix 7. Structure and composition of the Pozzallo trawl fleet. LOA indicates the length overall expressed in metres; GT indicates the gross tonnage expressed in tons; kW indicates the engine power expressed in kilowatts.

| SERIAL NUMBER | NAME OF VESSEL | LOA | GT | kW | GEAR |
|---|---|---|---|---|---|
| PO0667 | Raffaele Antonio | 13.39 | 12 | 58.82 | Trawling fishing |
| PO0689 | Osea | 13.44 | 6 | 162 | Trawling fishing |
| PO0690 | Andrea Primo | 13.88 | 12 | 108 | Trawling fishing, gill-net fishing, long-line fishing |
| PO0692 | Giovanna Madre | 14.16 | 8 | 85 | Trawling fishing, gill-net fishing, long-line fishing |
| PO0688 | Lady Miriam | 14.5 | 12 | 206 | Trawling fishing, gill-net fishing, long-line fishing |
| PO0564 | Fabiola | 14.7 | 22 | 161.76 | Trawling fishing, gill-net fishing, long-line fishing |
| PO0660 | Palma II° | 15.78 | 21 | 132.35 | Trawling fishing, purse-seine fishing |
| PO0664 | Anadro | 22.7 | 99 | 308.82 | Trawling fishing, long-line fishing |
| PO0673 | Dario | 26.2 | 82 | 457 | Trawling fishing |

Appendix 8. Structure and composition of the Sciacca trawl fleet. LOA indicates the length overall expressed in metres; GT indicates the gross tonnage expressed in tons; kW indicates the engine power expressed in kilowatts.

| SERIAL NUMBER | NAME OF VESSEL | LOA | GT | kW | GEAR |
|---|---|---|---|---|---|
| 3PE0634 | Agostino Padre III° | 14.26 | 27 | 161.7 | Trawling fishing |
| 3PE0721 | Mammarita | 14.34 | 8 | 206 | Trawling fishing, long-line fishing, gill-net fishing, purse-seine fishing, trammel net fishing |
| 3PE0699 | Fantastico II° | 14.49 | 19 | 162 | Trawling fishing |
| 3PE0636 | Portofino | 15.46 | 28 | 161 | Trawling fishing, gill-net fishing |
| 3PE0688 | Papà Giuseppe | 16.1 | 38 | 184 | Trawling fishing |
| 3PE0602 | Gaetano Catania | 16.61 | 34 | 162 | Trawling fishing, long-line fishing, purse-seine fishing |
| 3PE0709 | Maria del Soccorso | 16.8 | 28 | 110 | Trawling fishing, long-line fishing, purse-seine fishing |
| 3PE0074 | N. S. Francesco di Paola | 16.81 | 21 | 161.76 | Trawling fishing |
| 3PE0527 | Romana Madre | 17.17 | 41 | 205.88 | Trawling fishing |
| 3PE0635 | Adriana Madre | 17.35 | 25 | 161.8 | Trawling fishing |
| 3PE0328 | Nuova Unione | 17.54 | 36 | 161.76 | Trawling fishing |
| 3PE0609 | N. Meridiano | 17.8 | 38 | 269.85 | Trawling fishing, long-line fishing |
| 3PE0348 | Nuovo Ardor | 18.01 | 36 | 161.76 | Trawling fishing |
| 3PE0418 | Eliana | 18.01 | 38 | 145 | Trawling fishing |
| 3PE0542 | Irene | 18.36 | 38 | 198 | Trawling fishing |
| 3PE0622 | Santo Padre | 18.38 | 40 | 158.01 | Trawling fishing |
| 3PE0712 | Diamante | 18.4 | 39 | 287 | Trawling fishing, long-line fishing, purse-seine fishing, gill-net fishing |
| 3PE0647 | Padre Pio | 18.42 | 37 | 219.85 | Trawling fishing, gill-net fishing |
| 3PE0591 | Maria Ausiliatrice | 18.48 | 46 | 161.76 | Trawling fishing |
| 3PE0653 | Maria Giovanna | 18.54 | 47 | 185 | Trawling fishing, long-line fishing, gill-net fishing |
| 3PE0700 | Nuova Maria Stella del Mare | 18.66 | 33 | 184 | Trawling fishing |
| 3PE0400 | Slancio | 18.72 | 46 | 105 | Trawling fishing |
| 3PE0592 | Azzurra | 18.81 | 42 | 220 | Trawling fishing, long-line fishing, purse-seine fishing, gill-net fishing |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 3PE0329 | Nuova Maria Prima | 18.94 | 43 | 219.85 | Trawling fishing |
| 3PE0403 | Nuovo Vincenzo Padre M. | 19.07 | 33 | 161.76 | Trawling fishing |
| 3PE0723 | Zeus | 19.08 | 50 | 176 | Trawling fishing, purse-seine fishing |
| 3PE0503 | Carlo Primo | 19.19 | 56 | 205.88 | Trawling fishing |
| 3PE0641 | Immacolata C. | 19.6 | 48 | 219.85 | Trawling fishing |
| 3PE0562 | Nuovo Genitore | 19.66 | 52 | 88.24 | Trawling fishing |
| 3PE0630 | Ardito | 19.67 | 30 | 323 | Trawling fishing, purse-seine fishing |
| 3PE0551 | Nuova Virginia | 19.68 | 45 | 161 | Trawling fishing |
| 3PE0662 | Nuovo Stati Uniti I° | 19.82 | 57 | 220 | Trawling fishing, gill-net fishing |
| 3PE0639 | Trio | 19.88 | 77 | 294 | Trawling fishing |
| 3PE0625 | Calogero Padre C. | 19.98 |  | 205.88 | Trawling fishing, long-line fishing, purse-seine fishing |
| 3PE0545 | San Nicola Secondo | 20.06 | 50 | 198 | Trawling fishing |
| 3PE0417 | Umberto Luigi | 20.26 | 54 | 205.88 | Trawling fishing |
| 3PE0604 | N. Lealdo | 20.35 | 54 | 219.85 | Trawling fishing |
| 3PE0678 | Idra | 20.36 | 47 | 294 | Trawling fishing |
| 3PE0476 | Orizzonte Secondo | 20.38 | 53 | 120 | Trawling fishing, purse-seine fishing |
| 3PE0698 | Futura | 20.38 | 44 | 211 | Trawling fishing |
| 3PE0704 | Filippo Padre | 20.43 | 52 | 206 | Trawling fishing, long-line fishing, purse-seine fishing, gill-net fishing |
| 3PE0612 | Antonino Padre | 20.45 | 47 | 205.88 | Trawling fishing |
| 3PE0659 | Nuova Luigia | 20.45 | 67 | 81 | Trawling fishing |
| 3PE0685 | Nuovo Jesari Raffaele | 20.47 | 53 | 88 | Trawling fishing |
| 3PE0564 | Pietro Padre Primo | 20.6 | 62 | 205.88 | Trawling fishing, purse-seine fishing, gill-net fishing |
| 3PE0629 | Barbarico | 20.63 | 66 | 195 | Trawling fishing |
| 3PE0683 | Serafina Madre | 20.66 | 74 | 279 | Trawling fishing |
| 3PE0465 | Ermete Zacconi | 20.78 | 64 | 104 | Trawling fishing |
| 3PE0710 | Nuova Galilea | 20.8 | 69 | 293 | Trawling fishing |
| 3PE0643 | Anna e Giuseppe S. | 20.84 | 29 | 220 | Trawling fishing |
| 3PE0705 | Nuovo Segugio | 20.86 | 58 | 324 | Trawling fishing, long-line fishing |
| 3PE0671 | Nuovo Leonardo | 20.89 | 50 | 206 | Trawling fishing |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 3PE0651 | Palazzi Ermenegildo | 20.94 | 52 | 109 | Trawling fishing, long-line fishing |
| 3PE0605 | Nuovo San Pio | 21 | 55 | 323 | Trawling fishing |
| 3PE0668 | Samantha | 21.05 | 43 | 220 | Trawling fishing, purse-seine fishing |
| 3PE0674 | Nuova Orchidea | 21.15 | 44 | 143 | Trawling fishing, purse-seine fishing |
| 3PE0593 | Immacolata Concezione | 21.27 | 61 | 95.59 | Trawling fishing |
| 3PE0610 | Mauro Paolo | 21.3 | 75 | 294.12 | Trawling fishing, long-line fishing |
| 3PE0713 | Madonna del Carmine | 21.51 | 43 | 220 | Trawling fishing, long-line fishing, purse-seine fishing, gill-net fishing |
| 3PE0623 | Sacro Cuore di Gesù | 21.7 | 50 | 215.96 | Trawling fishing, gill-net fishing |
| 3PE0691 | Sabrina e Giada | 21.77 | 59 | 206 | Trawling fishing |
| 3PE0650 | Nuovo San Pietro | 21.8 | 73 | 205.88 | Trawling fishing |
| 3PE0697 | Eva | 21.85 | 41 | 162 | Trawling fishing, purse-seine fishing |
| 3PE0702 | Grazia Teresa | 21.88 | 57 | 350 | Trawling fishing |
| 3PE0708 | Vittorio il Grande | 21.88 | 67 | 441 | Trawling fishing, long-line fishing, purse-seine fishing, gill-net fishing |
| 3PE0412 | Loretta Pulcini | 21.93 | 61 | 131.62 | Trawling fishing, purse-seine fishing |
| 3PE0556 | Samuel Figlio | 21.97 | 55 | 104 | Trawling fishing |
| 3PE0684 | Madre SS: di Pompei | 21.97 | 63 | 294 | Trawling fishing |
| 3PE0707 | Accursio Padre | 22.02 | 90 | 335 | Trawling fishing, long-line fishing |
| 3PE0533 | Paola Prima | 22.65 | 70 | 161 | Trawling fishing, long-line fishing |
| 3PE0606 | Angelita | 22.89 | 64 | 128 | Trawling fishing |
| 3PE0515 | Padre Peppino | 22.95 | 120 | 397 | Trawling fishing, purse-seine fishing |
| 3PE0646 | Serena | 23.07 | 58 | 302 | Trawling fishing |
| 3PE0715 | Giovanni C. | 23.3 | 56 | 331 | Trawling fishing, purse-seine fishing |
| 3PE0550 | San Francesco C. | 23.41 | 84 | 206 | Trawling fishing, gill-net fishing |
| 3PE0663 | Vincenzo C. | 23.45 | 65 | 317 | Trawling fishing, long-line fishing, purse-seine fishing, gill-net fishing |
| 3PE0595 | Luna D’Argento | 23.85 | 89 | 308.82 | Trawling fishing, long-line fishing |
| 3PE0487 | Magellano Primo | 23.95 | 82 | 140 | Trawling fishing |
| 3PE0580 | Moby Dick I° | 25.07 | 96 | 185.29 | Trawling fishing, long-line fishing |
| 3PE0654 | Nuovo Volga | 25.24 | 112 | 313 | Trawling fishing, purse-seine fishing |

Appendix 9. Structure and composition of the Scoglitti trawl fleet. LOA indicates the length overall expressed in metres; GT indicates the gross tonnage expressed in tons; kW indicates the engine power expressed in kilowatts.

| SERIAL NUMBER | NAME OF VESSEL | LOA | GT | kW | GEAR |
|---|---|---|---|---|---|
| 1PO1082 | Sacro Cuore | 13.06 | 18 | 95.59 | Trawling fishing |
| 1PO0929 | Grande Otello | 14.33 | 16 | 110 | Trawling fishing, purse-seine fishing, gill-net fishing, long-line fishing |
| 1PO0913 | Sandokan | 14.44 | 14 | 161.76 | Trawling fishing, purse-seine fishing, gill-net fishing, long-line fishing |
| 1PO1109 | La Lupa | 14.8 | 14 | 106 | Trawling fishing, gill-net fishing, long-line fishing |
| 1PO0963 | Santa Maria | 15.2 | 14 | 141.91 | Trawling fishing, gill-net fishing, long-line fishing |
| 1PO0926 | S. Giovanni | 15.8 | 16 | 162 | Trawling fishing, purse-seine fishing, gill-net fishing, long-line fishing |
| 1PO1097 | Forza Nove | 16.17 | 16 | 110 | Trawling fishing, gill-net fishing, long-line fishing |
| 1PO1081 | Sakalleo | 16.2 | 17 | 106.62 | Trawling fishing, purse-seine fishing, gill-net fishing, long-line fishing |
| 1PO1085 | Montevideo | 16.25 | 24 | 205 | Trawling fishing, gill-net fishing, long-line fishing |
| 1PO0921 | Antonella | 16.33 | 24 | 161.76 | Trawling fishing, gill-net fishing, long-line fishing |
| 1PO1089 | Nunzio Padre | 17.8 | 31 | 132 | Trawling fishing |
| 1PO0942 | Giovanni Padre | 19.6 | 51 | 219.12 | Trawling fishing, purse-seine fishing, gill-net fishing, long-line fishing |
| 1PO1075 | Eolo | 20.1 | 49 | 240 | Trawling fishing, gill-net fishing, long-line fishing |
| 1PO0953 | Sirio I° | 23.75 | 87 | 335 | Trawling fishing, long-line fishing |
| 1PO1088 | La Madonnina | 25.7 | 61 | 324 | Trawling fishing, gill-net fishing, long-line fishing |

Appendix 10. Structure and composition of the Trapani trawl fleet. LOA indicates the length overall expressed in metres; GT indicates the gross tonnage expressed in tons; kW indicates the engine power expressed in kilowatts.

| SERIAL NUMBER | NAME OF VESSEL | LOA | GT | kW | GEAR |
|---|---|---|---|---|---|
| TP2030 | Esmeralda | 12.73 | 10 | 73 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| TP1768 | Nuovo Salvatore | 12.8 | 11 | 44.12 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| TP2096 | San Vito | 13.17 | 7 | 55.15 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| TP2038 | Leopardo | 13.2 | 9 | 73 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| TP2235 | Roberto | 13.23 | 13 | 107 | Trawling fishing, long-line fishing, gill-net fishing |
| TP2062 | Alpitur | 13.3 | 12 | 95.59 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| TP1946 | S. Ignazio | 13.35 | 10 | 73.53 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| TP2252 | Alberto B. | 13.45 | 12 | 162 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| TP2219 | Madonna del Carmine | 13.5 | 11 | 83 | Trawling fishing |
| TP2090 | Danilo | 13.55 | 11 | 73 | Trawling fishing, long-line fishing, gill-net fishing |
| TP2313 | Luna Rossa | 13.92 | 11 | 110 | Trawling fishing, purse-seine fishing, gill-net fishing |
| TP2283 | Osea | 14.45 | 18 | 162 | Trawling fishing, purse-seine fishing, long-line fishing |
| TP2209 | Giuseppe C. | 14.5 | 15 | 140 | Trawling fishing |
| TP2277 | Lucia | 14.97 | 15 | 104 | Trawling fishing |
| TP2084 | Mare Azzurro | 16.57 | 32 | 153.68 | Trawling fishing, purse-seine fishing, gill-net fishing |
| TP2224 | Simona | 17.31 | 31 | 185 | Trawling fishing, long-line fishing, gill-net fishing |
| TP1766 | Spigola Prima | 17.6 | 37 | 110.29 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| TP1406 | N.va Madonna di Grazia | 17.74 | 35 | 161.76 | Trawling fishing, purse-seine fishing |

| | | | | | |
|---|---|---|---|---|---|
| TP1982 | S. Calogero B. | 18.06 | 40 | 219.85 | Trawling fishing, gill-net fishing |
| TP2189 | Atlantica | 18.2 | 33 | 216 | Trawling fishing, purse-seine fishing, long-line fishing |
| TP1866 | Ringo | 18.32 | 42 | 205.88 | Trawling fishing, gill-net fishing |
| TP1872 | Vincenzo B. | 19.25 | 42 | 162 | Trawling fishing, purse-seine fishing, gill-net fishing |
| TP2127 | Salvatore Folres | 19.75 | 57 | 183.82 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| TP2215 | Domenico C. | 20.11 | 48 | 147.06 | Trawling fishing |
| TP2188 | Nuova Cara Madre | 20.25 | 56 | 220.59 | Trawling fishing |
| TP2150 | Giuseppina Flores | 20.4 | 59 | 183.82 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| TP2104 | Maddalena Madre | 22.34 | 75 | 205 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| TP2136 | Sansone Primo | 23.01 | 57 | 185.29 | Trawling fishing, purse-seine fishing, long-line fishing, gill-net fishing |
| TP2182 | Cosimo Padre | 23.28 | 79 | 272.06 | Trawling fishing, long-line fishing |
| TP2299 | Città di Portoferraio | 27.3 | 93 | 385 | Trawling fishing, purse-seine fishing |