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Institut Català de
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Fisheries advisory report for the Northern GSA6 2021

Generalitat de Catalunya
Departament d'Acció Climàtica,
Alimentació i Agenda Rural

EUROPEAN UNION
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Institut
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CSIC
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This report conveys ICATMAR's considerations on fisheries management actions supported by data from its monitoring program.

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Glossary

L_{inf}: Length infinity or asymptotic length at which growth is zero (Von Bertalanffy Growth Function)

M: Natural mortality

SPR: Spawning Potential Ratio of the stock (proportion of the unfished reproductive potential left at any given level of fishing pressure)

F: Fishing mortality

F_{MSY}: Fishing mortality at a maximum sustainable yield

SL50: Length where 50% of individuals are caught

DCF: Data Collection Framework

GSA: Geographic Sub-Area

B_{lim}: Biomass limit

B_{th}: Biomass threshold

LFD: Length Frequency Distribution

1. ICATMAR fishery monitoring in the Northern GSA6

The Catalan Institute of Research for the Governance of the Sea (ICATMAR), a collaboration organism between the Directorate-General of Sustainable Fisheries of the Catalan Government and the Spanish National Research Council, has designed and established since 2018 a detailed fisheries monitoring program for the Northern part of the Geographical Subarea 6 (GSA6). The sampling program collects data by a fisheries-science partnership to update and produce new knowledge in life-history traits of target and by-catch species and understand local fishery dynamics. It concerns bottom trawling, purse seine fishing, and small-scale fisheries, as well as marine recreational fishing, although for the purposes of this report, only the issues regarding the bottom trawling fleet will be discussed.

ICATMAR aims to complement the sampling defined in the European Union Data Collection Framework (DCF), and to provide data to help implement the management measures for the bottom trawling fishery defined in the Western Mediterranean Multiannual Plan (WMMAP, Regulation (EU) 2019/1022).

1.1. A sampling design for bottom trawling fisheries in the Northern GSA6

The trawling fisheries sector of this area has a markedly local character: the fleet of each port fishes in fishing grounds located directly off the port, with almost no overlapping between fleets of different ports (Fig. 1A). Among the total 36 ports of the Catalan coast, 19 have a fishing auction, and 32 have their own fishermen's association, a structure that supports and unifies administration tasks, from operating sales to regulating management actions. In fact, through their fishermen's associations, each port has its own implementation of some fisheries regulations, and some of them host local co-management plans focused on limiting fishing effort and enforcing biological monitoring of the target species and the communities (e.g. the deep-sea blue and red shrimp in Palamós) (BOE, 2018). These particularities entail the need for a richer set of data that can inform decisions at a fine and local scale.

Regarding the target species of the fleet, the sampling is centered around three species which, together, represent over 50% of the fishermen's associations annual revenues over the years: the Norway lobster (*Nephrops norvegicus*), the European hake (*Merluccius merluccius*), and the deep-sea blue and red shrimp (*Aristeus antennatus*), all of them included in the WMMAP regulations. Vessel Monitoring System (VMS) was used to geolocalze vessel daily catches, pairing the VMS data with data of the daily fishing auctions. Thanks to these geolocalized catches, the 3 main target species of the Catalan fishery werefound to be linked to a particular depth range (Fig. 1B), and this pattern led us to define three different sampling depth ranges along the Catalan coast (Fig. 1C). It is important to note that landings data are particularly useful in this case because of the obligation in the Mediterranean Sea to land all catches at the base port and the daily fishing time restriction of maximum 12 hours, which in practice translate to consistent one-day fishing trips in all Catalan ports. This allows to link each vessel position of a particular day with its total landings, which are reliable data since all sales are managed through the auction and this obligation is strictly respected.

With both the biology of the target species and the socioeconomic structure of the sector in mind, the designed sampling tracks are both representative of the main ports of the region and cover the high fishing effort areas for the main target species of the bottom trawling fleet (Fig. 1C).

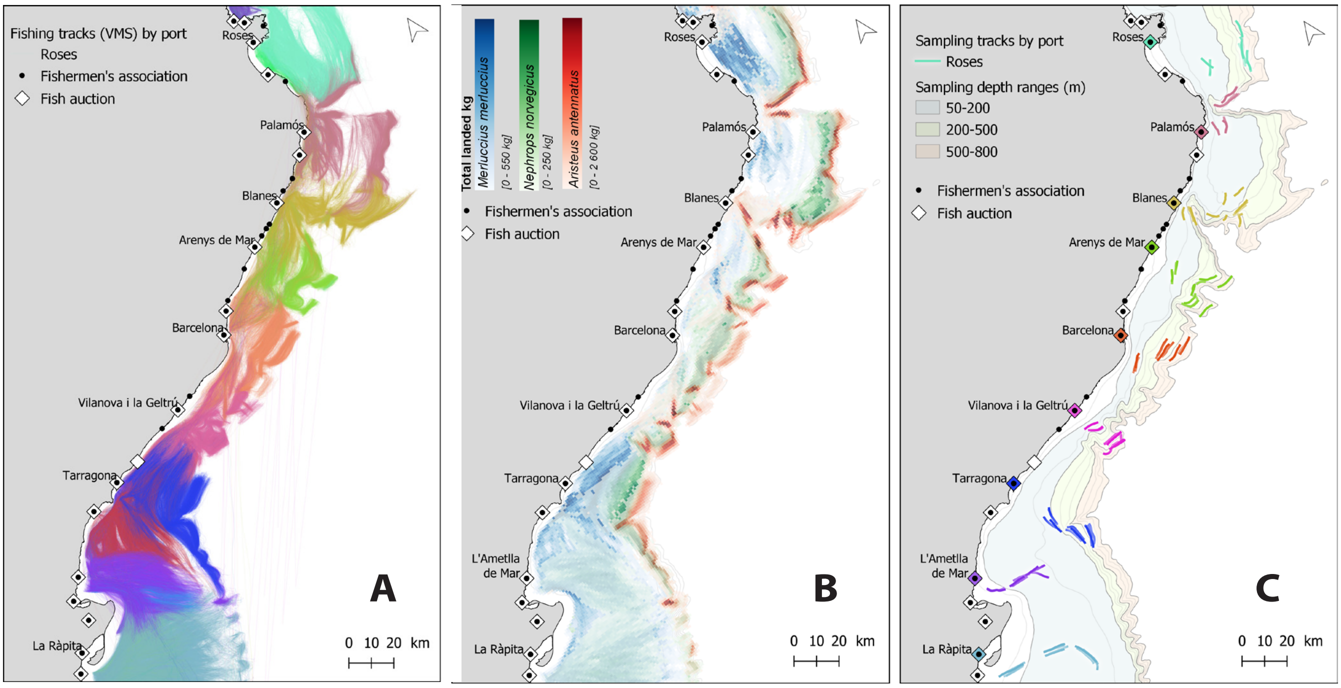

Figure 1. Spatial distribution of fishing activity, selected species catches and sampling tracks. A) Fishing tracks from VMS data by port; B) Total catch in 2021 (in kg) for European hake (*Merluccius merluccius*), Norway lobster (*Nephrops norvegicus*), and blue and red deep-water shrimp (*Aristeus antennatus*); C) Sampling depth ranges and tracks by port.

1.2. Sampling structure and data quality

The main objective of ICATMAR monitoring program is to complement the data collection procedures already in place, according to the particularities of the fisheries in the Northern GSA6. The current data collection protocol, in place since 2000 and coordinated by the General Secretariat of Fisheries of the Spanish government, collects on-board samples in ports along the whole GSA6 and carries out an experimental trawl cruise once a year (MEDITS), with 10 to 25 hauls within the Northern GSA 6 area (STECF EWG 22-03).

ICATMAR sampling methodology stands halfway between fisheries-dependent and -independent methods, with sampling trips carried out on board commercial fishing vessels, with no change to their usual fishing gear, over defined sampling tracks within commercial fishing grounds. Each sampling day includes three hauls on board the same vessel, each one at a different depth range, within the high-fishing-effort areas of each port (Fig. 1C).

ICATMAR sampling covers 9 ports in the Northern GSA6, divided in 3 areas (North, Center and Ebre Delta, the southernmost part of the Catalan coast) with a monthly sampling per zone and a quarterly sampling per port (Fig. 2). In the North and Center zones, the sampling depth ranges are continental shelf (75 – 200 m), upper slope (200 – 500 m), and lower slope (500 – 800 m), corresponding to high-fishing-effort areas for the European hake, the Norway lobster and the blue and red shrimp, respectively. In the Ebre Delta zone, with a distinct geomorphological structure, fishing activity takes place exclusively in the wide continental shelf, thus requiring a more detailed sampling of this area. The defined sampling depths are then shallow shelf (< 40 m), middle shelf (40 – 75 m), and continental shelf (75 – 200 m).

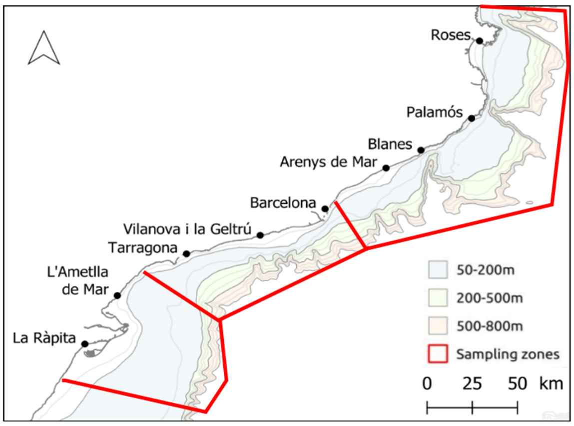

Figure 2. Sampling layout for A) DCF in the whole GSA6, and B) ICATMAR monitoring program in the Northern GSA6. Red lines indicate sampling zones, colored polygons indicate sampling depth ranges.

Another objective of ICATMAR sampling is to revisit the population and biological parameters of target species to better adjust stock assessment models and reduce their uncertainties. The following parameters are being calculated using data from our monitoring:

- Growth rates
- Size at first maturity (L_{50})
- Reproductive periods
- Selectivity parameters

For instance, Sardà et al. (1991) found a L_{50} value of 30-31 mm cephalothorax length (CL) for the Norway lobster, and the 2021 stock assessment report of the GFCM (reference year 2020) presents a

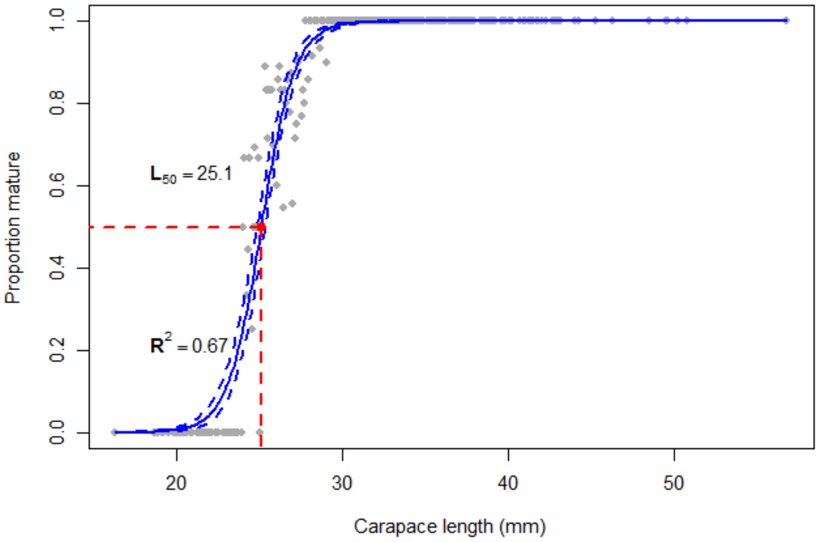

Figure 3. Maturity ogives at length of Norway lobster females (ICATMAR data).

value of 32 mm CL. In contrast, a preliminary analysis with ICATMAR data shows an L_{50} value of 25.1 mm (Fig. 3). In addition, when tested for significant differences through a Kolmogorov-Smirnoff test, ICATMAR length-frequency data show low variability over the years and significant differences by season and zone (Annex 1), which reflects both the robustness of the data over time and the necessity to carry out a more spatio-temporally detailed sampling.

1.3. Fisheries monitoring in the Western Mediterranean management context

Under the current legislation, the bottom trawling fleet in the Northern GSA6 is fishing an average of 7 to 8 months a year, depending on fleet segment. This is a combination between temporal fishery closures already in place before WWMAP and the ongoing fishing days reduction established in WMMAP to achieve the F_{MSY} for the species of concern by 2025 (Article 7, WMMAP). In a theoretical projection of this scenario over time, starting from 2020 (established as the status quo year), the fleet would see their fishing time reduced to 238 annual days per vessel, i.e. a reduction of 68% in only 5 years (Table 1, ICATMAR, 20-07). Being that most vessels are family-owned, an important part of the fleet is likely to not survive in this scenario. Considering the history, structure and organization of the fisheries sector in the area, this prospect seems to be neither socially nor economically feasible for the Spanish Mediterranean Fisheries. Even then, in the case of an outright reconversion of the sector as a consequence of these measures, the availability of quality, detailed data on the fleet would be yet a more pressing matter, since its repercussions in society are bound to have major consequences.

Table 1. Projection of the reduction of days at sea scenarios according to Article 7 in WMMAP.

Scenarios / Fishing segments		**< 12**	**12 < X < 18**	**18 < X < 24**	**> 24**
Status quo (2020)	**Year**	**152**	**181**	**193**	**201**
(1) 30% effort reduction	**2021**	136	163	174	181
	2022	126	150	161	168
	2023	117	139	149	155
	2024	108	129	137	143
	2025	100	119	127	133
(2) Effort reduction to achieve F_{MSY} for hake	**2021**	121	145	154	161
	2022	97	116	123	129
	2023	78	93	99	103
	2024	62	74	79	82
	2025	50	59	63	66

The objective of this report is to convey our advice that other management strategies be equally considered in order to accomplish the WMMAP objectives, namely the regulation of gear selectivity and the establishment of closure areas. A technical report on selectivity trials results was published last year (ICATMAR, 21-05), and for this reason no specific details on selectivity results will be shown in this Advisory report. However, the following sections lay out our considerations on these two management strategies.

2. Spatial WMMAP fishing closures effectiveness. Effort redistribution and spillover effect

2.1. Introduction

In the Spanish Mediterranean Sea, Article 11.1 was derogated adopting 11.2 measures in all GSAs. Closure areas in response to Article 11.2 were first published in (Orden APA/753/2020, de 31 de Julio and areas responding to Article 11.3 in Orden APA/1397/2021 de 10 de diciembre. In most cases, the established areas were the result of an intense negotiation process including all stakeholders concerned: fishing sector, administrations and scientific organizations. After a first round of negotiations and publications, some areas had to be amended, with the final changes being included in Orden APA/825/2022 de 24 de agosto.

A total of 41 marine protected areas (MPAs) were established along the Spanish Mediterranean coast, 21 of which are permanent (973 km^2) and 16 temporary (6013 km^2, Figure 4). While in the GSAs 1, 2 and 6 temporary and permanent areas were established, in the GSA 5 all closure areas were temporary. Moreover, two extensive temporary areas were established in the GSA7 (Figure 1) where some vessels of the northern GSA 6 Spanish fleet also operate.

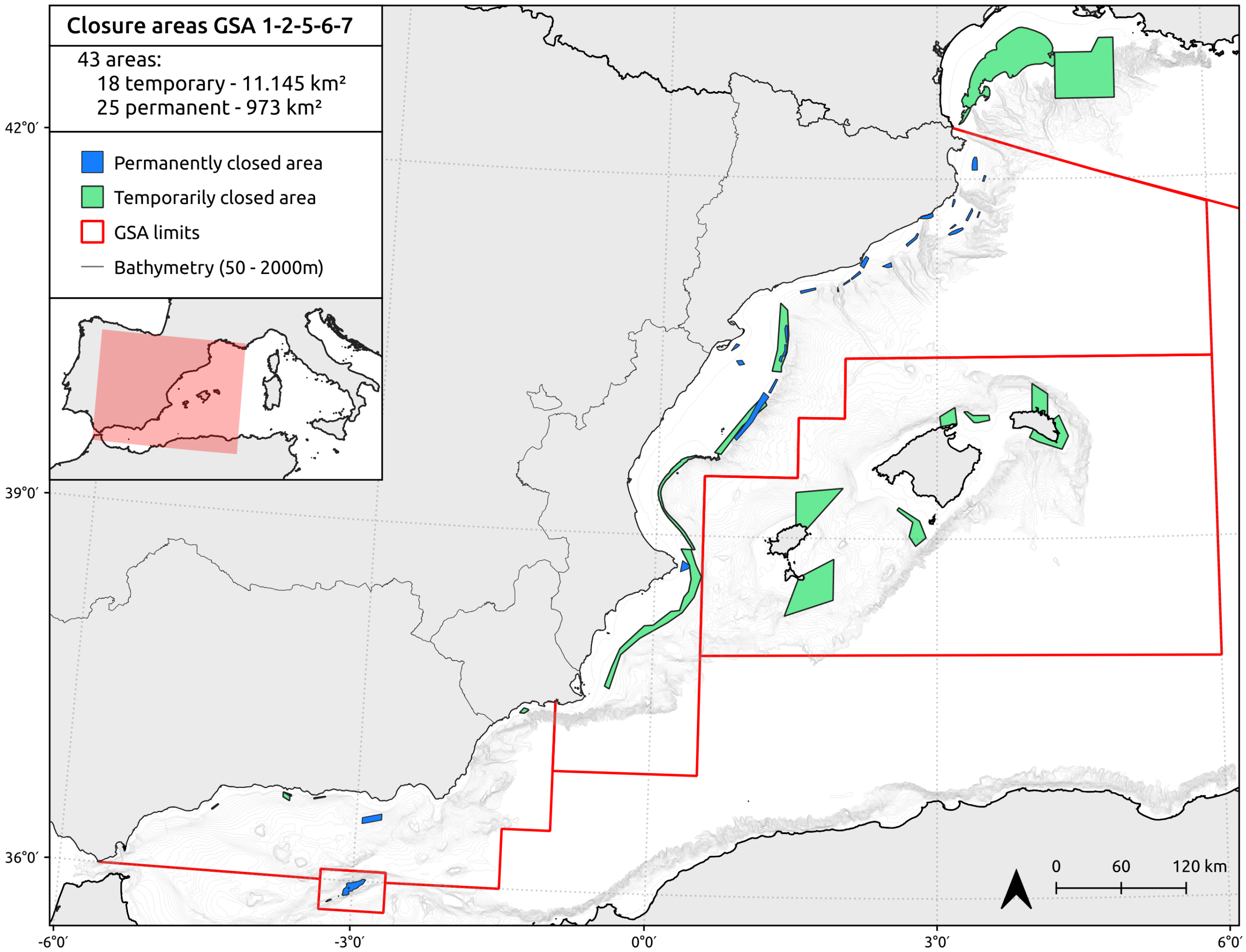

Figure 4. Established closure areas in the Spanish Mediterranean GSAs and GSA7 in response to WMMAP regulations.

It is known that the establishment of an MPA does not reduce the general effort of the fleet operating in it; instead, the effort is expected to redistribute (Cabral et al., 2017). For this reason, we did not expect that establishing MPAs would reduce the overall commercial species juvenile mortality. However, even if the stated conditions in WMMAP Article 11.3 will probably not be reached with these measures, several scientific studies have shown that closed areas could benefit fishing stocks sustainability through other mechanisms (di Lorenzo et al., 2016, 2020; Forcada et al., 2009; Goñi et al., 2008, 2010; Harmelin-Vivien et al., 2008; Sala-Coromina et al., 2021).

After the protection of an area, species abundances are expected to increase within its boundaries as a consequence of habitat restoration and fishing mortality reduction (di Lorenzo et al., 2016, 2020). In turn, intraspecific competition would increase, triggering species to cross MPA borders and therefore making commercial species available for fishing activity (di Lorenzo et al., 2016, 2020).This phenomenon (spillover effect, (Rowley, 1994)) is then predicted to have a role on fisheries yields sustainability.

The effects of an MPA are not straightforward and depend on various variables (di Lorenzo et al., 2020; Edgar et al., 2014). MPA size, MPA age, species mobility and biology, habitat continuity, the presence of a buffer zone and fishing surveillance are some of the key features that will determine MPAs effectiveness (di Lorenzo et al., 2020; Edgar et al., 2014). WMMAP closure areas in the Spanish Mediterranean Sea have a wide range of sizes, closure regimes and habitat/depths, and there is an extensive list of commercial species that could be affected by these management measures.

Developing robust, replicable and long-term planned monitoring strategies is crucial to assess MPAs effects and disentangle the reasons why positive effects for fisheries may or may not appear. This section aims at developing the first steps towards the implementation of a monitoring for all Spanish Mediterranean closure areas that allows the evaluation of effort redistribution and spillover effects after the areas establishment, in order to evalute the effects of the closed areas in the status of the main target species of the Catalan fisheries.

2.2. Method

This section focuses on the evaluation of the effects of a spatial fishing ban in three zones in the Northern GSA6 (Figure 2). These closed areas represent an interesting variety of protection time and depth ranges that will allow to test the evaluation methods in different species and situations:

- **Roses area** (130-179 m depth): permanently closed in 2013 targeting the protection of European hake juveniles and *Mullus* spp. juveniles.
- **Palamós area** (330-450 m depth): permanently closed in 2017 targeting the protection of Norway lobster populations.
- **Blanes area** (170-260 m depth): permanently closed in 2013 targeting the protection of various fish species, among which adult individuals of *Mullus* spp.

The analysis of closed areas effectiveness was based on the evaluation of fishing time (in days), total landings (in kg or Tn) and Landings Per Unit Effort (LPUE) before and after the protection around protected areas. To this aim, an experimental design based in buffer zones around the protected areas

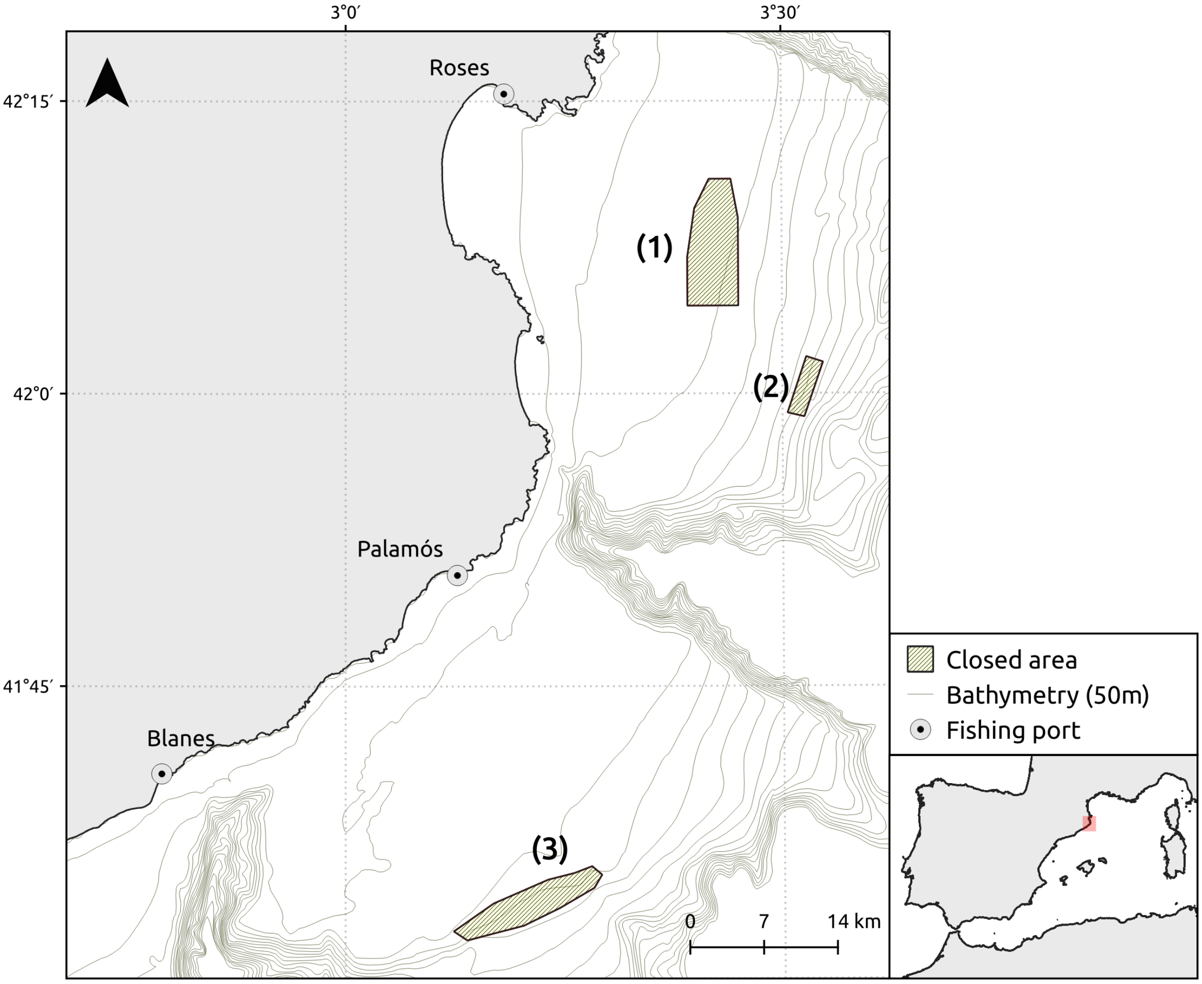

Figure 5. Protected areas in which the methodology to evaluate MPAs effectiveness has been developed: Roses area (1), Palamós area (2) and Blanes area (3).

was outlined (Figure 5). This approach would also allow to detect not only changes in fishing yields patterns around protected areas, but also gradients that may appear as distance to MPA border increases which are considered a proof of spillover (Goñi et al., 2010; Harmelin-Vivien et al., 2008). Overall, a 5000 m-wide buffer ring around each protected area was evaluated, divided in two 500 m-wide rings, two intermediate 1000 m-wide rings, and an external 2000 m-wide ring (Figure 6). A reference period for before and after protection states was defined for each area so that the same amount of years for each state were evaluated. Data corresponding to the year the protection started was not included as it was considered a transitional period. For Roses area, 2008 – 2012 was considered before the protection and 2014 – 2018 after the protection. For Palamós and Blanes areas, 2013 – 2016 was considered before the protection and 2018 – 2021 after the protection. For further details on this preliminary methodology, see Annex 1.

First, we evaluated if there was an actual decrease of fishing effort inside protected areas after closure. Second, we checked if fishing effort redistributed around the protected area after the closure, and third, we evaluated the landings and LPUE changes for commercial species. A first analysis was done including the species concerned by WMMAP: *M. merluccius*, *N. norvegicus*, *Mullus barbatus*, and *P. longirostris*. *Mullus barbatus* could not be evaluated as an independent species as landings data do not correctly discern between this species and *Mullus surmuletus*, and therefore both species were

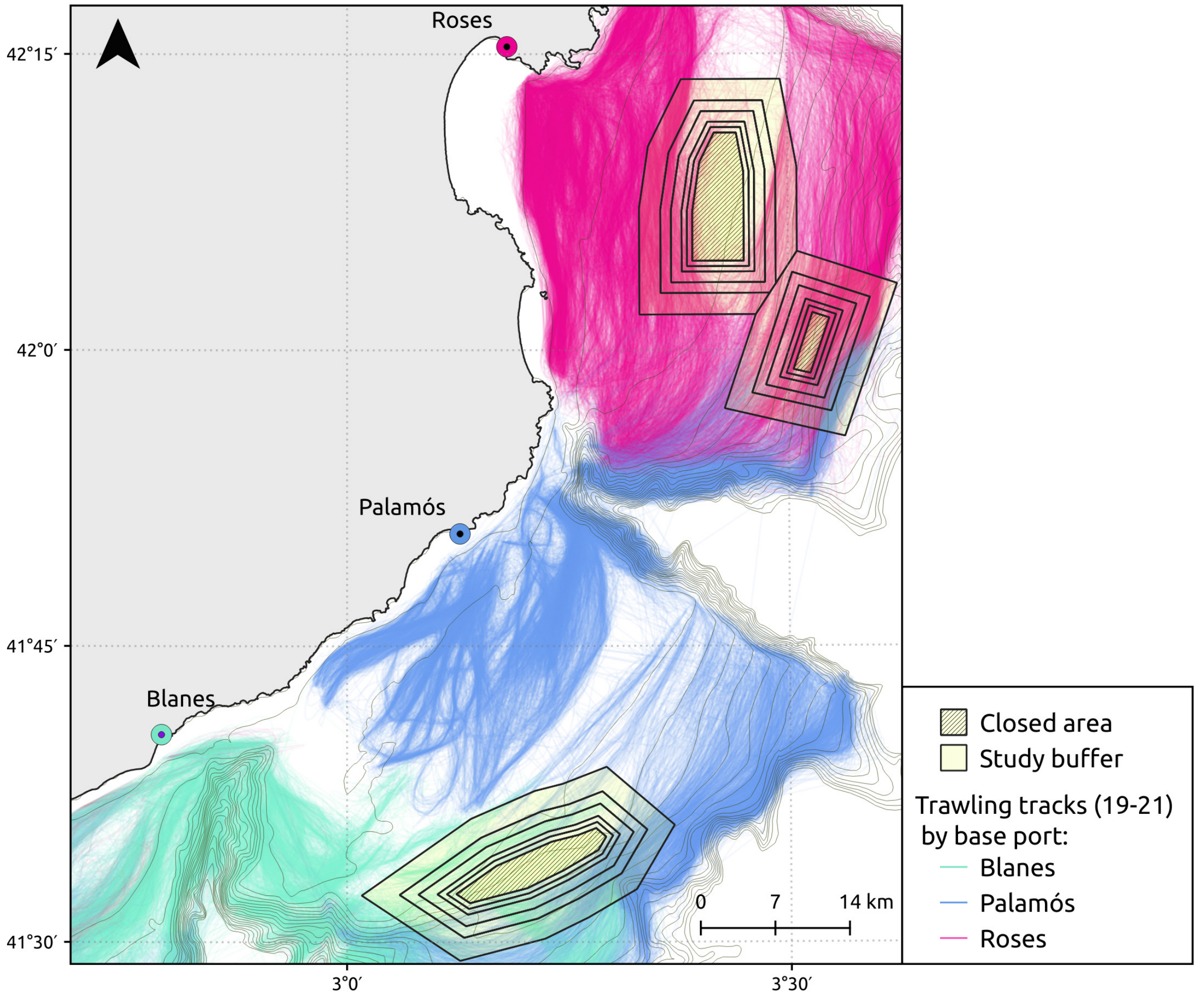

Figure 6. Buffer zones around protected areas used to evaluate effort redistribution and spillover effects before and after the closures.

analyzed together (*Mullus* spp.). After gathering the data and results from this analysis, some other species were included: *Helicolenus dactylopterus*, *Argentina sphyraena*, Triglidae spp., and *Lepidorhombus boscii*. The deep-sea blue and red shrimp *A. antennatus* was not considered as it is not fished in the depth ranges where studied areas are located. *Aristeomorpha foliacea* was neither included in the analysis as it is not present in the study zone.

2.3. Results and discussion: closure areas

2.3.1. Effort reduction

The results show that, after the protection, effort inside protected areas is effectively reduced (Figure 4). However, after the protection, fishing effort inside protected areas is not exactly zero. For Roses and Blanes area fishing time inside protected areas is reduced around five times and for Palamós area around 3 times (Figure 4). To deeply analyze these changes it is necessary to check specific fishing effort distribution. As it can bee seen in effort distribution maps (Figure 7), effort has disappeared in the inner parts of the protected areas. However, it seems that there is a fishing-the-line behavior of the fleet, that is, there are some fishing points inside the protected area but only in its margins. These results can be explained with two reasons. First, it is possible that derived from VMS interpolation methods (Russo et al., 2011), some interpolated points between real VMS positions may fall inside protected areas. Even if these algorithms are precise in fishing effort quantifications, some imprecisions can be made and therefore *unreal* fishing points could fall inside the areas.

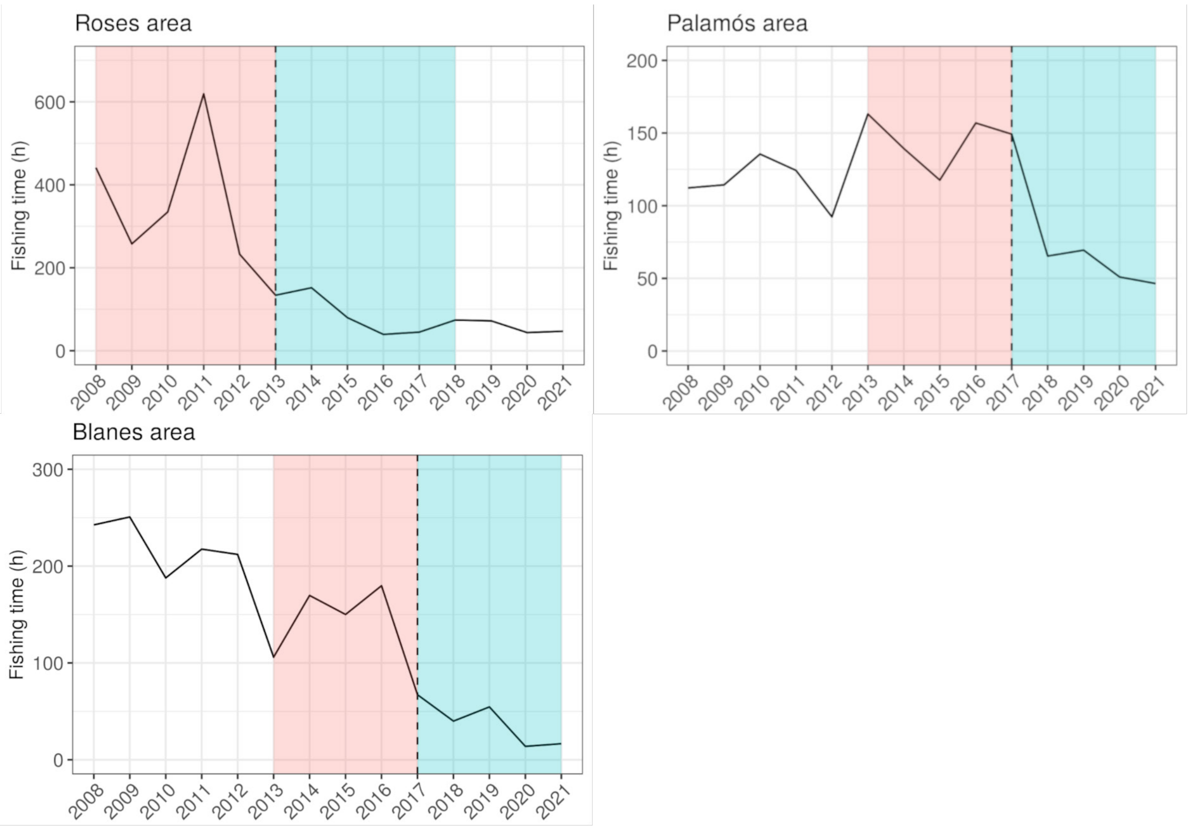

Figure 7. Total fishing time (hours) of trawling fleet inside protected areas. Red and blue shades correspond to before and after the protection reference study periods for each area.

The second possibility explaining the results could be that there is actual fishing at the MPA margin that truly falls inside its boundaries. The three studied areas were, before its official publication (Orden APA/753/2020, de 31 de Julio), closed after internal agreements of each fishers association. Therefore, there was no real time surveillance of fishing vessels obeying these fishing closures. It will be interesting to see if this behavior changes in coming years as, with the official areas publication, there will be an effective surveillance of these zones via VMS data.

The main result is that even if some real fishing may have occurred in the protected area margins, in most parts of the protected areas fishing effort was actually zero as shown in maps (Figure 8). Therefore, it is consistent to expect and hence further analyze the consequences of this fishing effort reduction.

2.3.2. Effort redistribution

The fishing time in each buffer zone gradually increases as from the MPA border outwards (Figure 8), as expected since some buffer areas (e.g. 5000 m) are larger than others. There is no clear evidence that fishing effort that has been removed from inside the protected area has been relocated in its surroundings. None of the three studied areas present an increase in fishing time after the protection, with even a reduction in the case of Blanes area (Figure 9).

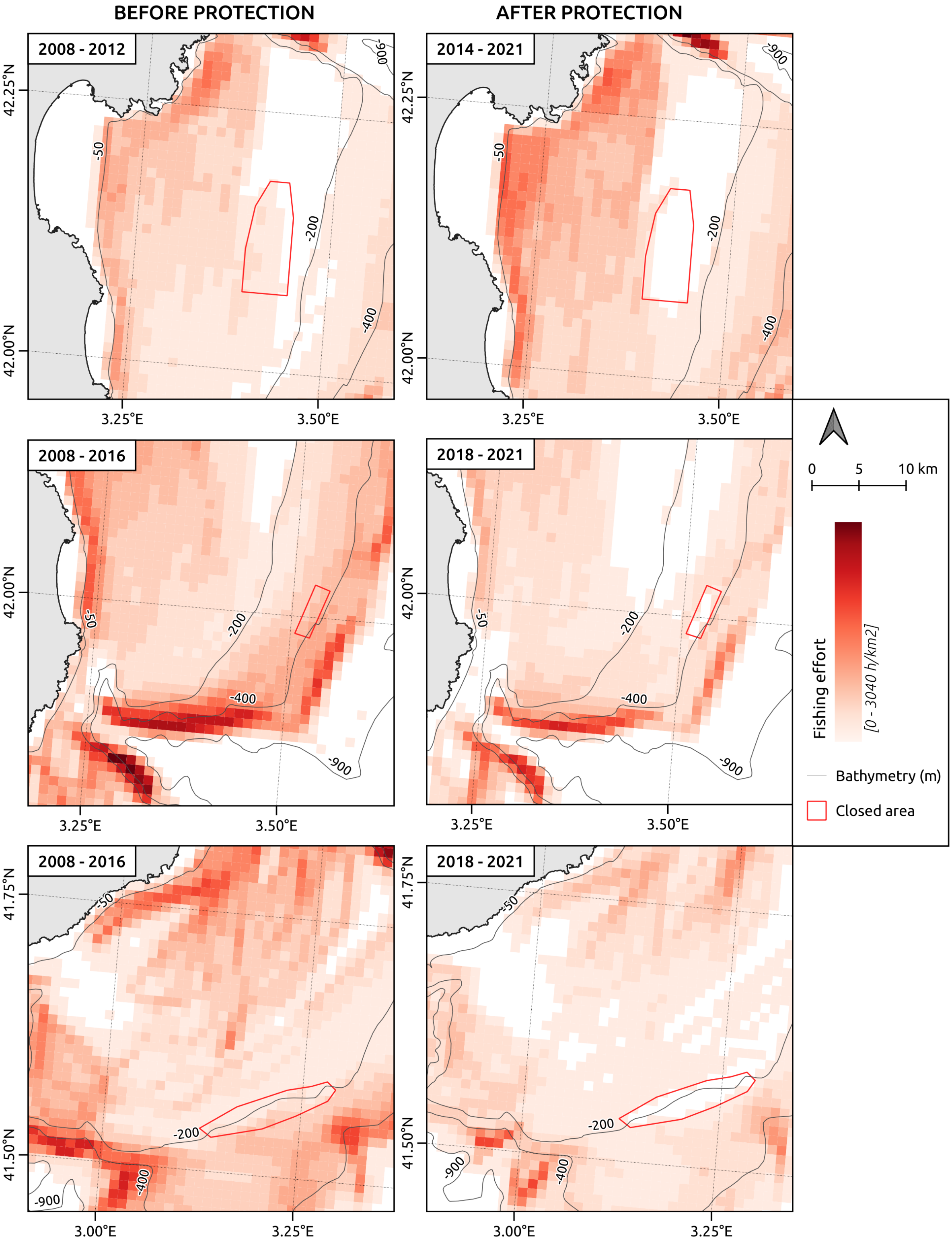

Figure 8. Before/after the protection trawling fishing effort (hours by km$^{2)}$ around Roses, Palamós and Blanes areas.

The possible reasons underlying these results are, on the one hand, that the effort inside the protected area may not have redistributed in the immediate surroundings of the protected zone, but rather within other fishing grounds where the fleet normally operate. On the other hand, there has been a general reduction of fishing days, mainly as a consequence of fleet reduction. There should have also been a fishing days reduction derived from WMMAP application. However, for Roses area, WMMAP period is not included at all in the analysis (after the protection period: 2014-2018) and for other areas (after the protection period: 2018-2021) only two years of WMMAP are included, of which the year 2020 has to be considered with caution due to the effects of the COVID-19 global pandemic. Therefore, the decrease in fishing days may have had benefits in terms of smoothing the effort redistribution effects derived from closed areas establishment. However, all fishing grounds where these fleets operate should be studied to confirm that effort has not been allocated to other zones.

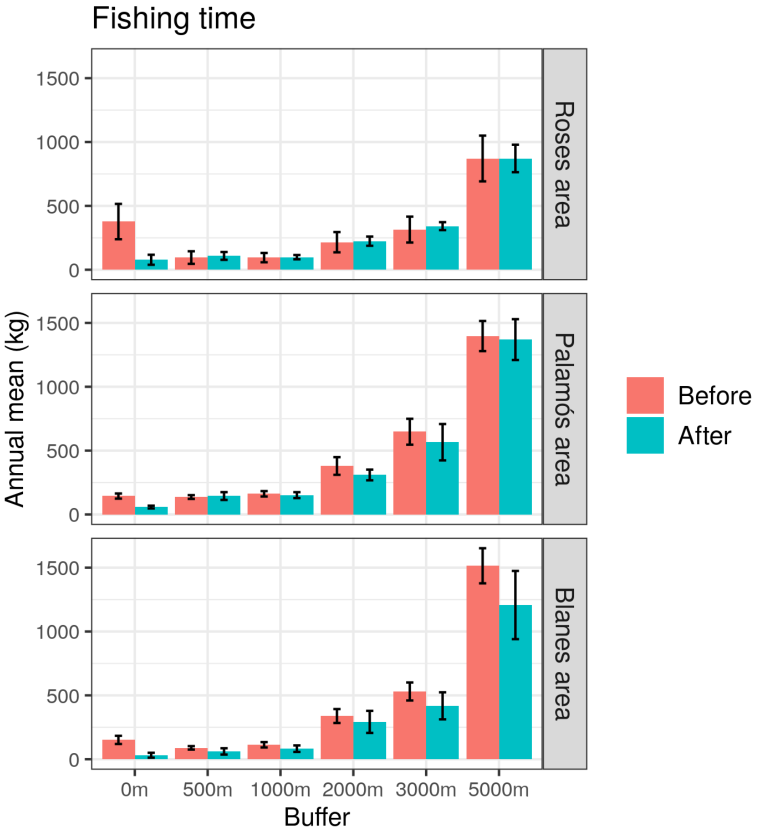

Figure 9. Fishing time before and after the protection in each buffer zone by fishing closure area. Values correspond to the variable anual mean and its standard error for before and after reference years. Buffer names represent their maximum distance to MPA border, i.e 5000m buffer corresponds to the ring between 3000 and 5000m distance from protected area border.

2.3.3. Spillover effect

2.3.3.1. *Mullus* spp.

Data on *Mullus* spp. are presented only for Roses and Blanes areas, since Palamós area is not located within the species habitat depth range. In the case of Roses area, there is a clear increase both in landings and LPUE after the protection (Figure 7). For Blanes area, the increasing trend is particularly clear for LPUE.

The effect of the protection in the case of *Mullus* spp. can be observed both spatially and over time. First, after the protection, LPUE gradually decreases from the MPA border outwards, while no clear trend was visible before (Figure 10). Second, LPUE increases over the years after the protection, with a stronger trend the closer the buffer zone is to MPA borders, a difference that was not present before the protection (Figure 11). Furthermore, the overall LPUE fleet trend for *Mullus* spp. does not show clear increasing trends over time, especially since 2013 (Figure 12) - the increase in LPUE in 2012-2013

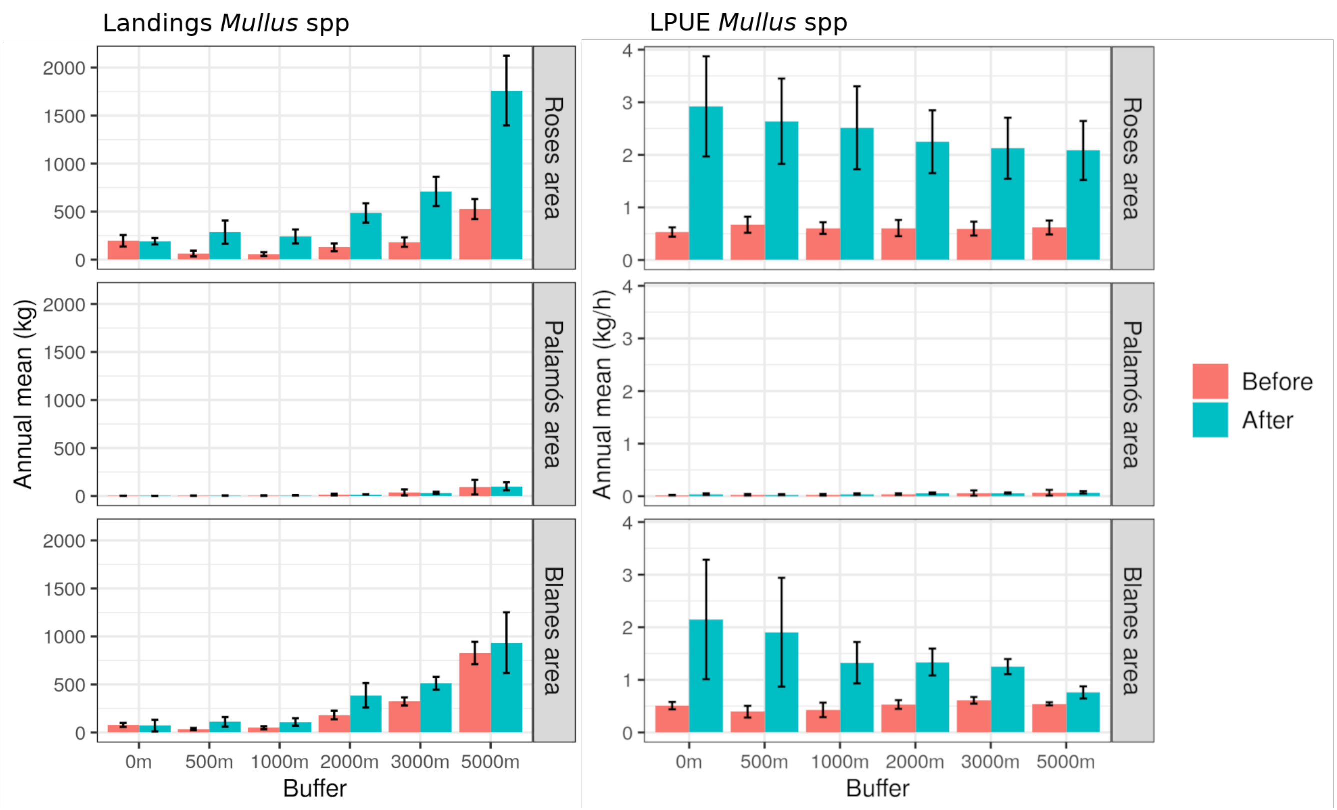

Figure 10. *Mullus* spp landings (A) and LPUE (B) before and after the protection in each buffer zone by fishing closure area. Values correspond to the variable anual mean and its standard error for before and after protection reference years. Buffer names represent their maximum distance to MPA border, i.e 5000m buffer corresponds to the ring between 3000 and 5000m distance from protected area border.

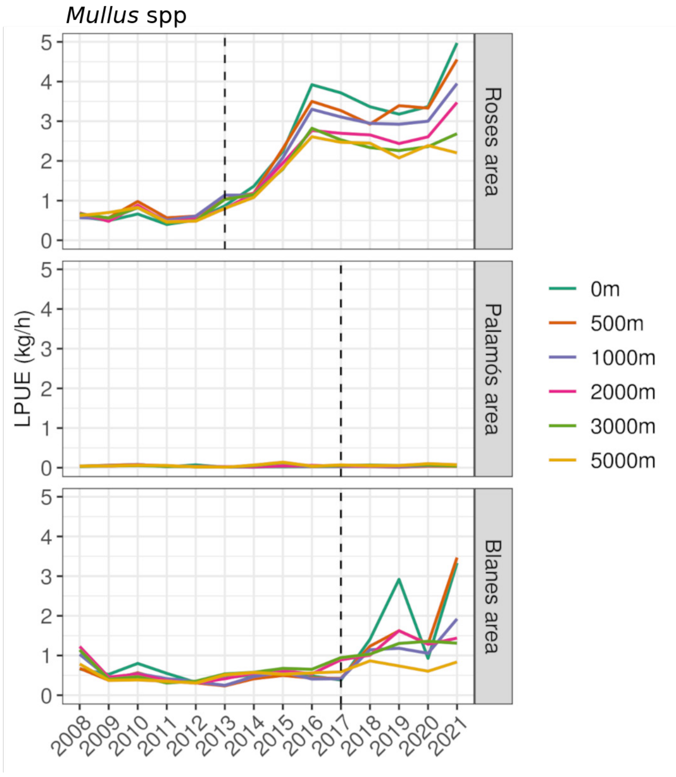

Figure 11. *Mullus* spp LPUE in each buffer zone by year and fishing closure area. Vertical dashed line correspond to the moment when each area was closed. Buffer names represent its maximum distance to MPA border, i.e 5000m buffer corresponds to the ring between 3000 and 5000m distance from protected area border.

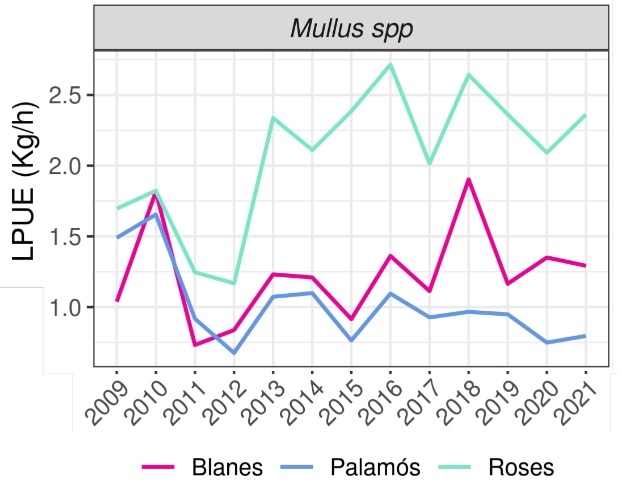

Figure 12. General fleet LPUE trends for *Mullus* spp. Overall landings and fishing time for all vessels with base port Roses, Palamós and Blanes are taken into account as these are the fleets operating in the protected areas surroundings.

could be a response to a mesh size increase in 2010-2011. Trends in the MPA buffers across the years do not show a pattern that could be directly linked to general fleet trends, and so it is clear that the onset of the LPUE gradient in the protected areas can be read as a spillover evidence.

2.3.3.2. *Merluccius merluccius* and *Nephrops norvegicus*

In the case of the European hake, there is a decrease in landings across all buffer zones for Roses and Blanes area, while landings in Palamós area seem to remain more stable (Figure 13). LPUE shows a decreasing trend across all areas and buffer zones (Figure 13). The data we present show no evidences of LPUE gradients after the protection that could be linked to a spillover effect in hake (Figure 13).

Data on Norway lobster are present only for Palamós and Blanes areas, since Roses area is not located within the species habitat. Both LPUE and landings show a decreasing trend across all areas and buffer zones (Figure 10). The data we present show no evidences of LPUE gradients after the protection (Figure 10) that could be linked to a spillover effect in Norway lobster.

For both species, data about local fleet general LPUE trends show a strong decreasing trend in all fleets since the beginning of the time series (Figure 14) - as in the case of mullet., the observed LPUE increase in 2013 could be related to the mesh size change in 2010-11. Taking this into account, as well as the trends in LPUE observed in all buffer zones (Figure 15), it seems clear that general stock trends are affecting the dynamics of the buffer zones, and could be masking whatever effects the protection may have in the areas.

Another point worth considering is that the present methodology analyzes landings data, and therefore we do not have information on juvenile (under MCRS) individuals since they are not sale on the daily auctions. Roses area is reportedly located in hake nursery grounds and depths (Druon et al., 2015) and therefore the expected spillover effect in this zone would be related to the smallest, non-commercial size classes. This would be a density-independent spillover effect related to an ontogenic change in the mobility capacity of this species. Indeed, there are other studies demonstrating the effect on hake juveniles of this closure area. Recasens et al. (2016) showed how inside the protected area juveniles abundances are higher than in surrounding zones and Sala-Coromina et al. (2021) found spillover evidences on the smallest commercial size classes.

The Norway lobster is a territorial species with a small home range, i.e., it does not perform large distance moves (Vigo et al., 2021). Therefore, it is not a species where a marked spillover effect would be expected. However, studies inside this area have already been made and show a clear improvement in the stock status inside the protected area compared to its surroundings (Vigo et al., 2022, submitted). It is probable that the small home range would favour that individuals inside MPAs grow up to large sizes with great reproductive capacity, making these MPA a pool of egg and larvae exportation for this species.

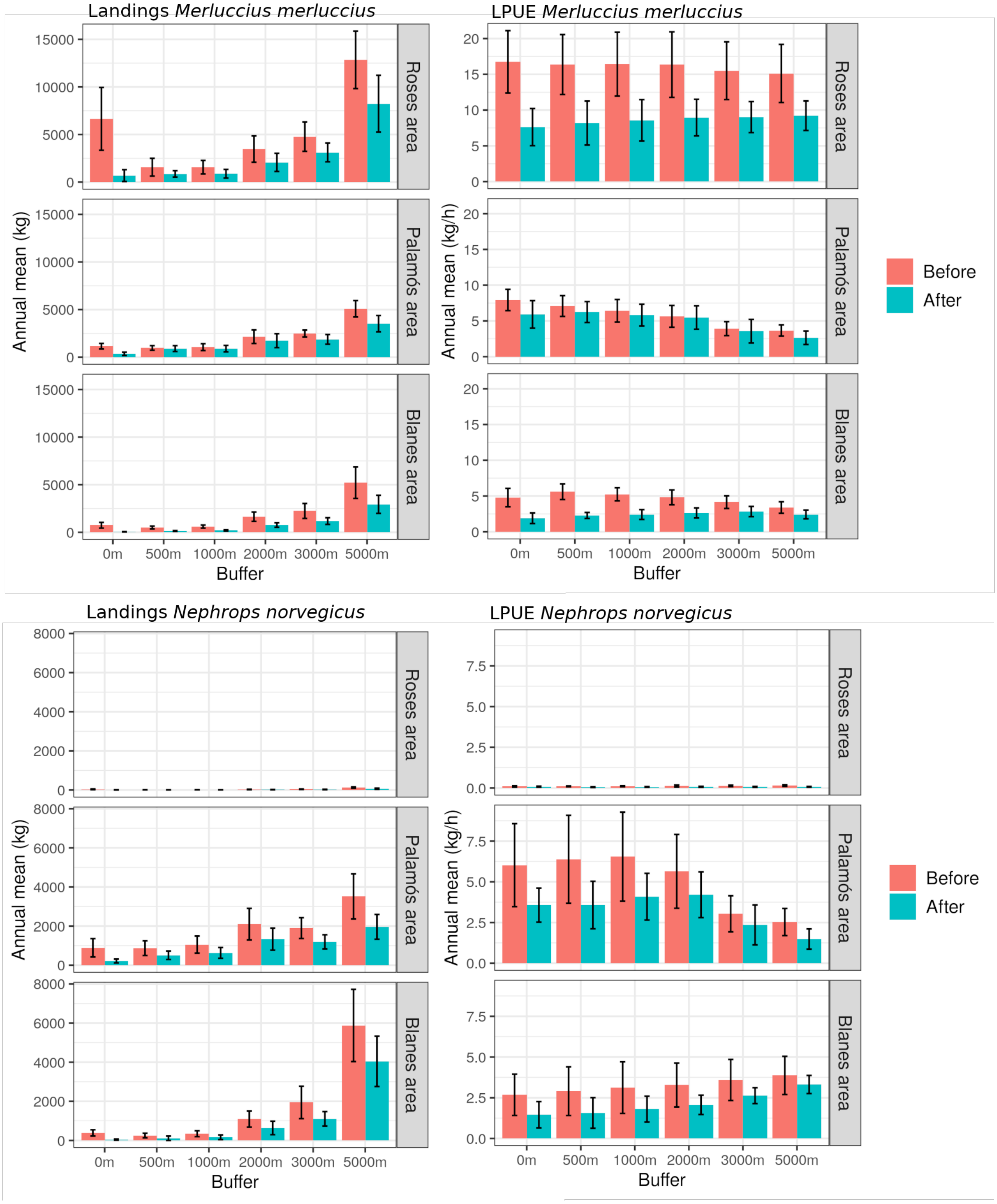

Figure 13. *M.merluccius* and *N. norvegicus* landings and LPUE before and after the protection in each buffer zone by fishing closure area. Values correspond to the variable anual mean and its standard error for before and after protection reference years. Buffer names represent their maximum distance to MPA border, i.e 5000m buffer corresponds to the ring between 3000 and 5000m distance from protected area border.

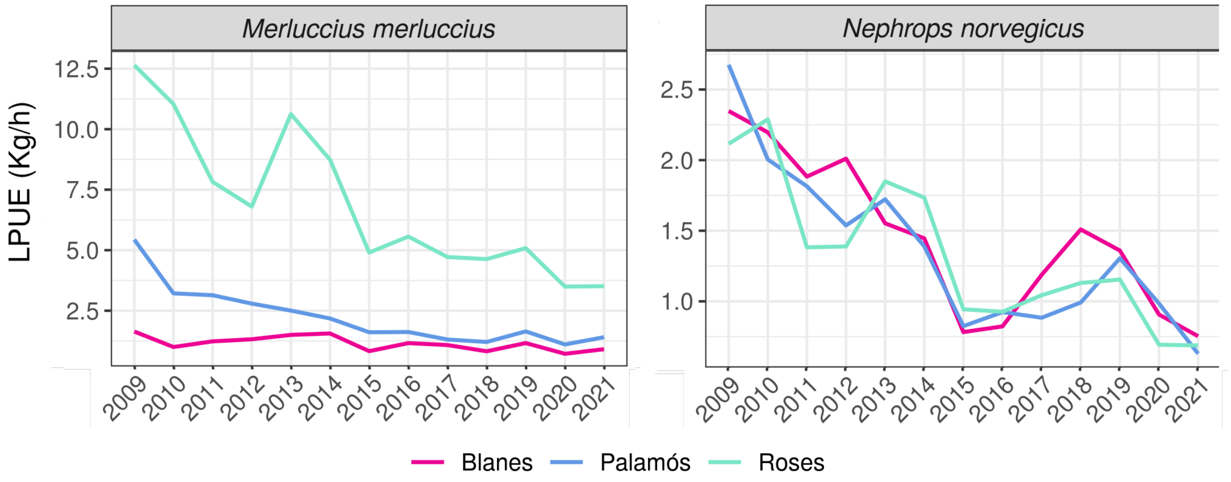

Figure 14. General fleet LPUE trends for *M. merluccius* and *N. norvegicus*. Overall landings and fishing time for all vessels with base port Roses, Palamós and Blanes are taken into account as these are the fleets operating in the protected areas surroundings.

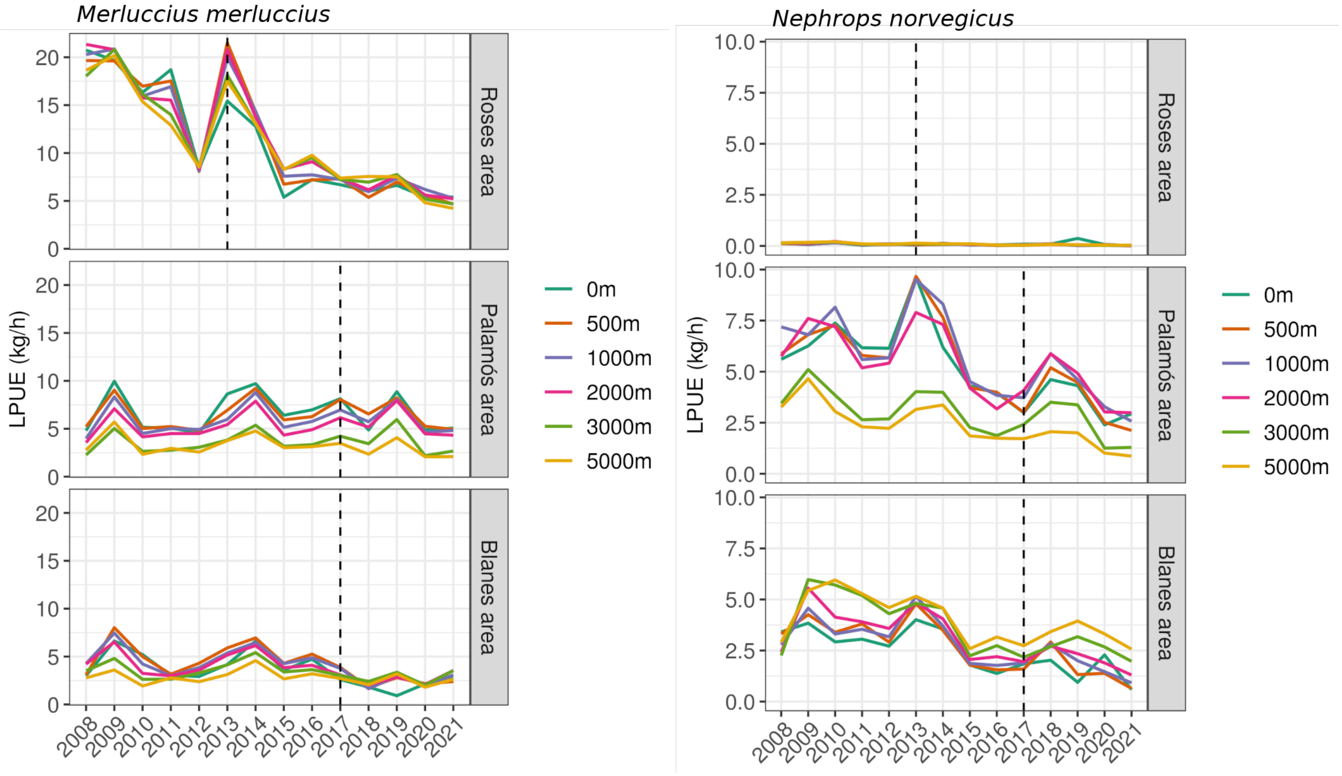

Figure 15. *M. merluccius* and *N. norvegicus* LPUE in each buffer zone by year and fishing closure area. Vertical dashed line correspond to the moment when each area was closed. Buffer names represent their maximum distance to MPA border, i.e 5000m buffer corresponds to the ring between 3000 and 5000m distance from protected area border.

2.3.3.5. Other species. Results summary

In order to visualize the spillover effect of protected areas four other species not included in WM-MAP were analyzed: *Helicolenus dactylopterus*, *Argentina sphiraena*, *Triglidae spp.* (include all species of *Triglidea* as they were not separated and well identified in the fishing auction) and *Lepidorhombus boscii*. These four fish species have small-medium sizes and probably reduced home ranges (Woolnough et al., 2009) which make them good candidates for density-dependent spillover effects (di Lorenzo et al., 2016). Before-after analysis showed a positive effect of the selected protected areas for the

LPUE of the four species selected. The results showed a negative LPUE gradient across MPA borders that could be matched with a spillover effect as in the case of *Mullus* spp. (Tuset et al., 2021) demonstrated how most species were benefited from a fishing closure in the study zone, especially those characterized by sedentary behavior such as *H.dactylopterus* and *Triglidae spp.*

Table 2. Summary of the studied species results for spillover effect.

	ROSES AREA		PALAMÓS AREA		BLANES AREA		
	LPUE increase	**LPUE gradient**	**LPUE increase**	**LPUE gradient**	**LPUE increase**	**LPUE gradient**	
Mullus spp	🟩		No habitat		=	🟩	**Spillover evidences**
Merluccius merluccius	▨		=	▨	▨		Stock trends affecting
Nephrops norvegicus	No habitat		▨		▨		Stock trends affecting
Parapenaeus longirostris	No habitat		🟩		🟩		Stock trends affecting
Helicolenus dactylopterus	No habitat		=	🟩	🟩		**Spillover evidences**
Argentina sphyraena	=		**No habitat**		🟩		**Spillover evidences**
Triglidae spp	=		=	🟩	🟩		**Spillover evidences**
Lepidorhombus boscii	=	🟩	▨	=	=	🟩	**Spillover evidences**

2.4. Other data supporting closure areas effectiveness

Besides the preliminary methodology to quantitatively evaluate the effectiveness of the closure areas in the GSA6, information from experimental hauls inside and outside the closure areas is also available on some of these areas. Some of these data may shed light on the reasons why spillover effect is not always detectable with methods based on landings data. For example, for the European hake area in Roses (Fig. 13A), overall catch also seemed to be more abundant inside the closure area (Fig. 13B). In fact, small-sized (non-commercial) individuals are clearly more abundant inside the closure area (Fig. 13C). The fact that these individuals do not show in landings data may me masking a spillover effect that is in fact present. For the Norway lobster closure area off Palamós (Fig. 14A), qualitative data show similar results, with the target species being notably more abundant inside the closure area (Fig. 14B). Furthermore, the restoration of the habitat is clearly visible from ROV images (Fig. 15).

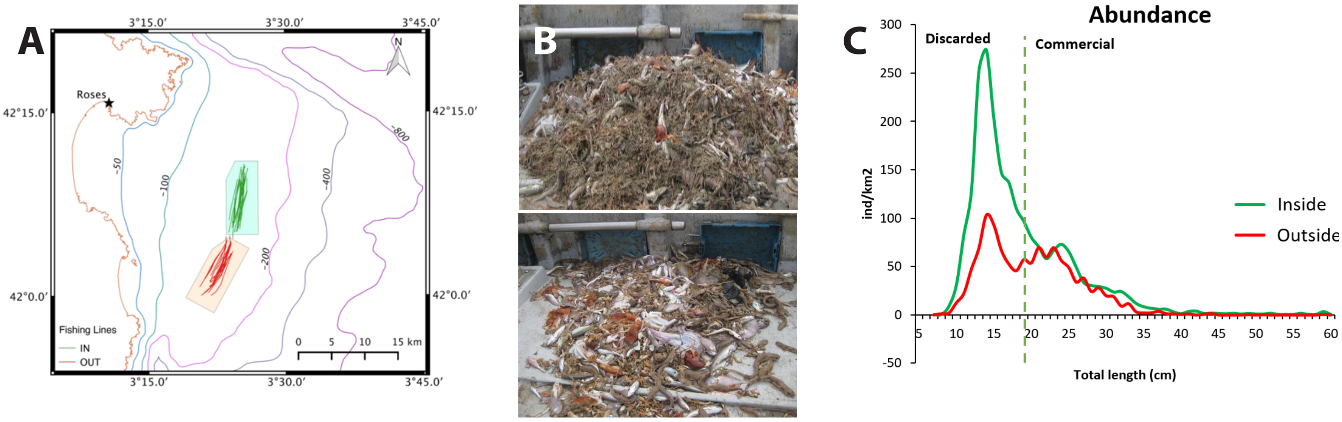

Figure 13. A: Experimental hauls carried out inside (green) and outside (red) of the closure area. B: Images of the total catch inside (top) and outside (bottom) of the closure area. C: Length frequency distribution of European hake inside (green) and outside (red) of the closure area.

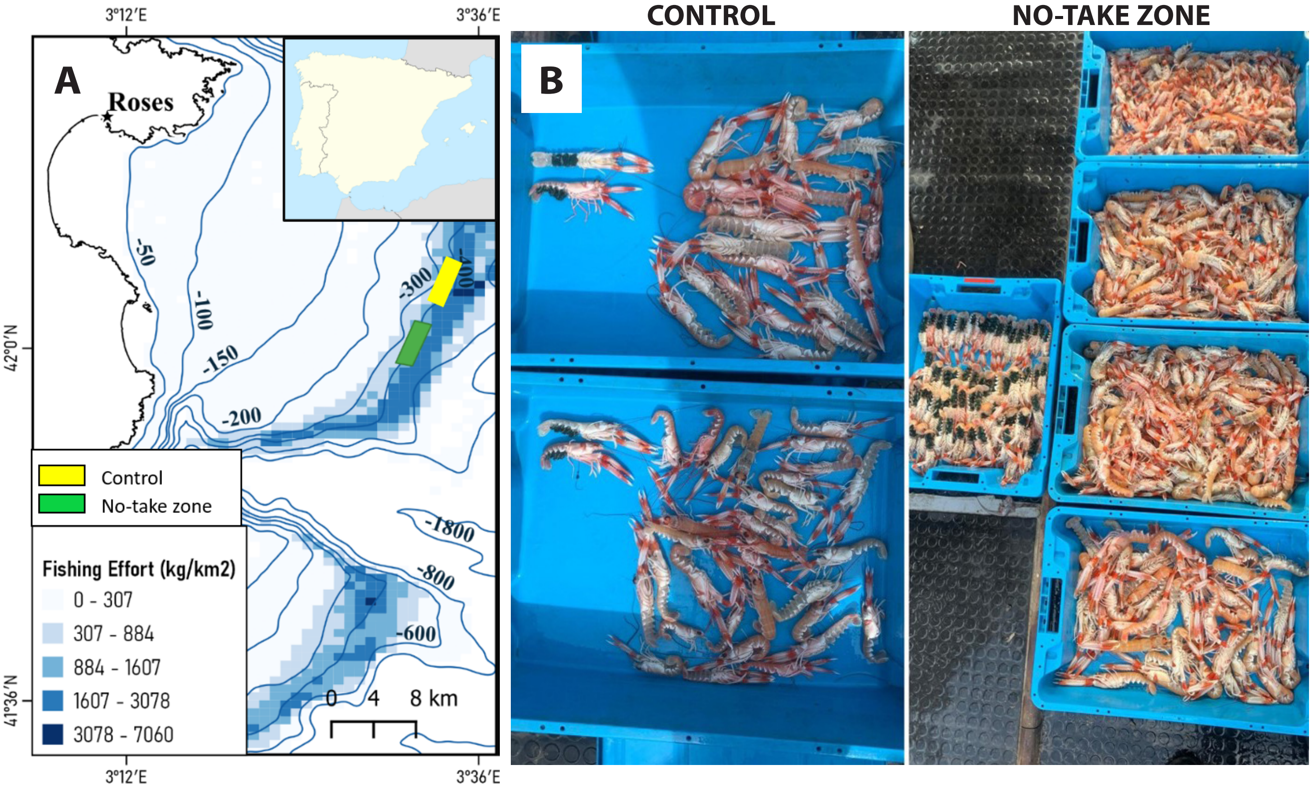

Figure 14. A: Experimental hauls carried out inside (green) and outside (yellow) of the closure area. B: Images of the total catch outside (left) and inside (right) the closure area. From Vigo et al. (2021).

Figure 15. ROV images of a regularly trawled bottom (left column) and of the closure area off Roses 2 and 3 years after closure (right column). Source: own data; submitted paper (Vigo et al.)

2.5 Conclusions on closure area effects as a management strategy

The protection of the three studied areas entailed an effective effort reduction inside them. Some fishing-the-line behavior may occur that has to be monitored in the coming years.

- The fishing effort reduction inside protected areas did not result in a redistribution of it in the areas surrounding. Protection did not imply an increased impact around the closed area.
- There is an effective spillover effect for *Mullus* spp, *Helicolenus dactylopterus*, *Argentina sphyraena, Triglidae* spp and *Lepidorhombus boscii*. After the protection LPUE increased and showed a negative gradient as distance increased from the MPA border. This confirms the capacity of established closed areas to sustain fishing stocks in the zone.
- It was not possible to confirm a spillover effect for *Merluccius merluccius, Nephrops norvegicus* and *Parapenaeus longirostris*. These species have a marked stock LPUE trends that are also affecting protected areas dynamics and therefore masking possible spillover effects underlying them.
- The methodology developed in this section is effective to detect spillover and effort redistribution effects and therefore is a good method to be applied in all other closure areas established with WMMAP. However, it has to be improved mainly in two aspects:
  - A data standardization should be applied in order to disentangle general stock LPUE trends and spillover effects around protected areas particularly for species with marked historical LPUE trends.
  - If possible, landings should be classified in size classes and therefore be able to detect potentially different protected areas effects for distinct species life stages.
- The methodology used in this section should be combined with non – invasive surveys inside protected areas to check for non – commercial sizes information and habitat restoration evidences.

3. Stock assessment exercises for the Northern GSA6

The first stock assessment results for the Northern GSA6 using data from the existing three years of the ICATMAR monitoring program have been recently published (ICATMAR, 22-05). The models used were data-resource limited (LBSPR, LBPA and LIME), with inputs of life history of the target species from STECF and GFCM reports and length data from ICATMAR. These models assume equilibrium in the population (constant mortality and recruitment) and thus lead to a qualitative advice. A later stage of the analysis will be focused on running models with local estimations.

An example of the data fit using ICATMAR data and the published data from the DCF is presented in Figure 16. Overall, all stocks studied (*M. barbatus*, *M. merluccius*, *P. longirostris*, *N. norvegicus*, and *A. antennatus*) were found to be overexploited and in overexploitation on a precautionary basis, as per reference to standard values of spawning potential ratio (SPR) and fishing mortality (F) relative to F_{target} (fishing mortality value on which the stock is exploited under a precautionary scenario, Fig. 17 and 18). However, results differ among species, and the selectivity curve is clearly closer to the maturity in the cases where the fishery is in consonance with the species biology, namely *A. antennatus* and *Mullus* spp., while in the other species the curves are more distant (Fig. 19). This is visible even in the case of the deep-water rose shrimp, a species in expansion in this area of the GSA6, but with no specific measures or co-management plans regulating the fishery.

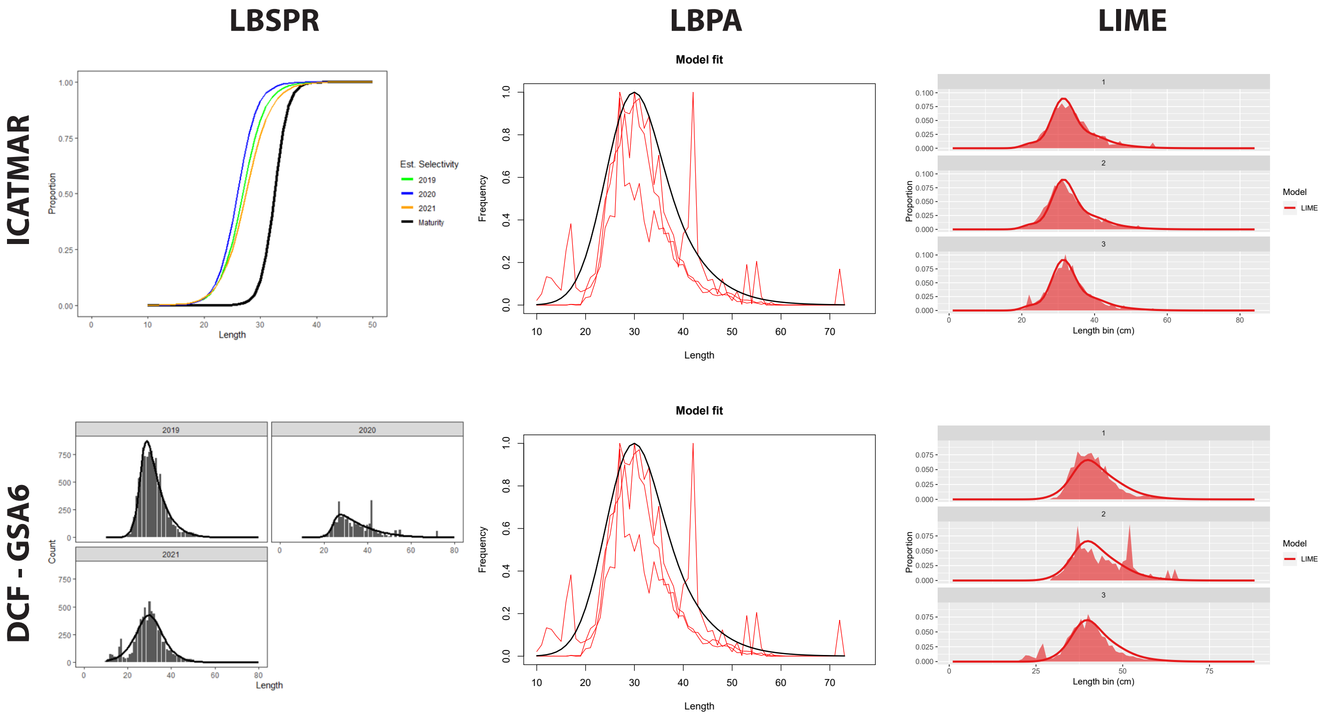

Figure 16. Example of data fit for Norway lobster with ICATMAR (top) and DCF (bottom) data for the three stock assessment models used. LBSPR: Length-Based Spawning Potential Ratio; LBPA: Length-Based Pseudo-cohort Analysis; LIME: Length-based integrated mixed effects. NOTE: further details on results for all MAP species are published in the ICATMAR Technical Report (ICATMAR, 22-05).

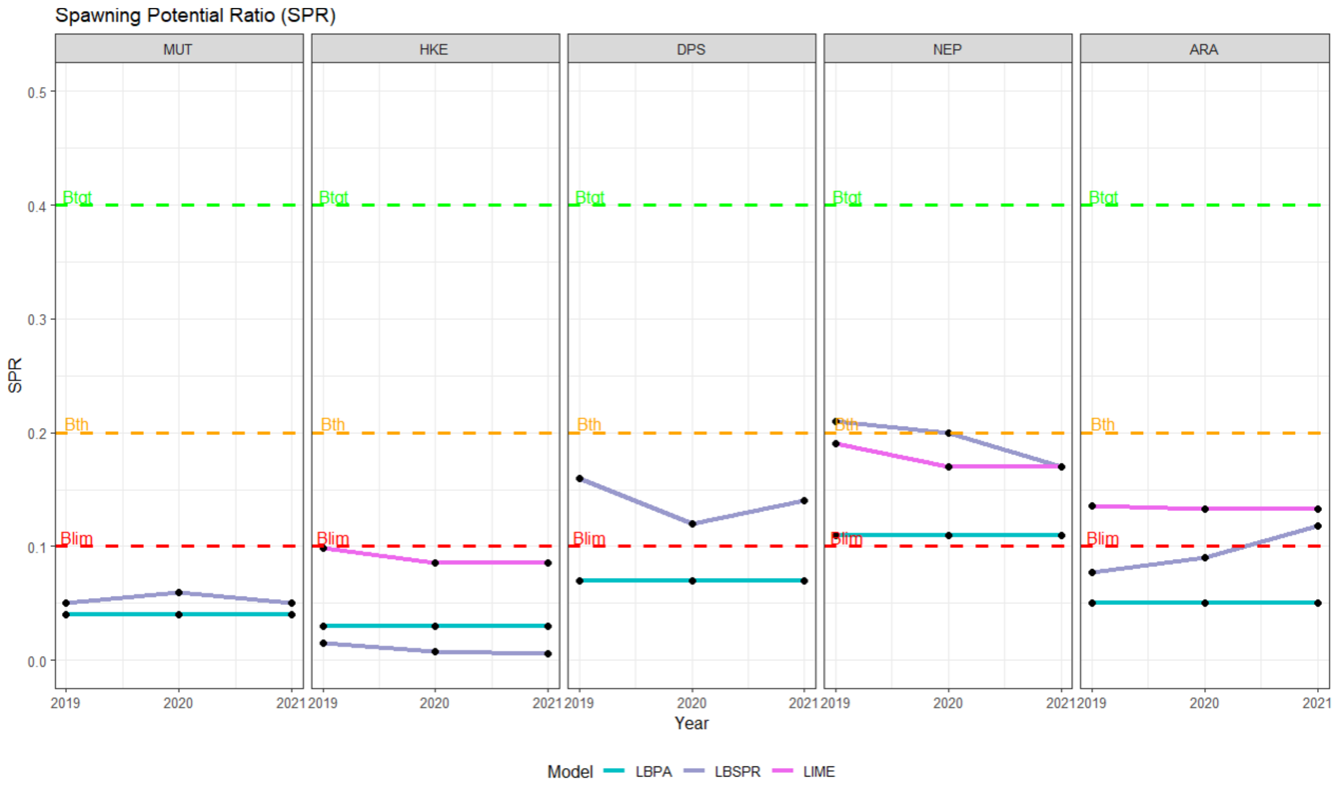

Figure 17. Spawning potential ratio (SPR) by year for the five stock evaluated with three models tested. MUT: red mullet, HKE: hake, DPS: Deep-water pink shrimp, NEP: norway lobster and ARA: blue and red shrimp. LBSPR; LBSPR: Length-Based Spawning Potential Ratio; LBPA: Length-Based Pseudo-cohort Analysis; LIME: Length-based integrated mixed effects. Btarget, Bthreshold and Blim are estimated values from empirical analysis, and thus no specific reference points are estimated for SPR by species.

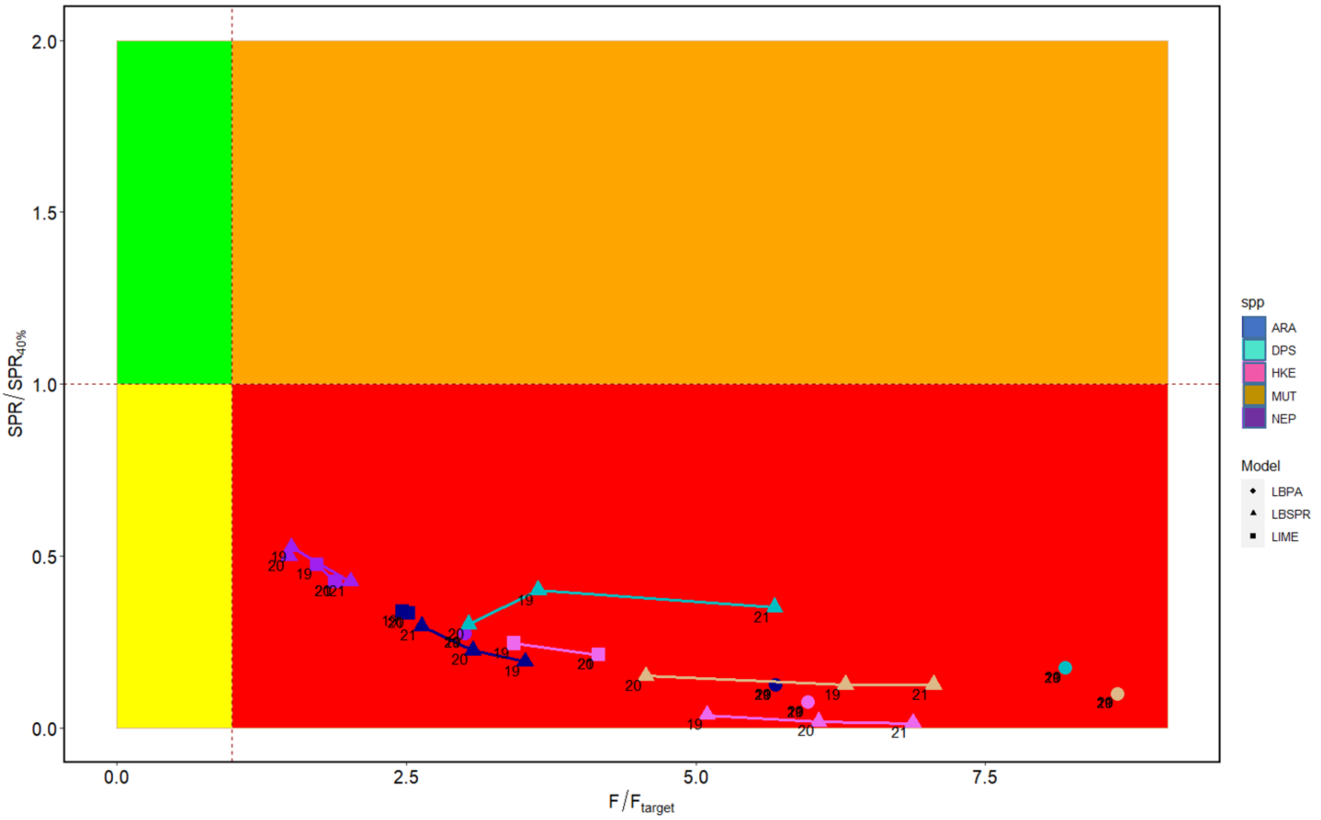

Figure 18. Kobeplot for the five stock evaluated with three models tested. Colours indicates the species tested. MUT: red mullet; HKE: European hake; DPS: Deep-water rose shrimp; NEP: Norway lobster; ARA: blue and red shrimp. Shape indicates the model tested. LBSPR: Length-Based Spawning Potential Ratio; LBPA: Length-Based Pseudo-cohort Analysis; LIME: Length-based integrated mixed effects. SPR: spawning potential ratio; SPR0.4: SPR with 40%; F: fishing mortality and Ftarget; fishing mortality of target species.

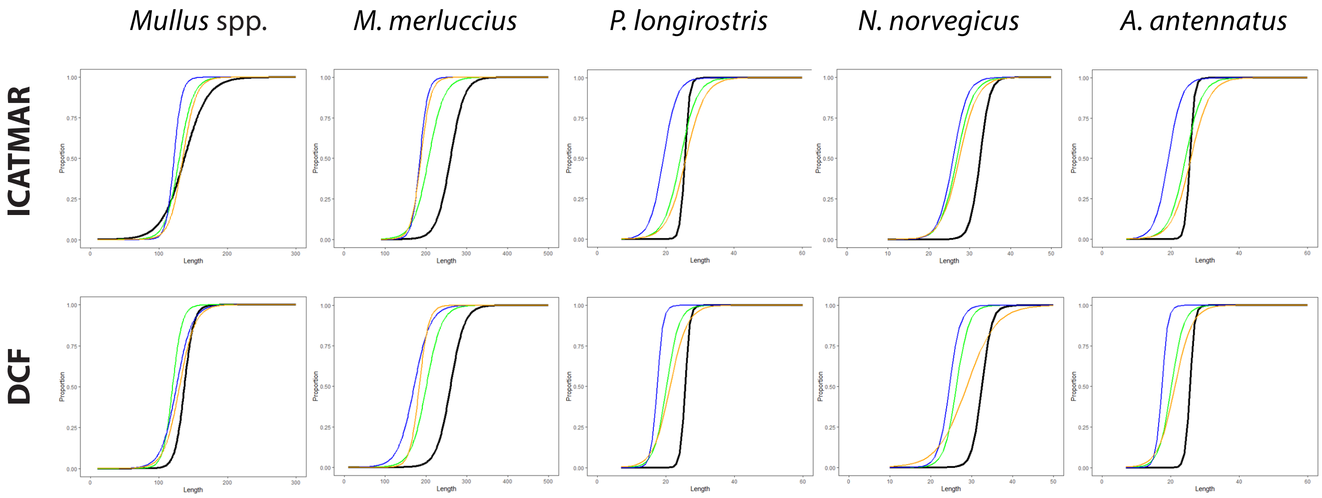

Figure 19. Length at maturity (black) and estimated selectivity outputs of the LBSPR model for 2019 (green), 2020 (blue), and 2021 (orange) for the studied species. Top line: ICATMAR data for the Northern GSA6; Bottom line: DCF data for the GSA6.

The following sections explore six theoretical scenarios using the European hake length frequency data from the GSA6 DCF for 2021 (provided by the General Secretariat of Fisheries of the Spanish government) as input to these same stock assessment models. This series of exercises seeks to observe the impact of changes in length data, namely through a modification of the gear selectivity, reducing the catch of small sizes, and through the inclusion of missing larger size classes. In both cases, an increase of the SPR is expected.

3.1. Modelling gear selectivity in stock assessment

Previous studies carried out in the Northern GSA6 showed that adopting selectivity measures that increase codend mesh size of bottom trawling gears can significantly reduce juvenile mortality (ICATMAR 21-05). In particular, for the species of concern in the WMMAP, an increase of codend mesh to 45 mm yielded juvenile catch reduction rates that were in line with the 15-25% values presented at the Statement of the Presidency published in December 2020. On this basis, the first theoretical exercise (Run 2, Fig. 20) uses a length frequency dataset that simulates a codend increase to 45 mm square as an input to the LBSPR model used in our analysis of the Catalan stocks (ICATMAR, 22-05).

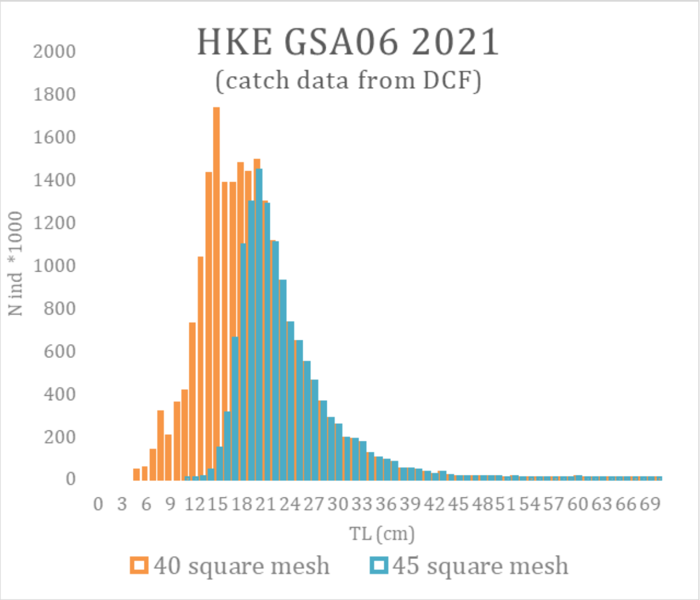

Figure 20. Catch length frequency distribution (LFD) in 2021 from GSA06 data for European hake (HKE). The orange bars represent the original dataset with a codend mesh size of 40 mm (from now on, Run 1). The blue bars represent the simulation of the LFD with a codend mesh size of 45 mm (from now on, Run 2).

As a result of this modification, the selectivity curve draws closer to the maturity curve, as would be desirable (Fig. 21), and the SPR slightly increases while the F value slightly decreases (Table 3).

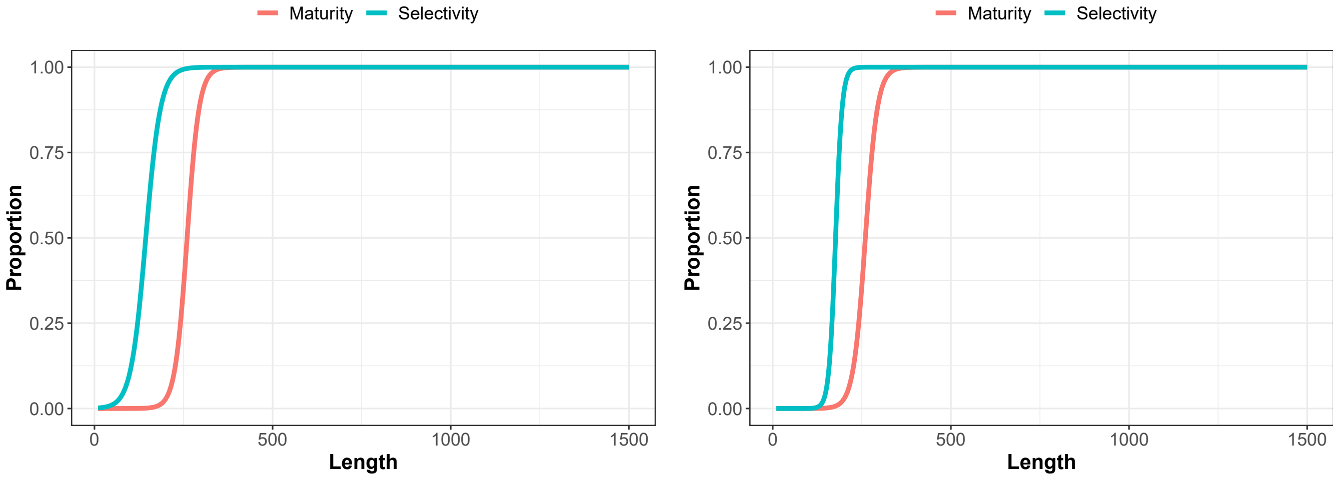

Figure 21. Red mullet length at maturity and estimated selectivity outputs by the LBSPR model. Left: original data (40 mm mesh size). Right: simulated 45 mm mesh size.

3.2. Simulating the supplementation of existing data for hake

For some species such as hake, on-board data are unequally available throughout all size classes. The bottom-trawling fleet misses the larger individuals, mainly the large reproductive females, and the Mediterranean longline fleet which catches them is sparse. Data on larger sizes are scarce, and as a result the length frequency distributions appear truncated. When large individuals are missing, but the input fed to the model still establishes L_{inf} (asymptotic maximum length) at 110 cm (Mellon-Duval et al., 2010) the model may assign higher values of F and lower values of SPR and results may be biased. In this exercise, larger sizes of *M. merluccius* have been added to the published dataset from the DCF in order to simulate changes in the length frequency distribution, preserving the simulation of a 45 mm mesh size in all cases.

In Runs 3, 4 and 5, the orginal length frequency distribution of the data was displaced so that the larger individuals corresponded to 80, 90 and 100 cm, respectively, instead of the original distribution where the largest individuals measured 70 cm (Fig. 22). F values progressively decrease while SPR increases, but both parameters only draw close to the desirable values in Run 5, when larger sizes are around 100 cm (Table 3).

In Runs 6 and 7, the original length frequency distribution was not displaced, but complemented with additional individuals, up to 70 and 90 cm, respectively, looking to modify the shape of the distribution to achieve the usual bell curve seen in non-truncated populations (Fig. 23). Similarly to Runs 3 to 5, the reaction of the model to this modification is clearly visible, and in Runs 6 and 7 the F values progressively decrease while SPR increases (Table 3).

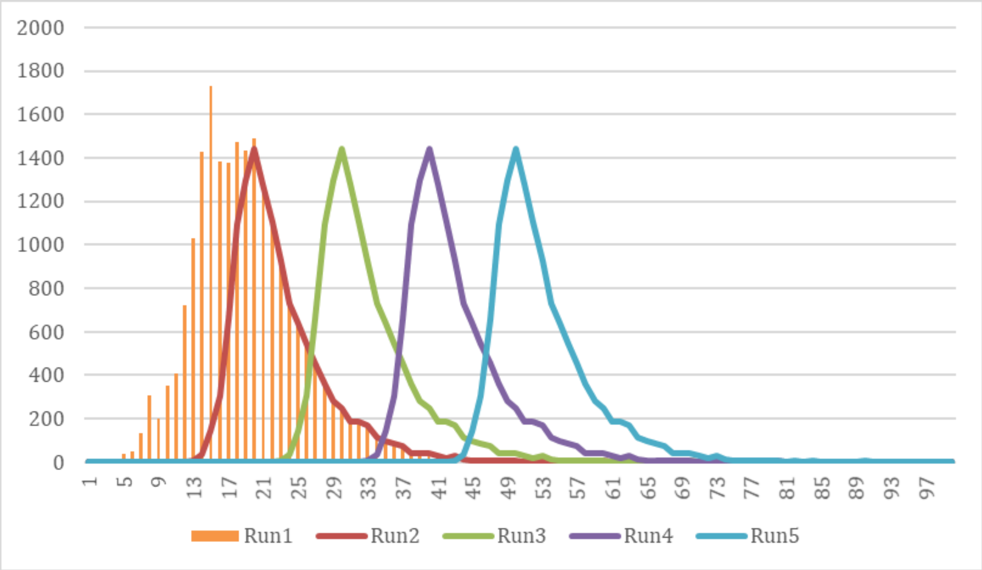

Figure 22. Comparison of length frequency distributions from GSA06 data for European hake. Run 1: original dataset for 2021, codend 40 mm; Run 2: original dataset for 2021, codend 45 mm; Runs 3 to 5: displaced LFD so that the largest individuals correspond to 80 cm (Run 3), 90 cm (Run 4), and 100 cm (Run 5), all of them with a simulated codend of 45 mm.

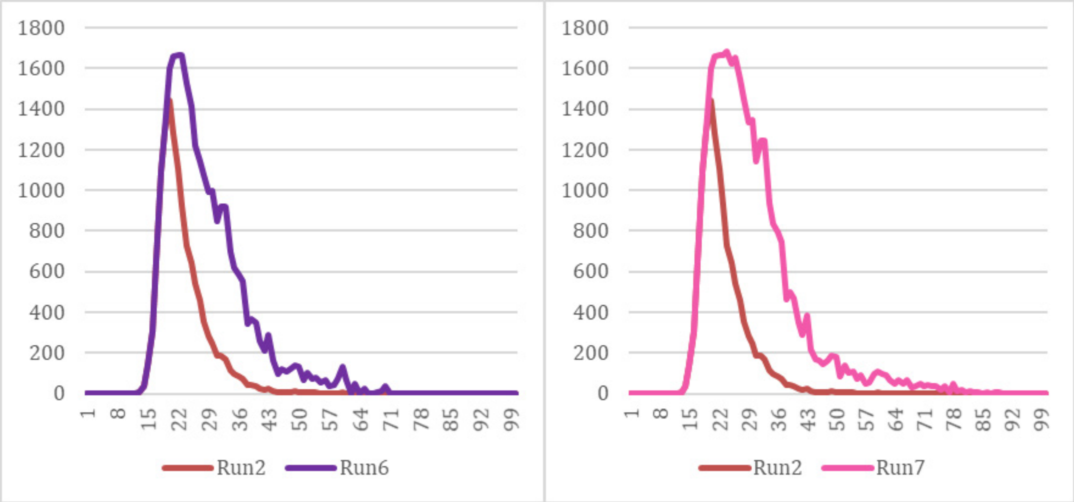

Figure 23. Comparison of length frequency distributions from GSA06 data for European hake. Run 2: original dataset for 2021, codend 45 mm; Run 6: dataset supplemented with individuals up to 70 cm total length: Run 7: dataset supplemented with individuals up to 90 cm total length

Table 3. Summary of the results of the stock assessment exercises.

	Scenarios	**SL50**	**SPR**	**F/M**
Run 1	70 cm + 40 mm mesh size	145.98	0.004	6.14
Run2	70 cm + 45 mm mesh size	177.21	0.006	6.12
Run3	80 cm + 45 mm mesh size	277.20	0.030	5.41
Run4	90 cm + 45 mm mesh size	377.04	0.094	4.71
Run5	100 cm + 45 mm mesh size	477.41	0.201	4.04
Run 6	Run2 + adults 70 cm	183.76	0.042	2.70
Run7	Run6 + adults 90cm	186.49	0.067	2.15

The length structure of the harvested stock is highly truncated, missing sizes higher than 70 cm (L_{inf} = 110). The reading of these exercises is that, in addition to reduce juvenile mortality, keeping large individuals at sea is paramount.

4. Summary

- ICATMAR biological sampling data are robust and reliable, comparable over the years, and appropriately reflect the existing variability at a local and seasonal scale.
- The monitoring program will allow to revisit the biological parameters of target species in order to better adjust stock assessment models.
- No effort redistribution was observed in the surrounding areas of closure areas, and there are clear evidences of both spillover and habitat recovery.
- ICATMAR stock assessment results are in line with those of the STECF report 22-09, providing support to management advice at a scale lower than GSA.
- Combined, the regulation of gear selectivity and the establishment of closure areas arise as a biologically centered management measure.

5. Other considerations

5.1. Additional measures for European hake and Norway lobster

Following the local-scale structure of the fishing sector in Catalonia, each port establishes different applications of management or cautionary measures. One example of this practice is the establishment of seasonal closures for the bottom trawling fleet, which typically have an extension of two months in central and northern ports and mainly take place during the winter months, when the blue and red shrimp *A. antennatus* recruitment at its maximum. In southern Catalonia, where this species is not present, the closure is established in spring summer months (Fig. 24). However, in the particular case of two species of the most concern in the WWMAP, the European hake and the Norway lobster, the data either published in literature or extracted from our monitoring program locate the reproductive periods when the fishing fleet is fully active, namely in the autumn months for the Norway lobster, and in autumn and winter for the European hake (Fig. 25). It would be advisable to adequate the established closure periods to the existing data on species reproductive seasons.

5.2. Factors besides fishing effort

When considering the management of fisheries, it is only reasonable that the first decisions concern fishing effort and its gradual reduction. However, the availability of a detailed, long-term series of data may shed light on other factors that play a key role in marine resource dynamics. For instance, the combination of landings and VMS data for the deep-water rose shrimp (*P. longirostris*) shows a gradual increase of the catches from 2009 to 2020 (Fig. 26), as it has in fact emerged as a new fishing resource in Catalan waters.

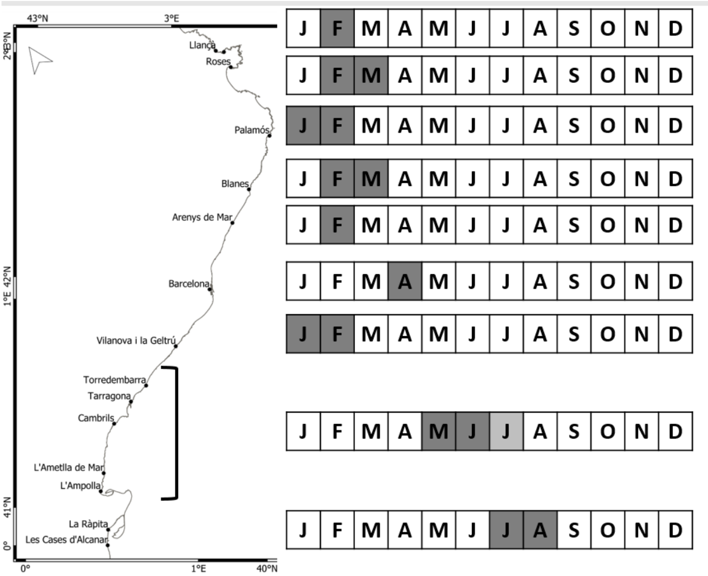

Figure 24. Seasonal closures along the Catalan coast.

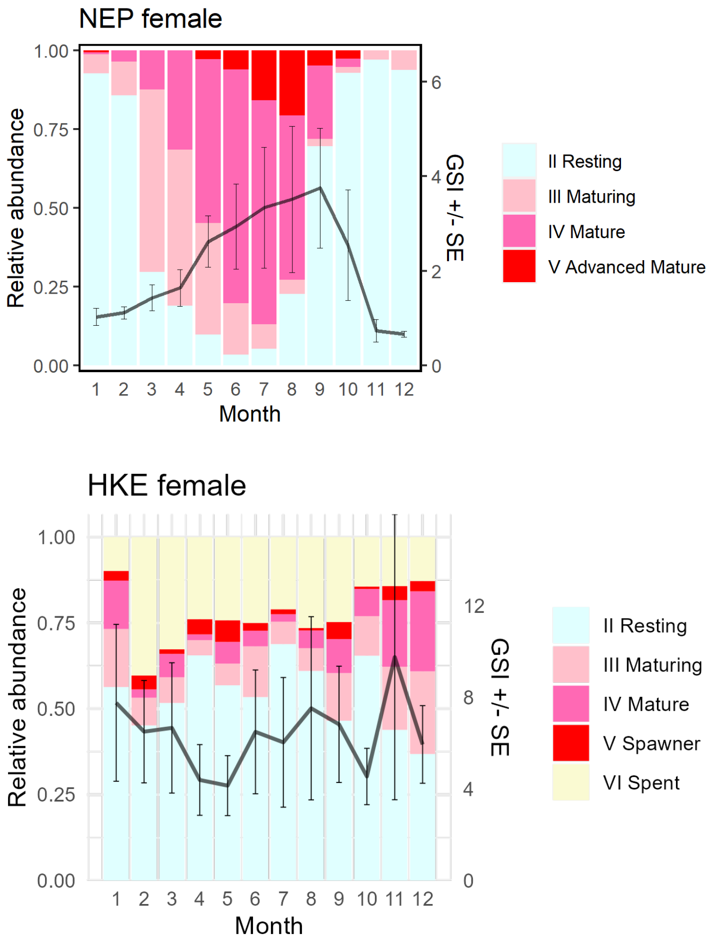

Figure 25. Monthly seasonal variation of female Norway lobster (top) and European hake (bottom) reproductive state and gonadosomatic index (ICATMAR, 22-04).

At the same time, and with the opposite trend, catches of Norway lobster have declined especially in years 2015 and 2016, with full time-overlapping of incresing landings of deep-water rose shrimp (Fig. 27). Both species are distributed in very similar fishing grounds (in terms of bottom characteristics and depth ranges), and so it is not clear that the only cause for this shift in ecosystem dynamics is the fishing activity. It is plausible that it is related to changes in habitat and/or environmental conditions, or to interactions between both species.

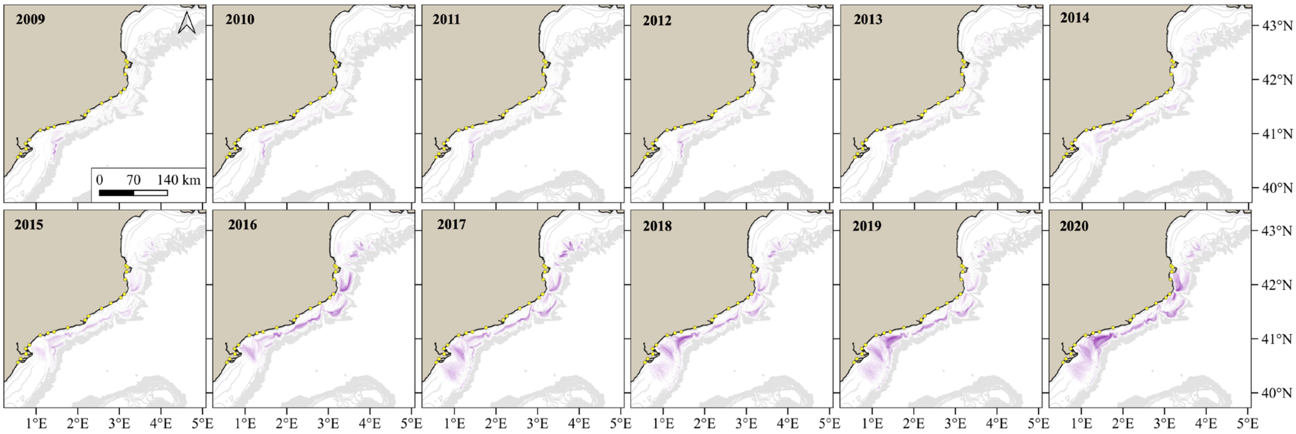

Figure 26. Spatial distribution of landings of deep-water rose shrimp (*P. longirostris*) in the Northern GSA6 from 2009 to 2020. NOTE: see how in 2016 the landings increased to 250 kg/km^2 in some areas of the Catalan coast, being almost zero between years 2009 and 2014. In 2020, the landings increased up to 400 kg/km^2.

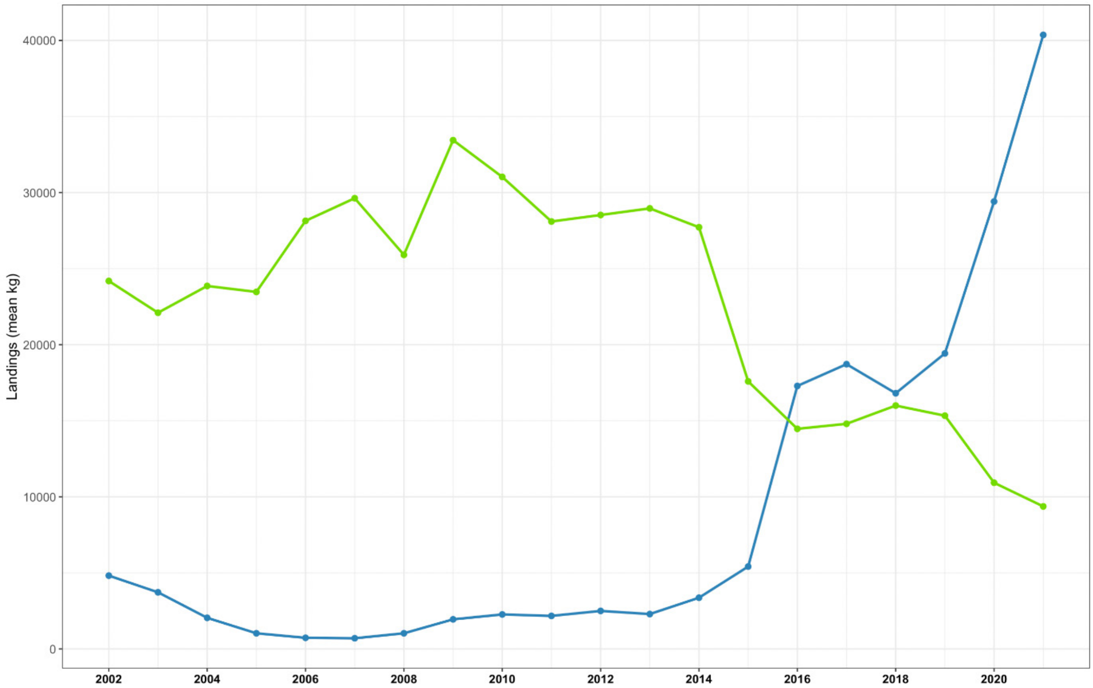

Figure 27. Historical series of landings data for deep-water rose shrimp (blue) and Norway lobster (green) in the Northern GSA6.

A different case concerns the historical series of catches for hake, where the general trend is periodically truncated in years where regulation changes have been applied (Fig. 28). For example, in 1994 the usual 35 mm diamond mesh with 6 mm tick was changed to 40 mm diamond mesh with 5mm tick, and in 2009 to 2011 the regulation changed to establish a 3mm tick and a 40 mm square codend mesh size, and a Minimum Conservation Reference Size (MCRS) of 20 mm total length. Progressively, since 2011, auctions prohibited the selling of European hake individulas below the MCRS. As a consequence, the modal length of the catches between 1988 and 1991 was 8-9 cm total length (Aldebert et al., 1993; Recasens et al, 1998), while in 2021 this value was 13-14 cm total length (ICATMAR, 22-04; Fig. 29).

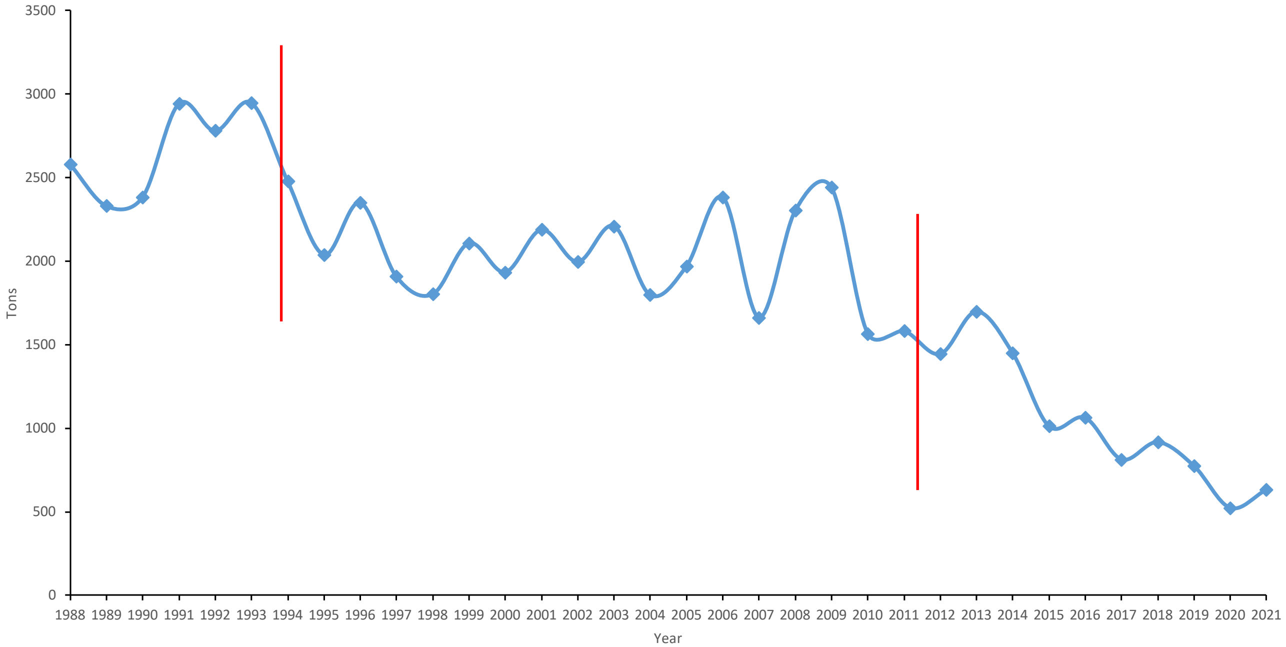

Figure 28. Historical series of landings data for the European hake in the Northern GSA6. Red lines indicate changes in gear or regulations. NOTE: the decrease in landings is not only related to species biological status, but can also be an artifact of the historical reported landings on each auction.

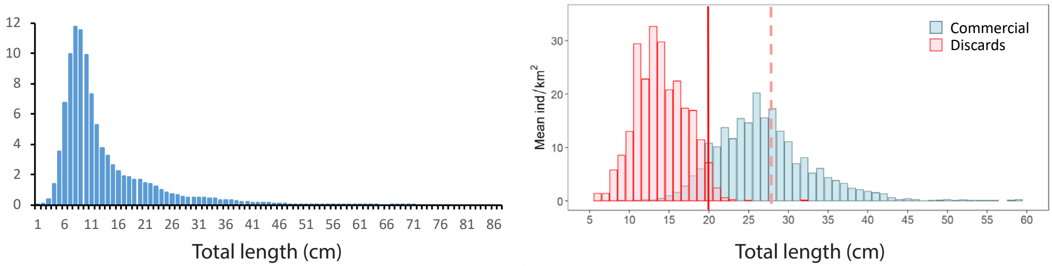

Figure 29. Length frequency distribution for European hake from 1988 to 1991 (left; Aldebert et al., 1993; Recasens et al, 1998) and in 2021 (right). Red line indicates minimum legal size, dotted line indicates size at first maturity.

6. Fisheries management advice

Besides the reduction in fishing effort (in days) that has been enforced up to date through WMMAP regulation, we advice that the following fisheries management measures be taken into consideration as a compensation mechanism:

- Implementing the regulation of gear selectivity to Increase mesh size, namely to 45 mm in coastal fisheries and 50 mm in deep-sea fisheries.
- Monitoring the spatial permanent closures to follow the effect on fishing stocks status and ecosytem recovery. Maintain the promotion of new closure areas.
- Matching seasonal closures with target species biological traits, in order to better protect reproductive individuals and their spawn.

It is worth pointing out that under the current management strategy, i.e. enforcing a gradual reduction of fishing days and/or increasing MCRS but not regulating gear selectivity, the mortality of juveniles will remain unchanged, as will the discard proportion of the catch (Blanco et al., 2022).

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Annexes

Table A1. Kolmogorov-Smirnoff distances (Ds) between length frequency distribution data by A) year, B) season, and C) zone. Asterisks indicate level of significance: * p < 0.05; ** p < 0.01; *** p < 0.001.

	HKE	ARA	NEP
2019 vs 2020	0.237***	0.073	0.038
2019 vs 2021	0.314	0.139	0.035
2020 vs 2021	0.124	0.073	0.012

B	HKE	ARA	NEP
Autumn vs Spring	0.337**	0.109	0.133
Autumn vs Summer	0.345*	0.291***	0.103
Autumn vs Winter	0.119	0.087	0.070
Spring vs Summer	0.256	0.238**	0.041
Summer vs Winter	0.335	0.257*	0.059

C	HKE	ARA	NEP
Center vs North	0.169	0.181***	0.058
Center vs South	0.227	0.139	0.342***
North vs South	0.171	0.300**	0.312***

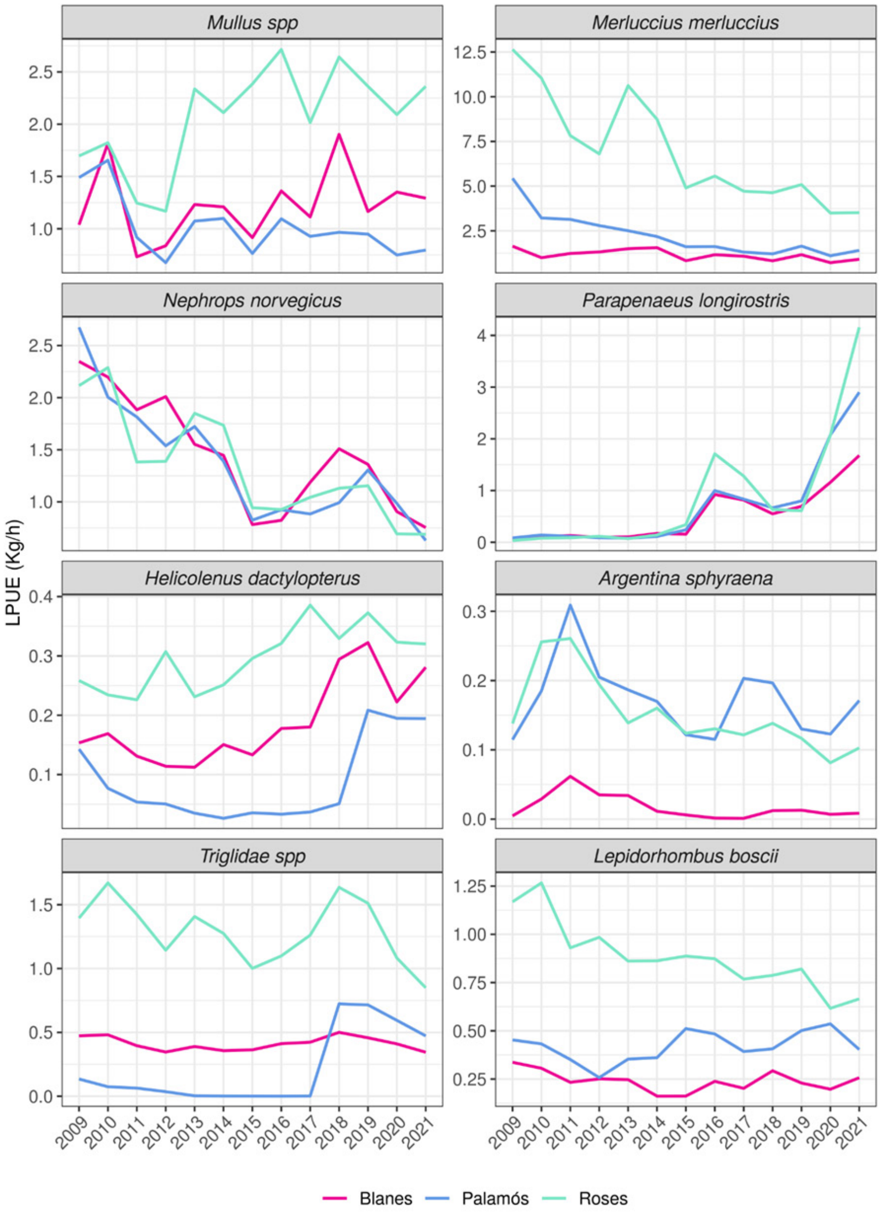

Figure A1. General fleet LPUE trends for all studied species. Overall landings and fishing time for all vessels with base port Roses, Palamós and Blanes are taken into account as these are the fleets operating in the protected areas surroundings.