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Spatial WMMAP fishing closures effectiveness in GSA 6

Effort reduction, redistribution and spillover effect

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

CSIC
Consejo Superior de Investigaciones Científicas

Institut de Ciències del Mar

This report presents the analysis of the spatial WMMAP fishing closure areas in the GSA 6. Part 1 describes the effects of the closures in fishing activities, and part 2 describes their effects on the benthic communities.

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How to cite this document
Institut Català de Recerca per a la Governança del Mar (ICATMAR). Spatial WMMAP fishing closures effectiveness in GSA 6, Effort reduction, redistribution and spillover effect (ICATMAR, 23-06) 61 pp, Barcelona. DOI: 10.57645/10.8080.05.9

Image credits:
Front page (Marta Blanco), introduction (Marta Blanco), part 1 (Ricardo Santos), part 2 (project LIFE-ECOREST, Reference: LIFE20 NAT/ES/001270).

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Executive summary

Between 2014 and 2021, a total of 27 closure areas have been established in the GSA 6 (Spanish Mediterranean coast), 23 of which are permanent and 4 temporary, with different fisheries and ecological conservation objectives (e.g. protecting European hake juveniles, Norway lobster habitat recovery). The effects of a closure area are not straightforward and depend on various variables, such as area size, time since protection, species mobility and biology, habitat continuity, the presence of a buffer zone, or fishing surveillance.

This report aims at developing the first steps towards the implementation of a monitoring for all closure areas within the GSA 6 in order to evaluate the fishing effort trends, effort redistribution and spillover effects after the establishment of the closures. The first section of this report uses fisheries data to evaluate before and after protection changes in fishing yields and effort around protected areas. In the second section, we present some preliminary material from a recent cruise using Remotely Operated Vehicle (ROV) imaging inside and outside some of the protected areas.

Our results show an overall reduction of the fishing effort in both permanent and temporary closure areas after protection. In the case of temporary areas, fishing effort values do indeed decrease during the closing period, but this does not translate into an effective reduction in the yearly effort in the area. This reduction of the fishing effort inside the protected areas is not related with a redistribution of the fishing effort on the surrounding areas. We found spillover evidence in 6 out of 13 analyzed species, with the first spillover evidence detected between 1 and 3 years after protection and stabilizing after at least 5 years of protection.

As for data from ROV imaging, the trawl marks and plowed bottoms are visible in control areas where no protection is applied. In general, the ecological succession of the benthic community starts with the return of mobile species such as fish and small crustaceans, then sessile organisms that structure the habitat for different commercial species. The seabed is progressively restored from plowed ground to a smooth surface as the trawl marks are erased, then to tridimensional structures with an abundance of burrows and slow-growing sessile species such as soft corals.

In conclusion, our data show that permanent closures are more efficient in reducing yearly fishing effort than temporary closures and therefore more suitable for promoting habitat recovery and generating a spillover effect. The establishment of the closures is not related to a redistribution of the fishing effort to adjacent areas, and spillover effect differs among species groups. The preliminary data on habitat recovery show positive results over all areas, even after a short period of time.

Introduction

Spatial management in the GSA 6

Established closure areas in the Spanish Mediterranean after WMMAP

In June 2019, the Western Mediterranean Multiannual Plan (WMMAP) was published including various measures to manage the bottom trawling fishery (Regulation (EU) 2019/1022). Specifically, its article 11 established that spatial closures must be adopted by member states to regulate trawling activity. Article 11.1 stated that a three-month closure should be implemented within six nautical miles from the coast, except in areas deeper than 100 m. By repeal of 11.1, article 11.2 stated that member states could establish other closure areas that provide a reduction of 20% in hake juvenile catches. Finally, Article 11.3 established that member states should create other closure areas in spawning grounds or in areas where there is evidence of high concentration of juvenile individuals below Minimum Conservation Reference Size (MCRS), particularly for the stocks concerned in WWMAP: hake (*Merluccius merluccius*), deep-sea blue and red shrimp (*Aristeus antennatus*), mullet (*Mullus* spp.), deep-water rose shrimp (*Parapenaeus longirostris*) and the giant red shrimp (*Aristeomorpha foliacea*). At a later stage, Article 11.3 was modified according to the joint statement by France and Spain in December 2020 (European Council, statement 5415/1/21 Rev1) to state that the additional closures should result in a reduction of between 15% and 25% in the catch of juveniles and spawners of each stock covered by the WMMAP. The WMMAP did not specify where 11.2 and 11.3 areas should be placed, nor whether areas should be temporarily or permanently closed, and left these aspects to be based on the best available scientific advice. As a consequence, different strategies were adopted by different member states and geographical subareas (GSAs).

In the Spanish Mediterranean Sea, Article 11.1 was repealed 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.

Expected effects after spatial closure

Previous studies have shown that the establishment of a closure area does not reduce the general effort of the fleet operating in it; instead, the effort is expected to redistribute throughout adjacent areas (Cabral et al., 2017). For this reason, we did not expect that establishing closures would reduce the overall commercial species juvenile mortality. However, even if the stated conditions in WMMAP article 11.3 will not probably 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).

The establishment of closure areas is a management tool geared towards enhancing biodiversity and habitat conservation (Gell & Roberts, 2003). Closure areas have also been predicted to have a benefit on the adjacent fisheries through two main factors: the emigration of adults and juvenile individuals to zones where fishing is allowed, known as “spillover effect” (Rowley, 1994; di Lorenzo et al., 2016), and the exportation of pelagic eggs and larvae from the spawning stocks inside MPA (Gell & Roberts, 2003).

Potentially, spillover can contribute to sustain local fisheries. The mechanisms underlying the presence of spillover effects may not be the same in all cases (di Lorenzo et al., 2016) and should be considered either for marine spatial planning or closure area evaluations. After the protection of an area, both density-dependent and -independent effects are expected (di Lorenzo et al., 2016). Species abundances may increase within its boundaries as a consequence of habitat restoration, and in turn, intraspecific competition would increase, which would trigger species to cross closure area borders. On the other hand, the density-independent spillover effects may derive from home range movements, ontogenetic mobility changes and seasonal reproductive migrations (di Lorenzo et al., 2016). Under this framework, it is necessary to stress that permanent protected areas would probably allow a more complex ecosystem restoration and therefore the theoretical chances to positively affect fishing stocks would be higher for permanent than for temporary closed areas.

The effects of a closure area are not straightforward and depend on various variables (di Lorenzo et al., 2020; Edgar et al., 2014), such as area size, time since protection, species mobility and biology, habitat continuity, the presence of a buffer zone, or fishing surveillance. WMMAP closure areas in the Spanish Mediterranean have a vast diversity of sizes, closures regimes and habitat/depths, moreover, there is a large list of commercial species that could be affected by these management measures.

Objectives

Developing robust, replicable and long-term planned monitoring strategies is crucial to assess closure area effects and disentangle the reasons why positive effects for fisheries may or may not appear. This report aims at developing the first steps towards the implementation of a monitoring for all closure areas within the GSA 6 in order to evaluate the fishing effort trends, effort redistribution and spillover effects after the establishment of the closures.

The first section of this report uses fisheries data to evaluate before and after protection changes in fishing yields and effort around protected areas similarly to Sala-Coromina et al., 2021. In the second section, we present some preliminary material from a recent cruise using Remotely Operated Vehicle (ROV) and Autonomous Underwater Vehicle (AUV) imaging inside and outside some of the protected areas.

PART 1
Effects in fishing activities

Methodology

Study area

A total of 27 closure areas have been established in the GSA 6 (Spanish Mediterranean coast), 23 of which are permanent and 4 temporary (Figure 1), with different fisheries and ecological conservation objectives, detailed in Table 1.

Most areas were only officially declared during 2021 and 2022, but three of them (numbers 1, 2, and 8) have been closed to fishing activity for several years and allow for a more thorough analysis of the effects of the protection. These three 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 hake juveniles.

Palamós area (330-450 m depth): permanently closed in 2017 targeting the protection of *Nephrops norvegicus* populations.

Blanes area (170-260 m depth): permanently closed in 2013 targeting the protection of various fish species.

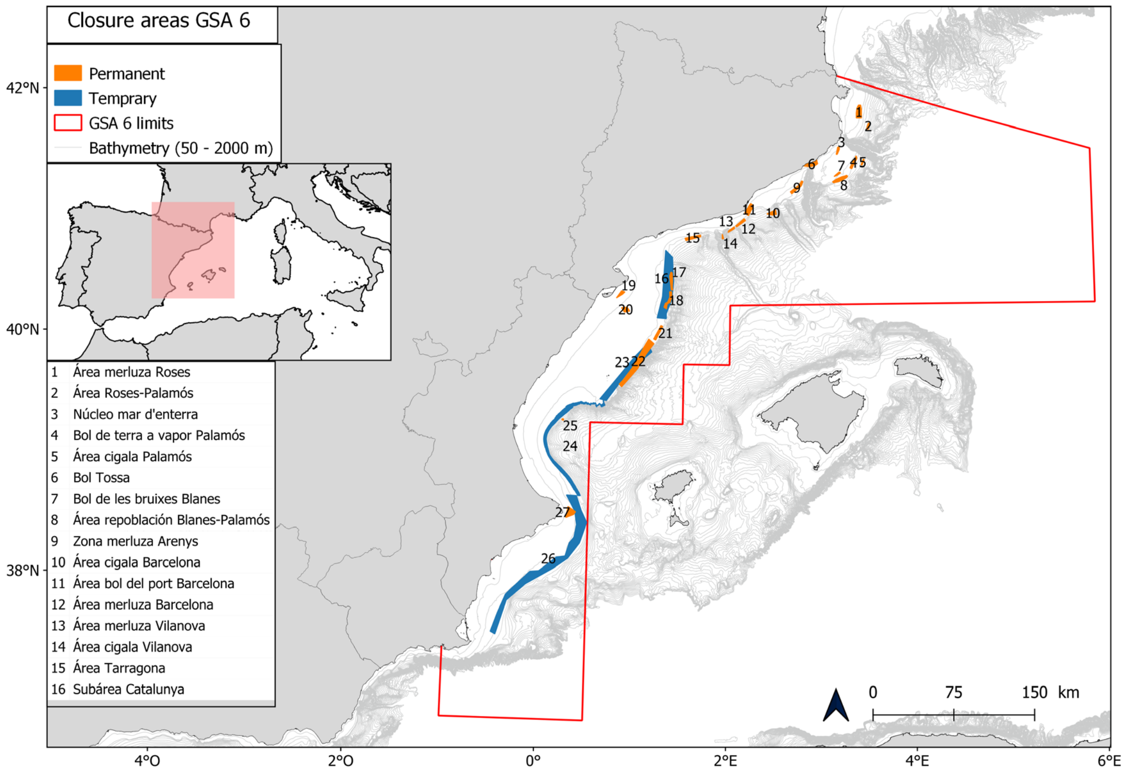


Figure 1. Closure areas in the GSA 6.

Table 1. information on closure areas in the GSA 6. Primary objective indicates the main protection aim and secondary objective indicates complementary aims.

Num	Name	Type of protection	Clousing year	Primary objective	Secundary objective
1	Área merluza Roses	Permanent	2013	HKE recruitment	MUT spawning
2	Área Roses-Palamós	Permanent	2017	NEP habitat	DPS spawning
3	Núcleo mar d'enterra	Permanent	2021	MUT habitat	HKE recruitment
4	Bol de terra a vapor Palamós	Permanent	2021	HKE recruitment	MUT spawning
5	Área cigala Palamós	Permanent	2021	NEP habitat	DPS spawning
6	Bol Tossa	Permanent	2021	MUT recruitment	
7	Bol de les bruixes Blanes	Permanent	2021	HKE recruitment	DPS recruitment
8	Área repoblación Blanes-Palamós	Permanent	2017	MUT spawning	Shelf habitat recovery
9	Zona merluza Arenys	Permanent	2021	HKE recruitment	
10	Área cigala Barcelona	Permanent	2021	NEP habitat	DPS spawning
11	Área bol del port Barcelona	Permanent	2021	MUT recruitment	
12	Área merluza Barcelona	Permanent	2021	HKE recruitment	
13	Área merluza Vilanova	Permanent	2021	HKE recruitment	
14	Área cigala Vilanova	Permanent	2021	NEP habitat	DPS spawning
15	Área Tarragona	Permanent	2021	HKE recruitment	
16	Subárea Catalunya	Temporary (May - June)	2021	HKE recruitment	
17	Zona Cambrils	Permanent	2021	HKE recruitment	
18	Zona l'Ametlla	Permanent	2021	HKE recruitment	
19	Zona exclusión la Ràpita	Permanent	2021	MUT recruitment	
20	Área Barques la Ràpita	Permanent	2021	Shelf habitat recovery	
21	Zona fora la Ràpita	Permanent	2021	HKE recruitment	
22	Veda permanente Castelló	Permanent	2021	HKE recruitment	
23	Subárea Castelló	Temporary (May - September)	2021	HKE recruitment	
24	Subárea Valencia	Temporary (May - September)	2021	HKE recruitment	
25	Área les Moletes	Permanent	2021	Habitat recovery	
26	Subárea Alicante	Temporary (June - August)	2021	HKE recruitment	
27	Roca dels Felius	Permanent	2021	HKE recruitment	Habitat recovery

Methodology

There are a variety of methods to evaluate spillover effects derived from the establishment of a closure area. (di Lorenzo et al., 2016), after reviewing the literature evaluating spillover, described three main data sources used: species tag and recapture methods, underwater visual census and fisheries catch data. Studies using the last two data sources were centered on the evaluation of density/biomass patterns across closure area borders. In general, the presence of a negative biomass/abundance gradient from the inside of the closure area to its surrounding areas is considered a proof of spillover. It is important to consider that, in order to correctly evaluate closure area performance, a BACI (before-after-control-impacts) approach should be used that combines data gathered both inside and outside the closure area. This approach allows linking a potential increase in abundances inside the closure area with the protection effect and potential gradients across area borders with the abundance increases inside the area.

For the analysis of fisheries data, information on georeferenced catch data and fishing time was needed. For this purpose, Vessel Monitoring System (VMS) data was analyzed together with the landings dataset. For data processing, a similar protocol described in (Sala-Coromina et al., 2021) was applied. First, VMS data was cleaned of duplicated and on-land points. Then, ping series corresponding to the same vessel tracks were identified with a unique track code, unique for each fishing trip (day and vessel). The result data was introduced in a PostgreSQL-PostGIS database for further treatment. Since there is no distinction between vessels fishing or inactive, we applied a speed filter to VMS data between 1.5 and 4.5 knots that included the speed range for trawling while excluding the steaming and inactive moments. Then, the total fishing time (hours) was calculated for each filtered track. Although interpolation has become a standard procedure when working with VMS data (Hintzen 2010 , Russo 2011), in this case we have decided not to interpolate the data to preserve the accuracy and precision of the location of the VMS signals. Interpolated data would inevitably result in additional VMS positions that might fall inside the protected areas, thus corrupting the results of this analysis.

The trawling activity in the zone is characterized by daily fishing trips and sales in auction. Therefore, the landings dataset includes information of landed species biomass by species, vessel and day. The fishing VMS positions dataset was combined with the landings dataset through shared track codes by each fishing trip. In this way, total fishing time, landings and revenues by species were distributed equally among all fishing positions by fishing trip.

The analysis of closed areas effectiveness was based on the evaluation of fishing timeand Landings Per Unit Effort (LPUE) before and after the protection around protected areas. First, we evaluated whether there was an actual decrease of the fishing effort inside protected areas after closure for all GSA6 closure areas (*Table 1*). Second, for the three oldest protected areas (areas number 1, 2 and 8, *Table 1*) we checked if the fishing effort redistributed around the protected area after the closure and third, we evaluated, for the same three areas, the LPUE changes for commercial species. A first analysis was done including the species concerned by WMMAP: *Merluccius merluccius, Nephrops norvegicus, Mullus barbatus* and *Parapenaeus longirostris. M. barbatus* could not be evaluated as an independent species as landings data do not correctly discern between this species and *Mullus surmuletus*, both species were analyzed together (*Mullus* spp).

Besides the species of concern in the WMMAP, eight other species were analyzed for spillover effects. Fish species were chosen considering two criteria: species must have a commercial value and must belong to different functional groups (see. Tuset 2021). Moreover, *Eledone* spp. was analyzed as representative of the cephalopod group.

Epibenthic species

Flat fishes: *Lepidorhombus* spp

Oblong fishes: Triglidae spp, *Helicolenus dactylopterus*, *Scorpaena* spp and *Lophius* spp

Benthopelagic species

Oval shaped: *Zeus faber*

Anguilliform: *Conger conger*

Effort redistribution and spillover analysis were performed usingan experimental design based in buffer areas around the closure, allowing for the detection not only of changes in fishing yield patterns around the protected areas, but also of gradients that may appear as distance to the closure area border increases. A 5000 m-wide buffer ring around the protected area was evaluated, divided in five concentric sections: two 500 m wide rings immediately adjacent to the closed area, two intermediate 1000 m wide rings and an external 2000 m wide ring (Figure 2).

For comparison of the data before and after protection, a transition period has been defined corresponding to the year of publication of the protected area in the official regulations. This has been done to preserve the yearly frequency of the calculations while at the same time isolating the period when the official protection may have started mid-year.

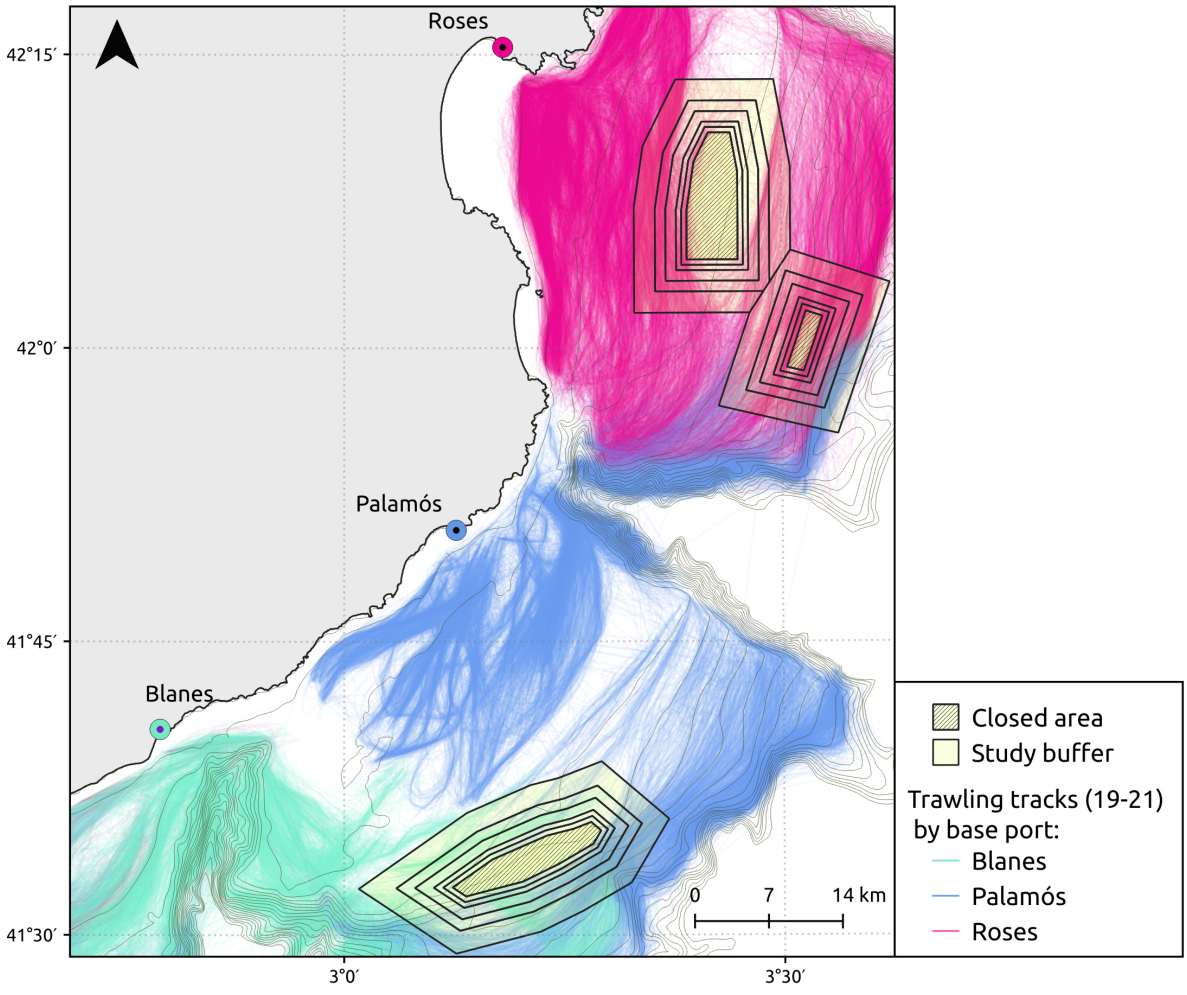


Figure 2. Example of buffer areas design shown around three closure areas. Colored lines represent the bottom trawling fishing tracks (from VMS data) of three ports near the areas: 1 (pink), 2 (blue) and 8 (green).

Results

Effort reduction

A summary of the results in effort reduction is shown in Figure 3. Overall, there is a reduction of the fishing effort in both permanent and temporary closure areas after protection. In the case of temporary areas, fishing effort values do indeed decrease during the closing period, but this does not translate into an effective reduction in the overall yearly effort in the area (Figure 4). Our results show that the fleet is fishing more intensively inside the temporary areas during the open periods than before the establishment of the closures.

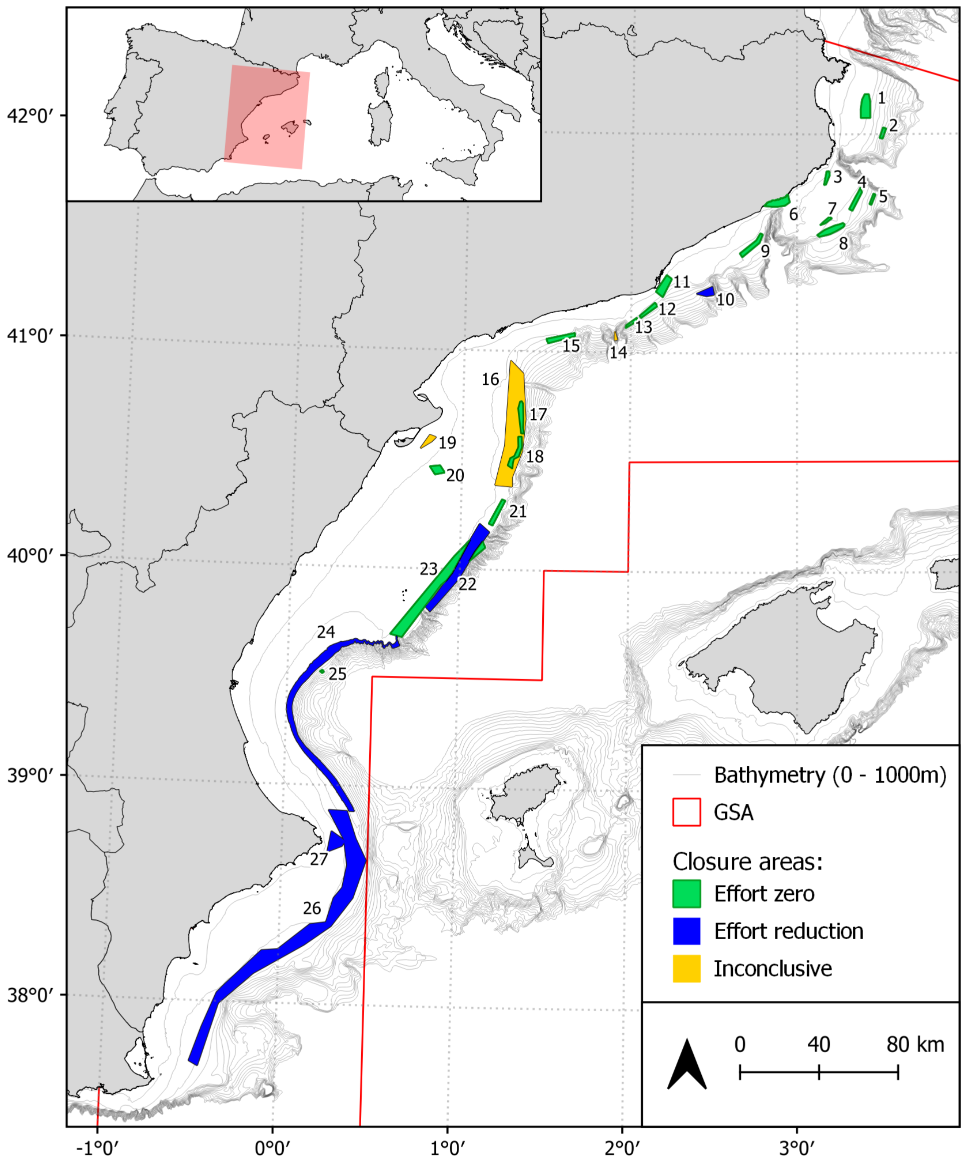


Figure 3. Effort reduction results summary in closure areas in the GSA 6. Effort zero indicates areas with no fishing effort after the protection (green), effort reduction indicates areas where the effort has been reduced after the protection but not achieving zero (blue) and inconclusive indicates areas with no clear trend in results (yellow).

Concerning the transition years of the areas (year of the publication of the fishing ban in official regulation), fishing effort values decrease only in the case of temporary closures, and not in the permanent closures. This may be explained because for temporary closures, we are only analyzing a period of the year, and it is more likely that a reduction in effort be observed in that specific period even if the closure was established that same year.

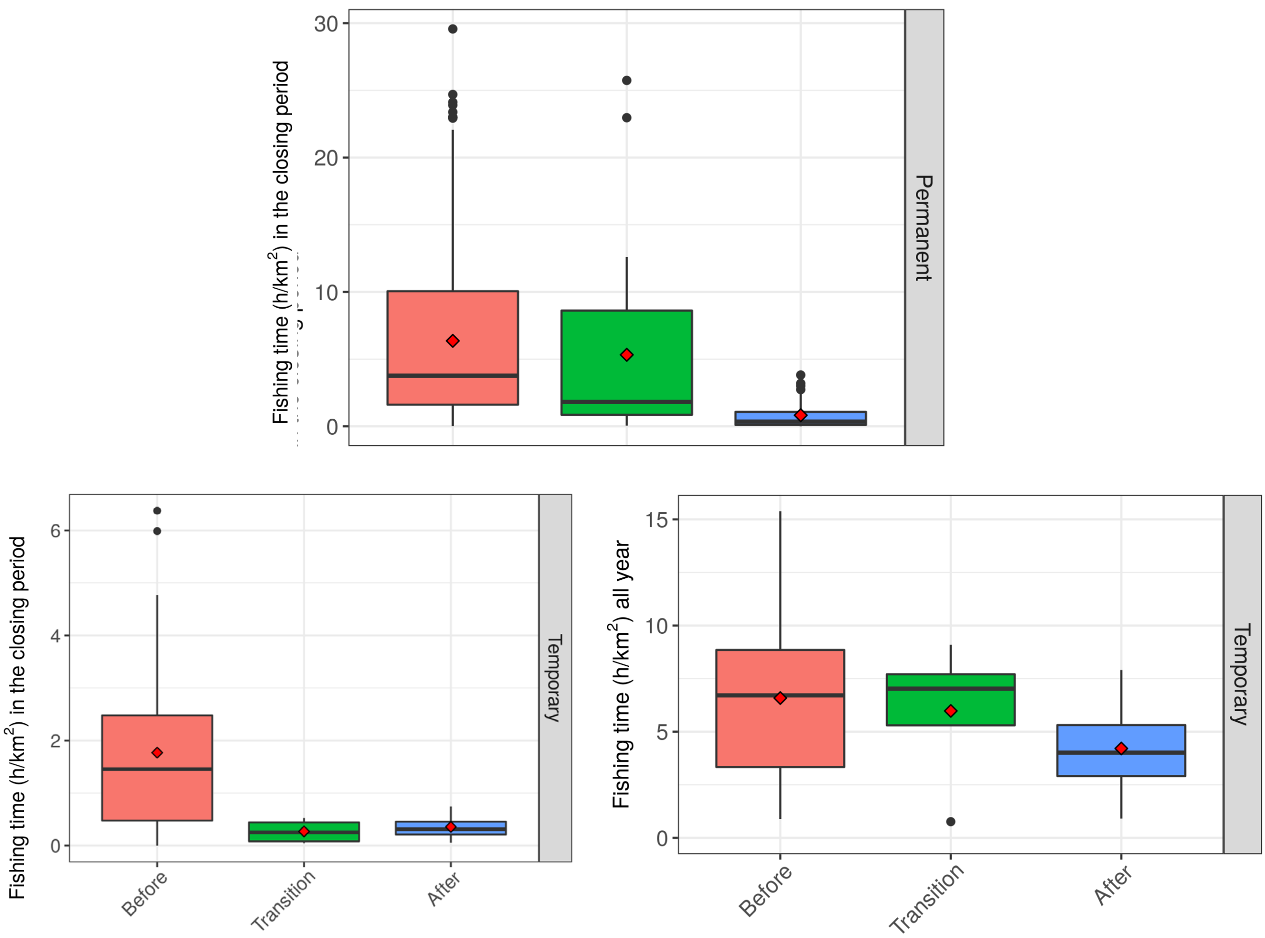


Figure 4. Effort reduction in all closure areas in the GSA6. For temporary areas, left panels show the effort corresponding only to the closing period (spring and/or summer) and right panels is the fishing effort in these areas for all year. Transition period represents the year of the official closing of each area.

Permanent closure areas

For clarity purposes, only the graphs for the areas closed in 2013 and 2017 (areas 1, 2 and 8), are presented in this section, along with one of the more recent areas as an example. For these recent areas, closed between 2021 and 2022, there is only one year of data after protection, and thus no clear trends can be statistically confirmed. The graphs for the rest of the areas can be found in Annexes 1-24.

For areas 1, 2 and 8, effort has been efficiently reduced to zero in all three cases (Figure 5 and Figure 4). However, effort values did not reach zero right after the transition year, but two or three years after. For area 2, effort has only reached zero in 2022, suggesting that the official publication of the area might have played a role in the final effort reduction. In the case of areas closed earlier than 2021, effort has effectively been reduced after the fishers agreement (2013 and 2017). However, in two of the three areas (1 and 2) effort has not been reduced to zero until the official publication in the regulation. For areas published in 2020-21, effort has efficiently been reduced in the period 21-22 for 18 of 20 areas. In most of them, effort has been reduced to zero or nearly zero in one year (15 out of 18).

For areas 10, 22 and 27, fishing effort has decreased but does not reach zero. For area 10, the fishing effort in 2022 was less than 25% of the average of the previous 13 years, and it is likely that it will reach zero values next year. Area 22 is a permanent closure crossing a temporary one (area 23) and fishing occurs in the overlapping zone during the period where the temporary closure is open to fishing. This points to a possible misunderstanding of the management regime, where it is not clear which closure prevails, the temporary or the permanent. The case of area 27 needs further analysis to clarify the reasons why the fishing effort is not equal to zero after protection.

There are two cases where, contrary to expectations, the fishing effort has increased after protection. In area 19, this can be explained by a change in the behavior of the fleet, which after the establishment of the MPA starts to “fish the line”, that is, exert more effort right along the edge of the closure area, where the biomass of target species is expected to be higher. In the case of area 14, it is worth noting that it is one of the smallest areas (2.8 km^2) and is located entirely inside a submarine canyon with rapidly changing bathymetry. Steering vessels in such a narrow area attempting to avoid the limits of the MPA may be complex, and it is also relevant that, since isobaths are so close together, the geolocation device may be located at a very different depth than where the vessel is actually fishing, thus difficulting the monitoring of this particular closure area.

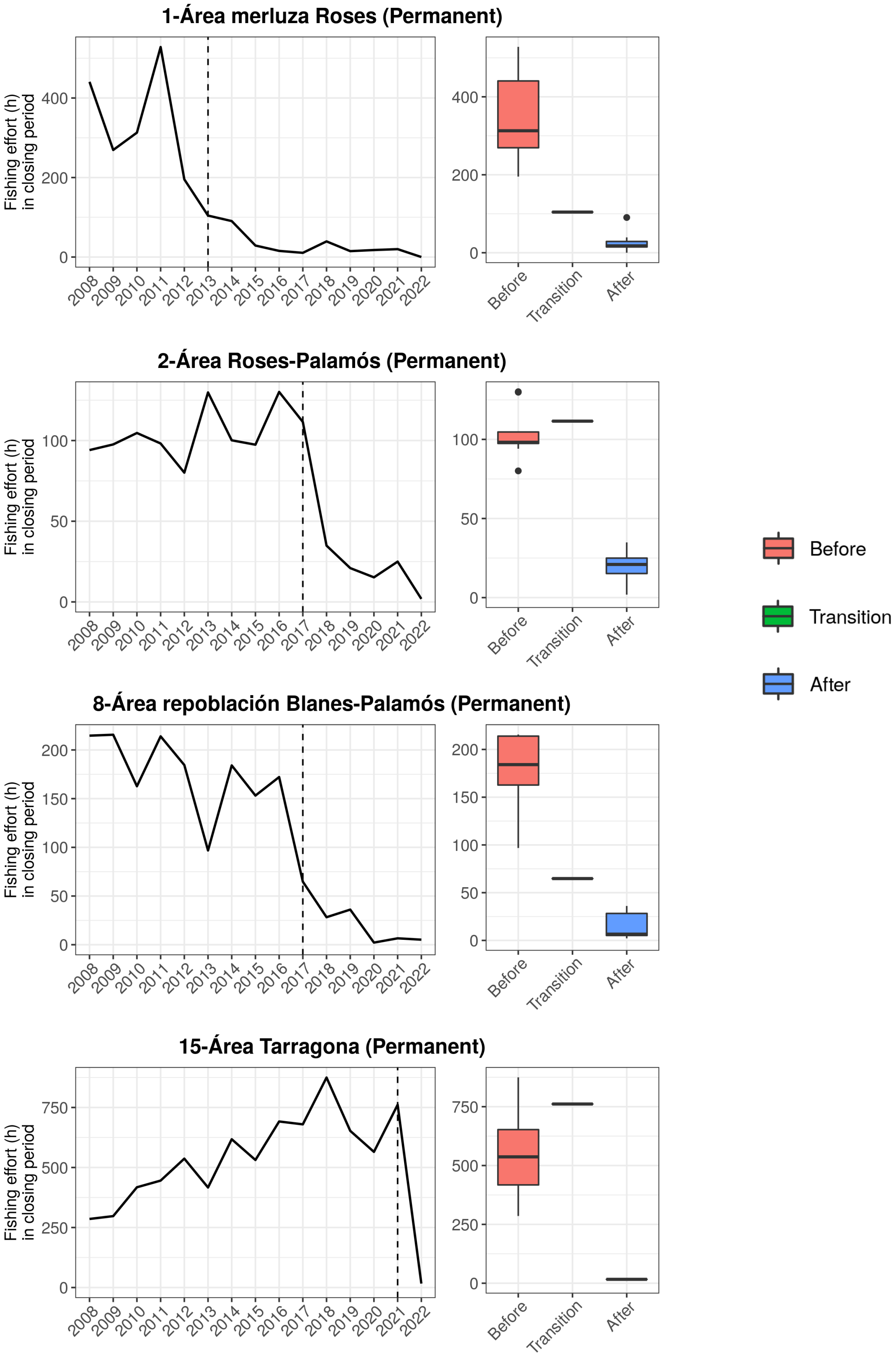


Figure 5. Effort reduction in areas 1, 2, 8, and 15. Left: historical fishing effort in the areas. Dashed line indicates the year of the official closing of each area, which has been considered a transitional period in the analysis. Right: differences in fishing effort before and after closure. Transition period represents the year of the official closing of each area.

Temporary closure areas

Examples of fishing effort trends in different areas are shown in Figures *6*, *7*, *8*, and *9*. Out of the four temporary closed areas, three of them (areas 23, 24 and 26) clearly show a decrease in effort values during the closing period. In addition, the overall yearly effort has also decreased in area 23 (Figure 7), while no clear trend is observed for the yearly effort of areas 24 and 26. Area 16 needs to be further analyzed as the effort during the closure has increased after protection but the yearly effort values have decreased (*Figure 6*).

Temporary closures can indeed be suitable for protecting a particular phase of the life cycle of well-known species, but do not reduce mortality on the species since, as shown in this report, the effort is merely displaced to the period of the year when fishing is permitted, thus defeating the purpose of habitat recovery. In this region, where the continental shelf and slope are intensively fished, the most suitable option for restoring ecosystem health is to generate a network of permanent no-take zones where the seabed structure can regenerate and species can thrive without the perspective of being exploited once again when the protection ends.

In addition, timing the period of a temporary protection with the reproductive or recruitment period of the species fished in one particular area is much more suitable to monospecific fisheries such as those in the Atlantic Ocean. In the GSA 6, although fishers do usually have one main target species, bottom trawling is highly multispecific, and can catch a dozen commercial species in one haul. Deciding which species should be prioritized when establishing the protection periods of temporary areas is no simple matter.

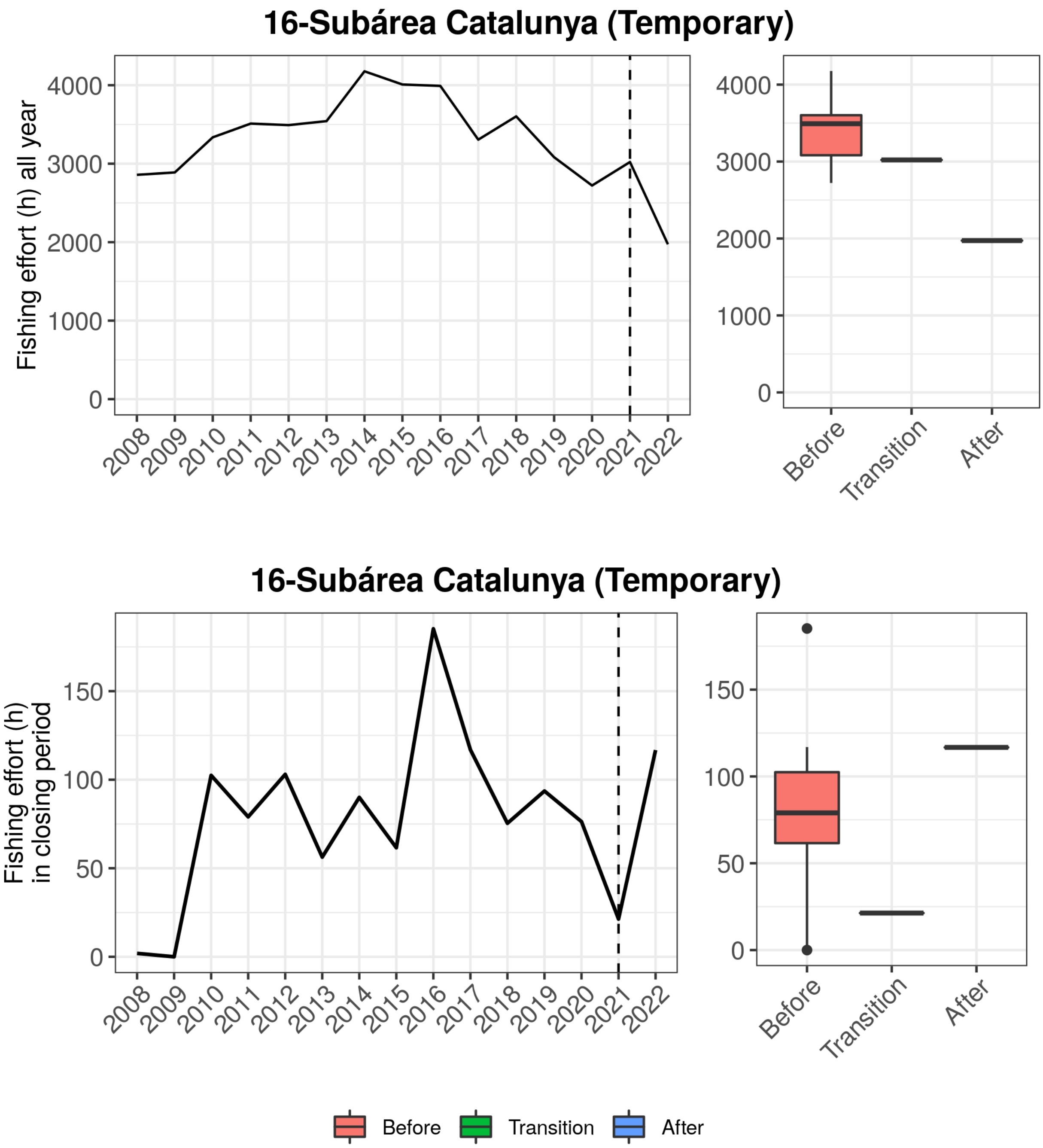


Figure 6. Fishing effort in all year in area 16. Top panels show the yearly fishing effort in the area. Bottom panels show the fishing effort only during the yearly closing period (May - June). Left panels indicate historical fishing effort in the area. Right panels indicate differences in fishing effort before and after closure. Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.

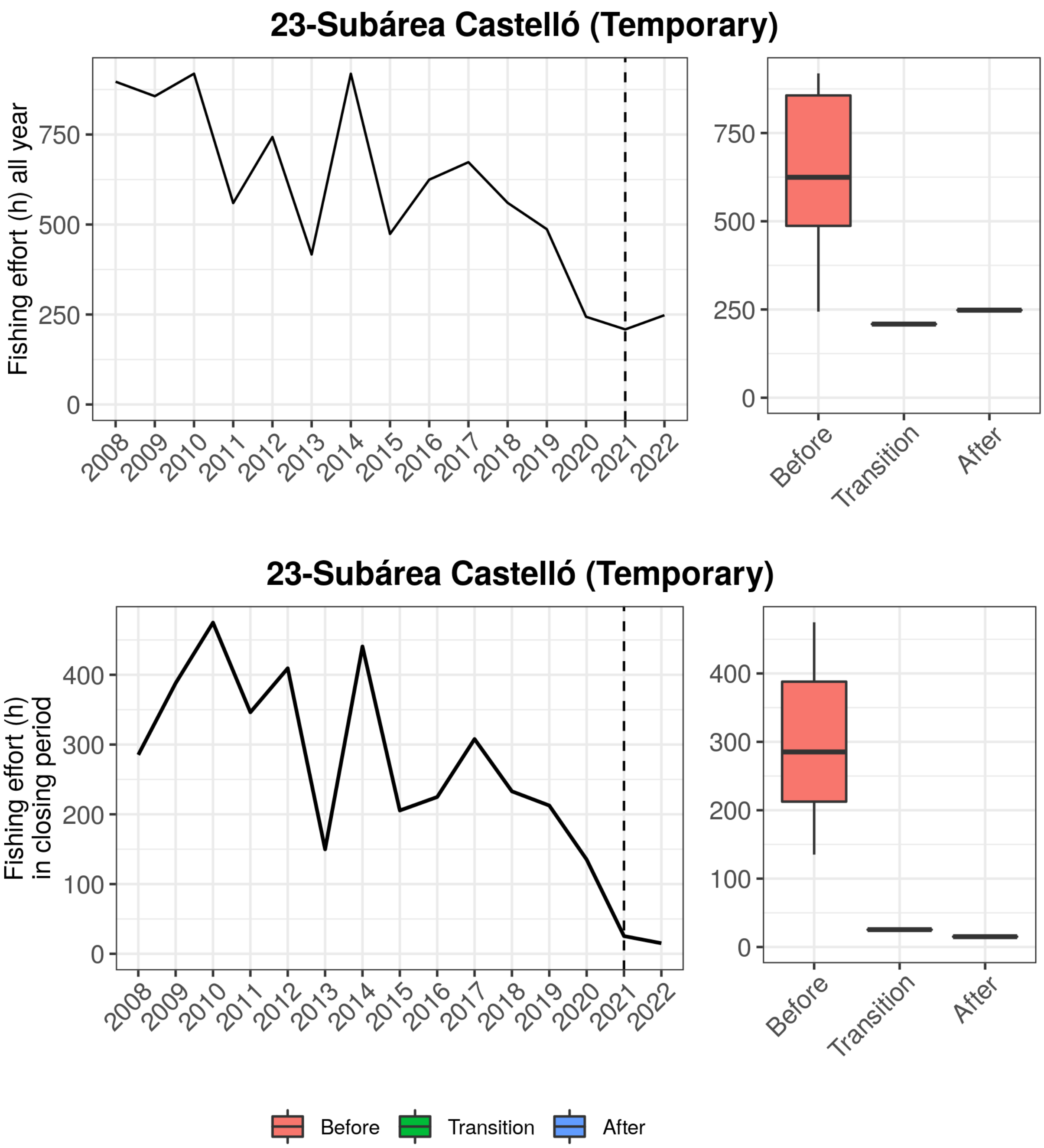


Figure 7. Fishing effort in all year in the area 23. Top panels show the yearly fishing effort in the area. Bottom panels show the fishing effort only during the yearly closing period (May - June). Left panels indicate historical fishing effort in the area. Right panels indicate differences in fishing effort before and after closure. Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.

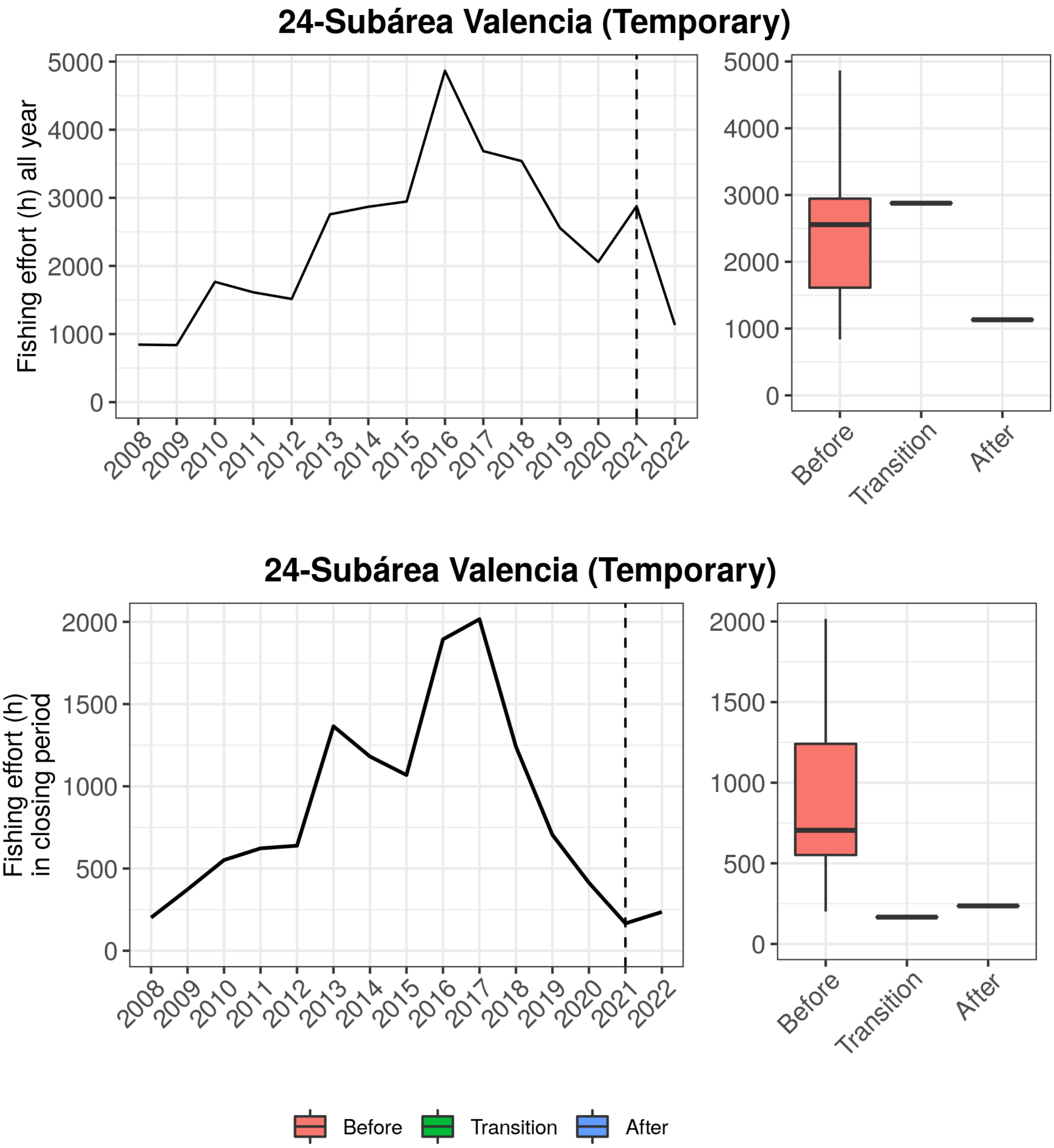


Figure 8. Fishing effort in all year in the area 24. Top panels show the yearly fishing effort in the area. Bottom panels show the fishing effort only during the yearly closing period (May - June). Left panels indicate historical fishing effort in the area. Right panels indicate differences in fishing effort before and after closure. Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.

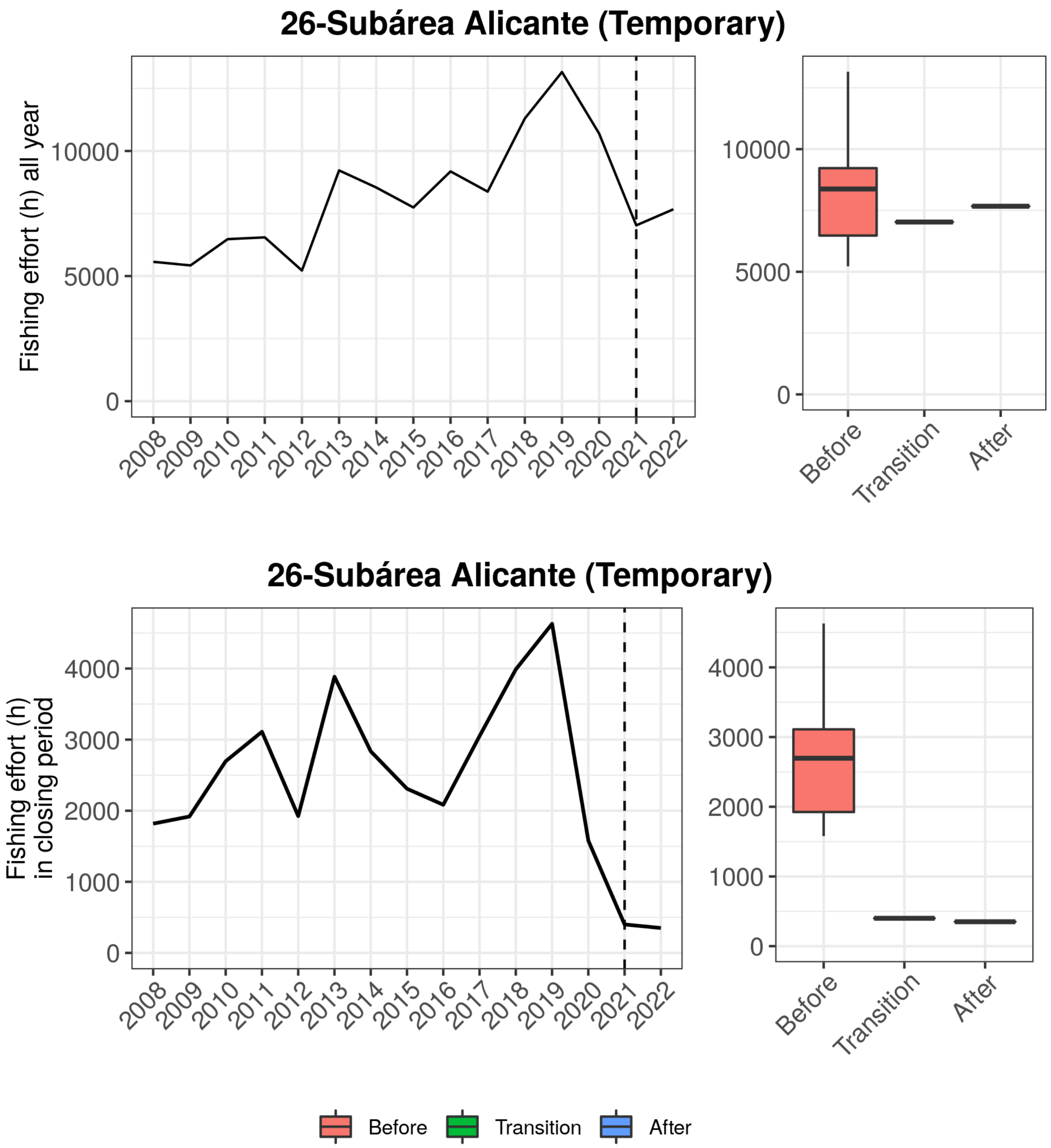


Figure 9. Fishing effort in all year in the area 26. Top panels show the yearly fishing effort in the area. Bottom panels show the fishing effort only during the yearly closing period (May - June). Left panels indicate historical fishing effort in the area. Right panels indicate differences in fishing effort before and after closure. Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.

Effort redistribution

According to our results, the reduction of fishing effort inside the protected areas is not related with an increase in the effort exerted on the surrounding areas. Specifically, in areas 1 and 2 a slight increase of the effort in the 500 m buffer is observed but it is not maintained over time (Figure 10). For the rest of buffer zones, the effort is maintained. The yearly trends indicate that the effort increase in the 500 m buffer does not follow a steady trend, but shows only occasional effort peaks in the area. In the case of area 8, effort has decreased for all the buffer zones after the protection.

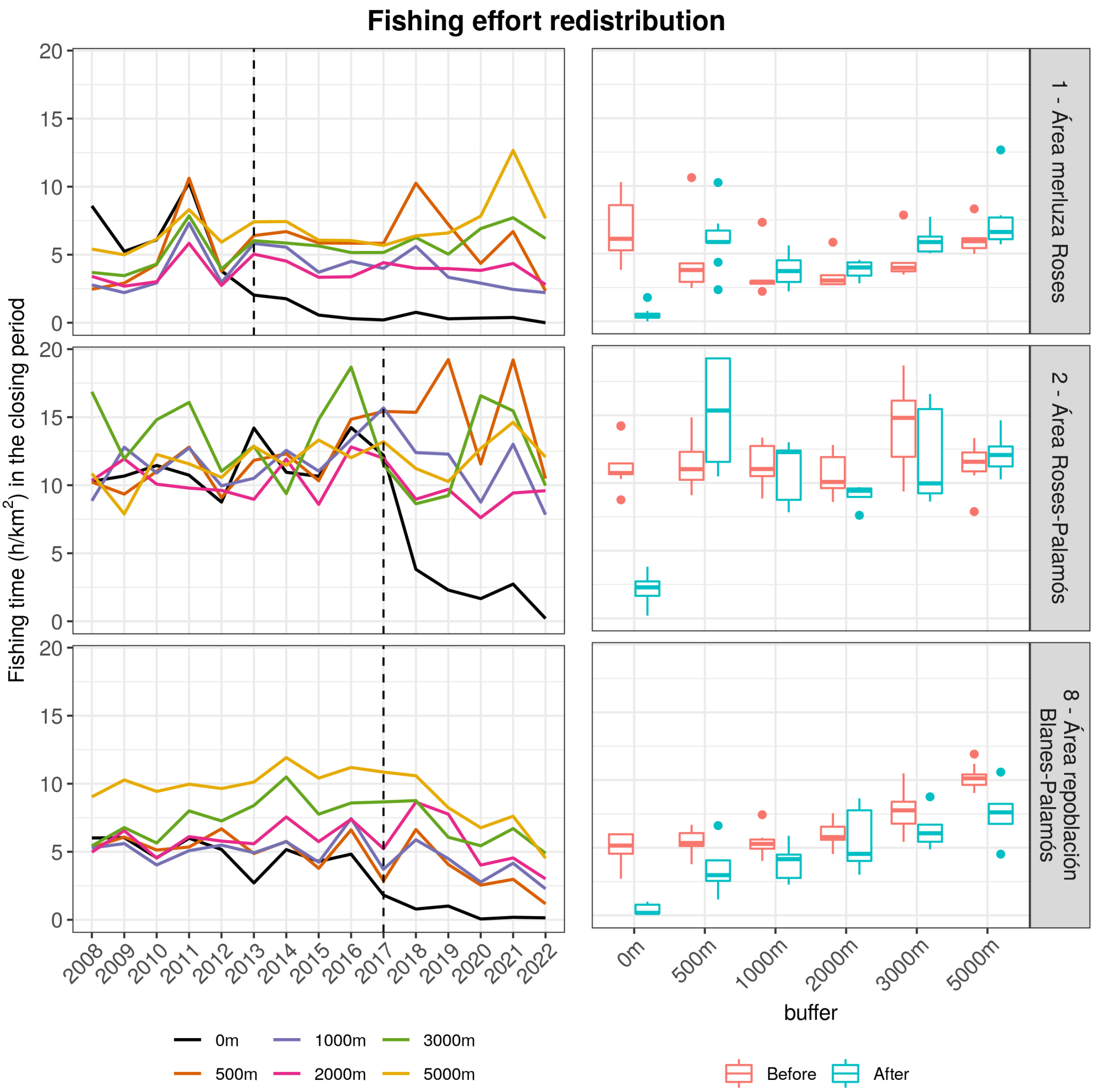


Figure 10. Effort redistribution in areas 1, 2, and 8. Left panels indicate historical fishing effort in the buffer areas around the closures. Effort in the border of the closure area is indicated in black. Right panels show fishing effort before and after closure in each buffer area. Dashed line indicates year of closure.

Spillover effect

The results on spillover effect analysis are summarized in Table 2. Overall, we found spillover evidence in 6 out of 13 analyzed species, with the first spillover evidence detected between 1 and 3 years after protection and stabilizing after at least 4-5 years of protection.

In general, permanent closure areas show good results for the spillover of middle-sized epibenthic and benthopelagic fishes. For territorial species such as *N. norvegicus*, permanent closures are effective at increasing density values and individual size inside the closure (Vigo et al. 2022). While studies on egg and larvae spillover are still in preliminary stages, this result may point in the direction that permanent closures are successful at improving egg/larvae spillover for these species. For highly mobile species (*M. merluccius*, *C. conger*, *Lophius* spp.), permanent closures might not be effective in protecting the entire species life cycle, at least when their dimensions are relatively small like the ones analyzed here.

Table 2. Summary of the spillover effects for the 12 species analyzed in the three closed areas assessed. "LPUE increase" is indicated when landings per unit of effort (LPUE) for each species in each closure area increased after protection in the buffer areas. "LPUE gradient after" is indicated when there is a gradient in LPUE from nearest to farthest buffer around the closure area. "No habitat" is indicated when the closure area is not located within the species depth range distribution.

			1-Área merluza Roses		2-Área Roses-Palamós		8-Área repoblación Blanes-Palamós	
Species information		Scientific name	LPUE increase	LPUE gradient after	LPUE increase	LPUE gradient after	LPUE increase	LPUE gradient after
MAP species		*Mullus spp.*	yes	yes	no habitat	no habitat	yes	yes
		Merluccius merluccius	no	no	no	no	no	no
		Nephrops norvegicus	no	no	no	no	no	no
		Parapenaeus longirostris	yes	no	yes	no	yes	no
Epibentic species	Flat shaped	*Lepidorhombus spp*	no	yes	no	no	yes	yes
	Oblong shaped	*Triglidae spp*	yes	yes	yes	yes	yes	yes
		Helicolenus dactylopterus	no habitat	no habitat	no habitat	no habitat	yes	yes
		Scorpaena spp	yes	yes	no habitat	no habitat	yes	yes
		Lophius spp	no	no	no	no	no	no
Benthopelagic species	Oval shaped	*Zeus faber*	no habitat	no habitat	no habitat	no habitat	yes	yes
	Anguilliform	*Conger conger*	no	no	no	no	no	no
Cephalopod		*Eledone spp*	no	no	no	no	no	no

Species of concern in the WMMAP

Red mullet (*Mullus* spp.) MUT, MUR, MUX

Data on *Mullus* spp. are presented only for areas 1 and 8, since area 2 is not located within the species habitat. In the case of areas 1 and 8, there is a clear increase of LPUE after the protection.

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 closure border outwards, while no clear trend was visible before (Figure 11, left). Second, LPUE increases over the years after the protection, with a stronger trend the closer the buffer zone is to closure borders, a difference that was not present before the protection (*Figure 11*, right).

Furthermore, the overall LPUE fleet trend for *Mullus* spp. does not show clear increasing trends over time, especially since 2013 (See Annex 19). The increase in LPUE in 2012-2013 could be a response to a mesh size increase in 2010-2011. Trends in the buffer areas 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.

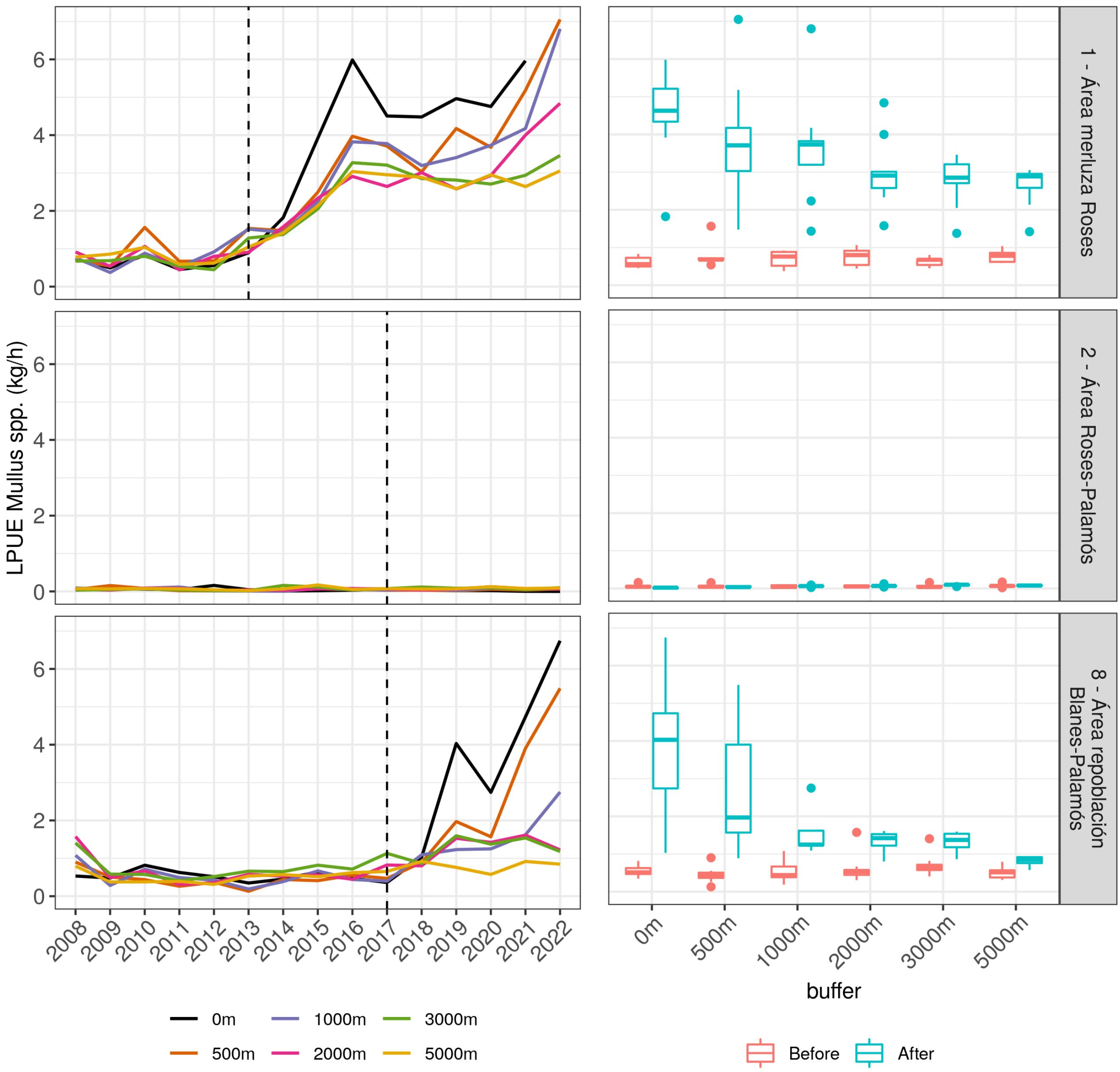


Figure 11. Landings per unit effort (LPUE) for *Mullus* spp. in areas 1, 2 and 8. Left panel indicates historical fishing effort in the buffer areas around the closures. Effort in the border of the closure area is indicated in black. Right panel shows fishing effort before and after closure in each buffer area. Dashed line indicates year of closure.

European hake (*Merluccius merluccius*) HKE

In the case of hake, there is a decrease in landings across all buffer zones for areas 1 and 8, while landings in area 2 seem to remain more stable (Figure 12). LPUE shows a decreasing trend across all areas and buffer zones. The data we present show no evidences of LPUE gradients after the protection that could be linked to a spillover effect in hake. It seems clear that general stock trends (see Annex II) are affecting the dynamics of the buffer zones, and could be masking whatever effects the protection may have in the areas. This is especially apparent in the case of area 1.

Another point worth considering is that the present methodology analyzes landings data, and therefore we do not have information on juvenile (under MCRS) individuals. Area 1 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 ontogenetic change in the mobility capacity of this species. Indeed, there are other studies demonstrating the positive effect on hake juvenile abundance in this closure area. Recasens et al. (2016) showed how inside the protected area juvenile abundances are higher than in surrounding zones and Sala-Coromina et al. (2021) found spillover evidence on the smallest commercial size classes.

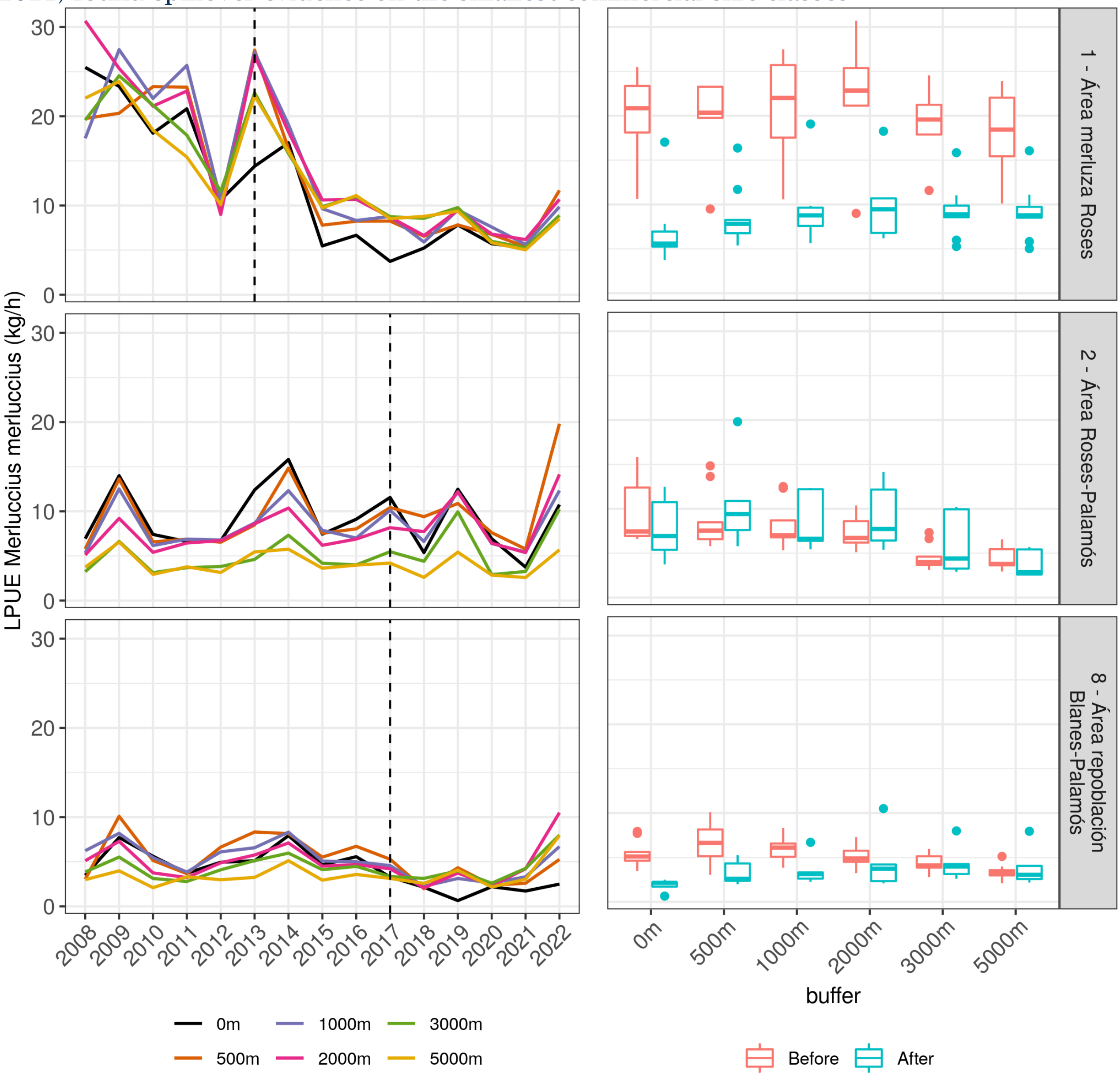


Figure 12. Landings per unit effort (LPUE) for *Merluccius merluccius* in areas 1, 2 and 8. Left panel indicates historical fishing effort in the buffer areas around the closures. Effort in the border of the closure area is indicated in black. Right panel shows fishing effort before and after closure in each buffer area. Dashed line indicates year of closure.

Norway lobster (*Nephrops norvegicus*) NEP

Data on *N. norvegicus* are presented only for areas 2 and 8, since area 1 is not located within the species habitat. 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 Norway lobster.

In addition, *N. norvegicus* 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., 2023, in review). It is probable that the small home range of the species would favor that individuals inside closures grow up to large sizes with more reproductive capacity, making these closures a pool of egg and larvae exportation for this species.

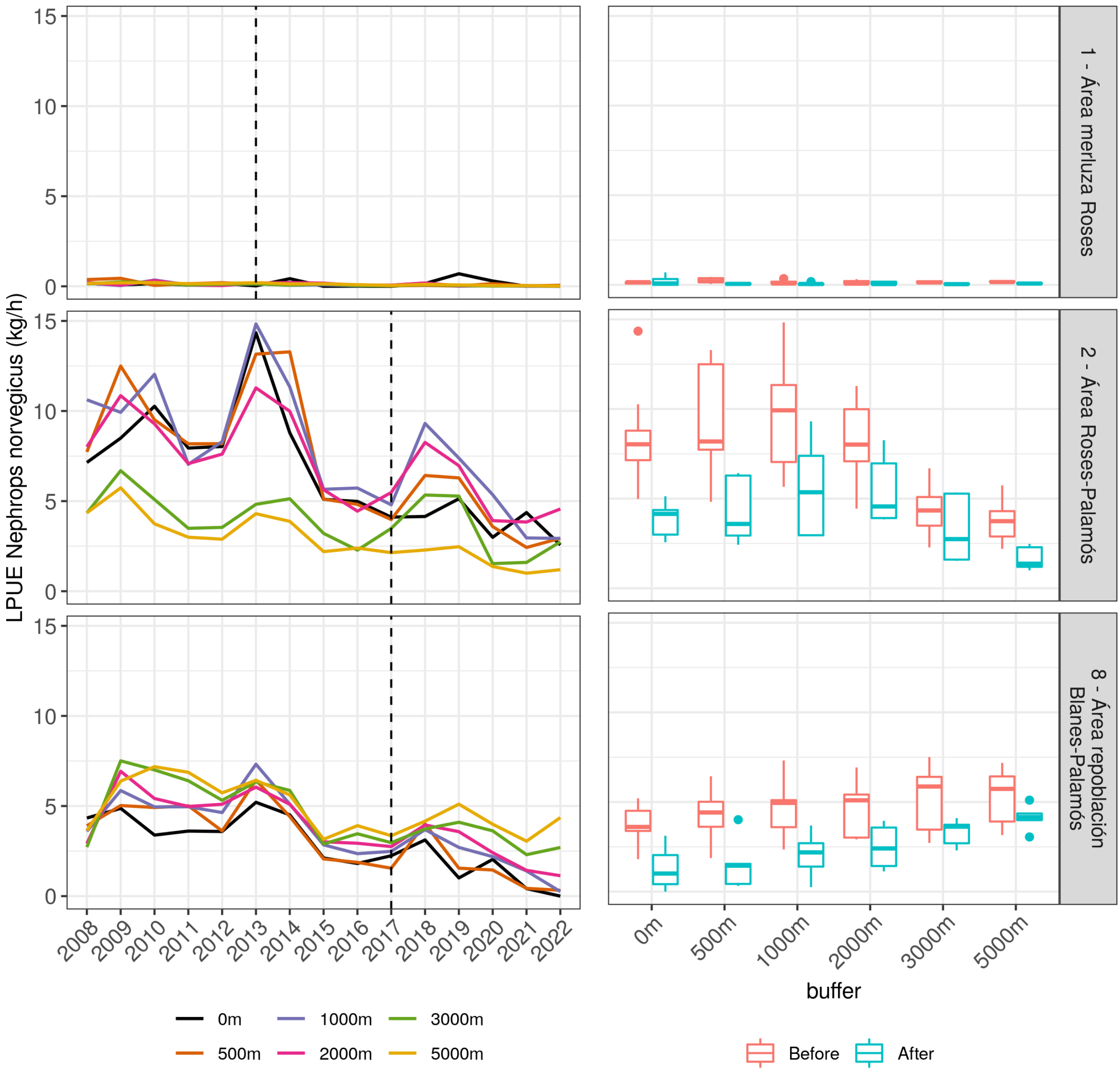


Figure 13. Landings per unit effort (LPUE) for *Nephrops norvegicus* in areas 1, 2 and 8. Left panel indicates historical fishing effort in the buffer areas around the closures. Effort in the border of the closure area is indicated in black. Right panel shows fishing effort before and after closure in each buffer area. Dashed line indicates year of closure.

Deep-water rose shrimp (*Parapenaeus longirostris*) DPS

In the case of the deep-water rose shrimp, data show a marked increase both in LPUE in all areas and practically all buffer zones, with a higher variability compared to other studied species (Figure 14). Despite the overall increase in LPUE, there is no clear trend or gradients after the protection for any of the three studied areas. For areas 1 and 8, LPUE values show an increase with distance to closure border, and for area 2 the values decrease.

General fleet LPUE values for *P. longirostris* reveal a clear increasing trend since 2015-2016 (see Annex 19). The species has rapidly emerged as a new fishing resource in the northern GSA 6, probably linked to global climate change (Quattrocchi et al., 2020). Similarly to previous cases, dynamics in the buffer zones *P. longirostris* seem to be masked by overall stock trends.

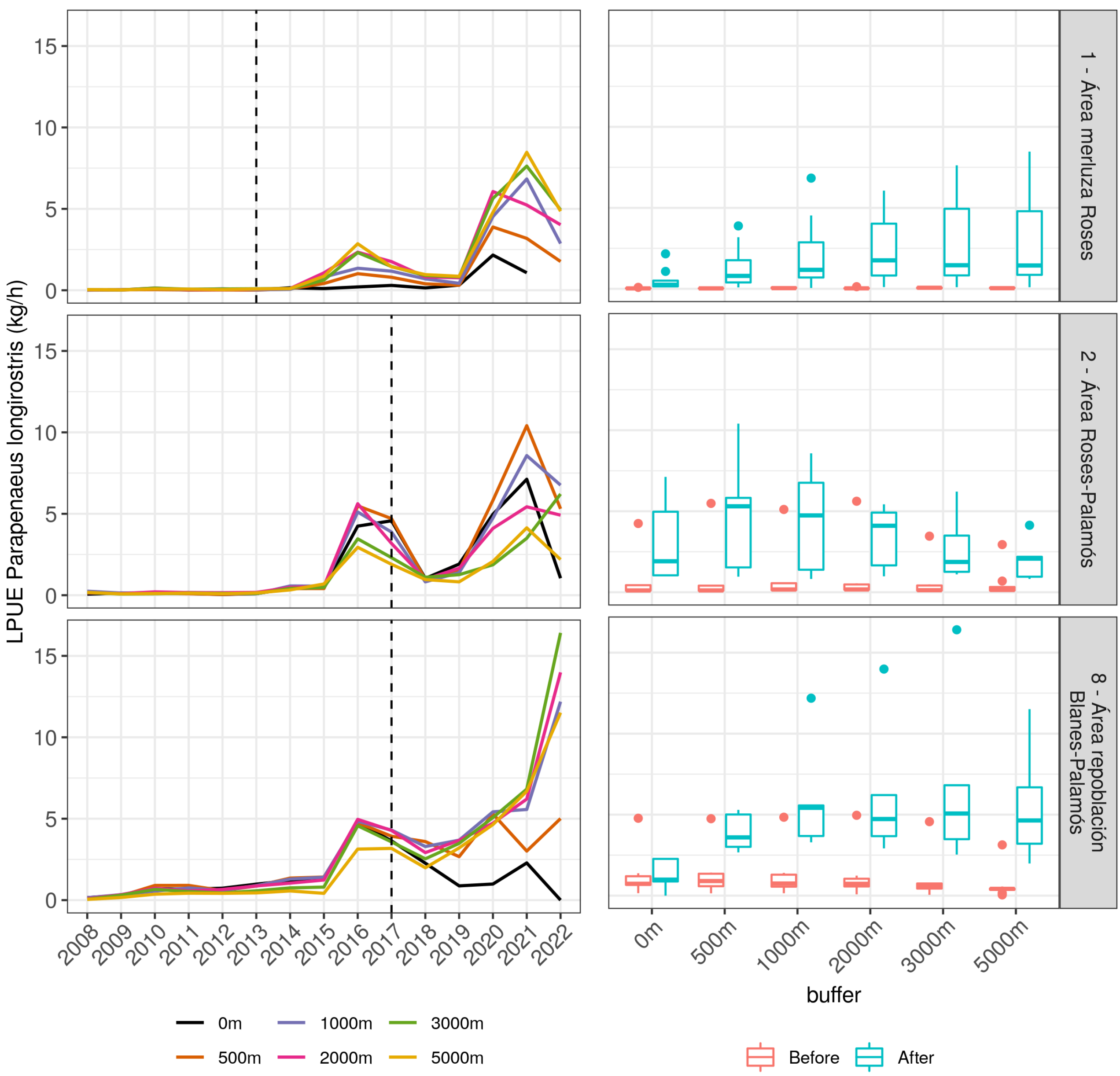


Figure 14. Landings per unit effort (LPUE) for *Parapenaeus longirostris* in areas 1, 2 and 8. Left panel indicates historical fishing effort in the buffer areas around the closures. Effort in the border of the closure area is indicated in black. Right panel shows fishing effort before and after closure in each buffer area. Dashed line indicates year of closure.

Other species

Evidence of spillover effect was observed for five of the eight analyzed species: *Lepidorhombus* spp, Triglidae spp, *Helicolenus dactylopterus*, *Scorpaena* spp. and *Zeus faber* (Figures 15, 16, 17, 18 and 19*).*

No evidence of spillover was found for *Lophius* spp., *Conger conger* and *Eledone* spp. (Figures 20, *19*, *21* and *22*). The area showing a spillover effect for more species is area 8 (170-260 m depth).

Our data show that not all areas are visibly beneficial for all species according to the parameters we analyzed. However, further analysis of juvenile populations, or exportation of eggs and larvae, might show clearer results.

Lepidorhombus boscii LDB, LEZ, MEG

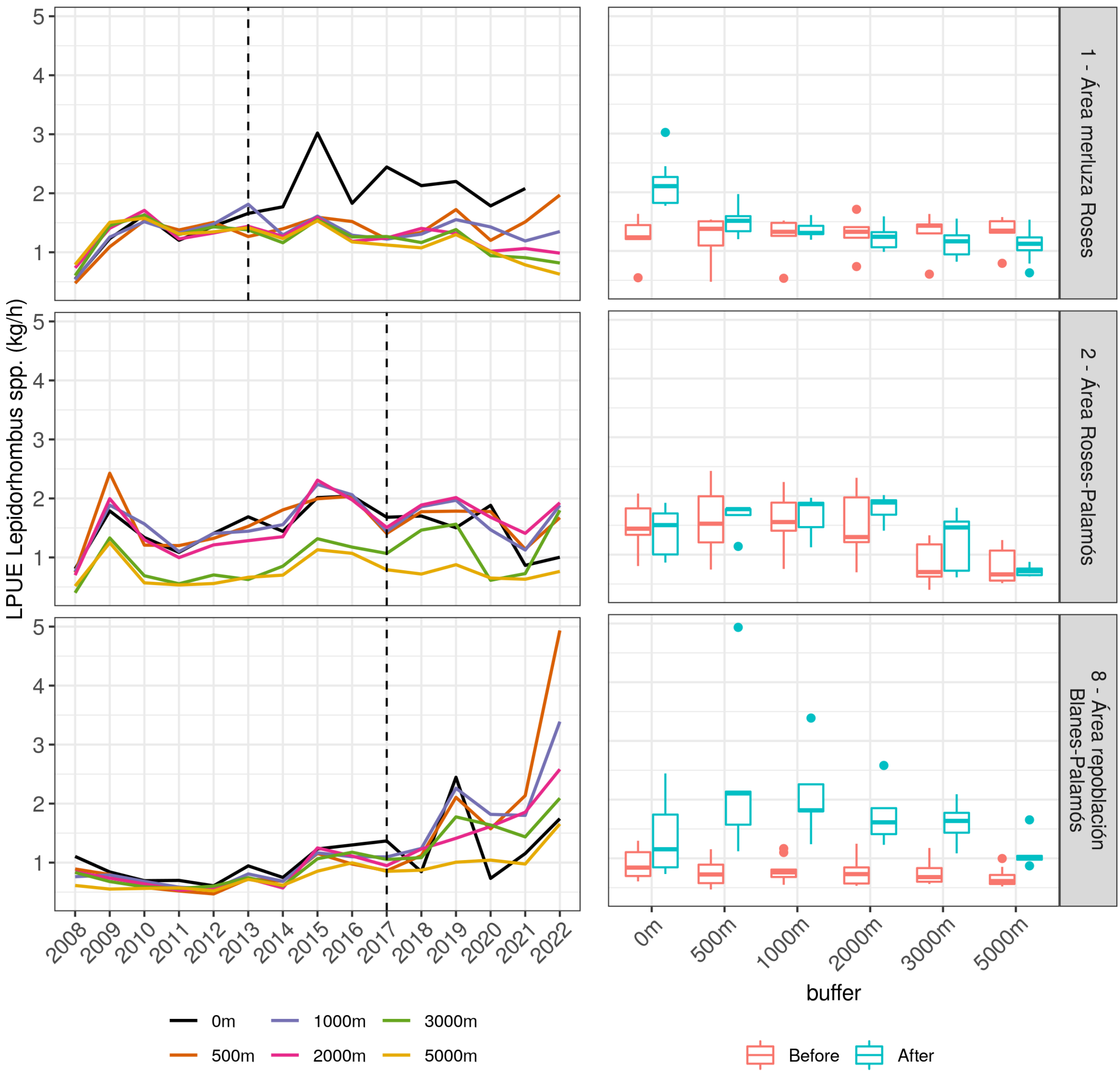


Figure 15. Landings per unit effort (LPUE) for *Lepidorhombus spp.* in areas 1, 2 and 8. Left panel indicates historical fishing effort in the buffer areas around the closures. Effort in the border of the closure area is indicated in black. Right panel shows fishing effort before and after closure in each buffer area. Dashed line indicates year of closure. Three FAO code where selected because these species are usually not well-identified in the fishing auction but in the GSA6 all of these codes correspond to *Lepidorhombus boscii.*

Triglidae spp. **GUG, GUI, GUN, GUU, GUX, GUY, LDV**

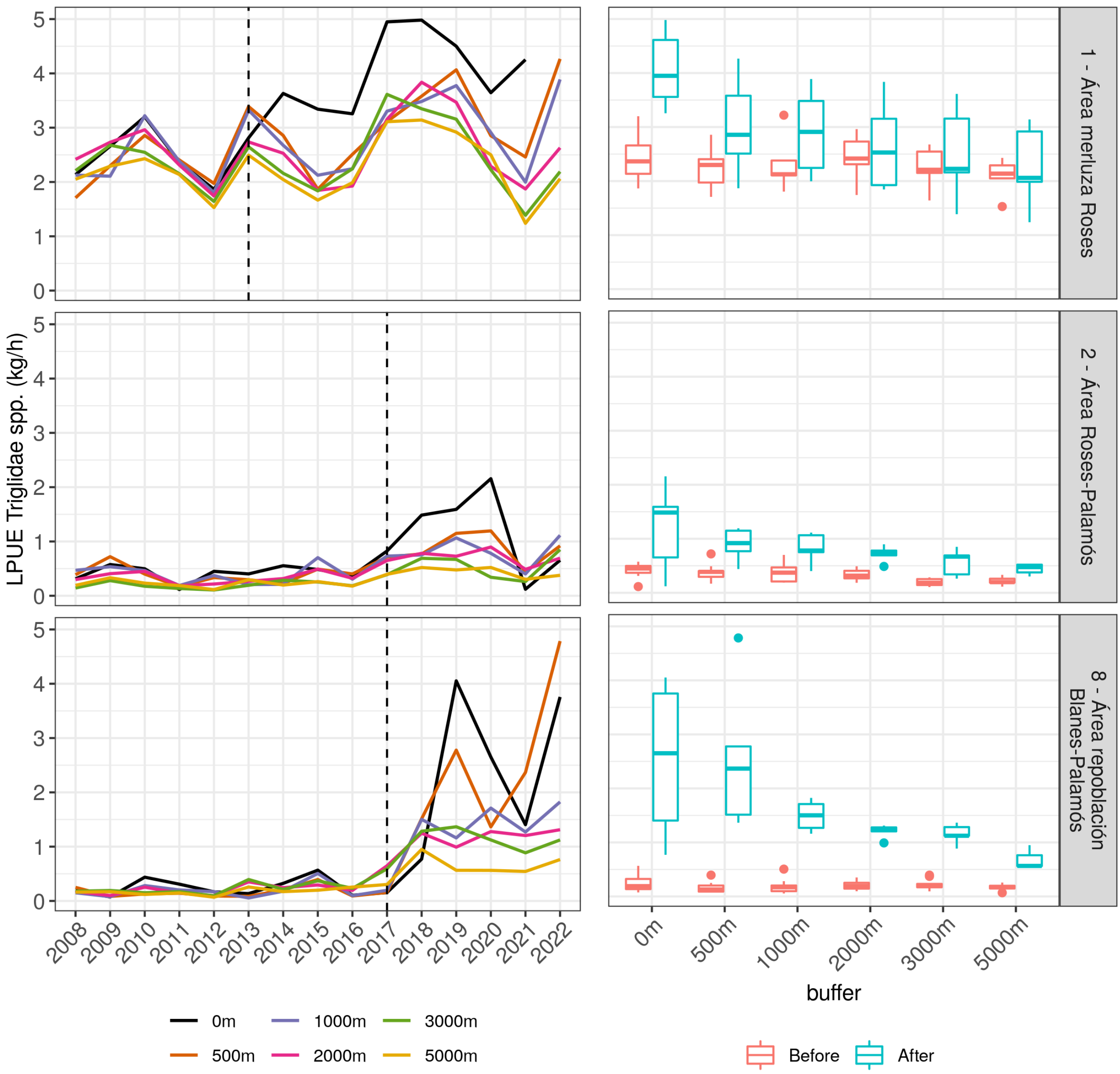


Figure 16. Landings per unit effort (LPUE) for *Triglidae spp.* in areas 1, 2 and 8. Left panel indicates historical fishing effort in the buffer areas around the closures. Effort in the border of the closure area is indicated in black. Right panel shows fishing effort before and after closure in each buffer area. Dashed line indicates year of closure.

Helicolenus dactylopterus BRF

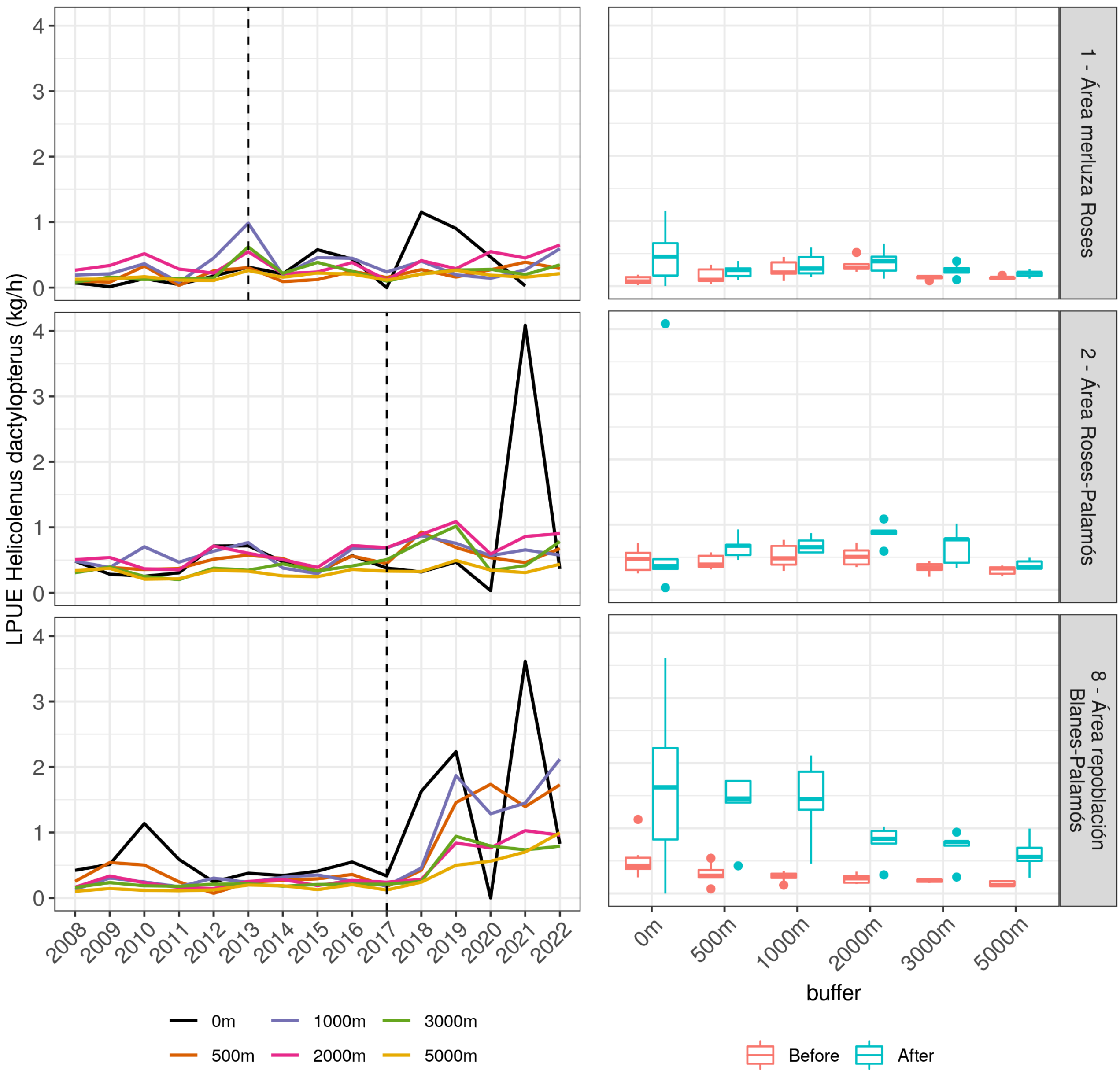


Figure 17. Landings per unit effort (LPUE) for *Helicolenus dactylopterus* in areas 1, 2 and 8. Left panel indicates historical fishing effort in the buffer areas around the closures. Effort in the border of the closure area is indicated in black. Right panel shows fishing effort before and after closure in each buffer area. Dashed line indicates year of closure.

Scorpaena spp. EZS, MZS, RSE, SCO, SCS, SNQ

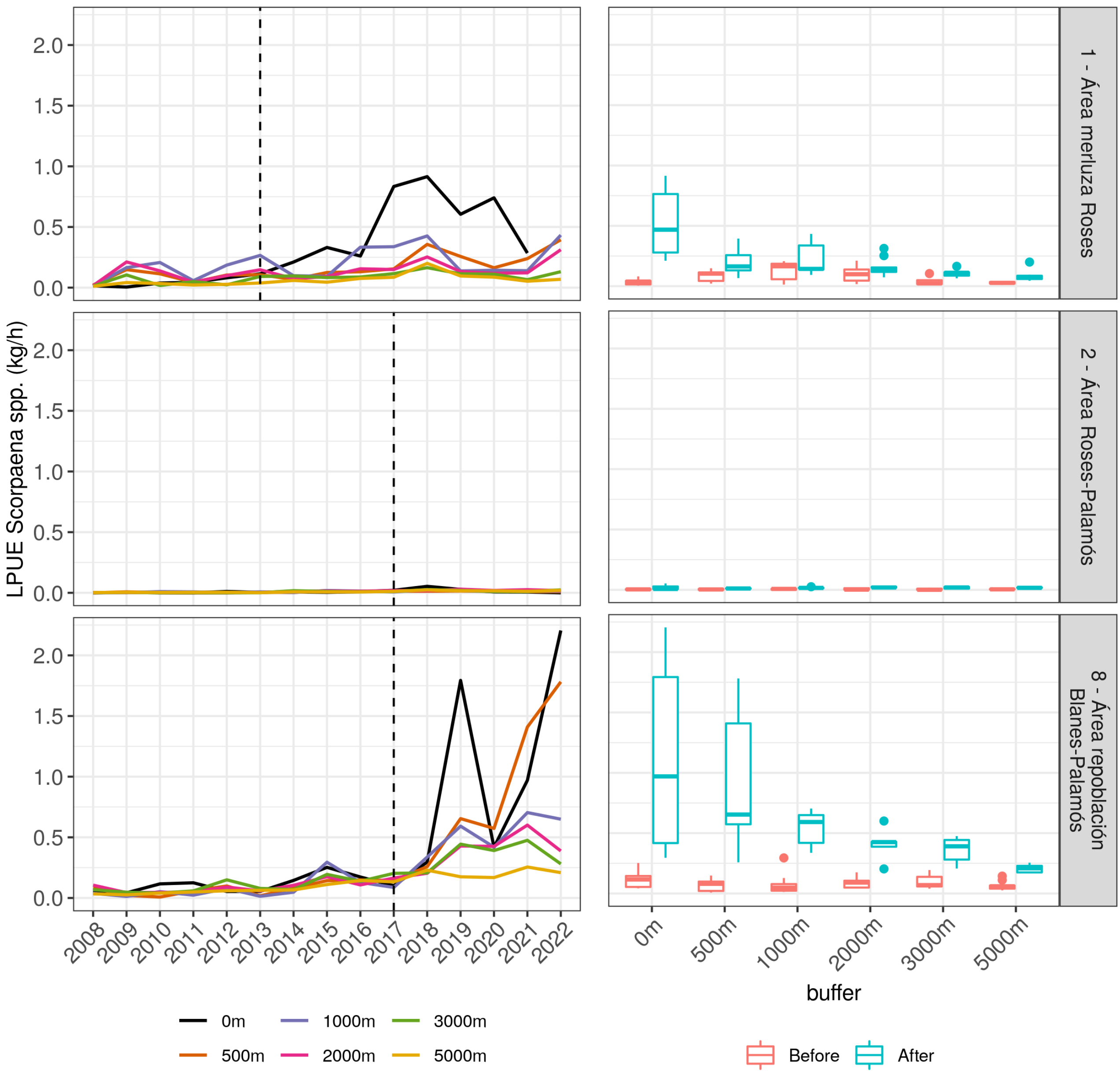


Figure 18. Landings per unit effort (LPUE) for *Scorpaena spp.* in areas 1, 2 and 8. Left panel indicates historical fishing effort in the buffer areas around the closures. Effort in the border of the closure area is indicated in black. Right panel shows fishing effort before and after closure in each buffer area. Dashed line indicates year of closure.

Zeus faber JOD

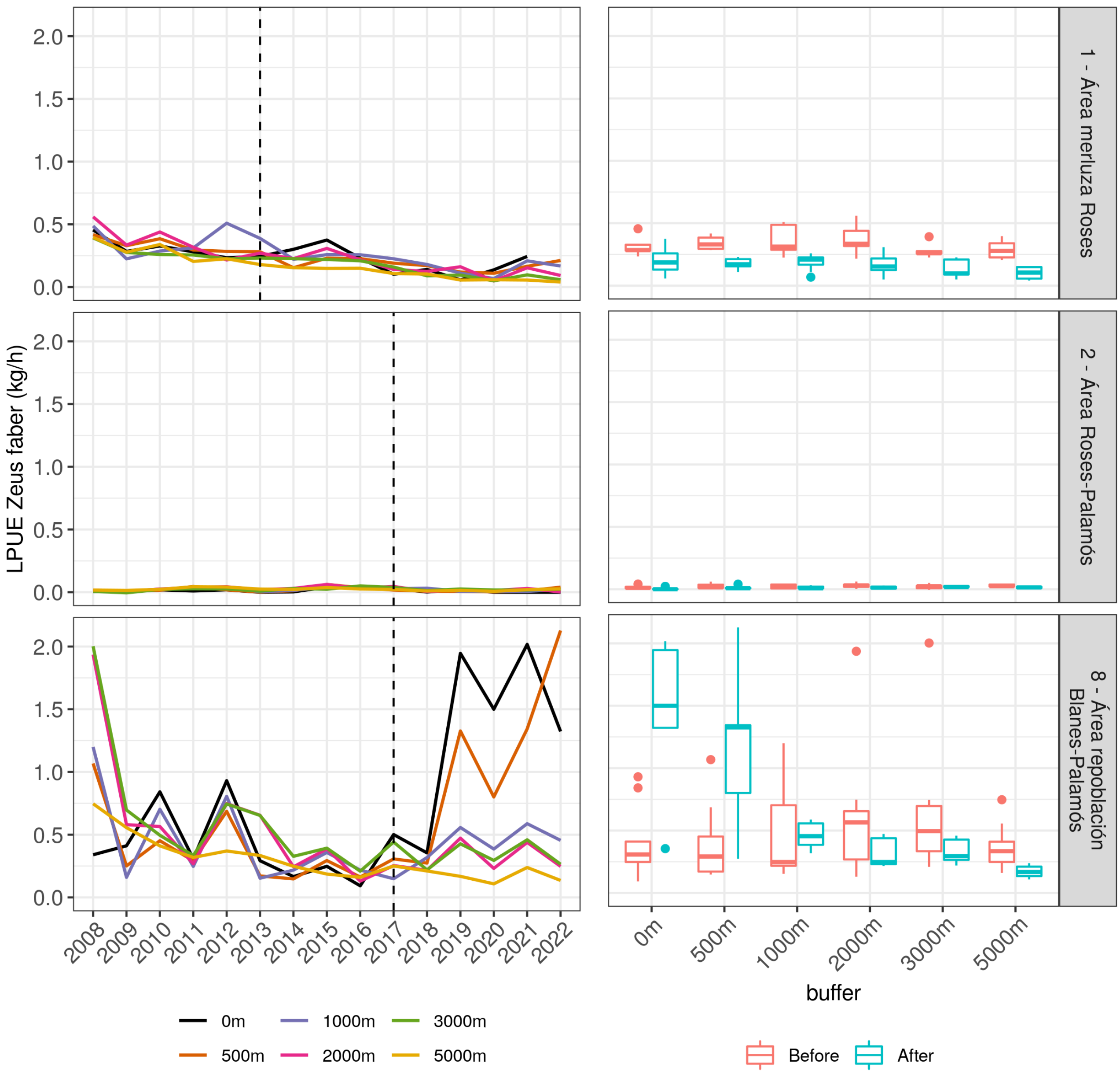


Figure 19. Landings per unit effort (LPUE) for *Zeus faber* in areas 1, 2 and 8. Left panel indicates historical fishing effort in the buffer areas around the closures. Effort in the border of the closure area is indicated in black. Right panel shows fishing effort before and after closure in each buffer area. Dashed line indicates year of closure.

Lophius spp. ANK, MNZ, MON

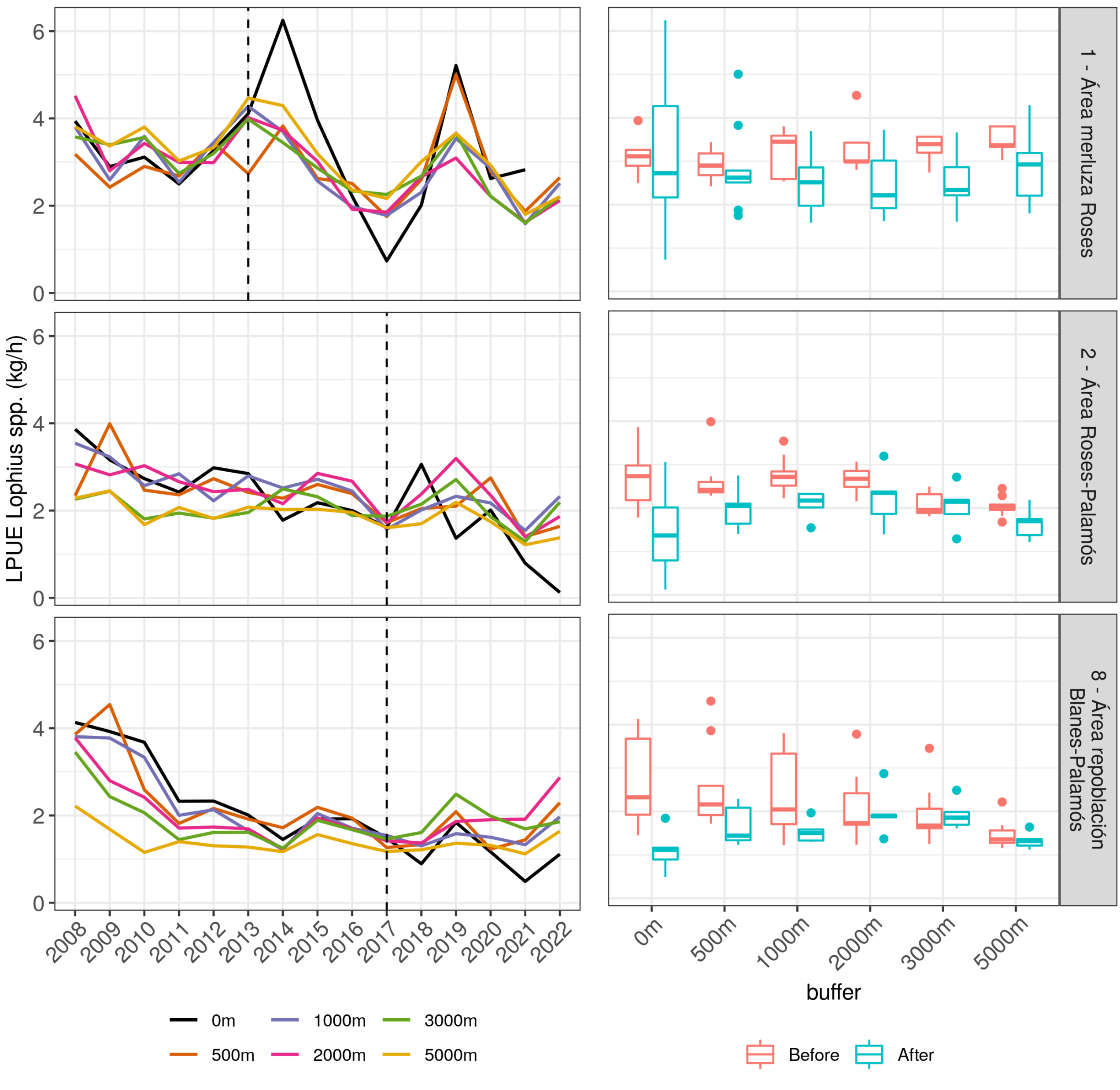


Figure 20. Landings per unit effort (LPUE) for *Lophius spp.* in areas 1, 2 and 8. Left panel indicates historical fishing effort in the buffer areas around the closures. Effort in the border of the closure area is indicated in black. Right panel shows fishing effort before and after closure in each buffer area. Dashed line indicates year of closure.

Conger conger COE

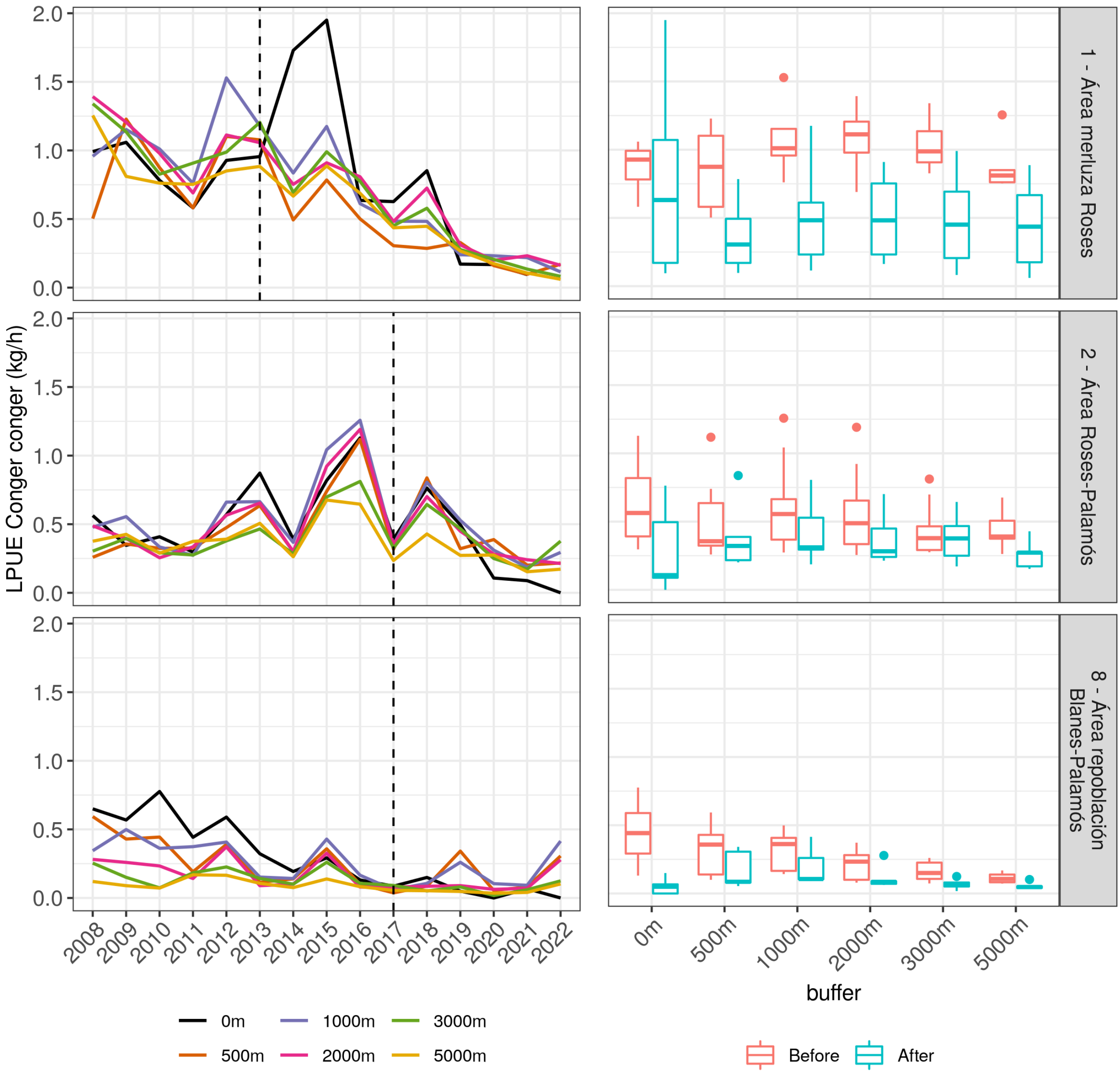


Figure 21. Landings per unit effort (LPUE) for *Conger conger* in areas 1, 2 and 8. Left panel indicates historical fishing effort in the buffer areas around the closures. Effort in the border of the closure area is indicated in black. Right panel shows fishing effort before and after closure in each buffer area. Dashed line indicates year of closure.

Eledone cirrhosa EOI, EDT

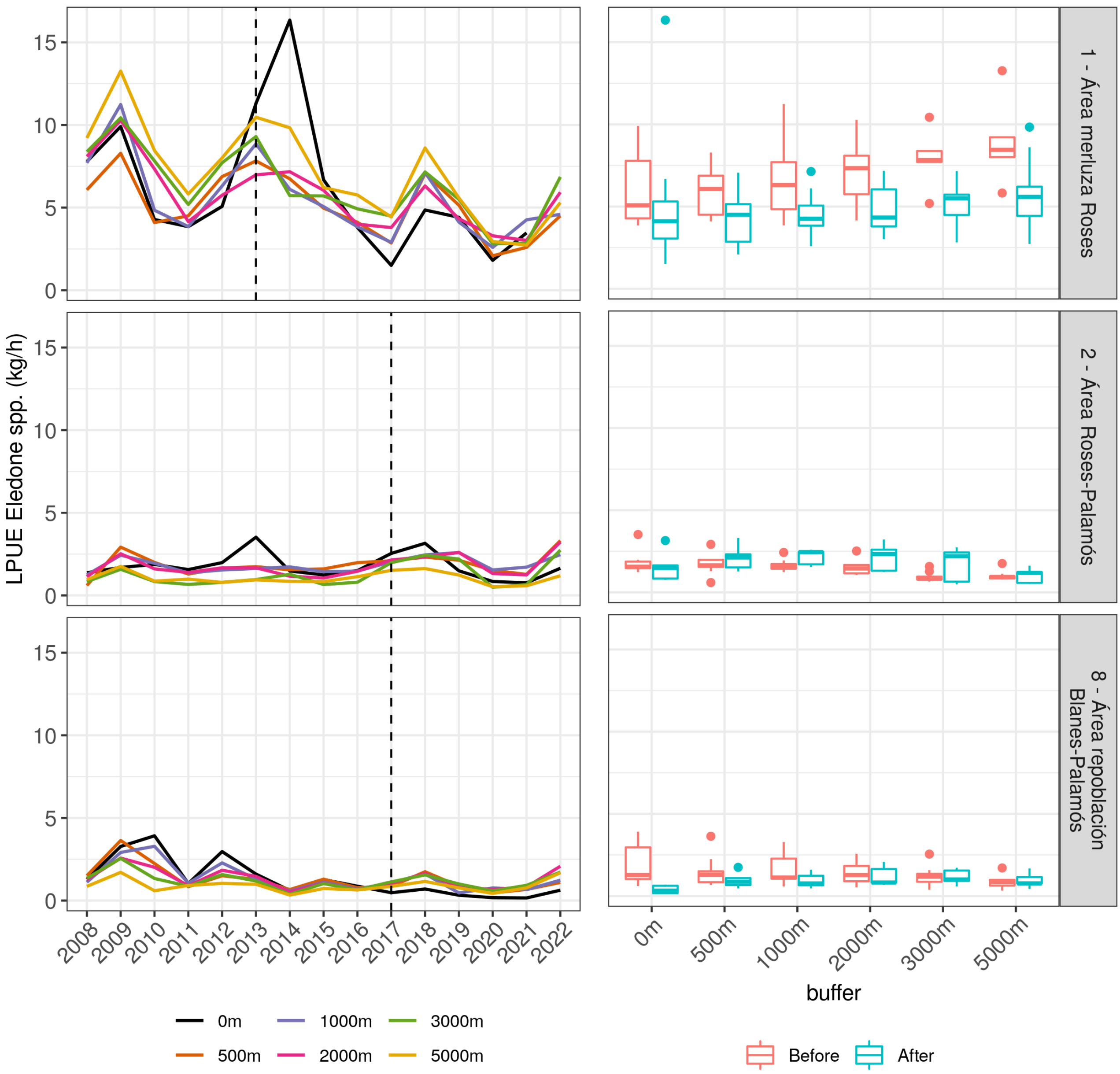
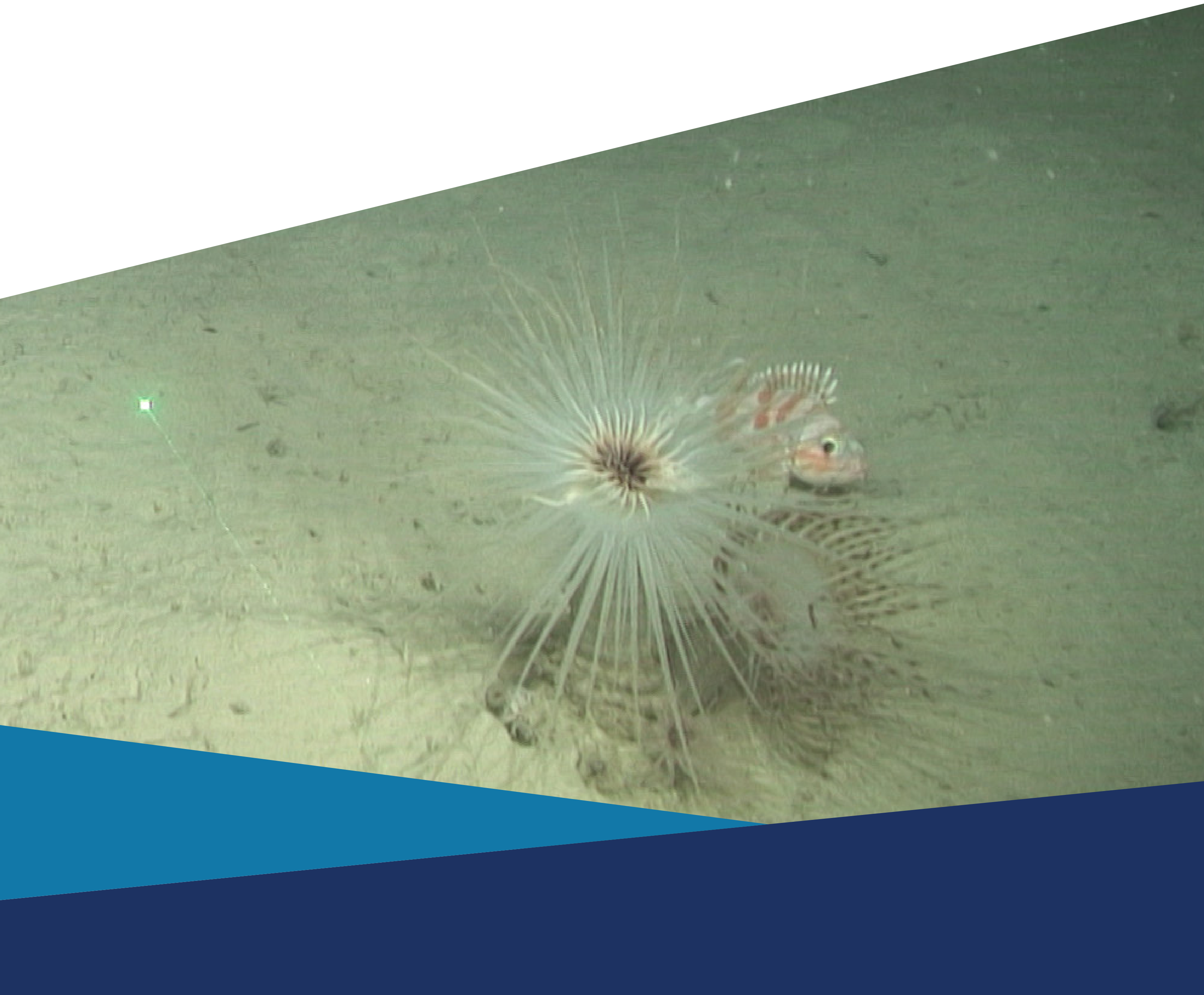


Figure 22. Landings per unit effort (LPUE) for *Eledone spp.* in areas 1, 2 and 8. Left panel indicates historical fishing effort in the buffer areas around the closures. Effort in the border of the closure area is indicated in black. Right panel shows fishing effort before and after closure in each buffer area. Dashed line indicates year of closure. Two FAO code where selected because these species are usually not well-identified in the fishing auction but in the GSA 6 both codes correspond to *Eledone cirrhosa.*

Future directions

The immediate steps in the standardization of this methodology for closure area effectiveness analysis include removing overall stock trends (general fleet LPUE values) from trends around protected zones, to better differentiate the effect of the protection, and analyzing LPUE after several years have passed since the declaration of the temporary closures.

PART 2
Effects on the benthic communities



The effect of the protection of marine areas has been previously studied in the Western Mediterranean with focus on certain taxonomic groups such as fish of crustacean assemblages (Padilla et al., 2022; Tuset et al., 2021, respectively). Since 2023, project LIFE-ECOREST ("Ecological restoration of human-impacted benthic marine ecosystems through active strategies and participatory approach", LIFE20 NAT/ES/001270) aims to carry out a monitoring of the fishing closure areas in the GSA 6 with non-invasive methods, using Remote Operated Vehicles (ROVs), adding an ecosystemic perspective while gathering information about the main commercial target species. A recent cruise within the project yielded images of 14 closure areas in the GSA 6 at different stages of protection and different depth ranges.

Method

A total of 140 hours of ROV video footage were filmed during a cruise in June 2023 on board R/V *García del Cid*, within project LIFE-ECOREST. The images correspond to transects both inside and outside closure areas at different points in time after protection: non-protected control areas, areas protected for 1.5 years, for 5 years and for 10 years (Table 3). The footage was visualized to select captions that could represent the state of the seafloor of the different areas, as a preliminary layout of the state of the closure areas. Further analysis will start once the set of cruises is completed.

In addition, 35 hours of Autonomous Underwater Vehicle (AUV) imagery are being processed with Agisoft Metashape software to combine a collection of images into an orthomosaic, a photogrammetrically orthorectified imagery product where the geometric distorsion and the color balance have been corrected to produce a seamless mosaic dataset. This technique is starting to be used in seafloor analysis, similarly to the use of drones in land, with the added limitations of working in the marine environment. In each mosaic, the surface covered was 50 x 30 m, with a lateral overlapping of 70% between image lines. At the same time, these operations have also produced microbathymetry maps of the surveyed areas using the AUV multibeam echosounder. Since the cruise has recently ended and the processing of these images is time-consuming, we are presenting one orthomosaic as an example of the data that will be available for the yearly monitoring of the closure areas.

Table 3. Information on areas surveyed with ROV and AUV in the frame of project LIFE-ECOREST.

Area number	Area name	Years since protection	Depth range (m)
1	Merluza Roses	10	140
8	Regeneración Blanes	5	250
2	Cigala Roses Palamós	5	400
10	Cigala Barcelona	1.5	400
9	Lluç Arenys	1.5	150
7	Bol de Bruixes	1.5	200
2	Control Cigala Roses/Palamós	0	400

Results

A) ROV imagery

Effects of time since protection

The trawl marks and plowed bottoms are visible in control areas where no protection is applied (Figure 23). In general, the ecological succession of the benthic community starts with the return of mobile species such as fish and small crustaceans, then sessile organisms such as hydrozoa or the tall sea pen *Funiculina quadrangularis*, which is classified by the GFCM as indicator of Vulnerable Marine Ecosystems (VME) and key to hosting commercial species such as the deep-water rose shrimp or the Norway lobster (Figure 24A). The structure of the seabed is progressively restored from plowed ground to a smooth surface as the trawl marks are erased (Figure 24B), then to tridimensional structures with an abundance of burrows (Figure 25). In the areas with a longer protection, slow-growing sessile species such as the soft corals of the genus *Alcyonium* can be seen (Figure 26).

a. Control areas with no protection

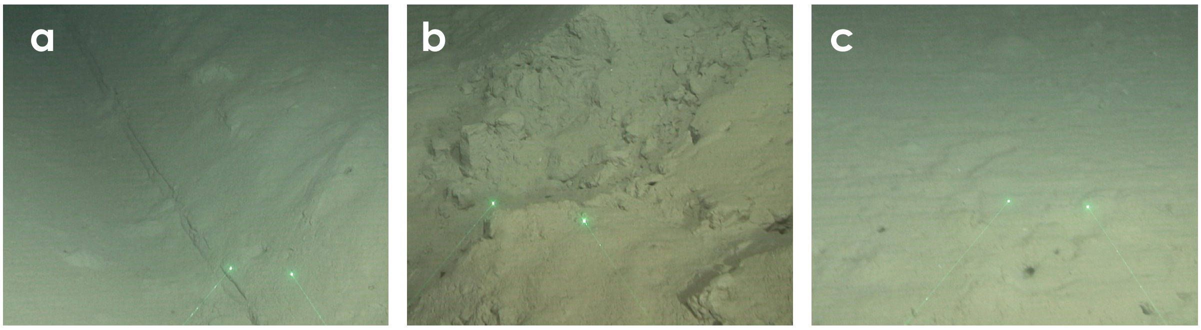


Figure 23. ROV images of control areas in Roses/Palamós, depth (a) and (b) 380 m and (c) 400 m.

b. 1.5 years closed

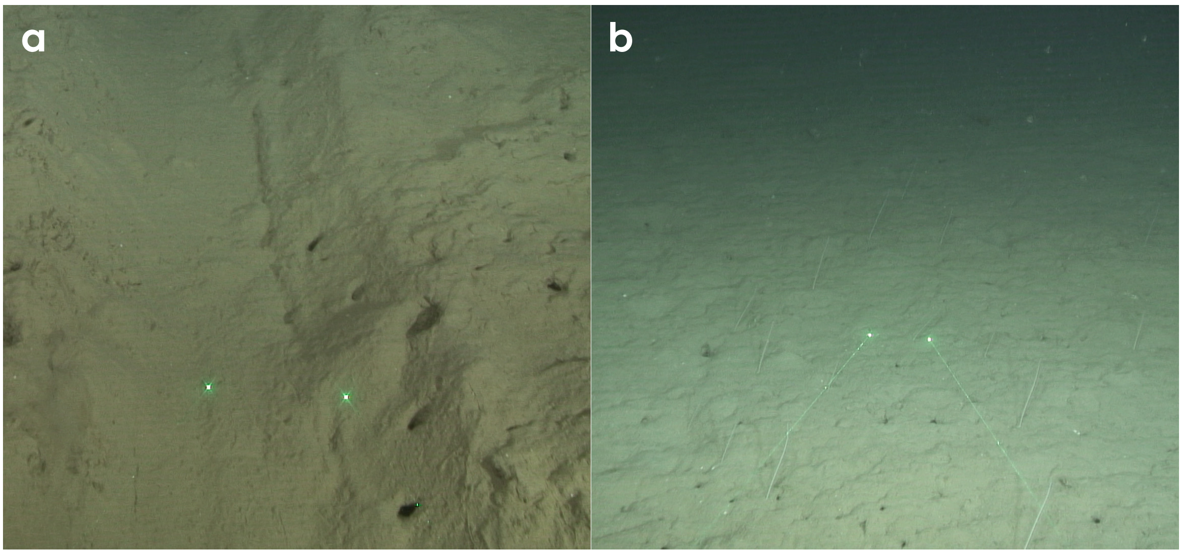


Figure 24. ROV images of closure areas in (a) Barcelona, 400 m depth the protection objective is Norway lobster and (b) Arenys de Mar, 145 m depth the protection objective was European hake recruitment, both areas are closed since 2021 (1.5 years).

c. 5 years closed

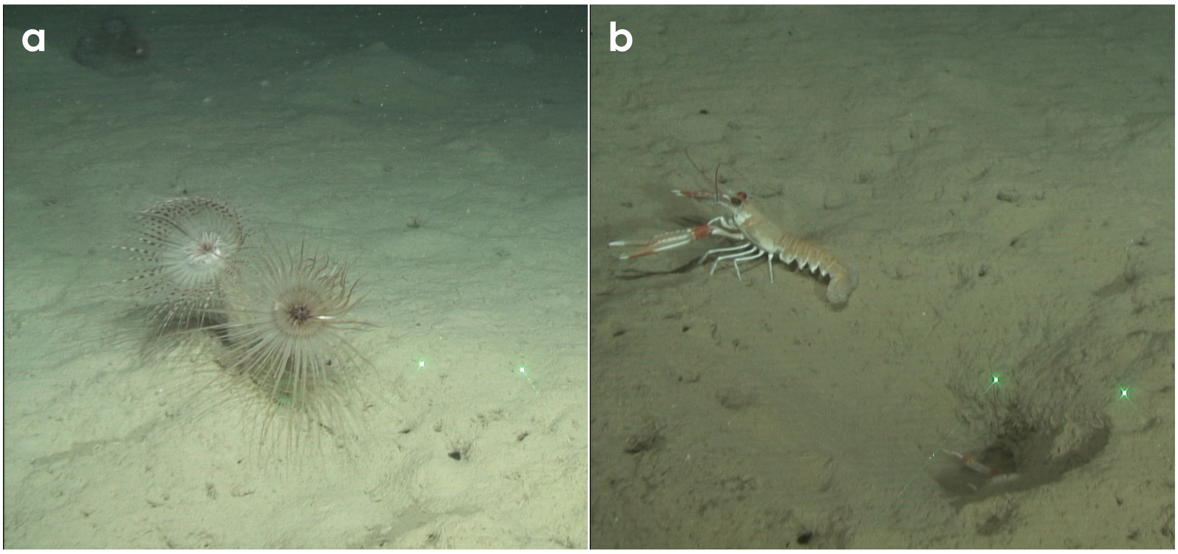


Figure 25. ROV image of closure areas in Roses/Palamós, depth 330-450 m, closed since 2017 (5 years), the protection objective is Norway lobster. (a) Benthic invertebrates, *Cerianthus spp.* and (b) two Norway lobsters.

d. 10 years closed

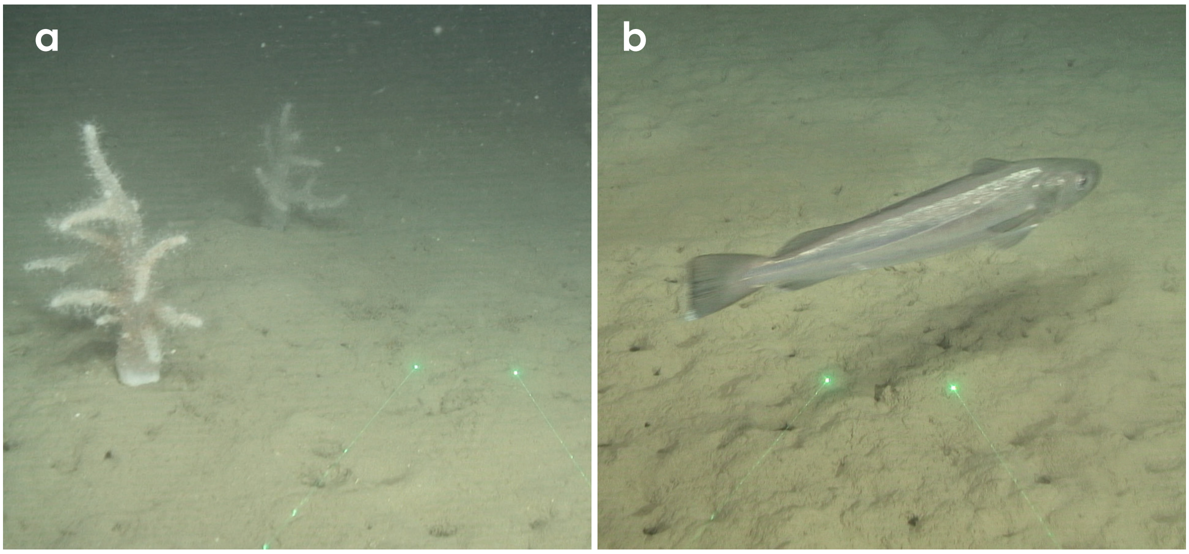


Figure 26. ROV images of closure areas in Roses, depth 130-170 m, closed since 2013 (10 years), the protection objective is European hake recruitment. (a) Benthic invertebrates, *Alcyonium spp.* and (b) European hake.

Effects of protection at different depth ranges

The effects of the protection are sensibly different depending on the depth range of the closure. The shallower monitored areas at 150 m show hydrozoa with a seabed structure of burrows in the protected areas (Figure 27A). Over bottoms of 250 m there is presence of small crustaceans, flatfish (*Lepidorrhombus boscii*) and other fish species such as *Helicolenus dactylopterus* (Figure 28). The deepest monitored areas have bottoms of 400 m and show a tridimensional structure with the presence of cylinder anemones of the genus *Cerianthus* (Figure 29A). In contrast, the control areas outside of the MPAs show trawl marks and plowed seabed, or flat surfaces with few or no burrows (Figure 29B, Figure 27B, respectively).

a. Continental shelf (150-200 m)

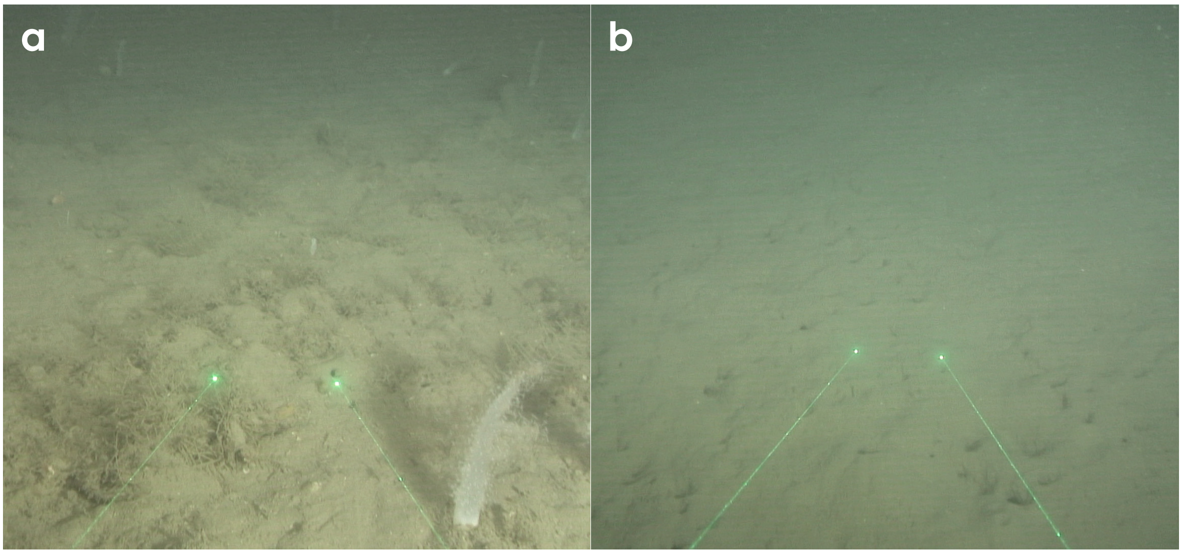


Figure 27. ROV images of (a) closure area and (b) fished control area in Bol de bruixes (Blanes), depth 150-200 m.

b. Upper slope (> 200 - 400 m)

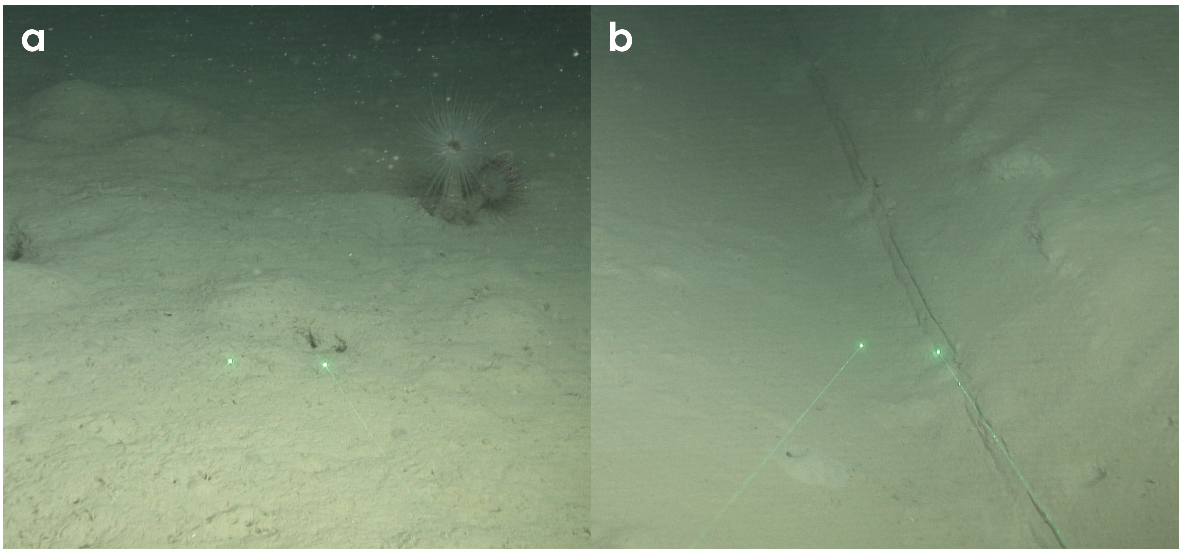


Figure 28. ROV image of (a) closure area and (b) fished control area in Blanes, depth 250m.

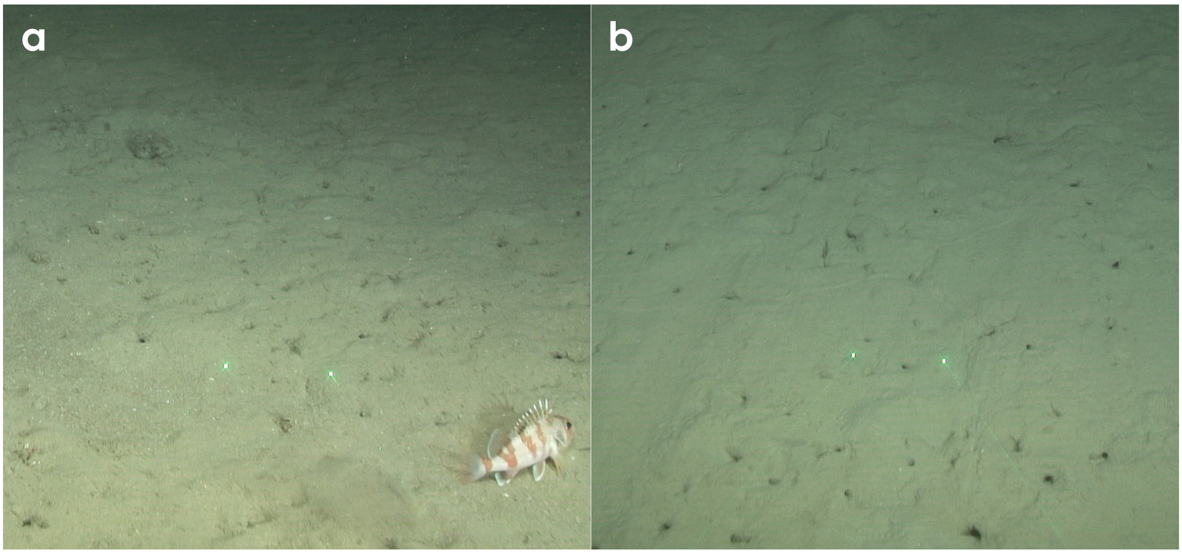


Figure 29. ROV image of (a) closure area and (b) fished control area in Roses/Palamós, depth 400 m.

B) AUV imagery

The othomosaic of the closure area 10 (Cigala Barcelona) was captured in an area between 360 and 370 m. The general views (Figure 30.2 and 30.3) show 9 ensembles of burrow openings, while Figure 30.4 shows burrow openings for Norway lobster, with an individual in one of the openings. The dark bands in Figure 30.2 and 30.3 are artifacts due to the difference in lighting in the sides and center of the images. Figure 30.3 clearly shows three trawl marks, which gives a glimpse of the utility of this technique to thoroughly monitor the state and recovery path of the closure areas every year.

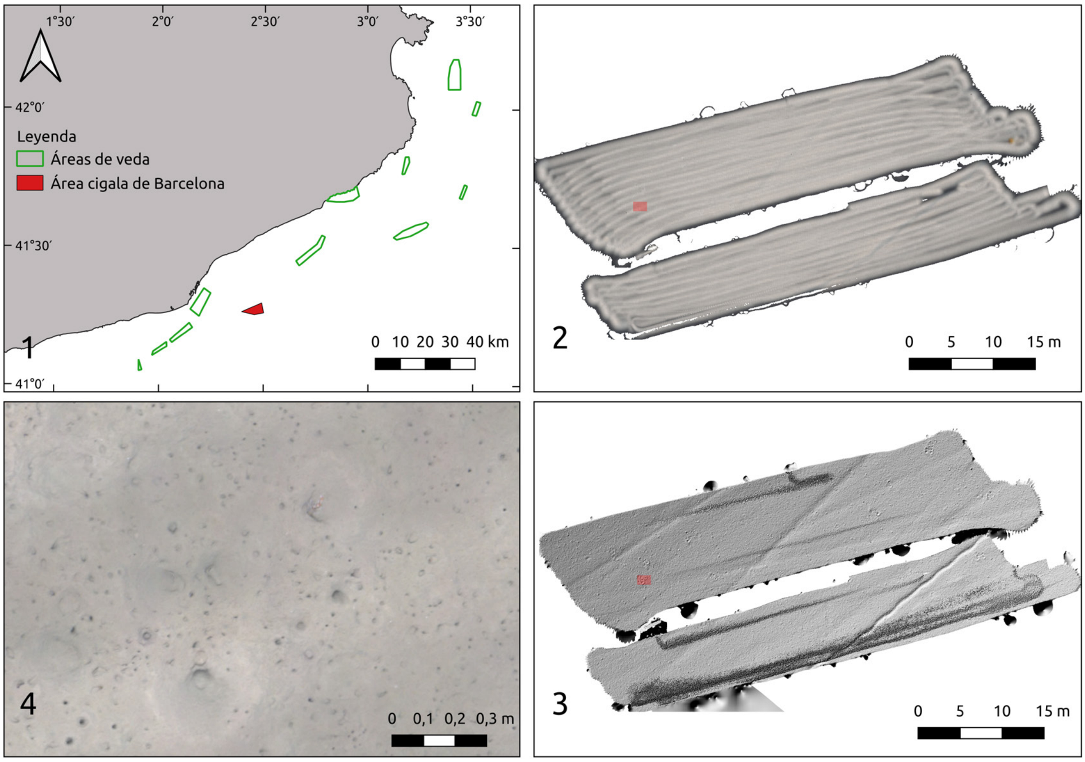


Figure 30. General views (1,2, 3) and orthomosaic image (4) of area 10 (Cigala Barcelona) captured with an Autonomous Underwater Vehicle (AUV). 1: Overview and location of the closure area. 2: Overview of the AUV track, red square represents orthomosaic area. 3: Overview of the surveyed area showing the relief, red square represents orthomosaic area. 4: Orthomosaic image.

Next steps: methodology for monitoring of closures with ROV and AUV data

Since the project has only recently started and the data have not yet been analyzed, we here present an overview of the methodology we intend to follow in order to evaluate the effects of the protection of these 25 areas with non-invasive techniques. It is an extension to the whole GSA 6 of the work done by Vigo et al. (2023) on a Norway lobster closure in the northern part of this region.

The ROV images will be analyzed and all species identified to the lowest possible level. The data will be standardized to obtain abundance values (in number of individuals per km^2). The Chao index will be calculated in order to check the representativity of the sampling. A community matrix can then be built from the data both in and outside the closure areas, and a NMDS representation of the data can give an idea of the dissimilarity of the communities in adjacent habitats with and without protection. Then, to determine which species are most responsible for the differences in the communities inside and outside the closure areas, a percentage similarity analysis (SIMPER) will be performed. The statistical analysis can take into account the following factors: protection (inside vs. outside the closure area), time since protection (control, 1 year, 5 years and 10 years, with the necessary annual adjustments for the subsequent cruises), and depth range (150-200 m, 250 m and 400 m).

For target species, the biomass can be estimated from measurements using the available length-weight relationships. These data can then be compared to ICATMAR monitoring data and distribution estimations for the main commercial species of the Northern GSA 6, for a better understanding of the effects of the protection of these areas in a wider context.

Regarding AUV imagery, this newly applied technique will ensure a thorough yearly monitoring of the structure and recovery stage of the closure areas, which can effectively complement the ROV imagery analysis and elaborate on certain aspects such as relief and presence of fauna.

Conclusions

- Permanent closures are more efficient in reducing yearly fishing effort than temporary closures. Temporary closures do not ensure habitat regeneration or ecosystem services restoration, since overall effort is not reduced.

- No evidence of fishing effort redistribution in the closure areas surroundings were found in the analyzed areas.

- Consistent spillover evidences were found for 6 of the 13 species analysed (*Mullus* spp, *Lepidorhombus* spp, Triglidae spp, *Helicolenus dactylopterus*, *Scorpaena* spp. and *Zeus faber*). In general, this effect seems more likely to appear for middle-sized epibenthic and benthopelagic fishes. First spillover evidences are detectable 4-5 years after the permanent protection of the area.

- Preliminary results show a reduction of trawl marks and a steady recovery of the seafloor structure and associated species inside permanent closure areas that are progressive after the establishment of the protection.

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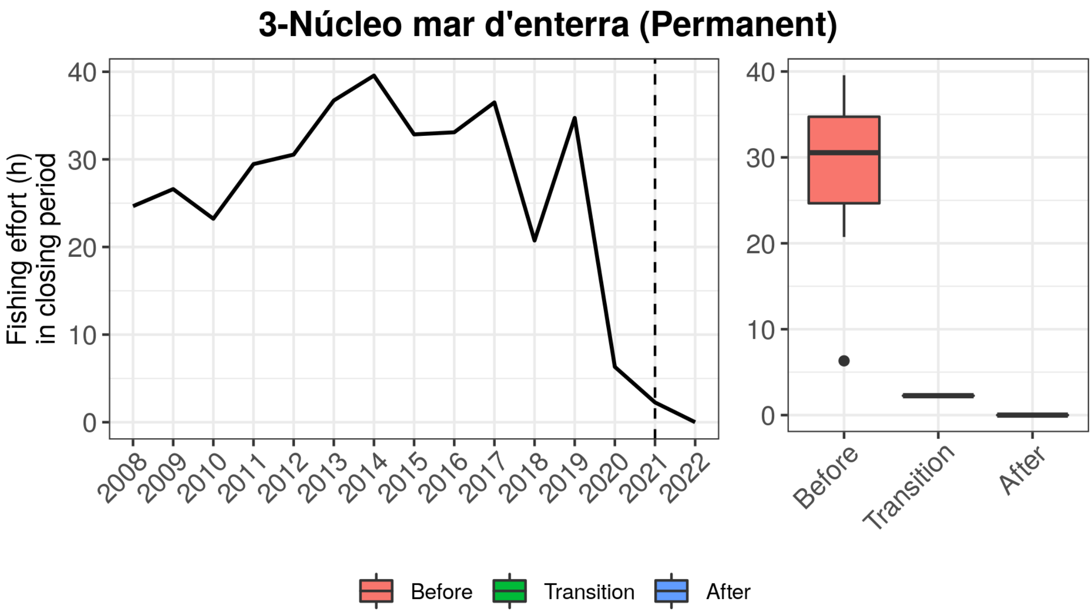
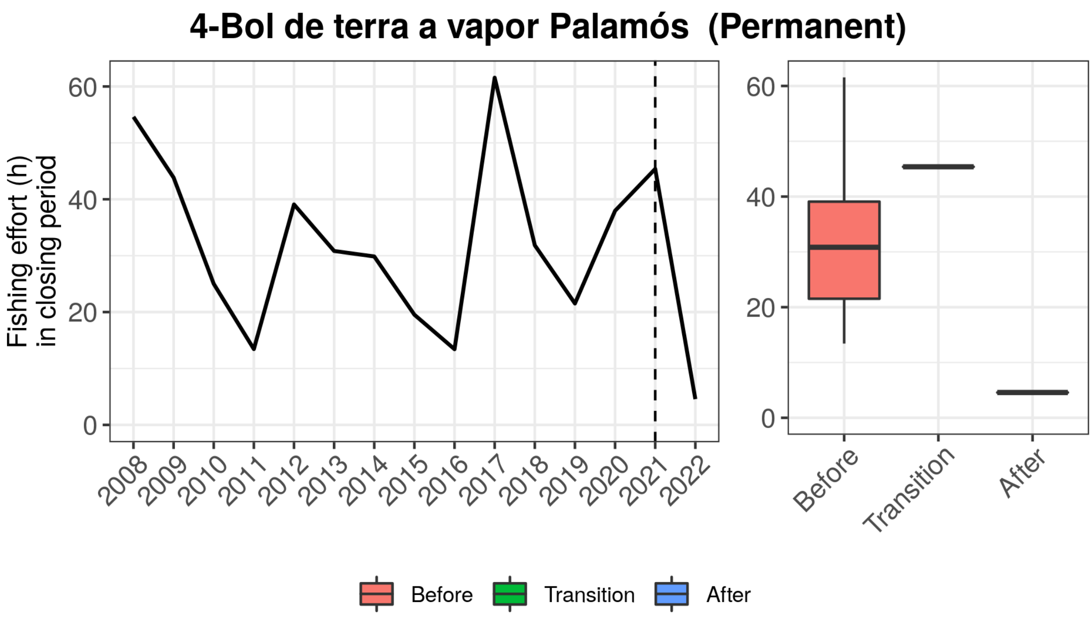
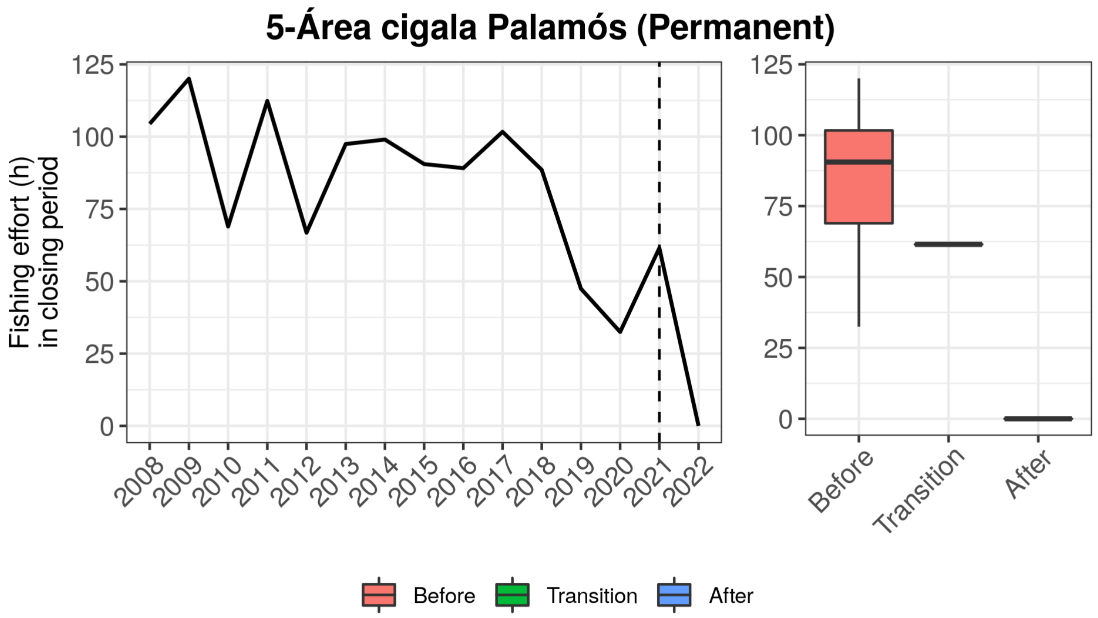
Annexes



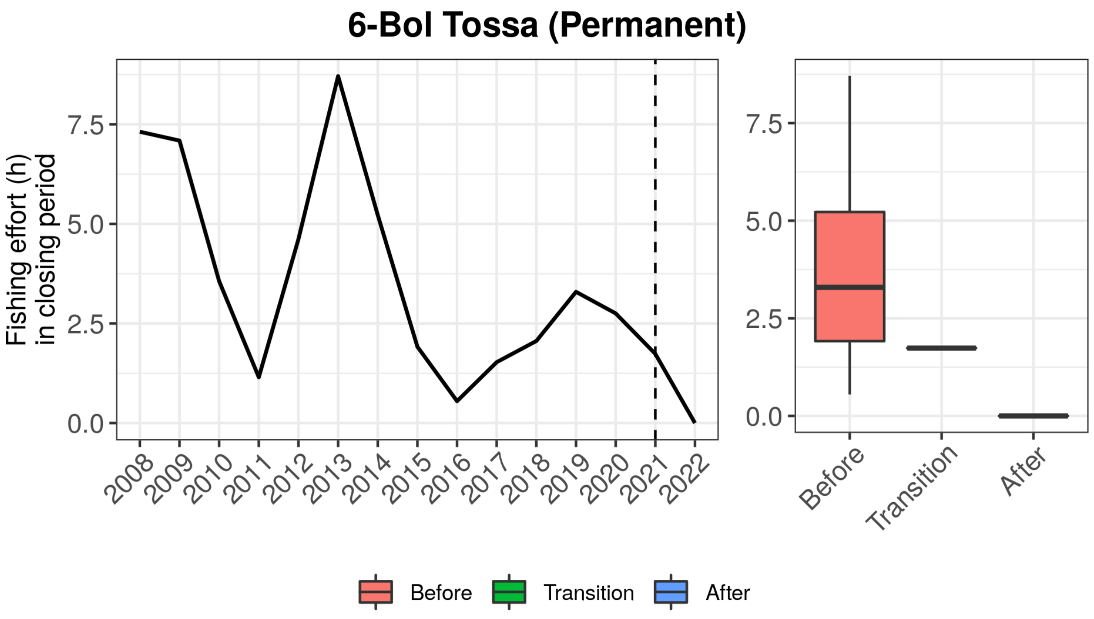
Annex 1. Effort reduction in the area 3, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



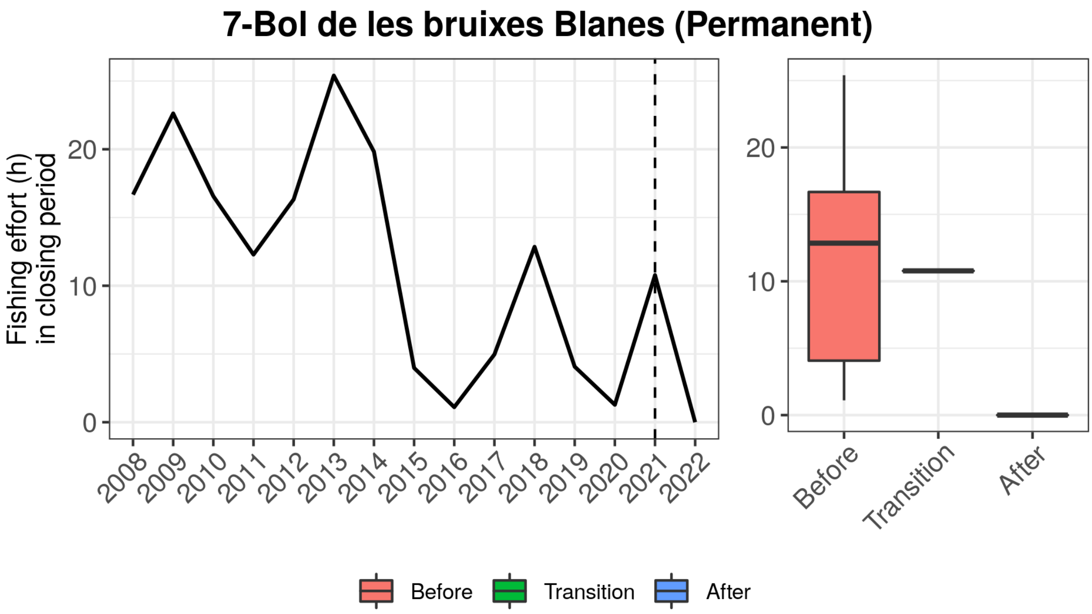
Annex 2. Effort reduction in the area 4, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



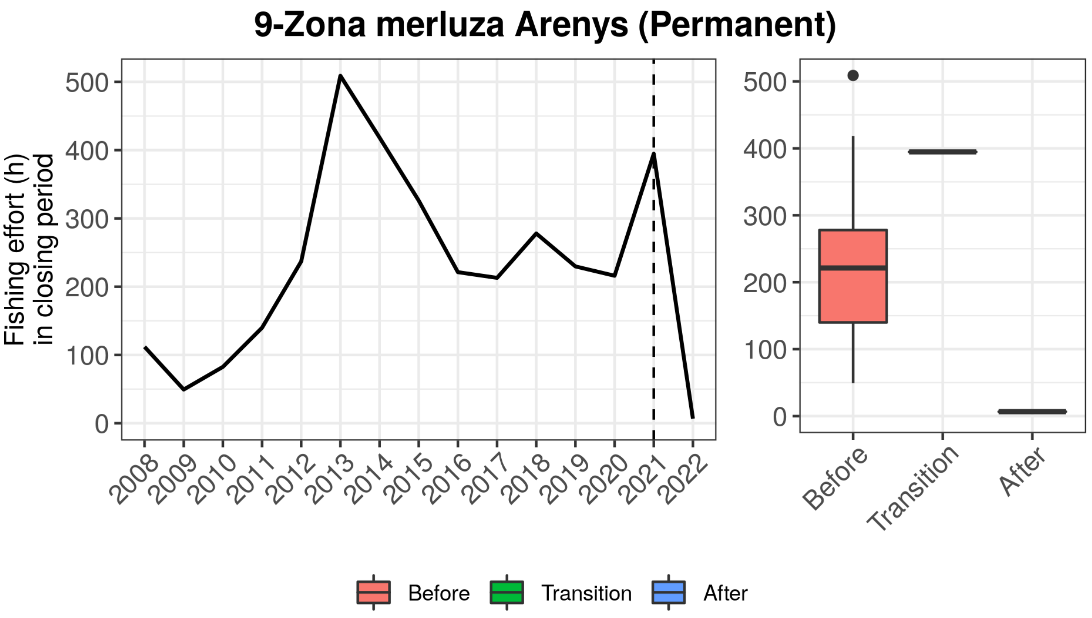
Annex 3. Effort reduction in the area 5, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



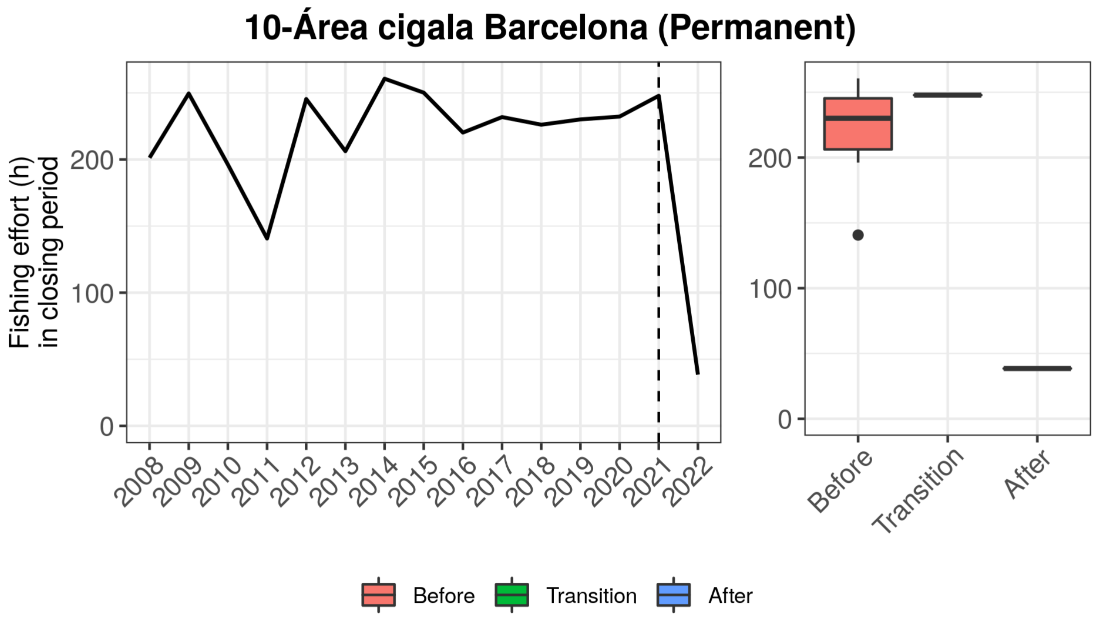
Annex 4. Effort reduction in the area 6, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



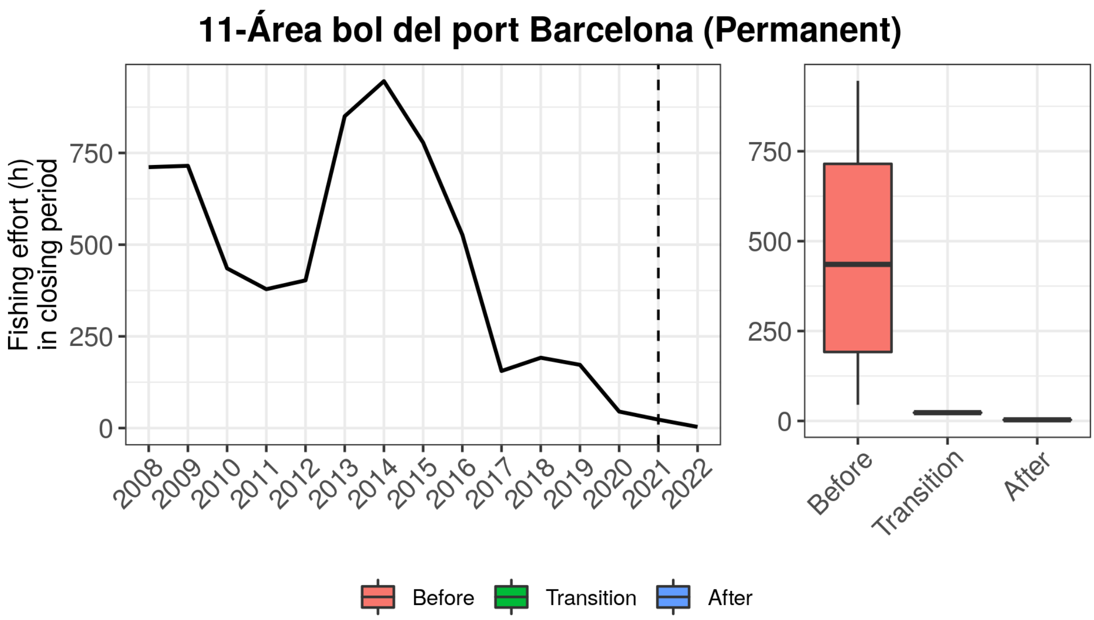
Annex 5. Effort reduction in the area 7, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



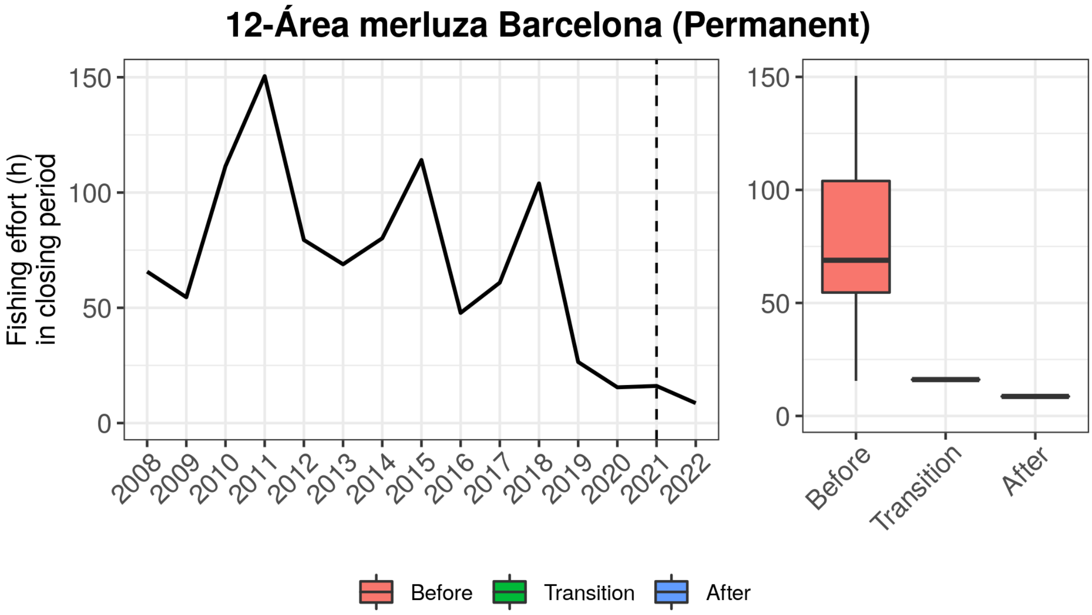
Annex 6. Effort reduction in the area 9, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



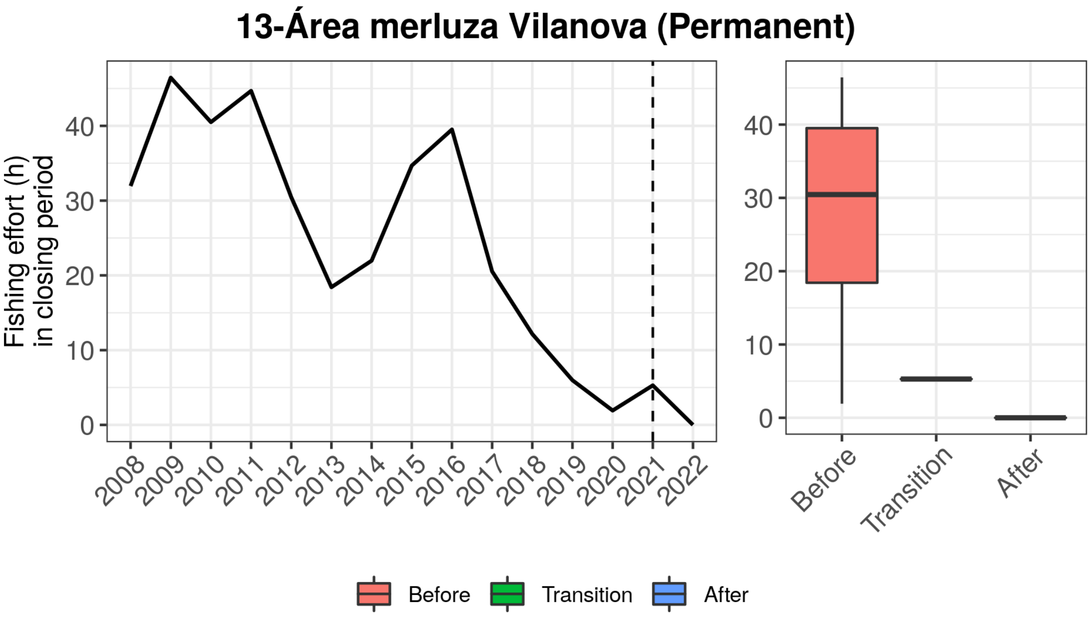
Annex 7. Effort reduction in the area 10, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



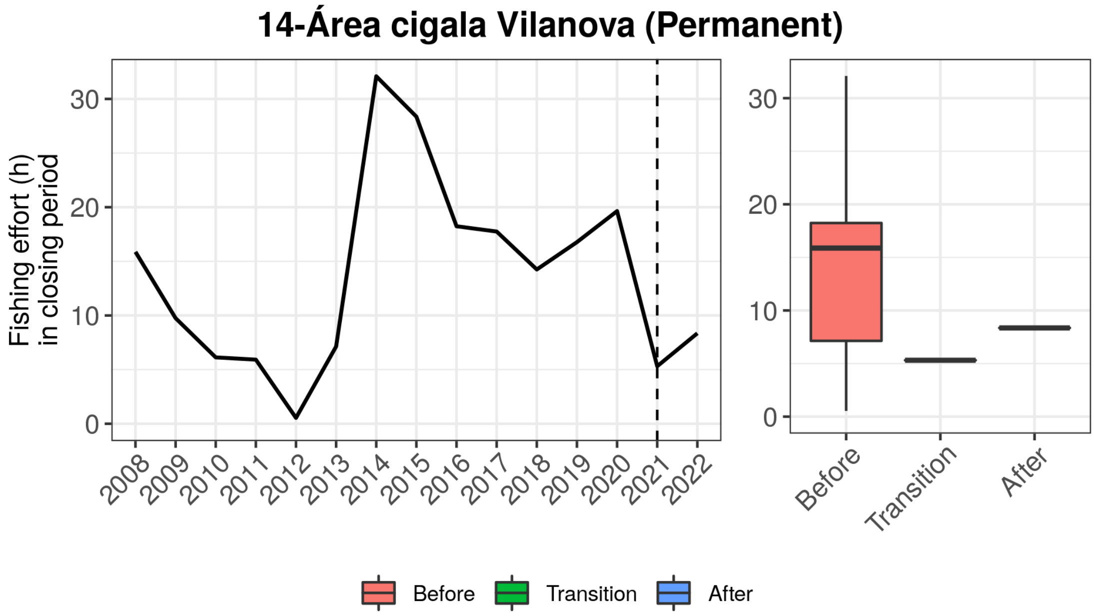
Annex 8. Effort reduction in the area 11, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



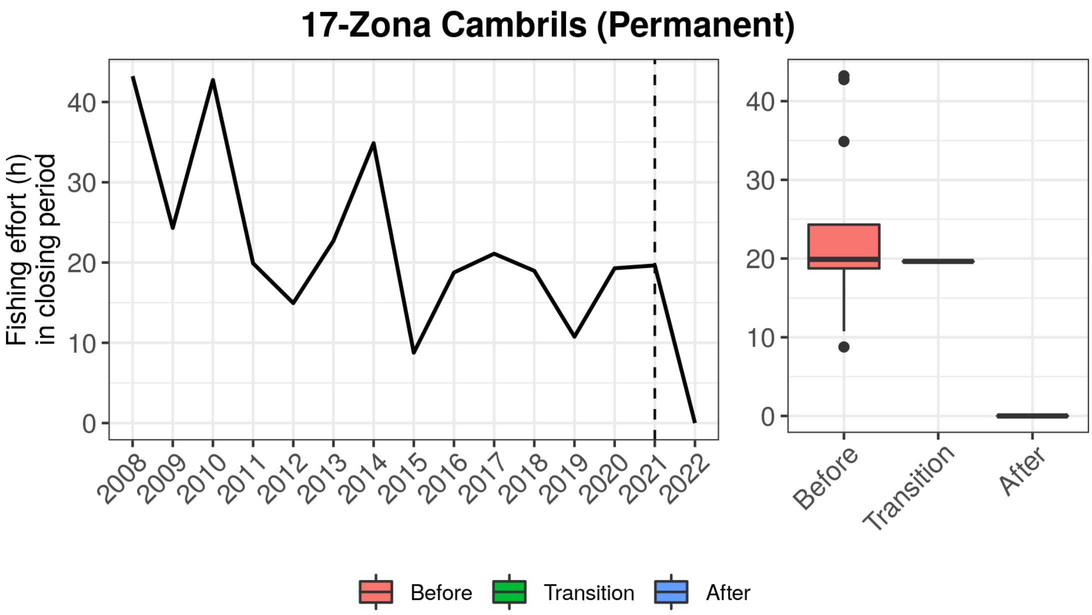
Annex 9. Effort reduction in the area 12, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



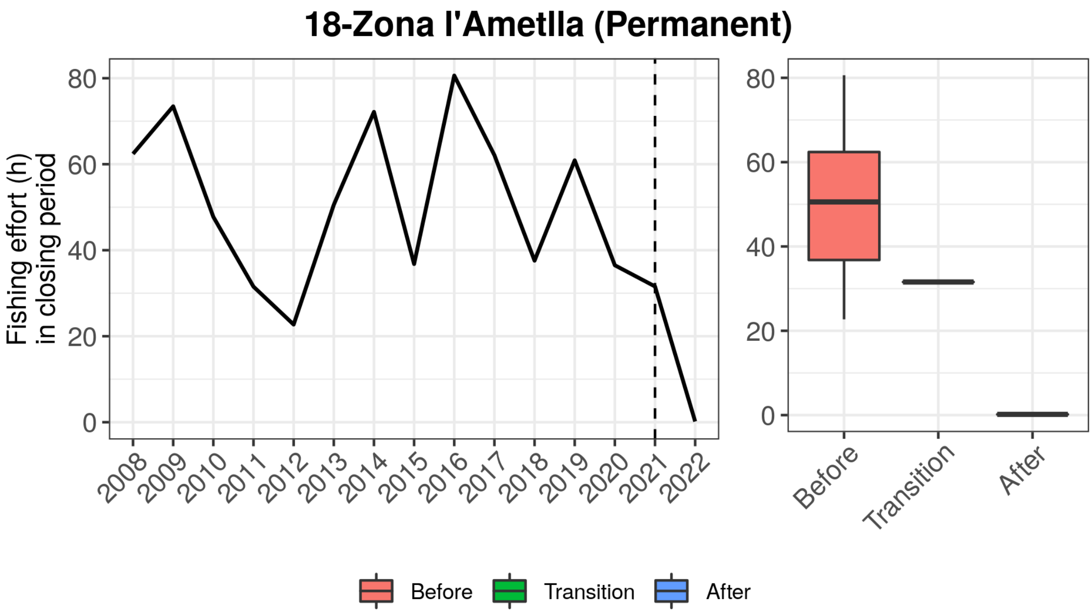
Annex 10. Effort reduction in the area 13, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



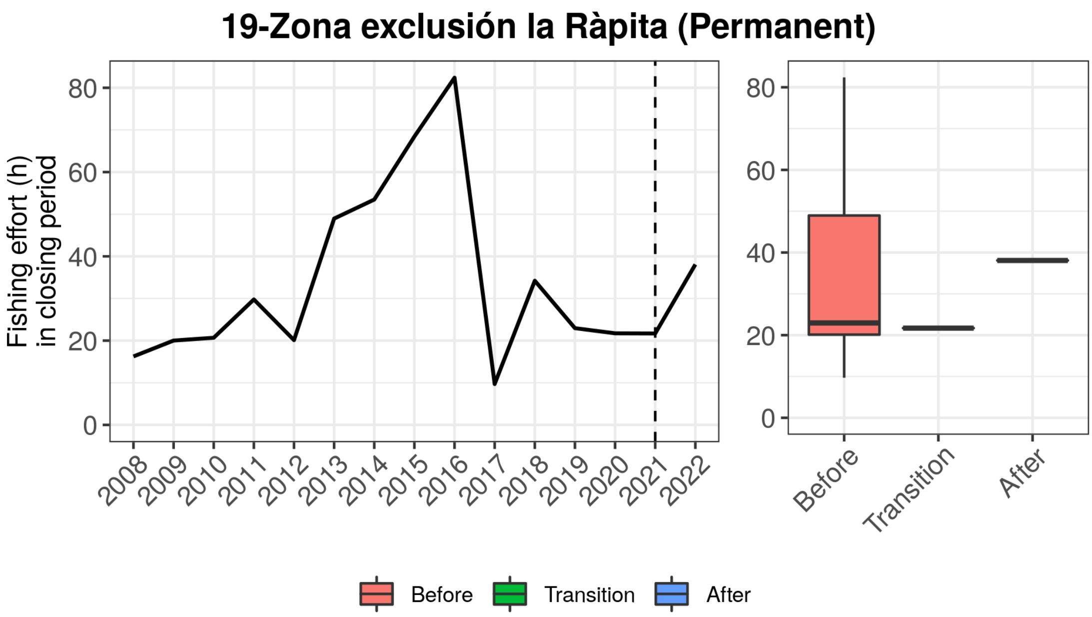
Annex 11. Effort reduction in the area 14, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



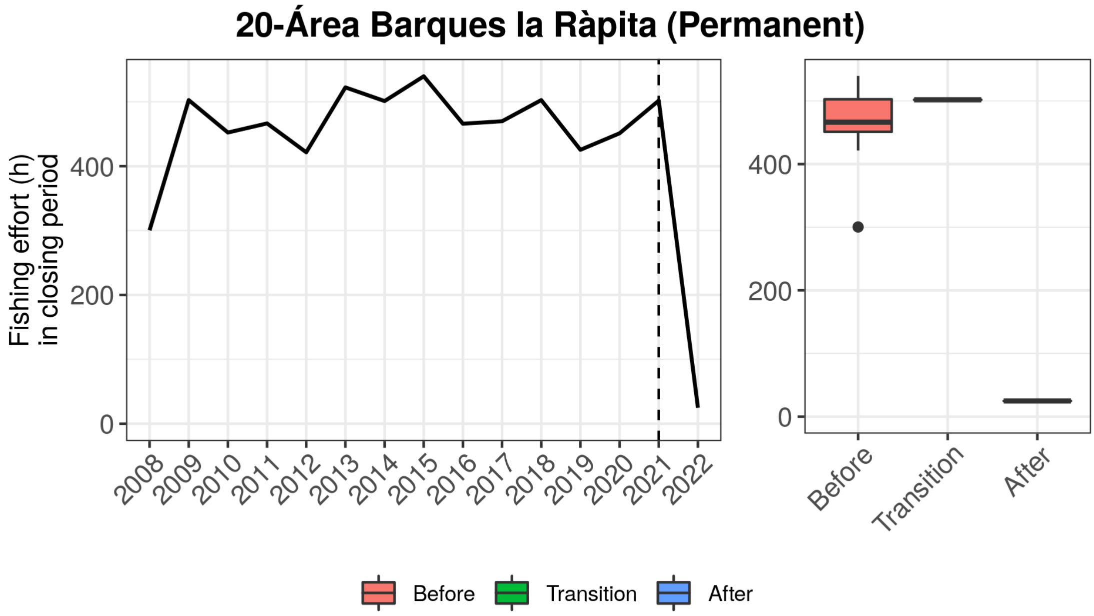
Annex 12. Effort reduction in the area 17, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



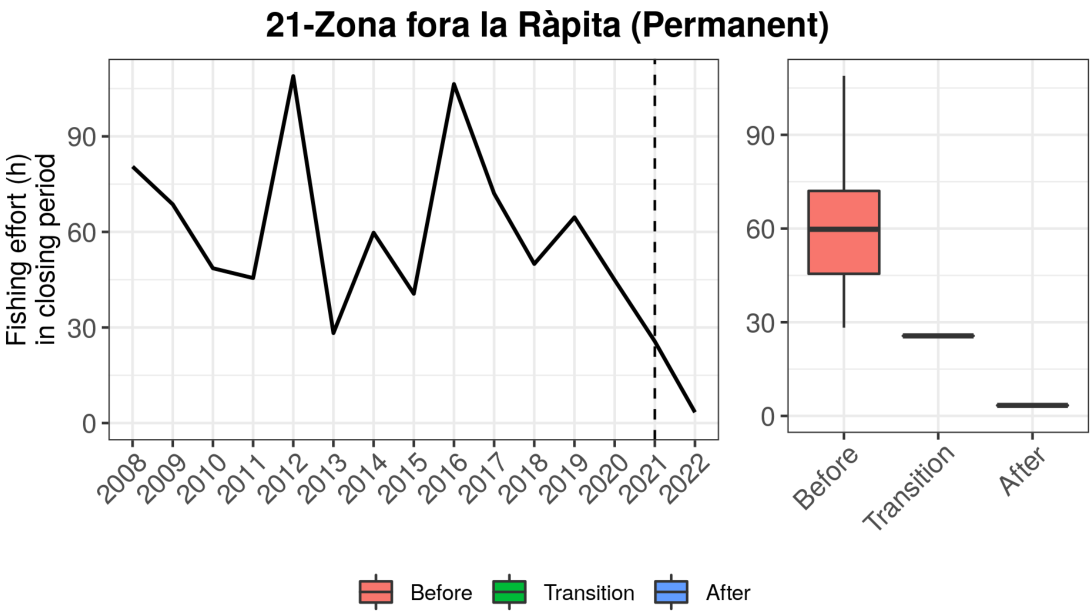
Annex 13. Effort reduction in the area 18, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



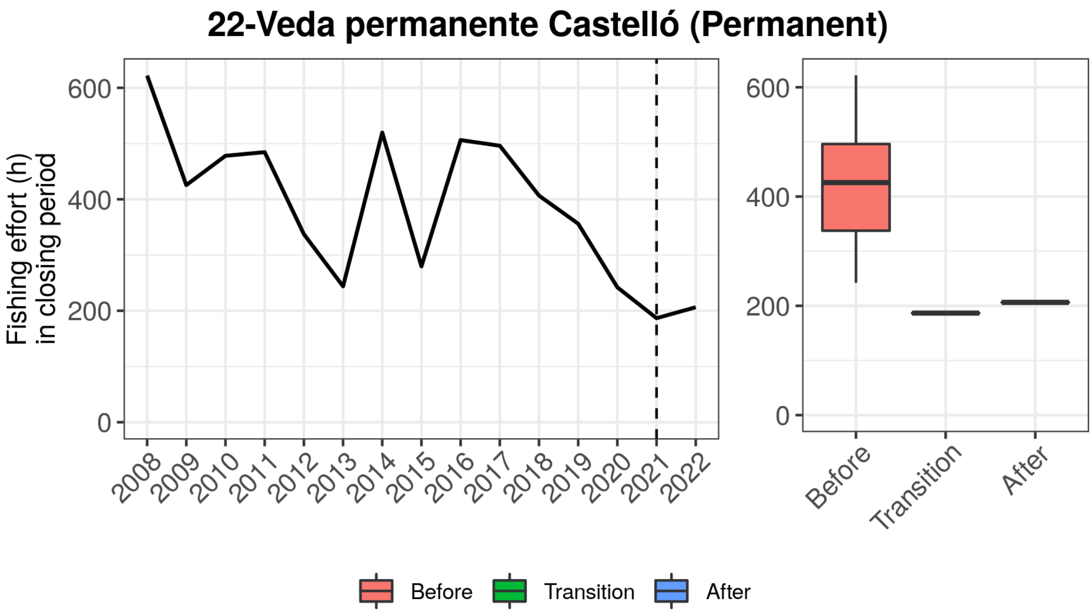
Annex 14. Effort reduction in the area 19, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



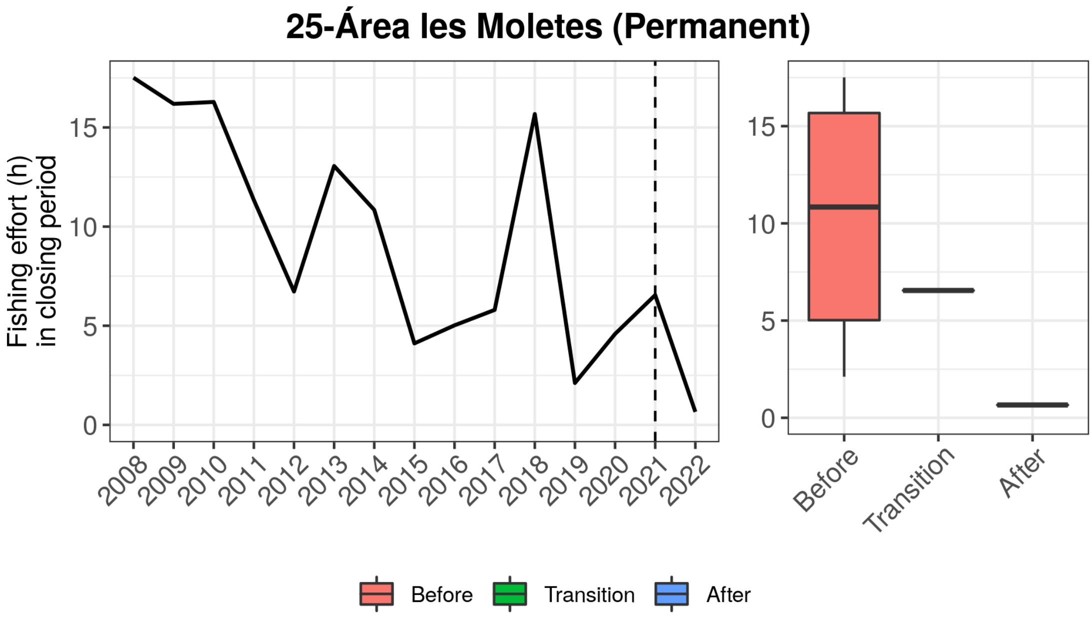
Annex 15. Effort reduction in the area 20, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



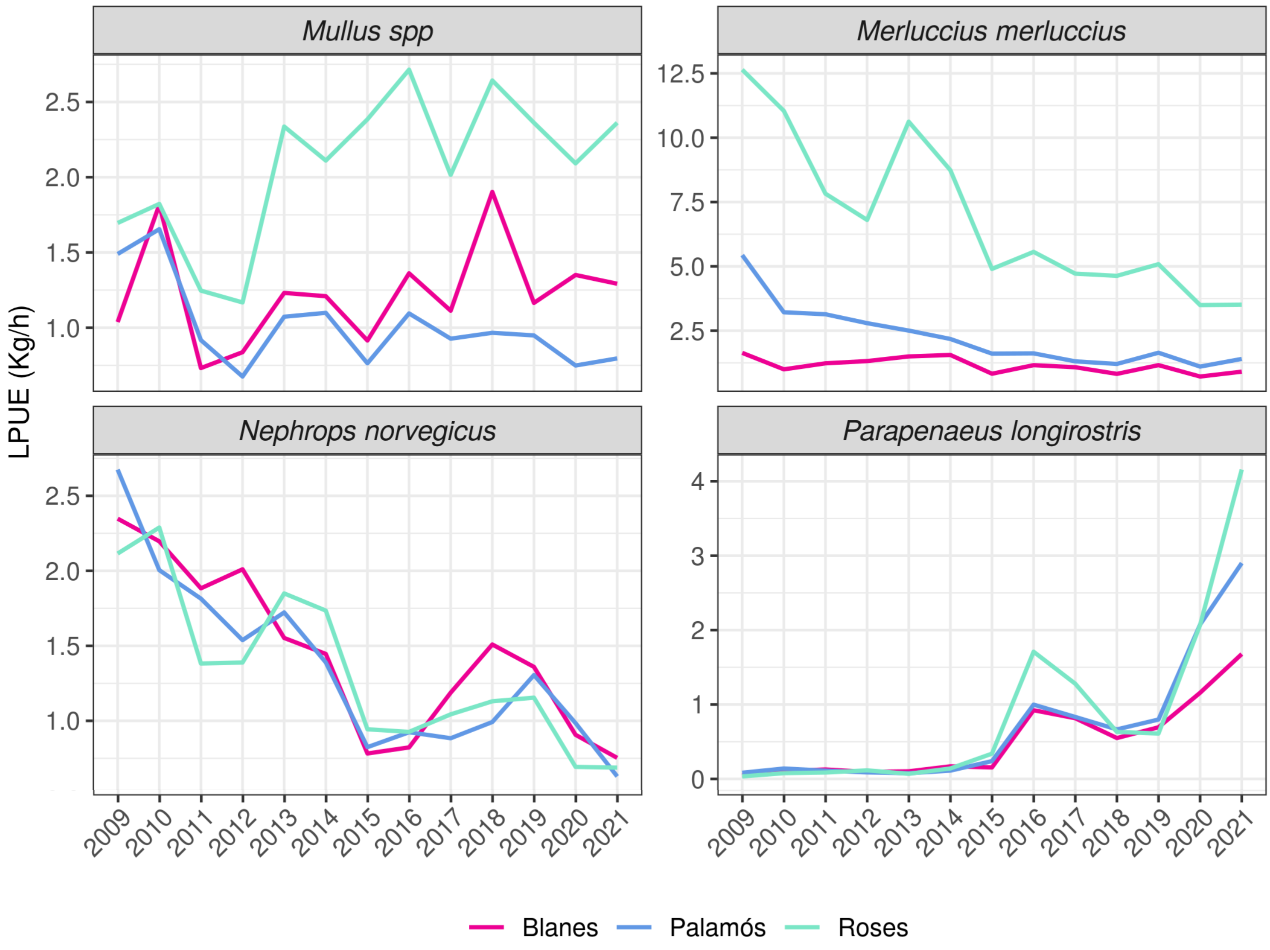
Annex 16. Effort reduction in the area 21, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



Annex 17. Effort reduction in the area 22, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



Annex 18. Effort reduction in the area 25, permanent closure area since 2021. Historical fishing effort in this area (left), differences in fishing effort before and after closure (right). Transition period represents the year of the official closing of each area. Dashed line indicates year of closure.



Annex 19. Historical LPUE (landings per unit of effort) for the four indicator species of MAP (Multiannual Plan) in the three ports located nearest the closed area tested for spillover effects.

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