ASSESSING SPILLOVER FROM MARINE PROTECTED AREAS TO ADJACENT FISHERIES

Baltic and North Seas, Atlantic EU Western Waters and Outermost Regions

Final Report

Annex 6: Case Study Reports

European Maritime, Aquaculture and Fisheries Fund (EMFAF)

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ANNEX 6: CASE STUDY REPORTS

Fifteen case studies in the Baltic Sea, North Sea, EU Atlantic Western Waters and some outermost regions (focusing on the Azores, Madeira and Canary Islands) were selected to gather insights into potential spillover effects of different types of marine protected areas (MPAs) (Table 1). The majority of the case studies (11) is located in the European Union (EU) waters (Belgium, France, The Netherlands, Poland, Portugal, Spain and Sweden); four case studies are located in non-EU waters (Norway and the United Kingdom).

In this case study work, besides studying typical MPAs, 'other effective area-based conservation measures' (OECMs), including offshore wind farms (OWFs) were also investigated, as they might be as relevant in the study of spillover effects. OECMs represent geographically defined areas outside formal protected areas which contribute to positive and sustained long-term outcomes for the *in situ* conservation of biodiversity.

The selection of case studies was made mainly based on geographical coverage and data availability to assess potential spillover effects. The case studies are well-spread in the different sea basins, cover an array of Member States and nations, but also vary in the type of species (e.g. fish, crustacea, bivalves) and type of data that are available (e.g. fishery data, trap data, tagging data, capture-recapture data). In the case studies, the spillover effects are analysed based on qualitative and/or quantitative analytical approaches, using available data and/or a stakeholder survey.

Case studies on the assessment of potential spillover effects. The numbers in the first columns are hyperlinked to the relevant case studies.

Nr	Case Studies	Country	Regional Sea
1	Gotska Sandön Marine Protected Area	Sweden	Baltic Sea
2	Słowiński and Woliński National Parks	Poland	Baltic Sea
3	Tvedestrand Marine Protected Area	Norway	Skagerrak
4	North Sea Coastal Zone	The Netherlands	North Sea
5	Borssele offshore wind farm zone	The Netherlands	North Sea
6	Belgian offshore wind farm	Belgium	North Sea
7	Lyme Bay Marine Protected Area	United Kingdom	English Channel
8	Flamanville Protected Area	France	English Channel
9	The Écréhous and the Minquiers	Jersey	English Channel
10	Lamlash Bay and South Arran	United Kingdom	Celtic Sea
11	Atlantic Islands National Park of Galicia	Spain	Iberian Coast
12	Professor Luiz Saldanha Marine Park	Portugal	Iberian Coast
13	Formigas Marine Protected Area	Portugal	Macaronesia
14	Selvagens Islands Marine Protected Area	Portugal	Macaronesia
15	La Graciosa Marine Protected Area	Spain	Macaronesia

1. CASE STUDY REPORT:

THE GOTSKA SANDÖN MARINE PROTECTED AREA

SWEDEN – BALTIC SEA


Juvenile turbot (*Scophthalmus maximus*), the main target species of the no-take zone at Gotska Sandön in the Baltic Sea. © Ulf Bergström

Analysis of potential spillover effects from the Gotska Sandön MPA via larval export of flatfish

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LIST OF ABBREVIATIONS

Term	Description
CPUE	Catch per unit effort
NTZ	No-take zone
SE	Standard error

1 EXECUTIVE SUMMARY

In 2006, a 360 km^2 no-take zone prohibiting all fishing activities was established around the island of Gotska Sandön in the central Baltic Sea (Sweden), with the primary aim of protecting the flatfish nursery grounds in the area. Local populations of both turbot (*Scophthalmus maximus*) and Baltic flounder (*Platichthys solemdali*) initially responded positively to the establishment of the no-take zone and the densities remained higher in the no-take zone in comparison with a fished reference area at the eastern coast of the island of Gotland.

Previous modelling work showed that larval export rates from the no-take zone to the fished reference area could be substantial, suggesting that the reference area may benefit from spillover effects. The goal of this case study was to estimate the magnitude of the larval export from the no-take zone to the reference area for both turbot and Baltic flounder, based on monitoring data of densities and size structure in the no-take zone, as well as modelled larval export rates. The data consist of 5 years of gillnet survey data (2006−2009, 2021) providing catches per species and size group, for both the no-take zone and the reference area. The previously published modelled larval export rates are based on particle-tracking using output from a hydrodynamic model.

Our results suggest that the larval export from the no-take zone to the reference area is of a similar magnitude to the local larval production in the reference area, and in some years even larger in the case of flounder. As densities of both large flounder and large turbot in the no-take zone, and thus also larval export from the no-take zone, initially increased following the establishment of the no-take zone, this suggests that the fishery closure may have generated spillover effects benefitting the flatfish populations and fisheries at the eastern Gotland coast.

There were initially some positive signs in fish densities and landings in the reference area following the establishment of the no-take zone, but these were not consistent across time or species. Lower densities of large flounder and large turbot in the early 2020s, compared to the time of establishment of the no-take zone, have likely resulted in reduced larval export to the reference area. No clear cause for the decline has been identified, but predation from seals and cormorants may have contributed. More years of data on the densities of flounder and turbot are needed to establish whether this is a stable long-term trend, or only interannual variation.

Estimates of spatio-temporal variability in egg and larval mortality rates, as well as empirical confirmation of the estimated contribution from the no-take zone to the reference area, would be helpful for better assessing spillover effects. In a wider perspective, our results suggest that species with a pelagic drifting phase will be more likely to generate spillover effects if no-take zones or other protective measures are implemented in areas with hydrodynamic conditions that favour dispersal to other suitable habitats.

To sum up, the estimated spillover of flatfish larvae from the Gotska Sandön no-take zone to a fished reference area at Gotland is surprisingly large, especially considering the long distance between the no-take zone and the area benefitting from the larval export (ca. 100 km). However, due to declines in turbot and flounder densities in the no-take zone in recent years, this spillover effect may have diminished over time, and there are no clear signs of a positive long-term effect on flatfish densities and fishery landings in the reference area. Further empirical work would be necessary to verify the spillover effect. Nonetheless, this study points to the importance of considering the ecological connectivity between areas to maximise the benefits of spillover effects on species with a pelagic drifting phase when designing a protected area.

2 BACKGROUND

A no-take zone (NTZ) was established around the island of Gotska Sandön in the central Baltic Sea in 2006 (Figure 1; see Bergström et al. 2022 for details). The NTZ prohibits all types of fishing, commercial and recreational, and was established as part of a government commission to introduce and evaluate the effects of NTZs on fish and fisheries in Swedish waters. The NTZ covers 360 km^2 of soft sediments, the majority of it is sand. Gotska Sandön itself (44.9 km^2) is a national park, and the surrounding waters are part of the Natura 2000 site Gotska Sandön-Salvorev, meaning that the area is also protected from construction and extraction. The main purpose of the Gotska Sandön NTZ is to protect local populations of flatfish, in particular turbot (*Scophthalmus maximus*), the endemic Baltic flounder (*Platichthys solemdali*) and the European flounder (*Platichthys flesus*), for which the area serves as important nursery grounds.

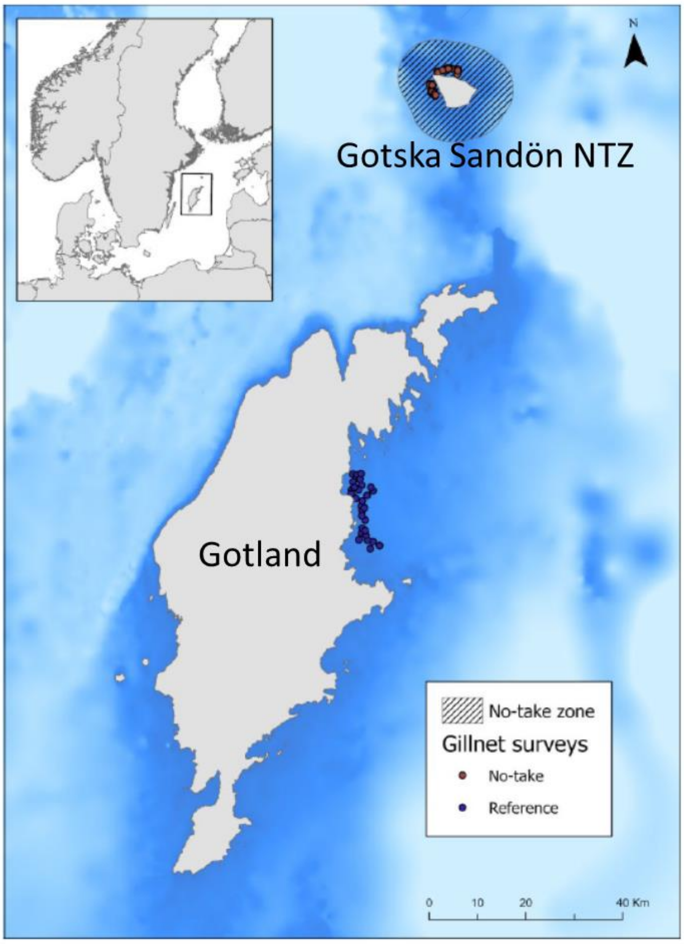

Figure 1: Map of the Gotska Sandön no-take zone (NTZ) and the location of each gillnet survey station in the NTZ and in a fished reference area on the eastern side of the island of Gotland. Inset shows the location of the NTZ within the Baltic Sea. From Bergström et al. 2022.

The waters around Gotland have traditionally been one of the most important grounds for flatfish fisheries in the Baltic Sea. While flounder catches remained fairly constant during the 1990s and early 2000s, the catches of the more valuable turbot declined significantly during the period, likely as a result of the high fishing pressure (Florin et al. 2013). The recreational catches of flounder and turbot have been estimated to be of the same magnitude as the commercial landings (Florin et al. 2013). In recent years, the landings of both turbot and flounder have continued to decrease (Bergström et al., 2022), attributable to the decline in the coastal fishing sector.

The fishing closure initially resulted in a significant increase in the densities of flounder and large turbot (with sizes of at least legal retention size: 21 cm and 30 cm, respectively) within the NTZ (Florin et al. 2013; Figures 2, 4−5). However, new data collected in 2021 show that Catch Per Unit of Effort (CPUE) in the NTZ was lower than just after establishment (2007-2009), in particular for large turbot (Bergström et al. 2022; Figures 2, 4−5). CPUE of small (smaller than 30 cm) turbot in 2021, however, was similar to CPUE just after NTZ establishment (Figure 3). The development of the flatfish stocks in the NTZ has also been compared to the developments in a fished reference area off the east coast of the island of Gotland, located to the south of Gotska Sandön. The reference area was chosen because its habitat is similar to that of the NTZ, and fishing pressure in this area was expected to be relatively high (Florin et al. 2013). There is no comparable data on the fish stocks in the reference area prior to the fishing closure, but after the NTZ was established, it hosted higher densities of both large and small turbot compared to the reference area (Florin et al. 2013; Figures 2−3). Turbot in the NTZ were also older and displayed a more even sex ratio (Florin et al. 2013). Densities of flounder were also higher in the NTZ (Figures 4−5), although growth was slower, suggesting density-dependent growth (Florin et al. 2013). The higher densities in the NTZ compared to the reference area have remained over time (Bergström et al. 2022; Figures 2−5). The CPUE of large turbot, however, was substantially lower in both areas during the last survey in 2021 compared to just after NTZ establishment.

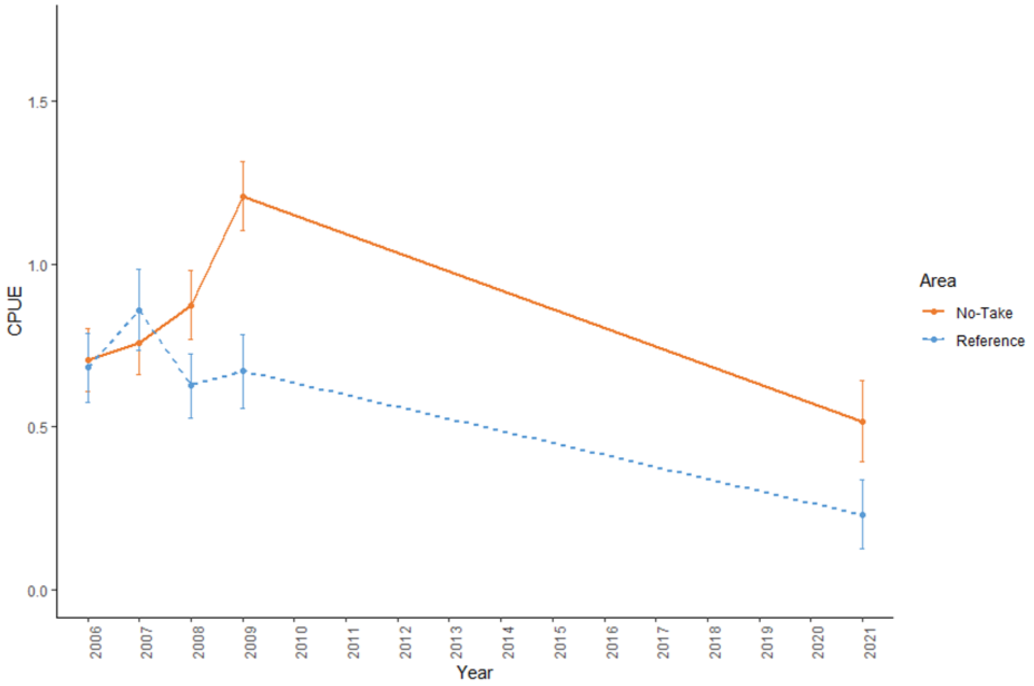

Figure 2: Mean catch per unit of effort for large turbot (above minimum legal landing size; ≥30 cm total length) in the no-take zone and reference area. Values are fourth square-root transformed numbers per station, mean ± SE. From Bergström et al. 2022.

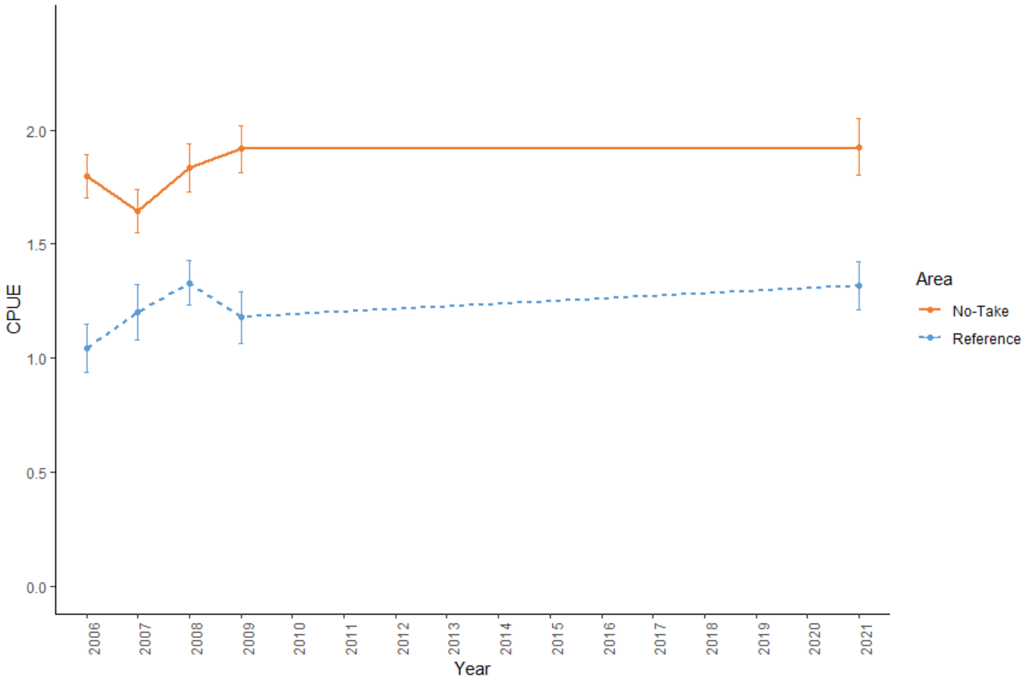

Figure 3: Mean catch per unit of effort for small turbot (below minimum legal landing size; <30 cm total length) in the no-take zone and reference area. Values are fourth square-root transformed numbers per station, mean ± SE, and adjusted for an effect of temperature. From Bergström et al. 2022.

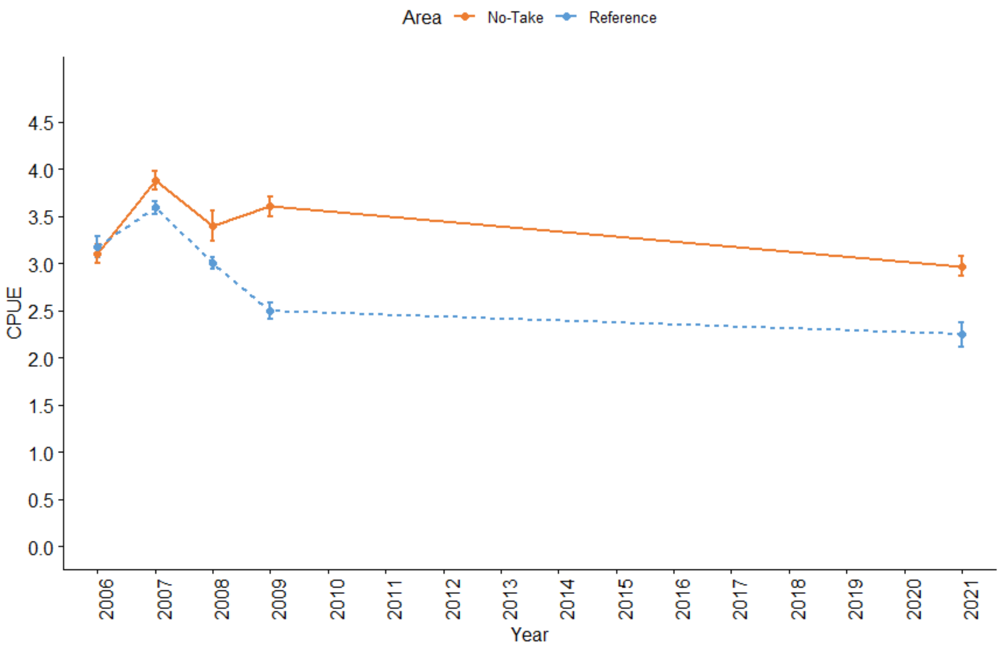

Figure 4: Mean catch per unit of effort for large flounder (above minimum legal landing size; ≥21 cm total length) in the no-take zone and reference area. Values are fourth square-root transformed numbers per station, mean ± SE. From Bergström et al. 2022.

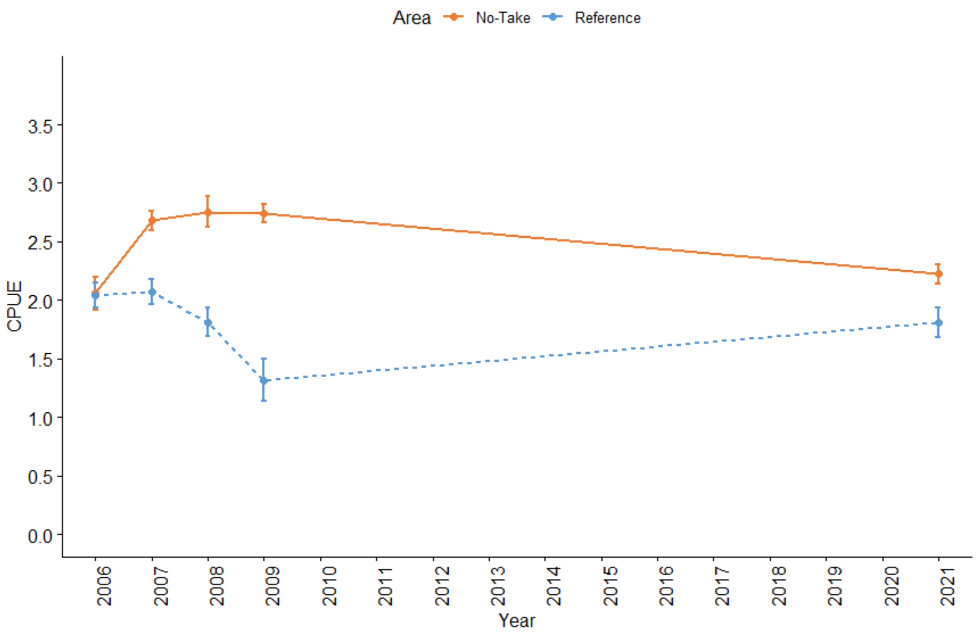

Figure 5: Mean catch per unit of effort for small flounder (below minimum legal landing size; <21 cm total length) in the no-take zone and reference area. Values are fourth square-root transformed numbers per station, mean ± SE, and adjusted for an effect of temperature. From Bergström et al. 2022.

3 AIMS AND OBJECTIVES

As the estimated larval export from the NTZ to the flatfish grounds off eastern Gotland is substantial, it has been hypothesised that the establishment of the NTZ could also result in spillover effects benefitting flatfish on Gotland (Florin et al. 2013). Here, we combine the estimated larval export rates from the NTZ with data on CPUE and size structure to calculate the magnitude of larval export from the NTZ to the reference area off eastern Gotland, and compare this estimate to the level of retention of larvae produced within the area. If there is an estimated net export of larvae from the NTZ to the reference area, we consider this as indicating a potential for ecological spillover. For context, we also present reported fishery landings in both the NTZ and the reference area. As the NTZ was introduced as part of a government programme to evaluate the effects of fishing closures on fish and fisheries, understanding not only the effects on the local populations but also potential spillover effects are important as it can inform future policy and management decisions.

4 METHODOLOGY

Monitoring in the NTZ and reference area

Fish densities and size structure were surveyed by the Swedish University of Agricultural Sciences using 195 m multi-mesh gillnets, comprising 5×9 m sections of mesh size 25, 30, 38, 50 and 60 mm and 3×50 m sections of 75, 100 and 120 mm meshes. The nets were deployed for one night in early June in 2006−2009 and in 2021, in 36 sampling stations in each area (NTZ and reference area). However, not all stations provided data in each year due to unfavourable weather conditions or due to the equipment being tampered with, resulting in smaller actual sample sizes (Table 1). All caught fish were identified, counted and measured. Catches from the 9 m long sections of the net were standardized to 50 m section length to give the same effort for all mesh sizes. These data provide us with the number of fish caught per length per species per net. This can be interpreted as a form of density estimate.

Table 1: Sample size by location and year

Year	No-take zone	Reference area
2006	36	30
2007	35	26
2008	30	36
2009	36	30
2021	29	30

Temperature affects fish activity patterns, meaning that it also affects catch rates. Higher temperatures generally result in higher activity, and thus higher CPUE. An effect of temperature on the catch rate of small turbot and small flounder has previously been identified in the area, but no effect of temperature was identified for large turbot and large flounder (Bergström et al. 2022). As we were only concerned with the larger, reproductive individuals, we ignored the effect of temperature here.

There are two closely related species of European flounder found in the region; the offshore pelagic spawning flounder (*Platichthys flesus*) and the coastal benthic spawning Baltic flounder (*Platichthys solemdali*). During the monitoring period in early June, *Platichthys flesus* are still mainly offshore after spawning and therefore we consider most of the European flounder caught during sampling to be the coastal spawning Baltic flounder *Platichthys solemdali*.

Egg production

Based on the measured lengths, the total weight of each fish was calculated according to the following length-weight relationships, as implemented in the Swedish national coastal fish database:

$$turbot\ weight\ (g) = 0.00689 \times length(cm)^{3.30906}$$

$$flounder\ weight\ (g) = 0.0138 \times length(cm)^{2.9425}$$

We then re-calculated these total weights to somatic weights. This was done by combining length and somatic weight measurements on turbot from Nissling et al. (2013) and on flounder from Nissling and Dahlman (2010) with the estimated total weight based on the measured length and the equations above. From these data, we estimated the ratio between total weight and somatic weight as a function of length (see Appendix), and then applied this to our dataset to obtain somatic weights for each fish.

Then, the potential fecundity (the estimated number of vitellogenic oocytes that are expected to result in spawned eggs in a given season) was calculated. Based on 128 fish caught pre-spawning in the Gotska Sandön NTZ, the reference area and a third location (Hoburgs Bank – also in ICES sub-division 28) in 2010, the following relationship between somatic weight and potential fecundity has been calculated for turbot (Nissling et al. 2013):

$$turbot\ potential\ fecundity = (e^{7.745} + somatic\ weight(g)^{1.061}) \times somatic\ weight(g)$$

Similarly, the relationship between somatic weight and potential fecundity of flounder was based on measurements of 136 pre-spawning *Platichthys solemdali* (at the time considered a coastally spawning ecotype of the species *Platichthys flesus*, rather than a separate species), collected 2005−2006 (Nissling & Dahlman 2010). The following relationship was provided:

$$flounder\ potential\ fecundity = e^{4.684} \times somatic\ weight(g)^{1.042} \times condition^{-0.469} \times oocyte\ density^{0.368}$$

Since we had no data on condition or oocyte density, these were set to the average values for the fish sampled in eastern and northern Gotland in the study, 0.863 and 11,630 (number per g gonad weight), respectively.

Based on these equations and the measured lengths of all caught individuals, the total potential fecundity was calculated for each net. To correct for the fact that not all individuals are female, sex ratios female:male (Table 2; Florin et al., 2013) estimated for the NTZ and the reference area for larger sizes (≥30 cm turbots and ≥21 cm flounders) were multiplied by the estimated total potential fecundity.

Table 2: Sex ratios female:male estimate for large (≥30 cm) turbot and large (≥21 cm) flounder, based on measurements from the NTZ and the reference area (Florin et al. 2013).

Location	Turbot (≥30 cm)	Flounder (≥21 cm)
No-take zone	0.92	0.48
Reference area	0.73	0.52

Larval export rates

To estimate larval transport between the NTZ and the reference area, as well as retention rates within each area, we made use of published estimates based on hydrodynamic models and particle-tracking (Florin et al., 2013). Velocity fields were produced with a three-dimensional ocean circulation model, with a horizontal spatial resolution of 3.7 km and 84 depth intervals. The particle tracking used the velocity fields to calculate expected dispersal trajectories, with updates to the velocity fields at 3-hour intervals, and tracking calculations performed at 15-minute intervals. For each simulation experiment, 49 larvae were released in each of the 12 model grid cells around the NTZ and 49 larvae were released in each of the 73 grid cells in the reference area. This was repeated for 8 years (1995−2002) to cover a range of hydro-dynamic conditions.

In the calculations of larval dispersal, mean values for these years have been used. Turbot were assumed to begin their drifting on the 15th of June and drift for 30 days, while flounder were assumed to begin drifting on the 15th of April and drift for 60 days. Based on these simulations, averaging over two simulated drift depths (0−2 m and 12−14 m) and over the simulated years, the rate of export between the NTZ and the reference area, as well as the retention rate of each area, was calculated (Table 3).

Table 3: Probability of dispersal between the NTZ and the reference area, as well as probability of retention, for flounder and turbot based on particle tracking models (see Florin et al. 2013). The estimates represent mean values for years 1995−2002 and for two depth strata (0−2 m and 12−14m). The probabilities should be read from row (the source) to column (the destination).

		TO			
		Turbot		Flounder	
		NTZ	*reference*	*NTZ*	*reference*
FROM	*NTZ*	0.11	0.063	0.05	0.056
	Reference	0.0006	0.33	0.001	0.31

Larval export from the NTZ to the reference area

To estimate the relative larval export from the NTZ to the reference area (i.e., a potential spillover effect), the estimated potential fecundity per station per year from the NTZ was multiplied by the larval export rate from the NTZ to the reference area, for turbot and flounder respectively. To get one value per year, an average was taken across stations within each year. Uncertainty boundaries were obtained by the corresponding standard errors. As a comparison, the same calculations were repeated looking at dispersal from the reference area to the NTZ, as well as retention rates within each area.

5 RESULTS

While the larval retention of the reference area was very high (see also Table 3), the estimated larval export from the NTZ to the reference area was of a comparable magnitude (Figure 6). In one year, the estimated export from the NTZ to the reference area was even higher than the reference area's retention for flounder, and for both flounder and turbot it was more than half of the retention rate in several years. The export from the reference area to the NTZ was consistently low, in line with the modelled export rates (Table 3).

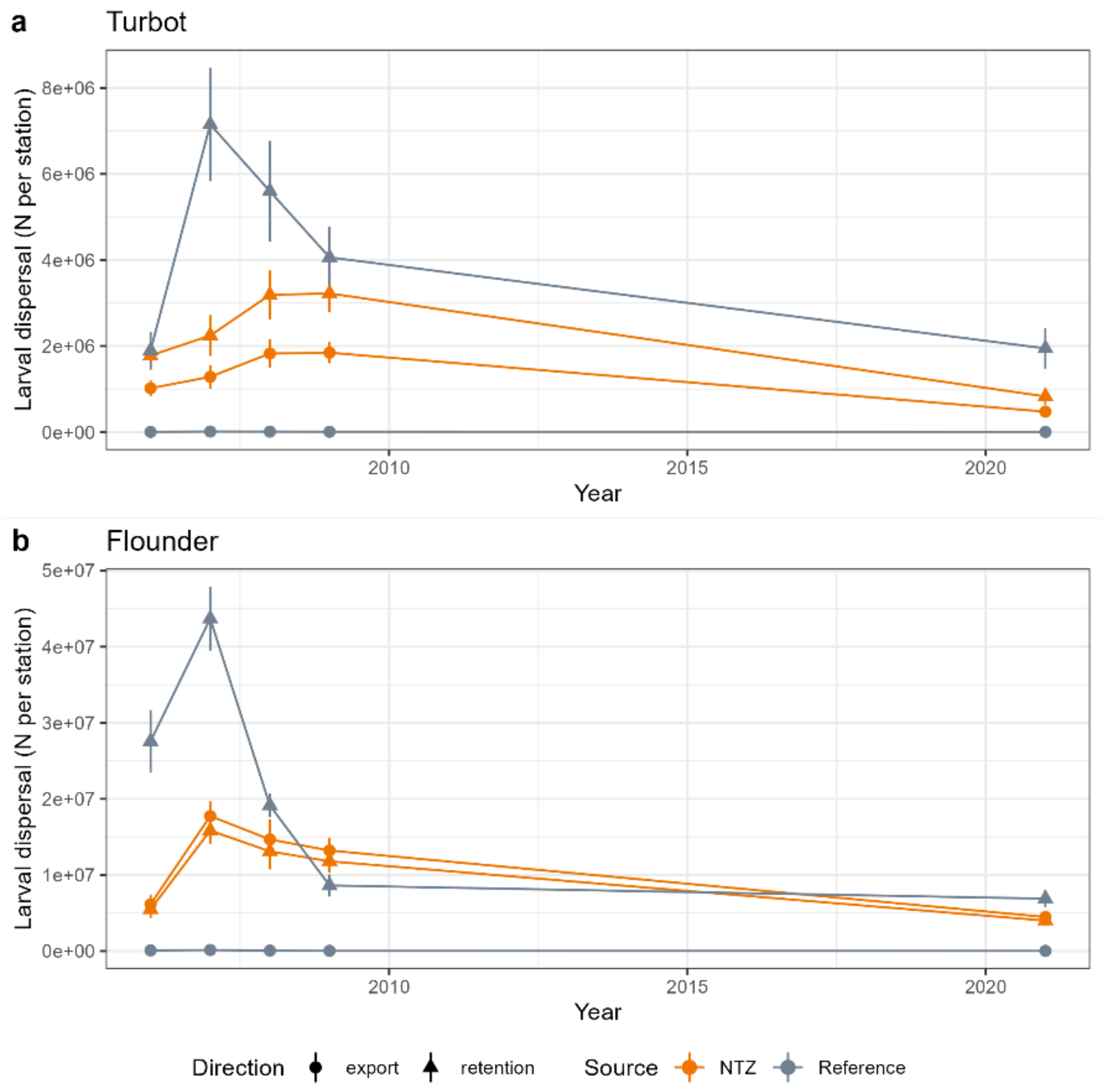

Figure 6: The estimated larval dispersal per sampling station for (a) turbot and (b) flounder. Shape indicates direction, i.e. export (from the NTZ to the reference area or vice versa) or retention (from the NTZ to the NTZ or from the reference area to the reference area). Colour indicates the source population. Points represent means and error bars standard errors, as estimated from the variability in catches between stations within each area (export rates were assumed to be constant across years).

6 DISCUSSION

Our results suggest that **the potential larval export from the Gotska Sandön NTZ to the reference area on the east coast of Gotland was of a comparable magnitude to the larvae produced and retained within the reference area**. This may seem surprisingly high, given the fairly long distance between the NTZ and the reference area (ca. 100 km), but can be explained by the higher overall larval production in the NTZ in combination with a clear directional transport of larvae towards the waters of Gotland south of the NTZ. Usually, spillover effects are mostly considered and detected at a local scale, up to ca. 800 m (Halpern et al. 2009). As **densities of both large flounder and large turbot initially increased following the establishment of the NTZ** (Figures 2 and 4), this suggests that the **fishery closure has increased the larval production and hence spillover to the flatfish populations on the east coast of Gotland** (Figure 6). In line with this, **densities of small turbot (i.e. possible recruits from the NTZ) increased initially after the establishment of the NTZ** (Figure 3). **However, no similar effect was seen in small flounder** (Figure 5). With the exception of a small, temporary increase in the landings of turbot, there were no signs that a potential spillover effect had a positive effect on the fishery in the reference area (Figure 7 and 8). However, the number of fishers and the fishing effort in the reference area has been in decline, and flatfish landings cannot be used as a reliable estimate of fish availability.

While the CPUE of both turbot and flounder remains higher in the NTZ compared to the reference area in the gillnet survey, there were signs that densities have declined in recent years, at least for large turbot (Figures 2–5). This is also reflected in the calculated larval export from the NTZ to the reference area, which in the most recent years are back to similar levels as at the establishment of the NTZ (Figure 6). The reason behind the declines is not clear, but predation from grey seals (*Halichoerus grypus*) and cormorants (*Phalacrocorax carbo*) may have contributed (Bergström et al. 2022).

While the calculations were based on the best available information, the estimated larval dispersal rates should be interpreted as a relative measure only. For example, we do not account for mortality during the egg or larval stage and how this may vary over time and space, nor do we take year-to-year variation in hydrodynamic patterns into account. Better estimates of spatio-temporal variation in egg and larval survival would improve our estimates, but are unlikely to drastically alter our qualitative conclusions. A more recent study of Baltic flounder dispersal around Gotland, but not including Gotska Sandön, suggests that drift depth has a large impact on where and how far the larvae drift (Corell & Nissling 2019). Drifting in the lower part of the water mass, at a similar depth to the preferred spawning depth, favours local retention and it may be that the larvae actively stay deeper in the water mass to increase the chance of remaining in suitable habitat along the coast.

Further studies are needed to establish at what depth the Baltic flounder larvae are typically found, but if it is the case that the larvae tend to stay at lower depths, the larval export from Gotska Sandön may to some extent be overestimated in our study. At the same time, genetic studies of both turbot and demersal spawning flounder (now recognised as *Platichthys solemdali*) suggest that gene flow across populations is high (Florin & Höglund 2007;2008), suggesting a high level of connectivity. **As such, several sources of uncertainty remain, so in order to confirm our conclusions regarding the dispersal of larvae from the NTZ to the reference area, and to assess whether these contribute to the spawning population, empirical studies would be needed, relying on, for example, high-resolution genetic data.** More years of monitoring are also needed to follow up the results from 2021, to ascertain whether the low densities observed are part of a long-term trend or only due to interannual variability.

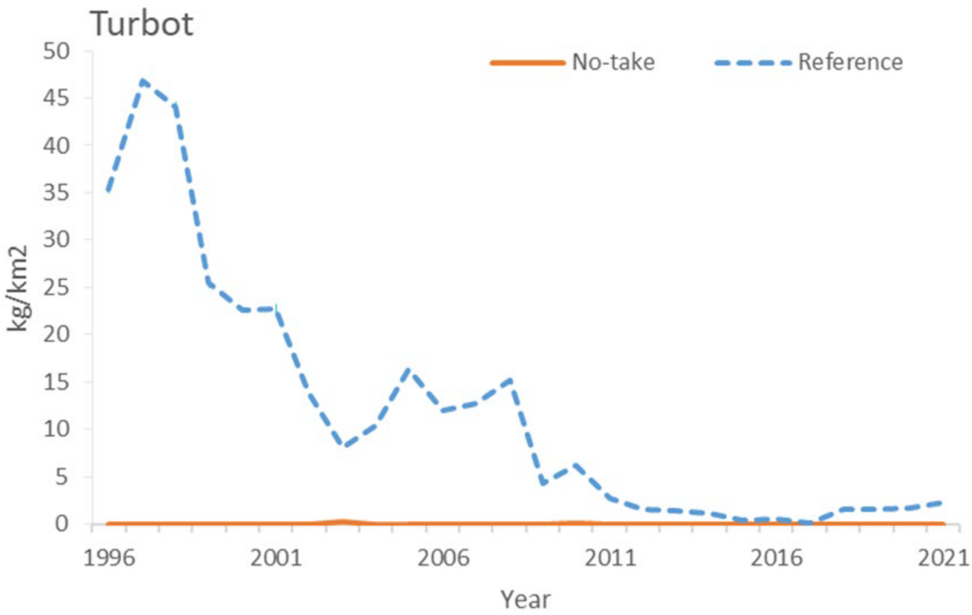

Figure 7: Commercial landings per unit area per year of turbot (*Scophthalmus maximus*) in the no-take zone around Gotska Sandön (almost zero) and the fished reference area outside Gotland. From Bergström et al. 2022.

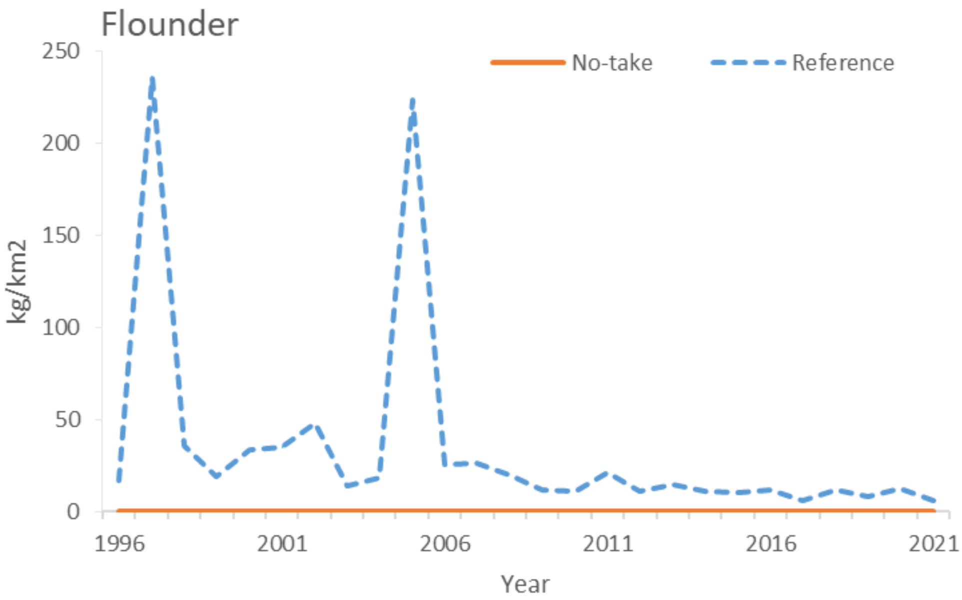

Figure 8: Commercial landings per unit area per year of flounder (*Platichthys solemdali*) in the Gotska Sandön no-take zone (almost zero) and the fished reference area outside Gotland. From Bergström et al. 2022.

7 CONCLUSIONS

The estimated larval export from the NTZ to the reference area was of a similar magnitude, and sometimes larger, than the local, retained larval production in the reference area. The high level of larval spillover can be explained by the higher overall larval production in the NTZ in combination with a clear directional transport of larvae towards the reference area in the waters of Gotland. As densities of both large flounder and large turbot initially increased following the establishment of the no-take zone, this suggests that the fishery closure has increased the larval production and hence spillover to the flatfish populations in the reference area.

There were initially some positive signs in fish densities and landings in the reference area following the establishment of the no-take zone, but these were not consistent across time or species. Declines in the densities of large flounder and large turbot in recent years, likely to some extent connected to increasing populations of grey seals and cormorants, have likely resulted in reduced larval export to the reference area.

Further work is needed both to establish whether the lower densities observed in recent years are part of a long-term trend and to confirm the magnitude of the dispersal rates empirically, but our approach was helpful for estimating the potential for spillover effects via larval dispersal. In a wider perspective, our results point to the importance of considering the ecological connectivity between areas to maximise the potential spillover effects on species with a pelagic drifting phase when designing a protected area.

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APPENDIX

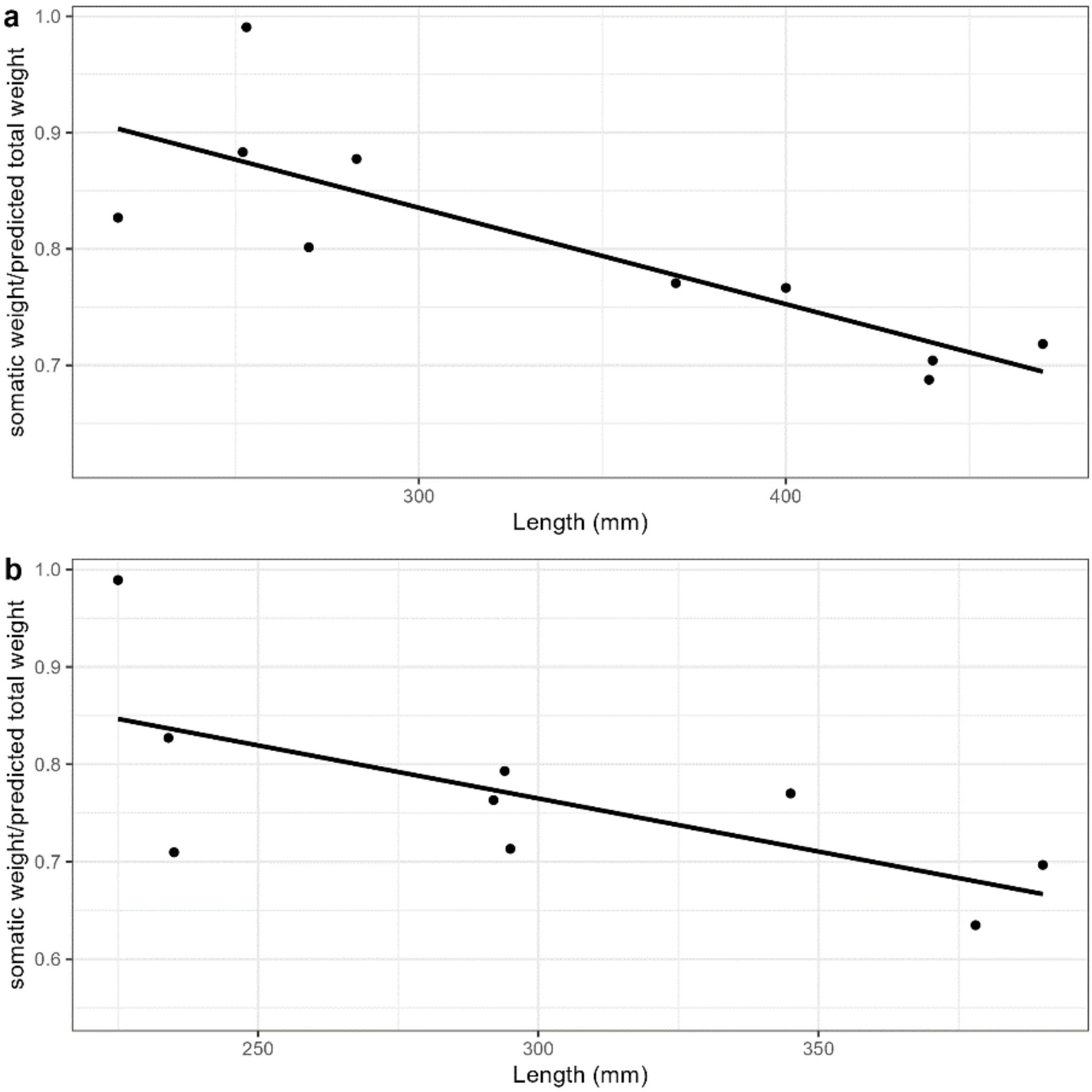

Figure A1: Points show (a) the reported minimum and maximum lengths of turbot (Nissling et al. 2013) and (b) the reported minimum, median and maximum lengths of flounder (Nissling & Dahlman 2010), plotted against (a) the corresponding reported minimum and maximum somatic weights of turbot (Nissling et al. 2013) and (b) the corresponding reported minimum, median and maximum somatic lengths of flounder (Nissling & Dahlman 2010), divided by the estimated total weight based on the measured lengths and published relationships between length and total weight (see main text). The black lines show fitted linear models.

The fitted linear models (Figure A1) provided the following relationships:

$$turbot\ somatic\ weight/total\ weight = 1.08 - 0.008 \times length(mm)$$

$$flounder\ somatic\ weight/total\ weight = 1.09 - 0.00109 \times length(mm)$$

2. CASE STUDY REPORT:

SŁOWIŃSKI AND WOLIŃSKI NATIONAL PARKS

POLAND – BALTIC SEA

Fishing vessel leaving port of Lubin (community Międzyzdroje, near Woliński National Park) to collect nets. Photo: M Rakowski

Analysis of potential spillover effects around the Słowiński and Woliński National Parks

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LIST OF ABBREVIATIONS

Term	Description
DCA	Detrended correspondence analysis
DCF	Data Collection Framework
JCWP	Jednorodnych Części Wód Powierzchniowych (homogenous surface water bodies)
MPA	Marine protected area
NMFRI	National Marine Fisheries Research Institute
WFC	Water Framework Directive

1 EXECUTIVE SUMMARY

This case study aims to evaluate the potential spillover effects around two marine protected areas (MPAs), namely the Słowiński National Park and the Woliński National Park, located in the Polish marine areas of the Baltic Sea. The marine areas, covered by the park boundaries, are two nautical miles along the 33 km coast of Słowiński National Park and one nautical mile along the 17 km of the coast of the Woliński National Park. Since 2005, the Minister of the Environment has separately issued a 'regulation on protective tasks' for each national park. Then, within these marine areas, only 'cultural fishing' based on licences was allowed. Fishing took place in shallow water by local fishers using boats and passive gears. The establishment of these MPAs did not change the area used by fisheries and the number of vessels registered in the ports around parks were stable in the past 10 years.

To study the potential effects of spillover from the Słowiński National Park and Woliński National Park to adjacent areas, a quantitative method was applied based on total catches in the Baltic Sea fishing squares where the MPAs are located, for the period 2014-2023. Due to a lack of more detailed quantitative information, this was the only spatial resolution that could be used in the analysis. The low spatial resolution resulted in the data covering a much larger area than that within the parks' boundaries and challenged the detection of potential spillover in the areas surrounding the MPAs. Nevertheless, declining trends in total volume of fish catches in the study areas over the years, indicate that spillover from the MPAs is unlikely. A more in-depth analysis of the 2019-2023 catch data would be required, however additional events in that period of time are likely to have affected catches, i.e. the cod ban, the Covid-19 pandemic, and the Russian war of aggression against Ukraine.

Another approach to study potential spillover effects in this case study used desk research and interviews with key stakeholders. Four focus group meetings with fishers took place in which, in total, 22 fishermen participated. Also, seven surveys were conducted, with nine respondents, including scientists, environmental non-governmental organisations and a fisherman. MPA managers (from the Słowiński National Park) and government fishery authorities completed a questionnaire prepared for both areas of this case study. The fishermen of the focus group demonstrated a high degree of social responsibility and understanding of the MPA's operation, as reflected in the strong convergence between their statements and those of other study participants.

The survey indicates that there have been no perceptible spillover effects of the two MPAs, most likely due to the small marine surface and the relatively short period since the introduction of restrictions. The fishery sector considered that MPAs are neither a conservation nor a fishery management tool, contrary to what they expected. Currently, fishers claim that the implementation of the MPAs increases the cost of fishing activities due to access fees and the time needed for reporting. They see that the volume of catches has not increased since the implementation of the MPAs, and the MPAs have no significant impact on the economy of fishers and their revenue. Current conditions are acceptable to fishers and the fishers see no need for permanent closure of the MPAs for fishing. In their opinion, to create some spillover effect for the small marine areas of these parks, other tools such as temporary closures during spawning season and limitations of gear types and number of gears should be implemented. MPAs may be seen as advantageous for the condition of fish stocks by limiting the number of fishers active in the area. Additionally, in the parks the natural growth of aquatic plants, which limit catching opportunities, creates a 'natural' protection for the fish species.

Park authorities and scientists claim that MPAs already are or will be a conservation tool and a fisheries management tool at the same time. They see positive effects on the environment, biodiversity and fish stocks health conditions. In their opinion, the spillover effect will be seen in a few more years and will apply mostly to the young stages of fish. The Protection Plans for the Słowiński National Park and Woliński National Park are still under development and the current protective tasks do not result in a decrease in fishing activity. Therefore, in the current situation it is too early to expect spillover effects. Additionally, the parks are small, reducing the probability of spillover effects. A robust quantitative analysis of spillover effects currently is challenging, and would require more detailed data and targeted studies.

2 BACKGROUND

This case study covers two marine protected areas (MPAs): the Słowiński National Park and the Woliński National Park. Both MPAs were established as national parks and included land areas and inland bodies of water. Słowiński National Park has as its primary task the protection of coastal dunes, while Woliński National Park has as its primary task the protection of the cliffside and forest complex of Wolin Island. In 1996, the areas of Woliński National Park and in 2004 Słowiński National Park were expanded to include the nearshore strip of sea waters and, in the case of Woliński National Park, the adjacent waters of the Szczecin Lagoon. In both cases, this measure was primarily for the sake of coastline protection. The managers conducted environmental assessments of the new areas, inventoried the flora and fauna resources present and introduced regulations for the use of the areas.

Both national parks are part of a larger protected area. For these larger areas, there are Plans of Protective Tasks (see Appendix), describing the conservation regulations. For both national parks, Protection Plans (see Appendix) are currently being developed, describing conservation regulations for marine areas. These Protection Plans have a higher priority than the Plans of Protective Tasks.

The similarities in management, the size of the marine areas covered by the boundaries of these parks and the advancement of the creation of regulations, as well as the results of interviews conducted with stakeholders in these areas, formed the basis for combining the results into a single case study instead of presenting two separate case studies.

The **Słowiński National Park** (Figure 1) is located on the Central Coast of Poland, between the ports of Rowy and Łeba. The park was created to protect swamps, marshes, coastal lakes, forests and meadows and especially the dune belt of the spit with moving dunes that are unique in Europe. It was established on January 1, 1967[1], with an area of 18 618 ha, of which 10 213 ha are water areas and 4 599 ha include terrestrial forest areas. Strict protection, meaning the absolute and permanent elimination of human intervention in the state of ecosystems, covers 5 619 ha in total (including both water and land surface). In 1977, Słowiński National Park was recognized as a UNESCO World Biosphere Reserve. In 2004[2] the area was enlarged by 14 675 ha, including 11 000 ha of surface waters (a strip 33 km long and two nautical miles wide, with a maximum depth of 20 m). Since then, the park covered an area of 32 744 ha. The Baltic Sea water area is characterised by a sandy bottom, prone to changes caused by sea currents and wave action. The relatively stable area, which is the western part of the park waters, is home to brown, red and green algae, as well as mussels and barnacles. In this area, fish species common for the Baltic Sea are found (mostly flounder, turbot and herring). Seals and porpoises are also found in the area.

The **Woliński National Park** (Figure 2) is located in the western part of the Polish Baltic Sea coast, between the ports of Międzyzdroje and Dziwnów and Lubin on the side of the Szczecin Lagoon (Zalew Szczeciński). The park was established in 1960[3] and, at the time, it covered an area of 4 844 ha on Wolin Island. In 1996[4], the marine waters, the waters of the Szczecin Lagoon, and the archipelago of coastal islands in the delta of the old riverbed of Świna were included in the park area, making Woliński National Park the first marine park in Poland. The current surface area of the park is 10 937 ha, including aquatic ecosystems of 4 681 ha. A one nautical mile wide, 17 km-long strip of cliff coastline east of Międzyzdroje is included in the park's boundary, as are areas of Lake Wicko and a part of the Szczecin Lagoon, which are used for fishing activity.

The aquatic areas in the southern part of Woliński National Park are a refuge for phytoplankton and phytobenthos, as well as rush vegetation and reed beds, while the marine area of the park has the character of a sandbank with occurring rock covered with green, red and brown macroalgae. Among the ichthyofauna, 61 species were identified, including lampreys (2 species), migratory fish (4), marine fish (22) and freshwater fish (33)[5].

[1] Rozporządzenie Rady Ministrów z dnia 23 września 1966 r. ws. utworzenia Słowińskiego Parku Narodowego (Dz.U. z 1966 r. nr 42, poz. 254).
[2] Rozporządzenie Rady Ministrów z dnia 2 marca 2004 r. w sprawie Słowińskiego Parku Narodowego (Dz.U. z 2004 r. nr 43, poz. 390)
[3] Rozporządzenie Rady Ministrów z dnia 3 marca 1960 r. ws. utworzenia Wolińskiego Parku Narodowego (Dz.U. z 1960 r. nr 14, poz. 79)
[4] Rozporządzenie Rady Ministrów z dnia 3 stycznia 1996 r. w sprawie Wolińskiego Parku Narodowego (Dz.U. 1996 nr 4 poz. 30).
[5] https://wolinpn.pl/przyroda-parku/ekosystemy-wodne/

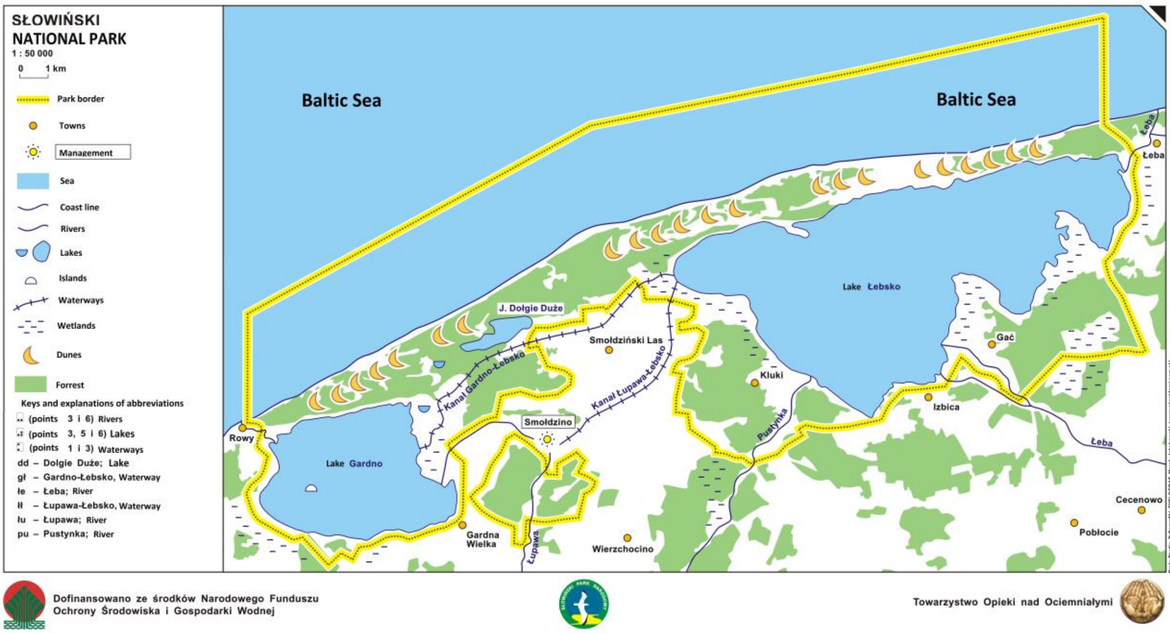

Figure 1: Map of the area of the Słowiński National Park (Olczyk et al 2011).

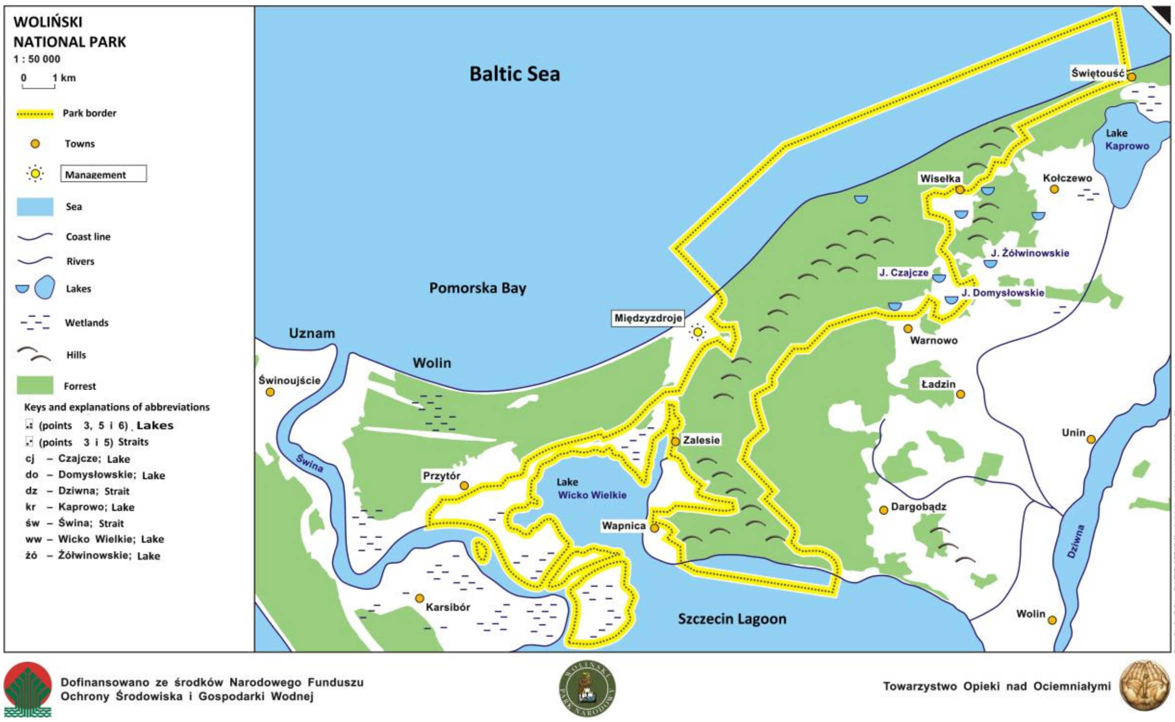

Figure 2: Map of the area of the Woliński National Park (Olczyk et al 2011).

As described above, for both national parks a Protection Plan is under development. Until these Protection Plans are implemented, a decree describing conservation tasks is in place. Every three years since 2005, the minister responsible for environment protection issued a separate regulation on protective tasks for each national park. The current decree for the Słowiński National Park for 2023-2025[6] is the Decree of the Minister of Climate and Environment dated December 28, 2022, on the protective tasks. For the Woliński National Park, the current decree is the Decree of the Minister of Climate and Environment dated January 13, 2023, amending the Decree on protective tasks for the Woliński National Park for 2020-2023[7]. The documents specify, among other things, protective actions in aquatic ecosystems. The indicated method of active protection in marine waters is as follows for the Słowiński National Park:

> '*Protection of the resources of the Baltic Sea - maintenance of cultural fishing carried out by the inhabitants of the communities where the Słowiński National Park is located with the help of boats of an overall length not exceeding 10 m, from the home ports in Łeba and Rowy*'.

Meanwhile, for the Woliński National Park, the indicated objectives have changed:

> '*1. Controlling the performance of fishing in marine waters including jointly with the Sea Fisheries Inspector,*
> *2. Protection of habitats and fauna sites and preservation of species diversity by limiting the availability of Woliński National Park water areas for fishing and recreation,*
> *3. Protection of habitats and sites of aquatic flora and preservation of species diversity by limiting the availability of Woliński National Park water areas for fishing and recreation,*
> *4. Monitoring of surface waters'.*
>
> *The Baltic Sea area within the boundaries of the parks is designated as an 'active protection area'.*

An important element for evaluating potential spillover effects for both MPAs is the fishing activity potentially present in the study area. Commercial fishing in the area up to 3 nautical miles from the shore is limited to vessels up to 12 m in length fishing with passive gears. Trawls and other towing gears are not allowed in this 3-miles zone. As shown in Table 1, the number of active commercial vessels in the ports around the parks was stable in the past 10 years. Not all of vessels were allowed to operate in the National Park areas: only **cultural fishing** is allowed in the marine areas of the parks, by residents of the municipalities where the park is situated (see description of cultural fishing in Appendix). Fishing is carried out with boats of an overall length not exceeding 12 metres, from home ports in Łeba, Rowy (Słowiński National Park) and Dziwnów, Międzyzdroje, Lubin, Świnoujście Przytór, Świnoujście Karsibór (Woliński National Park). Furthermore, the regulations governing cultural fishing in the parks are determined by internal directives issued by the park directors. To be added to the list of authorized entities conducting cultural fishing within the National Park's territory, fishers must apply, and each permission is subject to an administrative fee of 100 zł (approximately €25). Obtaining permission for cultural fishing in the marine waters within the parks' boundaries requires an individual permit from the Director. In 2024, the permit of the Director of the Słowiński National Park is held by seventeen vessels. Eleven of these vessels' home port is Łeba; six of these vessels' home port is Rowy. Permits from the Director of the Woliński National Park are held by a total of twelve vessels, from the ports of Lubin (4), Międzyzdroje (3), Świnoujście Przytór (2), Świnoujście Karsibór (1), Świnoujście (1), and Dziwnów (1). Fishers are bound by EU and national law. Furthermore, the parks have introduced additional restrictions. The fishing gear consists exclusively of set nets. The minimum distance for spacing fishing gear from the shore must be at least 200 meters. Fishing for sea trout and Atlantic salmon is permitted from January 1 to September 14. Commercial fishing with a fishing rod from fishing boats is not permitted.

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[6] https://dziennikurzedowy.mos.gov.pl/fileadmin/Dziennik_Urzedowy/user_upload/ZO_Slowinski_PN_2023-25_zarzadzenie_do_podpisu_MKiS.xml.xades

[7] https://dziennikurzedowy.mos.gov.pl/fileadmin/Dziennik_Urzedowy/user_upload/DO_PODPISU_-_ZZO_Wolinski_PN_2020-23_zarzadzenie.xml.xades

Table 1. Number of active commercial vessels (<12m) at the end of each year in ports around Woliński National Park and Słowiński National Park (2013-2023).

MPA	Port	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Woliński NP	Wolin	13	14	15	15	15	15	14	15	15	15	15
	Lubin	8	8	8	8	8	8	8	7	7	8	8
	Świnoujście-Przytór	4	4	4	4	4	4	4	4	4	4	4
	Świnoujście-Karsibór	7	10	9	9	9	9	9	9	9	9	9
	Międzyzdroje	4	4	4	4	4	4	4	4	4	4	4
	Dziwnów	13	14	14	13	13	13	14	14	14	14	14
Woliński NP Total		**49**	**54**	**54**	**53**	**53**	**53**	**53**	**53**	**53**	**54**	**54**
Słowiński NP	Rowy	6	6	6	6	6	6	6	6	6	6	6
	Łeba	18	19	19	17	19	20	18	18	18	18	18
Słowiński NP Total		**24**	**25**	**25**	**23**	**25**	**26**	**24**	**24**	**24**	**24**	**24**
Total		**73**	**79**	**79**	**76**	**78**	**79**	**77**	**77**	**77**	**78**	**78**

Source: National Marine Fisheries Research Institute (NMFRI) elaboration on data from Fishing Fleet Register and Fishery Monitoring Centre of Department of Fishery of The Ministry of Agriculture and Rural Development, Poland.

3 AIMS AND OBJECTIVES

The main objective of this case study was to evaluate the potential spillover effects of the fish resources around the seawaters of the Słowiński National Park and Woliński National Park. A quantitative and a qualitative approach was used to do this.

The quantitative approach aimed to study trends in catches and changes in fishing vessel numbers (as a proxy for effort) in the area. The hypothesis was that if MPAs should create spillover effects, it could potentially be detected by positive trends in the catches per unit of effort in the areas surrounding the MPAs (see also Annex 5, Advisory Protocol, Table 28).

The qualitative approach aimed to study stakeholders' perceptions on potential spillover effect from the MPAs, by assessing stakeholders' level of knowledge about MPA regulations and their socio-economic impacts, particularly related to fisheries; assessing MPAs' perceived role as management and or fishery conservation tool; identifying key factors linked to spillover effects, according to stakeholders.

4 METHODOLOGY

Two approaches were used to study the potential spillover effects: a quantitative analysis to look at trends in catches inside and outside of the MPAs and a qualitative analysis using interviews to assess stakeholder perceptions on spillover effects. Due to lack of publications on this topic in the area, the literature review was marginal and focused on environmental effects of the MPA implementation.

4.1 Quantitative approach

The quantitative analysis relied on commercial catches within designated Baltic Sea fishing squares (see Appendix) corresponding to each respective park's location. Specifically, for Słowiński National Park, these squares are N6 and M6, and for Woliński National Park, it is square D1 (Figure 3). Unfortunately, a more comprehensive spatial analysis of catches is currently unfeasible due to the absence of higher resolution data, such as GPS data. Only data from commercial vessels using passive gear and with a maximum length of 12 m were considered, as these are the only vessels allowed in the area and the primary operators in the coastal zone.

The Baltic Sea fishing squares grid is a scale commonly used to locate fishing grounds in the Baltic Sea (Figure 3). It is used in fishing logbooks and statistical studies. This grid comprises parallels spaced at 10 geographic minutes and meridians spaced at 20 geographic minutes, forming standardized "squares" with dimensions of 10 x 11.5 nautical miles (nm). These squares are designated from west to east with alphabetical letters (A through Z) and from south to north with numerical values (1 through 31).

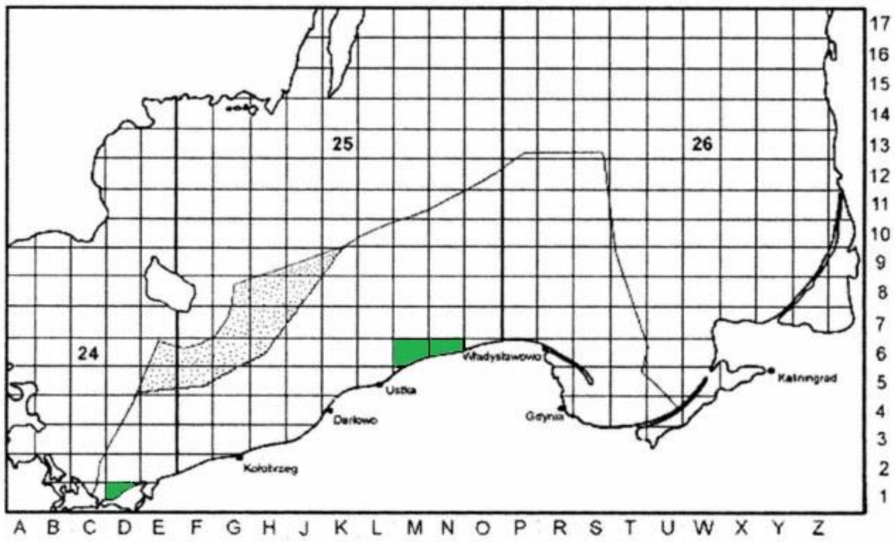

Figure 3 Baltic Sea fishing squares grid with marked squares (in green) bordering the two national parks *(Source: National Marine Fisheries Research Institute).*

Given the stable number of vessels recorded in the relevant ports (Table 1), catch volume was used as the primary parameter in the catch analysis. A sustained increase in the overall weight of species caught within the Baltic Sea fishing squares corresponding to the parks could potentially indicate of spillover effect, while maintaining a constant vessel number (see Annex 5, advisory protocol, for more details). It should be noted that the catch volumes may have been influenced by other events: first, there was the cod fishing ban, effective as of mid-2019. Second, the Covid-19 pandemic impacted the market and value chain between 2020-2023. And finally, the Russian war of aggression against Ukraine resulted in increased costs.

4.2 Qualitative approach

The qualitative research methodology employed for this case study encompassed desk research and interviews conducted with key stakeholders. The structured questionnaire aimed to delve into the perceptions of both users and authorities regarding the presence of designated areas and the potential spillover effects within the MPAs. To accommodate variations in expertise among representatives of four stakeholder groups (fishers, MPA managers and authorities, scientists, and environmental non-governmental organizations), the questionnaire (Annex 4) was tailored in different formats.

Comprising three sections, the questionnaire sought to comprehensively explore various facets:

1. Background: aiming to gain insights into the respondents' backgrounds and affiliations.
2. Fishery Impact: examining the respondents' perspectives on the socio-economic implications of MPA spillover.
3. Management Tool: gauging the respondents' views regarding the efficacy of MPAs as management and conservation tools.

After identifying 30 potential respondents, primarily through established leaders within local harbours, relevant organizations, and administrative bodies, additional stakeholders were enlisted through a 'snowball effect', leveraging existing contacts to expand the participant pool. Subsequently, the questionnaire forms were disseminated to the management institutions of the MPA sites (such as the Management of Słowiński National Park and the Management of Woliński National Park), as well as governmental bodies like the Department of Fishery within the Ministry of Agriculture and Rural Development.

Following telephone interviews with representatives from environmental organizations and scientific communities, the questionnaire forms were forwarded to these groups as well, soliciting their input to corroborate statements. The bulk of responses were received during July 2023, with some arriving in early August 2023.

A different approach was adopted to engage fishers who initially declined to fill out the questionnaires independently. Responding to requests from fishermen in specific ports surrounding the MPAs, a series of four group interviews were organized, conducted as meetings in the ports situated around the protected areas. These meetings took place between July 20th (around the area of Woliński National Park) and July 27th (around the area of Słowiński National Park) of 2023. The format of these meetings mirrored the questionnaire prepared for fishers, facilitating a greater level of participation from the fishing sector. This approach yielded positive results, with fourteen fishers from three ports surrounding Słowiński National Park (Łeba, Ustka, and Rowy) and nine fishers from three ports surrounding Woliński National Park (Dziwnów, Wolin, and Lubin) participating in the meetings. In total, we received 5 questionnaires from the fishery sector. An individual interview request was declined by a fisherman from the port of Międzyzdroje.

In total, the study involved 31 respondents (Table 2), comprising one representative from the park authorities, 23 fishers, two representatives of the scientific community and two representatives of non-governmental environmental organisations. Furthermore, respondents from three different departments within the Department of Fisheries of the Ministry of Agriculture and Rural Development returned the questionnaire. The research was conducted in the period of July and August 2023.

Table 2. Number of respondents and methods in Słowiński National Park & Woliński National Park Case Study Qualitative research.

Group of respondents	Number of questionnaires	Number of respondents	Technique
Managing Authorities	1	3	Online questionnaire
Park Authorities	1	1	Online questionnaire
NGO's	2	2	Online questionnaire
Scientists	2	2	Online questionnaire
Fisherman	1	1	Online questionnaire
Fishermen	4	22	Focus groups in ports (based on questionnaire)
Total	**11**	**31**	

5 RESULTS

5.1 Quantitative research

Catch analysis

Fishery is an activity which may be potentially affected by MPA establishment. Given the stable number of vessels observed in the analyzed areas over the past decade (Table 1), an analysis of catch volume emerges as a preferred indicator for assessing the potential spillover effect resulting from MPA establishment.

Figure 4 shows the volume of commercial fish catches from 2014 to 2023, by vessels with lengths lower than 12 meters, in the Baltic Sea fishing squares where the MPAs are located. In the area of Pomorska Bay, where Woliński National Park is located, mostly fishing vessels up to 12 m length using passive gears are active. Catches decreased over the studied period, both in square D1 (covering waters within the boundaries of Woliński National Park) and in squares M6 and N6 (covering waters of Słowiński National Park). In terms of species composition in square D1, the dominant species in the catch were roach, bream and perch (32%, 25% and 13% in 2023, respectively). In squares M6 and N6, cod (57%) and flatfish (30%) dominated the catch in 2014. The cod fishing ban was implemented in May 2019, and after that, in 2023, catches were dominated by flatfish (75%) and herring (20%).

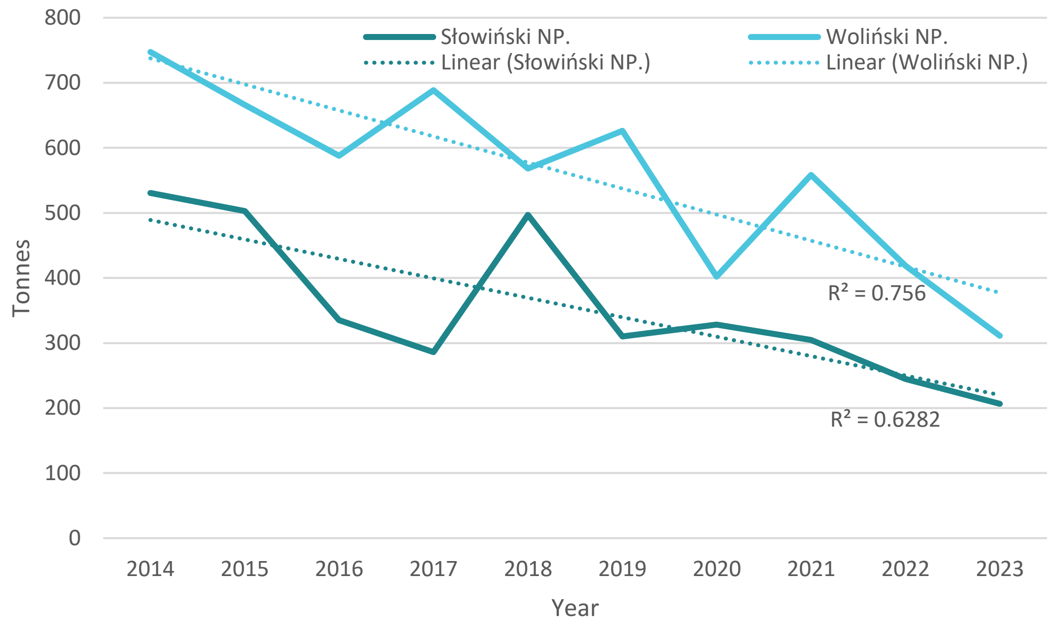

Figure 4. Catches of fish of the fleet up to 12 m in length, in Baltic Sea fishing squares D1 (covering waters of the Woliński National Park) and M6, N6 (covering waters of the Słowiński National Park) in years 2014-2023.

Since 2017, the Polish fishery has undergone a notable reorientation away from cod toward other fish species. This shift was prompted by significant reductions in available quotas for cod, culminating in the eventual imposition of a total ban on cod catches. The exclusion of cod catches from the analysis has allowed for the identification, to some extent, of changes in the volume of fish catches from year to year (see Figure 5, presenting catches excluding cod). The trend in catches in areas adjacent to the Woliński National Park has remained relatively stable, with a slight decline observed. This is largely attributed to cod constituting a small portion of the overall catch composition (with at a maximum of 2% between 2014 and 2019). Conversely, the ban on cod fishing has had a more pronounced impact on catches in squares M6 and N6, which encompass the fisheries around the Słowiński National Park. There, an increasing trend in catches was evident as early as 2018. One notable observation is the significant increase in catch volume of flounder, which tripled from 87 thousand tonnes in 2017 to 234 thousand tonnes in 2018. This surge can be attributed to the use of similar fishing gears employed in cod fishing. However, this increase was not sustained in subsequent years, indicating a decline. Additionally, herring catches increased, although this required changes in fishing gears and vessel adjustments.

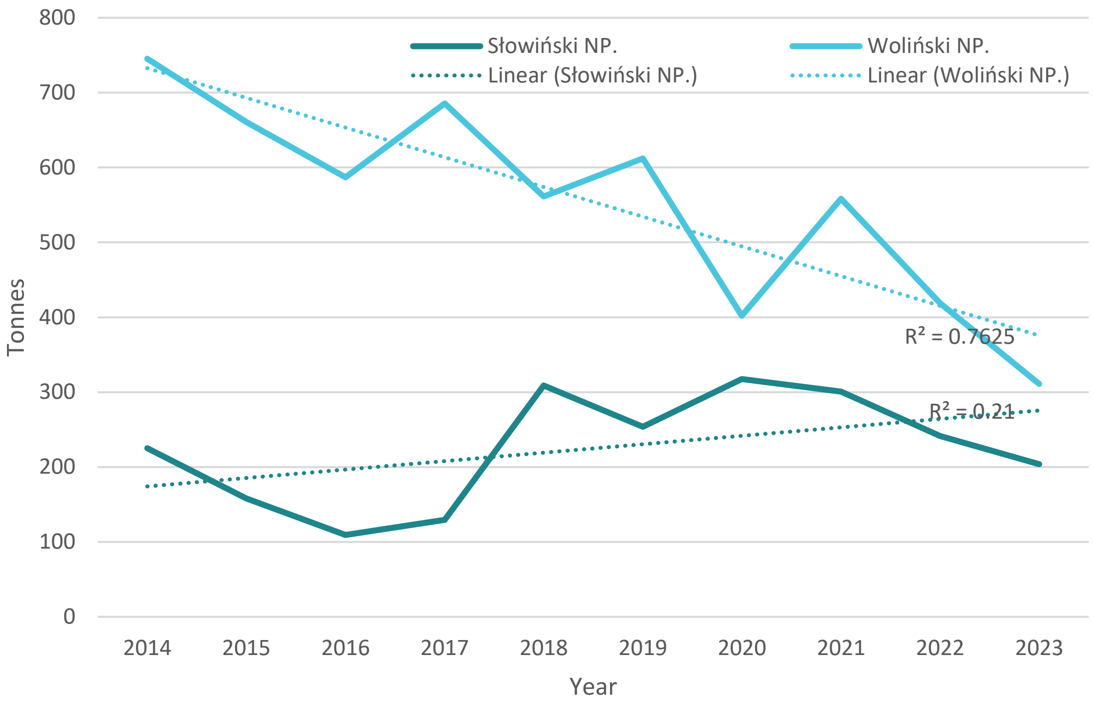

Figure 5. Catches of fish (without cod) of the fleet up to 12 m in length, in fishing Baltic Sea fishing squares D1 (covering waters of the Woliński National Park) and M6, N6 (covering waters of the Słowiński National Park) in years 2014-2023.

The interpretation of the results of this quantitative analysis is complicated by disruptions in fishing activities after 2019, related to restrictions on cod fishing and the temporary suspension of fishing during the Covid-19 pandemic. Also, increased energy costs related to the Russian war of aggression against potentially had an impact on fleet activity.

Desk research and literature studies

Findings of our desk research show that there is a lack of relevant data analyses or publications describing the spillover effects in these areas. Consequently, the authors of the report drew upon many studies conducted during the formulation of the Protection Plan for each respective area. For the maritime areas of both National Parks, these studies were limited to inventories of flora and fauna species, as well as assessments of physical and chemical conditions of water within the administrative boundaries of the respective National Park. The information in these studies were used to determine the conservation tasks within the MPAs.

The Nature Protection Act[8] underscores that the National Park is the highest form of nature protection in Poland, and all nature and landscape values are protected. The Act does not explicitly indicate a catalog of protection activities, but obliges the Director of the National Park to develop a Protection Plan. This Protection Plan has to include specific elements aimed at facilitating the development of a robust protection concept for inventoried elements, assessing potential threats, and, most importantly, delineating the type, scope, and location of protection measures. In the Protection Plans, measures for fisheries are the limitation of the number of vessels, geographical origin of vessels, and elimination of the trawling fishing technique.

Based on monitoring data from 2014-2019, an assessment of the ecological status and classification of surface waters was carried out in 2020 (Anon, 2020). Of the 4 047 homogenous surface waterbodies (JCWP) in marine areas, studies were conducted in 19 JCWPs, mainly transitional waters (Szczecin Lagoon, Vistula Lagoon, individual parts of the Gulf of Gdansk) and coastal waters. It should be noted that according to the typology of waters resulting from the

[8] Ustawa z dnia 16 kwietnia 2004 r. o ochronie przyrody, tekst jedn. Dz.U. z 2018 r. poz. 1614 z późn. zm.

Water Framework Directive of the European Union (WFD 2000/60/EC[9]), coastal waters include the area of surface waters from the shoreline, the outer boundary of which is determined by a distance of one nautical mile on the seaward side, calculated from the baseline. In the case of coastal waters, the following elements were assessed:

- biological (phytoplankton, macroalgae and angiosperms, benthic invertebrates);
- hydro-morphological (tidal regime, morphological conditions);
- physicochemical (biogenes, oxygen conditions, transparency, temperature), specific synthetic pollutants and specific non-synthetic pollutants.

The research of water quality (Anon, 2020) has been prepared for all coastal waters in Poland and generally indicates poor ecological status (54% very bad, 38% poor and 8% moderate). The condition was poor also in parts of the waters of the two national parks of this study.

No separate catch statistics are collected for protected areas, which is another obstacle to assessing the impact of MPAs on fish stocks. Despite the small marine areas covered by the boundaries of the national parks, representatives of the Ministry consider these zones to be a conservation tool, and park authorities also consider them to be part of the fishery management tool.

In 2015, Smoliński and Całkiewicz proposed a fish-based index for assessing the ecological status of Polish transitional and coastal waters, with initial trials conducted in both parks (Smoliński & Całkiewicz, 2015). This initiative arose in response to EU directive for Member States to take responsibility for water quality control, recognizing the significant anthropogenic impact on these environments. Utilizing fish as bioindicators, which are reliable proxies for evaluating water quality and specific components, the authors proposed a multimetric fish index inspired by the Helcom Baltic Sea Impact Index, tailored to assess the condition of coastal and transitional waters.

Data on the ecosystem of coastal waters in Poland were collected, selected and analyzed during the years 2011, 2013, and 2014. For all fish specimens utilized for testing, species identification took place and weight and length were measured. Freshwater species dominated the dataset, comprising 94% of observations. Detrended correspondence analysis (DCA) showed that salinity was the most important environmental factor affecting the fish community. While transitional and coastal waters theoretically serve as excellent habitats, owing to their brackish salinity, they also function as unique feeding grounds for freshwater fish. However, field observations revealed that both the Słowiński National Park and Woliński National Park are subject to substantial anthropogenic pressure, which adversely affects the environment and fish stocks. This impact is reflected in the diminished number of species within these ecosystems (Smoliński and Całkiewicz 2015). A decline in the overall species richness in aquatic ecosystems typically indicates a deterioration in habitat condition.

Margoński (2016) conducted a basic analysis of the impact of environmental conditions on fish recruitment in the Baltic Sea. The variability of recruitment of some species (sprat) was analyzed taking into account spring water temperature, intensity of ice cover and the North Atlantic Oscillation. However, environmental changes are so dynamic and significant that analytical models cannot include these changes in long-term forecasts.

In conclusion, the existing literature on the potential effects of MPAs in influencing the environment and fish stocks in the two investigated MPAs and more widely in Poland is notably scarce. The studies available, where coastal protected areas in Poland were mentioned, primarily focus on environmental aspects, with limited research scale and methodology. Consequently, there is a noticeable absence of benchmark data necessary for studying spillover effects in the future.

[9] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy - https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32000L0060

5.2 Qualitative research

The responses gathered from interview participants and focus group attendees revealed a divergence of opinions, often aligning with the expectations and perspectives of their respective industries: fishery, tourism, environmental protection entities, and others. Notably, during group interviews with fishers, the majority emphasized the challenges in assessing the impact of these small MPA areas on both fish resources and the local economy. Many local fishermen asserted that there is insufficient scientific evidence supporting the need for protection of these specific areas. They contended that the marine areas were included in the park primarily for the protection of the coastline rather than for the preservation of marine habitats.

The viewpoints expressed by fishers, scientists, environmental organizations, managing and park authorities collectively suggest that it is too early to discern the results of MPA management actions for both MPAs. Additionally, due to the limited availability of data and publications on this issue, it remains premature to observe tangible outcomes from these management actions. Therefore, there is a clear need for enhanced exchange of information among the various entities involved in managing and benefiting from the MPAs. The structured results of the qualitative survey are summarized in Table .

Evaluation of the spillover effects is difficult due to the unavailability of data and the lack of scientific research in this area (e.g. scientific publications). According to fishers the MPAs have not affected adjacent fishing areas. Both fishers from ports around the Woliński National Park and the Słowiński National Park indicated that these particular MPA areas are too small, although even such an area can contribute to improving resources. On the one hand, they should be as large as possible to protect nature on the other hand, they should not be too large to avoid limiting fishing activities too much.

The protected areas are small and established in areas that, according to representatives of the fishing sector, do not have sufficient effects beyond increasing the operating costs of the fishing fleet. Interviews showed that for park authorities and fishermen, MPAs are perceived as a tool for both biodiversity conservation and fisheries management. Managing authorities, eNGOs and scientists perceive the MPA to be a biodiversity conservation tool. Fishers do not see these parks as a significant barrier for fishing, as the small depths of the area had naturally eliminated large vessels and active fishing methods.

Table 3. Views expressed by stakeholders in response to the qualitative survey.

Stakeholder	Any changes since the MPA implementation? Social perception	MPA implementation measures: size, regulation advancement	MPA as biodiversity conservation or fisheries management tool?	Catches change/ Biomass? Species composition?	Economic benefit for fisheries	Biodiversity protection/ Larvae habitat?
Managing Authorities	Not enough data, too preliminary to see results	No data/publications on this issue	Conservation tool	No data/publications on this issue	No data/publications on this issue MPAs would help to benefit fisheries communities only in case there are a lot of options around/outside an MPA to fish and MPA itself has a fisheries closure large enough to generate spillover effects that could be profitable for fishermen around	No data/publications on this issue Spillover effects could help fisheries, but only in case fisheries closure would be large enough
Park Authorities	Correlated with the overall negative trends in catches on Baltic Sea	Regulations for fisheries in the National Parks were established in 2010 and have not been changed. Changes are connected to general regulations.	Conservation and management tool	No data on this issue, but decrease of numbers of fish is similar to what happens in the whole Baltic Sea	Temporal cessation of fleet may be one of the issue for smaller catch. Anyway, limitation of number of vessels may positively impact local fleet up to 12 m (having permission)	Hard to say, no expertise
NGO's	Positive changes in habitat	Area of the marine area of the single park is too small to impact, but with other, bigger MPAs there should be a positive impact on the environment (cumulative effect)	Conservation tool, but in case of National Parks hard to assess impact	No data. In recent years many species are overfished	It is too early, but protection should economically benefit fisheries in the future	No data, but protection of habitat should benefit to that
Scientists	Changes are more likely to be caused by climate change	Size of MPA and time of implementation of protection is crucial	Conservation tool, but both approaches support each other	Establishing of MPAs should lead to improved environmental parameters. No research on this matter	Area of National Parks is not very important for commercial species. Local fishermen are neutral to MPA, but owners of bigger segments of fleet are concerned the area may be expanded	Even if positive effect occurs, its extent is small and it would need time to be noticeable and to impact a bigger area
Fishermen	No changes or changes due to other causes (i.e. overall condition of fish stocks in Baltic Sea)	Effectiveness of protection of marine waters of national parks is low. The areas are too small and there is a more strict protection of predators (seals, cormorants). More important for fish protection are temporary closures and limitations of gear types and number of gears	It acts as both management tool (3 respondents) and conservation tool (2 respondents)	Not at all (no changes in catches).	MPA didn't bring economic benefits and livelihood security (all respondents). They didn't see changes	For sure it may help to protect and enhance biodiversity, but for most commercially important species other areas are important.

Response of the managing authorities and park authorities

Ministry representatives highlighted that a team of employees actively contributed to crafting the responses to the questionnaire, ensuring comprehensive coverage and accuracy from the perspective of the Fishery Department. The ministry representatives perceive that MPAs are a conservation tool. They referred to the impact of the MPAs on the promotion of restoration of fish resources and thus on fisheries economics. In almost every answer they also highlighted the short duration of the restrictions, which do not allow for estimating spillover effects at this point. In their opinion, the MPA implementation process in Poland is in most cases too preliminary to see effects of the MPA. And in relation to management, the measures taken so far are limitations on certain fisheries and temporary area closures in spawning season. These measures are seen as sufficient to achieve protection for different species. Note that there is no scientific monitoring of catches in the MPA area and data collected under the Data Collection Framework (DCF) are aggregated, so it is challenging to have specific data on changes in fish species occurrence due to the MPA measures. Fishers have to send monthly reports of catches and by-catch (birds, seals, porpoises) to the park's authorities, and these reports are used as a monitoring tool for protection of birds and mammals.

The issue of the national park's function as an MPA was described quite thoroughly by a representative of the Słowiński National Park. His answers showed substantial experience with the functioning of fisheries in areas both inside and outside the MPA. He often referred to the relatively small area of the MPA under the jurisdiction of the Słowiński National Park; the generally weak condition of fishing opportunity in the Baltic Sea; and the limitation of users that is almost in line with the natural needs of local fishers. He claimed that fisheries are a natural activity. The park does not harm the business.

Response of the fishermen, NGO's and science stakeholders

A great deal of information was contributed by group interviews from the surrounding ports. Fishers from Dziwnów, Wolin, Lubin, Ustka, Rowy and Łeba responded similarly, focusing on assessing the impact of the establishment of the MPAs on their work. Everywhere, the fishers agreed that, apart from a few administrative duties and the cost of obtaining permission, they had not radically changed their nets' staging locations. They also pointed to non-obvious, non-planned effects of environmental changes that will potentially have an impact on resource protection.

Representatives of NGOs mainly pointed to the slowness of establishing mandatory Protection Plans for MPAs, confirming the limited area of parks in marine areas and the lack of plans for other established protected areas. They emphasised the long process needed for creating the conditions to stimulate potential spillover effects from MPAs.

In general, respondents from the fishery sector and scientific community asserted that MPAs neither solely serve as conservation tools nor exclusively as fishery management tools; rather, they represent a blend of both functions, mutually reinforcing each other. While MPAs do impose additional costs on fishery activities through access fees and reporting requirements, these costs are generally perceived as negligible. However, due to their limited spatial extent, none of the described MPAs have resulted in a noticeable spillover effect, or if such an effect exists, it cannot be reliably measured. Fishers perceived that the volume of catches has not increased since the establishment of the MPAs, and MPAs have no impact on the economy of fishers and their revenue. Despite this, the livelihoods of local fishers have not become more secure, although some fishers acknowledge that the limitation of vessel numbers in the MPA area could be viewed positively. Moreover, it was noted that all local fishers interested in accessing this area have been granted approval by the park authorities.

The current conditions for exercising protection of marine waters and their resources are acceptable to fishers, who see no need to permanently close MPA areas to fishing. The established rules for the use of the areas of these MPAs are not seen as restrictions by local fishers, as these rules do not limit fishers' rights for catching, and from the point of view of park managers, the rules allow control of fishing volumes, by-catch and sightings of birds, marine mammals and lampreys through the reporting system. Fishers pointed to the impact of water plant protection regulations in the areas of national parks. The growth of water plants has made fishing impossible in many areas due to the risk of damaging equipment (net clogging with macroalgae or seagrass). At the same time, fishers have identified areas in the border of the national parks as potentially important areas for fish spawning (not species-specific). Given the challenges in catching fish within areas rich in macroalgae or seagrass, these regions have naturally evolved into 'natural' protection zones, avoided by fishers.

According to respondents from the three groups (fishermen, NGOs and science stakeholders), the potential spillover effect of the small areas can be viewed as supportive of fish habitats, understood as the creation of conducive conditions for reproduction and the survival of juveniles. However, fishermen place greater emphasis on alternative tools, such as the temporary closure of certain areas (not necessarily associated with the MPA) during spawning seasons and regulations pertaining to the restriction of fishing gear. Remarkably, this perspective aligns closely with that presented by the managing authorities, indicating that communication between various stakeholders involved in marine resource utilization is at an appropriate level. This suggests that management decisions are made in consultation with stakeholders, facilitating a collaborative approach to sustainable marine resource management in the investigated areas.

6 DISCUSSION

The study of spillover effects in Poland is pioneering, yet limited by the lack of reference points in both literature (scientific research) and statistics (e.g. catch data). The knowledge on coastal area protection does not provide a methodology to extrapolate the results of the studies to a broader context, particularly to Polish MPAs. The **literature did not include any specific aspects of the parks but focused only on the overall characteristics** like: salinity, anthropogenic impact or interaction with invasive species, environmental protection and role of coastal areas in protecting biodiversity. The literature does not give any result on the characteristics of the MPA or effects of the management actions on nature restoration or potential spillover. The authors of this study underscore the necessity of a scientific survey in this area to assess effectiveness of park implementation and its impact on adjacent areas. This scientific inquiry could be juxtaposed with insights from stakeholder interviews, where it was suggested that **multispecies mechanisms in relatively small coastal areas may not be easy to evaluate** (Novaczek et al. 2017). While discussions can draw upon general studies on marine environment quality and the function of coastal areas for fish habitat and reproduction, it is imperative that such studies reference larger areas or MPA networks (Berkström et al. 2022). The disparities between studies should be acknowledged and discussed to provide a comprehensive understanding of the subject matter.

Data collected under the DCF focuses on the so-called Baltic Sea fishing squares, which give challenges in any scientific analysis that would aim to separate data according to the boundaries of the MPAs. This limitation was underscored by respondents from fisheries managers, park authorities, scientists, and NGOs, who highlighted the lack of knowledge to effectively assess and promote these MPAs as conservation tools. The aim of development in this area is **data aggregation adjusted to the needs of management purpose**. During interviews, it became evident that the absence (or limitation) of data significantly influences the perception of the role of national parks in marine areas. Consequently, social perception and knowledge about the role of MPAs, including the changes they bring, are limited among local fisheries (Silva & Lopes, 2015). The marine areas within the national parks are not perceived as an important conservation measure by them. No Protection Plan has yet been established for any MPA in Poland. Although areas within national parks are in the advanced stages of drafting Protection Plans, general regulations remain in force in practice. Environmental organizations, scientists and fishers share a similar opinion. There is a prevailing belief that the two approaches — conservation and management tools — mutually support and amplify each other, demonstrating a consensus among various stakeholders regarding the multifaceted role of MPAs.

The **advancement of regulations and their implementation for MPAs is still in the preparation phase**. Even the assessment of MPAs and their associated potential spillover effects is impacted by the fact that the regulation of MPA operation as part of national parks has not been finalized and implemented. The designation of areas without the establishment of Protection Plans undermines their proper functioning. According to the Polish regulation[10], National Parks, being legal entities, are obliged to prepare such plans. Moreover, they benefit from special regulations

[10] Ustawa z dnia 16 kwietnia 2004 r. o ochronie przyrody (tekst jednolity: Dz.U. z 2021 r. poz. 1098 z późn. zm.)

limiting access of economic activities and visitors. In the long term, there is a need to assess the efficiency of regulation in the protected areas (Kriegl at al. 2021).

The economic impact of the establishment of protected areas was not perceived by fishers. Instead, they link the decline in fishing income to the general condition of fish resources in the Baltic Sea. There was even a comment that a much more important area for improving the environmental situation (considered by fishers as improving cod stocks) is the Bornholm Deep (see Appendix), and that small and shallow areas such as those in the MPAs in this case study are of minor importance. The sentiment among fishers regarding reduced profit due to MPAs was echoed by the park authority of the Słowiński National Park. Conversely, respondents from the science sector and environmental organizations believe that the economic situation of fishers should be enhanced through the establishment of protected areas and would need time to be noticeable.

The **results of the catch analysis were corroborated by interviews with fishermen. Fishers perceived that the volume of catch did not increase since the establishment of the MPAs**, and that MPAs have no observed impact on the economy of fishers and their revenue (Leleu et al. 2012). They indicated that, for economic reasons, they were compelled to seek alternative species to replace lost income from cod fishing. Consequently, it is not feasible to attribute the increase in catches of other species in the Słowiński National Park to a potential spillover effect. Similarly, analyses of catches and interviews in the Woliński National Park confirmed the predominance of an economic approach in fisheries behaviour.

7 CONCLUSIONS

Park authorities and scientists acknowledge that MPAs are or will be simultaneously conservation and management tools. They see positive effects on the environment, biodiversity and fish stock health conditions. The spillover effect is expected to be seen in a few more years, and it will apply mostly to the young stages of fish. However, fishers have different views, and these expectations are not currently supported by scientific research and publications.

The literature does not give any insights on the characteristics of the MPA or effects of the management actions on fish stocks and potential spillover effects. In addition, the analysis of potential spillover effects requires detailed data and targeted biological and economic studies to allow spatial and temporal modelling of both the occurrence of fish schools, as well as the size, geographic dispersion and species composition of catches. Currently, the aggregated nature of fishing catch volume data poses challenges in assessing spillover effects based solely on this information.

Protection Plans for the Woliński National Park and Słowiński National Park are still under development. They are based on an inventory of the parks' resources and scientific advice. However, the parks primarily focus on protecting the terrestrial environment, with the coastal sea area regarded as a form of shore protection. The areas encompassed by the borders of these national parks are perceived by respondents as too small to have an impact on commercially exploited fish stocks. This was corroborated by the assessments of scientists and managing authorities, who also recognize a lack of knowledge and public awareness on the matter.

There is a need of scientific, targeted research to verify the effectiveness of park's implementation. The current scientific studies address mostly the effects of environmental protection on water bodies, the role of coastal areas in the protection of biodiversity, and related topics. New research on the effects of protection on commercial fish species within and surrounding the investigated and Polish MPAs, including on spillover, will motivate and educate stakeholders, and promote MPAs as a long-term management tool.

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APPENDIX

This Appendix contains a description of key terms used in the case study report.

Term	Description
Active methods/gears	Fishing methods/gears that require additional effort in the fishing process, such as trawls.
Baltic Sea fishing squares	A grid of Baltic Sea fishing squares was created by NMFRI in the early 1960s for location and statistical reasons. This grid comprises parallels spaced at 10 geographic minutes and meridians spaced at 20 geographic minutes, forming standardized "squares" with dimensions of 10 x 11.5 nautical miles (nm). These squares are designated from west to east with alphabetical letters (A through Z) and from south to north with numerical values (1 through 31)
Bornholm Deep	The Baltic Deep (105 m) is located on the eastern side of the Bornholm Island, which is an important breeding ground for cod.
Cultural fishery	Commercial fishery based on the use of traditional gear, equipment and fishing techniques, which is related to the tradition of the region, building the social and cultural identity of the region and its unique image. Fishers can participate in cultural fishing in a given National Park if they are included in the list of authorized entities. They have to apply to be on this list. The criteria of entry on the list includes vessels up to 12 meters in length, fishing with passive gear from ports around the areas of a particular National Park.
Passive gears	Fishing gears that do not require additional effort in the fishing process, such as entangling nets and traps.
Plan of protective tasks	The basic document regulating protective tasks for conservation zones in Poland (including MPAs, Natura 2000). The plan is implemented by ordinance of the regional director of environmental protection and has to be updated at least every 10 years. The plan of protective tasks can be considered as an equivalent for a management plan. Until the end of 2022, none of the management plans (i.e. plan of protective tasks) have been approved (Marchowski et al, 2022).
Protection Plan	The document regulating the protective tasks for National Parks in Poland, mandatory for marine areas. It is implemented by regulation of the Ministry of Environment and has to be updated at least every 20 years. The plan has a scientific basis. Note that the MPAs are only a part of the protected areas in Słowiński National Park and Woliński National Park

3. CASE STUDY REPORT:

TVEDESTRAND MARINE PROTECTED AREA

NORWAY – SKAGERRAK

European lobster *Homarus Gammarus.* © Havforskningsinstituttet

Analysis of potential spillover effects around the Tvedestrand Marine Protected Area

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LIST OF ABBREVIATIONS

Term	Description
ACF	Auto-correlation function
BACI	Before-after control-impact
CPUE	Catch per unit effort (number of lobsters per trap-day)
GAM	Generalized additive model
MPA	Marine protected area
SD	Standard deviation
UTM	Universal Transverse Mercator

1 EXECUTIVE SUMMARY

Spillover can be inferred with an increased abundance of target species right outside the boundary of a marine protected area (MPA) compared to fished areas further out. In this case study, we present evidence of spillover happening within 200 m from the boundaries of a small lobster MPA in Tvedestrand, located in the Skagerrak region of southern Norway. Since 2010, catch monitoring, with the use of a randomized sampling, using a before-after control-impact (BACI) design has produced a 12-year time series data on Catch Per Unit of Effort (CPUE) and total lengths for the European lobster *Homarus gammarus*. Results that are presented in this case study extend the work that was published by Nillos-Kleiven et al (2019), with the same generalized additive model analysis done on the extended data set until 2021.

Results show that CPUE inside the MPA has gradually increased over time and is currently at 1.47 lobsters per trap-day, more than 2 times higher than compared to fished areas (0.63 lobsters per trap-day), 9 years after the MPA was established. Within 200 m of the borders, CPUE is higher in 2021 compared to before establishment and implementation. At 1,000 m from the boundary, CPUE remains at a stable lower level, most probably due to the increased fishing pressure from local fishers in this area. A similar but more pronounced non-linear response of high abundance in the centre of the MPA, followed by a dip in the border and a plateau in fished areas further away was also detected in 2021 compared to results from 2016.

Data from interviews with local fishers indicate that many have moved their preferred fishing spots closer to the boundaries because they have experienced better (stable) catches there. Despite lower lobster abundance near the border, higher abundances further away in the fished area indicate that after close to a decade of protection, the fisheries seem to be finally benefitting from the nearby MPA.

The total lengths of caught lobsters are 20% larger inside the MPA compared to fished areas outside. Furthermore, a shift towards higher numbers of larger individuals is visible in the length distribution for catches inside the MPA.

On the other hand, the increase in the abundance and size of lobsters in and around the MPA cannot be attributed to protection alone, as it is only one of the tools in the expanding conservation toolkit for lobster populations in Norway. Also, there are not sufficient data on fishing pressure to support a conclusion that the increased fishing pressure may have caused erosion of the spillover gradient that should have been observed in this area.

The main scientific recommendations from this case study are the following: (i) To continue the monitoring series for CPUE for several years more, as European lobsters have a relatively long lifespan; (ii) To collect data on fishing pressure by conducting fishing gear survey during the open season in the next years; and (iii) To increase the duration of the annual sampling period.

To conclude, this study demonstrates that protection for severely targeted species works, but it takes a long period of time to be perceived in the fisheries. The dynamics of spillover and fisheries around MPA borders, as well as the interaction of protection time with other fishery management tools, are topics that should be investigated in more detail and in many other areas as these are important in developing sustainable fisheries and conservation of marine resources.

2 BACKGROUND

The Tvedestrand Marine Protected Area (MPA) (9°8′0″ E, 58°36′30″ N) is a 4.9 km^2 no-take zone for lobsters, located in the outer skerries of Tvedestrand municipality in the Norwegian Skagerrak region (Figure 1). The MPA is situated in an area generally classified as rocky substrate, originating from a glacial moraine that is running parallel to the coastline. Only hook and line fishing gear is allowed inside this MPA, and the use of sedentary fishing gear and all other methods that can potentially catch lobsters are prohibited. The outermost border, with a depth of 60 m, is adjacent to the rim of the Norwegian Trench which forms a natural deep-water barrier for lobster movement.

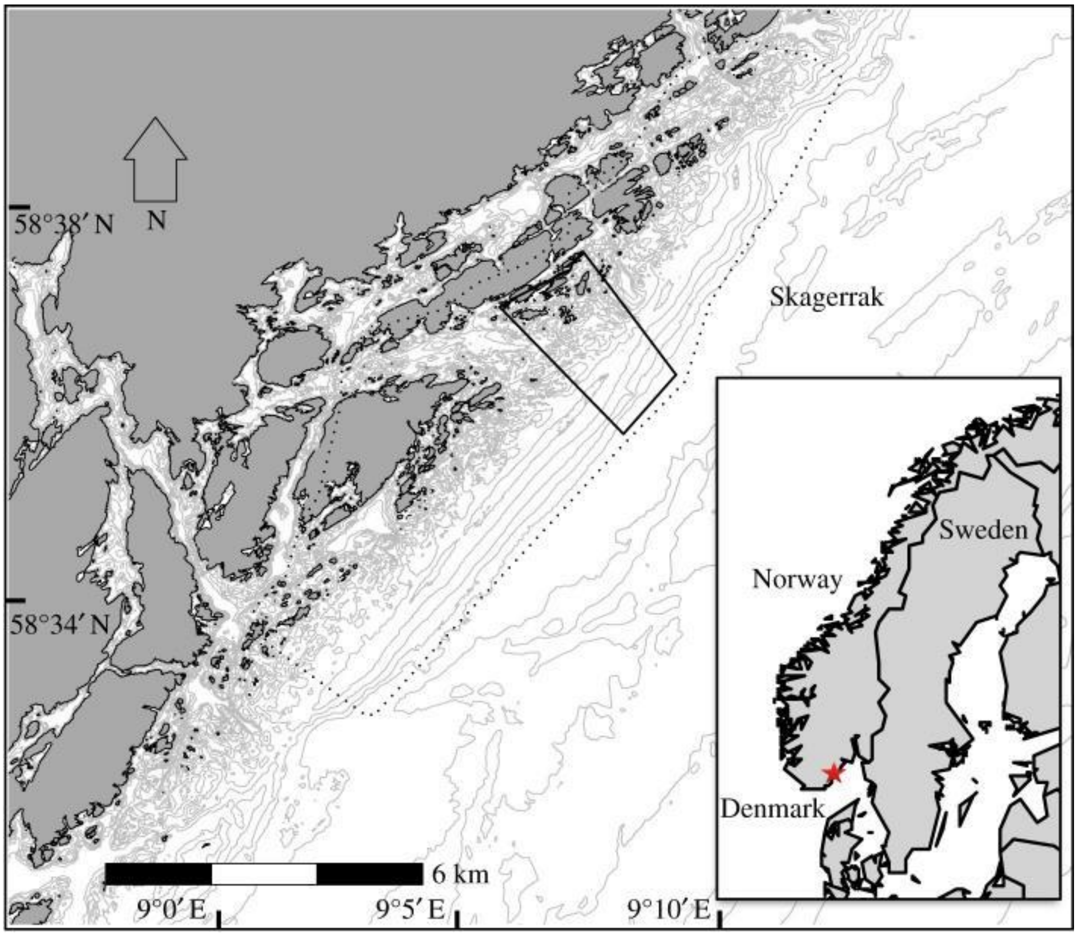

Figure 1: Detailed map of the Tvedestrand coast showing the MPA (box with solid line), and the study area (dashed line). Grey lines indicate depth contours. Inset: map of northern Europe indicating approximate location of the study area (red star).

The MPA, due to its location, was part of the preferred fishing grounds for local fishers. The MPA was established in 2012 after a long process that was initiated by the local government with help from government agencies and with strong support from the Institute of Marine Research station in nearby Flødevigen. Stakeholder consultation was conducted, and while the majority was in favour of the establishment of an MPA, a group of local fishers was also vehemently against. The fishers reasoned that there were already enough restrictions to lobster fishing in Norway, and that taking away part of the fishing grounds their grandfathers had always utilized is a violation of their constitutional rights to access their local natural resources. A more detailed narrative of the process is documented in Knutsen et al (2022).

In June 2012, a 5-year plan was adopted by the municipality of Tvedestrand with the provision that if the MPA proves to be effective, it can continue based on an agreed extension (Fiskeridirektoratet, 2023). In 2017, a hearing was conducted on the extension of the MPA ordinance, and its status as a protected area for another 10 years was acknowledged by the Norwegian Ministry of Fisheries. The ministry's decision was based, among other things, on the value of scientific data on spatial protection that was (and is being) collected as well as the ecological value of the area for the local struggling cod (*Gadus morhua*) population. Although several individuals from the local commercial fishery sector were vocally against the extension of the MPA ordinance, it was eventually approved. The documents on the hearing, statements from the stakeholders, as well as the decision of the national government on the continued protection of the Tvedestrand lobster MPA can be accessed at the Fiskeridirektoraret's website (only in Norwegian).

The MPA is also part of the larger Raet National Park. The park has zonation and regulations, but the implementation is generally non-existent (Fjeld, 2021). However, it must be mentioned that the local population and majority of recreational fishers who utilize the area are generally aware of the boundaries of the MPA, and generally abide by the rules and regulations.

The Tvedestrand MPA is in many ways unique because the push for its establishment came from scientists and local stakeholders in a municipality that are passionate about conservation of marine resources. In Norway, where the fisheries regulation is usually done using a top-down approach, this bottom-up approach was rarely heard of. The result is that the implementation of the local ordinance (spatial protection) is supported greatly by national regulations (temporal closures, legal size limits, etc.) that result in a good "toolbox" for lobster conservation.

Lobster fishing in Norway, at present, is generally considered to be a recreational activity, although there are a few fishers that sell their catch. The fishery used to be an important economic resource in southern Norway, but catches have been steadily plummeting since WWII and never really recovered. Populations of European lobster were so severely reduced that the species ended up in the IUCN Red List for a period of time. Therefore, several steps were taken by the government in the last 2 decades to mitigate the decline, and with the hope of improving current numbers (Kleiven et al., 2012).

Aside from the locally established no-take areas, lobster fishing is also regulated by many other rules that are implemented nationally. Recreational fishing is only allowed between October 1-30 and otherwise closed for the rest of the year. There is also a minimum and maximum size restriction in the Skagerrak area. The minimum size was increased from 24 to 25 cm, and since 2017, lobsters over 32 cm in total length cannot be harvested. All roe-bearing lobsters have been protected from harvest since 2008. Recreational fishers are allowed to have a maximum of 10 lobster pots per person per boat throughout the open season. Traps have to be marked with the fisher's name and address. In recent years, the Ministry of Fisheries imposed the registration of all recreational fishers prior to the start of the fishing season, as well as the use of an escape vent sewed shut with cotton thread that can degrade and prevent "ghost fishing" in the sea bottom if the trap is lost during fishing (Fiskeridirektoratet, Lobster fishing).

The Skagerrak region in Norway has a long history of trawling. Fisheries for cod used to be an important economic resource in the region, but this has continually declined over the years, and is currently considered non-profitable. A handful of shrimp trawlers still operate in the area, but it is a very small fraction of this previously existing lucrative fishing industry. In and around the MPA, the majority of fishers is recreational fishers with small boats, mostly older men who have fishing as a life-long hobby. The most popular target species are, for example, cod, pollack, lobsters, crabs. The "high season" for these recreational fishers is therefore during the summer and autumn holiday periods, the latter often coinciding with the open season for lobster fishing.

3 AIMS AND OBJECTIVES

The objective of this case study is to look into whether or not spillover is happening at the borders of the Tvedestrand MPA, 9 years after it was established. The answer is of great interest not only for scientists but also for the local government of Tvedestrand, since continued implementation of the MPA is dependent on whether the "experiment" has worked or not.

For this study, we looked at the development over time of the CPUE for lobsters relative to the boundary of the MPA. This study builds on an on-going before-and after-impact (BACI) monitoring that was conducted between 2010-2016, and published in 2019 (Nillos-Kleiven et al., 2019). New to this study are data from 2017, 2019 and 2021, which were incorporated into the same statistical model used for the earlier study.

The dataset for this analysis contains 3 years of data prior to MPA establishment, and 10 years of data from monitoring afterwards. And although monitoring after establishment has not been done on an annual basis due to personnel and budget constraints, the sampling method and time of year for sampling has remained the same. Also, by using the same statistical analysis, we expect to get a good picture of the temporal and spatial patterns of lobster abundance a decade after the MPA was established.

We hypothesised that the key factors that potentially influence spillover dynamics in the Tvedestrand MPA are the location of the MPA, development/increase of the recreational fishing pressure at the border areas, the implementation of other regulations and restrictions on lobster fishing over time.

4 METHODOLOGY

4.1 Data collection

Data from the study area have been collected with the use of lobster traps for experimental fishing in randomly determined points. Since 2010, the same two-chambered lobster traps (90 × 45 × 40 cm) with 11.5 cm entrance diameter and closed escape vents have been used. These traps are commonly known as Scottish lobster traps (Figure 2). Sampling is conducted at the same period every year (last week of August to first week of September), a month before the start of the lobster fishing season in Norway. Sampling effort (Table 1) was doubled in 2016 to obtain better-quality data for statistical analyses. Trap locations inside and around the MPA were selected at random during the pilot survey (2010). From 2011 onwards, the sampling regime was modified slightly using topography data to maximize sampling efficiency while still maintaining randomized trap locations (random stratification). Sampling was thus limited to only those areas that 1) have a rocky bottom; 2) have a slope between 5 and 20° and a maximum depth of 35 m from the MPA surface; and 3) are situated inside the study area (within 3 km northeast and southwest of the borders).

The traps are baited with frozen mackerel (*Scomber scombrus*) before deployment and attached to a marker buoy with a 40–45 m length rope. Marker buoys for each trap are individually numbered and carried information about the experimental fishing activity. Time, GPS position and depth are recorded for each trap haul. All lobsters caught are released at their capture location.

Figure 2: Lobster trap used for this study. Note that the escape vents are mandated to be open by law, but these are sewn shut (with special dispensation) for the purpose of this study. (Photo credit: Online catalogue of jula.no).

Table 1. Sampling effort: total number of traps deployed in the study area (2010-2021).

Year	2010	2011	2012	2013	2014	2015	2016	2017	2019	2021
Fished area	110	104	127	89	203	191	352	71	67	96
MPA	17	39	60	55	139	88	183	120	128	171
Total	**127**	**143**	**187**	**144**	**342**	**279**	**535**	**191**	**195**	**267**

4.2 Study design

This case study employed a BACI design with random sampling in and around the MPA with the use of Scottish lobster traps over time to determine the catch per unit effort for lobsters (as a proxy for abundance). The study area, with an area of 52.4 km^2, is indicated in Figure 1. It encompasses fishing grounds within 3 kilometres from the side boundaries of the MPA. The boundary towards the open sea was not included because it is a deep-water area that forms a natural boundary for lobster movement. Lobster abundance was the metric selected, because it is easily replicable and is well-suited for field work with small boat with a crew of 2-3 people and standard fishing equipment. As we are using the same traps as the local fishers, it gives us results that are easy to interpret and allow for easier dissemination to the stakeholders (e.g. "*A catch of 1 lobster per trap in 2 days is the norm in this area*"). Thus, we have a common metric to discuss, and catch over the years (as well as indications of spillover) can be easily monitored by the locals as well.

As to the duration of the study, the BACI design has been implemented from the start, thus we have 3 years of "before" data in the area that was eventually designated as an MPA. Monitoring of this area has been ongoing 11 years after implementation, and we hope to continue this monitoring for a decade or more. The Tvedestrand MPA is one of the few MPAs in Norway that have been established with the purpose of scientific monitoring, and as its location and the data we have – and will be – generating from it is of great importance in understanding the mechanisms of spillover.

The study area has a similar habitat inside and outside the MPA, so it is expected that habitat selection for lobsters will be evenly distributed. We also assumed the same catchability for the traps that are deployed inside and outside the MPA. The only difference is the (assumed) absence of fishing pressure inside the MPA, which over time should result in an abundance gradient that is highest in the middle of the MPA and with a steeply declining gradient towards the border and outwards to the fished areas. The fishing pressure was also assumed to eventually increase closer to the border over time due to fishers' expectations of bigger and more catch in fishing areas adjacent to the MPA border.

Since we covered a relatively small area for this case study, and have randomly placed sampling points collected over the same period time every year, it was feasible for us to detect eventual changes in abundance. The availability of precise GPS units as well as spatial analysis tools in R allowed us to ask if there is a gradient in and around the border, and how steep that gradient is. This is one approach in determining spillover.

4.3 Data analysis

For this study, we adopted the use of CPUE as a proxy for abundance, and the aim was to detect any change in the abundance in and around the MPA border over time, which is expected to develop a steeper gradient if spillover is happening.

The following section on data analysis for CPUE is taken from Nillos-Kleiven, et al. (2019).

To achieve parsimony in the analysis of CPUE, a zero-inflated Poisson generalized additive model (GAM) of the main factors (distance from border and years of protection) that influence CPUE was used. Depth was added as a random factor. The optimal model determined by backwards step Akaike selection criterion is as follows:

$$Chij=s1(Bh,Pi)+s2(Dj)+\beta k+\varepsilon ijk.$$

Here, the model predicted CPUE (C) for a trap at distance *h* and year *i* at depth *j* is given by the interaction between the distance from the border (B_h) and years of protection (P_i) as well as the depth of trap from the surface (D_j). The splines (s_1 and s_2) are the smoothing functions modelled as a product of quadratically penalized regression spline basis functions of B, P and D with software-determined automatic smoothness estimation. β_k is the model intercept and ε_{ijk} is the error term (see electronic supplementary material, S1 for intercept values and GAM output). The fitted values for CPUE (at model predicted optimal depth) were obtained by using the formula:

$$CPUE=\log(Chij).$$

The locations of traps (longitude and latitude) were converted into metric Universal Transverse Mercator (UTM) units for use in data analyses and mapping in R. Spatial and temporal correlation was checked using auto-correlation tests (ACF), to confirm that the data were neither spatially nor temporally correlated before proceeding with the analysis. The distance from the border for each trap was calculated as the shortest distance to the nearest MPA border. To aid interpretation, the border line was designated as 0. Distance from the border was negative inside the MPA and positive outside the MPA.

Data preparation and analyses, as well as generation of figures and maps were done primarily in the R environment for statistical computing (http://www.r-project.org) using the following packages: *mgcv*, *pscl*, *splancs*, *rgeos* and *sp*.

Validation for the optimal model is done by using the Pearson residual and the inspection of residual plots for the zero-inflated models.

4.4 Method for evaluation of spillover assessment

Our current method of experimental fishing in random sites throughout the study site is suitable for assessing spillover effects because it is easy and practical to execute in the field, as well as easily replicable. In terms of reliability, it is difficult to say, because the dataset is zero-inflated, with up to 60% empty traps on certain days, and therefore a large number of traps must be deployed. This zero-inflation reflects the many factors that affect catchability of lobsters, mainly patchiness of the habitat, presence of a large number of crabs, as well as weather and sea conditions. We do our best to ensure that the traps fall within a set range of conditions, but it has happened that these traps ended up in muddy patches, which lobsters are known to avoid. Also, it is not uncommon to pull up a trap full of crabs, and the question then is are there lobsters that *could* have gone in if the traps were not full of crabs. However, despite of these drawbacks, it is with a certain amount of confidence that we could say that spillover *can* be detected if it does occur in the MPA because sampling has been done in the same way over a relatively long period of time in the same study area. An increase in both abundance and lobster size at the border areas compared to areas further away that are heavily fished can be considered as evidence of spillover.

Of course, no method is foolproof. Increased size and abundance of lobsters in the border area is bound to attract higher fishing pressure, and we have seen this trend in our data set from 2012-2016. Spillover in the border area, if it does occur, will thus be harder to detect because of the greater loss to fisheries. Although we have no data on fishing pressure from 2017 onwards, interviews with recreational fishers who use the border areas confirm that this shift is happening even more as they experience improving catches near the border over time. Recreational fishers have reported stable yields, or slight increases in yields in the border areas despite the documented lower CPUE there. This is because they are not allowed to take home the larger individuals (more than 32 cm) as well as those that are smaller than the 25 cm minimum legal size that they catch. Fishers are reporting that they have to throw back more than half of their catches due to the legal restrictions (but they do so without complaining, because they are aware that the restrictions are in place to ensure stable yields in the coming years).

Our study is limited in that we have no means to monitor the actual fishing pressure that is happening at the MPA borders. We are aware that this fishing pressure peaks during a first two weeks of the open season, but the number of fishers can vary according to whether it is autumn break and on weather and sea conditions. Also, the MPA in Tvedestrand is not monitored by enforcement agencies, and poaching is happening at a chronic low level and “everybody knows it”. Fishers also catch lobsters that were tagged inside the MPA in the fished areas outside, but these are often unreported, and the numbers are too few to run a proper mark-recapture analysis to demonstrate spillover movement.

In an ideal world with unlimited budget and personnel, and the same ideal climate for fieldwork throughout the year, the same sampling procedure should be done both a month before and after the open season to determine if lobster movement to outside areas are occurring, and if there is a notable decrease in the CPUE after the open season. Sampling using the same experimental fishing method should also be done yearly, and the fishing pressure around the MPA should be quantified properly by doing a gear survey throughout the open season. A longer sampling period is also desirable.

4.5 Qualitative approach

In order to fill in some knowledge gaps on the perception of the local stakeholders on the occurrence of spillover, 4 interviews were conducted with local fishers who have been fishing in the area long before the MPA was established in 2012. The local resource manager of the municipality was unavailable for personal reasons. The interviewees were selected from a short list of known local lobster fishers, and they were interviewed using the standard questionnaire that was developed for this study (Annex 4).

5 RESULTS

Lobsters became bigger in the MPA immediately after protection, and more of them are growing bigger over time under protection.

The mean total lengths of lobsters caught in traps deployed in the MPA are significantly longer compared to those that were caught in fished areas outside the border, after 11 years of protection (see Figure 3). Prior to protection, the difference in the lengths of lobsters caught between these areas was relatively smaller. The results of length monitoring, although not a direct indication of spillover, clearly show that protection has a direct effect on the sizes of individuals. Interestingly, for 2021, the mean total length of lobsters caught outside the MPA is at 25.4 cm, which is just above the legal-size limit. Inside the MPA, mean total length is at 30.8 cm, which represents a 21% increase in length. These results also reaffirm the stories of local recreational fishers that many of lobsters caught just outside the MPA are now "safe from fishing" as they are nearing the 32 cm maximum legal catch size.

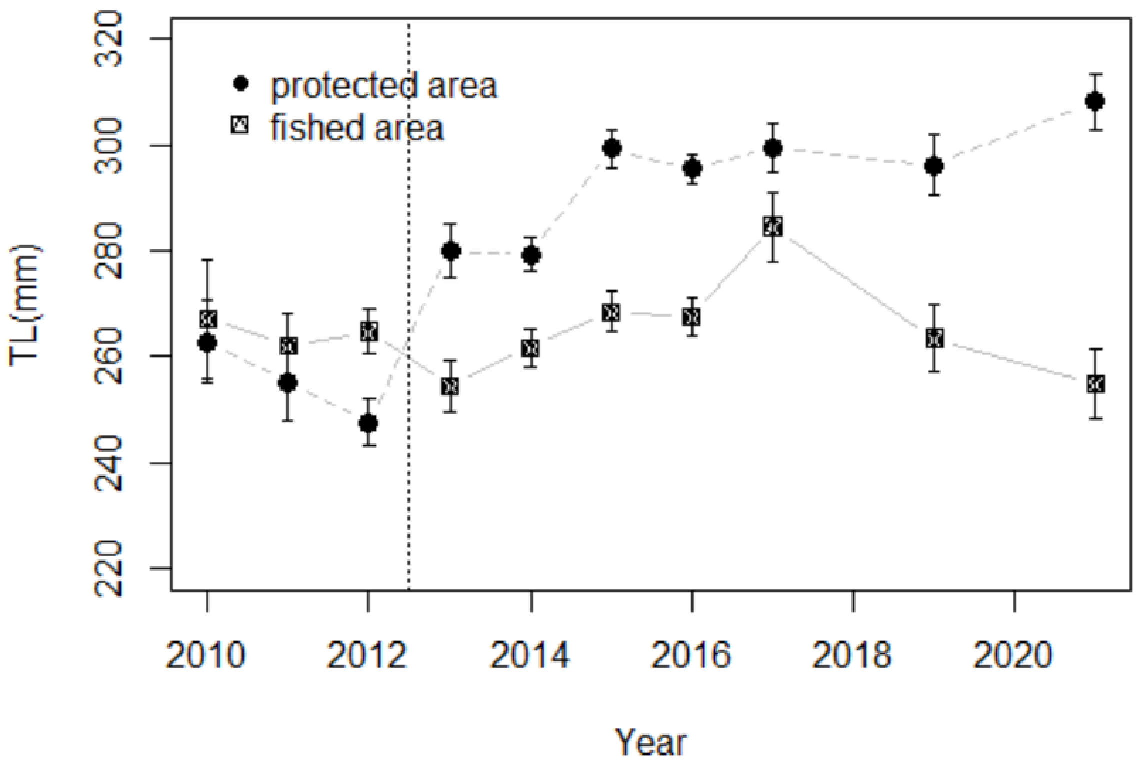

Figure 3: Total length of lobsters caught inside (black circles) compared to fished areas (boxes). Error bars are +/- 1 SD. The dotted vertical line indicates when protection was implemented.

Another way to look at the data for total lengths is to look at the histograms for length distribution based on area and implementation of protection. Figure 4 indicates that while the control area has a similar length distribution before and after protection status, the length distribution in the MPA area has shifted, with more individuals in the 30-cm-and-longer group. In this graph, one can easily see in the "after protection" side that there are more of the larger lobsters in the MPA compared to the fished area.

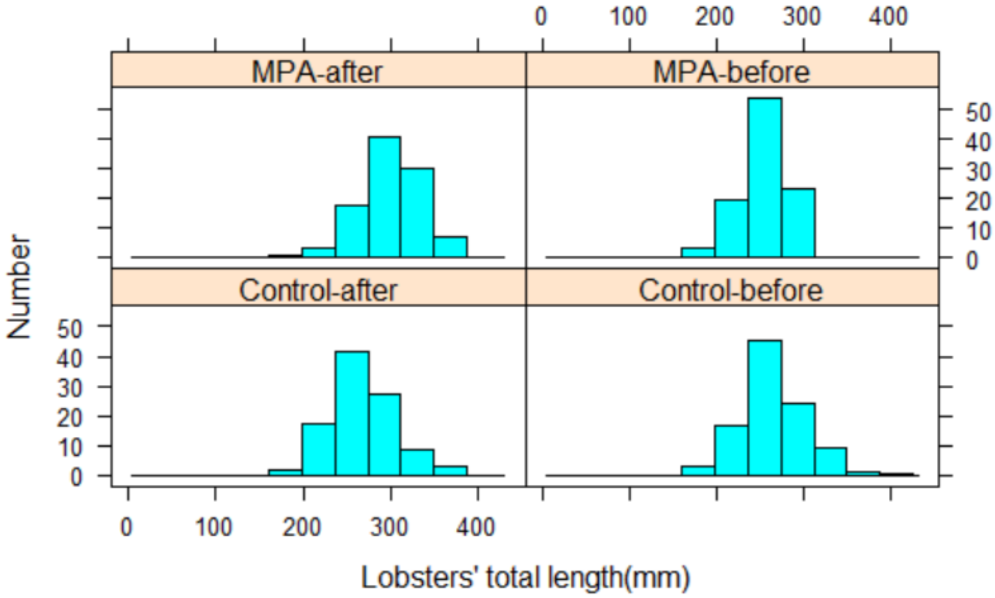

Figure 4: Length distributions for before and after protection in fished (control) and protected (MPA) areas. Data are pooled for the entire study period (2010-2021).

In general, the CPUE (number of lobsters caught per trap-day) in fished areas outside the MPA is low and has remained at the same level as prior to MPA implementation. CPUE inside the MPA, however, has gradually increased over time (see Figure 5) and is currently at 1.47 lobsters per trap-day, more than two times higher than compared to fished areas (0.63 lobsters per trap-day) 9 years after protection started.

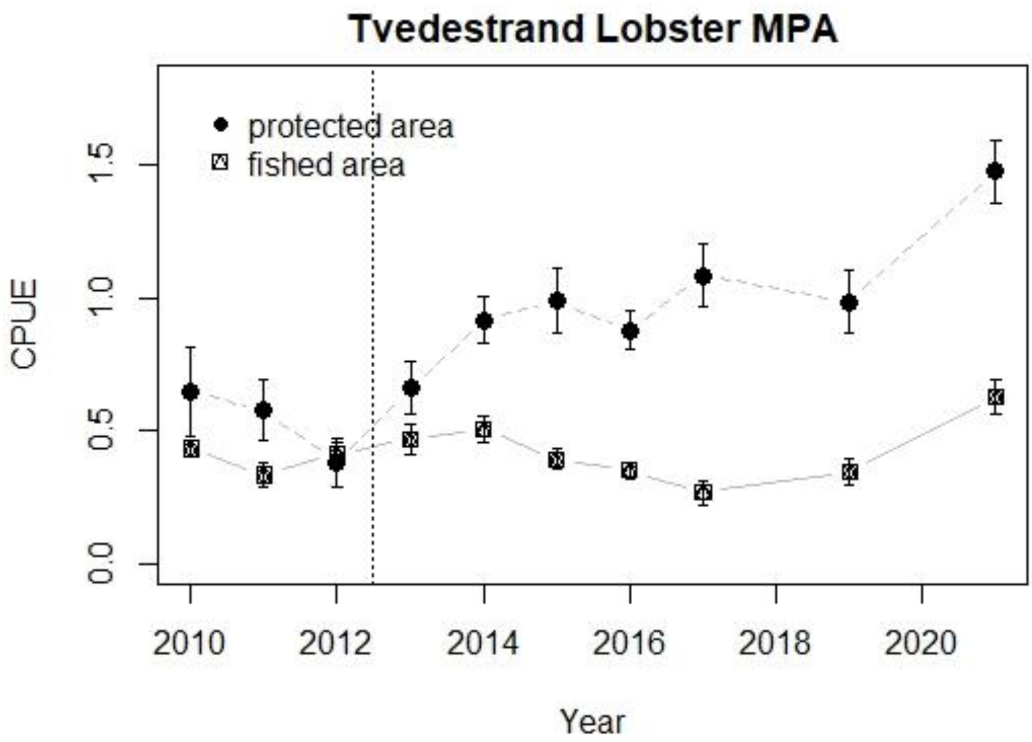

Figure 5: Trend over time for catch per unit effort (number of lobsters per trap-day) from 2010-2021 inside the protected area (dark circles) compared to the fished areas (triangles in a box) in the Tvedestrand lobster MPA. Error bars are +/- 1 S.D. The dotted vertical line indicates when protection was implemented.

Predicted values from the GAM has indicated a very clear response to CPUE to protection over time (Figure 6). The values are predicted by the model at the optimal depth of 25 m. The gradient inside the MPA has been increasing, and after 9 years of protection, a much higher CPUE at fished areas up to 200 m from the border is visible, an indication of spillover. Another interesting finding is the even more pronounced "dip" in CPUE in the fished area within 1 km of the boundary. This area corresponds to the same area that the fishers we interviewed referred to, where they indicated that they had stable catch since the establishment of the MPA.

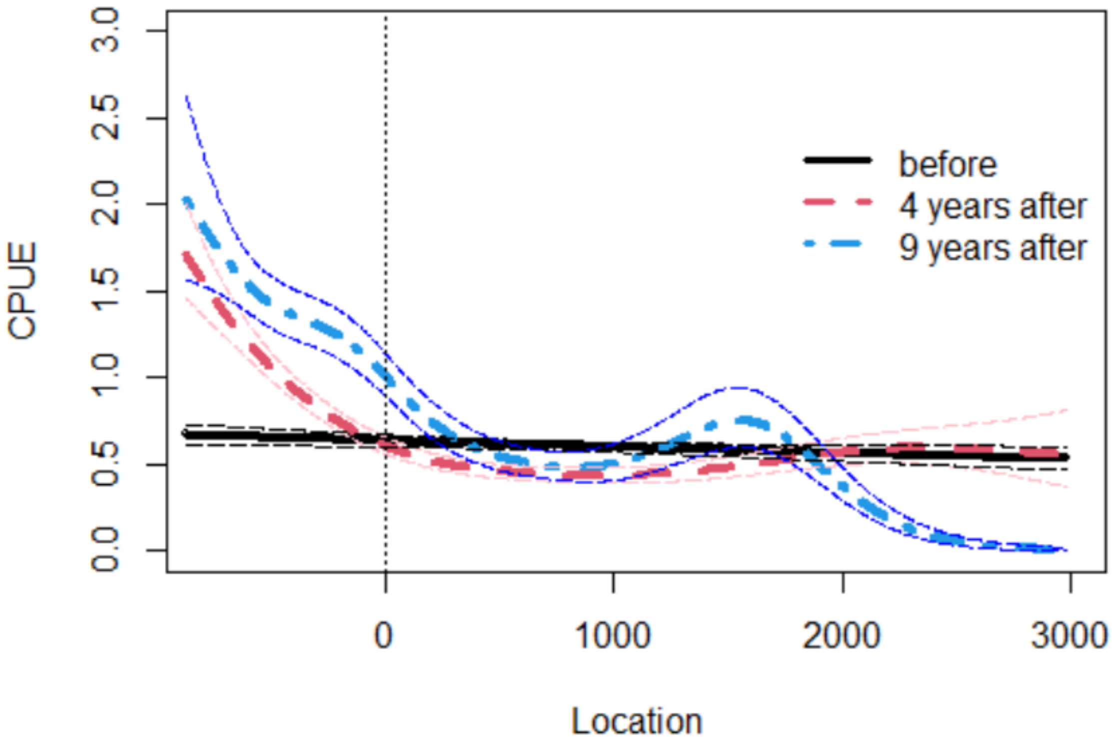

Figure 6: Model predicted CPUE response to years of protection and distance to border (bold lines), prior to, 4 years and 9 years after MPA implementation, at the optimal depth of 25 m. Thinner lines of the same colour indicate +/- 1 S.E. Vertical dotted line indicates the MPA boundary.

Results from the GAM on the interaction of trap distance from border and length of protection show a non-linear CPUE response, with catches being higher inside the MPA compared to fished areas outside (Figure 7). The general shape of these splines are similar, indicating the gradual but positive response of abundance to protection over time in areas within the border of the MPA.

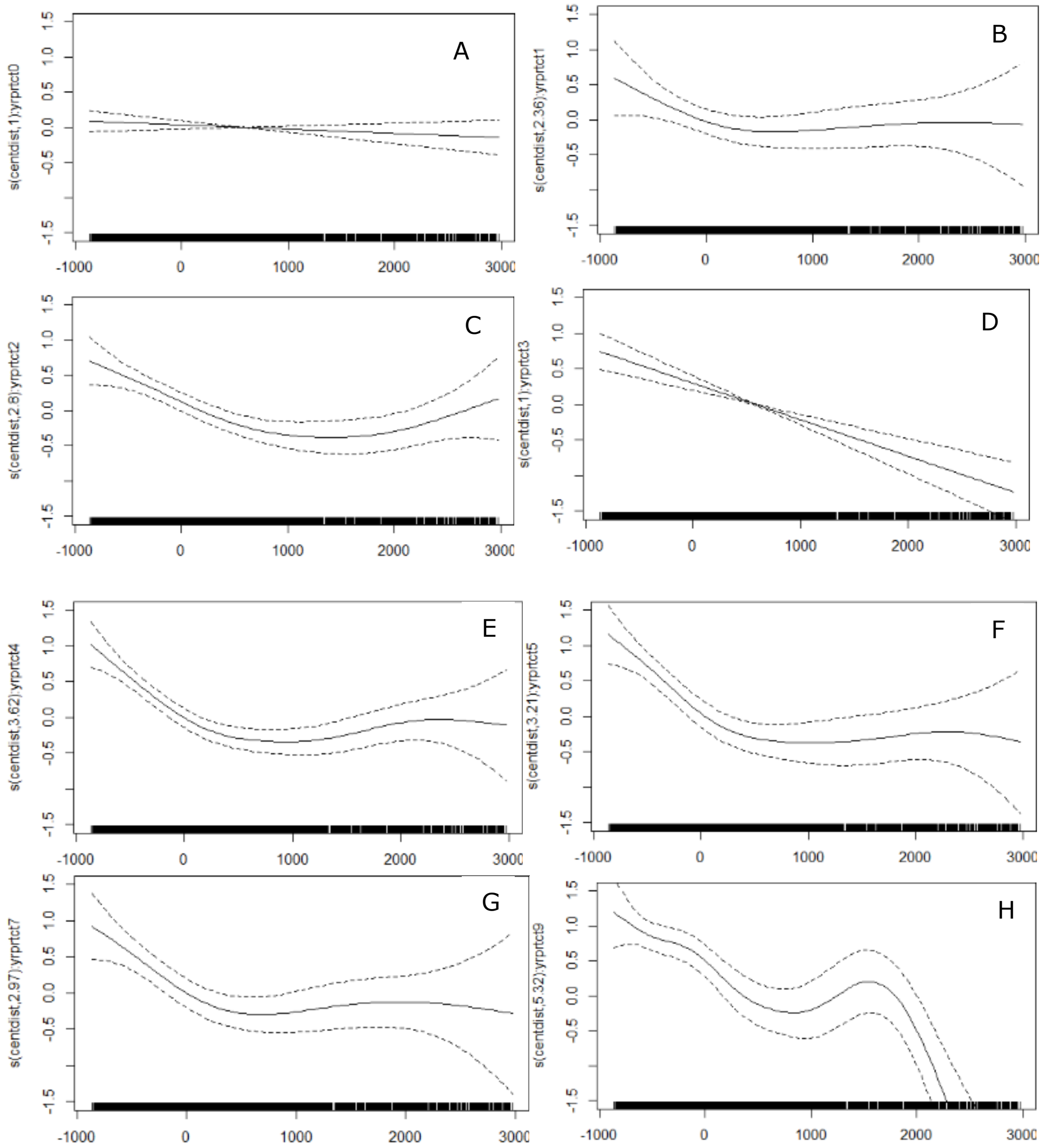

Figure 7: Splines showing the effect of the interaction of trap distance from the MPA border and length of protection to catch per unit effort, derived from GAM. A) Prior to protection; B) 1 year of protection; C) 2 years of protection; D) 3 years of protection; E) 4 years of protection; F) 5 years of protection; G) 7 years of protection; and H) 9 years of protection. X-axis numbers indicates distance to border, with negative values on the left side of the graph indicating distance inside the MPA. Dotted non-linear lines are 95% confidence intervals. Y-axis indicates the partial effect of the time protection variable, from 0 year to 9 years.

6 DISCUSSION

Compared to values prior to protection, the CPUE gradient 9 years after MPA implementation indicate that the catch within 200 m of the boundary increased. Together with higher catches further away from the preferred fishing area at 1000 m from the boundary, these values suggest that spillover is happening. If the fishing pressure in the 1 km area outside the border has maintained the same level as previously published in 2017, the fact that the abundance here has not been *lower* at present indicates that the MPA has had a positive effect on the nearby fished areas. The presence of **slightly higher catches further away (at around 1500 m) 9 years after implementation** compared to values from 4 years after implementation — and despite the much higher expected fishing pressure — are also a clear indication that protection benefits (spillover of adult individuals) are being felt in the fished areas.

The results of this extended analysis are similar to the findings of Goñi et al. (2006) on the spillover of the spiny lobster *Palinurus elephas*, where decreased CPUE values were also attributed to the fishing pressure outside the MPA. A similar pattern for abundance (a decline right by the border followed by a plateau) was reported.

On the other hand, while results of a few studies attribute the abrupt decline in CPUE by the border to increased fishing pressure in the area, **our lack of current data on fishing pressure in Tvedestrand weakens our argument for the negative effect of "fishing the line"** (Kellner, 2007) **on lobster abundance in this area**. However, since we documented that catches in this area were higher prior to MPA establishment, the currently lower level in this area outside the border is *probably* attributable to sustained higher fishing pressure here. **Local fishers interviewed for this study have mentioned that they had to "move" their fishing areas out of the MPA when it was implemented, and it is likely that they moved to the closest available fishing ground just outside the border.**

The results obtained from this case study highlight the need for improved data quality in the coming years, so that the factors that influence the steepness of abundance gradients can be examined further. Modelling with GAM requires good quality data. It is hoped that eventually, with enough fishing gear survey data, we will be able to incorporate fishing pressure data into our existing statistical model, and possibly provide interesting insights into the dynamics at the MPA border.

7 CONCLUSIONS

This study shows that long term monitoring with a good design can detect the occurrence of spillover for long-lived species like the European lobster. Over time, an abundance gradient builds up inside the protected area, and this builds up expectations as well for eager lobster fishers. Increased fishing pressure at the boundaries is therefore expected, and this unfortunately erodes the spillover effect, making it more difficult to detect earlier. However, with longer protection time, clearer abundance gradients develop, and positive effects to nearby fishing grounds happen eventually. In this study, we have shown that 9 years is sufficient to detect spillover at the border area of an MPA, despite the assumed increasing fishing pressure in adjacent fished areas.

On the other hand, the increase in the abundance and sizes of lobsters in and around the MPA cannot be attributed to protection alone, as it is only one of the tools in the expanding conservation toolkit for lobster populations in Norway. Also, there are not sufficient data on fishing pressure to support a conclusion that the increased fishing pressure may have caused erosion of the spillover gradient that should have been observed in this area.

This study is an extension of the work that has been published by Nillos-Kleiven et al. in 2019. The BACI time series, using a relatively simple method for experimental fishing, will hopefully be continued for many more years to come, as it sheds light on the dynamics between spillover and fishing pressure in the boundaries of a relatively small MPA. Lobsters, with their longevity and appeal to fishers, are in many ways the ideal species to monitor in the span or a decade or two. The dynamics of spillover and fisheries around MPA borders is an important mechanism for sustainability and conservation that should be investigated further and in more detail in many other areas as well around the world.

To conclude, this study demonstrates that protection for severely targeted species work, but it takes a long period of time to be felt in the fisheries. The dynamics of spillover and fisheries around MPA borders, as well as the interaction of protection time with other fishery management tools are topics that should be investigated further and in more detail in many other areas as well as these are important in developing sustainable fisheries and conservation of marine resources.

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4. CASE STUDY REPORT:

THE NORTH SEA COASTAL ZONE

THE NETHERLANDS – NORTH SEA

Grey shrimp *(Crangon crangon)*

Analysis of potential spillover effects: Shrimp fisheries in the North Sea Coastal Zone

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LIST OF ABBREVIATIONS

Term	Description
AIC	Akaike information criterion
AIS	Automatic Identification System
BACI	Before-After Control-Impact
CPUE	Catch per unit of effort
CSH	Grey shrimp
GLMM	Generalized linear mixed model
LNV	Ministry of agriculture, nature, and food quality
MPA	Marine protected area
NSCZ	North Sea Coastal Zone
VMS	Vessel monitoring system
VIBEG	Visserij in beschermde gebieden akkoord (NL) / Fisheries in protected areas agreement (EN)
WWF	World Wide Fund for Nature

1 EXECUTIVE SUMMARY

The grey shrimp *(Crangon crangon*) fishery is one of the largest fisheries in the coastal zones of the Netherlands. The majority of the shrimp landed at the auctions in the Netherlands comes from the North Sea Coastal Zone (NSCZ). The NSCZ is a valuable area which is designated for several habitat types and many animal species. To enable a combination of nature conservation and fisheries within the Natura 2000 areas in the North Sea, the Fisheries Protected Areas Agreement (VIBEG) was concluded. Four small areas, in total approximately 144 km^2 were completely closed for bottom-disturbing fisheries, including shrimp fisheries.

Studying spillover effects holds key insights into marine protected areas (MPAs) and their ecological impact. It can give true insight in the consequences for the shrimpers previously operating in the area and quantify any potential benefits. Interviews were conducted via questionnaires with stakeholders of the NSCZ, aiming to explore their insights, expectations, and their experiences regarding spillover in the region. Then, basic fishery statistics were assessed and generalized linear mixed models (GLM) were constructed to assess biomass (in cumulative kilograms), fishing effort (in cumulative hours), or mean catch per unit effort (CPUE) (kilograms per hour) per 0.05-degree c-square annually and tested to period (before or after the fisheries adherence to the MPAs' restrictions).

It was observed that shrimping effort significantly decreased within the NSCZ after the establishment of the MPAs. However, the quantity of shrimp caught did not show significant differences before and after the establishment of MPAs. Aligning with previous findings, CPUE did increase significantly. The increase in CPUE does not testify for a relative increase in biomass. As many fishers agreed with a buy-out proposal when the protected areas were established, fishing effort significantly decreased. As a consequence, there was much less competition, which could be an explanation for the increase in CPUE.

The indicators of potential spillover of shrimp in the four MPAs within the NSCZ were tested. In theory, perfect density-related spillover would exhibit a gradient of biomass or abundance originating at the boundaries of the MPAs, diminishing as distance from the boundary increases, and growing stronger over time. The analysis found no significant effects related to distance to the nearest MPA, years since MPA establishment, or the interaction between these two variables. Consequently, no conclusive evidence emerged to support the existence of spillover. Interestingly, the observed reduced effort contradicts some questionnaire assumptions, but it aligns with the conclusion of the absence of evidence for spillover. There are various hypotheses on why demonstrating spillover in this specific case could be difficult, ranging from the actual absence of spillover to the inherent difficulty in proving its existence. These findings highlight the challenges in attributing spillover effects to relatively small-scale MPAs, and the need for additional research in understanding their ecological impact.

2 BACKGROUND

2.1 The grey shrimp in the North Sea Coastal Zone

The grey shrimp (*Crangon crangon*) fishery is one of the largest fisheries in the coastal zones of the Netherlands. In 2019, around 200 Dutch-flagged vessels caught grey shrimp. That year, these vessels landed 13 400 tonnes of shrimp with an estimated export value of 98 million euros, which is estimated to be 80% of the total turnover (Quirijns et al., 2021) The auctions around the Wadden Sea in the North of the Netherlands (North Sea Coastal Zone, or NSCZ) accounted for 82% of the total landings of grey shrimp of the Dutch fishery (Turenhout et al., 2015).

The NSCZ is a is a rich body of water with a great diversity of marine life. The area was designated for many birds under the Birds Directive since 2000, and for many habitat types and habitat species since 2011 under the Habitats Directive (Natura2000).

The potential ecological effects of the grey shrimp fishery in the shallow shelf of the North Sea and the Wadden Sea are currently heavily debated, especially because the fishery operates for a large part in designated Natura2000 sites. Fishing with otter and beam trawls account for the major part of shrimp production, as these gears target species that form large schools over relatively level open ocean bottoms (Eigaard et al., 2017). Trawling physically disturbs the seabed by dragging fishing gear over the seabed to catch demersal fish and benthic invertebrates. The direct impacts are the physical disturbance on the habitat and on the organisms living on and in the seabed (Tulp et al., 2020). The shrimp fishery is known for its large amounts of bycatch of benthos, flatfish (in particular plaice) and undersized shrimp. A reason for the high bycatch levels high the use of the smallest mesh size (20 mm) of the entire Dutch fishing industry (Jongbloed et al., 2015; Catchpole et al., 2008).

The Netherlands have implemented marine protected areas (MPAs) to restore and conserve the environmental status and condition of the North Sea, including seafloor communities (EEA, 2018). In 2009/2010, the NSCZ was designated as a Natura 2000 area. This makes the area part of a European network of nature areas subject to special protection. To enable a combination of nature conservation and fisheries within the Natura 2000 areas in the North Sea, the Fisheries In Protected Areas Agreement (VIBEG) was concluded in 2011. This would be achieved through closure of several areas within the NSCZ. The core of the agreement involves spatial zoning of areas for different types of fisheries, allowing various types of fisheries in some of these zones, and complete closure to shrimp fisheries in other zones. Specific area names and sizes are given in Table 1 and Figure 1.

Table 1: Overview of shrimp-fishery restricted area sizes.

Area	Size
Petten I	30.8 km^2
Rottumeroog- en plaat I West	25.4 km^2
Rottumeroog- en plaat I Oost	34.0 km^2
Terschelling I West	18.7 km^2
Terschelling I Oost	34.9 km^2
Total	**143.8 km^2**

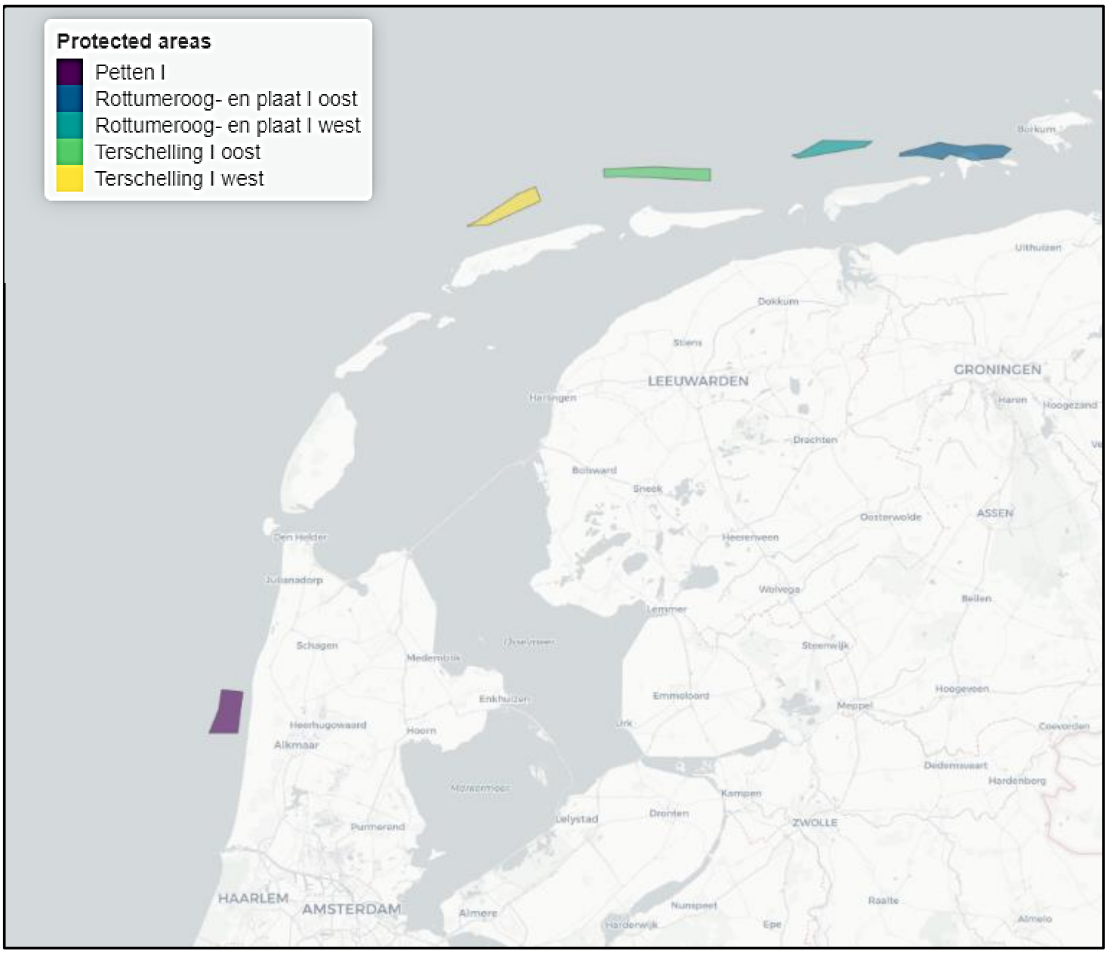

Figure 1: Overview of shrimp-fishery restricted areas in the North Sea Coastal zone, Netherlands.

Although areas were legally closed in 2013, January 2017 was considered as the cut-off point for adherence to the closure of the fishing areas. Officially, shrimp fishing was not allowed in these areas from 2013 onwards. At the time, shrimp fishers showed low compliance: the majority of the fishers continued to fish in the closed areas (Wilkes, 2022). However, when the first fines were handed out for not following legal spatial fishing restrictions in 2016, adherence to the restrictions in the areas appeared instantaneously (see Appendix). This was verified by looking at fishing effort in restricted areas over the years and months. In January 2017, there was a sudden drop in fishing effort in the restricted areas, corresponding with the time when the first fines had been distributed.

Closing areas to fishing has the potential to be beneficial for fish populations in the long term. By designating specific zones as protected areas, fish species get the opportunity to recover and replenish from the impacts of fishing. As these fish populations flourish within these protected zones, they can attain higher biomass and increased abundance levels (Kaplan et al., 2019). The same might apply to shrimp. Over time, this can lead to a spillover effect, where surplus shrimp move beyond the protected areas and disperse to adjacent fishing grounds. Studies from other cases have demonstrated that well-managed protected areas can indeed result in spillover, contributing to increased catches and yields in surrounding areas (Polacheck, 1990). This spillover effect not only benefits the fishing industry economically but also supports ecosystem health by promoting balanced populations and preserving biodiversity. Therefore, closing areas for fisheries can be a proactive measure to safeguard shrimp populations and enhance the sustainability of the fisheries in the long run. The focus of this study is to analyse the presence and extent of spillover from these closed areas and its potential benefits to fisheries. This study focuses on the permanently closed areas to shrimp fishing within the NSCZ. This study aims to provide insights into the dynamics of spillover in the NSCZ, its influence on fisheries, and about the methods to study them.

2.2 The potential spillover effects

In theory, spillover might benefit fisheries through increased or stabilized yields, making up for the lost fishing grounds caused by the creation of the MPA (Sanchirico, 2006; Gruss et al., 2011). Fish populations within MPAs contribute to the harvestable stock through two primary mechanisms. Firstly, there is fishery spillover, which is the migration of harvestable individuals from the MPA into the adjacent regions, further augmenting the harvestable stock in those areas. Observing or analyzing spillover can present significant challenges. The total effects on fish populations both within the MPA and in surrounding areas can be small and exceptionally difficult to detect (Ovando et al., 2021), and many reasons might prevent spillover from happening. Examples of these reasons are insufficient time since establishment of the MPAs (Friedlander et al., 2017), or ecological status of the species studied, as the chance of spillover occurring is higher for previously exploited species (Di Lorenzo, 2020).

The areas that were closed are of high ecological relevance, and the focal species is heavily exploited, which makes us think that taking out fishing pressure could have enormous ecological effects and conservation benefits. However, the areas were fully protected only recently. Although areas were legally closed in 2013, January 2017 was considered as the cut-off point for adherence to the closure of the fishing areas. As we will here analyse data until 2022, that gives us a time frame to see ecological effects that could have accumulated in 6 years only. Although this is not a long period of time, grey shrimp is considered a fast-growing and fast-reproducing species, with a relatively short life span of one-year only. They can reproduce multiple times during their life span. Shrimp larvae spend some time drifting with ocean currents before eventually settling to the seabed. Grey shrimps are generally mobile and can move between different areas in search of suitable habitats and food. While they might initially settle in the same general area where they were born, they are not strictly tied to those locations. However, the NSCZ does offer the best habitat for shrimp, increasing the chances of them staying there. In summary, the chances of grey shrimp replenishing in the protected areas in the NSCZ to the point where they spillover is theoretically possible.

3 AIMS AND OBJECTIVES

The main objective of this case study is to evaluate and quantify potential spillover effects around the closed areas in the NSCZ. We assessed changes in shrimp fisheries total catch in response to MPA implementation. A before-after-control impact design (BACI) observational experiment was set up. Changes in fishing effort, catch and catch value before and after the time at which the most substantial legal protections came into force were assessed, and focused in and around the protected areas during these two time periods. We evaluated and provided recommendations on the suitability and practicality of the chosen methodology for assessing spillover effects.

4 METHODOLOGY

4.1 Qualitative approach

We developed a questionnaire to assess the perceptions of key stakeholders regarding the MPAs' potential spillover effects, which was applied to the NSCZ area (see detailed questionnaire in Annex 4). Stakeholders were approached via an online questionnaire or through interviews. Four key stakeholder groups were targeted:

- commercial and recreational fishers,
- fisheries managers or government authorities,
- scientists, and
- NGOs.

The questionnaire aimed to gauge stakeholder perceptions on spillover effects around the closed areas. It had questions that covered the respondent's relation to the protected areas and views on the restrictions, explored their perceptions regarding socio-economic effects resulting from the area closure and asked about observed and expected spillovers, and views on MPAs as management tools in general.

4.2 Quantitative approach

The aim of our research is to investigate the potential presence of spillover effects. We examined the spatial distribution of biomass and abundance as indicators of density-related spillover. The biomass estimates are deduced from data obtained from both logbook and Vessel Monitoring System (VMS) records. If spillover effects are present, there will be a gradient in biomass, originating at the boundaries of the protected areas and diminishing with increasing distance from these boundaries (McClanahan and Mangi, 2000; Abesamis & Russ, 2005). We compared the spatial distribution of biomass before and after the establishment of the protected areas. If a gradient appeared, we additionally assessed whether this pattern strengthens with time since the establishment. Details on the statistical approach are given in section 4.4.

4.3 The data

The study area and MPAs

This study focusses on the NSCZ (Figure 2). A range of 14 km from the coastline was used to delineate the study area, as this area contains around 97% of all shrimp-fisheries fishing effort (Wilkes, 2022). The study area had to be bordered to ensure not too many grid cells would hold a 0-hour fishing effort, as this causes challenges in the analysis such as failures in model convergence. Coordinates of the MPAs were provided by the Ministry of Economic Affairs (2013).

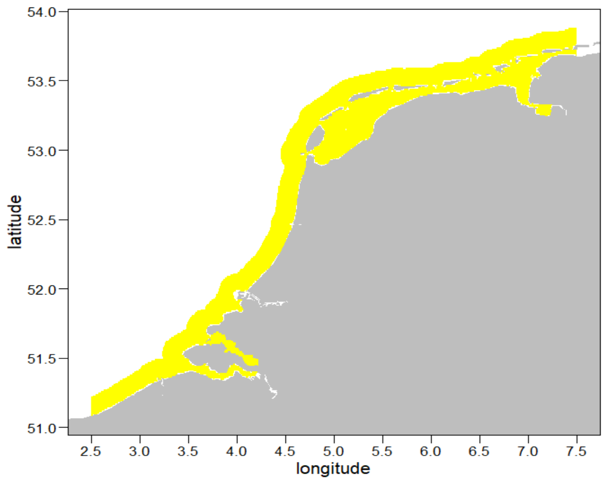

Figure 2: Map of the North Sea Coastal Zone (NSCZ) with the study area highlighted in yellow.

VMS and logbook data

Since 2005, all fishing vessels over 15 m have been obligated to be equipped with a Vessel Monitoring System (VMS). In 2012, this became obligatory for all vessels over 12 m. A VMS transponder sends a signal at regular intervals to a satellite providing information on the vessel's ID, position, time and date, direction, and speed. Hence, VMS is a valuable data source for studying the spatial and temporal distribution of fishing fleet. Wageningen Marine Research receives VMS and logbook data from the Netherlands Enterprise Agency (RVO) for scientific purposes. For this study, VMS and logbook data from the time period 2012 to 2021 were used. The VMS is coupled to fisheries logbooks, which contain information on when fishers leave the harbour, what gear has been used for fishing, their catch composition, and a rough estimate of the location of the catches for every 24 hours.

Data processing

First, VMS and logbook datasets were cleaned following steps of Hintzen et al (2022). They were then linked using the unique vessel identifier and date-time stamp in both datasets available. Fishing expeditions using bottom gear types known to fish shrimp, beam trawlers (code TBB), were selected. Lastly, cumulative fishing hours were aggregated by 0.05 degree C-square, and separated for year (and therewith, before or after restrictions).

4.4 Statistical analysis

The response variable is the catch (shrimp biomass in cumulative kg), fishing effort (in cumulative hours) or mean CPUE (kg/h) per 0.05 degree c-square per year. To test the hypotheses, generalized linear mixed models (GLM) with a gaussian error distribution were fitted. The specific analysis and model structure is described per theme below.

Changes in fishing effort and catches before and after MPA establishment

To assess changes in fishing effort, total catch and CPUE before and after spatial restrictions were established, three models were formulated with the above response variables in relation to the period (before or after restrictions) (models 1 to 3). This allowed to test whether effort, biomass or CPUE changed significantly since the enforcement of protected areas, and whether this is specific to a particular species or not.

- Fishing effort (hours) ~ Period (before vs after) (model 1)
- Fishing biomass (kg) ~ Period (before vs after) (model 2)
- CPUE (kg/hour) ~ Period (before vs after) (model 3)

Increasing biomass since establishment of MPA

To assess if any spillover effects are present, it should be tested if there is a gradient of biomass or abundance that starts at the boundary of the protected area and decreases with increasing distance from the boundary. To prevent that this is a coincidental natural spatial pattern of the species to occur, it would be conclusive if this effect gets stronger with time since establishment of the protected area. We therefore tested CPUE (as this already accounts for effort) in relation to an interaction of years since establishment, distance to the MPA, and species, as the effects might be specific per species (model 4).

- Δ biomass (before vs after) per 0.05 c-square per year ~ Offset (fishing effort) + Fishing distance from MPA (model 4)

Software

Analyses were carried out in R (R version 3.6.3, R Core Team, 2020 & R studio version 1.3.959 (RStudio Team, 2020). The data processing used the VMStools R-package (Hintzen et al. 2012) and all its dependencies.

5 RESULTS

5.1 Qualitative approach: key findings of the questionnaire

The questionnaire was filled in by three scientists of Wageningen Marine Research, one Policy Advisor North Sea Marine Protected Areas, Ministry Agriculture, Nature, and Food Quality (LNV), and one senior advisor of Rijkswaterstaat (the executive agency of the ministry of infrastructure and water management).

The following results were summarized from the questionnaire input. The coastal area has had a management plan in place since 2016, but it does not include spillover in its conservation objectives. Fishing within the NSCZ MPAs is regulated through permit conditions. Specific fishing methods are permitted, including beam trawl fishing with tickler chains, shrimp fishing, otter trawling, and shellfish dredging. These regulations aim to minimize the impact on conservation objectives. Certain zones within the MPA have restrictions, with some allowing only shrimp fishing, while others are entirely closed to commercial fishing. Professional fishing activities in the MPA require a Nature Act permit. Fishery management authorities believe that the most effective policy measures to promote spillover from MPAs are fishery restrictions or even full closure within the MPA.

There is currently no dedicated research or monitoring program aimed at studying spillover effects. While there are some related projects, most of them are ad hoc and primarily focused on stock and ecology for sustainable fisheries rather than the MPA's focus. Research Priorities: Spillover is not considered a priority topic in future research agendas. However, fishery management authorities do suggest collaborative initiatives between research groups, local fishing communities, and fisheries management authorities to understand and manage spillover impacts, although such initiatives have been limited, partly due to the small scale of MPAs.

Fishery management authorities have limited knowledge about whether fishers have experienced changes in catches within the MPA. They also do not believe that spillover from the MPA has significantly contributed to the recovery of overexploited fish stocks. They agree that there is no evidence of spillover of fish or larvae from the MPAs and suggest that the MPAs are too small to benefit fisheries. They maintain a neutral stance regarding the economic benefits for fisheries. The fishing community does not perceive increased livelihood security due to restrictions, which are generally not well-received.

Two out of three scientists are uncertain if there have been changes in seabed habitats, biodiversity, or structural complexity within the MPA. One scientist noted that a BACI-study showed no clear results, primarily due to fishing activity in the closed area. Two scientists have not observed changes in fish abundance, biomass, or species composition, while one noted significant within-year and between-year variations, making it challenging to determine significant changes. According to them, it is unlikely that spillover is occurring from fully protected areas and very unlikely from partially protected areas due to ongoing fishing activities, but they stress the need for further studies in this regard. One scientist believes that fisheries economically benefit from the MPA, as permits lead to a reduction in fishing effort, benefiting shrimp catches, provided shrimp prices remain stable. Scientists have varying opinions on the necessity of closures to develop commercial fisheries, emphasizing the need for further research before implementing such measures.

One scientist believes spillover is possible and highlights key factors, including the MPA's size, the time since its establishment, the effectiveness of total closure compared to partial closure with restrictions, the importance of habitat composition, and pressures around the MPA borders. A former WWF employee involved in VIBEG believes there is barely any spillover effect due to minimal decreases in fishing pressure. A scientist acknowledges the challenges of assessing spillover in shrimp fishing, citing the presence of shrimp fishing in areas near the coast and the Dutch Natura 2000 areas. They emphasize that many factors, beyond the coastal MPAs, affect the status of commercial fish species. The scientist notes that border effects have not been thoroughly studied, and there is a lack of knowledge regarding the movement and distribution of many species.

5.2 Quantitative approach: changes in fishing effort, catch and CPUE

First, we assessed whether there was a change in fishing effort before and after the MPAs in the NSCZ were established. Fishing effort was captured as time fished per year (in days) per 0.05 c-square. The model significantly diverged from the control model ($p<0.001$). There was significantly higher effort in the period before the establishment of the MPA compared to after (Intercept=24.620, estimate "before"=3.776, $p<0.001$). Potential changes in biomass were assessed similarly. Biomass is represented as the catch in kg per year per 0.05 degree C-square. This model did nod diverge from the control model ($p=0.307$). Lastly, the change in CPUE was tested to the period. The response variable here was catch in mean kg per day for every year per 0.05 degree c-square. This model significantly diverged from the control model ($p<0.001$). CPUE was significantly lower in the period before the MPAs were established (Intercept=1 337.70, estimate "before"=-187.04, $p<0.001$). An overview of catch statistics is given in Table 3.

Table 2: Model output for models 1 to 3. These tables display the estimates (coefficient) and p-values for predictor variables (p variable) and their sub-variables (p sub-variable). P values are not shown for the intercept and lower levels if an interaction is significant due to limited interpretative value. The model formula is specified below:

Model 1: Fishing effort (days per c-square per year) ~ Period (before vs after)
This model is significant ($p<0.001$)

	Estimate	Standard error	P-value
Intercept	24.620	0.763	-
Period (before)	3.776	1.080	< 0.001

Model 2: Fishing biomass (sum kg c-square per year) ~ Period (before vs after)
This model was not significant ($p=0.307$)

Model 3: CPUE (mean kg/day per c-square per year) ~ Period (before vs after)
This model was significant ($p<0.001$)

	Estimate	Standard error	P-value
Intercept	1 337.71	51.180	-
Period (before)	-178.04	72.450	< 0.001

Table 3: Catches, effort and mean CPUE (2012-2021)

	Year	Protected	Total KG	Total effort (days)	CPUE (kg/day)
Shrimp (Crangon crangon)	2012	before	7 571 238	8 803	914
	2013		10 695 780	9 923	1 199
	2014		12 393 851	11 293	1 309
	2015		9 662 993	9 309	1 300
	2016		9 166 405	10 196	1 024
	2017	after	5 725 544	8 215	693
	2018		15 402 237	8 455	2 016
	2019		10 306 681	7 207	1 575
	2020		10 914 527	9 768	1 267
	2021		9 656 004	9 464	1 152

Increasing biomass since establishment of MPAs, and closer to the border of the MPAs?

Lastly, we assessed whether there was an increasing trend in biomass for shrimp since the date of adherence to the fishing restrictions, and whether this was strongest near the MPA. CPUE was tested to a two-way interaction with period (before and after) and distance to the border of the nearest MPA (as there are four smaller areas) in the NSCZ. This model did not differ significantly from the control model (p=0.860). Additionally, we also selected data only after establishment of the MPA, and tested the potential interactive effect of the interaction between distance from the MPA and years since establishment of the MPA. As CPUE estimates are aggregated per year, time since establishment was counted per year as well. Again, this model did not differ significantly from the control model (p=0.665). The change in CPUE is visualized in space in Figure 3.

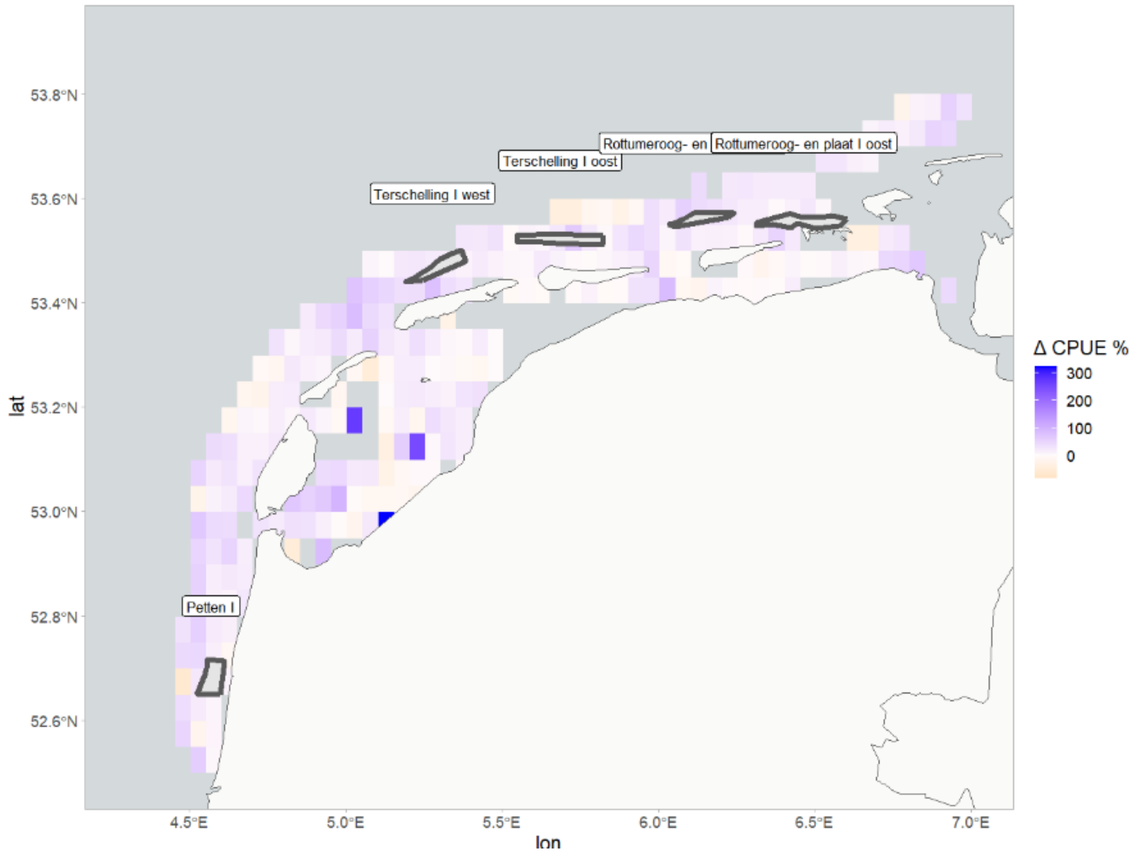

Figure 3: CPUE change (%) in NSCZ. This map displays the research area, with cells color-coded to represent the change in CPUE (the difference in mean CPUE per year) after establishment of MPAs in the NSCZ.

6 DISCUSSION

The analysis initially focused on descriptive statistics, examining changes in total effort, total catch biomass, and CPUE of shrimp following the establishment of the MPAs in the NSCZ. **It was observed that shrimping effort significantly decreased within the NSCZ after the establishment of the MPAs. However, the quantity of shrimp caught did not show significant differences before and after the establishment. Aligning with previous findings, CPUE did increase significantly.**

The increase in CPUE does not testify for a relative increase in biomass. As many fishers agreed with a buy-out proposal when the protected areas were established, fishing effort significantly decreased, as was seen in the results. As a consequence, **there was less competition, which could be an explanation for the increase in CPUE.**

Building on this understanding of shrimp dynamics before and after establishment of the MPAs, the analysis progressed into testing specific hypotheses related to spillover effects. It sought to determine if there was a growing trend in shrimp biomass closer to the borders of the nearest MPAs and whether this trend intensified over the years following MPA adherence. The analysis found no significant effects related to distance to the nearest MPA, years since MPA establishment, or the interaction between these two variables. Consequently, **no conclusive evidence emerged to support the existence of spillover in this case study**. If spillover occurs on a very small scale or at low abundances, the spatial and temporal resolution of the current dataset, constructed from VMS and logbook data, may be too coarse to capture such nuances. A recommendation for future studies could involve analysing biomass changes from the MPA border using non-binned biomass observations (not segmented into c-squares). Alternatively, distributing logbook catch data along a finer fishing vessel travel path, perhaps based on Automatic Identification System (AIS) data with more frequent observations in time, could enhance the precision of the analysis.

Comparing the **questionnaire** responses to the quantitative results led to the following conclusions. **Fishery management authorities exhibited limited awareness of changes in catches within the MPAs and held the belief that spillover had not significantly contributed to the recovery of overexploited fish stocks.** Furthermore, the **fishing community did not perceive increased livelihood security resulting from restrictions, which were generally met with resistance.** This study observed an increase in CPUE, and even though this is most likely not a result of spillover, it contradicts the lack of changes perceived by the fishery management authorities. Also, a significant reduction in effort was found after establishment of the MPAs, contrary to several beliefs from the questionees. Therefore, the absence of conclusive evidence for spillover cannot be attributed to an absence of reduced effort. Lastly, our findings align with the questionees lack of observed changes in earlier research assessing shrimp biomass or abundance in the overall area over the last years.

There may be several reasons why this study was unable to demonstrate spillover. It could be that spillover is not happening. Shrimp in the North Sea are generally abundant and not subject to significant conservation concerns. It could be that for this species, there were no spillover effects as fishing pressure was not a limiting factor for the species. The NSCZ had only recently implemented its MPAs, which might not have allowed sufficient time for spillover effects to become pronounced. Spillover can be a gradual process, and the relatively short timeframe of the study may not have captured long-term trends. The NSCZ MPAs were relatively small in scale, which could limit their potential to generate significant spillover effects. Larger MPAs often have a greater capacity to support spillover due to their size and the diversity of habitats they encompass (Di Lorenzo et al., 2020). **If spillover was happening, there could be other reasons.** While shrimp can move, they tend to stay within a relatively small spatial area on the seabed, making chances of shrimp spilling over to adjacent areas relatively small. It could be that our research area is inappropriate in size to capture the effect of proximity to the MPA adequately. It would be less complicated to study one MPA rather than four smaller MPAs in one research area. These reasons emphasize the complexity of assessing spillover.

7 CONCLUSIONS

In conclusion, the analysis of shrimp dynamics in the NSCZ post-MPAs did not provide conclusive evidence of spillover. Shrimping effort decreased significantly after MPA implementation, while total shrimp catch quantity remained largely unchanged. Consistently, there was an increase in CPUE, likely due to reduced competition following buy-out proposals, rather than due to spillover effects. The study aimed to test spillover hypotheses but found no significant evidence regarding MPA proximity or establishment duration. Interestingly, the observed reduced effort contradicts some questionnaire assumptions, but it aligns with the conclusion of the absence of evidence for spillover. There are various hypothesis on why demonstrating spillover seemed difficult, ranging from the actual absence of spillover to the inherent difficulty in proving its existence with the existing data. These findings highlight the challenges in attributing spillover effects to relatively small-scale MPAs, and the need for additional research in understanding their ecological impact.

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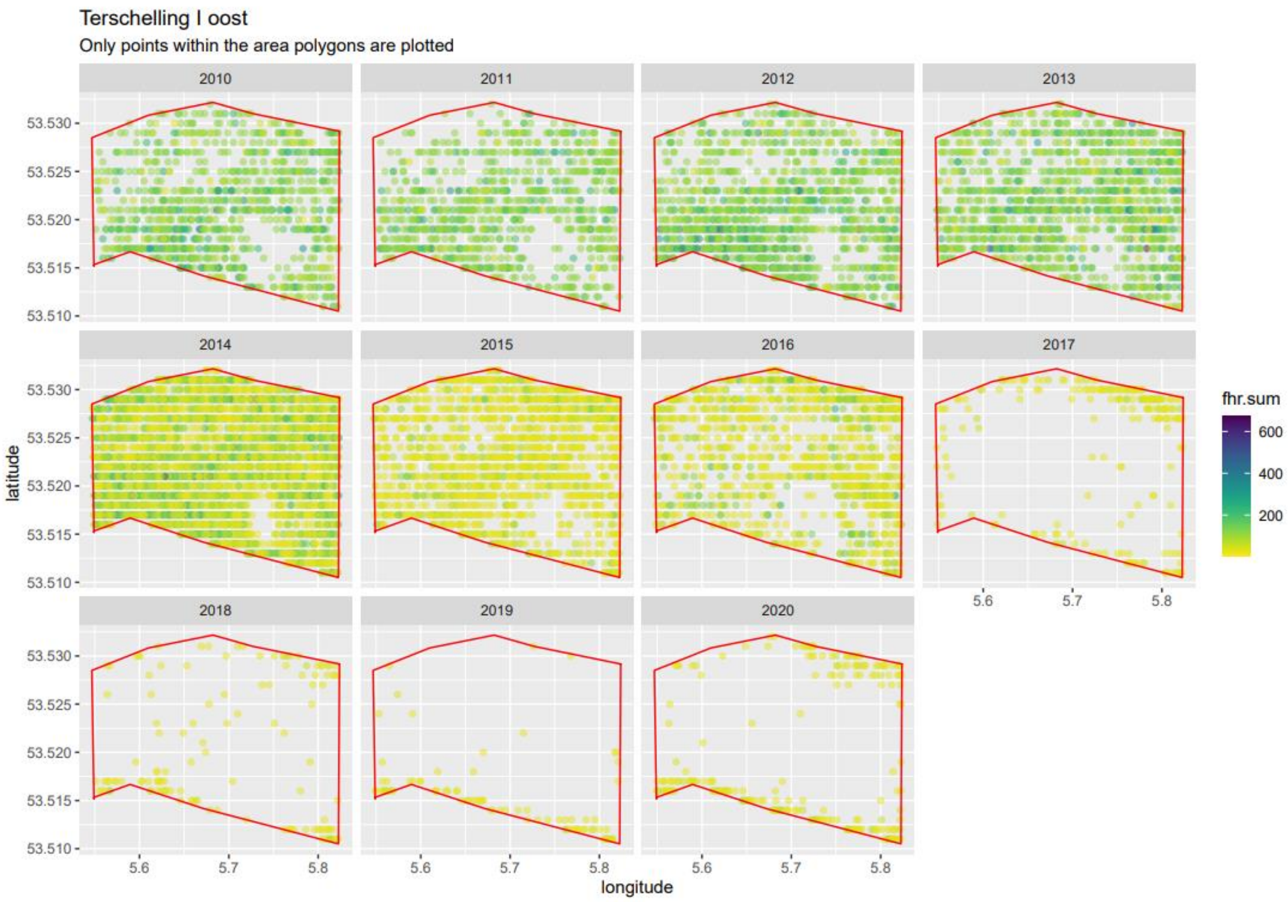
APPENDIX

Overview of shrimp-fishery activity in one of the restricted areas (Terschelling I Oost) in the North Sea Coastal zone over time, to establish when fishing regulations were adhered to by fishers. The variable shown is fishing hours (fhr) at a specific location, with the colour corresponding to the cumulative hours that year in that specific location (fhr.sum in the legend), with darker colors indicating more fishing hours. Only observations within the area polygon are plotted. From 2017, there is a sudden drop in overall fishing activity in the restricted area (Wilkes, 2022).



5. CASE STUDY REPORT:

BORSSELE OFFSHORE WIND FARM ZONE

THE NETHERLANDS – NORTH SEA

Analysis of potential spillover effects around Borssele offshore wind farm zone

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LIST OF ABBREVIATIONS

Term	Description
AIC	Akaike Information Criterion
BACI	Before-After-Control-Impact
BOWFZ	Borssele offshore wind farm zone
CPUE	Catch per unit of effort
DAB	Common dab
EEZ	Exclusive economic zone
GUU	Tub gurnard
LNV	Ministry of Agriculture, Nature and Food Quality
NL	Netherlands
OECM	Other effective area-based conservation measure
RVO	The Netherlands Enterprise Agency
SOL	Common sole
TBB	Beam trawlers
VMS	Vessel monitoring system

1 EXECUTIVE SUMMARY

The Borssele offshore wind farm zone (BOWFZ) is a recently established offshore wind farm of 344 km^2, situated in the North Sea off the coast of Zeeland province in the Netherlands. The wind farm zone prohibits any boating activity through its wind farms, resulting in a significant loss of space for fishing activities. In this study, the wind farm zone is considered as an 'other effective area-based conservation measure' (OECM). To better understand the consequences on the establishment of the BOWFZ for the local fisheries, there is a need to study the influence on fisheries catches, and examine the potential benefit of fish spillover from the BOWFZ.

This case study assessed qualitatively and quantitatively the potential of having spillover effects from the BOWFZ to adjacent areas. As wind farms share aspects of traditional marine protected areas (MPAs) such as the inability to enter and fish in the area, we consider the BOWFZ as a relevant case study. We analysed potential spillover of common sole (*Solea solea*), common dab (*Limanda limanda*) and tub gurnard (*Chelidonichthys lucerne*) biomass around the BOWFZ. This trio-species approach enriches our understanding of species-specific spillover dynamics.

In theory, perfect density-related spillover would exhibit a gradient of biomass or abundance originating at the BOWFZ boundary, diminishing as distance from the boundary increases, and growing stronger over time. To examine these hypotheses, we employed generalized linear mixed models (GLM). The models were constructed to assess biomass (in cumulative kilograms), fishing effort (in cumulative hours), or mean catch per unit effort (CPUE) (kilograms per hour) per 0.05-degree c-square annually for the three species. The analysis considered factors such as the time period, species, and proximity to the BOWFZ.

The analysis revealed a significant reduction in total effort, total catch, and CPUE following the establishment of the BOWFZ for all species. This suggests lower overall productivity in the later years. When testing whether there was an increasing trend in biomass for the focal species since the BOWFZ establishment, taking into account the distance to the BOWFZ, no evidence for an interactive effect was found. The magnitude of any effects near the borders of the BOWFZ for tub gurnard, sole or place were found to be biologically inconsequential. Consequently, no concrete evidence to substantiate the existence of spillover was found. These findings are however congruent to the insights gathered from the stakeholders via the questionnaires. It is reasonable to attribute the absence of conspicuous spillover effects in this study to the relatively recent establishment of the BOWFZ. Future research could continue monitoring and research spillover over a longer duration, explore non-linear responses of the species population in response to the BOWFZ establishment, and assess the potential long-term effects on the broader ecosystem.

2 BACKGROUND

The North Sea has historically been a vital fishing ground. In recent years, the quest for sustainable energy sources has led to a sharp increase in the establishment of marine offshore windfarms in the North Sea. One recently established wind farm is the Borssele offshore wind farm zone (BOWFZ), situated in the North Sea off the coast of Zeeland province in the Netherlands. Throughout its history and persisting presently, the province of Zeeland has remained an important centre within the Netherlands' fishing industry (Bennema & Rijnsdorp, 2015).

While wind farms play a pivotal role in advancing the sustainable energy agenda, they are often met with resistance from the fishing industry. To better understand the consequences on the establishment of the BOWFZ for the local fisheries, there is a need to study the influence on fisheries catches, and examine the potential benefit of fish spillover from the BOWFZ. As wind farms share aspects of traditional marine protected areas (MPAs), such as the inability to enter and fish in the area, this area qualifies as an 'other effective area-based conservation measures' (OECM), and we consider the BOWFZ as a relevant case study. Studying spillover effects will give us insight in the ecological effects of the BOWFZ. It will also give us insight in the consequences for the fishers previously operating in the area, and quantify any potential benefits.

The BOWFZ is home to two wind farms, operated by Ørsted and Blauwwind (Noordzeeloket). These two wind farms are divided into two sections each, known as Borssele 1 & 2 and Borssele 3, 4, and 5, as illustrated in Figure 1. The closest point to the shore is approximately 22 km, and under clear conditions, the wind farm is visible from Domburg. Comprising 173 wind turbines and covering an area of 344 km^2, the BOWFZ has been operational since 2020 and is anticipated to remain so until 2046. Compared to other existing wind parks, this represents a relatively expansive and substantial area dedicated to offshore wind energy production. Notably, the wind farm zone prohibits any boating activity through its wind farms, resulting in a significant loss of space for fishing activities.

The establishment of the BOWFZ involved a top-down approach where government authorities collaborated with industry stakeholders to create the wind farm zone. The BFWZ does not have an MPA designation, but as the wind farm zone prohibits any boating activity through its wind farm, it aligns with some standards of a no-take-zone MPA. These restrictions are in place to safeguard the structural integrity of wind turbines, ensuring their efficient operation and the safety of all parties involved. Fisheries agreement varied, but their engagement is considered essential in achieving an equilibrium between conservation and economic interests. Although there is ongoing research and experiments on opportunities on passive fisheries in the windfarm, fishers have mostly refrained from registering for this initiative (Nooitgedagt, 2021).

Adjacent to the BOWFZ is the Belgian wind farm zone, which has been under construction since 2007, including the latest sites that share some infrastructure with the Dutch wind farm. The combined area of the wind farm zones in both the Netherlands and Belgium currently exceeds 600 km^2 (Brasseur et al., 2022). As there was a major time gap between the construction of the Belgium and Dutch part of the wind farm zone, we focused here on the Dutch part only[11].

Figure 1: This map illustrates the spatial layout of the Borssele offshore wind farm zone, located off the Zeeland coast in the North Sea, Netherlands (Source: Netherlands Enterprise Agency 2023).

[11] Another case study under the SPILLOVER study dealt with the Belgian wind farm zone.

3 AIMS AND OBJECTIVES

The aim of this case study is to analyse potential spillover of sole (*Solea solea*), common dab (*Limanda limanda*) and tub gurnard (*Chelidonichthys lucerna*) from the BOWFZ to adjacent areas. The specific objective is to compare fishing effort, total biomass of landings and CPUE for these species for the period before the establishment in relation to the period after the establishment, and to test for spillover-related patterns in the distribution of these species. This trio-species approach enriches our understanding of species-specific spillover dynamics.

4 METHODOLOGY

4.1 Qualitative approach

A survey was designed to evaluate the perspectives of key stakeholders regarding potential spillover effects and was applied to the BOWFZ area. Several stakeholders were approached through an online questionnaire (see questionnaire in Annex 4). The survey targeted commercial and recreational fishers, fisheries managers or government authorities, scientists, and non-governmental organizations (NGOs). The questionnaire aimed to gauge stakeholder opinions on spillover effects in the proximity of the wind farm zone. The questions asked for the respondents' connection to the area, and asked for their perceptions about the inaccessibility to the zone, delved into their viewpoints concerning socio-economic implications arising from area closures, and asked for information on both observed and anticipated spillover effects. Additionally, it asked for their opinions on MPAs as a broader management tool.

4.2 Quantitative approach

Our research aims to explore the potential occurrence of spillover effects within the BOWFZ. Our investigation focused on analyzing the spatial distribution of fish biomass as indicators of density-related spillover. Biomass estimates were derived from comprehensive datasets obtained from both logbook and vessel monitoring system (VMS) records. If any spillover is present, we anticipated observing a gradient in biomass from the border of the BOWFZ. This gradient is expected to originate from the boundaries of the protected areas and decrease as distance from these demarcated zones increases (McClanahan and Mangi, 2000; Abesamis & Russ, 2005). We conducted a comparative analysis of the spatial distribution of biomass before and after the establishment of the protected areas. Moreover, we evaluated whether the spatial distribution of the observed biomass changed over time following the establishment. Details on the statistical approach are given in Section 4.4.

4.3 The data

The study area

This research focuses on the BOWFZ as illustrated in Figure 1. Coordinates for the BOWFZ were acquired from the Netherlands Enterprise Agency (RVO) (2023) to delineate the BOWFZ accurately. The study area was defined using a 25 km buffer from the BOWFZ boundary, chosen to encompass a sizeable region relevant for detecting potential spillover effects (Figure 2).

VMS and logbook data

Since 2005, there has been a mandate for all fishing vessels exceeding 15 meters in length to integrate a VMS. This requirement was extended in 2012 to encompass all vessels surpassing 12 meters in length. A VMS transponder continually transmits data to a satellite, providing details such as the vessel's identification, position, time, date, direction, and speed. Consequently, VMS serves as a valuable data source, enabling the examination of the fishing fleet's spatial and temporal distribution. For scientific purposes, Wageningen Marine Research receives VMS and logbook data from the RVO. In this study, we utilized VMS and logbook data covering the timeframe from 2017 to 2022. The VMS data are complemented by fisheries logbooks, which add information regarding the departure times from the harbour, gear employed for fishing, catch composition, and approximate catch locations recorded every 24 hours by fishers.

Data processing

First, VMS and logbook datasets were cleaned following steps of Hintzen (2022). They were then linked using the unique vessel identifier and date-time stamp in both datasets available. Only trips that caught either sole (SOL) or tub gurnard (GUU) or common dab (DAB) were identified. Per species, the main gear catching those species were identified by analyzing logbook data of vessels fishing in the Dutch Exclusive Economic Zone (EEZ). For sole, beam trawlers (TBB) and pulse fisheries (PUL) were responsible for 86 % of the total catch. For mullet, Scottish seine (SSC) was responsible for 90 percent of the total catch. Trips that caught these species with other gear were excluded, to prevent the chances of including trips that were mainly focussing on other species but caught these focal species as bycatch. From the gear types that were filtered for, only vessels were selected that caught less than 1000 kg of sole in a year, and less than 100 kg of mullet in a year, again to prevent including trips in which these species were not the main targeted species. Fishing trips using bottom gear types known to fish sole or mullet were selected. Lastly, cumulative fishing hours were aggregated by 0.05 degree c-square, and separated for year (and therewith, before or after restrictions). We considered aggregation per year most appropriate as it averages out seasonal fluctuations. We calculated total catch, effort and CPUE.

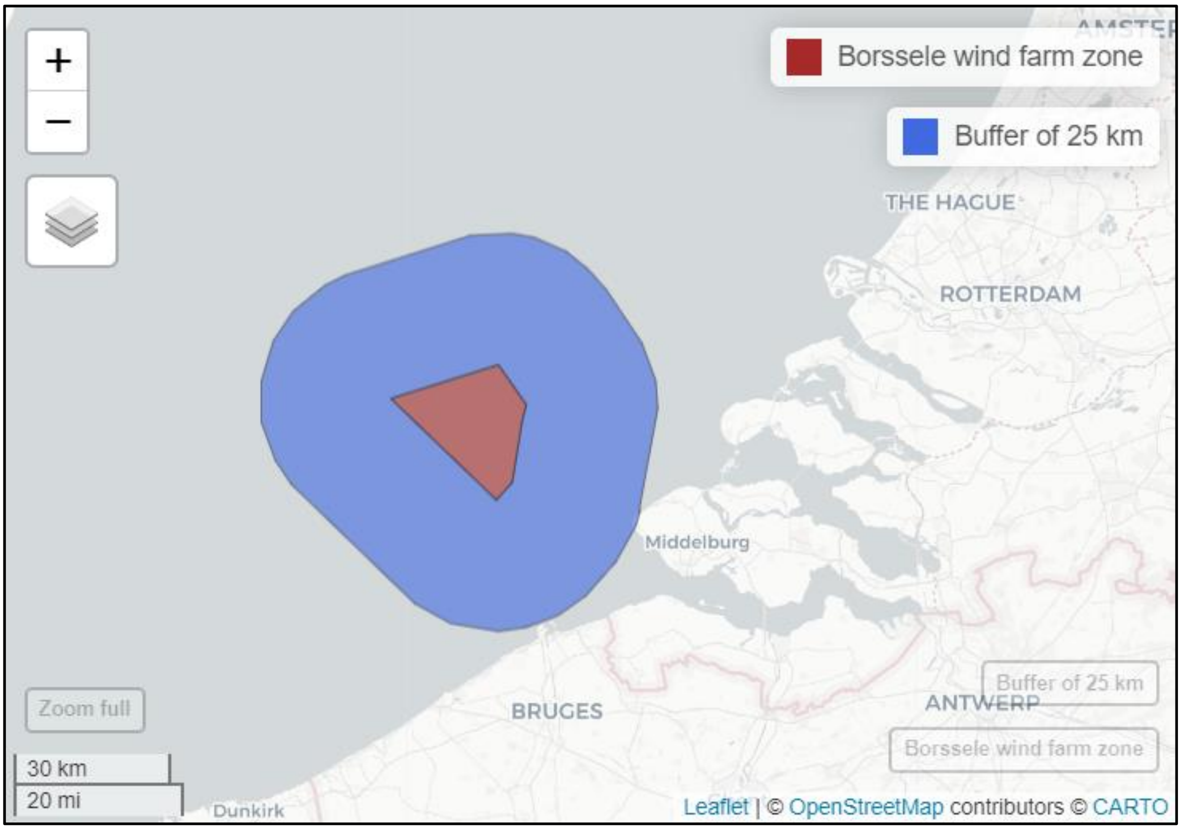

Figure 2: Spatial layout of the Borssele offshore wind farm zone, located off the Zeeland coast in the North Sea. The distinct zonation of the wind farm area is highlighted in red. The buffer of 25 km around the BOWFZ indicates the general study area.

Identifying relevant species

From the top 10 most heavily fished species in the area, we selected 3 demersal fish species for further analysis. By choosing the most commonly fished species (in biomass in the BOWFZ and buffer zone), we know that there is a pressure on the population, which increases the possibility that the closure of the areas would lead to significant protection of a previously pressured species. To detect potential spillover effects, the species cannot be too mobile, or any potential effects of the area will be impossible to test. That is reason why demersal species were selected. The selected species have varying commercial interest. Eventually, sole (*Solea solea*), common dab (*Limanda limanda*) and tub gurnard (*Chelidonichthys lucerna*) were selected (Table 1).

Table 1: Gear types responsible for species catch

				Gear type catching species	
Code	species (EN)	species (NL)	KG caught (2019)	2019	2022
SOL	Common sole	Tong	705 338	93 % PUL	87 % TBB
DAB	Common dab	Schar	129 104	72 % PUL	49% TBB & 37 % TBS
GUU	Tub gurnard	Rode poon	70 704	73 % PUL	87 % TBB

4.4 Statistical analysis

The response variable is the either biomass (in cumulative kg), fishing effort (in cumulative hours) or mean CPUE (kg/h) per 0.05 degree c-square (approximately 4 x 4 km) per year for common sole, common dab, and tub gurnard separately. To test the hypotheses, generalized linear mixed models (GLM) with a gaussian error distribution were fitted. The specific analysis and model structure is described per theme below.

Changes in fishing effort and catches before and after the wind farm establishment

To assess changes in fishing effort, fish biomass and CPUE before and after the wind farm was established, three models were formulated with the above response variables in relation to an interaction of the period (before or after restrictions) and species (sole, dab or tub gurnard) (models 1 to 3). This allowed to test whether effort, biomass or CPUE changed significantly since the enforcement of the wind farm, and whether this specific to a particular species or not.

- Fishing effort (hours) ~ Period (before vs after) * species (mod. 1)
- Fishing biomass (kg) ~ Period (before vs after) * species (mod. 2)
- Catch per unit of effort (kg/hour) ~ Period (before vs after) * species (mod. 3)

Increasing biomass closer to the wind farm, since establishment?

To assess if any spillover effects are present, it was tested whether there is gradient of biomass or abundance that starts at the boundary and decreases with increasing distance from the boundary of the wind farm zone. To prevent that this is a coincidental natural spatial pattern of the species to occur, it would be conclusive if this effect gets stronger with time since establishment of the wind farm. We therefore tested CPUE (as this already accounts for effort) in relation to an interaction of years since establishment, distance to the BOWFZ, and species, as the effects might be specific per species (model 4).

- biomass (only after) per 0.05 c-square per year ~ Distance from BOWFZ * years since establishment of the MPA * species (mod. 4)

Software

Analyses were carried out in R (R version 3.6.3, R Core Team, 2020 & R studio version 1.3.959 (RStudio Team, 2020). The data processing used the VMStools R-package (Hintzen et al., 2012) and all its dependencies.

5 RESULTS

5.1 Qualitative approach to stakeholders of the BOWFZ

The survey was filled in by a policy officer in fisheries at the ministry of agriculture, nature and food quality (LNV), and a sea fisheries employee at the government service for entrepreneurs (RVO).

The policy officer asserts that BOWFZ does not qualify as a true MPA. However, due to the prohibition of active fisheries like bottom trawling in the area, the circumstances are similar. Since the commencement of the wind park construction in 2020, fishing activities have been restricted. This region lacks a formal management plan, and consequently, spillover is not part of any conservation objectives. Fishing primarily occurs outside this area. Currently, there are limited experiments with passive fishing techniques within the zone, which might become more conventional in the future. Neither of the two respondents has reported any notable changes in fish abundance, biomass, species composition, or catches. Moreover, it is doubtful whether the wind farm can substantially benefit overexploited fish populations; other measures, such as effort limitations, would likely be more effective.

5.2 Changes in fishing effort and catches in the study area before and after the wind farm establishment

We assessed whether there was a change in fishing effort in the study area before and after the BOWFZ was established, and whether this was specific for the different species that were studied. We tested predictor variables to fishing effort in days per year per c-square. The model including an interaction between the period (before or after the establishment) and the species was not significant (p=0.645), meaning that there was no difference in fishing effort before or after the establishment for any of the species specifically. When the variables were analysed as separate predictors, the model significantly diverged from the control model (p<0.001), meaning that we can now interpret the predictor variables one by one. Whether it was the period before or after the establishment significantly influenced total fishing effort in the area ($estimate_{after}$=-0.843, p<0.001). Effort also significantly differed for species in general, where there was less effort for the species tub gurnard in particular (estimate =-0.704, p<0.001). An overview of the model effects is shown in Table 2.

Table 2: Model 1 – Fishing effort and predictor variables. Estimates (coefficient) and p-values for predictor variables (p variable) and their sub-variables (p sub-variable). P values are not shown for the intercept and lower levels if an interaction is significant due to limited interpretative value. The model formula is specified below:

Model 1: Fishing effort (days) ~ Period (before vs after) + species
This model is significant (p<0.001)

	p variable	sub-variable	coefficient	*p* sub-variable
Intercept			7.586	-
Period	< 0.001	*Period: after*	-0.843	< 0.001
Species	< 0.001	*Species: GUU*	-0.704	< 0.001
		Species: SOL	-0.997	0.948

Potential changes in biomass were assessed similarly. Biomass is represented as the catch in kg per year per 0.05 degree c-square. Again, the interaction between period and species was not significant, leaving us with a model assessing period and species separately. This time, there was no significant difference before and after establishment. However, there were significantly less catches for both tub gurnard and sole compared to mullet (estimate GUU = -0.704, SOL =-0.997, p<0.001). An overview of the model effects is shown in Table 3.

Table 3: Model 2 – Fish biomass and predictor variables. Estimates (coefficient) and p-values for predictor variables (p variable) and their sub-variables (p sub-variable). P values are not shown for the intercept and lower levels if an interaction is significant due to limited interpretative value. The model formula is specified below:

Model 2: Fishing biomass (kg) ~ Period (before vs after) + species
This model is significant (p<0.001)

	***p* variable**	**sub-variable**	**coefficient**	***p* sub-variable**
Intercept			7.586	-
Period	0.326	*Period: after*	-0.843	0.326
Species	< 0.001	*Species: GUU*	-0.704	< 0.001
		Species: SOL	-0.997	< 0.001

Lastly, the change in CPUE was tested to the same predictor variable. The response variable here was catch in mean kg per day for every year per 0.05 degree c-square. This time, the interaction between period and species was significant, where CPUE was lower in the period after establishment, but more so for sole, and less for tub gurnard. An overview of the model effects is shown in Table 4.

Table 4: Model 3 – CPUE and predictor variables. Estimates (coefficient) and p-values for predictor variables (p variable) and their sub-variables (p sub-variable). P values are not shown for the intercept and lower levels if an interaction is significant due to limited interpretative value. The model formula is specified below:

*Model 3: Catch per unit of effort (kg/day) ~ Period (before vs after) * species*
This model is significant (p<0.001)

	***p* variable**	**sub-variable**	**coefficient**	***p* sub-variable**
Intercept			58.734	-
Period		*Period: after*	-0.914	0.087
Species		*Species: GUU*	1.118	0.028
		Species: SOL	8.981	< 0.001
Species * Period	0.026	*Species: GUU*	1.127	0.108
		Species: SOL	-0.923	0.283

Table 5: Fish Catches, effort, and mean CPUE for the years 2017–2019 (before establishment) and 2020-2022 (after establishment) inside the wind farm zone (*in*) and in the area surrounding area within a 25 km radius (*out*) for the species Tub Gurnard (top), Common Dab (middle), and Sole (bottom).

			in		Out		Mean
	Year	**MPA**	**Total KG**	**Total effort (h)**	**Total KG**	**Total effort (h)**	**CPUE (kg/h)**
Common Dab (DAB)	2017	before	8 543.8	147.2	141 302.8	2 017.6	58.6
	2018		6 827.4	174.3	133 316.0	1 954.9	58.3
	2019		3 988.6	71.1	118 624.6	1 782.9	59.2
	2020	after	107.7	1.4	86 305.8	1 721.9	59.7
	2021		9.4	0.7	67 765.4	1 515.8	50.6
	2022		10.4	1.9	59 156.1	1 393.6	50.9

			in		out		Mean
	Year	**MPA**	**Total KG**	**Total effort (h)**	**Total KG**	**Total effort (h)**	**CPUE (kg/h)**
Tub Gurnard (GUU)	2017	before	19 151.7	135.7	94 299.5	1 491.8	91.4
	2018		6 881.9	145.1	74 247.2	1 458.4	59.3
	2019		2 587.2	56.3	52 798.6	1 286.6	46
	2020	after	43.7	1.2	59 471.6	1 099.6	77.4
	2021		34.7	0.7	40 084.7	959.9	53.8
	2022		65.1	1.8	52 082.9	926.7	71.5

			in		out		Mean
	Year	**MPA**	**Total KG**	**Total effort (h)**	**Total KG**	**Total effort (h)**	**CPUE (kg/h)**
Sole (SOL)	2017	before	113 414.1	146.8	950 810.4	1 790.9	638
	2018		104 089.5	179.6	803 142.0	1 971.5	515
	2019		41 586.8	77.3	663 679.7	1 861.9	428
	2020	after	496.6	1.4	577 302.0	1 748.9	449
	2021		387.5	0.7	515 274.3	1 599.3	468
	2022		988.2	2.0	344 890.9	1 355.8	419

Increasing biomass since establishment of wind farm?

We assessed whether there was an increasing trend in biomass for the focal species since the date of establishment, and whether this was strongest near the wind farm. We will therefore focus on CPUE, as that takes into account changes in effort. We tested CPUE to a three-way interaction from years since establishment, distance to the border of the BOWFZ and species. As CPUE estimates are aggregated per year, we counted time since establishment per year as well. This model with the three way interaction was significant ($p < 0.001$). There was a negative effect of years since establishment, meaning CPUE decreased with the years. This effect was strongest for the common dab. For GUU and SOL, CPUE seems slightly higher near the borders of the BOWFZ in later years, but the size of the effect seems negligible (estimate GUU = -0.003 and SOL =-0.005, p=0.015). An overview of the model effects is shown in Table 6. The changes in biomass and CPUE after establishment of the BOWFZ are visualized in Figure 3 and 4.

Table 6: Model 5 - Biomass and predictor variables: estimates (coefficient) and p-values for predictor variables (p variable) and their sub-variables (p sub-variable). P values are not shown for the intercept and lower levels if an interaction is significant due to limited interpretative value. The model formula is specified below:

*Model 5: CPUE ~ years since establishment (data only after) * Distance to wind farm zone + species*

This model is significant (p<0.001)

	***p* variable**	**sub-variable**	**coefficient**	***p* sub-variable**
Intercept			56.55	0.282
Years established			-9.12	0.701
Species		species: GUU	-76.573	0.304
		Species: SOL	357.374	0.000
Distance to MPA			0.000	0.907
Years * Species		Species: GUU	43.665	0.196
		Species: SOL	74.152	0.027
Years * Distance to MPA			0.000	0.815
Distance * Species		Species: GUU	0.005	0.189
		Species: SOL	0.004	0.376
Years * Distance * Species	0.015	Species: GUU	-0.003	0.163
		Species: SOL	-0.005	0.004

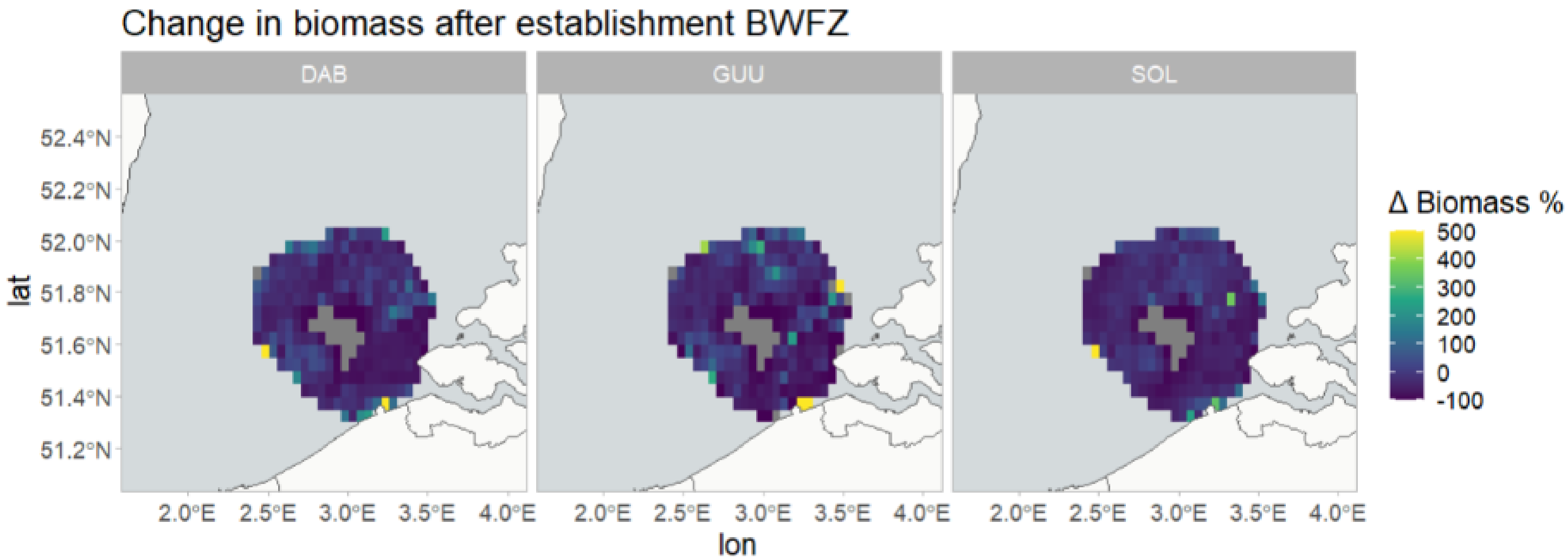

Figure 3. Biomass change (%) in the Borssele offshore wind farm zone (BOWFZ). This map displays the research area, with cells color-coded to represent the change in biomass percentage after the establishment of the BOWFZ.

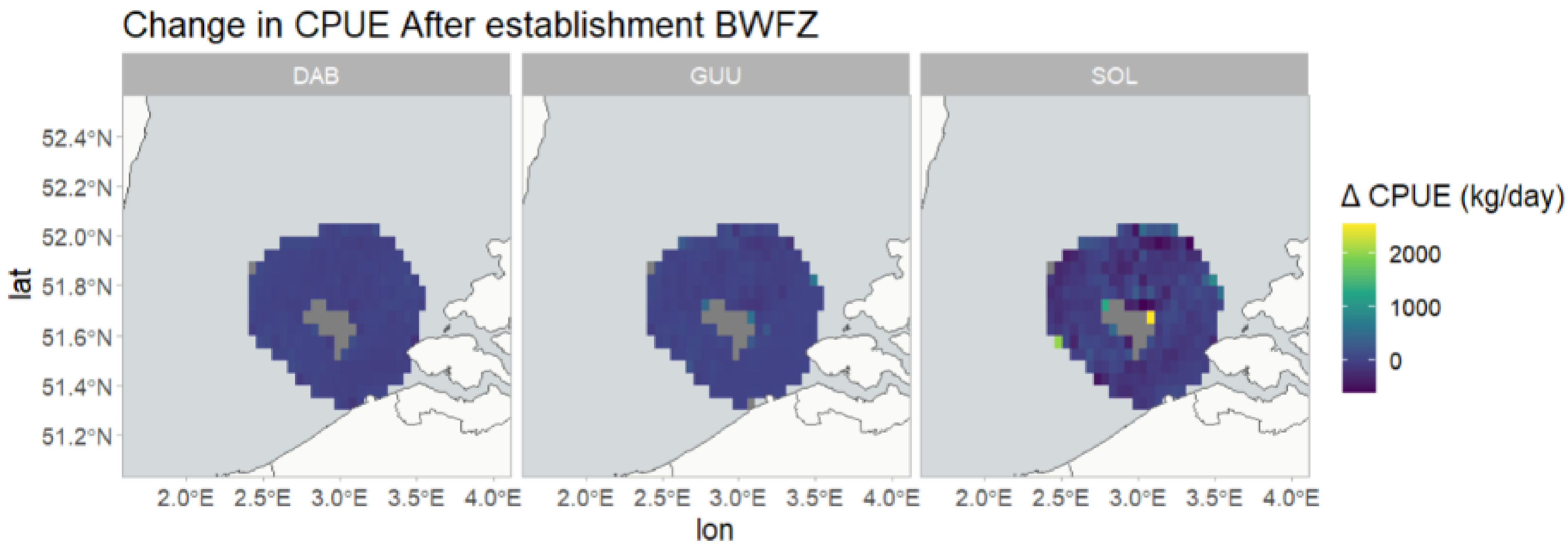

Figure 4: CPUE change (kg/day) in BOWFZ. This map displays the research area, with cells color-coded to represent the change in CPUE (the difference in mean CPUE per year) after establishment of the BOWFZ.

6 DISCUSSION

An assessment was made regarding whether there were changes in total fishing effort, total catch biomass, and CPUE following the establishment of the BOWFZ. **It was observed that fishing effort significantly decreased in the area encompassing the BOWFZ after its establishment.** This reduction in fishing effort was consistent across the three studied species, with no species showing a stronger effect. Although the **quantity of fish caught did not exhibit significant differences before and after establishment**, there were, non-surprisingly, significant differences in biomass caught between species. Turning our attention to CPUE, a significant interaction between the time period before and after establishment and species was identified. Upon closer examination, it was found that **CPUE decreased after the BOWFZ establishment for sole (SOL) and to a lesser extent for common dab (DAB), but this trend was not evident for tub gurnard (GUU).** It appears that, in general, the later years exhibited lower levels of productivity.

With a clearer understanding of what happened to the fish before and after the BOWFZ establishment, the analysis progressed to test hypotheses specific to spillover. An assessment was conducted to determine whether there was an increasing trend in biomass for the focal species since the BOWFZ establishment, taking into account the distance to the BOWFZ. The combination of the variables 'years since the establishment of the BOWFZ', 'distance to the zone', and 'species' significantly influenced CPUE. However, there was a negative effect associated with the years since establishment, indicating a decrease in CPUE over time. This effect was most pronounced for common dab. **While tub gurnard and sole did exhibit slightly higher CPUE near the borders of the BOWFZ in later years, the magnitude of this effect was deemed meaningless from a biological perspective. Consequently, no discernible indicators were found to support the conclusion of spillover.**

The quantitative results and the insights gathered from the questionnaires align in their scepticism about the BOWFZ's potential as a true MPA with substantial benefits for overexploited fish populations. Both sources indicate that fishing activities have been restricted, but neither has reported changes in fish abundance, biomass, species composition, or catches within the area. Moreover, both suggest that other measures, such as effort limitations, would likely be more effective in addressing overexploitation concerns. This consensus underscores the importance of considering a combination of management strategies to achieve conservation objectives effectively.

It is reasonable to consider that the absence of evident spillover effects in this case study may be attributed to the MPA's relatively recent establishment (Friedlander et al., 2017), which is a common occurrence in marine conservation. It would be valuable to conduct ongoing monitoring and research over an extended duration, and explore non-linear responses of the species population in response to the WFZ establishment (Babcock et al., 2010). **As fish populations within the BOWFZ gradually recover, there is the potential for them to eventually spillover into the surrounding areas. Furthermore, it could be insightful to explore the dynamics of less mobile species in this context, particularly given the relatively confined research area** (Di Lorenzo et al., 2020). One limitation of this study is that the baseline data are from years when the construction of the WFZ had already begun. A consequence of this could be that the data therefore represents a disturbed spatial temporal distribution of fish species. Having this as the reference frame for the current spatial temporal distribution of fish species could lead to faulty interpretation of what happened to the species long term. However, an underestimation of initial biomass could more easily result in the observation of 'spillover-like effects', which is not what we found in this study. Lastly, the proximity of the Belgian wind farm area adjacent to our study site might further complicate the pattern of population recovery or spillover in space and time.

7 CONCLUSIONS

In the research area, a reduction in fishing effort for all three studied species (sole, common dab, and tub gurnard) was observed after the establishment of the BOWFZ. Additionally, CPUE decreased for two out of three species (sole and common dab). Two indicators of spillover were tested: an increasing trend in biomass towards the windfarm zone border and increasing biomass surrounding the BOWFZ over time since establishment of the BOWFZ. Neither indicator yielded significant or biologically meaningful findings in this study. The absence of visible spillover effects might be attributed to the recent establishment of the BOWFZ. Further exploration of dynamics in other species within the confined research area may offer additional insights.

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6. CASE STUDY REPORT:

THE BELGIAN OFFSHORE WIND FARM ZONE

BELGIUM – NORTH SEA

Belgian offshore wind farm. © ILVO

Analysis of potential spillover effects around the Belgian offshore wind farm zone

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LIST OF ABBREVIATIONS

Term	Description
BACI	Before-after control-impact
EEZ	Exclusive economic zone
GAMM	Generalized additive mixed model
LPUE	Landing per unit effort
MPA	Marine protected area
NGO	Non-governmental organisation
OWF	Offshore wind farm
RI	Residency index
SPL	Scour protection layer
VMS	Vessel monitoring system

1 EXECUTIVE SUMMARY

The Belgian offshore wind farm (OWF) zone is situated in the eastern part of the Belgian Exclusive Economic Zone, covering a total surface area of 238 km². The construction of nine wind farms started in 2008, with two completed by 2011 and the remaining seven by 2020. From the start, the authorities prohibited fisheries activities within the OWF zone for safety reasons, and this closure was gradually implemented in tandem with construction activities. This phased closure is evident in fisheries activities within and around the OWF zone, which is extensively monitored and researched for its effects on the marine ecosystem and potential spillover effects. This case study outlines three distinct studies, complemented by stakeholder interviews.

The first study utilized vessel monitoring system (VMS) and landing data of key commercial species to study changes in fishing patterns and catches around the Belgian OWF zone. Results indicated that fishing activity at the periphery of active OWFs predominantly reflects edge effects, with a reduction in fishing effort within the OWF concession areas during turbine construction. Despite small alterations in fishing patterns near operational OWFs, the impact on fishing activities appeared modest, suggesting adaptation to the new circumstances and potential attraction of fishers to OWF edges. Nevertheless, the loss of 238 km² of fishing ground was acknowledged, and further investigation is warranted to comprehend the potential benefits of OWFs as nursery or feeding grounds for targeted fish species.

The second study investigated spillover effects from two distinct OWFs (C-Power and Belwind), assessing density changes in fish and epibenthic species using a before-after control-impact (BACI) approach. Long-term monitoring data revealed changes in the occurrence of several species, particularly 'hard substrate' species expanding their range of occurrence. These changes were attributed to the 'refugium effect' and 'artificial reef effect' due to the presence of the OWFs. Notably, the changes were not consistent between the two wind farms, emphasizing the site-specific nature of effects and the need for caution in extrapolating findings to other OWFs.

The third study describes an acoustic tagging study on plaice, focusing on their presence and movements within and around the Belwind offshore wind farm. Findings suggested that OWFs offer protection to plaice during the feeding season, primarily due to abundant food supply around hard substrates, potentially enhancing local fish production. However, this protection diminishes during spawning migrations when plaice leave the OWF, exposing them to fishing mortality. The study underscores the potential of OWFs as protection areas for certain species but advocates for larger OWF zones to effectively mitigate fisheries impacts. The research also showcases the successful integration of data from various acoustic telemetry manufacturers and recommends the inclusion of archival tags for three-dimensional fish position tracking, supporting further exploration of movement patterns, including spawning behaviours and migrations.

The interviews revealed a lack of communication or understanding among stakeholders regarding OWFs and the likelihood of spillover. Fishers perceive OWFs as a significant threat to their business due to the substantial loss of fishing grounds. Despite optimism among scientists and NGOs regarding spillover, fishers remain unconvinced due to the perceived absence of scientific evidence. Scientists and NGOs envision the OWF zone as a potential fishery and/or conservation management area based on ongoing research in the Belgian OWF.

2 BACKGROUND

The Belgian offshore wind farm (OWF) zone is situated in the eastern part of the Belgian Exclusive Economic Zone (EEZ), approximately 23 km off the coast of Zeebrugge (Figure). Covering an area of 238 km², this zone comprises nine distinct OWFs. The initial planning for the entire OWF zone dates back to 2004 and was subsequently incorporated into the first marine spatial plan (2014-2020). Authorities, prioritizing safety, opted to progressively exclude all fishing activities within the OWF zone during the construction phase. Consequently, a 500 m safety perimeter was enforced once the wind farm was operational. The chronological details of these closures are presented in Table 1. The initial prohibition of fishing occurred in 2008 within a small area surrounding six turbines (C-power). Subsequently, Belwind, developed after 2011, and the surrounding wind farms expanded this restricted area. Since the completion of the entire OWF zone in 2020, all fishing and shipping activities, with the exception of maintenance and research, have been strictly prohibited (Figure) (Verlé et al., 2023). A discernible transition in the closure of the area is evident in fishery activities within the OWF zone. During 2010-2013, fishing persisted in and around the first two operational wind farms (C-power and Belwind), with a third spot (Northwind) emerging as an unfished area from 2014 to 2017. Subsequently, the remaining part of the zone swiftly closed for fisheries from 2017 to 2019. Since 2020, no fishing activity has been observed within the entire 238 km² area (Figure). The Dutch beam-trawl fleet predominantly operated within this region when fishing was allowed, as the Belgian beam-trawl fleet was only an occasional user. In Belgian waters, the Belgian fishery primarily operates in coastal waters for brown shrimp fishing, minimally impacted by the OWF zone, particularly in the most southern part (Norther wind farm).

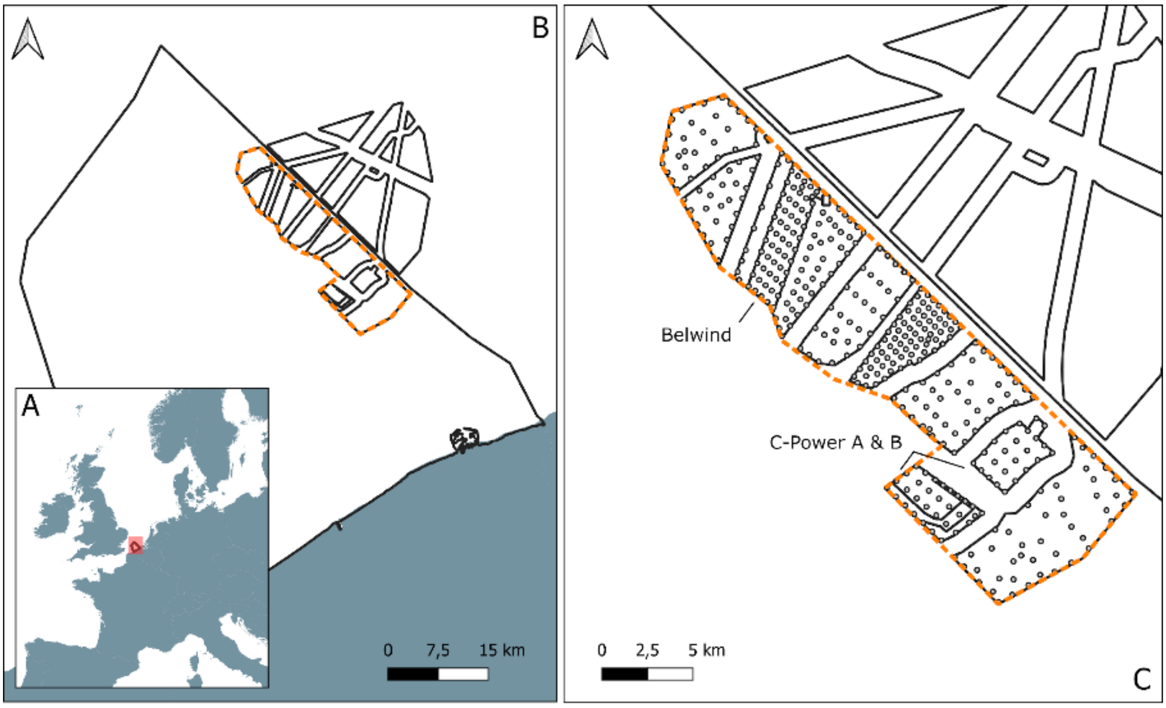


Figure 1: Position of the Belgian OWF zone and an indication of the nine different wind farms and their turbines. At the east side, the Dutch Borssele OWF zone is located[12].

During the initial delineation of the OWF zone, the fisheries sector was not consulted. Although a consultation process occurred during the implementation of the first marine spatial planning process, it had limited influence on the location of the planned zone or the fisheries restrictions. While fishers and sector representatives could offer comments on the initial marine spatial plan during this consultation, they had little say in location decisions, as most concessions were already granted. The opposition to OWFs by fishers persists due to the significant loss of fishing grounds, and they find it challenging to compete with the energy sector or align with green energy policy targets. Moreover, they have minimal influence on the location choices of OWFs and have received limited compensation, particularly in the context of Belgian fisheries.

[12] See also Case Study on the Dutch Borssele OWF.

Table 1: Overview of the nine wind farms, with indication of the moment of the fishery closure, in relation to construction and operability timing.

Wind farm	Start of sustained fisheries closure	Comments	Start construction	First power generated
C-Power phase 1	02/08	6 turbines with gravity-based foundations (+ 500 m safety buffer)	05/08	01/09
Belwind	06/09		09/09	01/11
C-Power phase 2 & 3	01/11	Both zone A and B	04/11	09/13
Northwind (NW)	01/13		04/13	05/14
Nobelwind (NB)	02/16	South and north of Belwind	05/16	12/17
Rentel (RE)	04/17		07/17	01/19
Norther (NO)	05/18		08/18	05/19
Northwester 2 (NW2)	04/19		07/19	05/20
Seamade (MM + SS)	06/19	Seastar + Mermaid concession areas	09/19	11/20

While OWFs are not designed with the explicit goal of protecting vulnerable species or habitats as in the case of marine protected areas (MPAs), they may inadvertently serve a protective function due to the absence of fishing activities within their boundaries. In this way, the OWF has been considered as an ‘other effective area-based conservation measure’ (OECM). Although the extent and nature of this protective function from OWFs, and its potential to trigger biomass spillover to adjacent areas, remain largely unknown.

The Belgian OWF zone, particularly the two earliest wind farms, C-Power and Belwind, has been studied extensively to explore the impact of OWFs on the biological communities within the area. Through a combination of basic monitoring and targeted studies, a comprehensive understanding has been developed regarding the effects of OWFs on various species groups. While spillover was not the primary focus of the basic monitoring, some targeted studies have assessed the potential existence of spillover from Belgian OWFs. The ensuing results, along with insights from stakeholder interviews, are detailed below to provide an integrated overview of the potential spillover dynamics from the Belgian OWF zone.

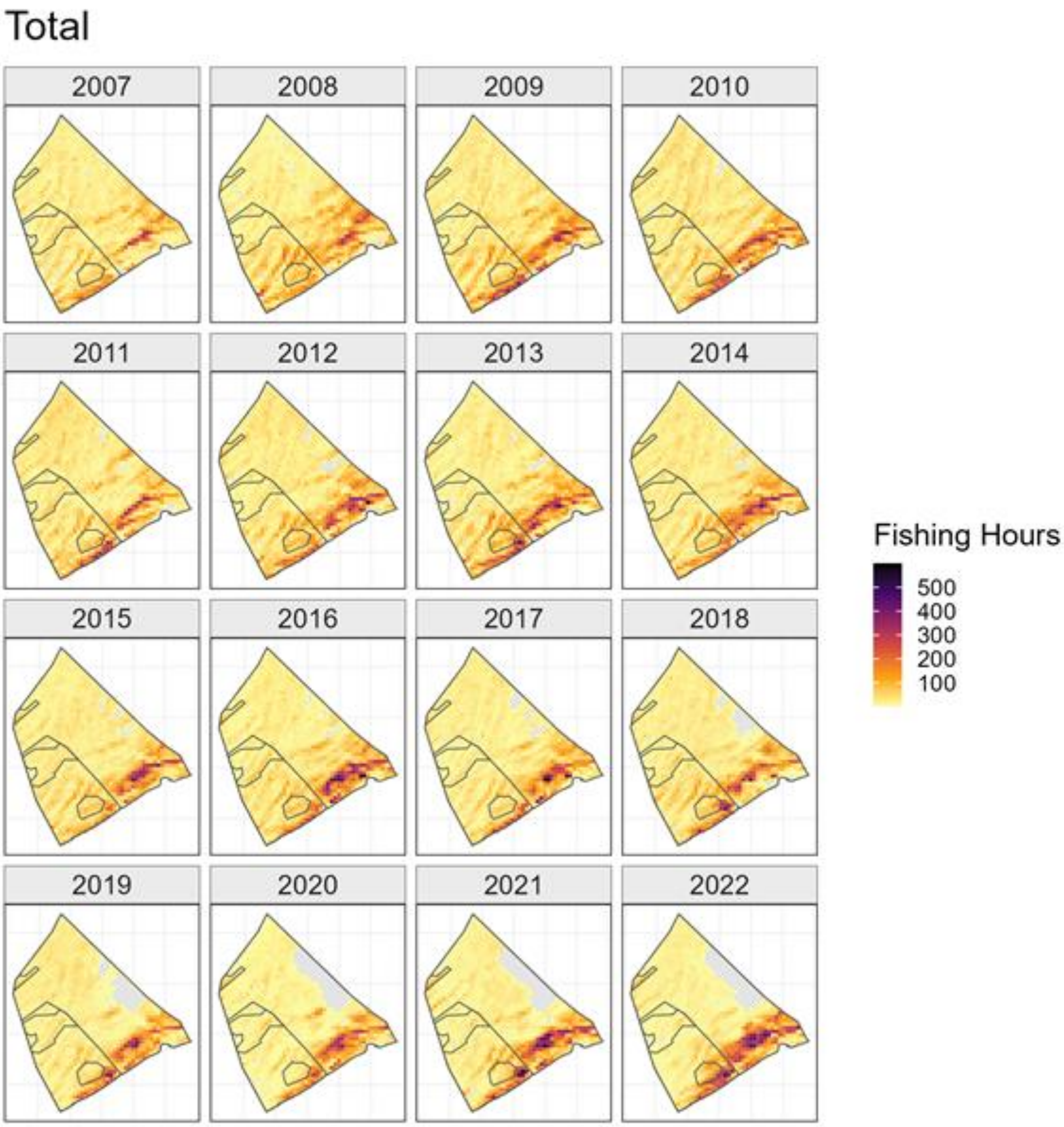


Figure 2: Total fishing effort in fishing hours in the Belgian part of the North Sea between 2007 and 2022 (all gears combined). Data includes activities of the Belgian and Dutch fleet (2007-2022) as well as the German, Danish and British fleet (2009-2022). France could not be included. The information is presented on a 1.6 x 1.6 km grid. The Flemish Banks is also represented along with the latest areas where the enforcement of fishing measures are planned.

3 AIMS AND OBJECTIVES

The general aim of this case study is to describe three separate studies each focused on a specific topic related to spillover effects from the Belgian OWF zone. Additionally, some interviews were executed to gain insight into how different groups of stakeholders perceived ecological or fishery spillover effects from the zone. The aims, methodology and results of each study will be described separately, while the discussion will integrate the findings of all three studies.

3.1 Fishing intensity and catches around the Belgian OWF zone

The first study investigated changes in fishing patterns and catches around the Belgian OWF zone using VMS and landing data of the most important commercial species in the area. This part is based on the report published as De Backer et al (2019). The aims of this study were:

- To study whether or not the effort, the landings and the landings per unit effort (LPUE) changed over the period 2006-2017 in relation to the presence of OWFs.
- To investigate whether spatial changes in fishing activity took place due to OWFs by comparing the period 2006-2007 (pre-turbines) with 2016-2017 (232 operational turbines).

3.2 Investigating spillover effects around two Belgian wind farms using beam trawl sampling

The second study investigated spillover effects from two different Belgian OWFs in terms of changes in fish and epibenthic communities using traditional beam trawl sampling within a BACI approach. This part is based on the paper published as Vandendriessche et al (2015). The aims of this study were:

- To investigate whether changes in species diversity, density, species composition, size distribution, and biomass of the epibenthos, demersal fish, and benthopelagic fish species could be related to the presence of offshore wind farms.
- To investigate whether such changes could be attributed to the absence of fisheries activities and/or the presence of hard substrates within the wind farm and whether edge or spillover effects could be detected.

3.3 Acoustic telemetry to study spatial movements of plaice within and in relation to an OWF

The third study describes an acoustic telemetry study on plaice that investigated the presence and movements of plaice within and in relation to the Belwind OWF. This part is based on the manuscript published as Buyse et al. (2023).

The aims of this study were:

- To assess plaice residency within the Belwind OWF.
- To analyse small scale movement patterns of plaice on and near the scour protection layer[13] (SPL).
- To examine plaice site fidelity to the OWF after their yearly spawning migrations.

Although this study had no direct aim of studying spillover, the presence data within the wind farm can give a good idea on the residency of plaice within the closed area and whether plaice leaves the area during the spawning season, which would indicate spillover towards fished areas.

3.4 Stakeholder questionnaire

The questionnaires aimed to explore the views of different types of stakeholders in terms of both ecological and fishery spillover from the Belgian offshore wind farm zone.

[13] A scour protection layer in the form of rocks or mattresses are added around turbine foundations where currents cannot pass through to ensure the stability of the surrounding sand, as the redirected currents cause turbulence in the water column that could wash away the sand (Whitehouse et al., 2011).

4 METHODOLOGY

4.1 Fishing intensity and catches around the Belgian OWF zone

Data description

The data for this study consist of VMS data and logbook data from 2006 to 2017 within ICES rectangles 31F2, 31F3, 32F2, and 32F3, which overlap with the Belgian OWF zone. VMS is a satellite-based vessel monitoring system that provides data on the location, time, course, and speed of vessels to the fisheries authorities at regular intervals (usually every 2 hours). Logbook data contains information on the daily catch composition, used fishing gear, engine power and visited harbours. These data were obtained for both the Belgian and Dutch beam trawl fleet, which includes small and large beam trawls, and Dutch pulse trawlers operational since 2011. The spatial resolution of the ICES rectangles was gridded at 0.05 x 0.025 decimal degrees, referred to as "grid cells." The processed Dutch data were provided by Wageningen Marine Research, while Belgian VMS and logbook data were collected by Dienst Zeevisserij (Departement Landbouw en Visserij; Afdeling landbouw- en visserijbeleid) and analysed by the Flanders Research Institute for Agricultural, Fisheries and Food (ILVO).

Data analysis

Data processing of both VMS and logbook data was carried out using the "vmstools" package in R, and an extensive quality control process was conducted, addressing data consistency, duplication, and the selection of VMS records indicative of actual fishing activity based on speed (Hintzen et al., 2012). VMS and logbook data were linked based on the vessel identity and the timestamp, after which a spatial overlay was performed to calculate the fishing activity and catch per grid cell. To entangle wind farms effects from general trends in fishing activities, yearly trends in fishing effort, landings, and LPUE for the top 10 species of the Dutch and Belgian beam trawl fleets were calculated for each ICES rectangle and for plaice and sole within each OWF concession area using the Geofish platform. Data for operational wind farms should be interpreted as edge effects, rather than infringements of fishing vessels within the concession areas. Comparisons of fishing effort and LPUE distribution were made between the pre-OWF period (2006-2007) and the period with operational and under-construction OWFs (2016-2017). The analysis focused on the large beam trawl segment (> 221 kW), excluding the small beam trawl segment (= < 221 kW) that operated primarily outside the OWF area before 2009. Deviations in proportional effort or LPUE were calculated, indicating relative changes in 2016-2017 compared to the reference period of 2006-2007. Effort and LPUE values were expressed as proportions relative to the average values for the study area (four statistical ICES rectangles) for each grid cell, excluding the general temporal trend. A negative deviation indicates reduced effort or lower LPUE in 2016-2017, while a positive deviation indicates increased effort or higher LPUE.

4.2 Investigating spillover effects around two Belgian wind farms using beam trawl sampling within a BACI-design

Data collection and study design

The study focused on two wind farms on the Thorntonbank (C-Power) and the Bligh Bank (Belwind), which are located in Belgian waters. The C-Power wind farm is situated 27 km from the coast and consists of 54 turbines, of which 48 on jacket foundations and 6 on gravity-based foundations, constructed at depths between 18 and 24 m. The Belwind wind farm, located about 40 km offshore, consists of 56 turbines constructed on monopile foundations and spans depths of 15 to 40 m. Samples were collected within the two wind farms, specifically between turbine rows approximately 200 m away from the nearest turbines (Figure 3). Edge stations just outside the wind farm concessions and reference stations away from the concessions with comparable soft sediments and depths were also sampled. Sampling encompassed three ecosystem components (epifauna, demersal fish, and benthopelagic fish) across two seasons (autumn and spring), two sandbanks (Thorntonbank and Bligh Bank), and two habitats (sandbanks and gullies). Ecological data were gathered through beam trawl samples taken at different locations and conditions. The Ecological data collection involved the deployment of an 8-metre beam trawl equipped with a shrimp net (mesh size of 22 mm). Samples were collected within the wind farms, specifically between turbine rows approximately 200 m away from the nearest turbines (Figure 3). Edge stations just outside the wind farm concessions and reference stations away from the concessions with comparable soft sediments and depths were also sampled. Monitoring in this concession area has been going on since 2005 (Sampling occurred every 6 months (February–March and September–October, from 2005-2012 for C-Power and from 2008-2012 for Belwind), and the sampling design was slightly adapted based on previous results and wind farm developments and accessibility. The data analysis consisted of a "Before After Control Impact" (BACI) design, in which years were nested within periods and sites. The expected changes in the OWF area are attributed to the artificial reef effect and the refugium effect (exclusion of fisheries).

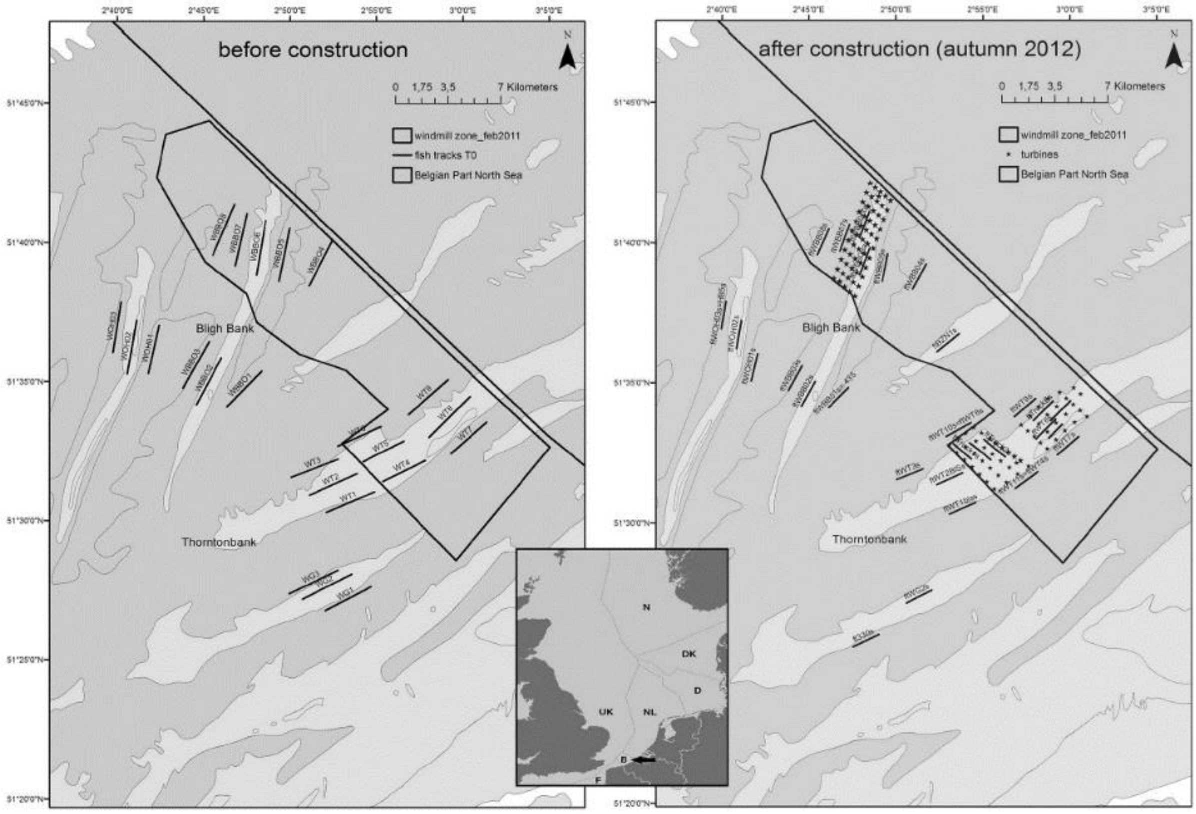


Figure 3: BACI sampling design showing trawl locations before and after construction (2012 and afterwards) of both the Thorntonbank and Bligh Bank wind farms, and reference stations on adjoining sandbanks. Bathymetry is indicated as grayscale (white <5 m; light gray 5–20 m; dark gray >20 m). Inset indicates the position of the Belgian part of the North Sea relative to Belgium and its neighbouring countries.

Data analysis

To investigate wind farm and edge effects, univariate measures density (ind./1,000 m²), biomass (g WW/1,000 m²), and diversity (number of species) were calculated for each combination of factors (season, sandbank, location, ecosystem component). Further, community structure for the different ecosystem components was assessed for each combination of factors. Time-evolution graphs were used to check for differences between treatment groups over the years (except for community structure). Non-parallelisms between the trend lines between control and impact areas was interpreted as a sign of an environmental impact (Schwarz, 1998). Statistical significance was assessed using two-way crossed PERMANOVA analyses, employing a BACI design that incorporates the factors BA (before/after), with years nested in BA, and site (control/impact). When interaction effects were significant, pairwise tests were conducted. Community differences were assessed using the Bray-Curtis similarity measure, with contributions of species differences calculated using the SIMPER routine. Additionally, the potential influence of temporary effects was considered, and differences between control and impact samples within specific years were evaluated. The statistical analyses were run in PERMANOVA for PRIMER (Anderson et al., 2007) PERMANOVA and employed Monte-Carlo tests when appropriate. The BACI design considered variations in the number of replicates and observations between pre- and post-construction periods.

4.3 Acoustic telemetry to study spatial movements of plaice within and in relation to an OWF

Data collection

The study was conducted within the Belwind offshore wind farm located in the Belgian part of the North Sea (51°39′36″ N, 2°48′0″ E). The wind farm is situated on the Bligh Bank, a natural sandbank located 40 km offshore from the Belgian coastline, at water depths ranging from 15 to 37 m. Construction of the wind farm began in 2009, involving the installation of 55 Vestas turbines (3 MW) on monopile foundations with a 5 m diameter. To mitigate sand erosion, each turbine was equipped with a scour protection layer consisting of a filter layer composed of pebbles and an armour layer with a median rock size of 370 mm and a density of 2.65 $ton.m^{-3}$. The entire concession zone with a 500 m safety perimeter was closed three months before construction began, and adjacent areas were later closed for vessel traffic during the construction of a neighbouring wind farm in 2016.

Thirty-one plaice individuals were tagged using Thelma Biotel MP9 transmitters (69 kHz) emitting unique acoustic signals. The transmitters were attached externally to fish using a stainless-steel wire and secured with heat shrink tubing and metal crimps. Fish were caught using hand line fishing or diving, ensuring a minimum size of 29 cm. Tags were attached anterior to the dorsal fin. The tagging procedure took approximately three minutes per fish. Fish were released near their capture locations after the procedure. The tagging protocol was approved by the ethical committee of ILVO.

Study design

Three successive arrays of VR2AR receivers (69 kHz, InnovaSea Systems Inc., USA) were deployed within the southern part of the Belwind OWF from May 2020 to August 2021 (Figure 4). These arrays were designed to study the movement patterns and site fidelity of plaice. Deployment and retrieval were conducted by the research vessel Simon Stevin using tripod moorings. The mooring setup comprised a receiver attached to a buoy connected to a steel tripod and a rope. The difficulty in using tripod moorings lies in their retrieval, as windy conditions can cause the ropes on the tripods to break. If this happens, the frames cannot be retrieved by winch, but need to be located by the use of divers. However, such a setup gave much better results in terms of decreased background noise compared to a surface setup using chains and buoys. The first array (May 2020-October 2020) had 18 receivers strategically positioned around three turbines for the calculation of fish positions, and ten additional receivers in between the turbines to investigate plaice presence within the OWF during the feeding season. The second array (October 2020-February 2021) included 28 receivers used to study plaice presence within the wind farm during the spawning period. The third array (February 2021-August 2021) featured 15 receivers for monitoring fish returns after spawning.

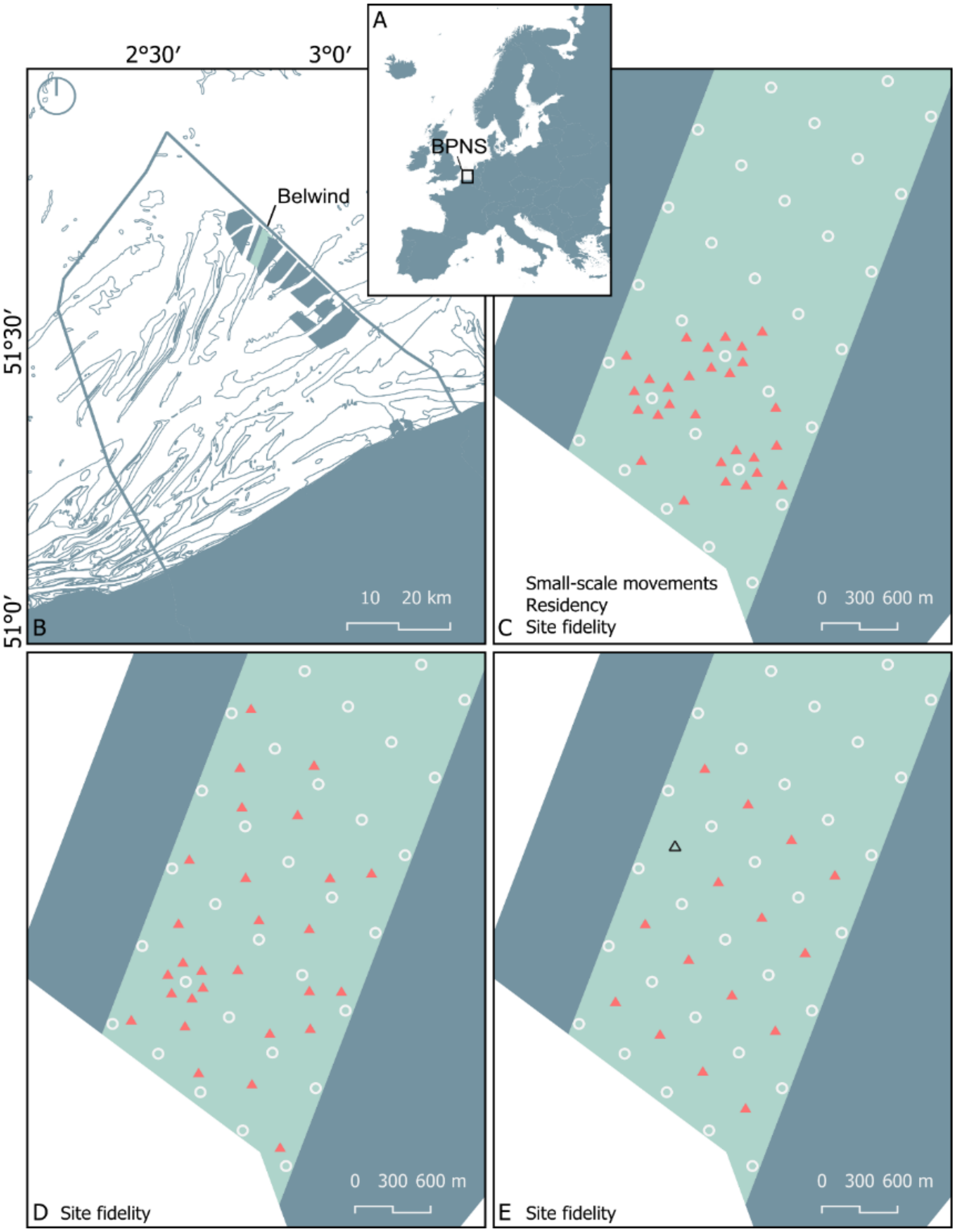


Figure 4: (A-B) location of the Belgian part of the North Sea and the Belwind offshore wind farm; (C-E) spatial design of the receiver arrays during the three study periods: May 2020–October 2020, October 2020–February 2021, and February 2021–July 2021, respectively. Turbine locations are indicated with white open circles, deployed receivers are indicated as red triangles, lost receiver indicated as a black open triangle.

Data analysis

The first array's data (May 2020-October 2020) were used to study plaice residency and small-scale movement patterns. Daily binary presence/absence data were analysed to assess the presence of fish in the study area. Residency index (RI) was calculated for each fish. The estimated positions of tagged fish were determined using the YAPS model. Associations with the scour protection were examined by calculating distances between fish positions and turbines. Generalized additive mixed models (GAMMs) were used to explore relationships between distance from turbines and environmental variables. Light conditions, bottom current speed, and tide-related factors were tested as explanatory variables. Models were evaluated using root mean square error (RMSE). Binary presence/absence data from all three receiver array periods (May 2020-July 2021) were analysed to study site fidelity and long-term presence within the wind farm area. Extended absences during spawning followed by returns indicated fish migration and site fidelity.

4.4 Stakeholder questionnaire

A questionnaire was developed to assess the perceptions of key stakeholders on the potential spillover effects. The questionnaire consisted of open-ended and closed questions to elicit stakeholder views and experiences on the different aspects of this study (see questionnaire in Annex 4). The open-ended questions aimed to capture stakeholder opinions on, for example, how aware the stakeholder was of the regulations and management measures. The closed questions were statement-based and used Likert scale answer categories (such as: Strongly agree; Agree; Neutral; Disagree; Strongly Disagree) for the stakeholder to choose from.

The questions were grouped into four broad categories to encapsulate the key issues being studied. These included:

(i) Respondent information. The first section required basic information from the respondent, including their name, institution and the type of stakeholder category they belonged to.

(ii) Background information. The second section of the questionnaire gathered background information from the stakeholder to understand more about the respondent and their use of the OWF. Questions included knowledge of when the OWF was established, the type of restrictions in place and how long the stakeholder has been associated with the OWF either through research, fishing or managing it.

(iii) Fishery impacts of OWFs. The third section explored the respondent's perceptions of the socio-economic impacts of spillover from the OWF. Stakeholders were asked to state whether the designation of an OWF area where fishing is limited has led to an increase in revenues for fishers, whether the fishing community in the area feel their fisheries livelihoods are more secure after the OWF was established, and the extent to which they believe spillover from the OWF has influenced the catch composition in adjacent fishing grounds.

(iv) OWFs as management tools. The fourth section of the questionnaire focused on the respondent's perceptions on whether OWFs are conservation or fisheries management tools. Stakeholders were asked to state whether the OWF was acting as a conservation tool, a fisheries management tool or both. Other questions under this section required stakeholders to state their agreement / disagreement on whether the establishment of OWFs is an effective conservation strategy to support fish populations and commercial fisheries in their area. Respondents were also asked to indicate what factors they thought were contributing to spillover effects.

Four key stakeholder groups were targeted under this consultation including commercial and recreational fishers, fisheries managers and government authorities, scientists and environmental non-government organisations (NGOs). Therefore, while the four sections of the questionnaire were the same, specific questions were included for each of the four respondent groups.

For this case study, we contacted and interviewed the four key stakeholder groups. For fishers, we had an interview with the producer organisation (Redercentrale) and one coastal fisher. Two scientists, one of ILVO and one of VLIZ were interviewed, both executing research within the Belgium OWF zone on fishery effects and fish movements. From the policy department, we had contact with the Flemish Fishery department, responsible for fishery management and with the

Federal Department of Environment, responsible for the management of nature conservation. Finally, we had 5 responses to the questionnaire for this case study.

5 RESULTS

5.1 Fishing intensity and catches around the Belgian OWF zone

The study investigated the fishing effort, landings of the top 10 species, and LPUE of sole and plaice in relation to the OWF development in Dutch and Belgian waters from 2006 to 2017.

Fishing effort and trends

Dutch and Belgian beam trawls spent an average of 108,000 hours within ICES rectangles 31F2, 31F3, 32F2, and 32F3 from 2006 to 2017. Fishing effort in the areas surrounding the OWF area displayed a general decreasing trend over the years. During the construction of an offshore wind farm, there was a noticeable drop (up to 50%) in fishing effort within its concession area (Figure 5). After OWFs became operational, reduced fishing effort persisted in C-Power and Northwind. However, in Belwind, the apparent increase in fishing effort during the operational phase was attributed to grid cell resolution, wherein fishing along the edges was seen as fishing within the wind farm, largely due to edge effects. With the expansion of non-fishing areas due to OWF construction (e.g. Nobelwind), fishing effort dropped again. For OWFs in the pre-construction phase (Seastar, Northwester, Mermaid), temporal variation in fishing effort was observed, with a decreasing trend in the later years.

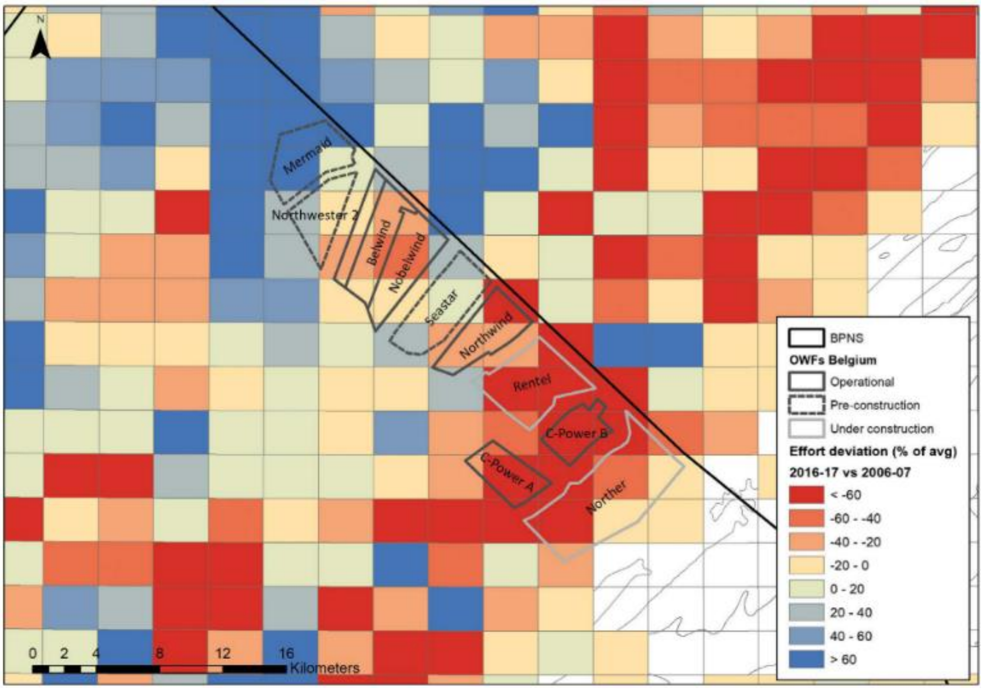


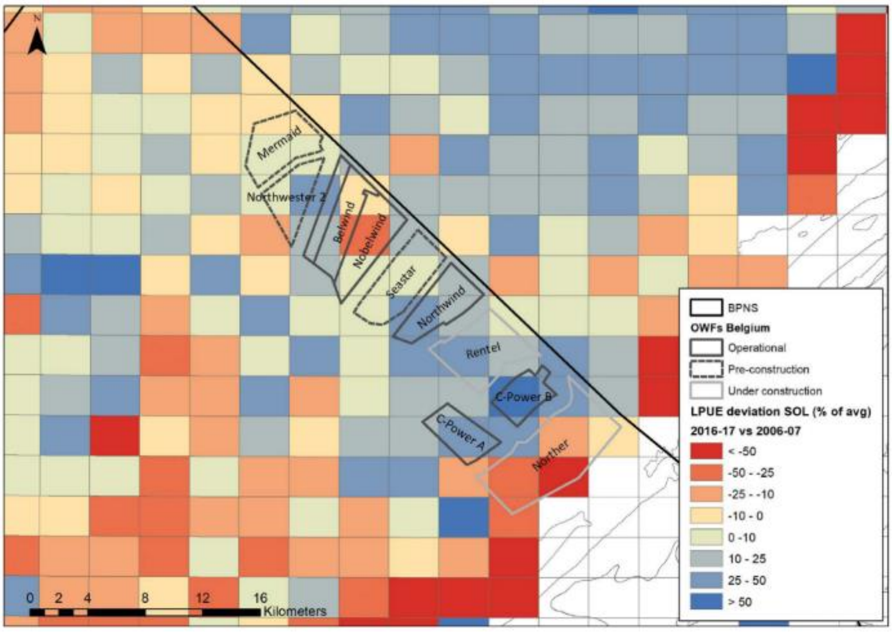
Figure 5: Spatial changes in fishing effort based on the deviation in proportional effort for Dutch and Belgian large beam trawls in 2016-2017 compared to 2006-2007.

Top 10 Species Landings

Within the four studied ICES rectangles, Dutch and Belgian beam trawlers landed an average of 2.8 million kg of sole and 3.4 million kg of plaice, their target species. Landings were generally correlated with fishing effort. Landings of dab and cod increased during the earlier years (2006-2009), but decreased from then on. Plaice landings showed an increase from 2006-2011, followed by a decline, while sole landings were more erratic over time with low values in 2011. Sole's landings showed a clear increase (26%) after 2012, while gurnard landings were also higher in 2015 and 2016. Landings of other species (turbot, brill, whiting, bib) remained relatively stable during the study period. In the OWF area, trends in total landings for the top 10 species were highly correlated with fishing effort, showing a drop during construction of the OWF and remaining lower when operational, except for Belwind. These trends represent edge effects and not actual fishing effort within the concession zones of the wind farms due to the low resolution of the data.

LPUE for sole and plaice

LPUE for sole in the four studies ICES rectangles increased significantly (almost 50%) from 2012 onwards, indicating higher catch rates (Figure 6). LPUE for plaice displayed more yearly variation and averaged 32 kg/h. LPUE of plaice followed the landing trend, increasing towards 2011 and decreasing in later years. LPUE of sole within concession areas increased from 2012 onwards, unaffected by wind farm presence. For plaice, higher catch rates were observed in wind farms farther offshore compared to coastal ones. The trend in LPUE of plaice within concession areas showed some year-to-year variation, deviating from the general trend.



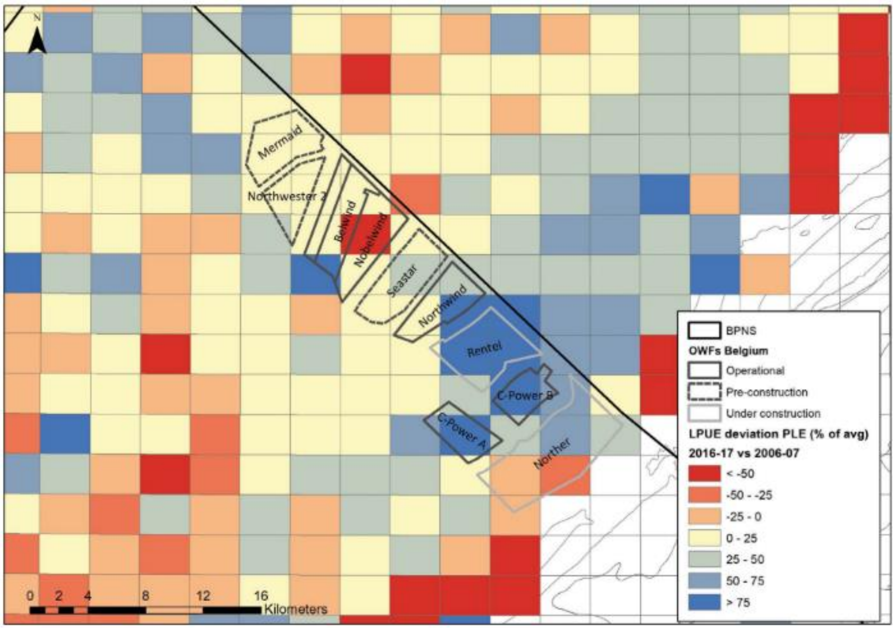


Figure 6: Spatial changes in LPUE of sole (top) and plaice (bottom) based on the deviation in proportional LPUE for Dutch and Belgian large beam trawls in 2016-2017 compared to 2006-2007.

Spatial changes in fishing effort and LPUE

Spatially, proportional fishing effort decreased around operational wind farms, with a general shift towards more offshore fishing activity. Fishing effort in wind farms further offshore (e.g., Belwind, Nobelwind) increased slightly, suggesting attraction to edges. Proportional LPUE changes did not clearly indicate a wind farm effect on sole. However, for plaice, a substantial increase in proportional LPUE was observed in certain wind farm areas, deviating from the general trend.

Intrusions and spatial patterns

The study also investigated fishing vessel intrusions within operational concession areas, which ranged from 0-17 per year per wind farm. Intrusions increased in later years, potentially due to improved detection tools.

Overall, the study demonstrated dynamic interactions between fishing effort, species landings, and LPUE in relation to OWF construction and operation, suggesting complex spatial and temporal patterns influenced by various factors, including fishing restrictions and fish behaviour.

5.2 Investigating spillover effects around two Belgian wind farms using beam trawl sampling within a BACI-design

The study examined the effects of edge and wind farm presence on various ecological components in different seasons and habitats, as summarized in Table 2.

Table 2: Summary of the statistical results for the Thornton bank and Bligh Bank. Bold text indicates significant effects (p < 0.05) of the BACI interaction term. Text in italics indicates significant control impact (CI) effects within specific years (but BACI effect not significant). Arrows indicate increase or decrease. Source: Vandendriessche et al (2015).

		spring			autumn		
		wind farm effect		edge effect	wind farm effect		edge effect
THORNTONBANK		top	gully	gully	top	gully	gully
community level	Density						
	Biomass			**epibenthos (BACI) ↑**	*epibenthos (2009)* ↑		
	Species number					*demersal fish (2008)* ↓	
	Species composition						
species level	density						
	mean length			**whiting (BACI) ↑**	*dab (2012)* ↓		
BLIGH BANK							
community level	Density						
	Biomass	**epibenthos (BACI) ↑**			**epibenthos (BACI) ↑**		
	Species number						
	Species composition					*demersal fish (2012)*	
species level	density	**sea star, sole (BACI) ↑**		*sole (2012) & dab (2012)*↑	*sole (2011) & dab (2011)*↑, *sea star (2009)* ↓, *sea star (2011)*↑	*sandeel (2012), ophiuroid (2009) & urchin (2009)* ↓	
	mean length						

Density, biomass, biodiversity and species composition at the ecosystem level

A significant effect on density was observed for demersal fish at the Thorntonbank top samples in autumn when years were nested within the Before-After treatment. However, pairwise tests didn't reveal specific differences within years. Biomass effects were seen at the Bligh Bank top in both autumn and spring, with increases in biomass after wind farm construction. Higher epibenthos biomass was observed at the Thorntonbank top stations in certain years, with significant differences found in 2009. A biomass effect was noted at the Thorntonbank edge in spring, but pairwise tests were not significant. Wind farm effects were detected for the number of species of demersal fish in the Thorntonbank samples in autumn 2008, though based on limited data. Differences in species composition were only observed for demersal fish at the Bligh Bank gullies in autumn 2012, attributed to different proportions of certain species.

Density at species level

Significant edge effects were observed for sole and dab at the Bligh Bank in spring 2012, with higher densities in edge stations. Significant BACI wind farm effects were observed for sea stars and sole at the Bligh Bank top in spring, mainly due to recruitment of small individuals. Effects within specific years were seen for various species including sandeel, sea stars, sole, dab, ophiuroids, and urchins, with varying impacts.

Size distribution

Significant mean length differences were found for whiting concerning edge effects at the Thorntonbank in spring. Effects within specific years were observed for dab and other species, with variations in size classes.

Anecdotal observations

Some observations were made that were not statistically analysed but worth noting. For instance, plaice density increased over the years, but in 2012, a decrease was observed in impact gully stations. Similar observations were made for turbot and sandeel, with episodic increases at wind farms. Lobsters, typically absent in monitoring surveys, were noted within the wind farm area in autumn 2012.

Longer- term observations

The later monitoring revealed some secondary effects with an expansion of the OWF effect beyond the immediate vicinity of the turbine on two fronts: (1) an expansion of the reef effect, and (2) signals of a refugium effect (De Backer et al., 2019). Expansion of the reef effect is suggested through the appearance of an increased number of hard substrate-associated species like long-clawed porcelain crab (*Pisidia longicornis*), edible crab (*Cancer pagurus*) and seabass (*Dicentrarchus labrax*) in the soft sediment trawls. However, the clearest indication for reef expansion was the significantly increased abundances of blue mussel (*Mytilus edulis*) and anemones (*Anthozoa* sp.), two species dominating the epifouling communities on the turbines. Slightly, but significantly, increased fish densities of some common soft sediment-associated fish species (common dragonet, *Callionymus lyra*; solenette, *Buglossidium luteum*; lesser weever, *Echiichthys vipera;* and plaice, *Pleuronectes platessa*) inside the C-Power wind farm compared to the outside reference area seem to be the first signs of a refugium effect, probably related to a combination of fisheries exclusion and increased food availability (Figure 7). More pronounced effects were found for C-Power than for the more offshore Belwind OWF, stressing that effects might be site-specific and that extrapolation of these findings to other OWFs should be considered with care.

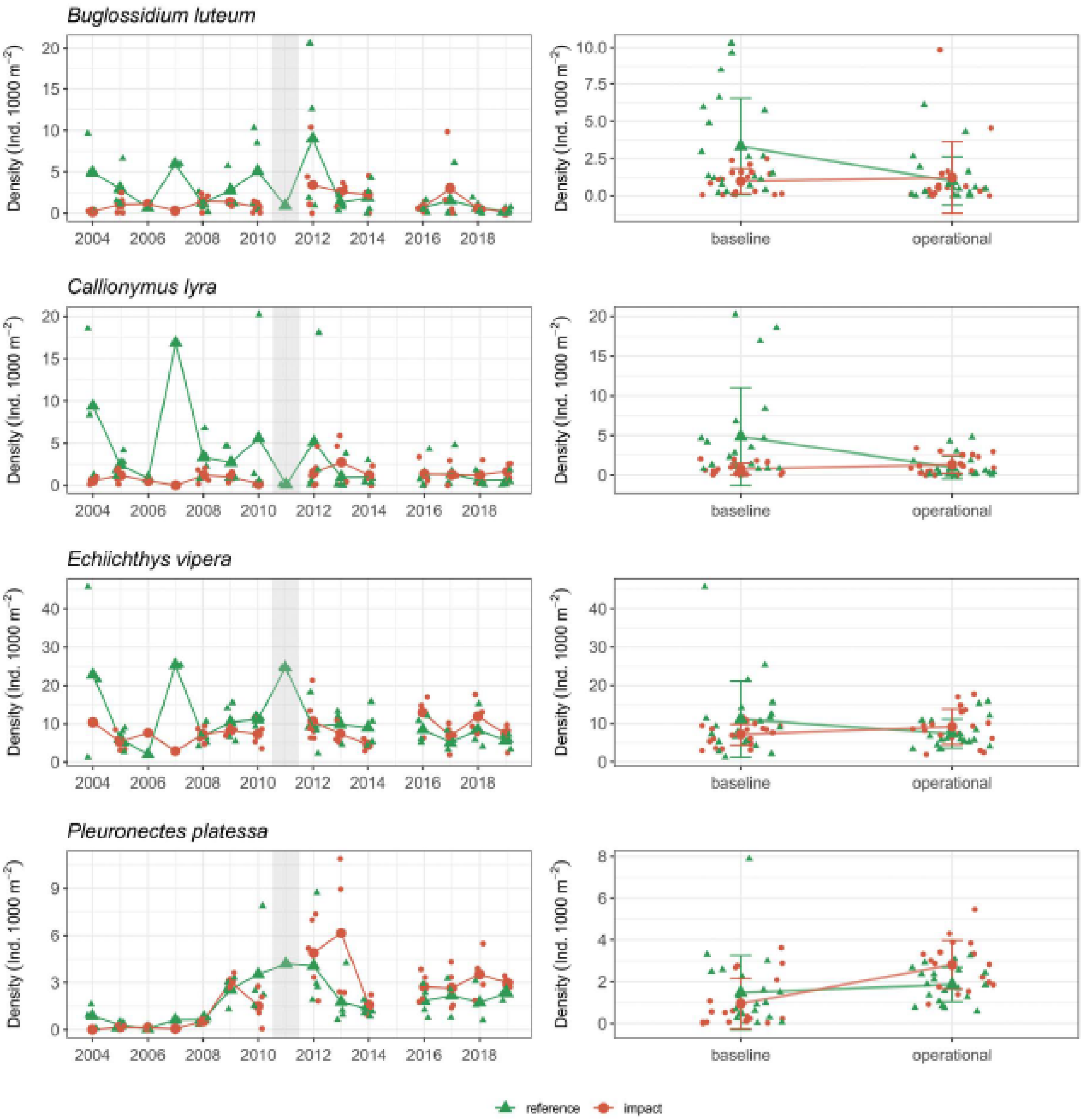


Figure 7: (Left) Time series plots of densities (individuals per 1000 m²). (Right) Mean density values (± SD) for fish species in C-Power for which a wind farm effect was detected in the baseline (2004-2010) and operational years (2014-2019). Construction of the second phase of C-Power was in 2011 indicated with a grey rectangle.

In summary, the study indicated various ecological responses to the presence of wind farms, with effects observed in density, biomass, species composition and size distribution. However, most wind farm effects were not significant and no substantial edge effects could be identified, which would indicate the presence of spillover. The complexity and inconsistency of these effects suggests the need for continued monitoring and investigation.

5.3 Acoustic telemetry to study spatial movements of plaice

In the initial study phase (May 2020-October 2020) lasting 150 days, we tagged and monitored 29 fish. Their tracking durations varied from 1 to 131 days. Subsequently, during the second study period, only two fish were tagged (totalling 31 tagged fish) (Figure 8). However, their data were omitted from the residency calculations due to the change in the study design after the first period. Most fish exhibited prolonged presence within the study area during summer and autumn, with the majority still detected at the study's end. However, three fish were briefly detected after release but not afterward. One fish was captured by a commercial vessel in April 2021 without specific identification.

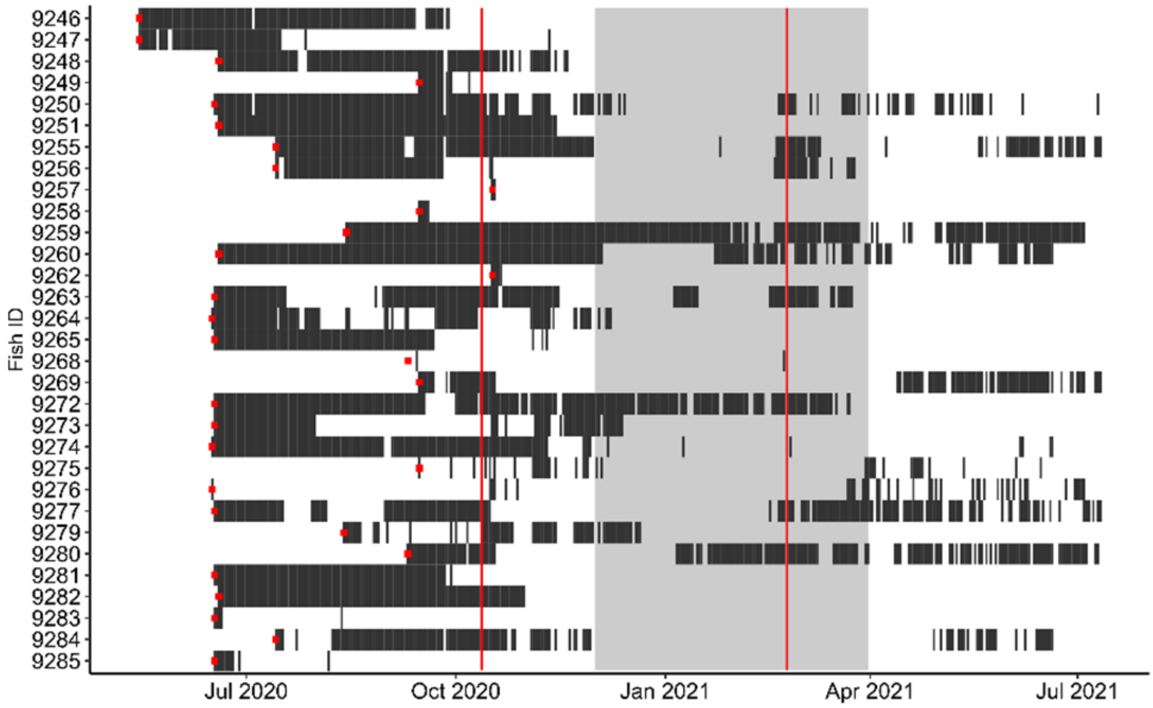


Figure 8: Presence per day of the 31 tagged plaice individuals over all study periods (15/05/2020-11/07/2021) in the Belwind OWF. Red squares indicate the tagging and release date of the fish. The red vertical lines show the change in receiver array design: study period 1: 15/05/2020-11/10/2020; period 2: 14/10/2020-22/02/2021; period 3: 25/02/2021-11/07/2021. The grey box represents the yearly spawning period for plaice in the southern North Sea (December-March). A fish was considered to be present in the study area if it was at least detected two times on that particular day.

For 24 fish detected for at least 20 days, their residency ranged from 0.09 to 1, averaging 0.78 ± 0.29 SD (Table 3). Around turbines B9, D9, and C8 in Belwind, 172,285 estimated fish positions were withheld for analysis. These positions had an average standard deviation of 5.1 m for the x-coordinate and 4.9 m for the y-coordinate.

Table 3: Residency index (RI) for the 29 fish that were tagged during the first study period. Days at large and last detections in this table are only given for the first study period (15/05/2020–11/10/2020, max. 150 days). As can be seen in Figure 8, several of these fish were still detected in the second and third study period.

Fish ID	Release date	Last detection	Days detected	Days at large	RI
9246	15/05/2020	28/09/2020	131	137	0.96
9247	15/05/2020	27/07/2020	61	74	0.82
9248	19/06/2020	11/10/2020	109	115	0.95
9249	15/09/2020	07/10/2020	15	23	0.65
9250	17/06/2020	11/10/2020	115	117	0.98
9251	19/06/2020	11/10/2020	115	115	1.00
9255	14/07/2020	11/10/2020	85	90	0.94
9256	14/07/2020	25/09/2020	72	74	0.97
9258	15/09/2020	19/09/2020	5	5	1.00
9259	14/08/2020	11/10/2020	59	59	1.00
9260	19/06/2020	11/10/2020	115	115	1.00
9263	17/06/2020	11/10/2020	76	117	0.65
9264	16/06/2020	10/10/2020	71	117	0.61
9265	17/06/2020	21/09/2020	97	97	1.00
9268	10/09/2020	14/09/2020	1	5	0.20
9269	15/09/2020	11/10/2020	21	27	0.78
9272	17/06/2020	10/10/2020	103	116	0.89
9273	17/06/2020	31/07/2020	45	45	1.00
9274	16/06/2020	11/10/2020	115	118	0.97
9275	15/09/2020	09/10/2020	3	25	0.12
9276	16/06/2020	16/06/2020	1	1	1.00
9277	17/06/2020	11/10/2020	80	117	0.68
9279	13/08/2020	06/10/2020	16	55	0.29
9280	10/09/2020	11/10/2020	31	32	0.97
9281	17/06/2020	29/09/2020	103	105	0.98
9282	19/06/2020	11/10/2020	115	115	1.00
9283	17/06/2020	12/08/2020	5	57	0.09
9284	14/07/2020	11/10/2020	69	90	0.77
9285	17/06/2020	06/08/2020	11	51	0.22

Plaice individuals were observed approximately 92 ± 48 m from the turbines, most frequently on the sand directly surrounding the SPL within about 25 meters from the turbine (Figure 9). Another smaller peak of detections occurred around 90 meters from the turbines. Fish-turbine distance was best described by a GAMM, revealing a diurnal pattern. Fish were closer to turbines during daylight hours compared to nighttime. During the day, fish were primarily detected on or near the SPL, while at night, higher densities were found on the surrounding sandy area.

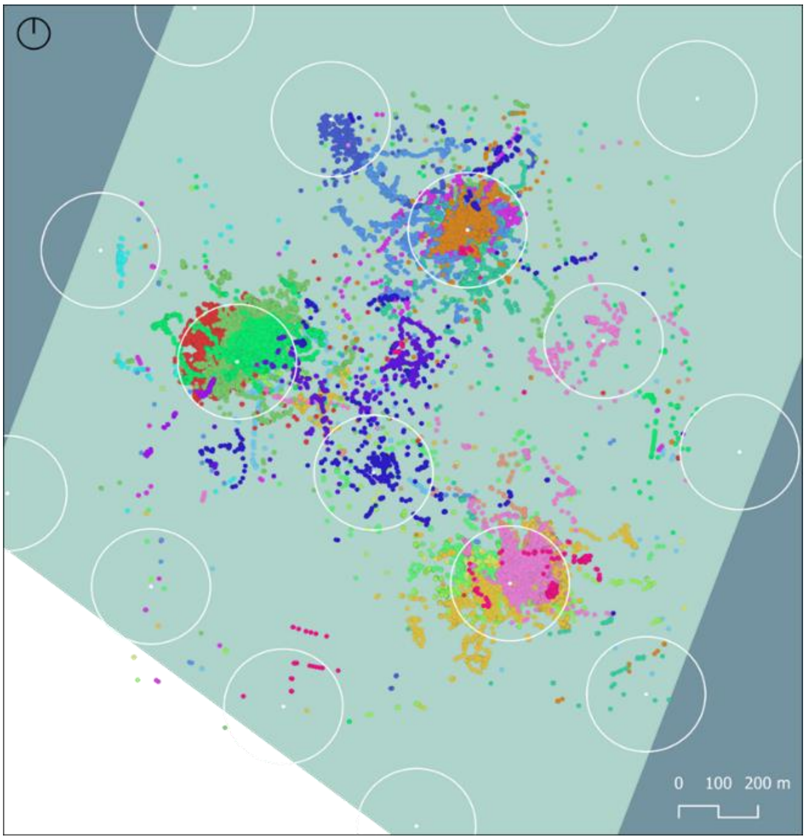


Figure 9: All estimated positions for the 21 fish that were present at least 20 days during the first study period (May 2020-October 2020). White dots represent the turbines at true scale (diameter = 5 m). White circles indicate a distance of 150 m from the turbine (distance at which the receivers were positioned around turbines B9, C8 and D9). Each colour represents the positions of a different fish.

Out of 31 tagged fish, eleven were detected again after a year, with seven fish remaining within the study area until the final two weeks. Fewer detections occurred during the winter months. Some fish exhibited absence for consecutive months, coinciding with plaice spawning (December-March), followed by their return during spring. For instance, fish 9277 was absent for over 111 days, reappearing twice on 5/02/21 at another receiver station outside the OWF area, then returning to Belwind OWF until the study's conclusion on 17/07/21.

5.4 Stakeholder questionnaire

The main observation is that there is a lack of communication or understanding between the stakeholders on OWFs and the likelihood of spillover. For fishers, OWFs are perceived a large threat to their business, as they lose a lot of fishing grounds. And due to the lack of scientific evidence, they are not convinced yet of potential spillover effects. The scientists and NGO representative, who are familiar with the research in the Belgian OWF zone, were more optimistic on spillover effects and see possibilities of an OWF zone as a fishery and/or conservation management area.

Windfarm effects on ecosystem and/or spillover?

A coastal fisherman and a fishery producer organisation were interviewed. The fishery consists of beam trawling and mainly targets sole, plaice, and brown shrimp, which are landed in Belgian ports. They are not allowed to fish within the OWF zone and are well aware of it. Before, there was only sporadic active in the area of the Belgium OWF zone, more specific at the southern border (but not in). During the interview, also some observations were mentioned, as in the area of the cable corridor, a decline in brown shrimp presence was precepted and at an OWF (Thames estuary), the disappearance of ray in the gully system. It is anecdotal information, but it illustrates that they are no sure of the effects that OWFs has on the marine ecosystem. At the other side, the fisher hopes that spillover will occur, but there is no evidence yet. He wants to believe in it, so that there is some positive effect possible (at least for a few species), but he is very unsure for the moment and not aware of any positive signal.

According to fishers, there was no apparent changes due to the wind farm. The wind farm seems to have no economic advantages for the fisherman and catches are not higher, no increase in revenue or number of fishers. This is also confirmed by the study on the fishery activity within the Belgian part of the North Sea (Verlé et al., 2023) and the scientists feedback. At the fishery policy department and producer organisation, they claim that the abundance of (flatfish) species have dropped within the wind farm, based on feedback they received from the sector. This is related to OWFs in general and was not specified for Belgium OWF zone.

The scientists, doing research in the area are observing effects, but are not yet sure of possible spillover. The biodiversity present changes (harder substrate associated species) as does the structural complexity of the seabed due to the artificial structures implemented. In the OWF zone, they found evidence of the presence of an artificial reef effect around the turbine foundations and scour protection. Their monitoring campaign also showed that the artificial reef effect extended to the soft sediment in between the turbines, resulting in higher densities of typical sessile fauna (e.g. mussels, anemones). They also found differences in diet, abundance increase and a change of habitat use of plaice (*Pleuronectes platessa*) within the OWF zone compared to outside. Plaice was found to actively use the scour protection for feeding during the day. They moved closer to the hard substrate during the day when feeding and moved further away during the night, possibly to rest in the surrounding sand. So, some species are becoming resident (or are visiting the area more frequently) since the implementation of the OWF, again associated to the artificial structures. The sea-bottom habitat differs also clear from the outside area, which has less species and structural habitat complexity. Scientists indicated that spillover can occur (likely), but that this spillover is not quantified yet. The studies show that there is a clear attraction of certain species, but if this led to increased biomass production for those species is still unclear.

The NGO is well aware of the OWF research, and their view is similar as the scientists. They are communicating that it will deliver healthy populations and habitats in the long run, which benefit fisheries. However, local fishers do not ‘believe' in the spillover effect and only see economic loss in closing areas. In addition, they do not ‘believe' that our North sea nature is in a bad condition, so they don't see the benefits in the long run from securing habitats and populations. In the questionnaire, the' NGO was the only respondent that perceives an economic gain for the fishery.

OWF as a conservation or fishery management area?

The fishery policy officer thinks that because in the wind farm no fishing or other activities are allowed, it could be seen as a conservation tool, but ideally if fishing activity is balanced and adapted, it should be possible to fish even within the OWF. The scientists think that the OWF zone has the opportunity to act as a fisheries management tool, specifically related to fisheries-induced selection effects for commercial species. However, this has not been quantified yet. We don't think it can act as a conservation tool, because no conservation targets are linked to the establishment of the area. Acting as fishery management tool, because the species have a place where they can grow to adulthood without the risk of being fished away, benefitting the species and the population. It is also a kind of conservation tool, as conservation and fisheries management always go hand in hand. There is no fishery without healthy populations.

The NGO representative thinks along the same line, and stresses that for Belgium, it can be a conservation tool in the first place, because our habitats (mainly gravel beds) are in such poor condition and OWFs can help to restore those habitats. In the long run, it will also have a positive effect on fisheries, because it keeps populations and habitats healthy. It could be useful to determine if spillover effects occur and if it helps fishers to compensate the economic loss of closing off some areas.

The fisherman hopes that OWFs can be used as a fisheries management tool, but he is very uncertain. He is also wondering if the OWFs are acting as a blockage for the migration of certain species. For example, sole become more and more surrounded by OWF areas in Belgian waters, so the migration of sole might be blocked. There is no tool for the moment, as long as there is no scientific evidence, to prove the advantages of OWFs and MPAs in terms of spillover. Nowadays, the fishery sector is frequently confronted with closures, which leads to high losses of fishing grounds and makes their future uncertain. In this way, the balance with food provision is not ensured, which creates more uncertainty for the fishery business. Fishers also believe that wind farms have a more negative impact on the ecosystem and their fishing activities than the regular MPA management. So, OWFs might have a positive effect on fisheries, but as long as there is not enough scientific evidence, the sector remains sceptical. Furthermore, fishers, together with fishery producer organisations and their management authorities, are not (or poorly) involved in any decisions related to the designation of OWF areas or measures taken within their boundaries, which leads to increased tensions between the fishery and offshore renewable energy sector. It is clear from this that a balance between food supply, renewable energy and conservation has to be defined, as they all have their own targets on Member State-, region- and EU-level.

6 DISCUSSION

The study finds that fishing activity at the edges of active OWFs is largely representative of edge effects. While there was a reduction in fishing effort within Belgian OWF concession areas during turbine construction, the Belgian and Dutch beam trawl fleets showed a "business as usual" approach regarding fishing effort and landings in the southern North Sea. However, the aggregated grid cell approach might have obscured potential edge effects. For more offshore wind farms, slight attraction towards the edges was suggested. During construction phases, reduced fishing effort was observed in the immediate surroundings of certain OWFs. Catch rate trends of target species, particularly sole, remained consistent in the presence of OWFs. Yet, there were indications of increased catch rates for plaice in the vicinity of certain OWFs, aligned with monitoring results that demonstrated increased plaice densities within OWFs. Notable changes in fishing practices occurred between 2011 and 2022, including the introduction of pulse trawl vessels and shifts/loss in fishing grounds due to the fully operational OWF from 2020 onwards. Despite small changes in fishing patterns near operational OWFs, **the impact on fishing activities seems modest, indicating adaptation to the new situation, and potential attraction to OWF edges**. Fishers kept fishing at the edge of the OWFs as long as possible (see Figure 2), but in the end the entire area became lost as a fishing ground. In the overall effort and landings, we currently do not observe any change that could be linked to this loss. It was probably other factors (i.e. pulse fishery ban, fuel crisis, covid crisis) that are causing changes in effort and landings in period 2019-2022 (Verlé et al., 2023). However, the effects on fisheries might become more pronounced with the planned further expansion of operational OWF zones. **Further investigation is required to understand if the potential benefits of OWFs as nursery or feeding grounds for targeted fish species will contribute to healthier fish stocks.**

At the Belgium OWF, dedicated monitoring on the epibenthic and demersal fish community in and around OWFs has been going on since 2005 to evaluate the potential 'refugium effect' and 'artificial reef effect'. This monitoring, according to a BACI design, showed that **soft sediment epibenthos and fish assemblages in between the turbines underwent no drastic changes due to the presence of the OWFs** at mid/longer term. There are **changes post-construction, with even a much higher abundance/biomass of certain species**, but this seems to normalise afterwards. In general, the assemblages were mainly structured by temporal variability due to changes in temperature and climate indices, i.e. North-Atlantic Oscillation and Atlantic Multidecadal Oscillation, and this degree of change is proportionally much larger than the local effect of the present OWF areas. Nevertheless, some **significant secondary effects could be clearly related to the presence of the OWFs** pointing to an expansion of the OWF effect beyond the immediate vicinity of the turbine on two fronts: (1) an expansion of the reef effect, and (2) signals of a refugium effect.

Expansion of the reef effect is suggested through the appearance of an increased number of hard substrate-associated species (e.g. *Pisidia longicornis, Cancer pagurus, Dicentrarchus labrax*), mainly by the significant increased abundances of blue mussel *Mytilus edulis* and anemones *Anthozoa sp.*, two species dominating the epifouling communities on the turbines. Although densities were still low, they could increase the heterogeneity in the soft-bottom sediments in between foundations in the future. First signs of a refugium effect were delineated based on the slight, but significantly, increased fish densities (*Callionymus lyra, Buglossidium luteum, Echiichthys vipera and Pleuronectes platessa*) inside the C-Power wind farm. This is probably related to a combination of fisheries exclusion and increased food availability. More pronounced effects were found for C-Power than for the more offshore Belwind OWF, stressing that effects might be site-specific and that extrapolation of these findings to other OWFs should be done with care.

The effects of wind farms on epibenthos, demersal fish, and benthopelagic fish warrant ongoing monitoring with species-specific focus. A more species-specific focus was implemented in the OWF monitoring in Belgium on plaice, based on acoustic telemetry. The findings of the acoustic tagging study reveal that **plaice exhibits high residency within a relatively small OWF area and displays specific spatial and diurnal movements**. The fish tend to stay close to the turbines, particularly around the SPL situated approximately 25 meters from turbine foundations. Diurnal patterns show that plaice are more frequently detected on the SPL during the day, suggesting feeding excursions towards this area. This behaviour aligns with plaice's opportunistic feeding habits and reliance on visual detection of prey (Gibson et al., 2015). During winter, plaice migrate away from the OWF, likely towards spawning grounds in deeper waters (Solmundsson et al., 2005). However, over **30% of tagged fish return to the study area after spawning, indicating high site fidelity**.

The study concludes that OWFs provide plaice with protection during the feeding season, primarily due to ample food supply around hard substrates. This protection might enhance local fish production. However, the effect wanes during spawning migrations when plaice leave the OWF, exposing them to fishing mortality. **The research highlights the potential of OWFs as protection areas for certain species but suggests that a larger, contiguous OWF zone might be even more effective in mitigating fisheries impacts**. The study also demonstrates the successful integration of data from different acoustic telemetry manufacturers and recommends incorporating archival tags to capture three-dimensional fish positions and support further research on movement patterns, including spawning behaviors and migrations.

Although clear convincing evidence of spillover effects could not be found within each of the studies, there were clear indications of positive wind farm effects and potential fish production within the OWF zone. To assess spillover effects more effectively within this study, a gradient design could have been adopted that included stations at different distances from the OWF. Whether the Belgium OWF zone will contribute to improving the state of the marine ecosystem by means of ecological or fishery spillover is not completely answered yet. This despite the very intense and in- depth monitoring programme within the area. Nevertheless, this has led to very valuable insights and is an example on how such research could be executed. For further investigating spillover, there is a need for an overall continuous monitoring, combined with species-specific investigations on their behaviour and migration would be recommended. The above data analyses show changes post-construction, based on BACI design, which is the best way to determine ecological and / or fishery spillover effects. This type of analyses is not yet repeated, because the focus in the further data analyses was more on describing changes within the farm, due to the possible ‘refugium’ and ‘artificial reef’ effects. It is planned to be done soon in the Belgium OWF program, based on a gradient BACI design approach, which should be most appropriate in determining spillover effects.

7 CONCLUSIONS

The Belgium OWF study demonstrates dynamic interactions between fishing effort, species landings, and LPUE in relation to OWF construction and operation, suggesting complex spatial and temporal patterns influenced by various factors, including fishing restrictions and fish behaviour. Fish behaviour and potential of using the OWF zone is species dependent. For two important commercial species within the Southern Bight of the North Sea, opposite effects were observed. For sole, the OWF area seems to create no additional benefits for the moment, whereas for plaice it creates opportunities, such as providing protection during the feeding season. Also, changes in the occurrence of several other epibenthic and fish species were observed based on long-term monitoring data, where ‘hard substrate’ species seems to extend their range of occurrence. These changes can be attributed to the ‘the refugium effect’ and ‘artificial reef effect’, created by OWFs. The changes were not consistent at the two wind farms, stressing that effects might be site-specific and that extrapolation of these findings to other OWFs should be done with care.

At the Belgian OWF area, benefits for certain species were observed, but not yet any clear evidence of spillover effects. Therefore, the effects of wind farms on epibenthos, demersal fish, and benthopelagic fish warrant ongoing monitoring with species-specific focus. Future edge effects, potentially due to fishing activities and closure benefits, could emerge as wind farm zones mature and integrate, influencing biomass and catch rate trends. Replication across wind farms and extended study durations are recommended to gain a deeper understanding of the evolving wind farm impacts and their implications. Specific for the monitoring and gaining evidence on spillover, a gradient sampling/data analyses, combined with species-specific research, is needed. The outcomes of the studies conducted within this Belgian OWF area illustrate this need clearly.

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7. CASE STUDY REPORT:

LYME BAY MARINE PROTECTED AREA

UK – THE ENGLISH CHANNEL


Fishing boats moored in the Lyme Regis Harbour, Dorset, England© Pixabay

Analysis of potential spillover effects around Lyme Bay Marine Protected Area

Catherine Whitley

MRAG Europe

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LIST OF ABBREVIATIONS

Term	Description
aMER	applied Marine Ecosystems Research
BACI	Before After Control Impact
BAP	Biodiversity Action Plan
BRUV	Baited Remote Underwater Video
CPUE	Catch Per Unit Effort
EFH	Essential Fish Habitat
FaSS	Fisheries and Seafood Scheme
IFCA	Inshore Fisheries and Conservation Authority
iVMS	Integrated Vessel Monitoring Systems
LBFCIC	Lyme Bay Fishermen's Community Interest Company
MCRS	Minimum Conservation Reference Size
MMO	Marine Management Organisation
MPA	Marine protected area
NGO	Non-government organisation
OC	Open control
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
SAC	Special Area of Conservation
SI	Statutory Instrument

1 EXECUTIVE SUMMARY

In this case study, a qualitative and quantitative approach was used to assess the Lyme Bay MPA potential spillover effects and help inform a methodology to identify potential areas where the designation of MPAs could lead to positive spillover effects. A combination of a literature review and stakeholder surveys were conducted to collect data from long-term monitoring studies and elicit perceptions from a range of stakeholders to understand the impact of the MPA on the marine environment and local fishing community.

The study's primary outcomes highlight an alignment between evidence obtained from the literature review and interview analysis. While it cannot be conclusively determined that spillover is currently occurring, there exists the possibility of future spillover into adjacent fisheries over an extended period. This conclusion is based on the changes in fish biomass within the MPA showing a much greater increase over time, relative to unprotected sites, indicating potential spillover effects could be detected with extended monitoring. This is supported by the stakeholder surveys which reflected general agreement that there is a high likelihood that spillover is occurring, informed by the increased number and diversity of epibenthic reef species and associated mobile fauna within the MPA, as well as changes in fisher catch composition. However, uncertainty prevails whether these changes are attributed to the MPA or external factors such as climate change, national legislation adjustments, or natural fish cycles.

Regarding MPA management, contrasting perspectives emerged among stakeholders, with fishery managers highlighting the MPA's role in conserving marine biodiversity, while certain fishers criticized its blunt approach and claimed increased fishing activity. Concerns focused on the lack of a comprehensive management plan and the MPA's location at the border of two managing authorities, resulting in regulatory disparities and an absence of a harmonized whole-site approach that impacted the MPA's effectiveness. The designation process through a Statutory Instrument was also criticized for potentially limiting management flexibility and leading to unintended consequences, such as increased fishing effort from static fisheries.

In summary, it is evident that the protection and enforcement of the Lyme Bay MPA is providing benefits to both conservation and fisheries, when compared to surrounding areas still open to bottom-towed gears. However, due to the paucity of research investigating spillover effects, there is a lack of evidence to confidently determine if spillover is occurring. Overall, the application of the Before After Control Impact (BACI) approach to assess spillover from the Lyme Bay MPA was successful. This was mainly due to the availability of baseline data collected before and after the MPA's designation, as well as the monitoring of reference sites outside the MPA. Recommendations for future assessments include monitoring additional reference sites farther from the MPA and ensuring equal numbers of sites in each treatment area to enable better data comparability.

2 BACKGROUND

Located along the south coast of England, Lyme Bay is an ecologically diverse marine area renowned for its unique underwater geology and rich biodiversity. This expansive bay is characterised by highly varied seabed habitats and features of national conservation importance, such as reef habitats, sand and gravel banks, subtidal muds, submerged sea cliffs and rare chalk reefs. Three different types of reef habitat are found in Lyme Bay: bedrock reef, stony reef and biogenic reef- which are all recognised as priority habitats under Annex 1 of the European Union Habitats Directive 92/43/EEC. These reef features support a rich fauna of sessile species, most notably pink sea fans (*Eunicella verrucosa*), a protected species under Schedule 5 of the Wildlife and Countryside Act, and nationally rare sunset coral (*Leptopsammia pruvoti*), both of which are priority Biodiversity Action Plan (BAP) species. Furthermore, Lyme Bay is one of only five areas where the sunset cup coral is known to occur in UK waters (Natural England, 2012). Important commercial species also reside in these reef habitats, including the edible crab (*Cancer pagurus*) and European lobster (*Homarus gammarus*). Together, the structural complexity and high species richness of Lyme Bay has resulted in the area being identified as a UK "marine biodiversity hotspot" (Hiscock and Breckels, 2007).

Along the coastline, Lyme Bay extends 2,460 km^2 from Portland Bill in east Devon to Start Point in west Dorset (Rees et al., 2010) and supports a thriving fishing community among the local ports of West Bay, Lyme Regis, Beer, Axmouth and Brixham. Prior to the establishment of the Lyme Bay MPA in 2008, the local fleet consisted of approximately 25 trawlers and scallopers measuring over 10 m, with similar numbers of under 10 m trawlers and scallopers, and around 90 vessels involved in netting, potting or "artisanal" fishing activities (Andrews, 2008). These vessels primarily operate within close proximity of their respective ports, particularly vessels stationed in the smaller ports, conducting their fishing operations predominately around the Lyme Bay Reefs (Andrews, 2008). Within the bay, King scallop (*Pecten maximus*) is a key fishery resource, primarily targeted by scallop dredging. Additionally, crab, lobster and whelks (*Buccinum undatum*) are commercially important to the local potting fishery. Most of the trawling is undertaken by otter trawls operating over mixed grounds targeting a diverse array of flatfish and demersal species, including sole (*Solea solea*), plaice (*Pleuronectes platessa*), skate and rays (primarily thornback ray *Raja clavata*), bass (*Dicentrarchus labrax*), pollack (*Pollachius pollachius*) and cod (*Gadus morhua*). These species are also targeted by netting and handline fisheries.

2.1 History of the Lyme Bay MPA designation process

In the early 1990s, increasing concerns regarding the damaging impact of bottom towed fishing gear on the seabed led to local petitioning for fishery closures to protect sensitive reef features. Led by the Devon Wildlife Trust, surveys highlighted the destruction of reef habitats caused by scallop dredging and in 2001, a collaborative agreement between environmentalist groups and local fishers voluntarily closed two small areas, measuring approximately 4.6 km^2 and 1.9 km^2, to bottom trawling and scallop dredging (Appleby, 2007). This Agreement was successful until the winter of 2005-2006 when increased dredging activity led to a Ministerial Stop Order under the Sea Fisheries Act 1967 to close 60 square nautical miles (206 km^2) to dredging to prevent further damage to mapped pink sea fan-dominated reef. In August 2006, the Secretary of State enacted a voluntary closure of four reef areas covering of 41.2 km^2, encompassing 90% of the habitat where pink sea fans occur (Devon Wildlife Trust, 2007, cited in Rees et al., 2010).

However, the decision to restrict the closure to 41.2 km^2, instead of the initially proposed 206 km^2, was deemed inadequate and a public consultation was undertaken in 2007 to propose additional protection. Over 100 substantive responses and over 7000 responses from conservation organisation campaigns were received, of which 70% were in favour of the full 206 km^2 closure (Defra, 2007, cited Rees et al., 2010). In June 2008, the Fisheries Minister announced the closure of 206 km^2 of the northern part of Lyme Bay, enacting statutory measures against scallop dredging and demersal trawling, while permitting other static forms of fishing, such as scallop diving, static potting and netting. The Lyme Bay Designated Area (Fishing Restrictions) Order 2008 came into force on 11 July 2008 through the Statutory Instrument (SI) 1584[14] (Mangi et al., 2011).

In 2010, Natural England put forward Lyme Bay as a candidate Special Area of Conservation (cSAC) under the European Habitats Directive (92/43/EEC) to protect Annex I reef features. The Lyme Bay and Torbay SAC was later established in 2011, overlapping and extending the SI to cover 312 km^2 (Figure 1). The combination of the SI and the SAC form the boundary of the Lyme Bay MPA.

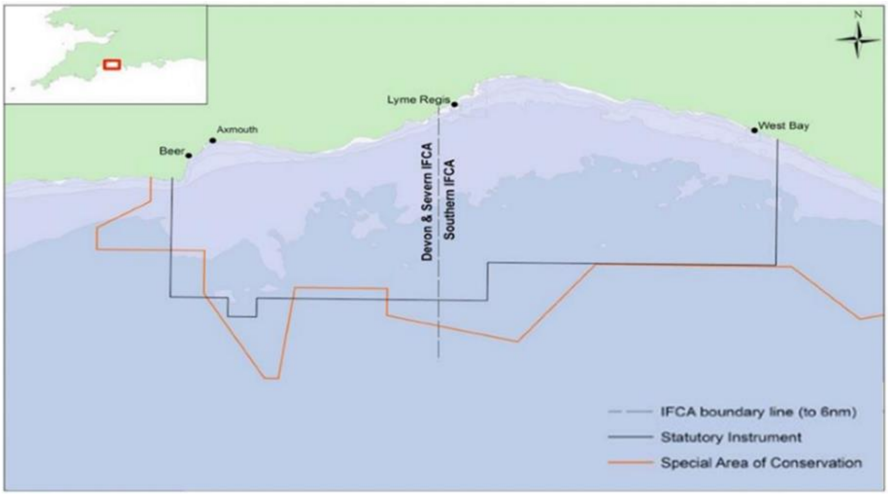

Figure 1. The Lyme Bay Designated Area (black line) and Lyme Bay and Torbay SAC (orange line) boundaries and associated ports. The dashed line indicates the boundary line between the two Inshore Fisheries and Conservation Authorities (IFCAs) (Sourced from Rees et al., 2019).

[14] https://www.legislation.gov.uk/uksi/2008/1584/contents/made

2.2 Management of the Lyme Bay MPA

The Lyme Bay MPA is managed by two Inshore Fisheries and Conservation Authorities (IFCAs), with the Devon and Severn IFCA district to the west and Southern IFCA district to the east (Figure 1). Despite both IFCAs having the same mandate to manage and protect designated reef features in the Lyme Bay MPA, these separate entities can create and enforce different byelaws (local regulations) within their designated areas of jurisdiction. For example, while both IFCAs introduced byelaws prohibiting bottom towed fishing gear across 236 km^2 of reef area in the Lyme Bay MPA (Southern IFCA, Devon and Severn IFCA 2014), differences in Minimum Conservation Reference Sizes (MCRS) for catch landings has caused contention within the fishing industry.

The lack in a harmonised approach to the management of the Lyme Bay MPA is exacerbated by the significant increase in unregulated static forms of fishing, which emerged shortly after the exclusion of bottom towed fishing gear. Without the worry of mobile vessels removing or damaging gear, the MPA became a magnet for static fishers operating pots and nets, resulting in more vessels and increased gear conflicts within and outside the MPA (Mangi et al., 2011; Rees et al., 2016). This escalation prompted the Blue Marine Foundation to form a collaborative working group in 2011, leading to the establishment of the Lyme Bay Consultative Committee. Comprising local fishers, conservation agencies, scientists, IFCAs, and Marine Management Organisation (MMO) representatives, this Committee devised voluntary best-practice measures. Among these measures is a Code of Conduct, limiting gear deployment and incorporating real-time monitoring systems (Integrated Vessel Monitoring Systems or iVMS).

While the Lyme Bay Consultative Committee is still operational, the most recent development has been the establishment of the Lyme Bay Fishermen's Community Interest Company (LBFCIC). Made up of 50 small-scale fishers from the four ports of Axmouth, Beer, Lyme Regis and West Bay, the LBFCIC provides an opportunity for all industries to come together and form a representative body to advocate for the local fleets. Through funding from the Blue Marine Foundation and Fisheries and Seafood Scheme (FaSS), administered by the Marine Management Organisation on behalf of Defra[15], the LBFCIC aims to unite the local fishers and work with the local IFCAs and Defra to support the sustainable management of Lyme Bay's marine resources.

2.3 Monitoring of the reef

Since the establishment of the SI in 2008, and subsequent designation of the SAC, the applied Marine Ecosystems Research (aMER) team at the University of Plymouth has conducted annual monitoring to assess the ecological effectiveness of the closed area (Attrill et al., 2011; Mangi et al., 2011). The focus of this research is to measure the 'recovery' of epibenthic reef fauna, defined as the protected areas in the SI and SAC becoming more similar to previously protected areas and less similar to areas which remained open to towed demersal fishing (Sheehan et al., 2016). This research assists in monitoring and evaluating the effectiveness of conservation measures and informing additional management strategies. However, the initial design of the survey limited the ability to measure spillover effects as the subsequent SAC designation encompassed the original control sites outside the SI. Consequently, there has been limited research specifically focussing on spillover effects from the Lyme Bay MPA. This indicates a notable knowledge gap that warrants increased attention to enhance our understanding of how MPAs may benefit fisheries through spillover.

[15] https://fass.marinemanagement.org.uk/Public/Home.aspx

3 AIMS AND OBJECTIVES

The aim of this case study is to investigate the occurrence of spillover effects within the Lyme Bay MPA. This was achieved by conducting a comprehensive literature review to determine the presence or absence of spillover effects in areas surrounding the Lyme Bay MPA. In addition, a series of stakeholder interviews have been conducted to gain an understanding on whether spillover is perceived to be occurring and its potential ecological and socio-economic impacts.

These aims and their associated research questions are listed below.

1. Conduct a literature review on the spillover effects of the Lyme Bay MPA.
   - Is existing data on spillover available from the Lyme Bay MPA?
   - Are there currently scientific research projects underway to quantify the extent, occurrence and magnitude of spillover from the Lyme Bay MPA?
   - What key factors or attributes of the Lyme Bay MPA could influence spillover dynamics?
   - Is there any research on the changes in temporal and spatial patterns of fish biomass after establishment of the MPA?
   - How effective are the current methodologies for assessing spillover effects and how could they be improved for future assessments?

2. Conduct a series of interviews to gain an understanding of stakeholder perceptions of spillover effects associated with the Lyme Bay MPA.
   - What level of knowledge do different stakeholders possess regarding the MPA regulations?
   - Is the MPA acting as a conservation tool or a fisheries management tool?
   - Have stakeholders observed a change in the temporal or spatial patterns of commercial stocks after the establishment of the Lyme Bay MPA?
   - Has the establishment of the Lyme Bay MPA generated any ecological and or socio-economic benefits to local fisheries?

4 METHODOLOGY

In this case study, a combination of a qualitative and quantitative approaches was employed to analyse the potential fishery and ecological spillover effects from the Lyme Bay MPA. For this case study, the methodology used involved both desk-based research (e.g. literature review) and conducting a series of stakeholder interviews and online questionnaires. The following sections provide a detailed description of each method and subsequent data analysis.

4.1 Study Area

The Lyme Bay MPA was chosen as a case study due to its unique marine ecosystem, ecological significance, controversial designation process and long-standing conflict between the local fisheries and conservation efforts to restore degraded seabed habitats while also sustaining a productive fishery. It is also important to note that the Lyme Bay MPA has been the focus of one of the longest monitoring projects in the UK, assessing the ecological effects and socio-economic benefits of removing destructive mobile gears to protect and aid the recovery of nationally important reef habitats and reef associated species, including key commercial taxa.

4.2 Literature review

First, an in-depth literature review was conducted to collect relevant information on spillover effects. The review followed a standard three-stage protocol: (i) collation and screening; (ii) extraction; and (iii) critical appraisal. Literature searches were conducted in Google Scholar, which has been shown to be useful for both peer-reviewed and grey literature, as well as broad searches to obtain information from government reports and competent authority websites. Searches used Boolean logic to combine terms for the Lyme Bay MPA and different topics. Two simple words, “OR” and “AND”, were inserted between each keyword. For example, “Lyme Bay” OR “Lyme Bay MPA” AND “spillover” OR “fish biomass” OR “fishery”. This resulted in each search generating outputs which included literature related to research conducted in the Lyme Bay MPA which focused on changes in fish populations, benthic community assemblages or impacts on the local fishery.

The results from the literature search were compiled and analysed to extract data on spillover from the Lyme Bay MPA. However, it soon became clear that assessing spillover effects was not a key research priority within the existing literature and there was a lack of available raw scientific data with which to conduct a quantitative analysis. Nevertheless, there was a substantial library on research which had assessed the recovery of sessile and mobile fauna within the MPA (impact), compared to areas outside the MPA (control), mainly focusing on fish abundance/ biomass and diversity of taxa. These data types were primarily collected using various underwater video systems, such as towed flying array systems and baited remote camera systems.

Using this secondary data, a comparative analysis was conducted to analyse and interpret the potential occurrence of spillover from the Lyme Bay MPA. Since the prohibition of bottom towed gear in 2008, consistent annual monitoring of the same sites, both within and outside the MPA, has occurred during the summer months, with the initial survey in 2008 serving as the baseline 'Before' data. Therefore, a before-after-control-impact (BACI) approach was used to compare the biomass before and after the establishment of an MPA (regarding the total biomass of the MPA and reference site), with potential spillover only occurring in three scenarios, as shown in Table 1. The data results from the literature will be compared against this table to indicate if spillover is occurring.

Table 1. Potential combinations of theoretic changes in biomass in the MPA site (Δ MPA) and in the reference site (Δ Ref) which indicate whether a conclusion can be drawn to indicate spillover is potentially taking place.

Δ MPA	Δ Ref	Scenario name	Biomass?	Protection?	Spillover?
10%	5%	Both increased, but MPA stronger	Increase	Yes	Potentially
5%	10%	Both increased, but ref. site stronger	Increase	No	Potentially
10%	10%	Mutual increased	Increase	Potentially	Potentially

4.3 Stakeholder survey

In addition to the literature review, a questionnaire was developed to assess the perceptions of key stakeholders on the potential spillover effects in their nearby MPAs. The questionnaire (Annex 4) comprised of open-ended and closed questions to elicit stakeholder views and experiences on the different aspects of this study. The open-ended questions aimed to capture stakeholder opinions on, for example, how aware the stakeholder was of the regulations and management measures of the MPA. The closed questions were statement-based and used Likert scale answer categories (such as: Strongly agree; Agree; Neutral; Disagree; Strongly Disagree) for the stakeholder to choose from.

The questions were grouped into four broad categories to encapsulate the key issues being studied. These included:

(i) Respondent information. The first section required basic information from the respondent, including their name, institution and the type of stakeholder category they belonged to.

(ii) Background information. The second section of the questionnaire gathered background information from the stakeholder to understand more about the respondent and their use of the MPA. Questions included knowledge of when the MPA was established, the type of restrictions in place and how long the stakeholder has been associated with the MPA either through research, fishing or managing it.

(iii) Fishery impacts of MPAs. The third section explored the respondent's perceptions of the socio-economic impacts of spillover from the MPA. Stakeholders were asked to state whether the designation of an MPA / area where fishing is limited has led to an increase in revenues for fishers, whether the fishing community in the area feel their fisheries livelihoods are more secure after the MPA was established, and the extent to which they believe spillover from the MPA has influenced the catch composition in adjacent fishing grounds.

(iv) MPAs as management tools. The fourth section of the questionnaire focused on the respondent's perceptions on whether MPAs are conservation or fisheries management tools. Stakeholders were asked to state whether their local MPA was acting as a conservation tool, a fisheries management tool or both. Other questions under this section required stakeholders to state their agreement / disagreement on whether the establishment of MPAs is an effective conservation strategy to support fish populations and commercial fisheries in their area. Respondents were also asked to indicate what factors they thought were contributing to spillover effects.

Four key stakeholder groups were targeted under this consultation including commercial fishers, fisheries managers and government authorities, scientists, and environmental non-government organisations (NGOs). Therefore, while the four sections of the questionnaire where the same, specific questions were included for each of the four respondent groups. Prior to the distribution of these questionnaires, the client provided feedback on the structuring and content of the questions. Once agreed, the questionnaire was set up as an online survey using LimeSurvey.

A stakeholder mapping exercise was conducted to identify key stakeholders and an initial email detailing the aims and objectives of the project was circulated. In total, 20 emails were sent to various stakeholder groups, including, but not limited to, the Devon and Severn IFCA, Southern IFCA and MMO (fisheries managers), scientists affiliated with the University of Plymouth; the Blue Marine Foundation (NGO); and the Lyme Bay Fishermen Community Interest Company (commercial fishers). Once initial contact was made, an offer of a one-to-one interview was proposed; either remotely via Microsoft Teams or face to face. Given the summer holidays and workload of stakeholders, every effort was made to accommodate each stakeholder's preference, including a brief trip to the local ports of Beer and Axmouth to speak to some of the commercial fishers.

The resulting qualitative data derived from the interviews was then analysed using comparative thematic analysis.

5 RESULTS

5.1 Literature review

Since the establishment of the SI in 2008, and subsequent SAC, long-term monitoring of the ecological effectiveness and socio-economic benefits of the closed area has been undertaken to measure the 'recovery' of epibenthic reef fauna (Rees et al., 2010; Attrill et al., 2011; Mangi et al., 2011; Sheehan et al., 2013a; Stevens et al., 2014; Sheehan et al., 2016; Kaiser et al., 2018; Rees et al., 2019; Davies et al., 2021; Davies et al., 2022). Over time, research on the closure of the Lyme Bay MPA to trawling and dredging has demonstrated significant positive impacts on the local ecosystem's recovery. Studies indicate that the reduction in collateral damage to habitat complexity has led to improvements in species richness, total abundance and benthic assemblage composition within the Lyme Bay MPA.

Within the literature, notable, observations reveal a resurgence in slow growing sessile species just three years after the closure, particularly in hydroids (229%), ross coral *Pentapora fascialis* (385%), branched sponges (414%) sea squirts (*Phallusia mammillata*) and pink sea fans (636%) (Sheehan et al., 2013a), as well as definitive evidence of significant increase in species richness, structural complexity of the seabed and body-size measurements of individual species compared to unprotected control sites still open to bottom towed fishing (Hinz et al., 2011; Sheehan et al., 2013a; Stevens et al., 2014; Sheehan et al., 2016; Kaiser et al., 2018; Davies et al., 2022). These sessile organisms are fundamental to the health and development of rocky reef habitats, capturing and recycling nutrients through filter feeding and producing planktonic larvae, further supporting higher trophic species such as fish and shellfish species (Sheehan et al., 2013a; Rees et al., 2016). Additional research has also observed sessile taxa (associated with reef habitat) colonising pebbly sand habitats within the Lyme Bay MPA, extending the 'known' boundary of the protected reef feature (Sheehan et al., 2013b; Pikesley et al., 2021).

In addition, a study by Davies et al. (2021) revealed a remarkable 56.9% increase in the number of taxa within the MPA between 2009 and 2019, in contrast to a less substantial 15.8% increase in non-protected control sites. While these results were just based on video analysis from baited remote underwater videos (BRUVs), a similar study by Davies et al. (2022), combined the results of BRUV and towed video data and demonstrated 38.9% increase in the number of taxa in the MPA (from 31.5 ± 1.09 in 2009 to 43.7 ± 2.16 in 2018: a) and a minimal decrease in the OC (from 26.2 ± 1.64 in 2009 to 25 ± 1.59 in 2018: a 4.8% decrease). Both studies highlight a significant increase in diversity within the MPA.

However, to effectively identify and quantify spillover effects, the primary types of fishery data suitable for potential analysis include fish abundance/biomass; larval biomass; fish size, weight and age; and fish movement patterns. The literature review revealed a noticeable paucity in spillover effect data from the Lyme Bay MPA, yet research into changes and potential recovery of fish abundance/biomass was available. To assess the area's recovery, prevailing literature predominately employed remote data collection methods such as visual detection surveys, operating high definition video within the MPA and in adjacent sites which remained open to fishing (Open Controls; (OC). Monitoring of sessile and sedentary species along benthic transects were conducted using towed underwater video systems referred to as "towed flying arrays," while BRUV systems were employed to sample reef-associated nekton species and mobile benthic assemblages (Sheehan et al., 2010, 2013a). The results of the data analysis from the literature are detailed below.

Total abundance (fish biomass)

Over the course of an 11-year study, the results of video analysis from a series of BRUV deployments reported the mean total abundance, calculated using MaxN, within the MPA had changed from 1.66 ± 0.09 in 2009 to 2.13 ± 0.09 in 2019, reflecting a 28.9% rise in total abundance (Davies et al., 2021). In comparison, within the OC, the total abundance shifted from 1.98 ± 0.04 in 2009 to 2.44 ± 0.1 in 2019, marking a 23.4% increase in total abundance (Davies et al., 2021). Based on these results, the difference in percentage increase indicate potential spillover effects could occur from the MPA into surrounding areas. However, for spillover to occur, it is crucial that the biomass of fish within the closed area is higher than outside it. Therefore, even though both sites showed a significant linear increase in fish biomass, the mean total abundance was greater in the OC and therefore spillover is unlikely at this time. Nevertheless, the increasing trend in total abundance was higher in the MPA, therefore, over time, there is the potential for spillover.

In the same study, Davies et al. (2021) investigated the change in total abundance of exploited fish over time in the MPA, relative to areas that remain open to bottom towed fishing. The indicator species included, but were not limited to, Ballan Wrasse (*Labrus bergylta*), Pollack (*Pollachius pollachius*), Small-Spotted Catshark (*Scyliorhinus canicular*), Sole (*Solea solea*), thornback ray (*Raja clavata*), Atlantic Horse Mackerel (*Trachurus trachurus*) and Pouting (*Trisopterus luscus*). After video analysis, the total abundance of exploited fish had increased inside the MPA by 370% (0.311 ± 0.09 in 2009 to 1.45 ± 0.05 in 2019), as well as within the OC by 420% (0.316 ± 0.13 in 2009 to 1.63 ± 0.17 in 2019) (Figure 2c). From these results, it can be concluded that even though the reference site showed a greater increase in total abundance, there remains the potential for spillover due to the overall increase in biomass.

Concurrently, the diversity of exploited fish (number of taxa) was also found to dramatically increase within the MPA by 430% (from 0.42± 0.12 in 2009 to 2.23± 0.18 in 2019) and the OC by 480% (from 0.28 ± 0.11 in 2009 to 1.61 ± 0.22 in 2019). This change over time was significant in both treatment areas, although Davies et al. (2021) observed a much greater increasing trend in the number of taxa within the MPA (gradient of 0.14) compared to the OC sites (gradient of 0.03) (Figure 2a). The study suggested the slower rate seen in the OC may be due to delayed 'spillover effects' from the MPA to the surrounding area, possibly driven by a combination of increased larval export and direct adult migration.

When investigating the difference in non-exploited fish, the indicator species included, but were not limited to, Gobies (*Gobiidae* spp.), Blennies (*Blenniidae* spp.), Whiting (*Merlangius merlangus*) and Poor cod (*Trisopterus minutus*). The results were very surprising as they demonstrated a significant linear decrease (3.3 %) in mean total abundance within the MPA (1.46 ± 0.09 in 2009 1.41 ± 0.1 in 2019) compared to the OC which exhibited a 37% increase in total abundance (1.14 ± 0.16 in 2009 to 1.56 ± 0.18 in 2019) (Davies et al., 2021). These results indicate the biomass of non-exploited mobile fish populations are decreasing within the MPA, but increasing within the OC. This scenario suggests spillover is not occurring but could be influenced by other drivers such as increased predation and competition with larger species (e.g. exploited fish) which may have decreased the area of favourable habitat to non-exploited fish within the MPA.

Interestingly for invertebrate species, there was a clear difference between the increase in total abundance of exploited and non-exploited species within the MPA, 110% and 37% respectively, compared to the outside the MPA, 85% and 0.47% respectively (Davies et al., 2021). Despite the greater increase in exploited invertebrates within the MPA, total abundance was significantly lower in the MPA compared to the OC, potentially due to greater fishing effort from the static fishery. However, it is interesting to note that for the main species targeted by static fisheries- whelks, brown crab and European lobster- there was no significant temporal change in total abundance, regardless of potentially higher fishing levels.

One of the drivers influencing the increase in total abundance of mobile species within the MPA could be due to changes in functional richness (variety and diversity of functional traits present within a given ecological community or assemblage) which reportedly increased by 64.6%, relative to the unprotected areas where it decreased by 1.85% (Davies et al., 2022). It is likely the increase in functional richness of the reef area, also known as Essential Fish Habitat (EFH), has contributed to the positive increases in mobile fauna over time, including the increases in exploited fish species targeted by the local fisheries (Davies et al., 2021). This highlights the protection and enforcement of the Lyme Bay MPA is providing benefits to both conservation and fisheries, when compared to surrounding areas still open to bottom-towed gears.

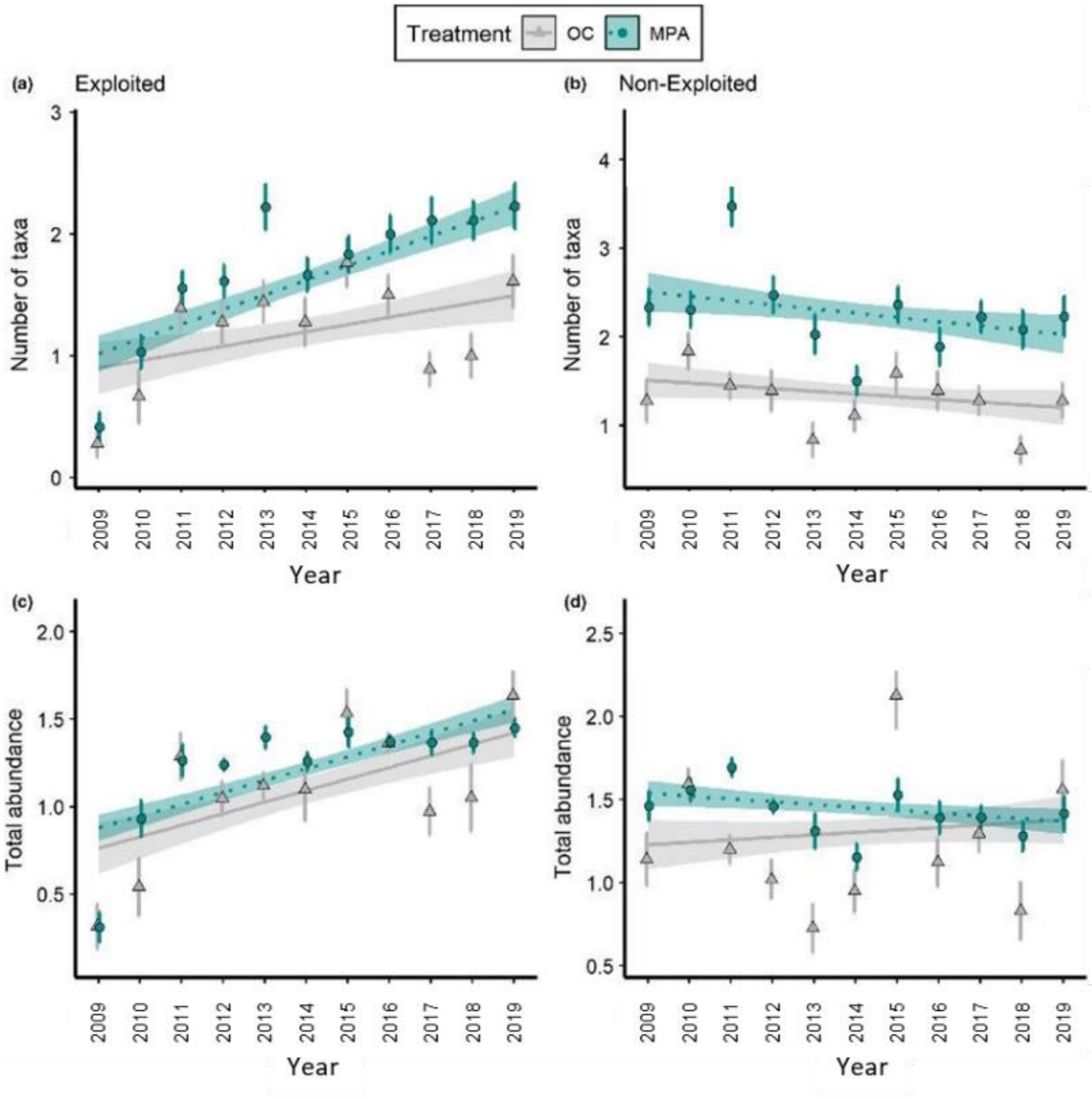

Figure 2 Number of taxa (a) and total abundance (c) of Exploited fish by year and treatments, and number of taxa (b) and total abundance (fourth root transformed: d) of non-exploited fish by year and treatments (marine-protected area [MPA]: blue circles, open controls [OC]: grey triangles). Lines and equations show linear regression equation coefficients. Points with errors bars show mean values and standard errors (Davies et al., 2021)

Catch and fishing effort (CPUE)

Changes in fishing activity is an important determinant of the success of an MPA demonstrating spillover effects. Therefore, in addition to comparing fish biomass before and after the establishment of an MPA, it is also important to consider the catch landings and fishing effort to analyse if the local fisheries have benefited from the presence of the MPA. Catch per unit effort (CPUE) represents the volume of catch obtained per unit of fishing effort and is commonly used as a proxy for fish abundance or biomass. However, it should not be used in isolation as other factors can have an influence on CPUE, such as seasonality, natural variability and fluctuations in market price.

In Lyme Bay, bottom towed fishing gear is prohibited within the SI and some parts of the SAC, covering an area of 236 km^2 within the MPA. The MPA is therefore recognised as a "partially protected area (PPA)" as demersal gear is still allowed in some restricted areas, as well as static fisheries, rod and line, scallop diving and other recreational activities. Shortly after the implementation of the Lyme Bay MPA, Mangi et al. (2011) assessed the socio-economic impact of the closure on the local fishing community. Initial results revealed the MPA had led to decreased incomes for displaced towed fishers, mainly due to increased travel times to fishing sites, longer fishing duration and lower quality of scallops harvested outside the MPA; and increased incomes for static fishers due to increased fishing effort (Mangi et al., 2011). For example, brown crab and lobster values and landing weights have increased within the Lyme Bay and Torbay SAC as a result of the increase in commercial potting effort (Rees et al., 2016; Rees et al., 2019).

Reports of increased fishing effort is corroborated by a recent study which observed a significant increase in the number of vessels and fishing trips (per month per vessel) of fishers using static gear inside and outside the MPA (Rees et al., 2021). Between 2005/6 and 2016/17, the approximate number of vessels per month increased by 7 (from 29 to 36) and 12 (from 40 to 52) for static gear inside and outside the MPA, respectively, while the number of fishing trips increased by 223 (from 58 to 281) and 185 (158 to 343) respectively, demonstrating a significant trend in increased fishing effort (Rees et al., 2021).

However, over time, Rees et al. (2021) reported static gear landings had decreased by 110 kg per vessel per month. Despite this, the value of landings had increased, represented by a £1,452 increase (per vessel per month) for vessels fishing inside the MPA compared to a £866 increase for vessels fishing outside the MPA (Rees et al., 2021). This is largely linked to catches of higher value species such as diver-caught scallops, with a 412 % increase in value, and crab and lobster landings from static potting, with a combined increase of 104 % in value. For net fisheries, landings of high value species such as lemon sole increased by 57 kg (5700%), resulting in a £285 increase (4750 %). Across the study region, the landings and value of whelk were highest, yet experienced a 37 % and 0.48 % decline in landings from within and outside the MPA respectively, while the value marginally increased by 4 % and 13 %, respectively.

Following the SI designation in 2008, there is a corresponding increase in mobile demersal gear effort outside the MPA. This increased effort raised the average value of landings by £2,231 per vessel per month during 2004/05–2007/08 and 2014/15–2016/17. Although the value of landings for vessels using mobile gears outside the MPA has shown some return, reaching £9,021 per vessel per month for 2016/17, it is still below the peak landings values reached prior to the SI closure (£15,311 per vessel per month) in 2005/06 (Rees et al., 2021). This is largely due to the loss of scallop grounds from within the MPA which has led to a 65% increase in weight and 136% increase in value from scallop landings outside the MPA.

5.2 Stakeholder survey

In total, 9 in-depth interviews were conducted with stakeholders from three different stakeholder groups: fishers (n=5), fishery management authorities (n=1) and scientists (n=3). The questionnaire was divided into sections to provide a background of each respondent and their use of the MPA, as well as gain an understanding of their views on the fishery impacts of the MPA and whether the MPA is acting as a conservation or fisheries management tool. During qualitative analysis, the interview transcripts were assessed to identify common themes, topics and patterns in stakeholder responses. The results of the qualitative analysis deriving from these interviews is provided below.

Fishery Impacts

Changes in fish biomass

Since the establishment of the MPA, stakeholders agreed they had observed changes in fish abundance and species composition, with a more diverse range of species found inside the MPA than outside. In particular, one scientist observed the main difference was the recovery of the sensitive biogenic reef and associated reef species inside the MPA, as well as an increased number of higher trophic level animals, such as pout, wrasse and shark and ray species, which rely more heavily on protection from mobile demersal gear. A small number of fishers also agreed some species had become more abundant within the MPA, primarily lobsters, dover sole and black bream.

Outside the MPA, one scientist revealed the results from grab samples found very little evidence of infauna residing in the muddy sediment compared to protected areas. They explained there was no time for species to live there as the area is constantly being trawled.

Changes in catch and number of fishers (MPA impact)

Since the establishment of the MPA, fishers have noticed changes in their catch, such as increased lobster, scallop and dover sole landings while crab catches have decreased. This was also noted by the fishery managers which emphasised an increase in scallop diving and netting for sole within the MPA, as well as decreases in crab landings which has been reported channel wide. However, there is uncertainty as to whether these changes are resultant from the MPA or other external factors such as climate change, improved national legislation for lobsters (e.g. returning berried lobsters and v-notching) or increased quota for dover sole. Further, two fishers attributed changes in catch to the natural cycles of fish species stating, "fish run a cycle of 7-10 years so yet to see if closure caused that or if species are running their cycle".

During the interviews, there were mixed views on the changes in the number of fishers operating within and outside the MPA. While two fishers disagreed there had been a change in the fishing community, three fishers agreed there were more fishers than before the MPA was established. One fisher explained more local vessels from Hastings, Devon and Cornwall were coming into the bay, in particular to target whelks due to considerable economic incentives, while another fisher attributed the increase in fishers to the changes in council policy on commercial moorings which he perceived had led to a huge leap in commercial boats in Lyme Regis and West Bay. One scientist agreed there had been an increase in the number of fishers operating in the MPA, especially scallop divers; however, the fishery managers disagreed and stated there were generally fewer fishing vessels now from the local ports, although it was noted there has been an increase in nomadic static gear (netting and potting) since the MPA was established.

Economic and social benefits

There were mixed opinions on whether the fisheries in this area benefit economically by having the MPA. Out of five fishers, two agreed they had, also stating fish catches had increased, while three fishers expressed neutral opinions on the matter, with two fishers referencing the restriction on towed gear had allowed static pots and nets to increase and spread out due to increase gear security and reduced conflict. One fisher stated, "some would argue yes and some would say no. For scallop diving I would say yes, but I used to trawl so I would say no. I can't go outside as there are so many nets, no room out there to fish". Moreover, the three interviewed scientists strongly agreed there has been an economic uplift to the fishers since the MPA was introduced, based on the increase in fish landings and quality of catches, reduction in conflict between the static and mobile sector and increase in scallop diving which is now quite a successful industry since the MPA.

When asked to comment on the impact of the MPA on revenues, three fishers agreed the MPA had led to an increase in revenues due to fishers changing their modes of fishing and increasing the amount of gear they work. However, one fisher commented that the increase in effort was not as envisioned when the MPA was established, while another fisher stated, "I believe the designation of the Lyme Bay MPA through a statutory instrument through parliament was the wrong way to create this MPA as it limited the flexibility of the MPA management."

There was general agreement across all stakeholder groups that fisheries livelihoods were more secure after the MPA was established. However, one fisher expressed concerns about the dramatic increase in vessels and gear which could impact the sustainability of the fishery. In contrast, one scientist strongly agreed, stating that "if you carry on business as usual, the fisheries will collapse".

Role of the MPA: Conservation vs. Fisheries Management

Throughout the interviews, multiple respondents emphasised the dual role of the MPA as both a conservation and a fisheries management tool, safeguarding the marine biodiversity and subsequently benefitting the local fishing community. However, while the fishery managers argued it was mainly a conservation tool, some fishers argued the MPA was "too blunt an instrument to use as a conservation tool" and contested that "there's more fishing in here now than before". When queried about the effectiveness of MPAs as a conservation strategy for supporting fish populations and commercial fisheries in the region, fishers provided mixed responses, ranging from disagreement to agreement. One fisher firmly disagreed, stating, "No, it's not effective conservation, it could be, but it isn't." This was later refuted by the fishery managers asserting that the designation of the MPA safeguards the benthic habitats and associated reef species through protection from damaging fishing gears, fostering collaboration within the fishing community and prompting discussion on management, such as the Lyme Bay Fishermen's Community Interest Company. Despite bring together more stakeholders, one fisher countered that some authorities had not been involved, citing the example of local councils altering mooring allocation, affecting the area's conservation effectiveness.

When asked if certain areas of MPA should be closed to develop commercial fisheries, the fishery managers clarified, "We close fishing to protect features, not to develop fisheries. We hope as a benefit there will be positive impacts on the fisheries but we do not manage based on commercial fisheries." In contrast, all interviewed scientist strongly advocated for such closures, with one scientist emphasising the need to have reference areas to monitor the recovery and progress towards achieving conservation goals and objectives. Another scientist claimed, "an MPA that doesn't have any fisheries closures is a paper park. You must close or partially close the fisheries that were previously occurring. Unless you do some management there is no management." On the other hand, fishers strongly disagreed with the notion to permanently closed certain areas of the MPA, reasoning that "it's ludicrous, there are areas which don't get fished at all, sometimes for years, and then come into their own. Close them off and they'll become stagnant." This was supported by another fisher claiming that "closing areas entirely to fishing just doesn't work. Under belief it would harm fishing but also actual fish species as the ecosystem is a very delicate and balanced instrument…. closing the box could well have impacted species not to come back here." By closing one area, one fisher explained that everyone else will go to different places, resulting in an "overspill of fishing activity to where it is permitted". Another fisher agreed, stating, "None of it should be closed to fishing. It should be managed using flexible measures agreed by industry and regulators."

Currently, the MPA does not have a management plan and operates without a "whole site approach", instead management is based on the status and distribution of designated "features" within the MPA. The fishery managers noted, "The presence of the MPA and conservation advice provides a direction for fisheries management". However, many fishers advocated for the MPA to have a dedicated management plan. Reflecting on the MPA's location at the border of two managing authorities, fishers deemed it a failure due to disparities in regulations on each side. One fisher observed, "there's an artificial line that is just the side of Lyme Regis and we can do certain things and it's all different on the other side. It's ludicrous to build box with that in place. It should've been a larger box with its own management…. If it had its own management plan it could work as a conservation area, until then, it will never work." These views were shared by another fisher stating, "Dorset boats land smaller fish. The minimum landing size should be the same across the bay, government size. In Lyme Regis they have smaller catches because its legal. I don't fish in southern waters now."

In addition to the geographic positioning of the MPA, one fisher argued that the designation process of the Lyme Bay MPA was also a failure. They explained, "the designation of the MPA through a Statutory Instrument through Parliament was the wrong way to create this MPA as it limited the flexibility in the management of it." Consequently, when asked if the MPA was acting as a conservation tool or a fisheries management tool, the fisher replied saying, "This MPA was created by people who didn't know the area. I would say it is a tool to constrain the fishing industry. If it had been created with the fishing industry where it was done in a way where the management wasn't so rigid, then it would've been much better and more beneficial to the fishers and those that wanted to protect the marine environment within the area."

Spillover effect from the Lyme Bay MPA

Overall, the **majority of respondents concurred that spillover of fish or larvae export was taking place from the Lyme Bay MPA**, leading to benefits for adjacent fisheries to some extent. Notably, the interviewed scientists collectively expressed the likelihood of spillover, with two considering it "likely" and the third characterising it as "highly likely". They indicated that spillover had likely influenced the catch composition in nearby fishing grounds "to a large extent". This conclusion is drawn from observed increased in species abundance and diversity, with potential spillover benefits, as well as findings from socio-economic studies conducted by Rees et al., (2016, 2021). Three other respondents, spanning both stakeholder groups, also aligned with the view that fishery spillover was probable, while two fishers expressed uncertainty. Yet, opinions diverged when asked about the contribution of MPA spillover to the recovery of overexploited fish populations in adjacent fisheries. One fisher agreed it had to a "moderate extent", while two acknowledged to a "small extent", another admitted uncertainty, and a final fisher disagreed, asserting "not at all. Can't see how any of it has, outside is trawler ground which now claimed by netters. Nothing gets outside."

Regarding the **factors driving spillover effects, respondents identified key influences as "years since the MPA was established"** (n=3), **"size of MPA"** (n=2), **"protection level"** (n=2), **"dominant habitat"** (n=1) and "other" (n=1), specified as the absence of scallop dredging in the area.

However, through the interviews, it became evident that many stakeholders were unable to confidently address spillover-related questions, primarily because of the insufficient research available on the topic. This was supported by the scientists confirming that **investigating the spillover effects of the MPA was not a primary focus in their research. Nevertheless, there was consensus that spillover would be prioritised in future research** and it was noted that ongoing research featured acoustic telemetry and tagging projects aimed at monitoring the movement, habitat use and residency of commercially important species like brown crab and lobster. A scientist noted, "spillover is a paradox where we don't know if the fish are moving inside to outside or outside to inside. Species may have grown inside and recruited outwards, or there might be an inward flow because they are safer within the MPA. It needs dedicated research such as telemetry and tracking fish movements and duration in each place to prove it, usually a gradient of a fish from outside the MPA, within a buffer zone and inside, the MPAs but takes years to know for sure."

6 DISCUSSION

From the results, it can be concluded that the data presented in the literature review and findings from the analysis of the interview transcripts positively correspond to **suggest that potential spillover effects are occurring from the Lyme Bay MPA**. However, within the literature on the Lyme Bay MPA, it is evident there is a **paucity of research focussing on spillover effects**. Despite this, it was confirmed in the stakeholder surveys that current scientific research projects are underway to quantify the extent, occurrence, and magnitude of spillover from the Lyme Bay MPA and wider English Channel. This work is mainly collecting data on fish movements, using acoustic telemetry and tagging; larval biomass from plankton samples; and continuing to monitor changes in fish abundance/biomass within and outside the MPA using underwater video systems.

Within the existing body of literature, numerous studies have evidenced the ongoing recovery of the benthic reef environment, leading to a significant increase in the abundance and diversity of reef associated species. Notably, the proliferation of sessile species which are known to be more sensitive and essential for reef formation, such as erect branching sponges and ross corals, has been documented within the MPA (Sheehan et al., 2013a; Sheehan et al., 2013b). Moreover, increases in the biomass of mobile fauna, including commercially valuable taxa (~400 % increase over 11 years) and higher trophic-level species, have also been observed (Davies et al., 2021, 2022). However, for spillover to occur, it is crucial that the biomass of fish within the closed area is higher than outside it. Therefore, even though both sites (inside and outside the MPA) showed a significant linear increase in fish biomass, the mean total abundance was greater outside the MPA and therefore spillover is unlikely at this time. Nevertheless, the increasing trend in total abundance was higher in the MPA, therefore, over time, there is the potential for spillover. It is worth noting that the total abundance of exploited fish is still increasing within the MPA, despite continued fishing activities and heightened efforts in static fisheries. This indicates that the protection and enforcement of management measures within the Lyme Bay MPA provides both benefits to conservation and fisheries alike.

Notably, the exclusion of demersal gear has been a key attribute to the recovery of the benthic habitat, particularly the revival of biogenic reefs which are recognised as essential fish habitats. The resultant increase in size and complexity of the reef area within the MPA, relative to the observed decrease in reference sites outside the MPA, is likely to be significant driver in the positive increase of taxa abundance and diversity over time (Davies et al., 2021). Over time, the greater increase in fish biomass within the MPA, compared to the reference sites, indicates spillover effects could theoretically occur, subsequently benefitting the local fisheries outside the MPA, such as the displaced mobile demersal fisheries.

Within the stakeholder surveys, there was **general agreement across all stakeholder groups that spillover could be occurring**. While the scientists agreed that the number and diversity of fauna within the MPA had increased, the fishers also agreed that their catch composition had changed and there had been an uplift in the number of lobster, dover sole and scallop landings, but also a downturn in crab landings. However, there was uncertainty whether these changes could be attributed to the MPA or external factors, such as climate change, national legislation or natural fish cycles.

Interestingly, one of the key findings from the surveys was the difference in perception regarding MPA management. In particular, the absence of a dedicated management plan for the MPA and its location on the border of two different managing authorities raised concerns among the fishers, who deemed it ineffective due to disparities in regulations, such as enforcing different MCRS for catch landings. In addition, the IFCAs are bound by legal duties to focus on the recovery of designated "features" within MPAs, which then dictates fisheries management. The lack of a whole site approach of the Lyme Bay MPA, enforced by one entity, could be seen to hinder the effectiveness of the site due to the lack of a harmonised approach across the MPA. This is exacerbated by the fact the MPA was designated through a Statutory Instrument, which one fisher argued limited the flexibility of the management, closing the area to bottom towed fishing gear but subsequently increasing the fishing effort of static gear, particularly netting, inside the MPA.

7 CONCLUSIONS

Key findings from the study highlighted there is corresponding evidence from the literature review and interview analysis to suggest that over time, potential spillover effects could occur from the Lyme Bay MPA, with ongoing scientific research projects currently focused on quantifying the extent, occurrence, and magnitude of these spillover effects. Within the literature, numerous studies have demonstrated the exclusion of demersal gear has contributed significantly to the continued recovery of epibenthic reef species, including slow growing sessile species (ross coral and nationally important pink sea fans), leading to significant increasing trends in mobile fauna biomass over time, including commercial species exploited by fishing activities which are still permitted in the MPA. Using the BACI approach, greater fish biomass was observed outside the MPA, indicating that spillover is unlikely to be occurring at this time. However, the increasing trend in total abundance was higher in the MPA, indicating the potential for spillover effects to be determined over a longer period of monitoring. This is supported by the stakeholder surveys which reflected general agreement that spillover could be occurring, informed by increased fauna diversity within the MPA and changes in fisher catch compositions. However, uncertainty prevails whether these changes are attributed to the MPA or external factors such as climate change, national legislation adjustments, or natural fish cycles.

Overall, the application of the BACI approach to assess spillover from the Lyme Bay MPA was successful. This was mainly due to the availability of baseline data collected before and after, at annual intervals, the MPA's designation, as well as the monitoring of multiple reference sites outside the MPA to assess the recovery of the epibenthic reef compared to sites which remained open to towed demersal fishing. It is recommended that in future assessments of spillover, additional reference sites positioned further away from the MPA should be monitored to measure the magnitude of spillover, as well as using an equal number of sites in each treatment to ensure comparability of data between treatment areas.

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8. CASE STUDY REPORT:

THE FLAMANVILLE PROTECTED AREA

FRANCE – THE ENGLISH CHANNEL

Lobster pots (or creel) in harbour storage © Pixabay

Analysis of the potential spillover effects from the Flamanville Protected Area

Paul Mosnier

MRAG Europe

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LIST OF ABBREVIATIONS

Term	Description
BACI	Before After Control Impact
CNPE	Centre nucléaire de production d'électricité / nuclear power station
CORPECUM	Comité Régional des Pêches et Cultures marines de Bretagne / Brittany Regional Fisheries and Marine Cultures Committee
CPUE	Catch Per Unit of Effort
ISTPM	Institut scientifique et technique des pèches maritimes / Scientific and technical institute for marine fisheries
MPA	Marine Protected Area
MSC	Marine Stewartship Council
NGO	Non Governmental Organization
PPA	Partially Protected Area
SE	Standard Error

1 EXECUTIVE SUMMARY

The *Zone de Cantonnement de Flamanville* (also known as the *Zone de Cantonnement de Dielette;* hereinafter the Flamanville Protected Area), is a protected area situated on the Northwest coast of the Cotentin Peninsula in Northern France. The protected area was officially established in 2000 with the aim to stall the declining population of lobsters (*Homarus gammarus*) and ensure the livelihoods of lobster fishers in this area. The area has been the attention of scientists from French state research authorities who have performed long term monitoring studies here since the 1980s, reporting on various physico-chemical, biological, and ecological parameters. Much of the research has been linked to monitoring of impacts from the nearby *Centre nucléaire de production d'électricité* (*CNPE) de Flamanville*, one of France's largest nuclear energy plants, which interacts with the local marine habitat by using seawater in its functioning mechanisms and discharging effluents into the adjacent waters.

The Flamanville Protected Area is unique in its designation as it is characterised by a complete no-entry zone within a wider partially protected area. This area is thus unique in its characteristics and a good candidate to investigate potential spillover effects. The current study aimed to analyse these potential spillover effects and to assess impacts on local fisheries.

Given the relatively small size of the protected area (making it unsuitable for mobile pelagic and demersal finfish), and given its intended functioning in the conservation of lobsters, the authors focused their assessment of spillover impacts on four crustacean species (the European lobster *Homarus gammarus*, the brown crab *Cancer pagarus*, the velvet crab *Necora puber* and the spider crab *Maja brachydactyla*) which are of commercial importance and have been the subjects of the aforementioned long term monitoring projects. The impacts of spillover on the fisheries were assessed through (i) a comprehensive literature review and quantitative meta-analysis to identify potential impacts using several fishery data types, and (ii) stakeholder interviews to garner wider socio-economic perspectives.

Although results were highly species specific (in addition to their variability due to potential biases in the sampling methodology), the meta-analysis indicated the potential occurrence of spillover effects (in terms of species abundance) for the European lobster (*H. gammarus*) and the spider crab (*M. brachydactyla*). These and other results could not be corroborated comprehensively with stakeholder opinions due to low levels of survey engagement. While there is evidence to support a spillover effect on lobsters and spider crabs, this does not automatically translate to positive benefits to fishers. Economic returns clearly depend on more than just an increase in abundance of the stocks, so other factors which influence the catch price would need to be considered.

Overall, this case study provides clear evidence that assessment of spillover and impacts on local fisheries is highly species specific, and that interspecies interactions, knock on ecological impacts and wider socio-economic issues must be considered when assessing the effectiveness of marine protected areas.

2 BACKGROUND

2.1 Protected area designation

The *Zone de Cantonnement de Flamanville* (officially stated as the *Zone de Cantonnement de Dielette* under *Arête noº120/2019;* hereinafter the Flamanville Protected Area) refers to a protected marine area situated adjacent to the Flamanville nuclear power station (*CNPE de Flamanville*) off the Northwest Coast of the Cotentin Peninsula in the department of La Manche within the Basse-Normandie region in Northern France. This protected area was established in 2000 with the backing of the *Comité Régionale de la Pêche Maritime – Normandie* (the Regional Committee for Marine Fisheries – Normandy) following concerns about declining catches of lobster (*Homarus gammarus*) since the 1990s (Schlaich *et al.* (2019)).

According to the legal regulations, this enforcement order prohibits all forms of 'dormant' (pots) and trawling fishing methods, with only hand lining for fish allowed. The area is classified as an IUCN Type IV (Nature Reserve) and a partially protected area (PPA) (Schlaich et al*.,* 2019).

Within the boundaries of the PPA, there is a complete no entry and no activity zone (measuring approximately 1.2 km^2) located at the area most adjacent to the *CNPE de Flamanville*. Under *Arête No 51/2012*, all forms of activity (navigation, stationing, fishing, anchoring, swimming, scuba diving and all other nautical activities) are completely prohibited. This was likely implemented for security purposes given the proximity to the nuclear power station, ultimately providing an additional 'layer' of protection for any species in this area, thus acting as a *de facto* refuge (Haines et al., 2018).

Therefore, the Flamanville Protected Area is ultimately a PPA (area designated by the red outer line in Figure 1) containing an inner no entry zone and *de facto* Highly Protected Marine Area (pink area in Figure 1).

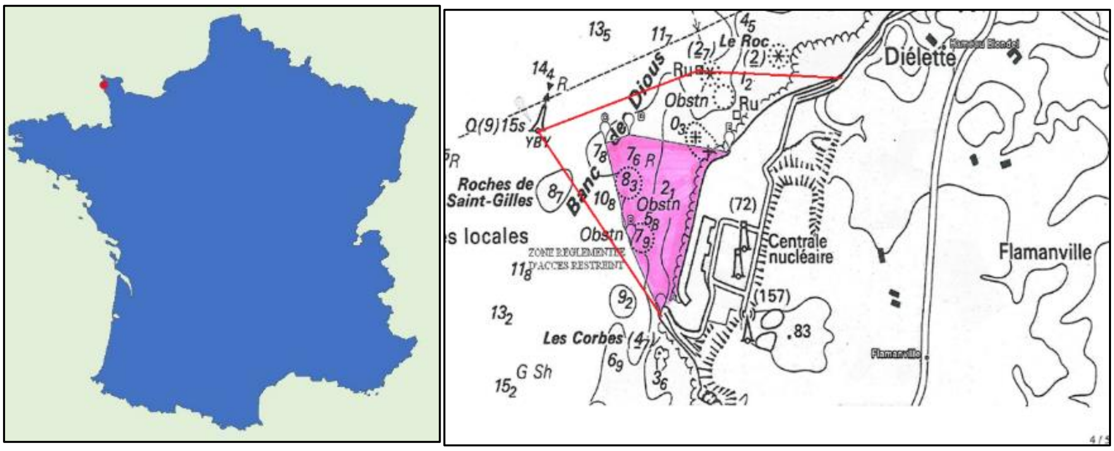

Figure 1. Location within France (left) and limitations (right) of the Flamanville Protected Area. The outer red line indicates the limits of the Partially Protected Area, while the inner pink area indicates the complete no entry/no activity zone. The figure is a combination of the delineated zones in *Arête No 51/2012* and *Arête 120/2019*[16].

2.2 Halieutic and ecological significance

The region has historically been home to one of the most commercially important shellfish and crustacean industries, contributing significantly to the total French annual landings of European lobster (*Homarus gammarus*), whelks (*Buccinum undatum*) and brown crab (*Cancer pagarus*). Other commercially important species in this area include velvet crabs (*Necora puber*) and the spider crab (*Maja brachydactyla*). The northwest coast of the Cotentin Peninsula is a particularly important lobster nursery, contributing to supporting of stocks in surrounding area, and falls under the Marine Stewardship Council (MSC) Certified lobster fishery (MSC Fisheries Standard v1.3), while the MSC certified whelk fishery also encompasses parts of this area[17]. Commercially important oyster and mussel farms are also located in the region.

The marine area is located immediately adjacent to, on the western seaward side of, the *CNPE de Flamanville*. The nuclear power station draws sea water into its facility which is used in cooling operations before the water is discharged into the sea again through an exit canal at its southeastern point. The power station also discharges a certain amount of waste through a dispersal pipeline located approximately 700m offshore to west of the power station. Despite treatment, certain amounts of radioactive and chemical wastes are discharged – constant monitoring ensure that discharge does not reach environmentally impactful levels. This monitoring program results in the publication of an annual report by scientists at Ifremer (the French state scientific research group), the *Surveillance écologique et halieutique du site électronucléaire de Flamanville* (with the latest publicly available report published in 2017, referenced throughout this report as Le Gac et al. (2018)). Monitoring of waters occurs frequently, and the latest data indicates that waters in the region are of 'good quality' (Agence Eau Seine Normandie, 2022),

[16]https://www.fnpsa-normandie.net/wp-content/uploads/2021/05/fbs-NwomcFEc7Z-wSYitJeRDZu8.png
[17]Although the Zone de Cantonnement de Flamanville is not technically located in Granville Bay (and as such would not come under the MSC Certified Granville Bay whelk fishery), the MSC notes that the certified fishery extends from Granville (to the south of Flamanville) and the Cap de la Hague (to the north of Flamanville).

with Le Gac et al. (2018) reporting no recorded effects of inputs from the *CNPE de Flamanville* on crustacean populations in the immediate vicinity of the region. This area supports a large diversity of flora and fauna including several cetacean species.

3 AIMS AND OBJECTIVES

The overarching objective is to provide a stronger understanding of whether the Flamanville Protected Area is generating ecological and/or economic benefits to commercial fisheries through spillover.

This report set out specifically with two main aims:

(i) Conduct a review of studies that have attempted to assess fishery spillover effects in the Flamanville region and analyse the suitability of indicators as evidence spillover effects.

(ii) Conduct stakeholder engagement surveys to gather opinions and perceptions of key stakeholders in the area. The success of MPAs will ultimately depend heavily on the engagement of stakeholders in the process of establishment and management of the protected zones, and thus it is critical to understand the direct (and perceived) impacts that these zones can have.

4 METHODOLOGY

This work consisted of two main parts including (1) a meta-analysis of data collected from publicly available scientific articles, reports and other grey literature, and (2) identification and surveying of key stakeholders.

4.1 Meta-analysis of monitoring projects and data related to spillover assessment

Ifremer, the French state marine research organisation, has been conducting sampling in this region since the 1970s, and many of the recorded parameters are applicable in the assessment of spillover. Two main studies (Le Gac et al., 2018 and Schlaich et al., 2019) were reviewed in this report (Table 1), and the data gathered was used to perform a meta-analysis to identify and assess potential spillover indicators in the study area.

Le Gac et al. (2018) is the most recent publicly available annual monitoring survey which firstly records ecological and environmental samples collected at 4 points (*Point canal, point rejet, point reference, point 3*) within and outside the protected area. Secondly, the report provides data on the size (measured as the cephalothorax length (mm)) and abundance (the catch per unit effort of individuals) of the crustaceans *Homarus gammarus* (European lobster), *Cancer pagarus* (the brown crab), *Necora puber* (the velvet crab) and *Maja brachydactyla* (the spider crab) at 15 different sites, as well as the larval abundance of *H. gammarus* and M*. brachydactyla*. Figure 2 below illustrates the sampling sites of this report.

Schlaich et al. (2019) report the same (but more recently updated) data as the second part of Le Gac et al. (2018) and consider an additional sampling point within the protected zone (point 16) (Figure 3).

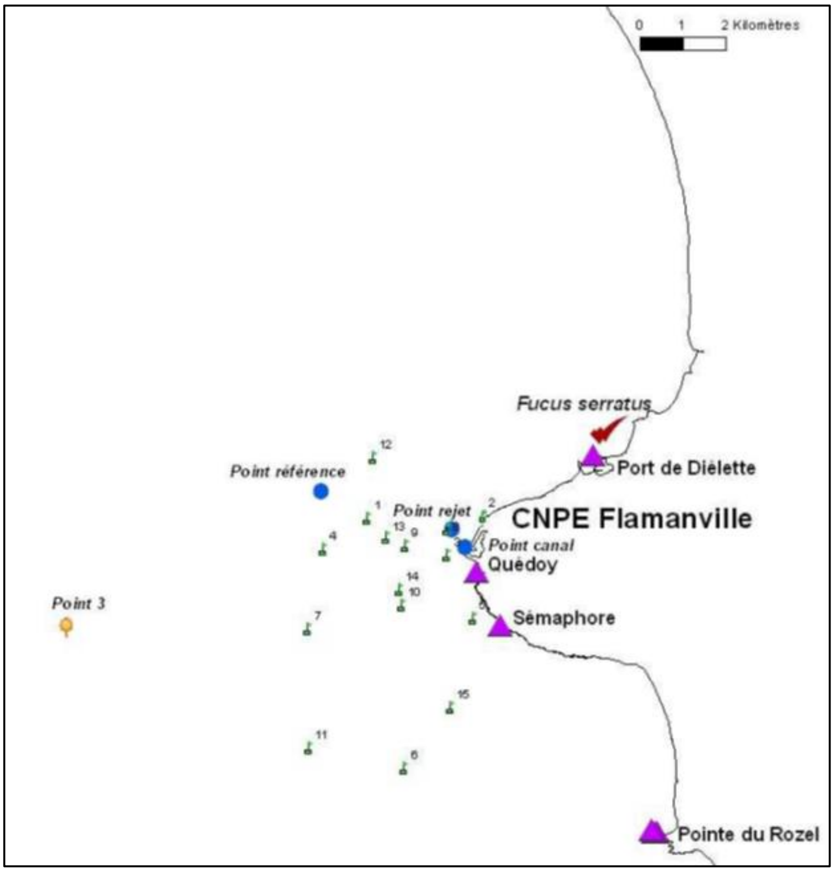

Figure 2. Illustration of the sampling sites of larval abundance (zooplankton), microbiology and hydrology (*Point canal, Point rejet, Point reference, Point 3*) and the crustacean sampling sites 1-15 (Figure adapted from Le Gac *et al.* (2018)).

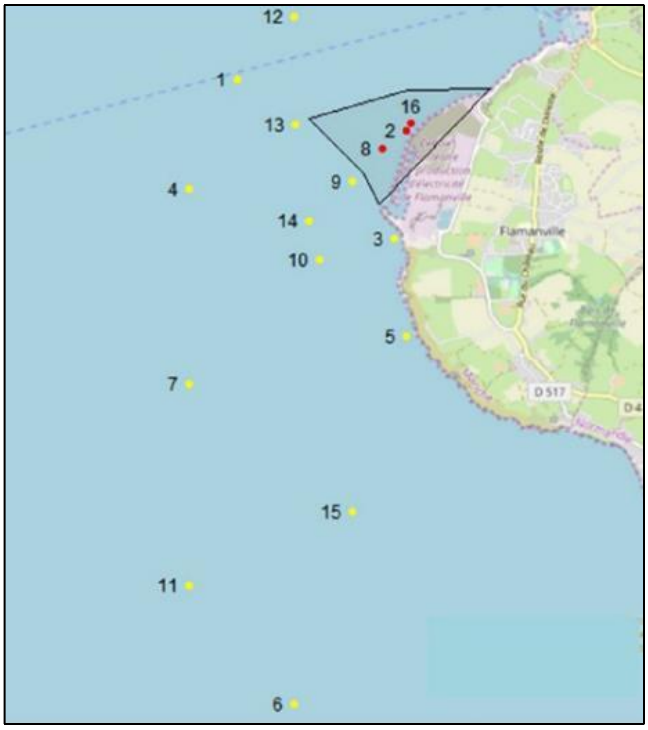

Figure 3. Locations (1-16) where crustacean samples were collected, noting the additional sampling point (point 16). The *Zone de Cantonnement* is delimited by the area surrounded by the black line (noting this is a rough outline of the area) (adapted from Schlaich *et al.* (2019)).

Table 1. Summary of the main data available and assessed as a spillover indicator in the case study region.

Fishery Data Type Analysed	Species	Source
Larval abundance	*Homarus gammarus* *Maja brachydactyla*	Le Gac *et al.* (2018)
Size (cephalothorax length, orbital or transversal width depending on weight (g))	*Homarus gammarus* *Cancer pagarus* *Necora puber* *Maja brachydactyla*	Le Gac *et al.* (2018) Schlaich *et al.* (2019)
Catch Per Unit Effort	*Homarus gammarus* *Cancer pagarus* *Necora puber* *Maja brachydactyla*	Le Gac *et al.* (2018) Schlaich *et al.* (2019)

Larval abundance

The four locations (*Point canal, Point rejet, Point reference, Point 3*) were surveyed twice a year since 1987, and since 1997 are now sampled four times per year. *M. brachydactyla* samples were collected using a submerged bongo net (following the methodology of Smith & Richardson, 1997) brought to the surface at a speed of 2 knots. *H. gammarus* were collected using a neuston net (following the methodology of Nichols *et al.* 1980) along a line pulled at a speed of 2 knots. All collected samples were stored in 2 litre flasks containing 0.9% formaldehyde solution for conservation. For each species, the number of larvae at each stage of development (3 for *M. brachydactyla*, 4 for *H. gammarus*) were counted under a microscope, and the number of individuals per volume of sampled water (extrapolated to number of individuals per m^3 of water) was calculated.

Population abundance (CPUE) and size

Size and abundance of the crustacean species have been reported in this area since 1987 during a twice-annual campaign (June and September) whereby 20-30 pots are dropped at each of the 16 points in Figure 3. Over a 4-day period, pots are lifted, and the number of each species is counted. For each species of crustacean, the number of individuals and size (mm) (cephalothorax, orbital or transversal length depending on the species) are recorded. The former is then used to calculate the Catch Per Unit Effort (CPUE; the number of individuals per 80 pots) and the latter to calculate the weight (g) using a length-weight formula developed by local fisheries biologists[18].

4.2 Statistical analysis

To compare data across the different areas (sampling site location within or outside the protected area), the time period (before or after the implementation of the protected area), the sampling point and the sampling campaign, a generalised linear model was adapted to the specific data. Zone and time period were considered fixed effects, while sampling point and sampling campaign were considered variables. For cephalothorax length (mm), an adjusted linear mixed model was used to assess variance. CPUE was analysed using an adjusted linear mixed model with a log link and negative binomial distribution. A Chi^2 test was conducted to test for statistically significant differences between samples before and after implementation of the protected area for each species, for both size (cephalothorax length (mm)) and CPUE. Data were analysed using R statistical programming software.

[18] This calculation was developed by biologists at the *Comité Régional des Pêches et Cultures marines de Bretagne (CORPECUM)*, the *Comité Local des Pêches de Blainville* and *the Stations ISTPM de Roscoff et de Ouistreham* in 1983 and has been used in the Manche Ouest region since. The equation is $W=aLc^b$, where W is the weight (g), Lc = cephalothorax length/width.

4.3 Before-After-Control-Impact assessment

Due to the data availability, a Before-after-control-impact (BACI) assessment could only be conducted using the abundance (CPUE) and size (cephalothorax length (mm)) as reported in Schlaich *et al.* (2019) for each of the four species. A BACI assessment using larval abundance and weight (g) was not conducted.

4.4 Stakeholder engagement surveys

Identification of stakeholders

Stakeholders were categorized according to four main groups: (1) commercial and recreational fishers, (2) fishery managers and government authorities, (3) scientists and (4) environmental NGOs. It was determined that this classification would cover a diversity of stakeholders and ensure different opinions were heard.

Overall, 7 scientists (from two different research organisations), 2 environmental NGOs, 2 commercial and recreational fishers (2 different representative groups through which fishers could be engaged) and 8 fisheries managers/governing authorities were contacted regarding the survey.

Development of the questionnaire

The questionnaire consisted of approximately 20 questions which were designed to elicit stakeholder views and experiences on different study aspects. Questions were structured in both open-ended and closed form. Open-ended questions aimed to capture stakeholder opinions more qualitatively, such as their general awareness of regulations and management measures of the protected area. The closed answer questions were generally required either a YES or NO response or required the respondent to select an answer from a Likert scale (e.g.: Strongly Agree/Agree/Neutral/Disagree/Strongly Disagree), which ensured that answers could be quantified. The questionnaire was translated to French and uploaded to an online questionnaire platform.

The questionnaire consisted of four categories, which were adapted slightly depending on the category of stakeholder (see Annex 4), and consisted of:

a. *Respondent information.* Name, institution, and the type of stakeholder category they belonged to.

b. *Background information*. Collected in order to understand more about the respondent and their use of the MPA. Questions included knowledge of when the MPA was established, the type of restrictions in place and how long the stakeholder has been associated with the MPA either through research, fishing, or management.

c. *Fishery impacts of MPAs.* Perceptions of the socio-economic impacts of spillover from the MPA. Stakeholders were asked to state whether the designation of an MPA / protected area has led to an increase in revenues for fishers, whether the fishing community in the area feel their fisheries livelihoods are more secure after the MPA was established, and the extent to which they believe spillover from the MPA has influenced the catch composition in adjacent fishing grounds.

d. *MPAs as management tools.* Perceptions on whether MPAs are conservation or fisheries management tools. Stakeholders were asked to state whether their local MPA was acting as a conservation tool, a fisheries management tool or both. Other questions under this section required stakeholders to state their agreement / disagreement on whether the establishment of MPAs is an effective conservation strategy to support fish populations and commercial fisheries in their area. Respondents were also asked to indicate what factors they thought were contributing to spillover effects.

Engagement of stakeholders

Key stakeholders were identified through the scientific and grey literature, word of mouth and general internet searches using the search terms "Flamanville MPA", "spillover Flamanville", "fisheries spillover Flamanville", "spillover Manche Ouest", "Flamanville Fisheries". Initial contact was established with stakeholders via email and later by phone. Potential respondents were provided with a summary of the project and were invited to participate in the survey through a video call. Upon confirmation, respondents were invited to an online conference call where the session was recorded so the answers provided could be reviewed. Participants were made aware of privacy policies and confidentiality agreements and were asked to state their permission for interviews to be recorded. The respondent was asked the questions and responses were noted by the interviewer. In cases where stakeholders did not have the availability or desire to participate in an online call, they were sent a link to the survey to complete directly.

5 RESULTS

5.1 Meta-analysis of monitoring projects and data related to spillover assessment

Population abundance

*Homarus gammarus (*European Lobster*)*

Results indicate an increasing trend of lobster abundances both inside and outside the protected zone since 2000 (Figure 4) and is corroborated by statistically significant increases ($p < 0.001$) in CPUE before and after implementation of the protected zone, both inside and outside across both sampling periods (Figure 5).

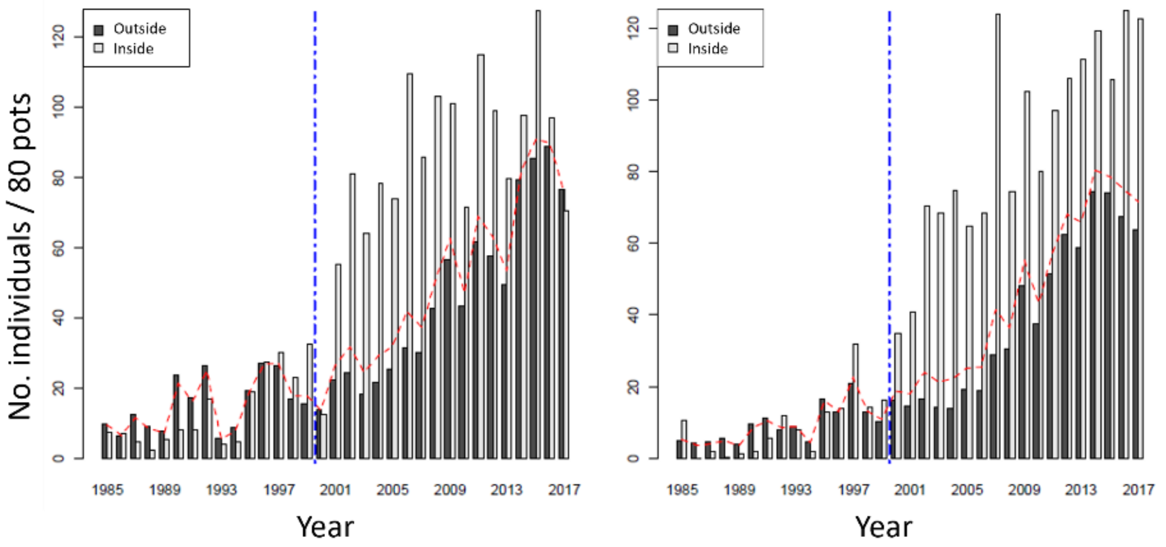

Figure 4. Abundance (CPUE) (number of individuals per 80 pots) of European lobsters (*H. gammarus*) between 1987 and 2017 inside and outside the protected area in June (left) and September (right). The red dotted line indicates total abundances, and the blue dotted line indicates the year of implementation of the protected area in 2000 (adapted from Le Gac *et al.* 2018).

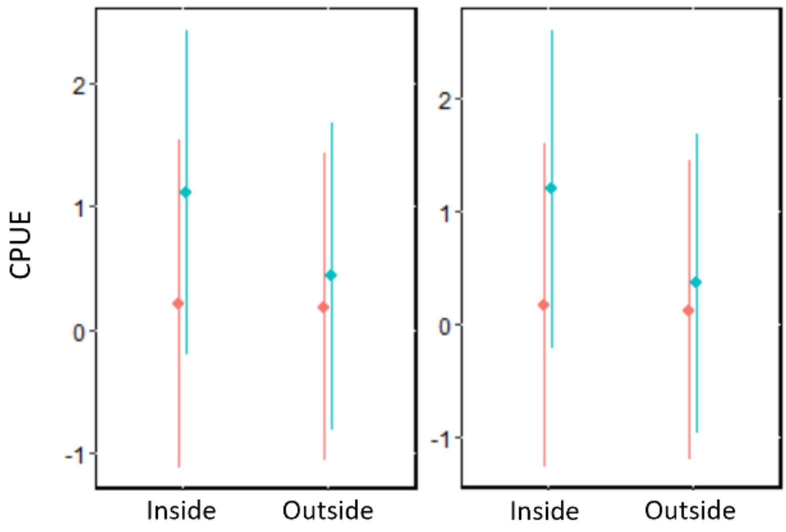

Figure 5. Abundance (mean CPUE ± SE) of European lobsters (*H. gammarus*) in June (left) and September (right) inside and outside the protected area sampling location before (red) and after (green) its implementation (adapted from Schlaich *et al.* 2019)

Cancer pagarus (Brown crab)

Figure 6 illustrates a much higher abundance of individuals outside and a marked decrease in abundance inside of the protected area following implementation of the protected zone, but results were not statistically significant (Figure 7).

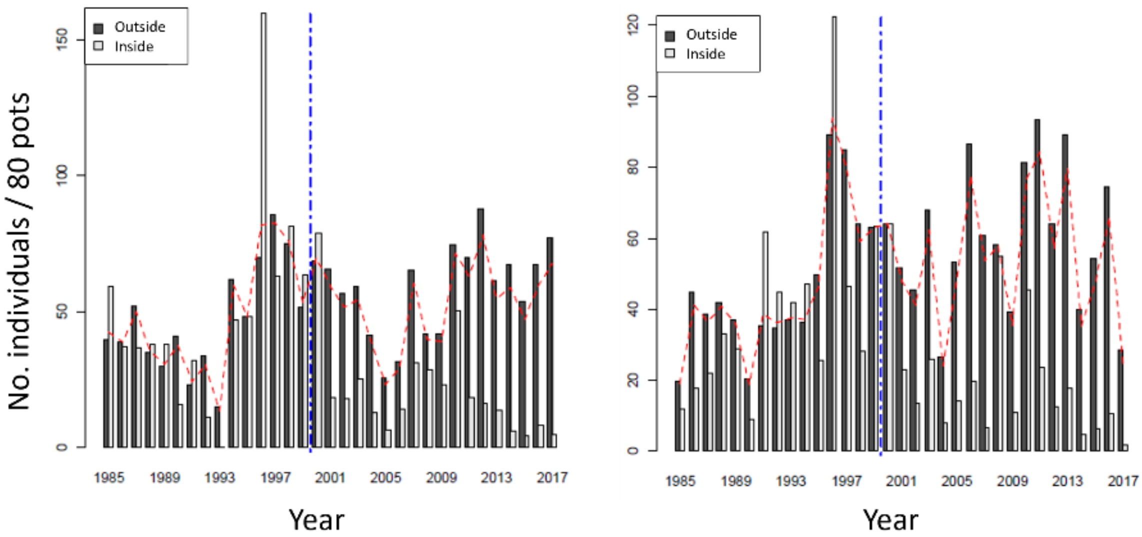

Figure 6. Abundance (number of individuals per 80 pots) of brown crab between 1987 and 2017 inside and outside the protected area in June (left) and September (right). The red dotted line indicates total abundances, and the blue dotted line indicates the year of implementation of the protected area in 2000 (adapted from Le Gac *et al.* 2018).

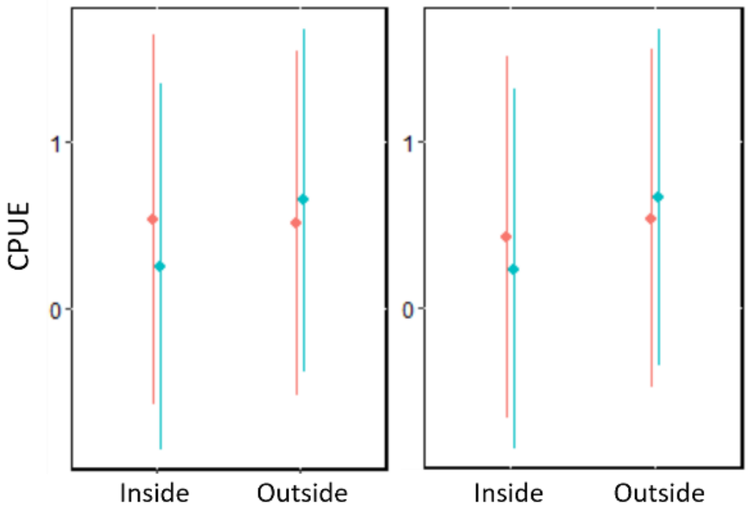

Figure 7. Abundance (mean CPUE ± SE) of brown crab (*Cancer pagarus*) in June (left) and September (right) inside and outside the protected area sampling site before (red) and after (green) its implementation (adapted from Schlaich *et al.* 2019).

Necora puber (Velvet crab)

Abundance of individuals has been declining since the implementation of the protected zone at sampling sites within the zone (Figure 8) with a slight non-significant increase in populations outside the zone (Figure 9).

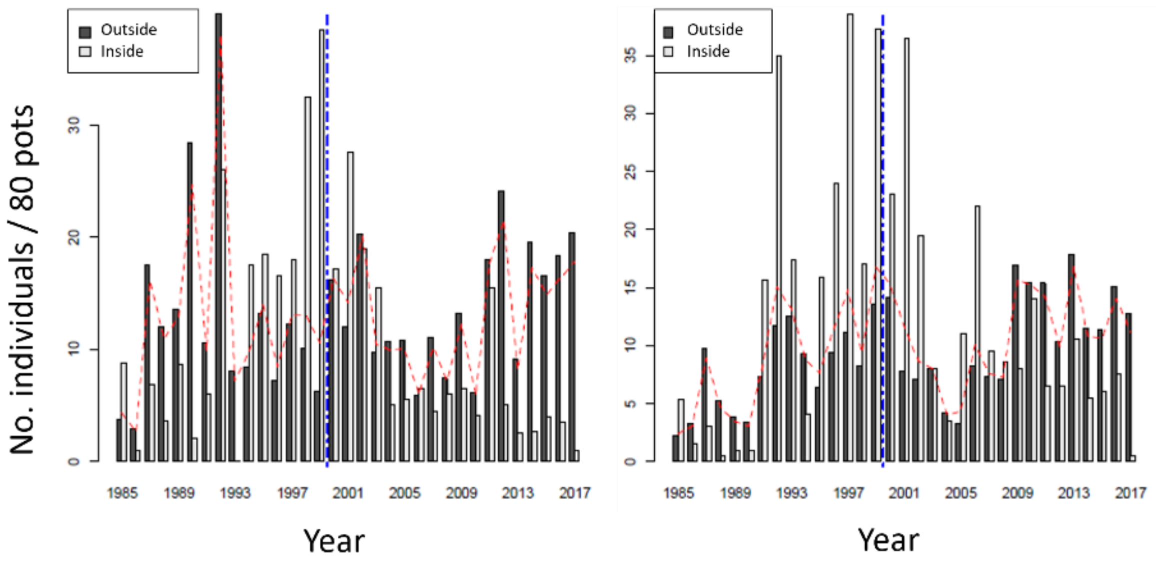

Figure 8. Abundance (CPUE) of velvet crab (*N. puber*) between 1987 and 2017 inside and outside the protected area in June (left) and September (right). The red dotted line indicates total abundances, and the blue dotted line indicates the year of implementation of the protected area in 2000 (adapted from Le Gac *et al.* 2018).

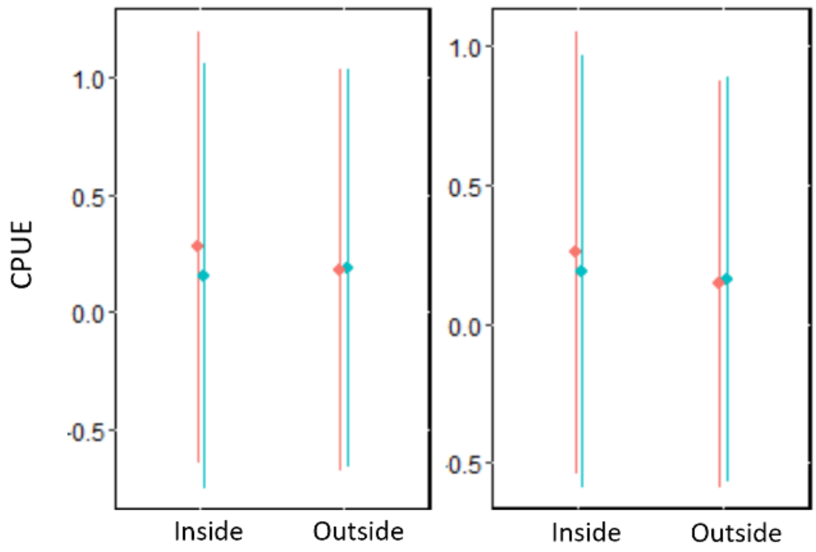

Figure 9. Abundance (mean CPUE ± SE) of velvet crab (*Necora puber*) in June (left) and September (right) Inside and outside the protected area sampling site before (red) and after (green) its implementation (adapted from Schlaich *et al.* 2019).

Maja brachydactyla (Spider crab)

Figure 10 and Figure 11 illustrate a general trend toward increasing populations of *M. brachydactyla* both inside (p < *0.*001) and outside (p < 0.001) the zone following implementation of protection.

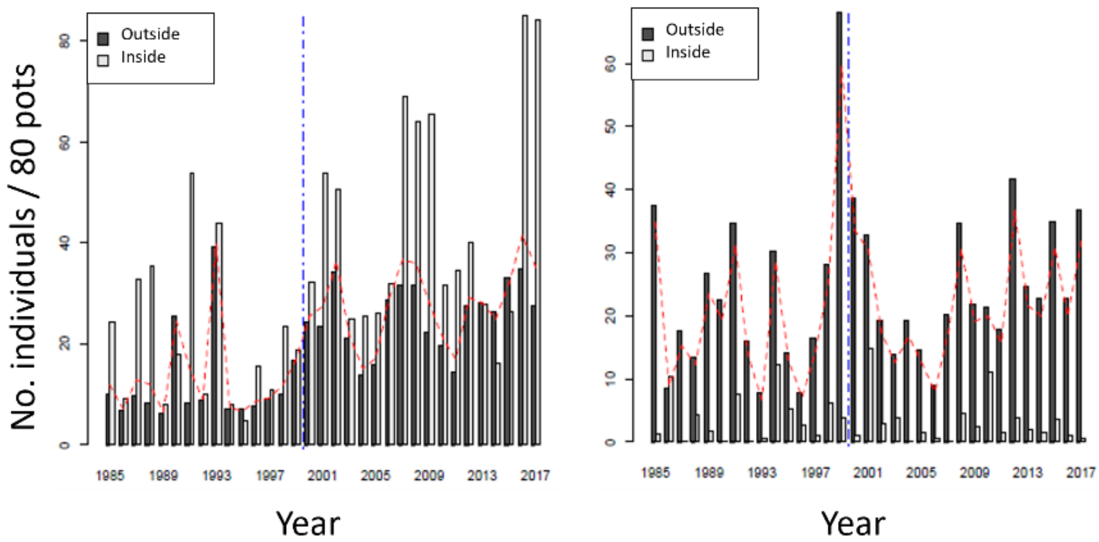

Figure 10. Abundance (number of individuals per 80 pots) of spider crab *(M. brachydactyla*) between 1987 and 2017 inside and outside the protected area in June (left) and September (right). The red dotted line indicates total abundances, and the blue dotted line indicates the year of implementation of the protected area in 2000 (adapted from Le Gac *et al.* 2018).

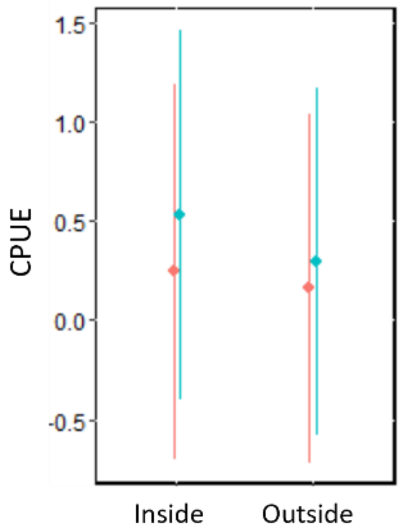

Figure 11. Abundance (mean CPUE ±SE) of spider crab *(M. brachydactyla*) in June inside and outside the protected area sampling site before (red) and after (green) its implementation (adapted from Schlaich *et al.* 2019).

Size

Homarus gammarus (European lobster)

Following implementation of the protected zone in 2000, average size (cephalothorax length (mm)) (Figure 12) of lobsters increased, but a decreasing trend in size is seen between 2006 – 2017 for all times of the year.

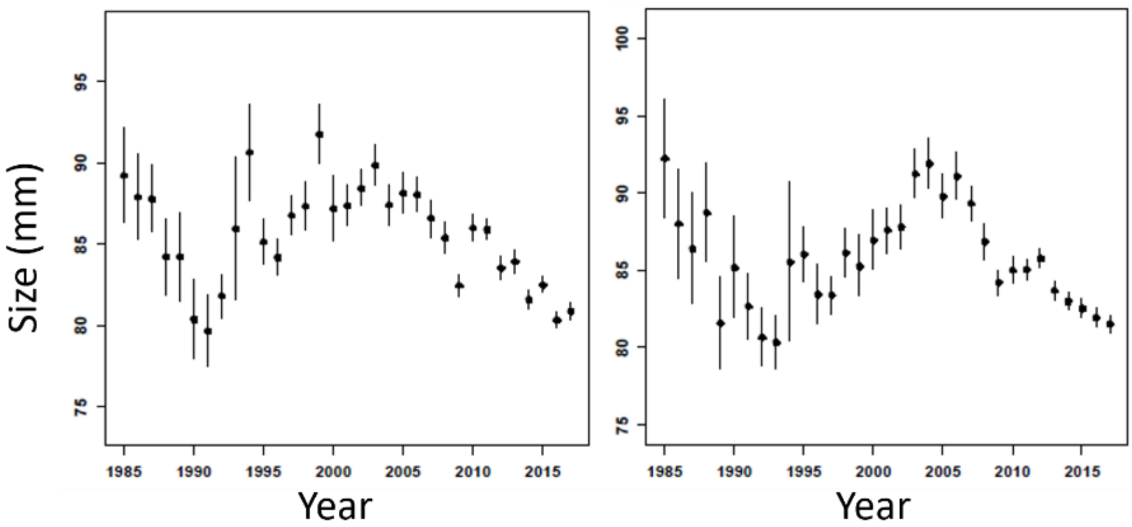

Figure 12. Average size (cephalothorax length (mm)) (mean ± SE) of European lobsters (*H. gammarus)* between 1985 – 2017 in June (left) and September (right) (adapted from Le Gac *et al.* 2018).

Despite this downward trend, the average size (cephalothorax length (mm)) of lobsters increased significantly inside the protected zone ($p < 0.001$), while it has decreased outside the protected zone across both months (Figure 13).

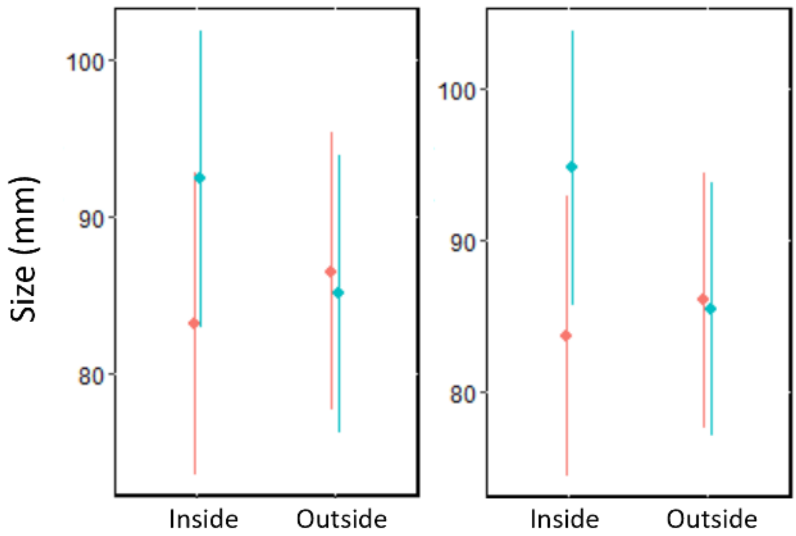

Figure 13. Average cephalothorax length (mm) (mean ± SE) of European lobsters (*H. gammarus*) in June (left) and September (right) inside and outside the protected area sampling site before (red) and green (after) its implementation (adapted from Schlaich *et al.* 2019).

Cancer pagarus (Brown crab)

Brown crab size (cephalothorax length (mm)) appears to have peaked between 1993 – 1995. Cephalothorax length appears to have been on a downward trajectory across all sampled months between 1995 and 2017 (Figure 14). Since the implementation of the protected zone, average cephalothorax length of crabs caught inside the zone has increased strongly, while outside the zone, average size has decreased (Figure 15), though non-significantly.

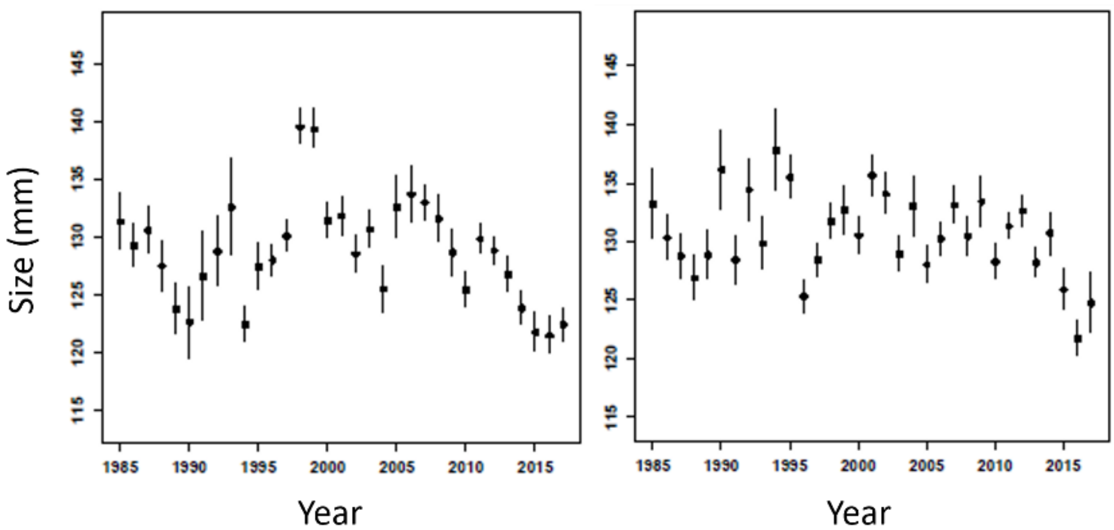

Figure 14. Average size (mean cephalothorax length (mm)± SE) of brown crab (*C. pagarus*) between 1985 – 2017 in June (left) and September (right) (adapted from Le Gac *et al.* 2018).

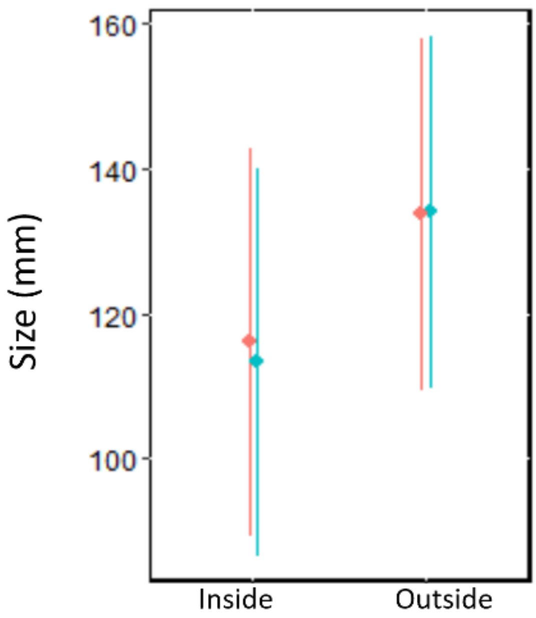

Figure 15. Average size (cephalothorax length (mm)) (mean ± SE) of brown crab (*C. pagarus)* in September inside and outside the protected area sampling site before (red) and green (after) its implementation (adapted from Schlaich *et al.* 2019) (data for June was not available).

Necora puber (Velvet crab)

Velvet crab size (in terms of cephalothorax length) (Figure 16) on average, has been decreasing since sampling began across all the sampling sites during both sampling periods. Significant decreases (*p* <0.001) within and outside of the protected area sampling site following implementation of protection are seen at both sampling periods (Figure 17).

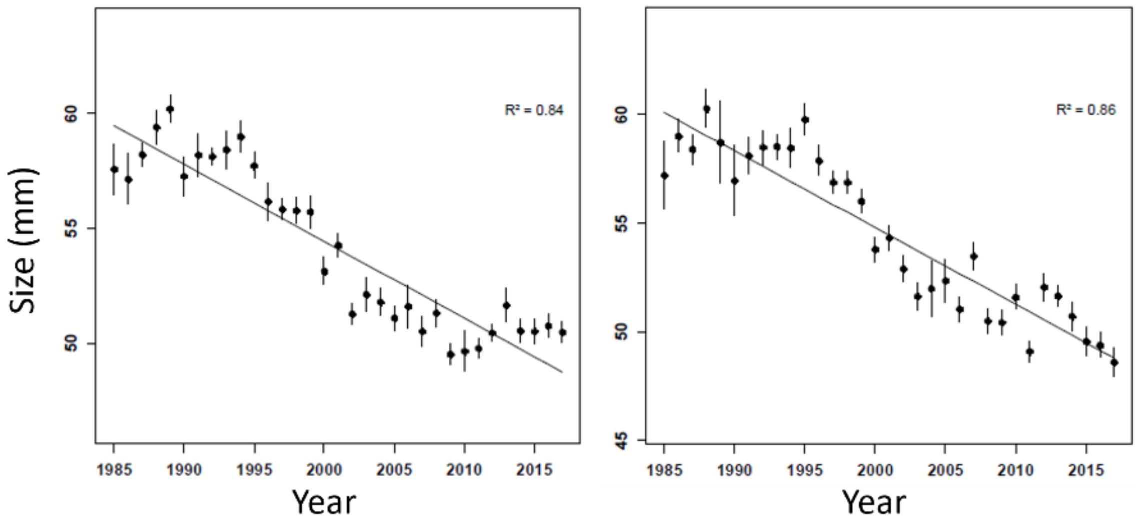

Figure 16. Average size (cephalothorax length (mm)) (mean ± SE) of velvet crab (*N. puber*) between 1985 – 2017 in June (left) and September (right) (adapted from Le Gac *et al.* 2018).

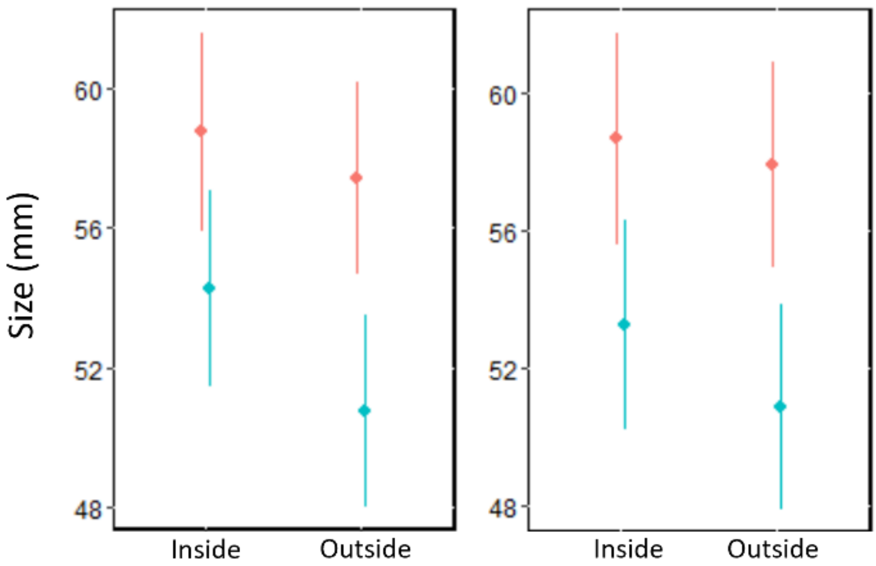

Figure 17. Average size (cephalothorax length (mm)) (mean ± SE) of velvet crab (*N. puber*) in June (left) and September (right) inside and outside the protected area sampling site before (red) and green (after) its implementation (adapted from Schlaich *et al.* 2019).

Maja brachydactyla (Spider crab)

Average size (cephalothorax length (mm)) (Figure 18) of spider crabs decreased between beginning of sampling times before levelling off and seemingly remaining stable until 2017, when the average size appears to have peaked again. Within the protected area sampling site, the average cephalothorax length has decreased significantly (for the sampling month of September at least) (p <0.001), while a smaller average decrease has also been seen outside the protected area following implementation of protection in 2000 (Figure 19)

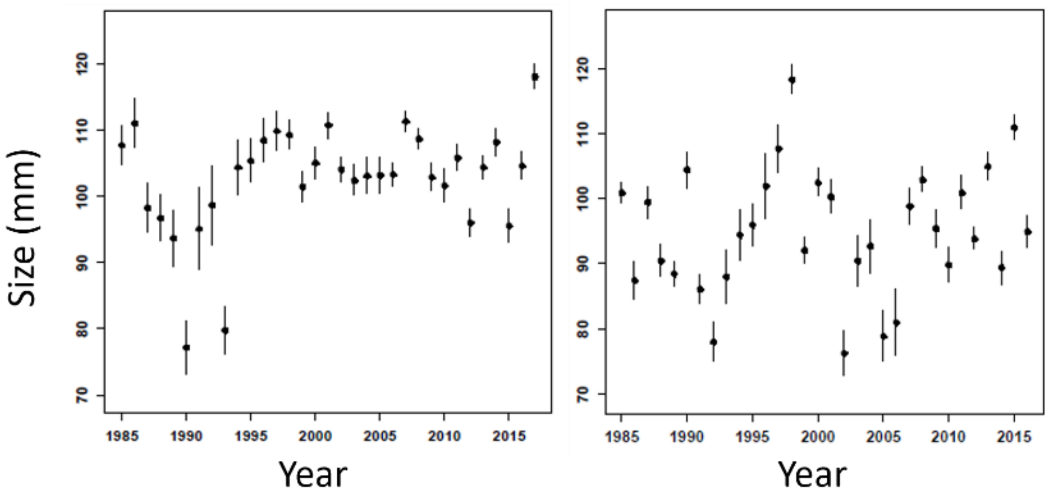

Figure 18. Average size (cephalothorax length (mm)) (mean ± SE) of spider crab (*M. brachydactyla*) captured between 1985 – 2017 across all sampling sites in June (left) and September (right) (adapted from Le Gac *et al.* 2018).

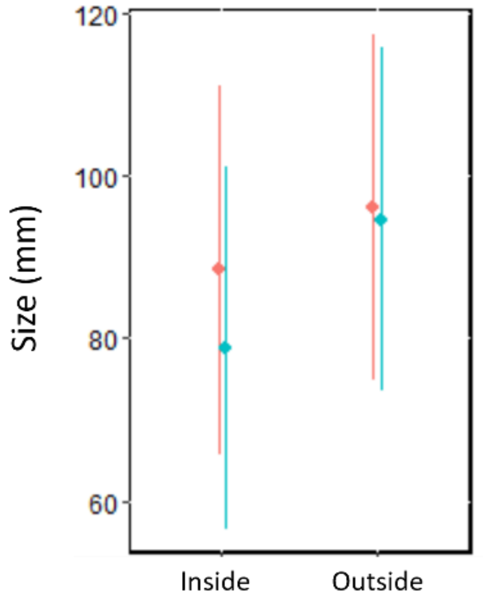

Figure 19. Average size (cephalothorax length (mm)) (mean ± SE) of spider crab (*M. brachydactyla*) in September inside and outside the protected area sampling site before (red) and green (after) its implementation (adapted from Schlaich *et al.* 2019) (data for June was not available).

5.2 Stakeholder survey results

Of the total number of stakeholders contacted (N = 23), only one was successfully engaged. The scientific stakeholder, who authored the paper Schlaich *et al.* (2019) referred to throughout this paper, provided a corroboration of the results presented in the paper, with some additional insights, perspectives and opinions on the study and to spillover more generally. A key insight provided was that pots have a maximum capacity of approximately 6 crustaceans, and thus results of species densities may be underestimated.

6 DISCUSSION

6.1 Assessment of Spillover

Based on a BACI approach, an assessment was carried out using the data (in section 5 Above) to assess whether the results showed the occurrence of spillover. Both the fishery data types abundance (measured in CPUE) and size (measured as the cephalothorax length (mm)), were used. The author of this report notes that the changes (delta) were not quantified numerically due to the unavailability of raw data for analysis but were based on observations of data in Figures 5, 7, 9, 11, 13, 15, 17 and 19 (above) from Schlaich *et al.* (2019).

CPUE

A summary of the relevant information to assess spillover occurrence using the BACI method in terms of species abundance can be seen in Table 2. The abundance of lobsters increased both inside and outside the protected area following implementation of protection, with a stronger increase seen within the protected area. This indicates that there may be a level of protection conferred on the populations inside, thus the potential for spillover to be occurring. This was consistent during both sampling periods.

Populations of *M. brachydactyla* demonstrated the same trend as *H. gammarus*, with an overall increase in populations following implementation of the protected area. The data demonstrate that some level of protection is being afforded, and thus an augmentation of abundance, and potential spillover of these populations is occurring. Data was only available for June, which reflects possible confounding variables of seasonality and species behaviour which were mentioned during the scientist stakeholder interview. This species demonstrates a seasonal migration and is generally quite elusive in comparison to *H. gammarus*, while data seem to indicate a possible spillover in terms of abundance.

Both *N. puber* and *C. pagarus* abundances declined inside the protected area but showed an increase in abundance outside the zone following protected area implementation. This is likely due to an effect of competition driving them out of the protected area as it became dominated by *H. gammarus* and *M. brachydactyla*. This was consistent across both sampling periods. This theory was supported by the scientist interviewed, who outlined the ecological impacts that a sudden change in protection level could have and demonstrates how anthropogenic influences ultimately lead to changes in species ecology.

Table 2. BACI determination using CPUE as a spillover indicator (Δ MPA = the change in CPUE at internal sampling sites after implementation of the protected area; Δ Ref = the change in CPUE at reference point after implementation of the protected area).

Species	Month	Reference Figure	Δ MPA	Δ Ref	Scenario Description	Pro-tection?	Spillover ?
H. gammarus	June	Figure 5	Strong increase	Increase	Population abundance increased in both locations, a stronger increase inside	Yes	Potentially
	September	Figure 5	Strong Increase	Increase	Population abundance increased in both locations, a stronger increase inside	Yes	Potentially
M. brachydactyla	June	Figure 11	Strong Increase	Increase	Population abundance increased in both locations, a stronger increase inside	Yes	Potentially
	September		n/a	n/a			
N. puber	June	Figure 9	Decrease	Increase	Decrease in CPUE in MPA, increase outside.	No	No
	September	Figure 9	Decrease	Increase	Decrease in CPUE in MPA, increase outside	No	No
C. pagarus	June	Figure 7	Decrease	Increase	Decrease in CPUE in MPA, increase outside.	No	No
	September	Figure 7	Decrease	Increase	Decrease in CPUE in MPA, increase outside	No	No

Size (cephalothorax length (mm))

Table 3 provides a summary of the key information used to assess the occurrence of spillover using size (cephalothorax length (mm)) as a potential indicator. Average size of *H. gammarus* sampled within the protected area showed a strong increase following protection implementation, and a decrease outside of the protected area. Some level of protection is granted, but clearly no migration of larger individuals outside the protected area is occurring at either sampling period.

M. brachydactyla populations, in June (the only month of available data) significantly decreased in average size in the internal sampling area after protection implementation and decreased moderately outside the protected area. One must note there is a potential confounding variable caused by the species and its migratory/mobile behaviour, which as the author of the scientific study admitted, may have influenced the data somewhat.

N. puber average size decreased strongly across both sampling periods in both sampling locations following the implementation of the protected area.

Where data were available for the month of June, *C. pagarus* size decreased moderately within the internal sampling area, while populations increased in average size in areas outside the area after protection implementation.

Table 3. BACI determination using the size (cephalothorax length (mm)) as a spillover indicator (Δ MPA = the change in cephalothorax length at internal sampling site after implementation of the protected area; Δ Ref = the change in cephalothorax length at reference point after implementation of the protected area)

Species	Month	Reference Figure	Δ MPA	Δ Ref	Scenario Description	Pro-tection ?	Spillover ?
H. gammarus	June	Figure 13	Strong increase	Decrease	Lobster size increased strongly inside the zone, but decreased outside	Yes	No
	September	Figure 13	Strong increase	Decrease	Lobster size increased strongly inside the zone, but decreased outside	Yes	No
M.brachydactyla	June	Figure 19	Strong decrease	decrease	Spider crabs got much smaller inside the zone, and smaller outside	No	No
	September		n/a	n/a			
N. puber	June	Figure 17	Strong decrease	Strong decrease	A strong decrease in size both in and out	No	No
	September	Figure 17	Strong decrease	Strong decrease	A strong decrease in size both in and out	No	No
C. pagarus	June	Figure 15	decrease	increase	Crabs got smaller inside, but larger outside	No	No
	September	Figure 15	n/a	n/a			

Larval abundance

Due to a lack of raw data, assessing spillover using larval abundance as an indicator type could not be fully conducted. The data assessed indicate greater abundance of larvae of both *M. brachydactyla* and *H. gammarus* along an increasing gradient further from the sampling points within the protected area. However, no statistical analysis could be conducted due to the unavailability of raw data collected in each sampling location to determine BACI.

6.2 General lessons and assessment of the case study

Overall, this case study demonstrates how a protected area can confer protection and possible spillover effects but provides a clear example of the species specificity and parameters to consider in the assessment of potential effects on local fisheries.

Strengths and limitations of the data/methodology

While access to raw data sets would have permitted the authors to provide further analysis and draw more accurate conclusions, the data provided from the long-term monitoring projects in the Flamanville area (described by IFREMER scientists through Schlaich *et al.* (2019) and Le Gac *et al.* (2018)) are strong to support an accurate assessment of spillover through a BACI approach. Two different data types (abundance (CPUE) and size (mm) allowed a bidimensional assessment of spillover. Having been conducted since the 1980s, the sampling programs conducted in Flamanville provide a comprehensive and long-term data set which provide for more accurate deductions. Considering the effects of spillover might only be visible and/or quantifiable 10 years after implementation (Smallhorn-West *et al.* 2020), the long timeframe here provides a clear picture of what has happened on a long-term basis. Additionally, multiple sampling sites inside and outside the protected area provide a large sample size which supports deductions and inferences.

The sampling methodology is crustacean-specific in its design (the small area is suited to the relative sedentary nature of crustaceans, when compared to pelagic fish for example), and thus extrapolating results to more mobile species would not be accurate. Additionally, as highlighted by the scientist interviewed, possible biases exist in data collection which may result in underestimations of species densities.

Stakeholder engagement

Despite multiple reminders via email and phone calls, the authors noted difficulties in engaging stakeholders in this area. One of the common responses was a lack of awareness of the existence of this protected area, as well as confusion as to the location and/or designation of the area.

It was not clear to the author who was responsible for the management of the protected area. Several government bodies/agencies were contacted, but the authors were often told that it was not under the jurisdiction of the local government there.

Fisher representatives were hesitant to provide responses and concerns were raised by them about the use of the fisher's data and how the survey might impact them. Although initially engaged and receptive to the authors explanations of data management and clear outlining of the aims and objectives of the study, the main fisher's organisation in the area became disengaged.

Further discussion and interview with a wider range and greater number of stakeholders would be needed to validate the results of the meta-analysis and to provide comprehensive insight to the wider socio-economic implications of spillover and protected areas.

7 CONCLUSIONS

Answers to the question of whether spillover is occurring and/or if it is having an effect on fisheries in the Flamanville Protected Area are not black and white. **While there is strong evidence to support a spillover effect on lobsters and spider crabs** (in terms of an increase in species abundance), **this does not automatically translate to positive benefits to fishers**. Economic returns clearly depend on more than just an increase in abundance of the stock, so other factors which influence the catch price would need to be considered (market demand, fisher operating costs, taxes). Moreover, the positive effects that the protected area has on one species may be outweighed by negative impacts on others. In Flamanville, while *H. gammarus* appear to be benefiting from the implementation of protection, *C. pagarus* stocks have been negatively impacted. Could possible increased revenue from higher lobster abundance be simply outweighed by the converse in relation to brown crabs? The case study also demonstrates potential impacts of seasonality which can influence species' presence, abundance and/or activity, adding further to the clear species specificity of a protected area. Considering these variables demonstrate that the occurrence of spillover, and whether it has an impact on fishers, is somewhat fluid.

In terms of future management of protected areas, the Flamanville Protected Area case study demonstrates the need to assess potential knock-on effects (mostly ecological, which can lead to other socio-economic impacts), which should be closely considered before, during and after MPA implementation. For example, recent news reports[19] have highlighted problems of the increasing spider crab populations on mussel farms in the Manche region: while we can't say that the protected area in Flamanville is directly responsible for this, changes in the ecology and/or behaviour of a species can cause wider impacts. This indicates that MPA implementation requires caution considering the potential to influence the abundance, ecology and thus behaviour of an individual species.

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9. CASE STUDY REPORT:

THE ÉCRÉHOUS AND THE MINQUIERS

JERSEY – THE ENGLISH CHANNEL

Analysis of potential spillover effects around the Écréhous and the Minquiers Marine Protected Areas in Jersey, Channel Islands

William Peat

MRAG Europe

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LIST OF ABBREVIATIONS

Term	Description
BACI	Before After Control Impact
BoGA	Bay of Granville Agreement
BRUV	Baited Remote Underwater Video
CPUE	Catch Per Unit Effort
LPUE	Landings Per Unit Effort
MLS	Minimum Landing Size
MPA	Marine Protected Area
NGO	Non-Governmental Organisation
NPPZ	No Parlour Pot Zone
NTZ	No-take Zone
TCA	Trade and Cooperation Agreement
TAC	Total Allowable Catch
iVMS	Inshore Vessel Monitoring System
VMS	Vessel Monitoring Systems

1 EXECUTIVE SUMMARY

In 2017, the Government of Jersey designated two marine protected areas (MPAs) within their territorial waters. One to the Northeast of the island, the Écréhous, and one to the South, the Minquiers. Both MPAs protect relatively shallow water, consisting of a matrix of rocky reefs, sandbanks, and intertidal areas as well as biogenic habitats in the form of seagrass and maerl beds. The Minquiers MPA covers an area of 47.5 km^2 while the Écréhous covers a much smaller area of 15 km^2. Both MPAs ban the use of any mobile fishing gear in their boundaries, with some separate Parlour Pot restrictions in place in parts of their waters and help Jersey government towards its goal of 30% protection of its marine space by 2030. Despite the ban on mobile fishing, static fishing is permitted along with hand diving for scallops. This case study assesses the potential for fisheries and ecological spillover of commercial target species from both the Minquiers and the Écréhous MPAs into their surrounding waters.

Typically, studies investigating the occurrence of spillover will apply a Before After Control Impact (BACI) approach. Here, data from sites within and outside the MPAs (control sites) are compared across years before and after the designation of the MPAs. This case study could not access any raw data from before the designation of the MPAs. For this case study, a literature review of all relevant studies that might indicate evidence of spillover was combined with a stakeholder survey.

Given the recent designation of both MPAs, relatively few studies have been completed on them. This meant the literature review needed to be supplemented by more extensive stakeholder engagement, including a visit to Jersey to interview those closest to the MPA who had not responded to the remote survey. The literature review found no direct evidence of spillover, with abundances of crustaceans above Minimum Landing Size (MLS) generally declining at both MPAs. Typically, crustacean abundances were comparable to historical surveys that have shown declining stocks, indicating these species (lobster, brown crab, and spider crab) may be being overexploited. However, high abundances of below MLS lobsters were seen at the Écréhous as well as low abundances of above MLS lobsters. This may be evidence that the Écréhous MPA is helping the area to act as a nursery for lobsters. A Baited Remote Underwater Video (BRUV) study assessing spider crab abundance also reported higher abundances at open control sites than within the Écréhous MPA. This may be evidence that potting vessels are preferentially targeting the MPAs as no mobile fishing is permitted in them. This has been observed at both Lyme Bay and the Isle of Skomer where increased static fishing effort has followed the banning of mobile fishing gear. Further management of crustacean fisheries may be required to curb this decline in stocks.

Despite no studies being carried out on scallop populations, stakeholder responses indicated that scallop stocks are healthy in Jersey's waters. Some stakeholders stated that some fishers were switching gear type to dredging or diving specifically to target them. Respondents generally felt scallop populations were likely being bolstered by net larval export from both the Minquiers and the Écréhous. However, one scientist respondent stated that detecting spillover would be challenging due to nearby scallop seeding projects taking place in French waters. Larvae may be exported from these projects into Jersey waters, giving the impression that this is due to larval export from the MPAs. As was found in the literature review, stakeholders were sceptical of any spillover of commercial crustacean stocks from the MPAs, with some stakeholders citing a lack of management of crustacean stocks.

Future studies should look to assess evidence for spillover of scallop populations within the MPAs. These have been reported to be more numerous, and larger in size – potentially pointing towards greater larval production. The designation of other MPAs in Jersey's waters should also be preceded by baseline surveys into all commercially important populations, both inside and outside the boundaries of the intended MPA. Finally, without strict fisheries control measures in MPAs it is highly unlikely that spillover will be observed. For both the Minquiers and the Écréhous to benefit neighbouring crustacean populations, further fisheries control measures should be applied to the gear types that target them.

2 BACKGROUND

Jersey is a self-governing dependency of the United Kingdom located off the north coast of Brittany, France. With a marine territory of around 2,500km^2, fisheries are both culturally and economically important to Jersey's 103,000 inhabitants. The marine environment surrounding the island is predominantly shallow coastal waters consisting of rocky reef, boulders, cobbles, gravel, sand, and biogenic habitats such as maerl and seagrass. Jersey's large tidal range of up to 12m creates a large intertidal area with a wide range of habitats that support diverse communities (Blampied et al., 2022). The shallow waters around Jersey support a fishery dominated by shellfish, particularly lobster (*Homarus gammarus*) and crab (*Cancer pagurus* and *Maja squinado*) which form around 70% of landings (by value). Whelks (*Buccinum undatum*) and Scallops (*Pecten maximus*) also account for 22% of landed value with wetfish and other species making up 8% (Marine Resources, 2021).

As a signatory of numerous conventions, agreements, and treaties for the protection of the marine environment (OSPAR, The Bern Convention, the Convention on Biological Diversity, and the Ramsar Convention), Jersey is committed to protecting its marine habitats in its waters (Government of Jersey, 2013). Historically, protection of Jersey's waters has been complex, with a divisional sea boundary known as the A-K line denoting where French and Jersey vessels may fish. This, as well as a three nautical mile exclusion zone around the Island for French vessels, were part of the wider Bay of Granville Agreement (BoGA) (Chambers et al., 2020).

In the wake of Brexit, most of Jersey's waters were fished by vessels from both France and Jersey. This was in line with the EU-UK Trade and Cooperation Agreement (TCA) that ensured vessels with a history of fishing in Jersey or France could continue to apply for temporary permits, so long as they provided evidence of fishing in the respective waters between February 2017 and January 2020. However, today Jersey controls the fishing activities of EU vessels in its waters through a permit system which may specify the number of allowed fishing days (up to 170 per year), target species, and gear types. As of March 2022, 131 French vessels were licenced to fish within Jersey's waters (Chambers et al., 2020). Before the TCA, historical fishing agreements between France and Jersey such as the BoGA have made fisheries management challenging, particularly the designation of MPAs (Blampied et al., 2022). However, in 2017 two MPAs were designated off Jersey's coasts, the Minquiers to the south of the Island and the Écréhous to the northeast.

Both the Minquiers and the Écréhous are shallow subtidal plateaus that consist of a matrix of rocky reefs, sandbanks, and intertidal areas. The Minquiers is located 18 km offshore and covers an area of around 47.5 km^2, while the Écréhous covers a smaller area of 15 km^2 roughly 9 km offshore (Figure 1). The reefs themselves have small terrestrial areas (0.1 km^2 for the Minquiers and 0.6km^2 for the Écréhous) with no permanent inhabitants despite the small huts found on them. Historically, both reefs have been subject to sovereignty claims from both Jersey and France. This was eventually resolved by the International Court of Justice that declared sovereignty of both areas to Jersey (Chambers et al., 2020).

In 2013, at a meeting of the Bay of Granville Agreement (BoGA), the States of Jersey Marine Resources team (that manages inland fisheries) expressed a desire to designate MPAs at both the Minquiers and the Écréhous. This was to protect the sensitive biogenic habitats found at both locations such as seagress (*Zostera* spp.) and maerl (*Lithothamnion* and *Phymatolithon* spp.) from mobile fishing gears such as dredging and bottom trawling (Blampied, 2015); both of which have been shown to damage and disturb benthic habitats (National Research Council, 2002). At the time, both the Minquiers and the Écréhous fell under the management framework associated with the BoGA. The designation of MPAs was not written into the agreement, and so the proposed ban on mobile fishing gears was assessed through the existing management procedures. Jersey's position was that the significant seabed habitats at both sites required protection in line with Jersey's commitment to OSPAR, the Ramsar Conventions, and the Convention of Biological Diversity. The opposition to the MPAs designation cited immediate negative economic impacts to several vessels, and limited evidence both in favour of banning mobile fishing and concerning the location and extent of the seabed habitats at both sites. This discussion continued at following BoGA meetings until February 2014 when both parties agreed that strong supporting evidence was required to demonstrate both the need for the MPAs, along with what the potential MPA boundaries would be (Chambers et al., 2020).

Coincidentally, both the states of Jersey and a local NGO called Société Jersiase had begun collecting offshore environmental data since 2012. These studies were combined to produce a coalition of over fifty professional and amateur researchers with their own respective aspects of the reefs which they were to study and report to a central team that coordinated the project. The entire study took three years to complete and covered several major research disciplines ranging from geology and political history to more relevant studies into the marine environment and the ecosystem services provided by both areas (Chambers et al., 2020).

In January 2016 the study into both candidate MPAs was completed, providing baseline data across the wide range of disciplines that were assessed. The study concluded that both the

Minquiers and the Écréhous possessed both high biological productivity and key habitats, principally seagrass and maerl beds which act as nurseries for shellfish and fish species. It was also concluded that these nurseries likely play an important role as a source for population recruitment, thereby helping to sustain stocks that are exploited in the surrounding waters off Jersey. It was recommended that protecting both areas to conserve the habitat in both areas would provide economic benefit to the whole Bay of Granville (Chambers et al., 2016; 2020).

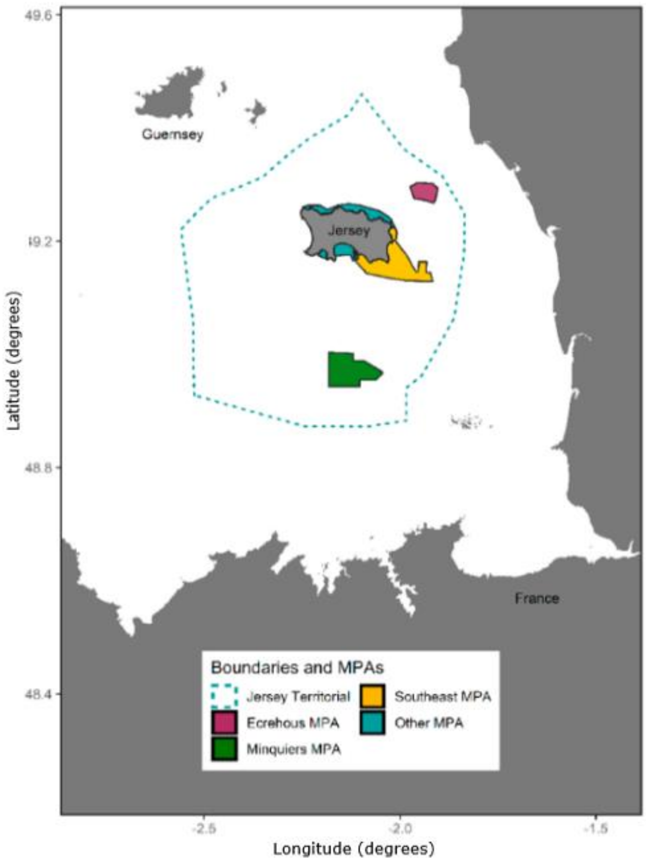

Figure 1: shows the location of all MPAs within Jersey's territorial waters, with the Écréhous shown in pink and the Minquiers in green (source: Blampied et al., 2022).

The results of the joint study were presented to BoGA participants with the recommendation that mobile fishing gear be banned at both the Minquiers and the Écréhous. This proposal was discussed and eventually accepted for both areas, after an intensive dive survey of the Écréhous was prompted by objections. These were mainly from French scallop dredgers over the loss fishing grounds containing maerl beds which they viewed as a viable fishing ground. A compromise was eventually found resulting in the removal a planned buffer zone, bringing the park boundary closer to the edge of the maerl beds. The law creating both MPAs came into force on October 4th, 2017, prohibiting any form of mobile fishing in either MPA at the Minquiers or the Écréhous (Hall-Spencer et al., 2008; Chambers et al., 2020).

It should be noted that separate static gear restrictions banning parlour pots are in place at both the Minquiers and the Écréhous. The boundaries of these restrictions do not directly match the MPA boundaries, with one No Parlour Pot Zone (NPPZ) covering all of the Minquiers and the other covering over half the Écréhous, with areas to the east of the Erehous having no potting restrictions (Figure 2). the Minquiers' NPPZ has been in place since 2007, while the NPPZ at the Écréhous was established after the designation of the MPA, in 2018 (Blampied pers comms., 2023).

This study attempts to assess the potential for ecological and fishery spillover from both the Minquiers and the Écréhous MPAs. Given both protected areas relatively recent designation, detecting spillover directly is unlikely. However, this study draws on the most up-to-date research into both areas, while also engaging with stakeholders closest to both MPAs to understand their opinions on spillover from the MPAs. Demonstrating the occurrence of spillover from protected areas can play a crucial role in ensuring stakeholder acceptance of marine protected areas like the Minquiers and the Écréhous.

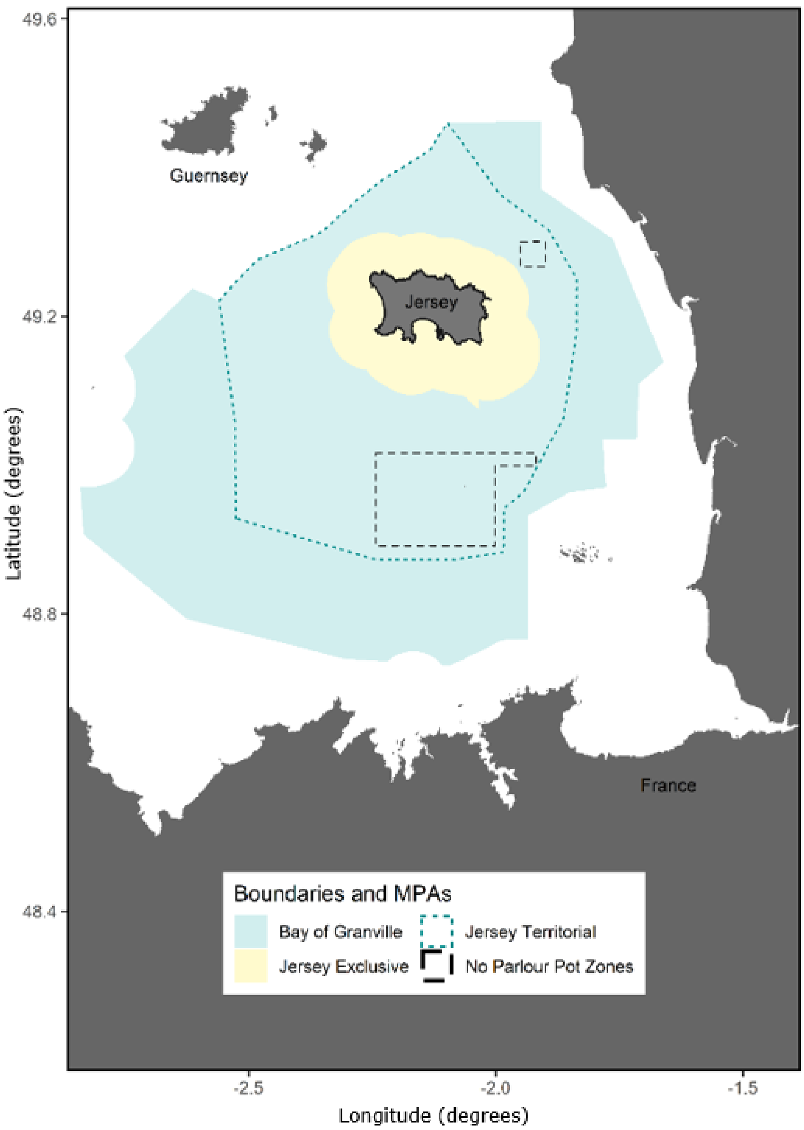

Figure 2: shows the No Parlour Pot Zones (NPPZs) in Jersey's waters (source: Blampied pers comms, 2023).

3 AIMS AND OBJECTIVES

Spillover is an important factor to assess when measuring the success of an MPA in relation to both ecological and socio-economic goals. Success on both fronts helps secure positive engagement from and between stakeholders, leading to a common goal of sustainable fisheries management under an ecosystem-based approach. This case study of the Minquiers and the Écréhous aims to inform whether spillover has been detected at both MPAs, whether it is perceived to be occurring by local stakeholders, and what methodologies are used for its assessment. These aims and their associated objectives are listed below:

1. Assess spillover effects at the Minquiers and the Écréhous
   - Investigate any potential ecological or fishery spillover in areas surrounding both MPAs;
   - Identify any key factors that may influence spillover dynamics such as MPA design, fishing practices, and habitat characteristics;
   - Assess changes in temporal or spatial patterns of commercial stocks after the establishment of the MPAs.
2. Gain an understanding of stakeholder perceptions of spillover associated with both MPAs
   - Understand local stakeholder perceptions of the MPAs and their associated restrictions;
   - Gather information on changes to catches before and after the designation of both MPAs in proximity to MPA boundaries.

3. Evaluate any current or previous studies investigating spillover effects at both MPAs
   - Assess the suitability, practicality, and effectiveness of methodologies used to assess spillover;
   - Identify any limitations associated with the methodology;
   - Provide recommendations for refining or improving the methodology for studies into spillover at similar MPAs.

4 METHODOLOGY

4.1 Literature Review

Initially, contact was made with researchers that had a history of studying both the Minquiers and the Écréhous, with any available raw data being requested. Due to a lack of available raw data on either site, a qualitative approach to spillover assessment was employed. It was hoped that a before, after, control, impact analysis (BACI) could be undertaken using outputs from previous studies, however, all monitoring of the MPAs came after their designation, meaning no data from before 2017 could be used as a benchmark for comparison. As a result, a literature review of all relevant scientific and grey literature relating to the ecology of the MPAs and their surrounding waters, and the fisheries that operate both inside and outside the MPAs. Literature searches used Boolean logic to combine terms for the Minquiers and the Écréhous and different topics. For example, "Les Minquiers" OR "Les Écréhous" AND "spillover" OR "fish biomass" OR "fishery". This produced searches that provided literature relating to research conducted in both MPAs focusing on changes in commercially exploited populations, fish community assemblages or impacts on the local fishery. Searches used ResearchGate, Google Scholar, and Science Direct, with all relevant literature being stored and managed in a Zotero library. Direct contact was also made with several people that were particularly familiar with the study sites, this produced some more relevant publications.

4.2 Stakeholder survey

We developed a questionnaire to assess the perceptions of key stakeholders on the potential spillover effects in their nearby MPAs. The questionnaire comprised of open-ended and closed questions to elicit stakeholder views and experiences on the different aspects of this study (Annex 4). The open-ended questions aimed to capture stakeholder opinions on, for example, how aware the stakeholder was of the regulations and management measures of the MPA. The closed questions were statement-based and used Likert scale answer categories (such as: Strongly agree; Agree; Neutral; Disagree; Strongly Disagree) for the stakeholder to choose from.

The questions were grouped into four broad categories to encapsulate the key issues being studied. These included:

(i) Respondent information. The first section required basic information from the respondent, including their name, institution and the type of stakeholder category they belonged to.

(ii) Background information. The second section of the questionnaire gathered background information from the stakeholder to understand more about the respondent and their use of the MPA. Questions included knowledge of when the MPA was established, the type of restrictions in place and how long the stakeholder has been associated with the MPA either through research, fishing or managing it.

(iii) Fishery impacts of MPAs. The third section explored the respondent's perceptions of the socio-economic impacts of spillover from the MPA. Stakeholders were asked to state whether the designation of an MPA / area where fishing is limited has led to an increase in revenues for fishers, whether the fishing community in the area feel their fisheries livelihoods are more secure after the MPA was established, and the extent to which they believe spillover from the MPA has influenced the catch composition in adjacent fishing grounds.

(iv) MPAs as management tools. The fourth section of the questionnaire focused on the respondent's perceptions on whether MPAs are conservation or fisheries management tools. Stakeholders were asked to state whether their local MPA was acting as a conservation tool, a fisheries management tool or both. Other questions under this section required stakeholders to state their agreement / disagreement on whether the establishment of MPAs is an effective conservation strategy to support fish populations and commercial fisheries in their area.

Respondents were also asked to indicate what factors they thought were contributing to spillover effects.

Four key stakeholder groups were targeted under this consultation including commercial and recreational fishers, fisheries managers and government authorities, scientists and environmental non-government organisations (NGOs). Therefore, while the four sections of the questionnaire where the same, specific questions were included for each of the four respondent groups. The questionnaire was set up as an online survey to improve ease of response for stakeholders.

The link was sent to three local scallop divers, the Jersey Fisher's association, individuals in the States of Jersey Fisheries and Marine Resources team, the Jersey Inshore Fishermen's Association, three local marine conservation NGOs operating in the area, a marine resources consultancy, and a local dive centre that frequently dives the MPAs. After poor uptake from remote stakeholder engagement via the survey link, the decision was made to visit Jersey for two nights, conducting in-person interviews, using the survey as a template so that responses were comparable.

5 RESULTS

5.1 Literature Review

Given the recent designation of both MPAs in 2017, few studies have investigated their effects on local fisheries or the ecosystems within their boundaries. However, there have been two studies that formed part of a PhD thesis published in March 2022. These assessed the responses of epibiotic and infaunal assemblages, mobile species biodiversity, and commercial crustacean populations to the removal of bottom-towed fishing within the Minquiers and the Écréhous (Blampied, 2022).

The study into epibiotic and infaunal assemblages assessed how the proportion of structure-forming organisms had changed inside both the Écréhous and the Minquiers, and at control sites outside of the MPAs (Figure 3). While this is not an assessment of spillover, understanding how habitat-building organisms' coverage (such as that of maerl and seagrass) is changing may be a good indicator of areas' ability to act as a nursery to commercially important species (Blampied, 2022). The three organisms studied were seagrass (*Zostera marina*), species of maerl, and *Lanice conchilega*. At the Écréhous, maerl alone was the only organism assessed, while at the Minquiers seagrass and *Lanice conchilega* were assessed.

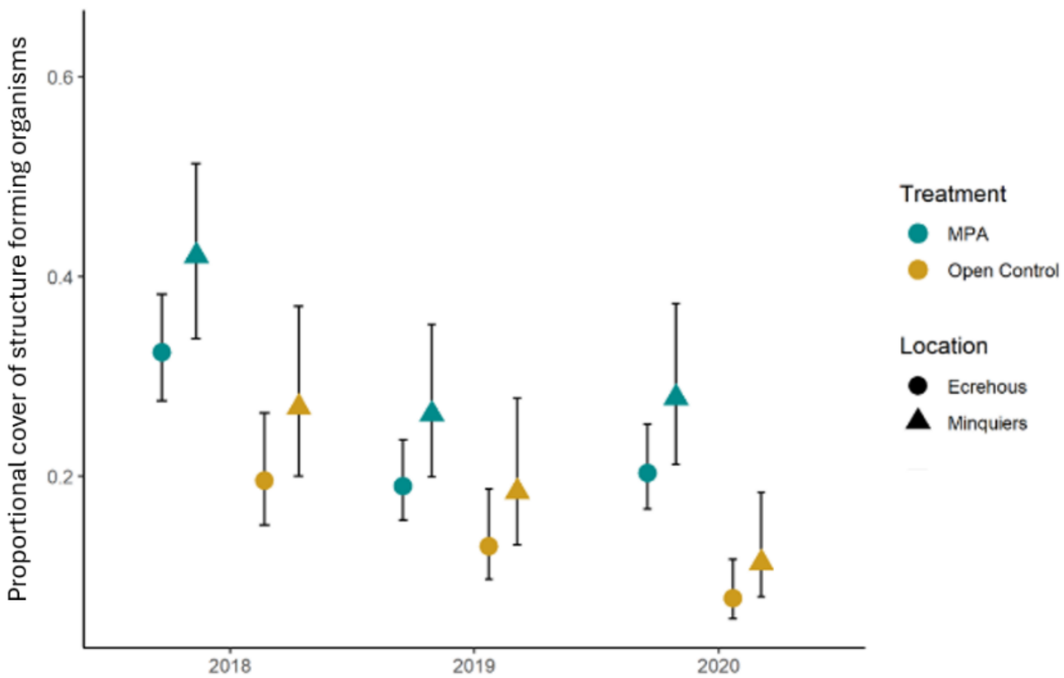

Figure 3: shows the mean (and standard error bars) proportion of structure-forming organisms for Year, Location, and Treatment (whether sites were in the MPAs or were control sites) (source: Blampied, 2022).

While mean values for the proportion of structure-building organisms are not quoted in the paper, Generalised Linear Mixed Effects Models showed the proportional cover of structure building organisms to be significantly greater in the MPAs compared to their open controls. This proportional value decreased for the MPAs between 2018 and 2019, before stabilising in 2020. In comparison, a decline was observed at the open control sites throughout the study, with a significant decline being observed in 2020 compared to 2018 and 2019 (Blampied, 2022) (Figure 3).

The assessment of mobile species biodiversity (Blampied et al., 2022) acted as a baseline survey for total diversity and total abundance of all mobile species that were detectable via baited remote underwater video (BRUV). Of these species, spider crab *Maja brachydactyla* was the only commercially important species recorded. Black bream *Spondyliosoma canthurus* was also observed and assessed, however this species is not caught in large quantities by commercial vessels.

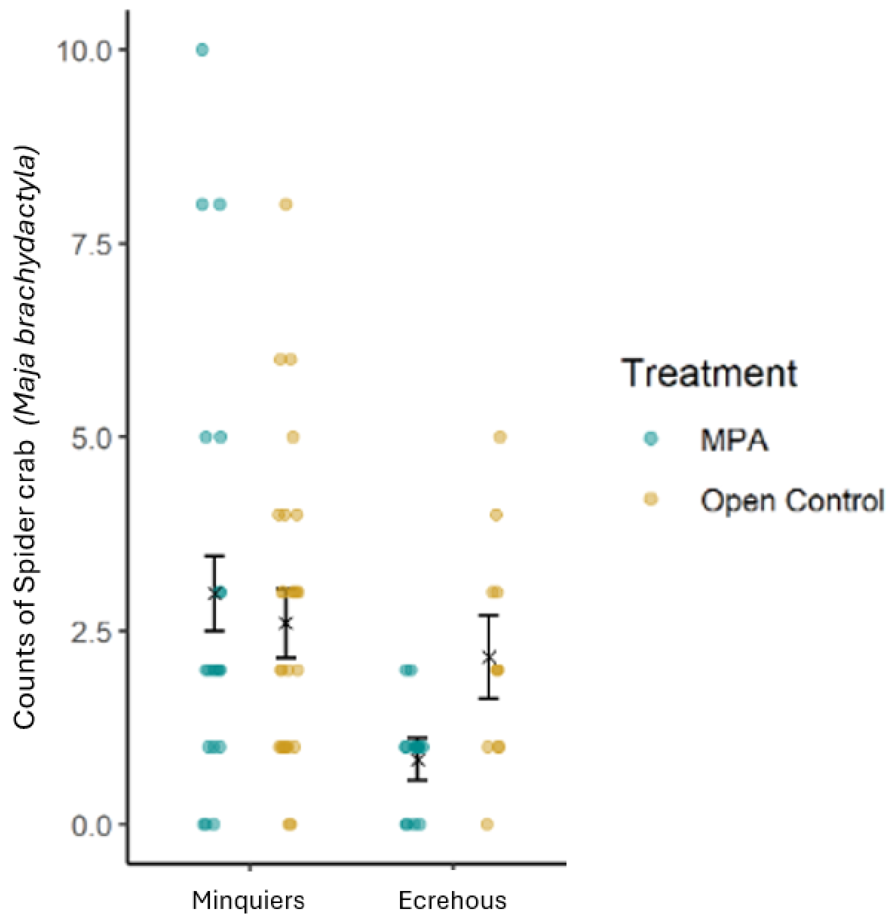

Figure 4: shows the total number (and standard error bars) of spider crab (*Maja brachydactyla*) recorded via BRUVs in sites across three of Jersey's MPAs (including the Minquiers and Écréhous) and associated control sites (source: Blampied et al., 2022).

Spider crab *M. brachydactyla* were recorded in greater abundance in open control sites (2.5 ± 1.8 individuals per BRUV deployment) compared to MPAs (1.9 ± 2.4 individuals per deployment) (Figure 4). Abundance of *M. brachydactyla* was greater at the Minquiers compared to the Écréhous (Blampied et al., 2022). This may be the result of the Écréhous being more accessible to fishers and thereby experiencing greater fishing effort.

The study investigating the recovery of commercial crustaceans after the removal of towed fishing gear measured species abundance inside and outside both the Minquiers and the Écréhous. One MPA site was used at the Minquiers, with two open control sites outside the MPA, whereas at the Écréhous, two MPA sites were used and one open control site. Pots used in this survey were modified to prevent escape of undersized individuals to allow individuals under minimum landing size (MLS) to be recorded, giving a reading for individuals in younger age classes (Blampied, 2022).

The results from this study show that responses of crustaceans to management strategies may vary greatly across species and size classes. Each species' response to the removal of bottom-towed fishing gear is varied, with many seeing a gradual decrease in abundance. At the Minquiers, there was no significant difference in abundance of lobsters between the MPA test site and the control site outside the MPA. At the Écréhous, abundance was significantly greater inside the MPA than at the control site, this was largely due to the high abundance of below MLS lobsters inside the MPA. Spider crab showed no increased abundance in either of the MPAs over the study period, although the Écréhous did show a significant difference in abundance between the MPA site and the control site. This was caused by a steady decline in abundance at the control site while the MPA spider crab abundance remained stable. Finally, brown crab abundance was only significantly greater in the MPA site at the Minquiers in 2019, with all other years and locations showing no significant difference. The generally decreasing abundances seen across the three commercial crustacean species is in keeping with historical potting surveys carried out by the States of Jersey. Spider crab were the only exception to this, with their overall abundance in Jersey's waters increasing in historical surveys (Figure 5), yet in this study the observed abundances were lower than those in the historical survey apart from a spike in abundance in 2019 at the Écréhous (Blampied, 2022).

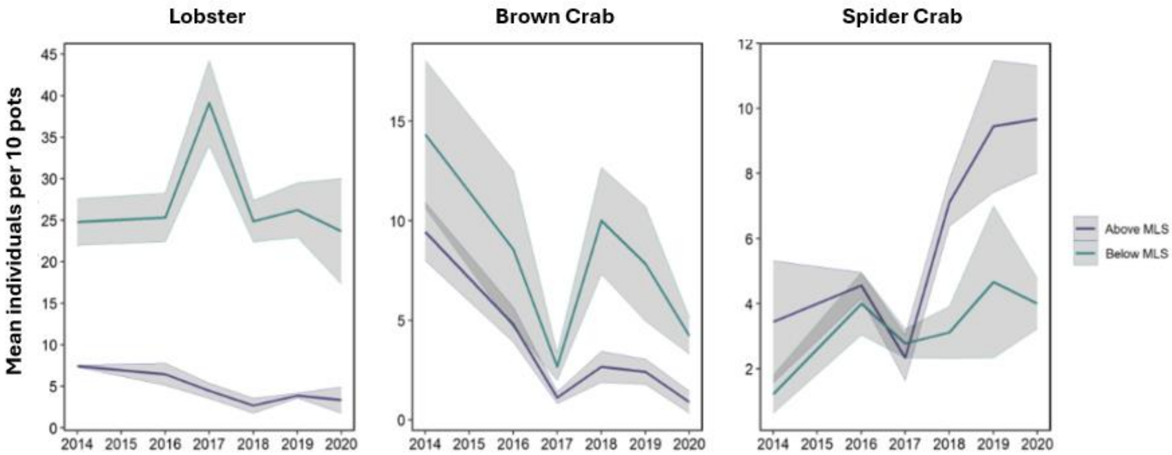

Figure 5: shows catch per unit effort (CPUE) data from historic potting surveys conducted by the States of Jersey Marine Resources team between 2014-2020. Lines represent mean values of lobster, brown crab, and spider crab (source: Blampied, 2022).

5.2 Stakeholder survey

Across in-person interviews and remote survey responses, eight survey scripts were returned for analysis, summarising the responses of ten stakeholders. These ten respondents included one NGO employee, two local Scientists, two local recreational divers, two scallop divers, one full-time commercial fisher, and two part-time commercial fishers.

Ecological changes after MPA designation

Scientists have observed improvements in maerl and seagrass coverage since the MPAs were designated. This has been anecdotally reported to them by divers and has been reflected in their video analyses of the sites. They also highlighted that much of the research undertaken on the MPAs involved data from the first three years after designation, and so it is unlikely to yield highly significant results, but it will act as a baseline study for the sites. Scientists also responded that scallop abundance and size of individuals have both increased in the MPA – this is consistent with responses from local divers that frequently dive the Écréhous. A scallop diver that also operates in and around the Écréhous also responded that spider crab, skate, and sole all seemed to be more abundant since the designation of the MPA.

Changes to catches after MPA designation

Scientist respondents stated that scallop dredger landings per unit effort (LPUE) outside of the MPAs has increased since their designation. Both scallop divers have seen high catches but are hesitant to attribute these to the MPAs, with both divers stating that scallop stocks have been healthy for several years as conditions have been ideal (low algae levels, correct temperatures, and high light levels in the water column). One scallop diver referenced French seeding projects as a factor that has contributed to high catches. The full-time commercial fisher has not heard of any of the fleet seeing increased catches as a result of either MPA. One part-time fisher suggested that bass catches have slightly increased and that the Minquiers is a bass nursery, however they did not think there was a strong direct link between the MPA and bass catches.

According to fisher responses, catches by static gear fishers have not increased and seem to be gradually declining with the exception of spider crab catches. One respondent stated that this was a result of no strong regulations on potting, save for the parlour pot restriction zones.

Fisheries management issues

The reported changes to the fishing community in Jersey differs depending on gear type. According to the scallop divers that responded, more people are beginning to dive for scallop and more fishers are shifting their mobile gear to fish scallop dredging gear. This is due to the high market value of scallops combined with their stock in Jersey's waters being healthy. According to part- and full-time commercial fishers, the fleet is decreasing. One scientist cited numerous factors that have negatively impacted fishers including Brexit, the Covid-19 pandemic, rising fuel costs, and dwindling stocks. Responses highlighted diverging views on closed areas between scientists and fishers. Fishers typically held the view that no take zones (NTZs) were not effective tools for sustainable fisheries management. One scallop diver responded that sustainable fisheries practices have very little impact on the marine environment, referencing his ability to pick and choose individuals as he surveys the seafloor. Numerous fishers emphasized that they were not opposed to measures that reduce fishing effort (e.g. MPAs), but stated that they felt these measures often ignore economic needs of the fishing community and that they were not always based on scientific findings. Two fishers felt that Jersey's management strategies lacked baseline surveys with which new data could be compared with. One scallop diver responded that the majority of the waters in the Minquiers MPA were already unfished due to being too shallow and that the MPA was in fact not acting to reduce fishing effort there. Part-time fishers felt certain measures could be tailored for larger vessels and that fleet-wide measures took their toll on smaller vessels in particular. These same fishers also felt that more parlour pot restrictions should be extended to the Écréhous in the summer. Views on MPA compliance differed between scientists and fishers, with scallop divers reporting that regulations are often broken while scientists felt that the fleet were mostly compliant with regulations.

Spillover

Scientist respondents both stated that fishery spillover would be difficult to detect at both the Minquiers and the Écréhous. This is due to both the composition of Jersey's fleet and the previous vessel monitoring systems (VMS) regulations. Currently, all but two of the Jersey commercial fleet are under 12m in length and so do not require VMS (and MPAs do not align with logbook reporting zones). The result of this is that live fishing effort data cannot be extracted from most of the fleet. In future, the entire fleet will be fitted with VMS which will better facilitate tracking of the fleet and fishing effort. Another issue with detecting spillover that was raised by scientists was the restrictions in place at both MPAs do not prevent fishing of any species. Potting effort inside the MPAs, particularly at the Écréhous, may have even increased after the MPAs designation according to a local fisher. Another fisher stated that more scallop divers are diving at the Écréhous since it was protected in 2017. The size of the MPA was also referenced by a scientist who stated that it is difficult to attribute increased catches to such small areas as the MPAs. Another important consideration raised by a scientist was scallop seeding projects, particularly in the Bay of Saint Breiuc. These seeding projects have the potential to supply scallop larvae as far as Jersey (up to 70km dispersal), and so act as a source population for scallop stocks around the island, thereby masquerading as spillover from local MPAs. Scallop dredge surveys are currently being completed by the fisheries and marine resources of the States of Jersey. These should provide more information on scallop stocks and any potential spillover from MPAs; however, spillover was not reported to be a topic of high priority for the States of Jersey.

Fishers' responses on whether spillover was occurring were sceptical of baseline data and stated that so far, only anecdotal evidence from scallop divers existed. Around half the fishers in the survey responded that they were unsure whether spillover was occurring with the other half stating that they did not believe it to be occurring. Two fishers said that they did think the MPAs were helping biodiversity, but that the only fisheries that were seeing a positive benefit were those targeting scallops.

6 DISCUSSION

The few studies that have been completed at both the Minquiers and the Écréhous MPAs since their designation in 2017 have shown no signs of spillover. This is perhaps unsurprising given none of them set out to directly assess it. Unfortunately, the lack of a baseline survey into commercially important species before 2017 means the BACI approach to assessing spillover cannot be taken. This, paired with the inability to access raw data meant this case study relied on a literature review of the few published studies into the MPAs since their recent designation in 2017, as well as stakeholder engagement assessing stakeholder perceptions of the MPAs.

The results of the literature review show no evidence, direct or indirect, of spillover occurring at either MPA. The historical pattern of commercially important crustacean stocks declining around Jersey seems to hold true at both MPAs (Blampied, 2022; Blampied et al., 2022). These results appear to show heavily exploited stocks, with little positive effect observed in the Minquiers MPA, however conversely, the Écréhous did show greater abundances of lobsters, especially for individuals below the MLS. This high abundance of below MLS lobsters, paired with low abundances of above MLS lobsters inside the MPA at the Écréhous, point towards the MPA being a nursery for lobsters rather than an area experiencing low fishing effort (Blampied, 2022). Spider crab abundance was shown to be greater in control regions than in either MPA, with greater abundances being observed at the Écréhous than at the Minquiers (Blampied et al., 2022). The generally stable or decreasing abundances of crustaceans inside the MPAs is perhaps unsurprising given potting is permitted in both protected areas, with no TACs in place for any of the three main target species. This fishing effort likely masks any potentially positive effect of the removal of bottom-towed fishing gear within the MPAs. Overall, no direct or indirect evidence of spillover is detected across all commercial crustacean species at both sites in this study.

The results from the BRUV study into mobile species biodiversity only assessed one commercially targeted species, the spider crab. Their greater abundances at the Écréhous open control site than at the MPA point towards a lack of fisheries management of crustaceans within the MPA (Blampied et al., 2022). It is possible that the Écréhous are preferentially fished by potters as dredging is not permitted. This increase in static fishing effort after the banning of mobile fishing gears has been observed at both Lyme Bay (Mangi et al., 2011; Rees et al., 2021) and the Isle of Skomer Marine Conservation Zone (Burton et al., 2016). If this is the case, it seems highly unlikely that spillover from the spider crab population in the Écréhous would be occurring. **The greater abundances seen in the Minquiers compared to open control sites** (Blampied, 2022) **may be a result of the entire Minquiers MPA falling within an NPPZ.** They may also be a symptom of a lower fishing effort at the Minquiers MPA due to its shallow waters making navigation challenging. The Minquiers MPA is also further from Jersey than the Écréhous, meaning more fuel is used to reach it making it a less popular fishing ground, particularly for Jersey's inshore fleet. Further study is required on both fishing effort and other ecological factors that affect crustacean abundances inside and outside the MPAs.

While no evidence of fishery spillover has been found at either MPA, the study assessing benthic assemblage changes found significantly higher proportions of structure-building organisms in the MPAs than at control sites. This could be an early sign of habitat recovery in the MPAs, which could in turn lead to habitats that support greater abundances of commercially important species. **However, the short time-series of just three years since designation will need to be further built upon to examine longer-term patterns associated with commercial species and the benthic communities in the MPAs.** Ten years since designation has been found to be an important milestone in the ecological recovery of MPAs. This meta-analysis of 52 studies found the mean percentage of positive impacts for MPAs less than ten years old was 36%, compared with 67% after the ten-year mark (Smallhorn-West et al., 2020). It should also be noted that the observed significant difference in proportion of structure-forming organisms in Blampied, (2022) may be the result of MPA site selection targeting seabed with greater abundances of these organisms.

Future study into the Minquiers and the Écréhous should include assessments of the scallop populations in and around both MPAs. The general view of stakeholders on spillover from both MPAs was that if it is occurring it will likely be for scallops. Stakeholders reported recent catches to have been high for several years to the point that fishers are switching to dredging or hand diving scallops. Currently, all evidence on the scallop populations in the area seems to be anecdotal, with local divers reporting that scallops inside the MPAs are both larger and more abundant. If this is the case, it's possible that spillover may be occurring; providing this increase in size has also resulted in increased reproductive biomass. Detecting this spillover in future research will be challenging as seeding projects taking place in French waters may also be facilitating larval export into nearby Jersey waters. One scientist respondent stated that scallop surveys are currently taking place outside of protected areas and that there are plans to survey inside both MPAs as well. This will provide a better understanding of how the MPAs are affecting the scallop population.

The overarching perception of stakeholders about the MPas at the Minquiers and the Écréhous is that they act more as a tool for conservation than they do as one for fisheries management. It seems their designation has been born out of concerns around habitat degradation and ecosystem health than concerns about declining commercial stocks. Respondents were sceptical of spillover of crustacean stocks occurring, given the lack of management measures applied to static fisheries inside the MPAs. However, there was a consensus that scallop populations in Jersey's waters could be benefitting from the lack of dredging inside the MPAs. Those respondents with a scientific background felt detecting fishery spillover would be very difficult given Jersey's current regulations on VMS (it is not required on vessels under 12m in length). The same respondents explained that this changing, with VMS being installed on all commercial vessels. This, when paired with catch reports, could allow the States of Jersey to better detect spatial variations in catches that may be the result of spillover – such as increased CPUE in proximity to MPA boundaries. Stakeholders also stated that the protected areas were too small to see significant spillover from mobile species, with less mobile species such as scallops and whelks being more likely to show signs of spillover from them.

Generally, stakeholder responses were well aligned with the results from the literature review. Stakeholders were not optimistic about long-term crustacean trends, apart from for spider crab, and generally did not feel there was any evidence of spillover of any crustacean populations. Unfortunately, their positive views on scallop stocks could not be confirmed due to lack of literature. Acceptance of the MPAs was relatively neutral across stakeholders. Scientists and NGO respondents were more positive about the MPAs typically, with fishers presenting more sceptical views. However, none of the fishers that responded were ardently against MPAs and all believed they have their place in conservation and fisheries management. One fisher stated that much of the Minquiers MPA waters were not fished before designation, as they were too shallow for some vessels to navigate in. They also cited Jersey's goal of protecting 30% of its waters by 2030 as a reason for this – so protection could be afforded with less resistance from the fishing community.

There are a number of lessons that can be learnt from this case study to help direct future MPA designation and assessment of spillover. However, the small body of literature, paired with a lack of access to raw data, mean these are not based on a large body of scientific evidence but are based on relatively few studies and the perceptions of stakeholders closest to the MPAs. Firstly, constant monitoring of all species of commercial interest is crucial to detecting spillover. **Where no baseline surveys exist and data is lacking, it will not be possible to attribute any increase in catches to spillover.** Secondly, **spillover requires strict fishing control measures**. This is clearly illustrated by the low abundances of crustaceans in both MPAs, especially of individuals larger than MLS. No TACs are in place for any crustacean species in jersey, and the removal of mobile fishing from both MPAs may have increased the effort of static gear fishing that targets crustaceans (Blampied, 2022; Mangi et al., 2011). Finally, **this case study illustrates the difficulty in detecting spillover. Not only are the characteristics of an MPA crucial to spillover occurring (e.g. size, time since designation, and fishing restrictions), but the monitoring regime employed by those who study it must also be exact; with ideally baseline surveys required before designation, the surveying of control sites, and fine-scale monitoring of the local fleet and its catches.** While monitoring is taking place at both MPAs, the lack of a baseline survey including control sites means that the BACI approach is not possible.

7 CONCLUSIONS

This case study has not been able to detect any direct evidence of ecological or fishery spillover. The main limitations of the study are a lack of raw data and a small body of literature on either MPA – this is largely due to the recent designation of both MPAs. In place of quantitative analyses stakeholder surveys were carried out to gauge perceptions of both MPAs with respect to spillover. The results from both the literature review and the stakeholder survey point towards little chance of spillover from any crustacean species. A lack of management measures in both MPAs, despite some restrictions on parlour pot usage, mean populations have not increased since both MPAs' designation. However, there was evidence of an increase in the number of lobsters below MLS at the Écréhous, indicating that it could be a nursery for lobsters. Stakeholder perceptions typically reflected the literature on crustaceans but were largely positive that scallop catches could be increasing, partially due to the establishment of the MPAs. Stakeholders also cited a potential increase in the number of fishers targeting scallops through dredging and diving. However, no reports based on scallop surveys have been released so these claims are merely anecdotal at this stage. This case study highlights the need for fine-scale fleet monitoring, a sound monitoring methodology that permits ideally a BACI approach to assessing spillover, and the need for strong management measures within MPAs to allow commercial species' abundances to increase. All of these are important prerequisites that are required to help detect spillover.

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10. CASE STUDY REPORT:

LAMLASH BAY AND SOUTH ARRAN

UK – CELTIC SEA

Analysis of potential spillover effects around the Lamlash Bay no-take zone and the South Arran Marine Protected Area

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LIST OF ABBREVIATIONS

Term	Description
BACI	Before After Control Impact
COAST	Community of Arran Seabed Trust
CPUE	Catch per Unit Effort
HPMA	Highly Protected Marine Area
MLS	Minimum Landing Size
MPA	Marine Protected Area
NGO	Non-governmental Organisation
NTZ	No-Take Zone
SACFOR	Super-abundant, Abundant, Common, Frequent, Occasional, Rare (abundance scale)

1 EXECUTIVE SUMMARY

In 2008, after persistent campaigning from locals on the Isle of Arran, the Lamlash Bay no-take zone (NTZ) was designated. Covering an area of 2.67 km^2 between the Holy Isle and Lamlash on the Isle of Arran, the NTZ is protected against all types of fishing that is not carried out for scientific purposes which requires a permit from Marine Scotland. The MPAs designation was prompted by local concerns that nephrops trawlers and scallop dredgers were degrading habitat and decreasing the biodiversity found in the waters around Arran. Much of this local pressure came from the Community of Arran Seabed Trust (COAST) – an NGO that advocates for and monitors the recovery of the seabed and biodiversity in the waters of Lamlash Bay and South Arran. Continued monitoring of the NTZ by COAST and the University of York has occurred since 2010, 21 months after the MPA's establishment. Evidence of recovery in the NTZ, paired with further advocacy for seabed protection, led to the designation of the South Arran Marine Protected Area (MPA) which protects a wider area of 250 km^2 around the NTZ from bottom trawling and dredging. This study assesses the potential for fisheries and ecological spillover of commercially important target species from both the Lamlash Bay NTZ and the wider South Arran MPA into their surrounding waters.

Ideally, a Before After Control Impact (BACI) approach to assessing spillover could have been used, however monitoring for the NTZ did not take place prior to designation meaning no "before" data exists for comparison with changes after the designation. Similarly for the wider MPA, all baseline sites sampled before designation were contained in the eventual MPA, meaning no control sites existed from before the MPA was designated. In the absence of these raw data from both protected areas, a literature review was completed covering all relevant studies and grey literature pertaining to the MPAs. To supplement this, a stakeholder survey was also attempted, with the views of those closest to the MPAs being surveyed relating to changes since designation, management of the MPAs, and spillover.

Results from both the literature review and the stakeholder surveys found potential indirect evidence of spillover. For king scallop, densities, reproductive and exploitable biomasses were shown to have increased inside the NTZ relative to those outside of the MPA in 2014. Increased reproductive biomass of king scallops also points towards increased larval export from the NTZ, potentially resulting in spillover. Furthermore, a negative gradient of scallop densities and distance from the NTZ boundary was found. This could be evidence of spillover, with larval dispersal decreasing with distance from the NTZ. However, this may be evidence of a phenomenon termed the "Halo effect", where fishing effort increases with distance from a MPA.

Results for lobster populations were mixed, with catch per unit effort (CPUE) patterns fluctuating between 2012-2018. A slight increase was observed between 2015-2017, before decreasing in 2018. However, CPUE was higher for the NTZ than surrounding controls. The decrease observed in 2018 is thought to be the result of density dependence as very large individuals were found in the MPA. These are thought to hold larger territories and potentially deter smaller lobsters and brown crabs from occupying nearby seabed. CPUE of above MLS lobsters was found to decrease with distance. Again, this may be evidence of spillover but may also be the result of the "halo effect". The greater lobster size found in the NTZ may also be indirect evidence of spillover as lobster fecundity is directly related to size. Larger individuals within the NTZ are likely contributing to a net export of larvae into the surrounding waters; potentially supporting sink populations in fished areas. Tagging studies of lobsters showed movement of individuals both into and out of the NTZ but no significant net movement was observed.

Future studies into spillover from both the NTZ and the MPA should look to assess catch data where possible, providing more insight into whether catches changed before and after the designation of either protected area. More directed research could also employ genetic methods to assess whether juveniles in surrounding waters were the sprat of adults inside the MPAs. For lobsters, acoustic tagging could reveal more fine-scale movement to determine whether there is significant net migration out of the MPA.

Despite the evidence for spillover identified in this study being indirect, it should be noted that monitoring of both the NTZ and the MPA has shown habitat recovery, increased biodiversity in benthic assemblages, and significant changes in abundance of some commercially fished species. MPAs can take many years to recover from intense bottom trawling and these results are encouraging that both protected areas may be able to support commercial populations that spillover into surrounding fisheries in the future.

2 BACKGROUND

Arran is an island off the west coast of Scotland, situated in the Firth of Clyde. With an area of 432km^2 and a coastline stretching over 100km, Arran's marine resources are important to both its inhabitants and to fishers operating in its waters from mainland Scotland. The wider Firth of Clyde has long supported diverse and productive finfish fisheries for Herring, Cod, Haddock, Turbot, and Flounder (Thurstan and Roberts, 2010). However, poor management strategies have caused these stocks to dwindle from the 1980s onwards (Mesquita et al., 2016). One of the important decisions affecting these stocks was the lifting of the ban on trawling within three nautical miles of the shore in 1984 (Stewart et al., 2020; Thurstan and Roberts, 2010). As finfish stocks declined, fishers shifted target species towards shellfish, particularly Dublin Bay prawns (*Nephrops norvegicus*), king scallops (*Pecten maximus*) to a lesser extent European lobster (*Homarus gammurus*) and brown crabs (*Cancer pagurus*) (Thurston and Roberts, 2010). Today, this shellfish fishery accounts for 98% of commercial landings throughout the Clyde, filling the economic gap left by dwindling fish stocks (Howarth et al., 2016). Lobster and crab are typically caught by potting from smaller vessels, prawns are mostly caught by otter trawls, and scallops are mainly caught by Newhaven dredges with some being collected by divers (Stewart et al., 2020). The bottom-towed fishing gear used to catch prawns and scallop have a significant effect on benthic ecosystems, with organisms either being caught or damaged by the heavy gear being towed over them (Kaiser et al., 2006). This homogenizes habitat, reducing its complexity and thereby reducing its ability to act as a nursery for juvenile fish, molluscs, and crustaceans.

The Community of Arran Seabed Trust (COAST) was established in 1995 by Howard Wood and Don MacNeish; two local divers from the Isle of Arran who were concerned about this decline in local habitat complexity caused by bottom-towed fish gear. COAST and its members set up a grassroots campaign that, after 12 years, led to the establishment of the Lamlash Bay No-take Zone (NTZ) in September 2008. The 2.67 Km^2 site is located in the north of Lamlash Bay between the Holy Isle and the northern shore of the bay (Figure 1). This zone prohibits all types of fishing except for that which is part of scientific surveys under a Marine Scotland permit. The NTZ has been surveyed since 2010, with the amount of research and output being based on the funding that has been available to COAST, the University of York, and to a lesser extent the University of Glasgow.

In September 2010 further concerns raised by COAST about the degradation of the marine ecosystems in the Firth of Clyde led to meetings with the Scottish Cabinet-Secretary for Rural Affairs and the Environment, Richard Lochhead. This meeting led to the Scottish Government commissioning their own research into the state of the area. The findings of this report confirmed findings of marine degradation within the Clyde (Thurstan and Roberts, 2010). Following this, a summit was held in April 2014 bringing together Scottish Ministers and over 100 stakeholders from the Clyde to discuss how the marine management of the area could be improved. Later that year in August 2014, the South Arran Marine Protected Area (MPA) became one of 30 MPAs that were designated in Scottish waters. Covering an area of 250km^2 including Lamlash Bay, the MPA had no specific management measures in place at the time of its designation. However, in 2016, off the back of consultations by the Scottish Government on potential management measures in which results from the Lamlash Bay NTZ were presented, scallop dredging was banned throughout the MPA. Trawling was allowed to continue in certain outer regions, with potting being permitted across much of the MPA, except where particularly seabed habitats were found (Stewart et al., 2020) (Figure 1).

The managing and enforcement of the both the NTZ and the MPA at south Arran are technically the responsibility of the Scottish Government, however most monitoring is undertaken by COAST, University of York and University of Glasgow. The designation process of both protected areas has largely been bottom-up, with very strong campaigning by the local community on Arran. The South Arran could be viewed as an example of top-down designation, as the MPA is one of 30 MPAs designated under obligations from the UK Marine and Coastal Access Act of 2009 (HM Government, 2009). However, without local involvement from COAST and the people of Arran, this MPA would likely not have been designated.

Given the Lamlash Bay NTZ was established over 15 years ago, it seems likely that some spillover effects might have been observed by studies or by the local fishing community of Arran. Up to this point in time, no study has collated all available data and evidence on the occurrence of spillover at the Lamlash Bay NTZ and the South Arran MPA. This study applies the findings of historical research with stakeholder surveys to assess whether spillover is occurring, or whether it is thought to be occurring in the eyes of those closest to both protected areas.

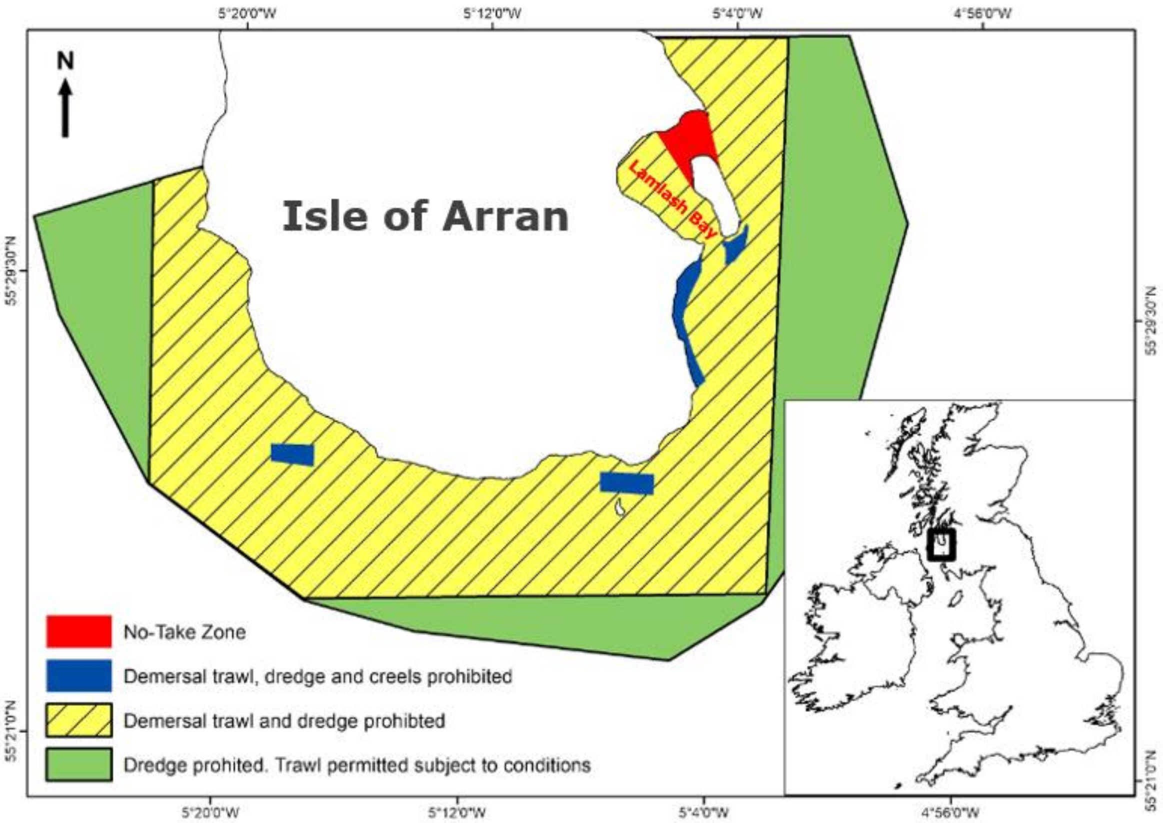

Figure 1: map of the Lamlash Bay no-take zone (shaded red) with the various zones of the South Arran MPA in the surrounding waters (Stewart et al., 2020).

3 AIMS AND OBJECTIVES

Spillover is an important factor to assess when measuring the success of an MPA in relation to both ecological and socio-economic goals. Success on both fronts helps secure positive engagement from and between stakeholders, leading to a common goal of sustainable fisheries management under an ecosystem-based approach. This case study of the Lamlash Bay NTZ and the South Arran MPA aims to inform whether spillover has been detected at both MPAs, whether it is perceived to be occurring by local stakeholders, and what methodologies are used for its assessment. These aims and their associated objectives are listed below:

1. Assess spillover effects associated with the Lamlash Bay NTZ or the South Arran MPA
    - Investigate any potential ecological or fishery spillover in areas surrounding both protected areas;
    - Identify any key factors that may influence spillover dynamics such as MPA design, fishing practices, and habitat characteristics;
    - Assess changes in temporal or spatial patterns of commercial stocks after the establishment of the respective protected areas.

2. Gain an understanding of stakeholder perceptions of spillover associated with both the Lamlash Bay NTZ and the South Arran MPA
    - Understand local stakeholder perceptions of the MPAs and their associated restrictions;
    - Gather information on any changes to catches before and after the designation of both areas in proximity to MPA boundaries.

3. Evaluate any current or previous studies investigating spillover effects from either the Lamlash Bay NTZ or the South Arran MPA
    - Assess the suitability, practicality, and effectiveness of methodologies used to assess spillover;
    - Identify any limitations associated with the methodology;
    - Provide recommendations for refining or improving the methodology for studies into spillover at similar MPAs.

4 METHODOLOGY

4.1 Literature review

Due to a lack of available raw data on either the Lamlash Bay NTZ or the South Arran MPA, a qualitative approach to spillover assessment was employed. It was hoped that a before, after, control, impact analysis (BACI) could be undertaken using outputs from previous studies, however, all monitoring of the MPAs came after their designation, meaning no data from before 2017 could be used as a benchmark for comparison. As a result, a literature review of all relevant scientific and grey literature relating to the ecology of the MPAs and their surrounding waters, and the fisheries that operate both inside and outside the MPAs. Literature searches used Boolean logic to combine terms for the Lamlash Bay NTZ and South Arran MPA and different topics. For example, "Lamlash Bay No-take zone" OR "South Arran MPA" AND "spillover" OR "fish biomass" OR "fishery". This produced searches that provided literature relating to research conducted in both protected areas focusing on changes in commercially exploited populations, fish community assemblages or impacts on the local fishery. Searches used ResearchGate, Google Scholar, and Science Direct, with all relevant literature being stored and managed in a Zotero library. Direct contact was also made with several people that were particularly familiar with the study sites, this produced some more relevant publications.

4.2 Stakeholder survey

We developed a questionnaire to assess the perceptions of key stakeholders on the potential spillover effects in their nearby MPAs. The questionnaire comprised of open-ended and closed questions to elicit stakeholder views and experiences on the different aspects of this study (Annex 4). The open-ended questions aimed to capture stakeholder opinions on, for example, how aware the stakeholder was of the regulations and management measures of the MPA. The closed questions were statement-based and used Likert scale answer categories (such as: Strongly agree; Agree; Neutral; Disagree; Strongly Disagree) for the stakeholder to choose from.

The questions were grouped into four broad categories to encapsulate the key issues being studied. These included:

(i) Respondent information. The first section required basic information from the respondent, including their name, institution and the type of stakeholder category they belonged to.

(ii) Background information. The second section of the questionnaire gathered background information from the stakeholder to understand more about the respondent and their use of the MPA. Questions included knowledge of when the MPA was established, the type of restrictions in place and how long the stakeholder has been associated with the MPA either through research, fishing or managing it.

(iii) Fishery impacts of MPAs. The third section explored the respondent's perceptions of the socio-economic impacts of spillover from the MPA. Stakeholders were asked to state whether the designation of an MPA / area where fishing is limited has led to an increase in revenues for fishers, whether the fishing community in the area feel their fisheries livelihoods are more secure after the MPA was established, and the extent to which they believe spillover from the MPA has influenced the catch composition in adjacent fishing grounds.

(iv) MPAs as management tools. The fourth section of the questionnaire focused on the respondent's perceptions on whether MPAs are conservation or fisheries management tools. Stakeholders were asked to state whether their local MPA was acting as a conservation tool, a fisheries management tool or both. Other questions under this section required stakeholders to state their agreement / disagreement on whether the establishment of MPAs is an effective conservation strategy to support fish populations and commercial fisheries in their area. Respondents were also asked to indicate what factors they thought were contributing to spillover effects.

Four key stakeholder groups were targeted under this consultation including commercial and recreational fishers, fisheries managers and government authorities, scientists and environmental non-government organisations (NGOs). Therefore, while the four sections of the questionnaire where the same, specific questions were included for each of the four respondent groups. The questionnaire was set up as an online survey to improve ease of response for stakeholders.

The link was sent to three scientists that have researched the MPAs, several individuals from a local marine conservation NGO on the isle of Arran, two local fishers, two local scallop divers, and one fisher association from the wider Firth of Clyde area. To ensure that more stakeholders respond, interviews were conducted over the phone with two key stakeholders using the survey as a template so that responses were comparable.

5 RESULTS

5.1 Literature Review

Monitoring of the Lamlash bay NTZ first began in July 2010, roughly two years after the MPA was designated. These surveys were carried out by a combination of researchers and students from the University of York, local volunteers from COAST, and local commercial fishers. Unfortunately, as no baseline survey was carried out prior to the NTZ's designation, it is inherently very difficult to produce concrete evidence of spillover as the Before, After, Control and Impact (BACI) approach (the best model analysis for detecting spillover) is not possible. However, the following section outlines studies that have taken place in and around the Lamlash Bay NTZ and the wider South Arran MPA. These can offer some insight into the state of the marine ecosystems and stocks within the MPAs from which spillover may be occurring.

Assessment of scallop abundance and biomass changes in Lamlash Bay NTZ

Initial Lamlash Bay surveys in 2010 involved photo-quadrats and transects as well as dissections of scallops (Howarth, 2014). These showed higher mean abundance of juvenile scallops within the NTZ than outside of it (Figure 2) as well as a positive correlation between these abundances and greater macroalgae and hydroid coverage (Figure 3). This was thought to be the result of reduced predation pressure in areas with habitat that provide greater cover for juveniles (Howarth et al., 2011; Lambert et al., 2011).

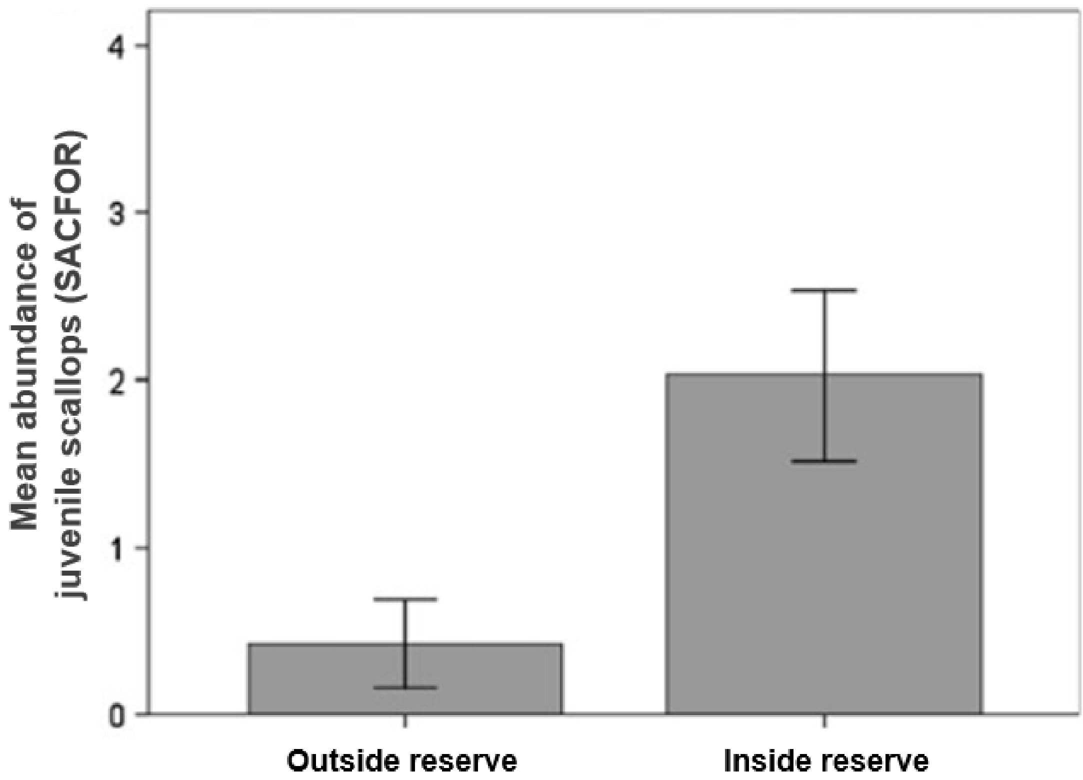

Figure 2: mean (and standard error) estimated abundance of juvenile scallops (using SACFOR) within and outside of the Lamlash Bay no-take zone (Howarth et al., 2011).

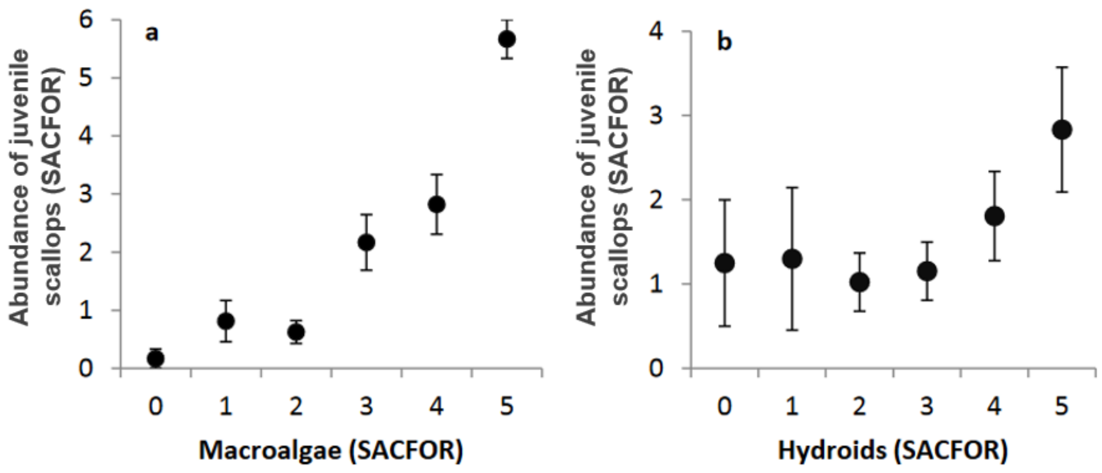

Figure 3: shows the significant trend in juvenile scallop abundance with (a) Macroalgal cover and (b) Hydroid abundance (source: Howarth, 2014).

Despite this relative increase in juvenile scallop abundance, surveys running up to 2014 showed no significant difference between adult scallop density inside and outside the NTZ. However, king scallop age, size, and exploitable and reproductive biomass were all significantly greater inside the NTZ than outside (Figure 4). Furthermore, incorporating government data on size composition of king scallops landed in the Firth of Clyde region showed individuals of legal landing size were largest in the NTZ, followed by those sampled directly outside the NTZ (Howarth, 2014).

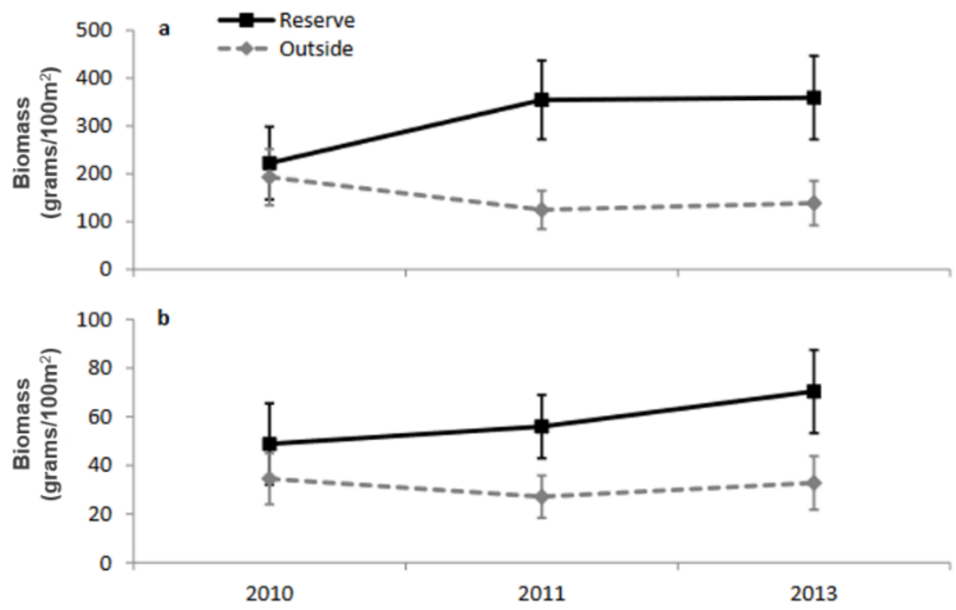

Figure 4: mean (and standard error) exploitable (a) and reproductive (b) biomass of king scallops at sites inside and outside the NTZ for years 2010-2013 (source: Howarth, 2014).

Further study on data up to 2014 (Howarth, 2014) also revealed a significant difference in scallop density along a distance gradient from the NTZ boundary (Figure 5), with densities inside the NTZ being up to three times greater than those seen at sites up to 2km from the MPA boundary (Howarth, 2014).

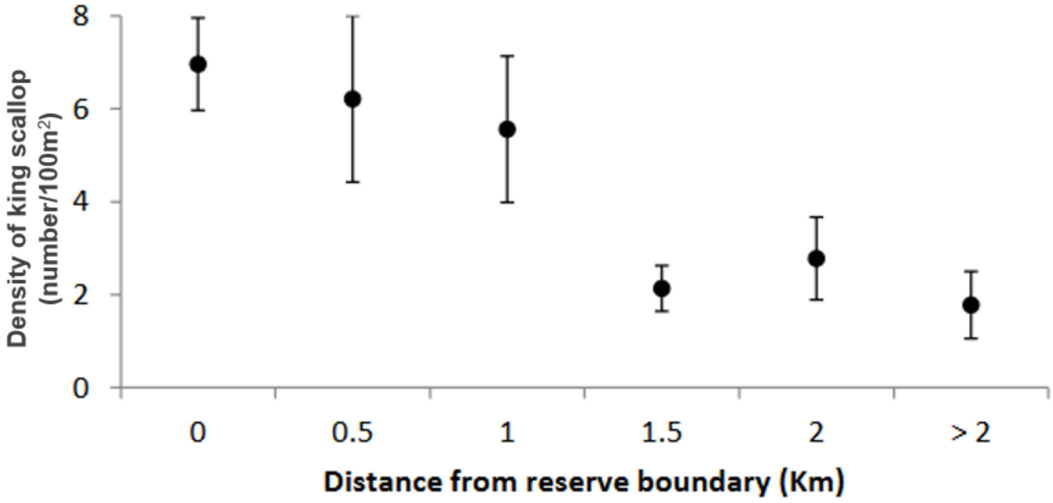

Figure 5: shows mean (and standard error) density of king scallops for the years 2010-2013 along a distance gradient from the NTZ boundary, distances of 0 represent sites located inside the NTZ boundaries (source: Howarth, 2014).

More recent surveys carried out in 2019 found that over a decade on from designation, king scallop density had increased dramatically inside the NTZ with a density 3.7 times higher than it was in 2013 (Figure 6) (James, 2019). The results showed densities inside the NTZ to be significantly higher than those seen at sites outside the wider MPA that were open to dredging. Scallop densities at the near-control site within the South Arran MPA were also high and not significantly different from those seen inside the NTZ. Figure 6 shows the mean density of king scallops across the four different site types surveyed in 2019 (James, 2019).

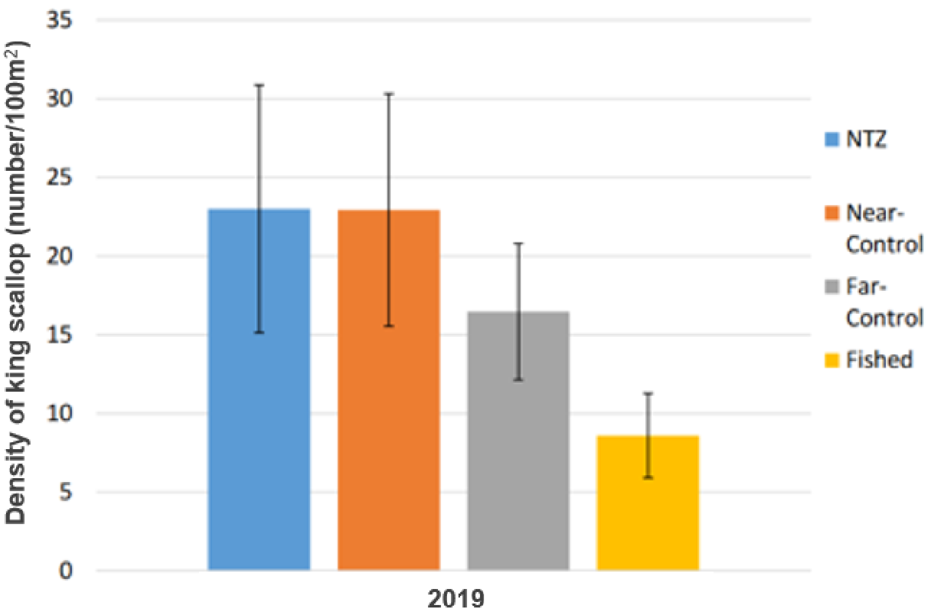

Figure 6: shows mean (with standard error) scallop densities within the NTZ, at near- and far- control sites within the wider South Arran MPA, and at sites that are open to dredging (source: James, 2019)

Published studies for the effects of the NTZ on crustaceans used survey data collected between 2012 and 2018. These assessed population dynamics of two commercially important species: the European Lobster *Homarus Gammarus* and the Brown Crab *Cancer pagurus*. Surveys consisted of potting and measuring both catches, and measurements of individuals caught, with some being tagged.

Assessment of Crustacean CPUE, size, and fecundity in Lamlash Bay NTZ

For most survey years, lobster CPUE was significantly higher inside the NTZ, with the greatest differences in catch rates being for lobsters above Minimum Landing Size (MLS) (e.g., roughly 4 times higher CPUE inside the NTZ than outside in 2018) (Figure 7). Howarth et al., (2016) also observed a decrease in lobster CPUE with increased distance from the NTZ boundary up to 20km away (Figure 8) (Howarth et al., 2016). Tagging and recapture studies showed that lobsters were moving both into and out of the NTZ. This is not direct evidence of spillover, but evidence of lobsters leaving the NTZ could indicate some density dependence at play in the NTZ lobster population (Howarth et al., 2016). Finally, lobsters within the NTZ had consistently larger size measurements which is directly linked to egg production. This, paired with increased survivorship of mature individuals, likely contributed to lobsters inside the NTZ having 5.7 times more eggs than those in an unprotected sampling site of equal size in 2018 (Stewart et al., 2020).) (Howarth et al., 2016). Tagging and recapture studies showed that lobsters were moving both into and out of the NTZ. This is not direct evidence of spillover, but evidence of lobsters leaving the NTZ could indicate some density dependence at play in the NTZ lobster population (Howarth et al., 2016). Finally, lobsters within the NTZ had consistently larger size measurements which is directly linked to egg production. This, paired with increased survivorship of mature individuals, likely contributed to lobsters inside the NTZ having 5.7 times more eggs than those in an unprotected sampling site of equal size in 2018 (Stewart et al., 2020).

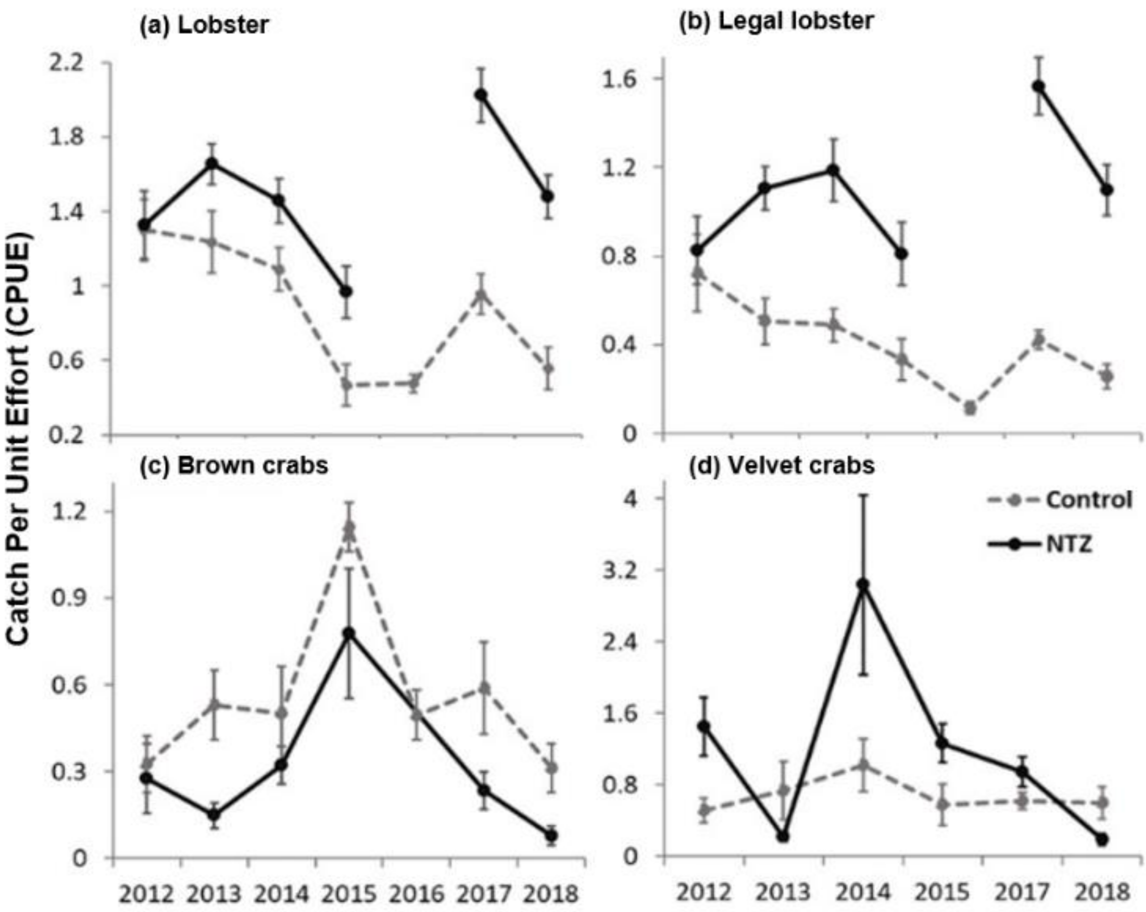

Figure 7: mean CPUE of lobsters, lobsters above MLS, brown crab, and velvet swimming crab within the NTZ and at control sites over a 6-year study period (2012-2018). Data from 2016 is missing because no surveys took place that year (source: Stewart et al., 2020).

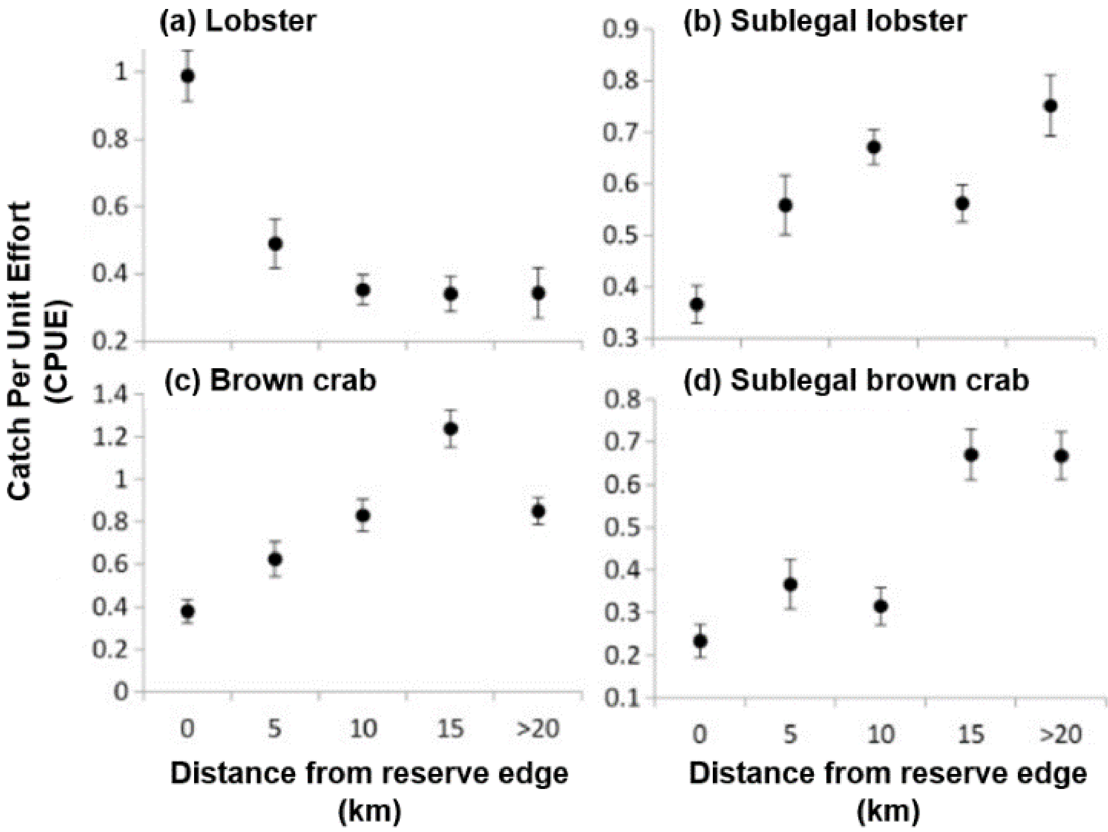

Figure 8: mean CPUE of both lobster and brown crab for individuals above and below MLS plotted against distance from the boundary of the NTZ, combined for years 2012-2015. Distance = 0 represents sampling sites within the NTZ (source: Howarth et al., 2016).

Research into brown crab population dynamics yielded very differing results to those seen for lobster. Throughout the crustacean survey period, catches of brown crab were consistently higher in surrounding sites than those inside the NTZ and CPUE increased with distance from the NTZ. It was hypothesized by Howarth et al., (2016) that brown crab abundance is negatively affected by lobsters through inter-specific competition, causing them to be driven from the NTZ which has high densities of large lobsters.

Assessment of observed changes since South Arran MPA designation

Monitoring in the waters of South Arran began before the MPA was designated in 2016. This offered an ideal baseline for comparison when assessing the effectiveness of the MPA as both a conservation tool and a fisheries management tool. Unfortunately, all baseline surveys were carried out in what is now the MPA meaning that, as with the NTZ, it is not possible to use the BACI approach to assess spillover due to a lack of a control site prior to the designation of the MPA. As with the NTZ, spillover assessment must rely on the outputs from previously completed studies and not on raw data.

Around 40 dive surveys were completed throughout 2014 and 2015 in the waters of the South Arran MPA prior to its designation. These typically involved videoed transects where recordings were kept for future reference against newly completed transects. Currently, the most recently published results are from the 2019 surveys (James, 2019). While no crustacean results are in the public domain, results on scallop densities show a rapid recovery of the king scallop population after only three and a half years of protection from dredging. Results show densities of king scallops within the MPA to be over six times those seen in previous surveys carried out in 2015 as part of the baseline study (James, 2019). Finfish studies have also been completed in the South Arran MPA via drop-down camera surveys, however these assessed behaviours in juvenile gadoids which do not represent commercially important species in the Firth of Clyde anymore.

5.2 Stakeholder Survey

Despite efforts to organise a visit to Lamlash Bay for interviews with stakeholders, it was not possible to carry out any in-person stakeholder engagement. This was primarily due to scientists and NGOs working at the site being too busy conducting their summer surveys. Also, despite numerous emails and phone calls to fisher associations in the Firth of Clyde, no survey responses were given by fishers of any kind. This is potentially the result of a combination of stakeholder fatigue and current political tension surrounding the now scrapped highly protected marine areas (HPMAs) plan by the Scottish Government. Overall, three stakeholders responded to the survey in full, with two being part of a local NGO, and one being a scientist that has researched the NTZ since 2010.

Ecological change after NTZ/MPA Designation

Respondents all concurred that significant ecological change occurred in the years after the NTZ was designated. For the NTZ, these changes were difficult to detect in the first few years after designation with one respondent citing no prior monitoring before designation as a potential explanation. Increases in abundance, complexity, and functional biodiversity were cited in the early stages of protection with very large examples of monkey-puzzle bryozoans that build habitat complexity. Furthermore, biological traits analyses of benthic organisms showed significant differences between the NTZ and the South Arran MPA and areas that are open to dredging. One NGO respondent also stated that there had been anecdotal evidence of increased numbers of juvenile gadoids in the NTZ.

Responses stated that scallop densities were initially slow to recover in the NTZ but are now 3.7 times the levels seen in 2010 surveys. For South Arran MPA sites, scallop densities increased far more rapidly, with current densities being seven times those seen in 2016 when the MPA was first designated. According to the scientist respondent, scallops inside the protected areas had significantly larger gonads than those outside.

Changes to crustacean populations have been more complex according to the scientist respondent. Lobster populations increased within the NTZ after designation in initial years of protection. However, in recent years the high lobster abundance has decreased and given way to lower densities with some very large individuals (with carapace measurements of up to 230mm – nearly three times the MLS). Brown crab densities have been consistently low since surveys began in 2010. According to the scientist respondent, this may be the result of high interspecific competition with lobsters for habitat and prey in what is a small protected area.

Management issues

All three responses agreed with the following statement: "in order to develop commercial fisheries, certain areas of the MPA should be permanently closed to fishing". Stakeholders felt that if the correct habitats that harbour and protect exploitable stocks are protected, there will be benefits to neighbouring fisheries. It was stressed by the scientist respondent that these protected areas are better placed where sensitive habitat is present such as maerl or seagrass beds. All respondents felt the NTZ and MPA act as both a conservation tool and a fisheries management tool, and that the MPA favoured lower impact fishing methods using static gear or picking scallops by hand. In terms of collaboration with the fisheries industry, stakeholders felt local collaboration with fishers from the Isle of Arran had been very important in the success of the NTZ and MPA. However, they responded that the wider fishing industry had strongly opposed both the NTZ and the MPA, particularly since the attempted introduction of the HPMAs by the Scottish Government.

Spillover

The importance of commercial fishery spillover was a topic of high priority for the scientist respondent but was of less importance to the NGO respondents, with seabed and habitat recovery and ecological spillover being of more interest to them. All responses stated that, in their opinion, spillover of either commercially fished species or their larvae was occurring from the protected areas. This was largely in reference to king scallop, with one NGO respondent stating that scallop diver catches were said to be higher since the designation of the South Arran MPA reduced competition with scallop dredgers. When asked about whether spillover from the protected areas has influenced catches of adjacent fisheries, all respondents were unable to answer due to a lack of data on local catches.

Regarding survey data on the NTZ and MPA, the scientist responded that there is a possibility of spillover from the scallop population inside protected areas around Arran. This is based on results showing larger gonad biomass inside the NTZ than outside and based on the high scallop densities seen in both the NTZ and the MPA. The respondent cited density as an important factor in the fertilisation rate of broadcast spawners. The higher densities inside both protected areas should lead to greater production and export of larvae from inside the protected areas than outside.

According to the scientist respondent, no concrete evidence of spillover has been found throughout the survey years. Tagging surveys did show movement of lobsters into and out of the NTZ, however there was no significant net movement that would indicate spillover. There is interest in carrying out more detailed acoustic tagging surveys that use receivers to give fine-scale spatial data, but this is subject to further funding. The respondent also cited previous research that assessed CPUE of lobsters along a distance gradient from the NTZ boundaries. Initially this showed a negative correlation between CPUE and distance from the NTZ boundary which may have been the result of spillover, however this pattern has since broken down.

The scientist respondent noted that little is understood about marine ecosystem succession after the establishment of a protected area in temperate waters. They also said that while little changes may be observed at the levels of some commercial stocks, once the habitat recovers the area may be able to support greater abundances of commercially important species. When asked if the NTZ and the MPA were benefitting from spillover all stakeholders responded positively, in particular when referring to scallop fisheries.

6 DISCUSSION

Based on results from both the literature review and the qualitative stakeholder surveys, there is no direct evidence of spillover occurring from either the NTZ or the MPA. This does not mean no spillover is occurring, in fact stakeholder responses were unanimous in their opinions that spillover from both protected areas was benefitting neighbouring fisheries. Despite a lack of concrete evidence, some results found in the literature may be indirect evidence of spillover. These results are summarized in Table 1.

Table 1: summarizes the results of the literature review and any potential evidence of spillover in each studied species.

Species	Reference Figure	Metric	Time frame	Δ MPA	Δ Ref	Scenario Description	Spillover?
P. maximus	Figure 4	Exploitable Biomass	2010-2013 (two years since NTZ designation)	Increase	Slight decrease	Exploitable biomass increased in the NTZ while decreasing at control sites outside the NTZ	No
	N/A	Reproductive Biomass	2010-2013	Relative increase compare with control site	Relative decrease compared with NTZ site	Reproductive biomass was up to 2.5 times greater inside the NTZ than outside	Potentially, greater reproductive biomass may increase likelihood of larval export
	Figures 5 and 6	Density (per 100m^2	2010-2013 (two years since NTZ designation)	Relatively higher	Relatively lower	Mean density of scallops decreased with distance from NTZ boundary	Potentially from NTZ, but may be result of "Halo effect")
H. gammarus	Figure 7	CPUE	2012-2018	Complex pattern, potential slight increase	Decrease	CPUE fell from 2012 – 2015, before increasing for 2017 and decreasing slightly in 2018	No
	Figure 7	CPUE of lobsters over MLS	2012-2018	Increase	Decrease	CPUE inside NTZ increased gradually with a slight drop in 2015. CPUE fell in control sites	Potentially – fecundity increases with size. Large individuals inside the MPA may export larvae.
	Figure 8	CPUE of lobsters at sites with distance from the NTZ	2012-2018	High for above legal lobsters, low for sublegal lobster	Mixed depending on age class	CPUE of legal lobsters decreased with distance from NTZ while sub-legal increased with distance	Potentially, but may be the result of the "Halo effect"

Dissections from Howarth (2014) found both the **exploitable and reproductive biomass of king scallops inside the NTZ to be 18% and 39% greater respectively than those dissected from sites outside the MPA**. By 2013, this disparity in biomass had increased so that exploitable biomass inside the MPA was twice that outside, and reproductive biomass was 2.5 times greater than outside (Howarth, 2014). While this result is not direct evidence of spillover, the greater reproductive biomass readings inside the NTZ, paired with the broadcast spawning strategies seen in scallops do point towards high potential for larval export from individuals inside the NTZ. This may supply scallop sprat to other areas around the Firth of Clyde that may be fished, thereby providing a benefit to surrounding fisheries.

In the same research, Howarth found that **density of king scallops declined significantly with increasing distance from the NTZ, with sites inside and adjacent to the NTZ supporting scallop densities of up to three times those seen at sites over 2km from the NTZ** (Howarth, 2014). This result further supports the notion that high larval export from the NTZ is occurring. A higher density of scallops in an area will increase the output from broadcast spawning, resulting in a higher number of fertilisations and larvae produced. This result may also be evidence of spillover as the decrease in the density of scallops from the NTZ boundary may be due to decreased larval supply from NTZ as distance increases. **However, this result should be presented with caution as it may be the result of an exploitation pattern referred to as the "halo effect" that gives similar results to those created by spillover.**

The halo effect occurs where fishing effort increases with distance from an MPA where that fishing method is prohibited (Howarth, 2014). In the case of Lamlash Bay, this might be caused by more dredging in sites further away from the boundaries of the NTZ as fishers are deterred from fishing close to the MPA boundary. This may be because of concern from fishers around incidental encroachment into the NTZ while hauling gear or due to some mechanical malfunction, thereby incurring a fine or penalty. In these results, scallop densities were similar outside the NTZ to those inside up to 1km from the boundary, before dropping to a lower level at 1.5km and remaining similar for sites greater than 2km away. This may be an indication of the halo effect occurring up to 1.5km away from the MPA where increased fishing effort by bottom-trawlers is observed. Further examination of dredging effort is required to overlay spatial patterns in fishing effort with scallop densities.

The evidence for spillover occurring in lobster stocks largely reflects those seen for king scallops. **Individual lobsters within the NTZ were both larger, and more likely to be carrying eggs (berried female lobsters)** (Howarth, 2014). The size-fecundity relationship from Lizárraga-Cubedo et al. (2003) suggested that the mean potential reproductive output per female lobster in number of eggs was 27.3% higher inside the NTZ than outside (Lizárraga-Cubedo et al., 2003). Considering European lobster larvae spend considerable time in the water column, it is likely that dispersal of larvae from these large lobsters facilitates net larval export from the NTZ.

As with king scallops, **lobster CPUE was also found to decrease with distance from the NTZ boundary, in particular legal sized lobsters** (Howarth et al., 2016). Again, this may be another case where results are confounded by the halo effect. On the other hand, creeling vessels do not face the same challenges as bottom-trawlers when hauling their gear. Setting and hauling creels on the edge of the NTZ should be more feasible than trawling along its boundary, meaning this observed decrease in CPUE may be the result of spillover of legal lobsters (Howarth et al., 2016). T-bar tagging surveys carried out on lobsters in the same year did show movement of individuals across the boundary, but with no significant net direction (Stewart et al., 2020). One stakeholder involved in the monitoring of the NTZ and the MPA stated that they were hopeful of conducting an acoustic tagging assessment of crustaceans, but this is subject to the availability of funding.

The results from the stakeholder survey align very strongly with results from the literature review. This is primarily because all respondents to the stakeholder survey are involved in the monitoring and assessment of the NTZ and MPA. Repeated attempts were made to gain responses from those in the fishing industry, but none were submitted. This is likely a reflection of the highly charged political debate around the Scottish Government's HPMAs which have now been scrapped.

With respect to the detection of spillover, the surveys completed at both the Lamlash Bay NTZ and the South Arran MPA have a number of limitations. This is not the result of a poor survey strategy by those involved in the monitoring of the MPAs, but more due to the different research questions the monitoring sought to address. Monitoring by COAST and the visiting researchers assessed how recovery of the habitats and their associated biodiversity in the

MPA has progressed since designation. For the NTZ, this did not include a baseline survey prior to its designation meaning the use of a BACI approach to assess spillover around the NTZ could not be undertaken. For BACI to be possible, a baseline survey of both the NTZ and a number of control sites (ideally increasing in distance from the MPA) would have been required before the establishment of the NTZ. Similarly, the data collected on the South Arran MPA also does not allow the use of the BACI approach to assessing spillover. However, unlike the monitoring of the NTZ, this is not because of the lack of a baseline survey. Surveys of the area occurred in both 2014 and 2015, but all sites that were sampled in this period would go on to fall within the boundaries of the new South Arran MPA (Stewart et al., 2020). This means that no "before" control site was sampled prior to the MPAs designation, meaning no comparison can be made with a control site that was sampled alongside the baseline survey of sites inside the MPA. Again, this is not a criticism of the survey methodology employed by those around Arran, but simply an illustration of the different research questions being asked to the ones in this study.

Another issue with detecting spillover is the lack of CPUE data from commercial fisheries around the MPAs both before and after their designation. Detecting actual commercial fishery spillover from the NTZ and the MPA requires the analysis of commercial landings, no studies have analysed this data specifically for the purposes of detecting spillover from South Arran. This would require accurate VMS data which does not exist for many vessels below 12m, as well as highly specific catch records that allow the assessment of catches along a distance gradient from the NTZ and MPA.

This case study highlights how difficult it is to obtain results that unequivocally show spillover. However, there are several lessons that can be learned should MPA managers in other regions wish to assess spillover. Firstly, **to assess spillover using the BACI approach it is crucial to have baseline data at both the site that is to be protected, and control sites that will not be protected**. Unfortunately, in the case of Lamlash Bay these data do not exist and therefore do not allow the approach to be used. Secondly, **detecting spillover often requires methods that produce fine-scale data patterns that cannot be affected by the uneven distribution of fishing effort.** Examples of these may include the tagging and live tracking of stocks, using acoustic tags, or the introduction of a genetic marker that can be tracked through generations, allowing the detection of larval dispersal beyond MPA boundaries. Unfortunately, these methods are expensive in terms of their financial cost, the resources and equipment required, and the time they take. Those managing and monitoring MPAs typically have low funding and few staff. Potentially the best approach to assessing spillover is to make it the number one research priority of a select few MPAs that can afford to carry out the arduous research involved.

7 CONCLUSIONS

This case study has assessed all available evidence of spillover of commercially important species from both the Lamlash Bay NTZ and the wider South Arran MPA. The lack of a baseline survey prior to the NTZ designation means it is impossible to carry out a BACI approach to assess spillover. Instead, a review of the literature and a stakeholder survey were completed to assess whether spillover is occurring in the fisheries surrounding both the NTZ and the MPA. The changes observed in commercially targeted populations after the designation of the NTZ in Lamlash Bay have not followed a clear pattern. Initially, lobster abundances increased drastically before falling to give way to a lower abundance of very large and fecund individuals. This is thought to be the result of intra- and inter-specific density dependence, with very large individuals driving out smaller lobsters and brown crab.

Stakeholder responses from those involved in the monitoring of the MPAs believe this pattern is changing once again. Crustacean tagging studies showed lobsters to be moving both into and out of the NTZ, with no significant net direction. It seems likely that larval export is occurring from Lamlash Bay's NTZ from highly fecund individual lobsters. This has the potential to benefit the local lobster fishery outside the MPA through spillover, however this has not been directly measured. The same evidence of larval export was found for king scallops, with individuals in the NTZ and the MPA having significantly higher reproductive biomass. Abundances for both scallops and lobsters were also negatively correlated with distance from the MPA boundaries. This may be evidence of spillover of both populations; however, it is impossible to tell whether this is a result of the "halo effect" or of spillover without doing a BACI analysis.

This study highlights the need for sound monitoring practices, ensuring a methodology that will allow ideally a BACI approach to be used. It also highlights the complex inter- and intra-specific interactions that can arise after protection is afforded to an area of seabed. Various aspects of an ecosystem will need to recover before spillover of certain commercially targeted species is observed. It appears scallop populations are able to recover faster around Arran, with crustaceans taking longer. Future studies of the NTZ and MPA should look to examine fine-scale spatial patterns of catches by the local fleet, and should continue to monitor abundance, exploitable and reproductive biomass, and if possible, the fine-scale movement of individuals into and out of the MPAs.

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11..CASE STUDY REPORT:

ATLANTIC ISLANDS NATIONAL PARK OF GALICIA

SPAIN – THE IBERIAN COAST

Small-scale fishing vessel operating in the waters of the Atlantic Islands National Park. © Bouzas

Analysis of potential spillover effects around the Atlantic Islands National Park of Galicia

Martin Aranda and Ainhize Uriarte

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LIST OF ABBREVIATIONS

Term	Description
AINP	Atlantic Islands National Park
MPA	Marine protected area
MR	Marine reserve
POM	Particulate organic matter
SCI	Site of Community Interest
SAC	Special Area of Conservation
SPA	Special Protection Area
VMS	Vessel monitoring system

1 EXECUTIVE SUMMARY

The Atlantic Islands National Park (AINP) of Galicia in Spain, comprises four archipelagos: Cíes, Onsa, Savora and Cortegada. They are classified under Natura 2000 as Sites of Community Interest (SCI), Special Areas of Conservation (SAC) and Special Protection Areas (SPA). This group of four archipelagos is classified by the Spanish government as a national park, an official designation for terrestrial or marine areas of high natural and cultural value that are recognised as part of the country's natural heritage. Professional fishing activities, including fishing and shellfish gathering, are not excluded in this marine protected area (MPA). In fact, a very large small-scale fleet operates in its waters. The only fishing activity prohibited in the MPA is recreational fishing. This report provides a description of the AINP, the fleet operating in its waters, the conservation and fisheries management measures implemented by the administration in this area, the governance mechanisms involving the fishing sector that are in place, and a review of the scientific and grey literature with the aim of informing about potential spillover effects to the surrounding areas of the MPA.

This work used both a literature review and a questionnaire-based method to gather insights from local stakeholders. The literature review identified a small number of references focusing on the Cíes archipelago. These references found little research on the potential ecological effects of the MPA and no research providing direct evidence of spillover effects beyond the boundaries of the MPA. Two studies analysed the effects of recreational fishing restrictions on the trophic structure and dynamics inside and outside the MPA. Both studies found no significant differences between protected and non-protected areas on the trophic structure of carnivorous fish assemblages. However, findings of one the study revealed a higher biomass of carnivorous fishes within the MPA compared to the outside areas open to fishing. As the trophic structure is not influenced due to the restrictions, it is unlikely to have some spillover effects. Indeed, before spillover takes place, populations of fish within an MPA must recover to make it possible for them to spill across the MPA boundaries. This implies that MPAs should be properly enforced, suggesting that these non-significant effects on the trophic structure may be the result of the lack of restrictions on commercial fishing activity, which the authors argue hinders the consistency of conservation outcomes.

Conservationists emphasise the need for stricter regulation of commercial fishing activities for the sake of bird conservation. In the survey questionnaire, one small-scale fisherman felt that closing certain areas of the MPA to commercial fishing could be beneficial for the development of commercial fishing. This fisherman felt that current measures only improve the conservation of non-target species and that this MPA is only a biodiversity conservation tool and not a fisheries management tool. Regarding the recovery of fish populations in adjacent areas, he felt that there may have been a very limited improvement due to the reduction in fishing activity in the MPA. However, this is not the result of restrictions on commercial fishing, but rather the result of the expansion of the Port of Vigo, pollution in the area and climate change. A recent scientific assessment of the fishing pressure in this MPA found that the level of fishing effort was lower than expected, leaving open the question of whether it would be necessary to impose restrictions on commercial fishing.

The literature review and stakeholder input through the questionnaire have shown that there is very limited data and high uncertainty about fishing pressure and the impacts of commercial fishing in the area. There is therefore a need for regular monitoring of fishing activity and assessment of its impact on the status of fish stocks in the area. Once the monitoring and assessments are in place, it would be up to managers and decision-makers to decide whether to restrict commercial fishing in the MPA or not. A restriction seems unlikely, because of the high economic dependence on small-scale fishing in the area. According to the literature review, spillover would occur and could be assessed if commercial fishing were restricted in part or all of the MPA.

2 BACKGROUND

2.1 Description of the MPA and fisheries measures

The '*Parque Nacional marítimo-terrestre de las Islas Atlánticas de Galicia*', hereinafter the Atlantic Islands National Park (AINP), was created the 1st of July 2002 by Law 15/2002 of the kingdom of Spain[20]. The purpose of national parks in Spain is to ensure their conservation and public use, to improve scientific knowledge of their natural and cultural values, to promote a conservationist social conscience, to exchange knowledge and experience in terms of sustainable development, among others. These are areas of high natural and cultural value, little altered by human activity, which, because of their exceptional natural values, the uniqueness of their flora, fauna or geomorphological formations, deserve priority attention for conservation and are declared to be of general interest to the nation, being representative of Spain's natural heritage[21].

The AINP extends across the provinces of Pontevedra y A Coruña of the Autonomous Community of Galicia. The national park is predominantly maritime and has a total area of 8 333 hectares: out of which 1 195 hectares are terrestrial, and 7 285 hectares are maritime. The national park comprises four archipelagos: Cíes, Ons, Sálvora, and Cortegada (Figure 1). These archipelagos have the following designation types:

- Cíes and Ons are special protection areas (SPA) since 1988 and 2001, respectively;
- Cíes, Ons, and Sálvora are sites of community interest (SCI) since 2004;
- Cíes, Ons, and Sálvora are special areas of conservation (SAC) since 2019.

In addition, in 2008, the maritime sector of the national park was incorporated into the marine protected area (MPA) network of the 'Convention for the Protection of the Marine Environment of the North-East Atlantic' (OSPAR). The Cíes, Ons, and Sálvora archipelagos were declared sites of special protection of natural values[22], as per Decree 72/2004[23]. Conservation in the national park is regulated by the Governing Plan of the park, as per Decree 177/2018[24].

[20] Law 15/2002, of July 1, which declares the Atlantic Islands National Park (AINP) of Galicia.

[21] https://www.miteco.gob.es/es/parques-nacionales-oapn/red-parques-nacionales.html.

[22] They are spaces where conservation is necessary due to their natural, cultural, scientific, educational or landscape values.

[23] Decree 72/2004, of April 2, by which certain spaces are declared as Areas of Special Protection of Natural Values. Council of Environment of the Autonomous Government of Galicia.

[24] Decree 177/2018, of December 27, which approves the Governing Plan for the use and management of the AINP.

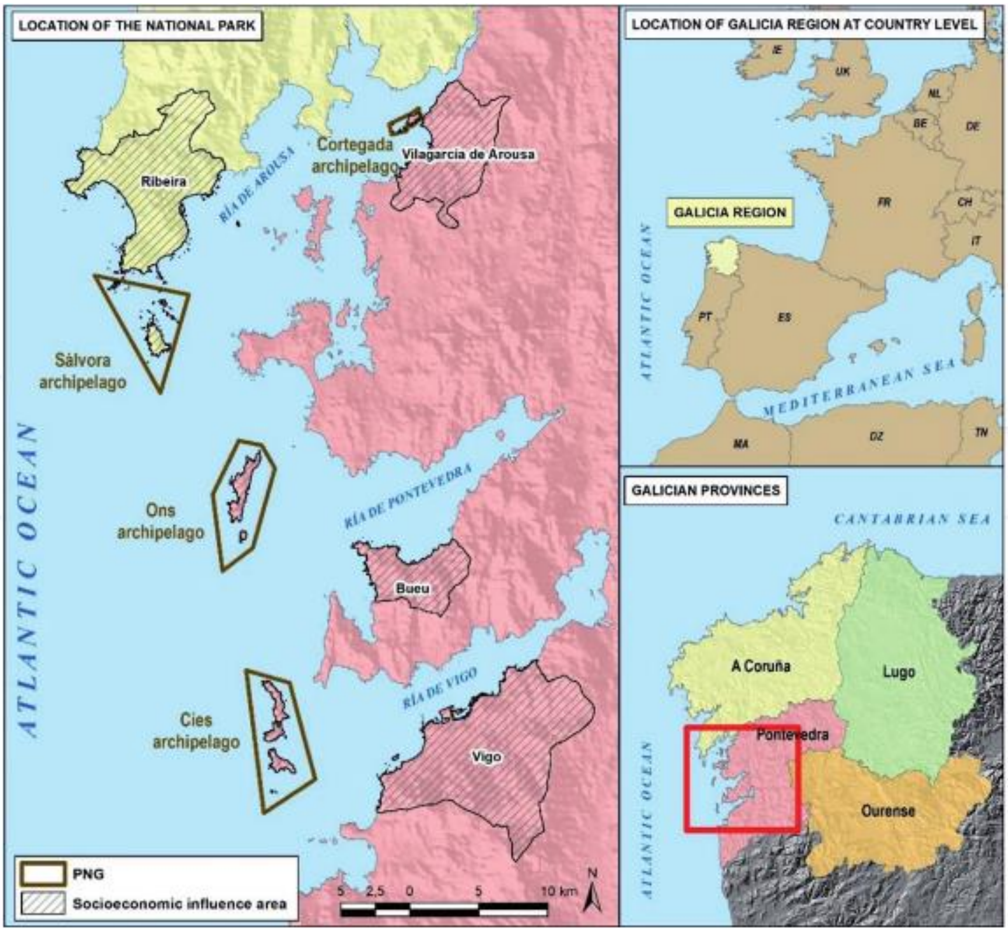

Figure 1: Geographic location of the Atlantic Islands National Park. From da Costa et al. (2022). PNG stands for the Atlantic Islands National Park.

The designation process of this MPA was conducted on a top-down basis from the general State's administration in coordination with the Government of Galicia. The fishing sector is engaged as members of the patronage of the park, where two representatives of the fishing guilds are present. The function of the patronage, which is established by the law for all national parks in Spain, is to supervise the fulfilment of the conservation objectives established for the national park.

This patronage is subject to the conservation of nature and the fulfilment of the objectives of Law 15/2002. This law prohibits recreational underwater fishing and recreational fishing in general in the national park. Professional fishing, on the other hand, is not prohibited in the park and is subject to the fishing regulations of the Fisheries Council of the Autonomous Government of Galicia. The current regional law on fishing is Law 11/2008 of the Autonomous Community of Galicia[25], enacted in 2008[26]. Law 11/2008 in turn derogated from Law 6/1993 of 1993. As can be seen, fishing in Galicia was already regulated before the designation of the National Park (in 2002) and is independent of the MPA. Law 11/2008 also regulates recreational fishing activities and explicitly prohibits recreational underwater fishing in MPAs (Article 23), and states that the regulation of fishing activities of any kind in MPAs shall be established by the Fisheries Council of Galicia and shall be subject to the fishing regulations in force. Therefore, measures for professional fishing in this MPA are not imposed by the management plan of the AINP which was enacted in 2018 as per decree 177/2018, but are strictly subject to the Regional Fisheries Law. A study commissioned by the Council of Vigo highlighted that there is not a specific fisheries management plan for this MPA with fisheries measures that considers the specific characteristics of this MPA (Fernandez et al. 2020).

[25] Law 11/2008 of the 3 of December of Fisheries in Galicia.

[26] Modified by Law 6/2009, of December 11, modifying Law 11/2008, of December 3, on fishing in Galicia.

Therefore, professional fishing in this MPA is regulated in the same way as in any other marine area in Galicia. Furthermore, the Governing Plan of the Park (Decree 117/2018[27]), in its article 6.2.3, considers that professional fishing and shellfish gathering are compatible with the conservation of the Park, provided that they are duly regulated by the fisheries regulatory framework. The management plan of the MPA has been challenged in court by conservation stakeholders, such as the Galician Ornithological Society, who consider that it lacks restrictions on professional fishing for the sake of bird conservation. The Supreme Court of Galicia has dismissed the case, stating that bird conservation measures do not fall within the remit of the management plan.

2.2 Description of the fishing sector in the MPA

The abundant resources found in the waters and seabed of the AINP have contributed to the livelihoods of the island populations through fishing and shell fishing (Bouzas, 2017). These activities are of small-scale nature and more respectful of the environment, as the catches are smaller and more selective. The regulation of fishing in the national park allows for conservation and sustainable use, while providing economic and social benefits to the entire surrounding community (Bouzas, 2017).

The region of Galicia, and in particular its coastal communities, is highly dependent on fisheries. In fact, the region depends heavily on small-scale fishing activities for income, employment, and food security (Garcia-Negro, 2018; Villasante et al., 2021). Parada and Nieto (2024) estimate that around 2,326 small-scale fishing vessels may operate in the four archipelagos of the national park. Considering that 3,139 small-scale vessels are registered in Galicia, around 74% of the regional small-scale fleet operate in the park waters. Cambiè et al. (2012) estimate the number of vessels fishing around the Cíes archipelago at 565 for at least one month per year. The professional fishing activity that takes place around the different archipelagos of the park is of a multi-species and multi-métiers nature. Of particular importance is the octopus fishery, the shellfish fishery, which mainly catches bivalves, the barnacles fishery and the shellfish fishery, which involves diving, e.g. for razor clams. There is an important multi-species fleet fishing with pots and gillnets.

The fact that these activities take place in a protected area requires careful management to avoid over-exploitation of resources, the impact on the seabed of certain gear used in the park, or the by-catch of seabirds or cetaceans in gillnets. According to Bouzas (2017), the administration of the park works in collaboration with the Department of the Sea of the Government of Galicia, which has competences on fishing in these interior waters, in order to reconcile fishing activity and biodiversity conservation. Shellfish exploitation plans are drawn up by the fishing guilds (cofradías) and approved by the Administration. Fishing and shellfish gathering exploitation plans are published every year by the government of Galicia. Bouzas (2017) adds that park agents collaborate in surveillance with fisheries inspection agents to ensure compliance with the normative.

3 AIMS AND OBJECTIVES

Spillover is an important process to assess when measuring the success of an MPA in relation to both ecological and socio-economic goals. This case study aims to inform whether the implementation of the MPA yields spillover effects on the surrounding areas of the AINP and whether it is perceived to be occurring by local stakeholders.

4 METHODOLOGY

Through a literature review and a questionnaire, information was obtained for our analysis of potential spillover from the MPA.

[27] Decree 177/2018, of December 27, which approves the Governing Plan for the use and management of the Atlantic Islands National Park of Galicia.

4.1 Literature review

We identified a list of papers related to the AINP by searching scientific references using the Web of Science and Google Scholar platforms. The Web of Science platform gives access to the databases of the Institute for Scientific Information (Thomson Reuters), covering all fields of academic knowledge. The Google platform is a US multinational company specialising in services and products related to software, the Internet, electronic devices and other technologies. Google Scholar is a search engine specialised in searching for scholarly articles, scientific reports, and technical papers, as well as theses, books and abstracts from a variety of sources (university publishers, professional associations, preprint repositories, universities and other academic organisations).

The string of words used in the bibliographic search was a combination of five words (Table 1): marine reserve (MR), marine protected area (MPA), spillover, fish, Galicia, and Atlantic Islands National Park (AINP). The term "Galicia" is preferable to "Spain" because it is more concise and avoids information relating to MPAs in the Mediterranean Sea and the Canary Islands. In Spain there are many protected areas under the term "marine reserve", so a search was also carried out using this terminology.

4.2 Stakeholder questionnaire

We developed a detailed questionnaire to assess the perceptions of key stakeholders on the potential spillover effects from the MPA to the surrounding areas (see Annex 4). The questionnaires originally drafted in English were translated into Spanish.

The questionnaires were distributed by e-mail between July and early September 2023. Ten stakeholders, comprising 3 administrators, 2 associations of fishers, 3 scientists, and 2 conservationist groups were invited to fill in the questionnaire.

5 RESULTS

5.1 Results of the literature review

The number of bibliographic references obtained according to Web of Science and Google Scholar and using the combination of five terms are presented in Table 1. The literature review revealed that very little research has been carried out to assess the potential effects of the establishment of the AINP. Only two papers, Blanco et al. (2021) and Cardona et al. (2023), were written about research on the effects of the AINP, of which one referred to potential spillover effects in the discussion. A synthesis of the results of these two pioneering studies are provided below.

Table 1. Number of bibliographic references obtained according to Web of Science and Google Scholar. Results obtained by combining 5 terms. (+) **indicates "not relevant" for the study purpose.**

Abbreviations: AINP: Atlantic Islands National Park; MR: Marine Reserve; MPA: Marine Protected Area

ID	Terms	Web of Science	Google Scholar
1	Marine Reserve (MR)	144 246	47 200
2	Marine Protected Area (MPA)	16 810	150 000
3	Spillover	40 894	1 100 000
4	Fish	1 137 146	4 750 000
5	Galicia	40 141	1 110 000
6	Atlantic Islands National Park (AINP)	650	214
7	MR & spillover	409	4 340
8	MPA & spillover	360	5 200
9	MR & fish	36 926	40 300

ID	Terms	Web of Science	Google Scholar
10	MPA & fish	9 601	54 600
11	Spillover & fish	903	71 900
12	MR & spillover & fish	360	5 060
13	MPA & spillover & fish	336	5 090
14	Galicia & MR	718	1 350
15	Galicia & MPA	78	1 930
16	Galicia & Spillover	41(+)	13 900
17	Galicia & fish	2 202	105 000
18	Galicia & MR & spillover	1(+)	148
19	Galicia & MPA & spillover	0	169
20	Galicia & MR & fish	215	1 260
21	Galicia & MPA & fish	44	1 760
22	Galicia & Spillover & fish	0	2 370
23	Galicia & MR & spillover & fish	0	145
24	Galicia & MPA & spillover & fish	0	164
25	AINP & MR	72	9
26	AINP & MPA	53	13
27	AINP & spillover	2(+)	3(+)
28	AINP & fish	221	123
29	AINP & MR & spillover	1	1
30	AINP & MPA & spillover	1	1
31	AINP & MR & fish	29	9
32	AINP & MPA & fish	32	13
33	AINP & spillover & fish	2	2
34	AINP & MR & spillover & fish	1	1
35	AINP & MPA & spillover & fish	1	1

Blanco et al. (2021) estimated benthic trophic levels to assess the effectiveness of MPA management in the AINP. The study provides the first multi-species information on stable isotope values throughout the boundaries of this MPA and surrounding areas. The authors underscore that there are no specific fishing restrictions in this MPA, and only recreational fishing is prohibited in the area. The MPA was designated in 2002 to provide ecosystem resilience while allowing for artisanal commercial fishing. Blanco et al. (2021) focused only on the three archipelagos facing the open sea (from north to south): Sálvora Island, the Ons and Onza Islands and the Cíes Islands. Sampling was carried out seasonally between March 2019 and September 2020. Four sites were sampled inside the MPA and another four sites were sampled outside the MPA as reference sites. Samples included particulate organic matter (POM), plankton, algae, filter feeders, omnivores and carnivores. Muscle samples were collected from all macroinvertebrates and fish for stable isotope analysis. The effects of protection on stable isotope composition and trophic level of each species were analysed using linear mixed effects models with size as a covariate and site (8 sites) as a random effect. Significance was assessed by ANOVA.

No differences in stable isotope composition were found between MPA and non-MPA waters at either the community or species level, even for species targeted by artisanal fisheries both inside and outside the MPA, namely *Paracentrotus lividus, Mytilus galloprovincialis, Maja sp., Polliceps pollicipes, Necora puber* and *Octopus vulgaris.* The results of the study showed that, despite some limitations of the study, the protection had no effect on the lower levels of the trophic web in the

MPA studied. As an example, the Figure 2 below shows results at the community level, stable isotope values of $\delta^{13}C$ and $\delta^{15}N$ were not significantly affected by the protection measures in place at this MPA ($p = 0.55$ and $p = 0.35$, respectively). The authors conclude that the observed limited effects of protection suggest that fishing regulations within the MPA do not affect the trophic level at the base of the food web in areas inside the MPA compared to areas outside the MPA. As the trophic level is not yet influenced or changed due to the MPA measures, it is unlikely to have already spillover effects at those archipelagos.

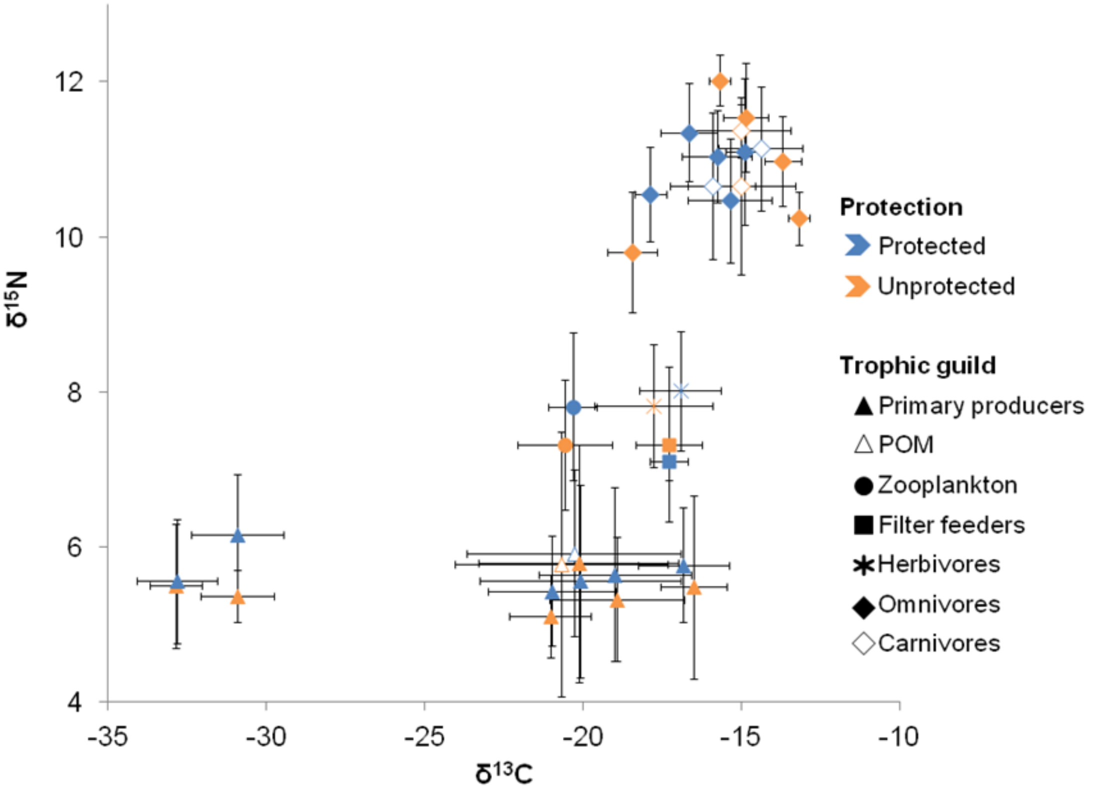

Figure 2: Biplot of $\delta^{13}C$ and $\delta^{15}N$ values in ‰ (mean± SD) of the main trophic guilds (primary producers, POM, zooplankton, herbivores, filter feeders, and primary consumers) inside (blue) and outside (orange) of the MPA. From Blanco et al. (2021).

In turn, Cardona et al. (2023) assessed the effects of protection from fishing on the food web structure of shallow rocky bottoms in two Spanish national parks: the National Park of the Archipelago of Cabrera on the Mediterranean (Balearic Islands) and the AINP. These MPAs are currently the two only maritime national parks in Spain. The authors assessed the abundance and biomass of nektobenthic fishes at two sites inside each national park, and two sites outside each park for control purposes. For the AINP, they used visual censuses carried out between June and July 2017. The fishes were measured, and their size was used to estimate the biomass. Once the censuses were completed, the researchers sampled several species of primary producers, macroinvertebrates, and fish at each site for stable isotope analysis. Generalized linear models were used to compare the effect of protection on the density and biomass of carnivorous fish, as well as on the isotope values and trophic level of the different species groups studied.

Findings revealed a higher biomass of carnivorous fishes within the AINP compared to the outside areas open to fishing (Figure 3). Results also showed an impact on the size structure of nektobenthic carnivorous fish. However, those changes did not modify the trophic structure. The authors suggest that MPAs with stricter fishing restrictions may allow for rebuilding the populations of nektobenthic carnivorous fish and restoring their size structure. Nonetheless, they are unlikely to restore the trophic structure to that of pre-fished ecosystems.

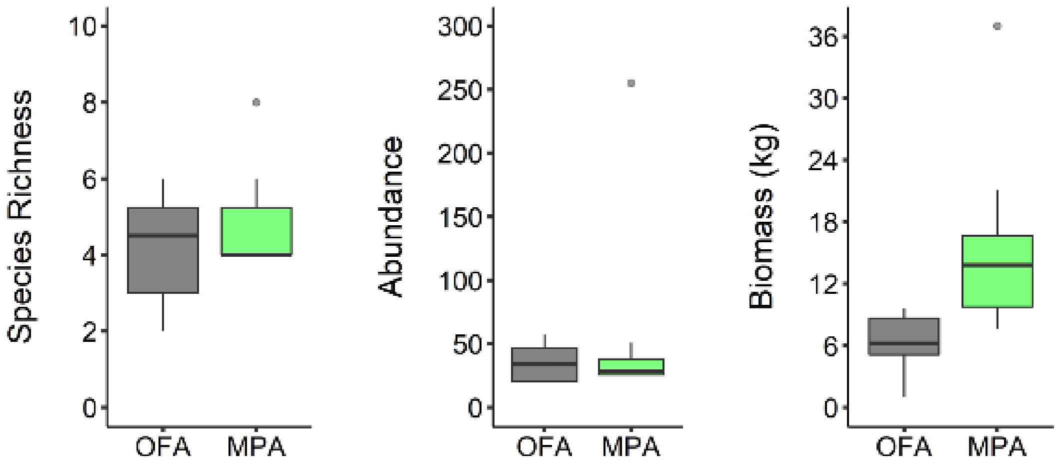

Figure 3. Descriptors of the fish communities inhabiting the shallow rocky bottom sites in the areas open to fishing (OFA, grey) and the MPA (green). The horizontal bar inside the box is the mean; the limits of the box are the upper and lower quartiles; and dots denote outliers. From Cardona et al. (2023).

5.2 Results of the online survey

From the ten invited stakeholders that were approached to participate in the online survey, only one response was received from a professional shellfish gatherer. We suspect that this is mainly due to the summer holidays of scientists, NGOs and administrators, especially in August, and their return to work in early September. The stakeholder consultation process overlapped with the summer season. The lack of responses occurred despite the fact that two reminders asking for cooperation had been circulated among these stakeholders. August is the high season for the HORECA sector in Spain and small-scale fishermen supply fish to this sector during the summer holidays. They are therefore unable to devote time to this. In general, it is possible that the lack of response from the different stakeholder approaches could also be due to stakeholder fatigue with requests to participate in this type of study.

The fisherman confirmed that there are no restrictions on commercial fishing inside the MPA. He commented that there are some differences between the yield of shellfish harvesting inside and outside the MPA. For example, catches of shellfish outside the park appear to be higher, but this is due to stricter monitoring of shellfish harvesting inside the park. In terms of shellfish species, he commented that he did not have data on catches. Regarding spillover effects on the recovery of fish populations in adjacent areas due to conservation measures, he replied that these may have improved, but to a very limited extent. In fact, he emphasised that commercial fishing was continuing at the same level as before the MPA was designated, albeit with a little more control. In general, he felt that there were fewer fishers than before the MPA, but this was probably the result of factors other than the MPA measures. Likely factors are a lower fish production due to the expansion of the port of Vigo, pollution and climate change. He argued that the MPA is primarily a biodiversity conservation tool and not a fisheries management tool. He also commented that in order to develop commercial fishing, some MPA areas should be permanently closed to fishing. He argued that the AINP was not an effective strategy for supporting fish populations and commercial fisheries because there were no restrictions on commercial fishing. Finally, he highlighted that this MPA only contributed to the conservation of non-target species.

6 DISCUSSION

There are only two papers that have used methodologies to assess potential ecological effects of the AINP. First, Blanco et al. (2021) assessed the effects on benthic trophic levels due to the implementation of conservation measures in the MPA. The authors suggest that the lack of differences in trophic level may be due to similar fishing pressure inside and outside the MPA, resulting from the very limited restrictions on fishing in the MPA, only affecting recreational fishing. Thus, **the lack of comprehensive fishing restrictions in the MPA makes it difficult to see differences in the low trophic level between unprotected and protected areas.** In turn, Cardona et al. (2023) conducted a comparison between two MPAs; one with fishing restrictions on commercial and recreational fishing (Cabrera MPA) and one with restrictions on recreational fishing only (AINP). They found that changes in biomass and size structure did not modify the trophic structure. The results presented by Blanco et al. (2021) provide evidence (no changes in food web structure) that **spillover has a limited probability to occur around the AINP, as no comprehensive fishing restrictions are in place.** Before spillover takes place, populations of fish or other organisms within an MPA must recover to make it possible for them to spill across the MPA boundaries. This implies that MPAs should be properly enforced (Edgar et al. 2014; Guidetti et al. 2008). Spillover in MPA science is a density-dependent mechanism where an increased competition within the MPA triggers a movement of individuals/biomass towards adjacent areas outside MPAs (Kramer & Chapman, 1999; Roberts & Polunin, 1991). In turn, Cardona et al. (2023) found evidence that fishing restrictions in MPAs may allow for rebuilding the populations of carnivorous fish and restoring their size structure, but they are unlikely to restore the trophic structure to that of pre-fished ecosystems. It should be added that the lack of restrictions on professional fishing might be the result of social pressure, as it has been observed in other MPAs (Cadiu et al. 2009; Parada and Nieto, 2024). **The AINP is in particularly highly dependent on small-scale fishing activities**, as two thirds of Galician small-scale fishing takes place in these waters. However, it should be noted that, according to one fisher, the number of fishers in the area has decreased. This reduction seems to be the effect of external factors such as pollution, growth of port infrastructure and climate change, rather than fishing restrictions.

Villegas-Ríos et al. (2013) provide another reason for the set-up of fishing restrictions. These authors applied **acoustic telemetry to provide information on fish movements of the ballan wrasse** (*Labrus bergylta*) **within and around the AINP**. This species is heavily targeted by the artisanal fleet in Galicia. The movements of a number of individuals were monitored in this MPA between September and November 2011. Fish were present in the monitored area for more than 92% of the time monitored, indicating a **high degree of site fidelity**. The sedentary behaviour of this species highlights the potential use of MPAs as a management tool to ensure sustainable fisheries for this species. However, it should be added that the MPA approach is not a fisheries management tool *per se*, and *ad hoc* fisheries management measures could be considered by decision-makers to protect species with high zonal fidelity. One may wonder whether fishing restrictions for low-mobility finfish species may have spillover effects. If population biomass of these species within these zones increases, density-dependent factors may force small and intermediate-sized fish to migrate and relocate their home range outside the MPA (Kramer & Chapman, 1999) thus being accessible to the fishery. This would require a rigorous scientific assessment.

However, there may be opposition to the implementation of fishing restrictions and decision-makers should have their decisions supported by the best available science. One key aspect to determine is the level of fishing effort in the area. Parada and Nieto (2024) assessed fishing effort in terms of fishing effort density, i.e. number of vessels per km^2 and number of sets per km^2 in the area and found that fishing effort density was not as high as expected and in many cases lower than in other MPAs with no-take zones. For example, these authors found that fishing effort density in terms of vessels per km^2 was lower than in the Cortegada and Tabarca MPAs (Forcada et al. 2010), similar to the Medes MPA (Stenzelmuller et al. 2008). The authors report that effort densities in terms of sets per km^2 are lower than in some areas of the fully protected MPAs of Banyuls and Medes, and lower than in Cabo de Palos (Stenzelmuller et al. 2008). **Given the finding that fishing effort was not as high as expected, the authors leave open the question of whether restrictions on commercial fishing in this MPA are necessary.** In particular, they consider that the establishment of a no-take zone could increase the intensity of fishing near the boundaries of the MPA. The authors also point to the lack of data on fishing effort and state that it is essential to carry out regular monitoring of fishing activities, preferably using vessel monitoring system (VMS) data. This will be useful in assessing the impact of commercial fishing on fish stocks. There appears to be a need for research to determine whether or not fishing restrictions should be applied in this MPA. It appears that some species have a site fidelity that may require ad hoc management measures, but these measures should be based on scientific evidence.

7 CONCLUSIONS

The AINP lacks restrictions on commercial fishing. In addition, as noted in the background section, conservation groups are calling for restrictions on commercial fishing to conserve birds in this MPA. This case study shows that there is a paucity of studies assessing the potential effects of the limited fishing restrictions in place, and no studies assessing directly spillover effects and different potential scenarios of more extensive fishing restrictions.

According to the literature review and questionnaire results, the removal of recreational fishing pressure in this MPA has not been sufficient to induce significant changes in fish communities within the MPA. Therefore, spillover effects outside the MPA appear to be unlikely, as populations of fish must recover first within the MPA to make it possible for individuals to spill across the MPA boundaries. A limitation of this study is the low number of stakeholders surveyed. In the future, engaging more stakeholders could potentially offer a more comprehensive representation of perspectives regarding the roles of the AINP as a fishery management tool and the perception on potential spillover effects toward the adjacent areas.

Further data could be collected, both on biological and socio-economic variables, to improve the current state of knowledge of fish resources and associated fisheries. This may also allow for better assessments in the future, e.g. comparing abundance and richness of fish species using a distance gradient sampling scheme (from the MPA to the outside areas) integrated over time using catch data and/or scientific surveys. In addition, tagging studies and / or the application of acoustic telemetry for additional commercial species, could provide useful information on fish movements within and outside the AINP which would allow a more robust assessment of spillover.

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12. CASE STUDY REPORT:

PROFESSOR LUIZ SALDANHA MARINE PARK

PORTUGAL – THE IBERIAN COAST

Fishing and recreational vessels at the Sesimbra port. © Sérgio Abreu

Analysis of potential spillover effects around the Professor Luiz Saldanha Marine Park

Sérgio Abreu

MRAG Europe

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LIST OF ABBREVIATIONS

Term	Description
BRUV	Baited remote underwater videos
CPA	Complementary protection area
INE	Instituto Nacional de Estatística
MPA	Marine protected area
NGO	Non-governmental organization
PNA	Parque Natural de Arrábida
PPA	Partially protected area
TPA	Total protection area
UVC	Underwater visual census

1 EXECUTIVE SUMMARY

The Professor Luiz Saldanha Marine Park, a marine protected area (MPA) located on the south-west coast of Portugal, represents a critical effort in marine conservation, aiming to balance ecological preservation with the socio-economic realities of the surrounding communities. MPAs are established with the dual goals of protecting biodiversity and enhancing the sustainability of local fisheries through the spillover effect, where protected areas potentially contribute to replenishing fish stocks outside their boundaries. However, the effectiveness of MPAs in achieving these objectives has been a subject of debate, reflecting the need for comprehensive studies that consider both ecological and socio-economic perspectives.

The main aim of this case study is to explore the perspectives of local stakeholders and the available literature on spillover effects in the Professor Luiz Saldanha Marine Park. An extensive literature review and a questionnaire-based method were used to target a wide range of stakeholders, including commercial and recreational fishers, fisheries managers and government authorities, scientists, and environmental non-government organisations.

The existing literature on the MPA and the stakeholder responses from researchers and governmental authorities demonstrated that this MPA can promote marine biodiversity and generate positive spillover effects. Findings from the literature review further substantiate claims of effective ecological recovery promoted by the establishment of the MPA. For example, several significant ecological changes in terms of fish diversity, species numbers and biomass have been observed by authors since the MPA implementation, both within its boundaries and in its surrounding areas. In addition, research observe that fish species may venture beyond MPA borders, potentially benefiting external fishing grounds. In contrast, other studies highlighted the potential socio-economic implications due to of a reduction in fish abundance post-MPA establishment.

Our study encountered limited stakeholder participation, with a total of five respondents – two researchers, two fishers and one government authority. Academic and governmental stakeholders corroborate positive ecological shifts and population improvements in fish owing to the spillover effect of the MPA regulations, citing improved biodiversity and fish abundance. This is in line with prevailing academic literature on the topic. On the other hand, the fishing sector expressed doubts and concerns regarding the MPA's advantages both economically and in terms of overall benefits.

The study shed light on the contrast between the encouraging ecological results gathered though several scientific studies and the doubts prevailing within the fishing sector. Flexible and collaborative management approaches are needed to tackle ecological and socio-economic issues in a holistic way. The literature-based evidence, in tandem with the inputs from various stakeholders, provide a comprehensive perspective on the potential advantages and challenges of the MPA. The report underscores the necessity of balancing socio-economic and ecological preservation goals in MPAs by promoting the inclusion of all stakeholders, including fishers, in MPA decision-making processes. The study confirms the potential for positive spillover effects from the Professor Luiz Saldanha Marine Park on marine biodiversity and fish resources, emphasizing the importance of further research to optimize these benefits alongside addressing socio-economic challenges.

2 BACKGROUND

Located on the south-west coast of Portugal, the Professor Luiz Saldanha Marine Park is a marine protected area (MPA) contained within the Arrábida National Park (‘*Parque Natural de Arrábida*’; PNA). The marine park is situated at the northern edge of the northeast-Atlantic upwelling zone and covers an area of 53 km^2, extending 38 km along the coast between Cabo Espichel and the Sado estuary. This transitional oceanographic and biogeographic area makes it a biodiversity hotspot, being the northern habitat for subtropical species and the southern habitat for certain temperate species (Wooster et al., 1976; Henriques et al., 2009). Historically, the rich biodiversity in the area has been an important resource for small-scale artisanal fisheries operating from Sesimbra and Setúbal.

The MPA is characterized by a varied subtidal rocky seabed with formations of rock blocks and boulder fields, reaching depths of 20-25 meters. Adjacent to the rocky base at the eastern section of the marine park (east of Sesimbra), sandy bottoms can be found up to 30 meters deep whereas in deeper sections of the park, muddy sediments remain a dominant feature (Henriques et al., 2014; Henriques et al., 2015). In 2006, the MPA was included in the Natura 2000 network and includes three habitats listed in the Habitats Directive: (i) 1110: Sandbanks partially covered with seawater; (ii) 1170: Reefs; and (iii) 8330: Submerged or partially submerged sea caves.

Created in 1998 under the Regulatory Decree Nº23/98 and following approval of a zoning plan in 2005, the marine park became fully operational in 2009 with the implementation of a designated no-take zone. It is designed to ensure marine conservation while facilitating certain fishing activities. The management plan defines three levels of protection within the MPA (Figure 1):

(i) **Total Protection Area** (TPA). This area spans 4.3 km², acting as a no-take and no-access zone, prohibiting all human activities.

(ii) **Partially Protected Areas** (PPA). Four areas covering 21 km² and permitting commercial fishing with specific gear types, such as octopus traps, jigging, and handlining.

(iii) **Complementary Protection Areas** (CPA). Three areas account for 28 km², are less restrictive, allowing recreational and traditional small-scale fishing methods under specific constraints, including licensing vessels under 7 m in length.

Figure 1. Map of the Professor Luiz Saldanha Marine Park with the three protection levels: Total Protection (orange), Partial Protection (blue) and Complementary Protection (green) (Source: Instituto da Conservação da Natureza).

Fishing activities like trawling, dredging, purse-seining, spearfishing, and discarding of fish are banned throughout the MPA. Commercial fishing, restricted to vessels from Sesimbra port, requires a permit and its renewal is dependent on the vessel's continued activity in the area. In PPAs, fishing is constrained to zones beyond 200 meters from the coast and solely permits traps and jigs.

Annual landings from small-scale vessels operating in the region between 1995 and 2022 have shown significant fluctuations. For example, annual landings in Sesimbra were lowest in 2001 (11 226 tonnes) and peaked in 2019 (36 003 tonnes), whereas in Setúbal landings have been consistently declining since 1995, reaching a significant low in 2013. Overall, Sesimbra generally had higher landing values than Setúbal, especially post-2005. More recently, while both ports showed slight variances from 2020 to 2022, Setúbal's total landings decreased in 2022.

Importantly, catch data reported by the Instituto Nacional de Estatística (INE) do not distinguish between different types of fishing gear. Instead, the aggregated data include both multi-gear fishing (which is allowed in the MPA) and seine and trawl fishing (which are not permitted within the MPA). However, a considerable volume of the multi-gear and seine fishing catches is likely sourced from the MPA or its nearby areas, suggesting these numbers provide a good representation of the trends in the MPA's landings. Given that Sesimbra also serves as a trawl fleet port, which does not operate within or in proximity to the MPA, the data require careful interpretation. However, the increasing trend in Sesimbra's landings, pointed out by Batista et al. (2011), seems to continue in later years as shown in Figure 2.

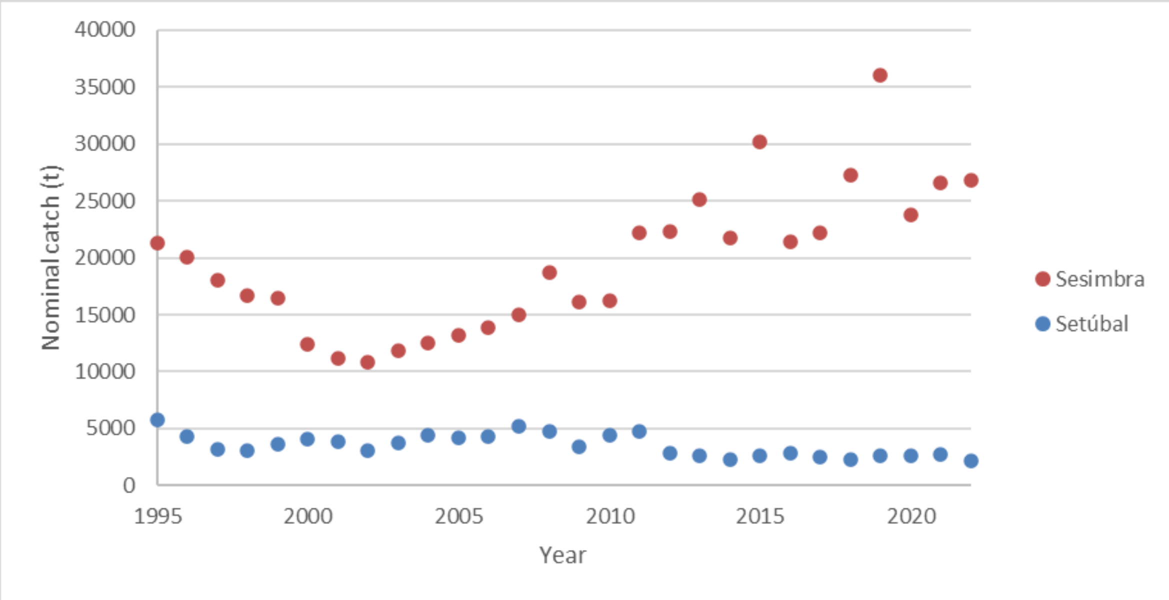

Figure 2. Annual nominal catch (tonnes) landed in Sesimbra and Setúbal ports between 1995 and 2022 (source: Instituto Nacional de Estatística).

Cunha et al. (2014) highlighted the performance of the MPA protection measures in each area, noting that the TPA showed higher species richness, indicating a diverse range of species compared to the other areas. The PPA, meanwhile, showed a high species diversity index, indicating a balanced species presence without any dominating. Finally, the CPA scored lower in terms of both species diversity and richness. Further research by Abecassis (2015) highlighted potential weaknesses in the operation of the MPA no-take zone. For example, highly mobile fish may not be fully protected within the MPA, thus putting them at risk. In this case, the small size of the no-take zone within the marine park might not be sufficient to encompass all essential fish habitats, which could present challenges to the park's natural diversity and well-being. A separate study by Pereira (2018) on the Portuguese MPA, Parque Natural do Sudoeste Alentejano e Costa Vicentina, illustrated the benefits of implementing buffer zones around no-fishing areas, providing a boost in both the spillover effect and fisheries productivity in less than five years.

The MPA in Arrábida witnessed significant conflicts with stakeholders upon the introduction of fishing restrictions. To address this, a systematic three-phase approach was carried out. The initial phase (2008-2011) saw the implementation of the MARGov project, aiming to engage stakeholders and foster knowledge co-production. The subsequent phase (2012-2014) introduced the PostMARGov Group, which focused on deliberations regarding the MPA's regulation. By 2014, the PNA Strategic Council incorporated the PostMARGov Group as the Group of the Sea, a committee dedicated to marine matters.

Over a decade after implementing the MPA's plan and regulations, positive ecological signs are visible, but opinions on socio-economic effects are mixed. An external assessment of the PNA regulation was concluded in 2016 and discussed within the Strategic Council of PNA in 2017, providing an opportunity for further dialogue and potential adjustments to the management of the protected area (Stratoudakis et al., 2019).

Stakeholder involvement in the MPA changed significantly from the 2008 MARGov project to the 2017 Group of the Sea phase. This transformation shifted from the politically driven MARGov to a more institutionally anchored Group of the Sea, as described by Vasconcelos et al. (2012) and Carneiro (2011). Key findings from the Stratoudakis study revealed an increased establishment and consolidation of mutual understanding, trust, and responsibility among the stakeholders (Stratoudakis et al., 2019). As time progressed, understanding process rules and strengthening of networks led to new forms of collaboration. Eight measures were proposed regarding changes to the fishing rights in the MPA (Stratoudakis et al., 2019). Out of them, three found common agreement among stakeholders. These consisted of allowing a passage corridor through the MPA during inclement weather, formalizing an exemption for traditional beach seines of Sesimbra for touristic purposes, and permitting the use of nets and longlines to fish in areas of partial protection (Cunha et al., 2014). However, other proposals such as granting MPA licenses to purse seiners from Sesimbra, provision of MPA licenses to all Sesimbra vessels less than 10 meters, distinction of management approach between smaller and larger vessels, and the development of stricter buffer areas didn't reach an agreement due to clear antagonism in perspective (Horta E Costa et al., 2016). These proposals showed changing views among stakeholders during the engagement process, highlighting both the difficulties and opportunities when everyone works together in an MPA (Stratoudakis et al., 2019).

3 AIMS AND OBJECTIVES

The general aim of this study is to better understand the potential spillover effects of the Professor Luiz Saldanha Marine Park on local fisheries and conservation efforts. This involves analyzing the extent to which the MPA contributes to ecological well-being and socio-economic benefits for the surrounding communities.

To respond to this general aim, we had the following specific objectives:

- Undertake a literature review on the spillover effects of the Professor Luiz Saldanha Marine Park. This helps to contextualize the study within the broader field of marine conservation and fisheries management, identifying gaps in current knowledge and setting a foundation for primary research.
- Utilize tailored questionnaires to collect data on stakeholder perceptions specifically related to the spillover effects of the Marine Park, aiming to understand its influence on conservation efforts and local fisheries. This method seeks to uncover the perceived benefits, challenges, and knowledge gaps associated with these spillover effects, to inform strategies for maximizing positive ecological and socio-economic impacts.

4 METHODOLOGY

4.1 Literature review

The literature review in this study was conducted using a thorough approach to provide an in-depth look at the spillover effects associated with the Professor Luiz Saldanha Marine Park. The research methodology included searching databases like ScienceDirect, SpringerLink and also Google Scholar using specific keywords. Additionally, academic journals grey literature, websites and recommendations from renowned researchers were considered to identify relevant publications related to the Professor Luiz Saldanha Marine Park. To ensure that both historical and current viewpoints were covered, no time constraints were applied. After an initial scan of titles and abstracts, the literature was narrowed down to studies that focused directly on the Professor Luiz Saldanha Marine Park and that delved into key themes such as spillover effects and fisheries, stakeholders. Consistency in the overall narrative was maintained through ongoing evaluations and the cross-referencing of sources. Each article was then critically analysed to identify its strengths and weaknesses and the findings from the different studies were contrasted with one another.

4.2 Stakeholder survey

We developed a questionnaire to assess the perceptions of key stakeholders on the potential spillover effects in their nearby MPA. The questionnaire comprised of open-ended and closed questions to elicit stakeholder views and experiences on the different aspects of this study (see questionnaire in Annex 4). The open-ended questions aimed to capture stakeholder opinions on, for example, how aware the stakeholder was of the regulations and management measures of the MPA. The closed questions were statement-based and used Likert scale answer categories (such as: Strongly agree; Agree; Neutral; Disagree; Strongly Disagree) for the stakeholder to choose from.

The questions were grouped into four broad categories to encapsulate the key issues being studied. These included:

(i) Respondent information. The first section required basic information from the respondent, including their name, institution and the type of stakeholder category they belonged to.

(ii) Background information. The second section of the questionnaire gathered background information from the stakeholder to understand more about the respondent and their use of the MPA. Questions included knowledge of when the MPA was established, the type of restrictions in place and how long the stakeholder has been associated with the MPA either through research, fishing or managing it.

(iii) Fishery impacts of MPAs. The third section explored the respondent's perceptions of the socio-economic impacts of spillover from the MPA. Stakeholders were asked to state whether the designation of an MPA / area where fishing is limited has led to an increase in revenues for fishers, whether the fishing community in the area feel their fisheries livelihoods are more secure after the MPA was established, and the extent to which they believe spillover from the MPA has influenced the catch composition in adjacent fishing grounds.

(iv) MPAs as management tools. The fourth section of the questionnaire focused on the respondent's perceptions on whether MPAs are conservation or fisheries management tools. Stakeholders were asked to state whether their local MPA was acting as a conservation tool, a fisheries management tool or both. Other questions under this section required stakeholders to state their agreement/disagreement on whether the establishment of MPAs is an effective conservation strategy to support fish populations and commercial fisheries in their area. Respondents were also asked to indicate what factors they thought were contributing to spillover effects.

Four key stakeholder groups were targeted under this consultation including commercial and recreational fishers, fisheries managers and government authorities, scientists, and environmental non-government organisations (NGOs). Therefore, while the four sections of the questionnaire where the same, specific questions were included for each of the four respondent groups. The questionnaire (in Portuguese) was set up as an online survey.

To gather stakeholder perceptions regarding potential spillover effects in nearby MPAs, various stakeholders affiliated with the MPA were approached during July and August of 2023. A total of 17 stakeholders were contacted via email, with 10 subsequently receiving follow-up emails to stimulate participation. Additionally, 8 phone calls were made across the stakeholder spectrum to enhance engagement. When disaggregated by category, three representatives from fisher associations were approached, three from governmental bodies, eight individuals who identified as researchers from different institutes, and three from NGOs. Regarding the stakeholder responses, six did not provide any feedback, despite the engagement efforts. Another two stakeholders submitted their responses to the survey with the content blank. A segment comprising two stakeholders indicated their unavailability due to holidays or mentioned potential engagement at a later date. Additionally, three stakeholders, recognised the intent of the study but deemed themselves less relevant, and proposed that other individuals be contacted for more pertinent insights.

5 RESULTS

5.1 Literature review

The literature review in this study explored the role of the Professor Luiz Saldanha Marine Park in improving marine biodiversity and fisheries' sustainability. Its results show that spillover from the Professor Luiz Saldanha Marine Park affects both ecological and socio-economic outcomes.

Several studies have examined how the MPA in Arrábida affects local communities, primarily focusing on the fishing sector. Every study emphasized how vital it is for all stakeholders, especially the local fishers, to be involved in the decision-making and management procedures of the MPAs. Vasconcelos' research (2012) examined the adoption of a collaborative governance model within the MPA (MARGov), a response to the disagreements initiated by the establishment of the park. The MARGov project instigated a participatory approach among stakeholders, notably the direct users of the MPA, cultivating a sustainable and constructive exchange (Vasconcelos et al., 2012). The project utilized negotiation techniques and collective decision-making to encourage the development of 'pedagogic development', thus enhancing the process with the input and learning experiences of all involved parties. This methodology matured across four phases - identifying stakeholders, initiating individual meetings, organizing collective sessions, and joint planning - leading to, as per Vasconcelos et al. (2012), more effective and enduring solutions in managing protected areas. The 2013 study by Marques pointed out that when MPA rules were imposed top-down, it led to conflicts, especially among the local fishers who depend on the protected region for their livelihood. While both recreational boaters and commercial fishers, who depended heavily on the area for their economic well-being, showed some resistance against the MPA restrictions, the researchers also highlighted a mutual recognition of the MPA's role in protecting coastlines, safeguarding biodiversity, and ensuring ongoing fishery resources (Marques et al., 2013).

Stratoudakis et al. (2015a) assessed the effects of the MPA on the local small-scale fishing community, several years after the phased introduction of regulation. They gathered information and viewpoints from MPA fishers regarding the ecological, socio-economic, and governance conditions in the MPA. Ecologically, most indicators remained unchanged, and there was a non-significant decline in the abundance of target species. The socio-economic and governance results indicated a general sense of pessimism, although the reasons for this pessimism or potential solutions were not explicitly identified. Interestingly, despite the majority of fishers expressing a reluctance for their descendants to pursue fishing and indicating a preference for the pre-regulation conditions, they also recognized the significance of the MPA license. Moreover, they were aware of others' interest in obtaining this license and believed that co-management with the MPA authority was the most effective approach to fishery management (Stratoudakis et al., 2015a). Another study by Stratoudakis et al. (2015b) explored the perspectives of users regarding the evolution of the MPA and its relationship with small-scale fisheries up to 2012, revealing a generally positive perception. However, some socioeconomic concerns emerged, particularly as perceived advancements in understanding and disseminating information about the MPA were counteracted by a perceived decline in the excluded fishers' ability to sustain their livelihoods from fishing, along with a diminished appeal of fishing as a career for the younger generation. Stratoudakis et al. (2015b) also observed a disparity in perceptions regarding ecological matters, with MPA fishers failing to recognize the improvements noted by other users. Nonetheless, there was consensus on socioeconomic and governance issues, encompassing both indicators of progress and signs of deterioration (Stratoudakis et al., 2015b).

Pita et al. (2020) recently investigated fishers' perceptions within the Professor Luiz Saldanha Marine Park, comparing attitudes before and after full park management implementation. They found that despite an increase in fishers' knowledge about the MPA, dissatisfaction persisted over the years. Many fishers believed their fishing activities were negatively affected, with a rise in fishing days and a drop in catches reported by around 42% of them. Fishers' acceptance and support for the MPA did not increase: the proportion of fishers unhappy with the park's creation rose from 65% in 2007 to 73% in 2015. The proportion of fishers reporting a negative impact of the MPA on their fishing interests decreased from 96% in 2005 to 85% in 2015, but only a small percentage believed the park improved fisheries management, and this percentage declined over time. Fishers raised multiple concerns during the MPA's implementation: a perceived negative impact on their fishing opportunities, poor fishery management, overcrowding, excessive park regulations, and limited participation in the decision-making process. Changes in fishing behaviour and concerns about exclusive access for local fishers were also major sources of contention. These findings underscore the need for fishers to have a more significant role in decisions, given their perceived lack of benefits from the MPA.

Between 2003 and 2022, there was a fluctuation in the number of fishers in Sesimbra port registered for multi-gear, permissible in specific zones of the MPA (Figure 3). The data indicate an initial increase up to 980 fishers in 2005, the year the MPA was implemented. After 2005, the number of fishers decreased down to 732 in 2012. A temporary rise occurred between 2013 and 2015, peaking at 952. By 2022, the number had significantly decreased to only 416, a substantial reduction compared to the number of fishers in 2005. Concurrently, the declining number of registered fishers in Sesimbra port from 2005 to 2022 post-MPA inception underscores the potential conservation measures' effects on fishing, corroborating the fishers’ dissatisfaction identified by several authors such as Stratoudakis et al. (2015a) and Pita et al. (2020).

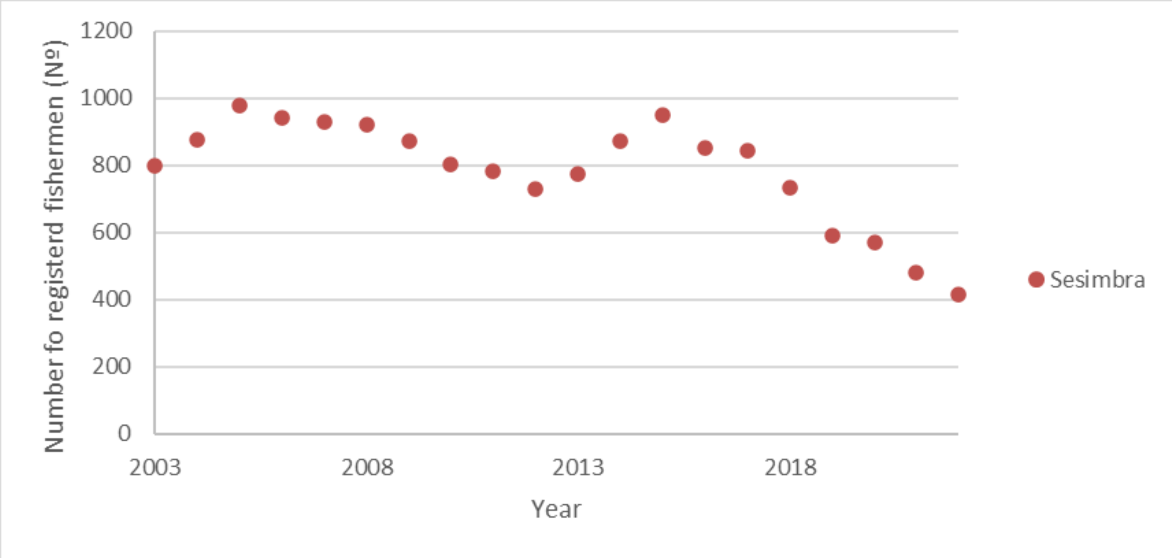

Figure 3. Number of fishers registered for multi-gear fishing in the Sesimbra port (Nº) per Year (Source: Instituto Nacional de Estatística)

Creating no-take MPAs that restrict fishing can change fish community structures, as seen in studies by Halpern (2003) and Claudet et al. (2008). Such shifts become apparent within a relatively brief period, often within 4 to 6 years, as outlined by Sousa's 2011 study concerning the Professor Luiz Saldanha Marine Park. In understanding the human responses, Horta e Costa et al. (2013) explored how artisanal fishers adapt to MPAs.

The research found that fishers adjust their efforts, picking new spots to fish and shifting closer to the boundaries of restricted zones. The study also showed that the choice of fishing gear is affected by many factors, ranging from the preference for specific species and proximity to ports to modifications in MPA regulations. Furthermore, every fishing group responded differently to the MPA rules, adjusting their operations to align with the new guidelines. Looking closely at the Arrábida region, Horta e Costa et al. (2013) dug into the complex relationships among the different fisheries. Factors such as the vicinity of ports, climatic conditions, and distance from the coast played pivotal roles in dictating fishing behaviours. For example, buoy-directed nets, influenced by their efficiency and environmental restrictions, saw prominent use close to home ports. In contrast, traps, owing to their adaptability to weather changes, found utilization in diverse locations. The research highlighted how closeness to the coast plays a role in the choice of fishing gear, noting that jigs are mainly used closer to shore, showcasing the strategies of local fishers (Horta e Costa et al., 2013).

For more than a decade, the Professor Luiz Saldanha Marine Park has been a focal point for extensive research. Between 2010 and 2019, the park underwent 14 experimental fishing expeditions as a part of various monitoring programs like BIOMARES, BUFFER, and INFORBIOMARES, aimed at observing the soft-substrate demersal fish community (with a break from 2015 to 2018 due to funding constraints) (Figure 4).

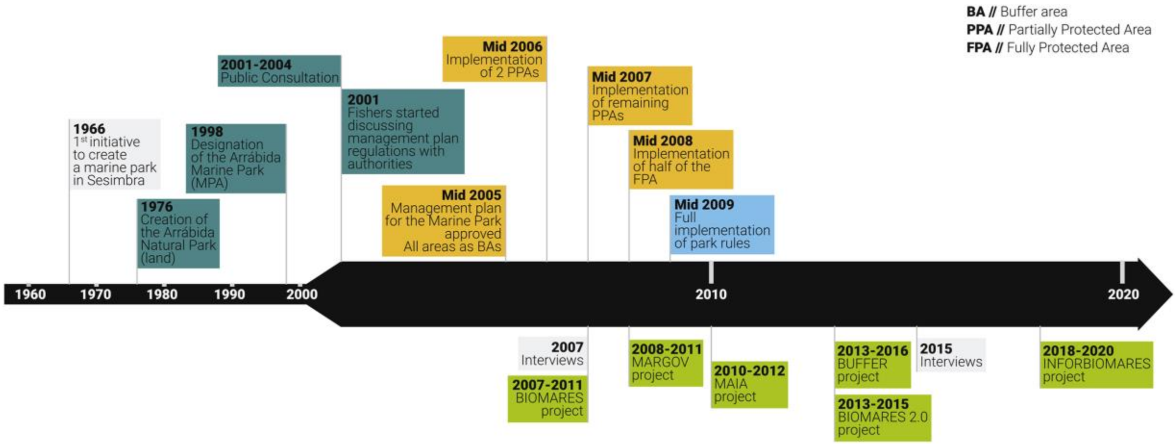

Figure 4. Timeline of events associated with the Professor Luiz Saldanha Marine Park (Source: Pita et al., 2020).

Borges (2006) pointed out that the MPA serves as a breeding ground for many nearshore and shelf-dwelling species such as sardines. The author speculated that the conservation efforts in the park might increase larval supply by encouraging spawning from adults, which could indirectly benefit external fishing grounds. Henriques et al. (2014) examined the rich biodiversity of benthic assemblages, pointing out that environmental factors play an important role in the distribution of these assemblages.

The establishment of the MPA had various impacts, as explored by Abecassis et al. (2015) and Batista et al. (2011), affecting from individual species to entire fisheries. Multiple studies, including those by Gonçalves et al. (2003), Sousa (2011), and Henriques et al. (2013), agree that there was an increase in fish diversity and species count in the protected zones. In concurrence, Martínez Ramírez et al. (2021) observed certain reserve effects when categorizing fish by their commercial value and size. Their research divulges a decline in fish abundance following the MPA's implementation, pinning potential reasons on socioeconomic factors. Parallel to these findings, Batista et al. (2015) tackled the impact of MPAs on fisheries, surmising that the recovery of coastal fisheries remains uncertain due to practical challenges and the nature of the protected areas. Meanwhile, Horta e Costa et al. (2013b) researched the MPA's influence on fish density and biomass. The authors suggested that the "reserve effect" positively impacts the sizes and densities of certain commercial species within the protected area. Lastly, Sousa et al. (2018) found that after full MPA implementation, there was a notable increase in fish biomass within the MPA, demonstrating the positive impact of reduced fishing mortality and prolonged fish longevity.

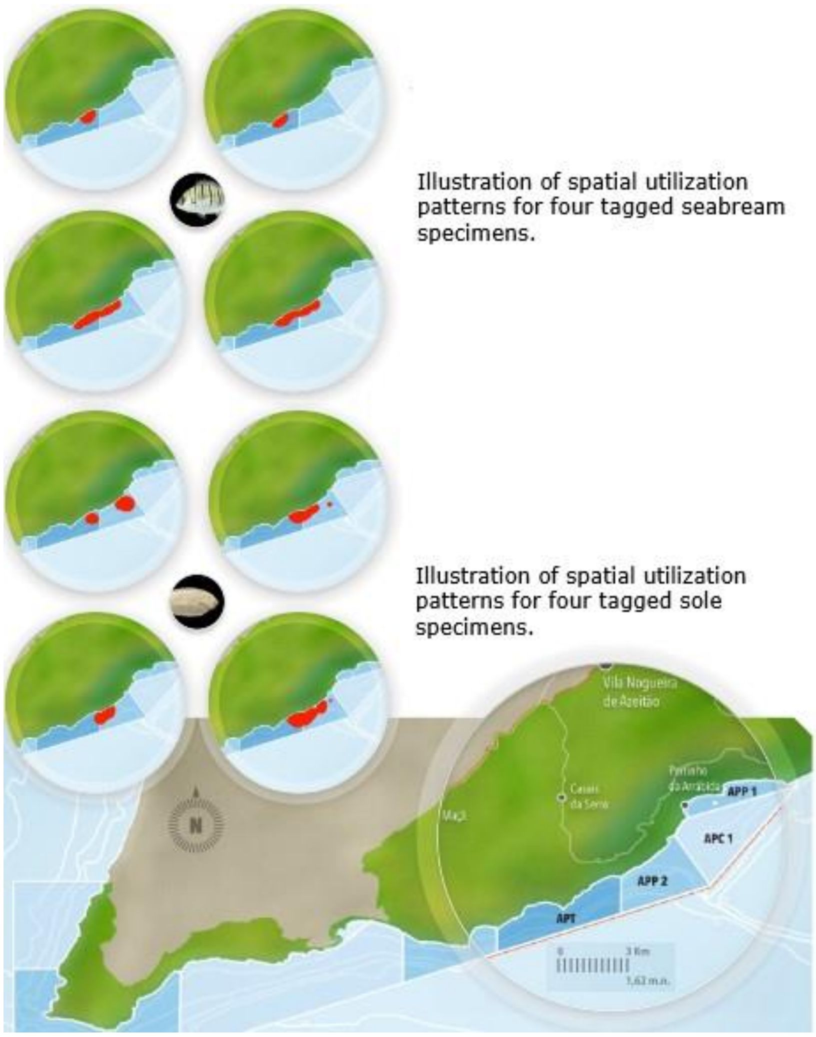

Figure 5. Patterns of spatial utilization for fish tagged with passive acoustic telemetry within the MPA (Adapted from Gonçalves et al., 2015)

Abecassis et al. (2014b) used passive acoustic telemetry to show that some species, like the Senegalese sole (*Solea senegalensis),* often venture beyond MPA borders. They underscored the need to look at individual species when evaluating the effectiveness of an MPA. Gonçalves et al. (2015) reported on the beneficial ecological effects of conservation, particularly for fish such as the white seabream (*Diplodus* spp). Seabreams occupy relatively small areas within the Marine Park, showing high fidelity to specific sites and remaining in the same zones for periods exceeding a year (within areas of higher protection) (Figure). Abecassis et al. (2014a) also engaged in a discourse on spillover effects, noting that while larger fish might venture out of MPAs, this phenomenon might not extend universally. This is corroborated by Gandra et al. (2018), who further revealed that some soles benefit directly from MPAs due to their sedentary nature, suggesting that small no-take areas could be protective, while more mobile soles might indirectly benefit from the spillover effect. Sousa (2019) also leveraged acoustic telemetry to determine the differential benefits of the MPA for the endangered white skate and emphasized the differential benefits of MPAs, highlighting that protective measures may not uniformly benefit all individuals within a species.

From a zoning perspective, Cunha et al. (2014) discerned that species size and biomass are considerably influenced by different protection levels. Sousa's 2011 research highlighted how different substrate types play a key role in shaping marine biodiversity and explored the potential impact of fishing methods on species diversity. Both Cunha et al. (2014) and Sousa (2011) emphasized how the park's designated zones affect marine life. They pointed out that the variety and number of fish are tied to the level of protection, the kind of habitat, and the fishing methods used. Despite indicating a possible spillover effect, these studies highlighted the need for more research to verify this hypothesis. Interestingly, the notion of the spillover effect is also discussed in other studies including those by Abecassis et al. (2014a) and Abecassis et al. (2015). These works suggest that while spillover could alleviate the pressure of fishing, its realization may vary depending on the species and their respective home ranges.

5.2 Stakeholder perceptions

For this study, several stakeholders were invited to participate through a questionnaire, sharing their insights on the spillover effects in the MPA. The response rate was low, as only five respondents completed the questionnaire. The main reasons for non-participation were most likely holidays, perceived irrelevance of the stakeholder's knowledge of the survey topic, or unavailability during the survey period. The five respondents comprised of two respondents from the research sector, two from the fisheries sector and one from a government authority.

One of the researchers who participated gave a general overview and highlighted that the MPA's management plan has specific rules, particularly around commercial fishing, and mentioned that these restriction zones were created based on research studies regarding the characteristics of the area and species distribution patterns. He stated that he had used underwater visual census (UVC) and statistical analysis methods to analyse changes in biodiversity and fish abundance numbers within the MPA. He mentioned that after the establishment of the MPA, noticeable ecological changes were observed, and the habitats within the MPA had become more complex, with a notable increase in the density and diversity of algae coverage. Additionally, larger individual organisms are predominantly found in zones where fishing is prohibited. Despite these habitat changes, the stakeholder considered that there had been no discernible alteration in fish abundance or biomass either within or outside the MPA but he considered that **it was likely that spillover was occurring from both fully protected and partially protected areas** and that it had a moderate influence on the catch composition. Regarding the impact on fishers' catches post-MPA establishment, his response is neutral, with the stakeholder mentioning a lack of specific data to make a concrete assessment.

The second researcher discussed both the size of the park and its management strategies. In addition to the UVC, this stakeholder also utilized Baited Remote Underwater Videos (BRUV) in his studies which facilitated data collection on fish species within the marine park. His findings showed an increase in the diversity, biomass and abundance of fish species which he attributed to the fishing restrictions currently in place in the protected area. For him, **there is a high probability that spillover from the fully protected areas is occurring** and that this phenomenon seems to have greatly influenced the catch composition in neighbouring fishing grounds, as data indicates a significant increase in catches at the Sesimbra auction following the MPA's implementation. Furthermore, according to him, the establishment of zones with limited fishing has undeniably raised the revenues for fishers. Yet, on the subject of whether the fishing community feels more secure about their livelihoods post-MPA, his opinion is neutral. He also added that the MPA's implementation was faced with criticism because it was imposed with force but that fishers have been recognizing its benefits over the last decades.

Two representatives from the Sesimbra fishing community described their fishing practices and target species. The first fisherman explained that his fishing methods included the use of traps, trammel nets, gillnets, hooks and lines, and jigs. He targeted species like the red mullet (*Mullus surmuletus*), breams (*Diplodus spp*), octopus (*Octopus vulgaris*), skates (*Raja spp*), and seabass (*Dicentrarchus labrax*). The stakeholder showed that he knew the rules and management of the MPA very well and highlighted changes in fishing areas after the MPA was set up. He also expressed **doubts about the idea that catches were better after the MPA and disagreed with the view that the local fisheries had gained economically from the MPA**. He was sceptical about the usefulness of MPAs as conservation tools, believing that the MPA did not help the local fishing industry or the jobs connected to it. The second response from the fisheries sector described similar fishing methods but added species like the Common cuttlefish (*Sepia officinalis*), Squid (*Loligo spp.*), Sole (*Solea spp.*), hake (*Merluccius spp.*), Brill (*Scophthalmus rhombus*), and some other flatfishes and crustaceans to the list of targeted species. This fisherman also knew the MPA rules and management well and described the changes he noticed after the MPA started. He mentioned shifts in fishing areas and a decrease in active licenses which is in accordance with the INE data. Like the first stakeholder from the fisheries sector, he also did not believe that the MPA necessarily led to more catches or better economic outcomes for fishers and was doubtful about the overall effectiveness of MPAs for conservation. Both individuals representing the fisheries sector expressed their concerns regarding the effects of recreational and tourism-related fishing within the MPA and that these activities could create potential challenges. These outcomes suggest that these stakeholders have a negative perception of the MPA's influence on fisheries and livelihoods.

The Portuguese governmental authority response confirmed that there is a comprehensive management plan for the MPA, dating back to 2005, in which 'spillover' is not explicitly incorporated into the conservation objectives. The stakeholder acknowledges the MPA’s vital role in species conservation and activity regulation despite the restrictions zones currently in place still permitting specific fishing activities within the MPA. He said that the MPA has witnessed a positive impact, with observed increases in species diversity, individual counts, and biomass, all of which highlight the potential benefits of the protected area. **The fisheries management authority supports the efficacy of MPAs as a conservation strategy and believes in the presence of spillover effects**, attributing these effects to factors such as MPA size, years since establishment, protection level, and habitat type. The stakeholder also mentions that the magnitude of the spillover effects is detectable a few kilometres from the border of the MPA.

6 DISCUSSION

Our case study on the Professor Luiz Saldanha Marine Park corroborates previous research, offering valuable insights on the presence and occurrence of spillover. By analyzing the literature and the views of researchers, government officials, and fishers, we investigated the potential spillover effects of the MPA.

Several significant ecological changes in terms of fish diversity, species numbers and biomass have been observed since the MPA implementation, both within its boundaries and in its surrounding areas. The significant increase in these variables within the protected zones, as confirmed by Gonçalves et al. (2003), Sousa (2011), and Henriques et al. (2013), confirms the positive influence of the MPA. Martínez Ramírez et al. (2021) found that fish abundance experienced a decline following the MPA's implementation, suggesting a possible link with socio-economic factors. Nonetheless, the notion of the "reserve effect," as explored by Horta e Costa (2013) and Sousa (2011), seems to indicate that MPAs can have positive outcomes, such as increased sizes and densities of certain commercial fish species.

There are different perspectives from various stakeholders including researchers and local fishers on how fishers' catches changed. **The consensus among researchers and the government official surveyed, is that the MPA has brought positive ecological results, especially spillover**. For instance, a respondent underscored that his studies within the Professor Luiz Saldanha Marine Park have consistently demonstrated positive shifts in species diversity and abundance, corroborating the overall effectiveness of MPAs in fostering ecological recovery. These insights are rooted in studies that showcase increased species richness and diversity indices within MPAs, corroborated by works like Halpern (2003), Claudet et al. (2008), and Sousa (2011).

Conversely, **local fishers express scepticism and dissatisfaction**, echoing the findings of Pita et al. (2020). Concerns about reduced catches and negative economic consequences post-MPA align with these stakeholders' viewpoints. The drop in the number of registered fishers in the Sesimbra port after the MPA's inception supports the idea that conservation measures influenced fishing activity. These outcomes underscore the need to reconcile differing viewpoints to develop efficient management approaches.

Fisheries management within the MPA has been a topic of debate and disagreement. Vasconcelos et al. (2012) and Marques et al. (2013) highlight the challenges arising from top-down imposition of MPA rules, leading to conflicts with local fishers. **The lack of recognition of the MPA's benefits among fishers also points to the importance of stakeholder engagement**. While some stakeholders acknowledge the potential conservation advantages of the MPA, the inherent difficulties in balancing conservation goals with the socioeconomic needs of local fishers persist. The cooperative governance framework suggested by Vasconcelos et al (2012) presents a viable resolution, advocating for the inclusion of all stakeholder voices in the decision-making process.

The spillover regarding the MPA, whereby the positive effects of MPAs extend to nearby areas, is an important concept that has been discussed extensively in the literature (Abecassis et al. 2014a, Abecassis et al. 2015) as well as the necessity of creating strategies that consider specific species, habitats, and external elements. Spillover effects, often a major focus when talking about how the MPA impacts local fisheries, are still a topic of debate. Some researchers argue its existence and potential benefits while others, like Abecassis (2014b), caution against assuming it applies universally to all species. The studies by Abecassis et al. (2014b) and Gandra et al. (2018) on species like the Senegalese sole and the white seabream suggest that some fish may venture beyond MPA borders, potentially benefiting external fishing grounds, a point also raised by Borges (2006). The divergent perspectives of stakeholders further emphasize this dichotomy. **While**

scientists highlight the probable advantages of spillover for nearby fishing areas and local economic benefits, fishers voice scepticism about its efficacy. One fisherman voiced that MPAs can be a double-edged sword for them: although they might help fish populations recover, they restrict fishers' access to traditional fishing zones. This raises questions about the specific species and scenarios for which spillover might be relevant and highlights the importance of considering context and ecological nuances.

The evolution of MPA governance models, as demonstrated by studies by Horta e Costa et al. (2013), Vasconcelos et al. (2012), and Marques (2013), underscores the shift towards more inclusive decision-making. One fisherman suggested that **collaboration with local fishing communities in designing MPA regulations could be a way forward**. The study from Pita et al. (2020) also corroborates this, emphasizing that fishers desire a greater role in decision-making. This suggestion to collaborate with local fishing communities in designing MPA regulations, in line with Vasconcelos et al. (2012) and Stratoudakis (2015), highlights a potential solution. This way, their input could be considered, and the negative impacts on their livelihoods minimized. In order to enhance strategies, for managing MPAs it would be advantageous to promote authentic collaboration that effectively addresses ecological and socio-economic concerns.

As our case study notes, and as further corroborated by Cunha et al. (2014), there are also overarching challenges in the practical implementation, monitoring, and enforcement of MPA regulations. A governmental stakeholder cautioned that the practical implementation of regulations is an ongoing challenge and that effective enforcement and compliance monitoring remain elusive.

A potential limitation of this study is the low number of stakeholders surveyed and the lack of participation from a non-governmental organization. In future, engaging more stakeholders could potentially offer a more comprehensive representation of perspectives.

7 CONCLUSIONS

The way well-structured MPAs can promote marine biodiversity and generate positive spillover effects was demonstrated in both the existing literature on the MPA and the stakeholder responses from researchers and governmental authorities. Yet, stakeholders from the fishing community shared their concerns about the potential socio-economic repercussions of MPAs. Although MPAs are understood to potentially enhance fish populations, there is a concurrent sentiment that they might negatively influence commercial fishing methods and the related economic dynamics. Stakeholders in the fishing community stressed the importance of creating MPA regulations with their views and needs in mind and highlighted issues introduced by fishing activities associated with tourism within MPAs. It is understood that MPAs serve a dual purpose, functioning not only as a conservation tool but also as a tool for managing fisheries. However, there seems to be a division in opinions about which role should be emphasized more. The ecological benefits of the Professor Luiz Saldanha Marine Park are evident, but this area must be managed in a manner that balances both conservation needs and socio-economic considerations. Although some scientific evidence has been identified on spillover in the literature, future research is necessary in order to gain a comprehensive understanding of the spillover effects of the Professor Luiz Saldanha Marine Park.

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13..CASE STUDY REPORT:

FORMIGAS MARINE PROTECTED AREA

PORTUGAL – MACARONESIA

Analysis of potential spillover effects around the Formigas Marine Protected Area

Sérgio Abreu

MRAG Europe

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LIST OF ABBREVIATIONS

Term	Description
AMN	Autoridade Maritima Nacional
BALA	Biodiversity at Azores' Lava Formations
DLR	Decreto Legislativo Regional (Regional Legislative Decree)
DRA	Direção Regional do Ambiente (Regional Directorate for the Environment)
DRAM	Direção Regional dos Assuntos do Mar (Regional Directorate for Sea Affairs)
EU	European Union
GAMPA	Grupo de Ação para o Mar dos Açores (Azores Marine Action Group)
GNR	Guarda Nacional Republicana (National Republican Guard)
IUCN	International Union for Conservation of Nature
IRP	Inspeção Regional das Pescas (Regional Fisheries Inspection)
MPA	Marine Protected Area
MONIAVES	Programa de monitorização de populações de aves marinhas dos Açores (Monitoring Program of Marine Birds in the Azores)
MONIZEC	Monitoring of Marine Fish and Invertebrates in the Azores
MSFD	Marine Strategy Framework Directive
eNGO	Environmental Non-Government Organisation
PAF	Prioritized Action Framework
PIMA	Projecto Invasoras Marinhas (Marine Invasive Species Project)
SCI	Site of Community Importance
SAC	Special Area of Conservation

1 EXECUTIVE SUMMARY

This case study aims to investigate whether spillover effects have been detected around the Formigas Marine Protected Area (MPA) in the Azores region. This work utilised both a literature review of the available research and a questionnaire-based method. The questionnaire targeted a wide range of stakeholders: commercial and recreational fishers, fisheries managers, government authorities, scientists and environmental non-government organisations.

The literature review revealed that the Formigas MPA, due to its unique underwater mountain habitat and geographical isolation, holds distinct ecological features and an overall low human impact. Findings showed that there is little direct evidence that the Formigas MPA has substantially impacted the marine communities within it, and no quantitative evidence that spillover effects are occurring from this MPA. Despite a limited range of studies on the MPA, there is likely the existence of potential spillover effects on another MPA in the Azores, with minor migration of fish from MPA to adjacent (non-MPA) areas.

There was a lack of response to the questionnaire by stakeholders that were approached. Nevertheless, some valuable information was obtained through a few stakeholders. A key governmental authority that was interviewed mentioned the potential spillover effects of the MPA on adjacent fisheries and the recovery of overexploited fish populations within and surrounding the MPA. In contrast, one diving school stakeholder expressed concerns about the decline in marine resources within the MPA over the past decade and the lack of enforcement.

Future research on the Formigas MPA should concentrate on quantitatively measuring spillover effects, utilizing statistical models to track biomass and diversity changes in adjacent areas. This focus will enable a precise evaluation of how protected zones influence surrounding ecosystems and fisheries, providing a clear metric for conservation efficacy and resource management. Overall, this work highlighted the potential interdependence between marine conservation and socio-economic benefits associated with the MPA, but also highlight the need for further examination of the ecological and fisheries effects of the MPA.

2 BACKGROUND

The Azores is a volcanic archipelago composed of nine volcanic islands. These islands hold limited shallow-water habitats, are impacted by strong tidal currents and swell, and are structured by substantial ecological isolation of its island habitats and the populations utilising such habitat (Santos et al., 1995; Tempera, 2008).

The Azores have achieved notable recent success in marine conservation, with substantial growth and strengthening of protection efforts in the last decade. According to Abecassis et al. (2015), the evolution of marine protected areas (MPAs) in the Azores has undergone three stages: the 1980s marked the initial creation of isolated MPAs, the 1990s saw the influence of international initiatives fostering research and conservation policies, and the 2000s saw the adoption of a holistic approach, acknowledging the necessity to incorporate MPAs into a broader marine management strategy.

Since the 1980s, the Azores have led the way in seamount ecosystem conservation. The first European offshore MPA was established here, specifically encompassing the Formigas Islets and the Dollabarat Reef (Santos et al., 1995). Following this, in 2004 a crucial coastal zone management instrument gained approval, setting the stage for more comprehensive conservation efforts. Within 2006, the Natura 2000 network sectorial plan was enforced within the Azores. Then in 2007, a thorough review of the Azores protected areas network took place, resulting in the improvement of conservation strategies. Between 2008 and 2011, the establishment of nine island natural parks was undertaken, with each island in the archipelago being allocated a park. 2010 saw the creation of the Regional Directorate for Sea Affairs (DRAM), established by the Regional Decree no.17/2010/A of September 21, which emerged as the environmental authority for the Azores. In 2011, the Marine Park of the Azores was created, while in 2012, the region introduced a detailed regional biodiversity law, merging both conservation and biodiversity initiatives. The same year also saw the approval of the final coastal zone management instrument, ensuring that all islands had a robust framework in place. In 2013 the implementation of the Prioritized Action Framework (PAF) of Natura 2000, further amplified conservation endeavours. Emphasizing a broader perspective, 2014 witnessed the full implementation of the Marine Strategy Framework Directive (MSFD) in the Azores, indicating the region's commitment to aligning with conservation directives. In 2016, the Marine Park of the Azores underwent an extensive review which led to a 122 % enlargement of its area.

The natural park of the island of Santa Maria, with its marine component, includes two natural reserves - the Formigas Islets and the Vila Islet, and three protected areas for resource management - São Lourenço Bay, the North Coast and the South Coast. The establishment of the natural park of the island of Santa Maria was motivated by the necessity to protect the island's distinct biological and geological attributes, as well as its paleontological heritage (Lopes et al., 2019).

The **Formigas MPA**, also known as the Reserva Natural dos Ilhéus das Formigas, is situated in the northeastern part of the Azores, approximately 43 kilometres northeast of Santa Maria Island (Figure 1). The MPA encompasses the Formigas Islets and a submerged seamount named the Dollabarat Bank. The MPA is divided into two zones:

1. the **core zone**, which includes the Formigas Islets and the surrounding waters up to a depth of 100 meters, where no-take restrictions are enforced to preserve marine biodiversity; and
2. the **buffer zone**, which extends from the edge of the core zone to the outer boundary of the MPA (DRAM, 2022). This buffer zone is subject to specific regulations that manage activities such as fishing and vessel traffic, aiming to minimize human impact while allowing for sustainable use of the area's resources (DRAM, 2022).

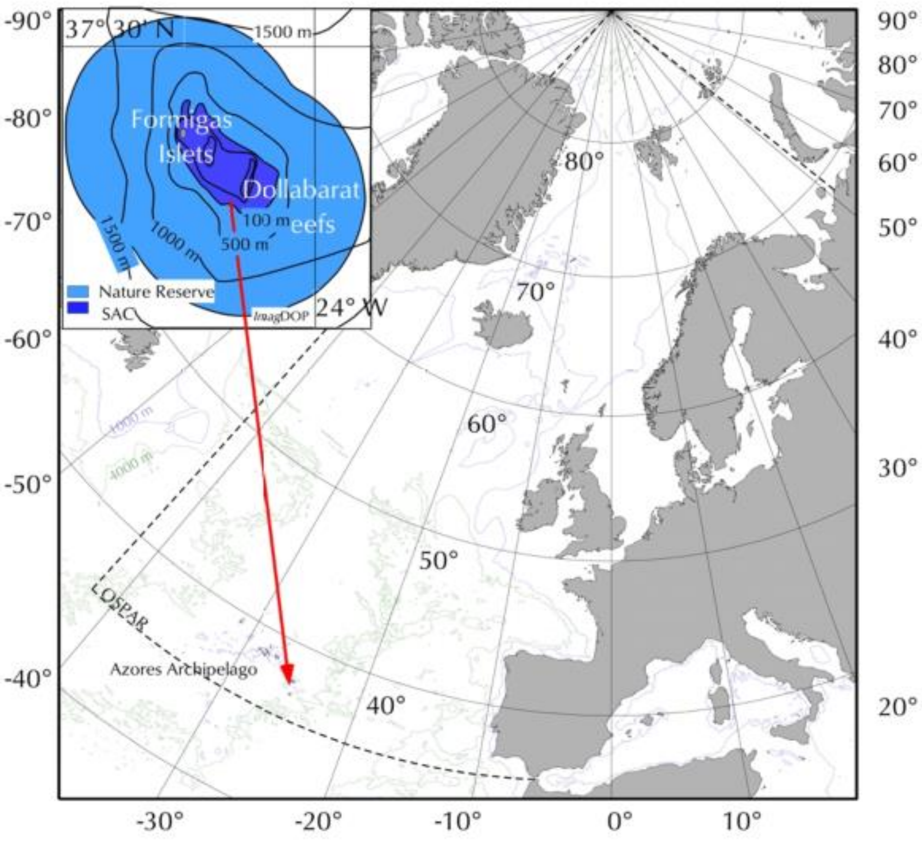

Figure 1. Geographic location of the Azores Islands and the Formigas MPA (Source: Christiansen and Tempera, n.d.). The dark blue area is the core zone (Nature Reserve), the light blue area is the buffer zone (Special Area of Conservation).

Established in 1988, the Formigas MPA is a vast marine sanctuary, spanning 57.4 km^2 (Regional Decrete n° 11/88/A). This MPA is home to a diverse array of habitats, from deep bathyal plains at the seamount's base, around 2,300 m deep, to shallow rocky outcrops. The seamount's shallow reefs alone, which are less than 50 m deep, cover an area of 3.26 km^2. The Formigas MPA is also characterized by its rich marine biodiversity, holding coastal and oceanic marine communities. Species which have been identified within the MPA include loggerhead sea turtles (*Caretta caretta),* cetaceans, tuna, pelagic sharks (e.g., the smooth hammerhead, *Sphyrna zygaena*), whale shark (*Rhincodon typus*), and a range of ray species (Lopes et al., 2019).

Initially, fisheries restrictions within the MPA only encompassed coastal habitats less than 200 m deep; fishing was still permissible in habitats deeper than 200 m for vessels under 11 m. However, a regulatory revision in 2003 led to a substantial expansion of the MPA's boundaries, which now encompass the entire seamount down to its base. The protection status was also bolstered, with fishing within the MPA restricted to just pelagic pole-and-line fishing for tunas. Importantly, the MPA's management plan includes measures to protect the area's biodiversity, regulate human activities, and monitor the health of the ecosystem (DRAM, 2022). In this MPA, the following activities are strictly prohibited: (a) underwater spearfishing, harvesting, or collecting marine organisms, with or without the aid of a vessel; (b) disturbance of nesting seabirds; (c) waste disposal; and (d) fishing, except for commercial handline or pole-and-line fishing targeting tunas by vessels equipped with the MONICAP continuous fishing activity monitoring system, subject to prior binding approval from the Regional Fisheries Inspection.

The Formigas MPA is internationally recognized under the RAMSAR convention and is part of the Natura 2000 network (European Commission, 2021). Within this, the Formigas Islet Natural Reserve is classified as an International Union for Conservation of Nature (IUCN) Category Ib protected area, an MPA - SMA01, a Site of Community Importance/Special Area of Conservation (SCI/SAC – PTSMA0023), and a Ramsar site (No. 1804 — Ilhéus das Formigas e Recife Dollabarat) and covers a 0.30 km² area within the territorial sea. The SMA01 area's protection is justified by its inherent natural value and its significance for safeguarding protected species, habitats, and ecosystems, as it includes the objectives and territorial boundaries defined for SCI Ilhéus das Antas and Recife Dollabarat (PTSMA0023) (Lopes et al., 2019).

This study is propelled by the critical need to understand how MPAs can enhance ecological networks and increase fish populations outside their boundaries, providing lasting benefits for fisheries management and surrounding communities. This research endeavours to better understand the spillover phenomenon and its wider consequences by combining findings from the literature and feedback from stakeholders. We aim to bridge the gap between theoretical understanding and practical application, contributing significantly to marine conservation discussions. However, it is important to clarify that the evaluation of policy frameworks was not included in the scope of this study.

3 AIMS AND OBJECTIVES

The main aim of this case study is to investigate whether spillover effects have been identified within and around the Formigas MPA. To achieve this, a multifaceted approach has been devised. Firstly, we examined the presence or absence of spillover effects within the Formigas MPA utilising a comprehensive review of existing literature. Subsequently, we then identified and compiled evidence from the literature that substantiates the occurrence of spillover effects, if any, within and around the Formigas MPA. Additionally, we sought to gather and analyse the perceptions, opinions, and experiences of key stakeholders, including fishers, fisheries managers, scientists, and environmental organizations, regarding spillover effects in the Formigas MPA through a questionnaire-based approach. More specifically, we assessed the level of stakeholders' knowledge concerning the regulations governing the Formigas MPA, with a particular emphasis on fishing restrictions. We also evaluated how stakeholders perceive the roles of the Formigas MPA, specifically as a conservation tool and a fisheries management instrument. Finally, we identified and explored the key factors that stakeholders associate with the occurrence or absence of spillover effects in the Formigas MPA.

4 METHODOLOGY

4.1 Literature review

The literature review in this study was conducted using a thorough approach to provide an in-depth look at the potential spillover effects associated with the Formigas MPA. The research methodology included searching in databases like ScienceDirect, SpringerLink and also Google scholar using specific keywords. Additionally, academic journals as well as grey literature, websites and recommendations from key researchers were considered to identify relevant publications related to the Formigas MPA and the region. After an initial scan of titles and abstracts, the literature was narrowed down studies that focused directly on the Formigas MPA and that covered key themes, including spillover effects, fisheries and stakeholders.

4.2 Stakeholder questionnaire

We developed a detailed questionnaire to assess the perceptions of key stakeholders on the potential spillover effects in their nearby MPAs. The questionnaire comprised open-ended and closed questions. Open-ended questions were developed to capture stakeholder opinions, while closed questions were statement-based and used Likert scale answer categories. Questions were grouped into four broad categories to encapsulate the key issues being studied (see Annex 4):

- **Respondent information**: Basic information on the name, institution and role of the respondent requested.
- **Background information**: Background information requested to understand the respondent and their (potential) use of the MPA. Questions included knowledge of when the MPA was established, the type of restrictions in place and how long the stakeholder has been associated with the MPA either through research, fishing or managing it.
- **Fishery impacts of MPAs**: Respondent's perceptions of the socio-economic impacts of spillover from the MPA were requested. Stakeholders were asked whether the designation of an MPA / area where fishing is limited has led to an increase in revenues for fishers, whether the fishing community in the area feel their fisheries livelihoods are more secure after the MPA was established, and the extent to which they believe spillover from the MPA has influenced the catch composition in adjacent fishing grounds.
- **MPAs as management tools**: The respondent's perceptions on whether MPAs are conservation or fisheries management tools was requested. Stakeholders were asked to state whether their local MPA was acting as a conservation tool, a fisheries management tool or both. Other questions under this section required stakeholders to state their agreement/disagreement on whether the establishment of MPAs is an effective conservation strategy to support fish populations and commercial fisheries in their area. Respondents were also asked to indicate what factors they thought were contributing to spillover effects.

Four key stakeholder groups were targeted: (i) commercial and recreational fishers; (ii) fisheries managers and government authorities; (iii) scientists; and (iv) environmental non-government organisations (eNGOs). Further, to gain insights into the possible spillover effects, we engaged with several stakeholders linked to the Formigas MPA. We emailed 23 stakeholders and sent follow-up emails to 14 to promote their involvement. We also made phone calls to incentivise participation among various stakeholder categories. Specifically, we reached out to six representatives from regional fisher associations, five from governmental bodies, three academic researchers, four members of eNGOs, and five diving schools active within the MPA. Our outreach was conducted during July and August 2023.

5 RESULTS

5.1 Literature review

Between 2014 and 2019, a range of scientific studies and monitoring initiatives were carried out in the Formigas MPA. These focused on various areas, including marine birds (MONIAVES), fish and invertebrates (MONIZEC and the BALA project in 2016), coastal marine biodiversity, non-native species (PIMA project in 2016), as well as work examining biodiversity, sediments, cetaceans, and turtles within the Azores, reflecting the region's commitment to preserving marine ecosystems (Governo dos Açores, 2020). Importantly, the 2019 report from Grupo de Acção para o Mar dos Açores (GAMPA) emphasizes the uniqueness of the Formigas region. Formigas stands out for its distinct fish community, distinguished by the presence of rare pelagic and mesophotic species, attributed to the high cover of underwater mountain habitat. The Formigas MPA contains a very high species diversity, and while its macroinvertebrate diversity aligns with other regions, its high sea urchin abundance is remarkable. Uniquely, lacking a port, Formigas experiences fewer intrusions from non-native species than the Azores mainland.

Despite the limited range of studies that have examined the Formigas MPA, there is a substantial dearth of studies focusing (or even encapsulating) studies that examine fishery or ecological spillover from the MPA. Despite this, there is evidence from the Azores (but outside of the Formigas MPA), to show that at least one fisheries finfish species may show MPA site specificity for, but also potential spillover from that MPA. Afonso et al. (2011) employed passive acoustic telemetry to examine the movement of dusky grouper (*Epinephelus marginatus*) within and across the Monte da Guia Marine Reserve (MGMR) located on the island of Faial in the Azores, which is approximately 366 kilometres northwest of the Formigas MPA. This work revealed that dusky grouper displays strong site-specificity to this MPA, while there is the potential for a spillover effect within these fish, with individuals migrating from the MPA to nearby fishing areas. This small coastal marine reserve enforces full protection (no-take reserve) within two small sunken calderas (8 ha), while the immediate volcano perimeter enjoys partial protection. Despite such movement of species, such behaviour was found to be limited to a 5 km radius from the MPA. While this suggests that marine reserves may have limitations as a fisheries management tool for increasing harvestable yield through fish migration, the study ultimately underscores the crucial role small reserves play in protecting endangered species like the dusky grouper.

The most recent examination of the Formigas MPA was undertaken as part of a wider study of the effects of MPAs, to determine the MPA impact on fish populations (Afonso et al., 2018). However, the study faced a significant limitation in attesting the impacts of the MPA, as there was no "before" data, with sampling started after the MPA was established, while there was no control area, as the full seamount is protected with no comparable unprotected habitat (Afonso et al., 2018). The study focused on two of the main shallow reefs within the Formigas MPA, the Formigas islets and the Dollabarat reef. These two sites are separated by 6 km and a stretch of water exceeding 80 m in depth (Afonso et al., 2018). The researchers were able to compare fish metrics between the two reefs over time, including "before" and "after" new 2003 restrictions came into place. This work showed that, although overall fish abundance showed a negative or unclear trend over time within the Formigas MPA, abundances of fish were significantly higher at the Dollabarat reef for both medium and large home range fishes. Lastly, the average size ratio in the Formigas MPA was only significantly different in the case of benthopelagic fishes, indicating a potential reduction in size in this group after the revised protection.

5.2 Stakeholder perceptions

Two stakeholders were willing to take part in the study, one from the governmental authority and another from the fishing sector. Given the limited engagement from such traditional stakeholders, the consortium extended the outreach efforts to include established diving centres that have been operating within the MPA for an extended period. This approach aimed to gather insights from a different angle and capture the perspective of entities closely connected to the marine environment. In addition, a marine scientist representing a diving centre and the maritime tourism sector also provided his insights on the MPA. Interestingly, the fishing sector stakeholder inadvertently provided insights on another MPA within the Azores - the Marine Protected Area of Condor. This MPA encompasses the Condor Seamount, an underwater mountain located southwest of Faial Island, designated as a protected area within the Azores Marine Park in 2016.

Of all the stakeholders contacted, eighteen stakeholders remained unresponsive. One stakeholder chose not to contribute, advising us to seek wider, more relevant input. Additionally, two stakeholders visited the questionnaire site but chose not to fill out the questionnaire. Interestingly, the sole stakeholder from the government who participated proactively shared the link with five other stakeholders, some of whom we had previously reached out to. Despite this, even after being prompted by a governmental authority, these stakeholders did not respond. The timing of our outreach conducted during July and August 2023, which are typical vacation months in Portugal, might have played a role in the unexpectedly low participation rate.

The governmental authority that replied to the questionnaire mentioned that the Formigas MPA has had a management plan in place since 1988. This allows some level of fishing, with special authorization for pole and line fishing gear at the MPA border. According to this stakeholder, fishing primarily occurs at the MPA border. **The extent of spillover effects from the MPA on adjacent fisheries is perceived to be significant in contributing to the recovery of overexploited fish populations**, but the magnitude of such spillover and contributing factors which may lead to such spillover remain unspecified. The stakeholder strongly agrees that fishers' catches in the area are higher post-establishment of the MPA, resulting in economic benefits for local fisheries. The governmental authority believes that the MPA not only contributes to marine conservation but it also aids in fisheries management; this stakeholder was strongly in favour of permanently closing certain areas of the MPA for commercial fisheries development.

Both the governmental authority and fisheries sector stakeholders consider that **the MPA contributes to both biodiversity protection and fisheries**. The fisheries sector stakeholder, although inadvertently addressing the Condor MPA rather than the intended Formigas MPA, shed light with his insights on the dynamics of marine conservation within the Azores. The stakeholder's observations noted marked shifts in fish abundance, biomass, and species composition within the MPA of Condor. He mentioned the **migration of juvenile individuals from the MPA to other areas, indicating potential spillover effects**. This stakeholder expressed a **strong**

disagreement with the notion of increased revenues for fishers and improved livelihood security post-MPA establishment and diverged from the governmental authority's perspective. This difference in perspectives emphasises the complexity of assessing the socioeconomic impacts of MPAs.

The diving school representative stressed the significant role that maritime tourism operators play in understanding the marine ecosystem. He pointed to the decline in marine resources that has been observed by operators and their clients for over a decade. The stakeholder observed that fishing activity is more intense during the off-season when diving operators are less active. He mentioned that in his perspective a larger MPA with stricter enforcement of regulations would be more effective. The respondent also believes the MPA is acting neither as an effective conservation tool nor a fisheries management tool due to its inadequate implementation. Furthermore, the **respondent does not consider investigating spillover to be a research priority due to the MPA's current ineffectiveness and rates the likelihood of spillover as "very unlikely".**

The diving school representative pointed out that the MPA's supposed inefficiency and decline are due to poor management. The comparison of the MPA to areas outside of it further highlights the severity of the issue, as the external areas were described as being "even worse". Within the MPA, the respondent notes a reduction in fish abundance and biomass, although the decline is comparatively slower than in the surrounding areas. The stakeholder also mentioned the emergence of urchin barrens in specific zones as a notable transformation within the MPA's ecosystem.

6 DISCUSSION

The Formigas MPA showcases unique ecological characteristics, including a diverse array of fish species and an exclusive underwater mountain habitat. The MPA's relative isolation from human impact could be allied to its geographical isolation and the absence of a port, which limits the introduction of invasive species. However, challenges related to effective fisheries management, enforcement, and multi-stakeholder collaboration are evident.

There is little direct evidence that the Formigas MPA has substantially impacted the marine communities within it, and no quantitative evidence that spillover effects are occurring from this MPA. This 'underperformance' of the Formigas MPA (relative to other coastal MPAs) highlights the potential need to further develop fisheries management procedures within this MPA. Deficient enforcement, exacerbated by exceptions for pelagic tuna fishing via handline or pole-and-line methods exclusively by vessels integrated within the MONICAP system, despite the MPA's "no-take" status, may then be potentially undermining the conservation objectives of the MPA. **Despite such lack of quantitative evidence to show that the designation of the Formigas MPA is resulting in spillover, recent work has shown that MPAs within the Azores, can play a crucial role in preserving sensitive reef fish species)** (Afonso et al., 2018). Studies such as Afonso et al. (2011) and Afonso et al. (2018) provide valuable insights into the behaviour of marine species within MPAs, such as the dusky grouper in the Monte da Guia Marine Reserve, and the potential for spillover effects. These studies, while not directly focused on the Formigas MPA, illustrate the importance of considering the ecological dynamics and species-specific behaviours in understanding and managing MPAs. The findings suggest that while MPAs like Formigas can play a crucial role in protecting sensitive species, their design, management, and enforcement need to be carefully evaluated to maximize their conservation and fisheries management benefits.

In comparison to the lack of quantitative data on fish stocks within and around the MPA, stakeholder perceptions acknowledge the MPA's role in biodiversity protection. However, such stakeholders also expressed concerns about the impacts of fishing restrictions on their livelihoods. The resurgence of fisher registrations in the Azores indicates that fisheries management has to consider evolving social and economic dynamics. In addition, the response from the governmental authority stakeholder indicates a belief that the Formigas MPA contributes significantly to the recovery of overexploited fish stocks through spillover. Despite this, the diving stakeholder was more critical of the MPA's effectiveness, believing that it is no longer an effective conservation tool and points to the decline in marine resources observed over the past decade. The governmental authority is more positive about the MPA's effectiveness, believing that it has been successful in protecting marine resources and providing benefits to local fisheries. There is a consensus among stakeholders that there is an existing need for stricter enforcement of regulations around the MPA.

The governmental stakeholder highlighted the dual role that the MPA has as a conservation tool and fisheries management tool. In this respect, **recent work** (Afonso et al., 2020) **has referenced the Formigas MPA as one of the locations known to host multiple marine megafaunas, and the authors mentioned that places like the Formigas MPA might prosper under better protective measures, perhaps through updated laws and MPA zoning**. In a similar perspective, the stakeholder's idea to close off certain MPA zones aligns with the proposal to establish designated areas that might serve as refuges for fish stock and lead to increased spillover benefits and sustainable fishing methods.

Collaborative initiatives between stakeholders are acknowledged by the respondents from the government and the fisheries sector as effective tools for understanding and managing spillover impacts. The stakeholder from the diving school is more concerned about the lack of collaboration between stakeholders, mentioning the lack of communication and cooperation among the different stakeholders involved in the management of the MPA.

The low questionnaire response rate in this study introduces a potential source of bias in the collected data and information since the perspectives were gathered from only three participating stakeholders, and may not accurately represent the broader range of perspectives within the stakeholder community. The timing of the survey, during the months of July and August, coincides with the typical holiday period in Portugal and this could potentially account for part of the reduced engagement among stakeholders who might have been unavailable due to vacation schedules. Moreover, the absence of responses could be attributed to the specific nature of the topic, as **the Formigas MPA's spillover effects appear to have very limited existing research**. In addition, the responding governmental authority acknowledged, when asked in conversation, that researchers and governmental authorities lacked knowledge about spillover effects in the Formigas MPA and suggested that this could be the reason why many did not participate in the survey.

7 CONCLUSIONS

The study of the Formigas MPA in the Azores, through the review of the available literature and stakeholder engagement, showed important details about its potential spillover effects. It is apparent that the Formigas MPA is a region of ecological significance. The isolation, due to its geographical and infrastructural limitations, has likely contributed to its relatively low exposure to human impacts, enabling it to maintain its distinctive ecological features. Despite these substantial ecological benefits, there is still little work that has examined the MPA and the long-term effects of protection on the associated marine communities. In addition, studies like Afonso et al. (2011) and (2018) showcase the intricate relationship within this region between the MPA, the associated fish populations, and the adjacent fishing grounds.

Despite this, the significance of spillover effects is acknowledged by the governmental authority stakeholder, who emphasizes the role of the MPA in aiding the recovery of overexploited fish populations. Quantitative data to support such claims are lacking. In fact, despite its "no-take" status, quantitative analyses of the Formigas MPA have shown that it may underperform (in terms of enhancing fish populations) in comparison to coastal MPAs, due to potential deficiencies in enforcement and allowances for pelagic tuna fishing.

While the governmental authority stakeholder views the MPA as a dual-purpose tool for both conservation and fisheries management, the diving school representative holds a more critical stance, indicating a decline in marine resources over the past decade and a need for stricter enforcement and improved protective measures. All of the stakeholders are in consensus about the necessity for stronger enforcement of the MPA. The significance of collaborative projects and the MPA's dual role in both conservation and fisheries management was also recognized.

Any future work would benefit from a higher participation rate among stakeholders to ensure a broader representation of perspectives. To evaluate the effectiveness of the Formigas MPA, continuous monitoring and research are imperative given that existing studies on spillover effects within and around this MPA are currently limited to non-existent. Future research on the Formigas MPA should concentrate on quantitatively measuring spillover effects, utilizing statistical models to track biomass and diversity changes in adjacent areas. This focus will enable a precise evaluation of how protected zones influence surrounding ecosystems and fisheries, providing a clear metric for conservation efficacy and resource management. Such targeted studies are essential for validating the MPA's role in promoting marine biodiversity and enhancing fish stocks beyond its boundaries.

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14..CASE STUDY REPORT:

SELVAGENS ISLANDS MARINE PROTECTED AREA

PORTUGAL – MACARONESIA


Port of Funchal with examples of small scale fishing vessels. © Nuno Castro

Analysis of potential spillover effects around the Selvagens Islands Marine Protected Area

Sérgio Abreu

MRAG Europe

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LIST OF ABBREVIATIONS

Term	Description
EEZ	Exclusive Economic Zone
IBA	Important Bird and Biodiversity Area
MPA	Marine Protected Area
PCIML	Permanent Commission of International Maritime Law
POGIS	Selvagens Islands' Management and Development Plan
RNS	Selvagens Natural Reserve
SAC	Special Area of Conservation
SPA	Special Protection Area
UNCLOS	United Nations Convention on the Law of the Sea

1 EXECUTIVE SUMMARY

This case study focuses on the Selvagens Islands Marine Protected Area (MPA) which is located in the North Atlantic and forms part of Madeira's Autonomous Region. In 2021, the Selvagens Islands MPA became Europe's largest MPA. This study examined whether spillover effects have been detected or not around the MPA by conducting a literature review and stakeholder engagement. The engagement utilised a questionnaire-based methodology, targeting commercial and recreational fishers, fisheries managers and government authorities, scientists and environmental non-government organisations.

The literature review underscores the Selvagens Islands MPA's critical role in marine biodiversity conservation. No evidence was found in the literature for spillover effects of the MPA, however with the richness of the area there is a probability that spillover takes place. The stakeholder engagement showed that there is a marked divergence in stakeholders' opinions in terms of the impact of the Selvagens Islands MPA, notably between representatives from the governmental authority and the fisheries sector. The governmental authority emphasized the benefits of conservation, while concerns were raised by the fisheries sector regarding impacts on livelihoods due to fishing restrictions. This duality in opinion also resulted in a divergence in viewpoints on the likelihood of spillover effects, with the governmental authority expecting positive outcomes and the fisheries sector expressing marked scepticism.

This divergence in opinions underscores the need for comprehensive discussions on MPA management optimization, aiming to merge conservation initiatives with the tangible needs of local fishers. In addition, future research should combine a qualitative approach with a quantitative approach, to elucidate the multifaceted impacts of the MPA. A quantitative approach could entail fish stock surveys, species movement tracking, and analysis of fisheries data, to quantitatively evaluate the spillover effects and socio-economic implications of the MPA.

2 BACKGROUND

The Selvagens Islands and their surrounding sea zones, are situated in the North Atlantic and are part of the Autonomous Region of Madeira. They represent the southernmost boundary of Portuguese land, situated between distinct latitudes and longitudes. These islands, which mark the most southern extent of Portugal's maritime domain, are positioned in the temperate-subtropical northeast Atlantic. They are closer to Spain's Island Tenerife than to Madeira and are about 600 km from the Moroccan coast.

The Natural Reserve of the Selvagens Islands, covering 9 471 hectares, is bounded by the 200-metre isobath and includes Selvagem Grande Island, Selvagem Pequena Island, Fora Islet, and other smaller islets (Figure 1). In November 2021, its protected area expanded significantly from 95 to 2 677 km^2.

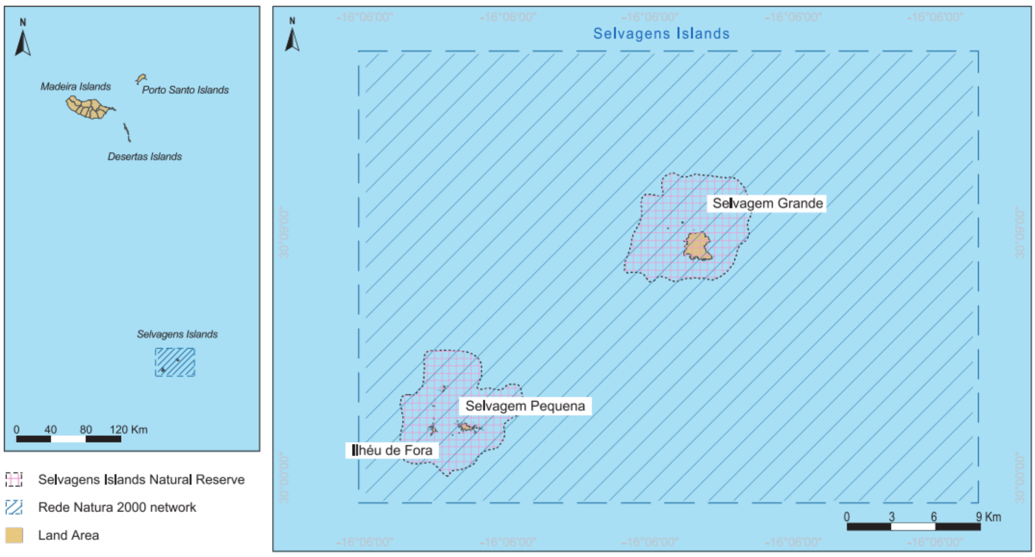

Figure 1: Map of the Madeira Region and the Selvagens Islands (Source: Instituto das Florestas e Conservação da Natureza [IFCN], 2022).

The Selvagens Islands have witnessed a dynamic history of discovery, ownership changes, and conservation efforts. The islands were officially found in the 15th century by the Portuguese explorer Diogo Gomes. These lands became a source of income through plant collection for dyes and tannery uses. Ownership shifted in the 16th century among private individuals. In the 18th century, the "urzela" trade flourished, providing rich colour to textiles. The sovereignty of the Selvagens Islands, settled by the Permanent Commission of International Maritime Law in 1938, remains a contentious issue between Portugal and Spain. Central to this dispute is whether the islands qualify as "islands" or "rocks" per the United Nations Convention on the Law of the Sea (UNCLOS) Article 121, impacting the southern boundary of the Portuguese Exclusive Economic Zone (EEZ). Spain asserts the islands should be designated as rocks, positioning them within the Spanish EEZ and granting Canary Islands' fisher access. Portugal points to permanent habitation and stationed research and ranger facilities, advocating for a 200-nautical-mile EEZ around the archipelago (Friedlander et al., 2016). At the start of the 20th century, the islands moved from private to regional administration, accompanied by the establishment of lighthouses. Conservation took centre stage in the 21st century, with the islands becoming part of Natura 2000 and hosting scientific missions (Instituto das Florestas e Conservação da Natureza [IFCN], n.d.).

The Selvagens Islands were designated as a Strict Nature Reserve in 1971 by Decree No. 458/71, imposing usage restrictions in both marine and terrestrial zones (Regional Government of Madeira, 1971). They were later reclassified as a Natural Reserve under Regional Decree No. 15/78/M (Regional Government of Madeira, 1978), which still stands today, albeit with modifications introduced by Regional Decree No. 11/81/M (Regional Government of Madeira, 1981). The Selvagens Islands were initially intended to protect its native fauna, flora, and marine ecosystems. An essential trigger for this was the conservation of the vulnerable Cory's shearwater colony (*Calonectris* spp). The Selvagens Islands are recognized as the world's largest breeding ground for Cory's shearwaters (Granadeiro et al., 2006). Recent regulations included the establishment of the Natural Monument of the volcanic structures in the islands via Regional Legislative Decree No. 7/2021/M (Regional Government of Madeira, 2021). This covers the emerged sections of Selvagem Grande Island and Selvagem Pequena Island's volcanic formations and their submarine pedestals, highlighting them as areas of scientific interest.

In 2021, the Madeira regional government initiated a vast marine conservation project, framing the Selvagens Islands Nature Reserve as Europe's largest MPA (Alves et al., 2022). This measure resulted in the extension of the protective zone to 2 677 km^2, ensuring protection against extractive activities, while aiming to protect diverse habitats and species, including bottlenose dolphin (*Tursiops truncatus*) and blue shark (*Prionace glauca*) (Alves et al., 2022). An updated legal framework for the MPA was then endorsed by Regional Legislative Decree No. 8/2022/M (Regional Government of Madeira, 2022).

In May 2022, the extension of the MPA highlighted its significance as a no-take zone, which has an IUCN 1A designation. Reflecting its ecological importance and the unique species and habitats it hosts, the Selvagens Island Nature Reserve is incorporated into the EU Natura 2000 Network, aligning its boundaries with the Natural Reserve. This MPA encompasses a Special Area of Conservation (SAC, PTSEL0001) and an overlapping Special Protection Area (SPA, PTZPE0062) covering 124 530 hectares, as dictated by Regional Regulatory Decree No. 3/2014/M on March 3 (Figure 2).

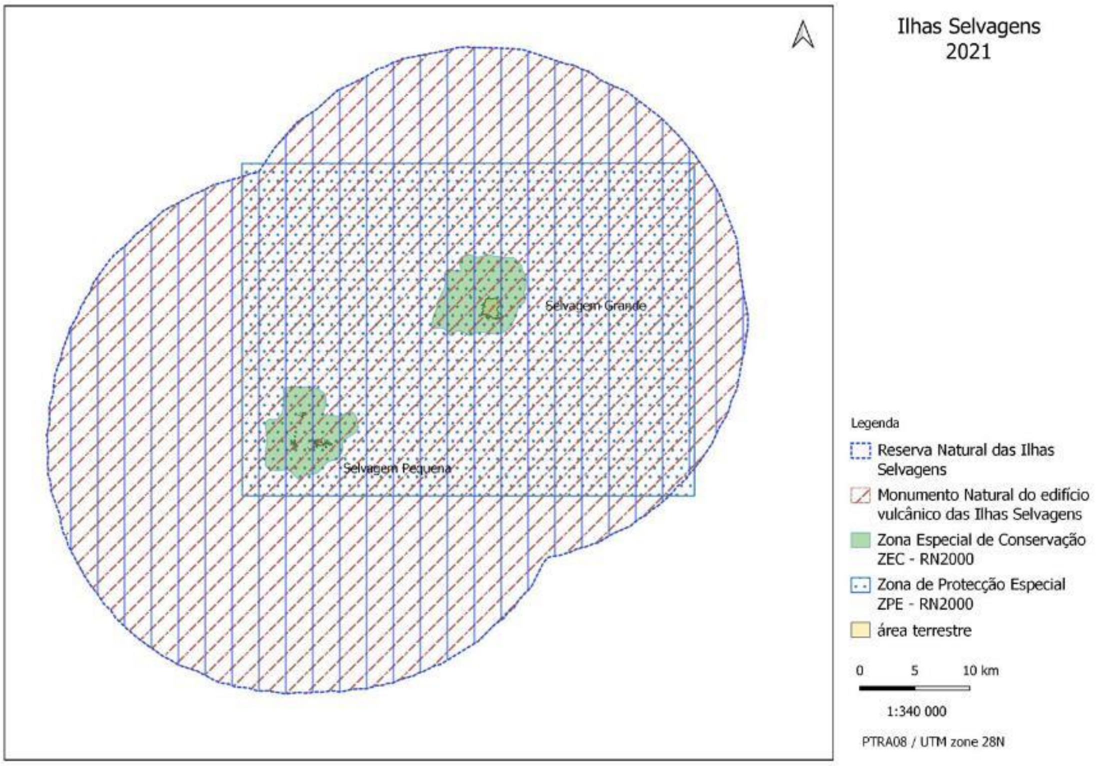

Figure 2: Map of the Selvagens Islands MPA with three protection areas: Selvagens Natural Reserve, Natura 2000 Special Conservation Area and Natura 2000 Special Protection Area (Instituto das Florestas e Conservação da Natureza, n.d.)

The management of the Selvagens Islands MPA, including its Natura 2000 sites, falls under the Selvagens Islands' Management and Development Plan (POGIS). Initially approved by the Regional Government Council Resolution No. 1292/2009 on October 2, it was revised in 2017 through Resolution No. 303/2017 on May 15 to address contemporary trends in various sectors (Presidência do Governo Regional, 2009) (Instituto das Florestas e Conservação da Natureza, n.d.). Notably, the updated plan addresses the creation and regulation of nature and scientific tourism on the islands. The MPA Management Plan covers terrestrial and marine regions of significant natural value and areas of socioeconomic activity, resulting in varying protection levels and usage permissions.

Following the enactment of Decree-Law No. 8/2022/M on May 3, 2022, the Selvagens Islands Natural Reserve has been consolidated under a new legal framework, thereby superseding previous zoning distinctions, such as the Total Protection Area and the Partial Protection Area. The decree establishes the Selvagens Islands Natural Reserve as a singular zone of integral protection, encompassing all terrestrial and marine areas up to a depth of 200 meters around the Selvagem Grande, Selvagem Pequena, Fora Islet, and adjacent islets. This zone is now subject to comprehensive conservation measures, with human activities strictly limited to research, monitoring, and conservation efforts. Notably, the decree has introduced a total ban on fishing within the entire Marine Reserve area of the Selvagens Islands, reflecting a significant shift towards stronger environmental protection. The management of the reserve and its adherence to conservation goals are under the purview of the Regional Secretariat for Environment and Natural Resources, in collaboration with relevant authorities, to ensure the preservation of its unique ecological value. Activities within the reserve are meticulously regulated, with a focus on promoting scientific research, environmental education, and sustainable nature-based tourism, thereby aligning with global conservation objectives and the safeguarding of marine biodiversity (Regional Government of Madeira, 2022).

Currently, the Madeira Natural Park Service supervises the management and surveillance of the islands (Friedlander et al., 2016; UNESCO, 2019). Two full-time rangers and two maritime police officers are stationed year-round on Selvagem Grande. Selvagem Pequena typically hosts two rangers from May to October, marking them as the islands' sole inhabitants (Friedlander et al., 2016). However, as indicated by Friedlander et al. (2017), insufficient protection in the deeper waters exposes species to risks arising from intensive fishing activities.

There is a need to better understand the role of MPAs in fostering biodiversity conservation and socio-economic growth through spillover effects. By focusing this case study on the Selvagens Islands MPA, we aim to assess how MPAs may enhance ecological connectivity and boost fish stocks beyond their boundaries, offering sustainable benefits for fisheries management and surrounding communities. The combination of a literature review and a stakeholder engagement survey provides a nuanced perspective on spillover effects and their wider implications. This research goes beyond academic inquiry, aiming to inform strategic management and policy decisions for the long-term sustainability of marine resources. By bridging theory with practice, the study seeks to contribute to future conservation strategies and enhance stakeholder involvement in MPA governance, thus adding valuable insights to the global marine conservation dialogue and offering evidence-based strategies to maximize MPAs' ecological and socio-economic advantages.

3 AIMS AND OBJECTIVES

The main aim of this case study is to investigate whether spillover effects have been detected around the Selvagens Islands MPA. To achieve this, a multifaceted approach has been devised. Firstly, we aimed to determine the presence or absence of spillover effects within the Selvagens Islands MPA through a comprehensive review of existing literature. Subsequently, we identified and compiled evidence from the literature that substantiates the occurrence of spillover effects, if any, within and around the Selvagens Islands MPA. Additionally, we sought to gather and analyse the perceptions, opinions, and experiences of key stakeholders, including fishers, fisheries managers, scientists, and environmental organizations, regarding spillover effects in the Selvagens Islands MPA through a questionnaire-based approach. More specifically, we assessed the level of stakeholders' knowledge concerning the regulations governing the Selvagens Islands MPA, with a particular emphasis on fishing restrictions. We also evaluated how stakeholders perceive the role of the Selvagens Islands MPA, specifically as a conservation tool and a fisheries management instrument. Finally, we identified and explored the key factors that stakeholders associate with the occurrence or absence of spillover effects in the Selvagens Islands MPA.

4 METHODOLOGY

4.1 Literature review

The literature review in this study was conducted using a thorough approach to provide an in-depth look at the potential spillover effects associated with the Selvagens Islands MPA. The research methodology included searching in databases like ScienceDirect, SpringerLink and also Google Scholar using specific keywords. Additionally, academic journals as well as grey literature, websites and recommendations from key researchers were considered to identify relevant publications related to the Selvagens Islands MPA. After an initial scan of titles and abstracts, the literature was narrowed down to studies focusing directly on the Selvagens Islands MPA and covering the key themes of spillover effects, fisheries and stakeholders.

4.2 Stakeholder questionnaire

We developed a detailed questionnaire to assess the perceptions of key stakeholders on the potential spillover effects from the MPA to adjacent areas. The questionnaire comprised open-ended and closed questions. Open-ended questions were developed to capture stakeholder opinions, while closed questions were statement-based and used Likert scale answer categories. Questions were grouped into four broad categories to encapsulate the key issues being studied (see Annex 4):

- **Respondent information**: Basic information on the name, institution and role of the respondent requested.
- **Background information**: Background information requested to understand the respondent and their (potential) use of the MPA. Questions included knowledge of when the MPA was established, the type of restrictions in place and how long the stakeholder has been associated with the MPA either through research, fishing or managing it.
- **Fishery impacts of MPAs**: Respondent's perceptions of the socio-economic impacts of spillover from the MPA were requested. Stakeholders were asked whether the designation of an MPA / area where fishing is limited has led to an increase in revenues for fishers, whether

the fishing community in the area feel their fisheries livelihoods are more secure after the MPA was established, and the extent to which they believe spillover from the MPA has influenced the catch composition in adjacent fishing grounds.

- **MPAs as management tools**: The respondent's perceptions on whether MPAs are conservation or fisheries management tools was requested. Stakeholders were asked to state whether their local MPA was acting as a conservation tool, a fisheries management tool or both. Other questions under this section required stakeholders to state their agreement/disagreement on whether the establishment of MPAs is an effective conservation strategy to support fish populations and commercial fisheries in their area. Respondents were also asked to indicate what factors they thought were contributing to spillover effects.

Four key stakeholder groups were targeted: (i) commercial and recreational fishers; (ii) fisheries managers and government authorities; (iii) scientists; and (iv) environmental non-government organisations (eNGOs). We engaged with several stakeholders linked to the Selvagens Islands MPA: 23 stakeholders were contacted through email and 13 of them received follow-up emails as an incentive to participate. Several phone calls were also made to promote engagement from the stakeholders of the different groups. Breaking it down by category: we approached two representatives from Fishermen's Associations, 12 from governmental entities, four researchers from various institutes, and five individuals from NGOs.

5 RESULTS

5.1 Literature review

While a considerable amount of research within the Selvagens Islands MPA has focused on the conservation of marine bird species, investigations into marine (intertidal and subtidal) communities are also present, albeit to a lesser extent. This conservation priority is evident in the establishment of the MPA, which was originally intended to maintain the islands' ecosystems, protect natural habitats, and counterbalance the impacts of unchecked human activities. In this context, a range of institutions and organizations have conducted research on the islands' ecology and wildlife, ranging from ornithological studies to geological research and ecosystem monitoring (Instituto das Florestas e Conservação da Natureza, n.d.). The Selvagens Islands' marine environment remains relatively unexamined, which has been attributed to its remote location and challenging sea conditions (Friedlander et al., 2017).

Despite the lack of research on marine species, the Selvagens Islands MPA comprises a variety of endemic, threatened, and vulnerable marine fish species, while also showcasing pristine habitats and globally rare marine species (Friedlander et al., 2017). Furthermore, these islands act as stepping stones for species colonization (Almada et al., 2015). Notably, the Selvagens Islands are home to a vast array of fish species, some of which hold commercial importance (Almada et al., 2015; Friedlander et al., 2017). Comprehensive studies by the M@rbis Project and the National Geographic Society have identified a rich ecosystem (UNESCO World Heritage Centre, n.d.). For example, the Selvagens 94 Expedition identified 115 marine molluscs, with 32 being new records for the islands. Additionally, the EMEPC/M@rBis/Selvagens 2010 mission discovered 29 new coastal fish species.

Recent research, although not focused on spillover effects of the Selvagens Islands MPA, was able to show the high abundance and diversity of fishes within the MPA (Friedlander et al., 2017). This work showed that total fish biomass was 3.2 times larger at Selvagens than within Madeira mainland, with the biomass of top predators more than 10 times larger at Selvagens Islands MPA. In addition, this study showed that there are a range of commercially important species (e.g., groupers, jacks), known to be overfished throughout the region, that were relatively common and of larger size at Selvagens Islands MPA than found within mainland Madeira. Lastly, this work also showed that a range of sea urchin predators (e.g., hogfishes, triggerfishes) were also in higher abundance at Selvagens Islands MPA compared to Madeira (Friedlander et al., 2017).

The waters surrounding the Selvagens Islands MPA also comprise a range of large and diverse marine fauna. Cetaceans, including minke whales, sperm whales, bottlenose dolphins, and pilot whales, some of which are listed as "Vulnerable" or "Endangered", have been identified. In addition, the nearshore marine ecosystem of the Selvagens Islands MPA holds a diverse algal collection of at least 47 taxa, while the limited presence of sea urchin barrens, covering just 8% of the seabed, attests to the region's health. While large molluscs like the spiny pen shell, top-shell snail, and African thorny oyster are prevalent in Selvagens Islands, they are under threat elsewhere in Macaronesia due to overfishing, habitat degradation, and pollution. The intertidal ecosystems around these islands remain largely untouched, with the sun limpet, nearly extinct in other parts of Macaronesia, thriving in abundance at Selvagens Islands (Friedlander et al., 2017).

Geologically, Madeira's narrow platforms, sharp slopes, and low-productivity oligotrophic waters, restrict the habitats for demersal species and the range of viable fishing methods (Delgado, 2007). As a result, Madeira's fisheries have been focused on a limited number of species, largely encompassing deep-water, large pelagic migratory, and small pelagic fishes. Fisheries landings in Madeira have shown high variability (Santos, 2010). The period from 1990 to 1998, peaking in 1995, is recognized as the golden era. Although 2019 was an exceptional year in recent times, 2020 saw a downturn with a slight recovery (6.7 %) in 2021 (Figure 4.).

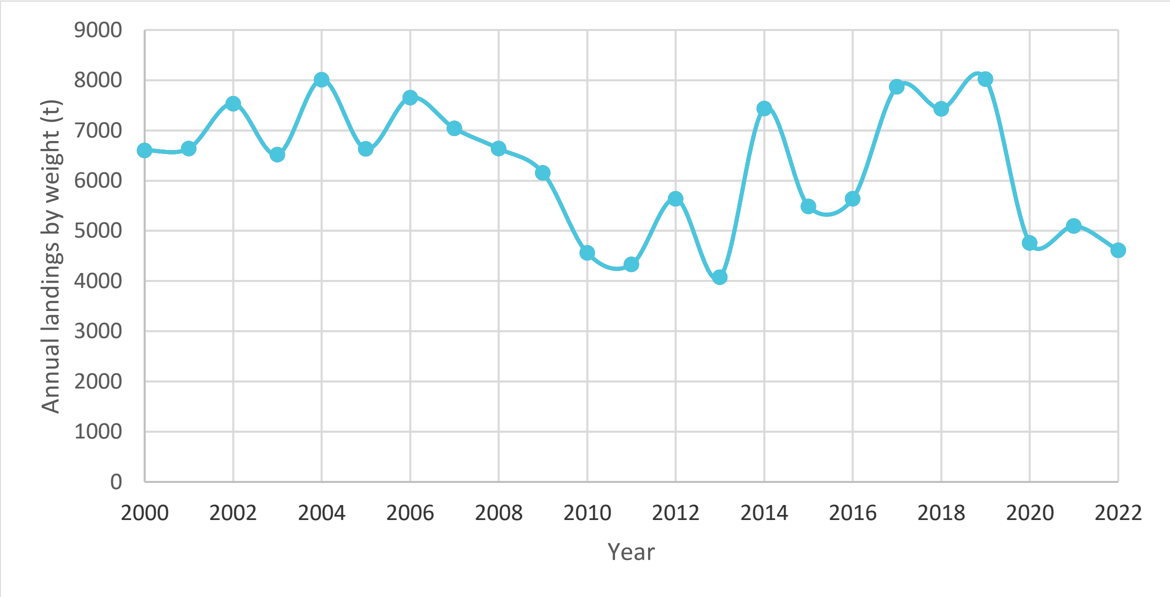

Figure 3. Annual Fish Landings in Madeira from 2000 to 2022 (in Metric Tons) (Instituto Nacional de Estatística, 2023)

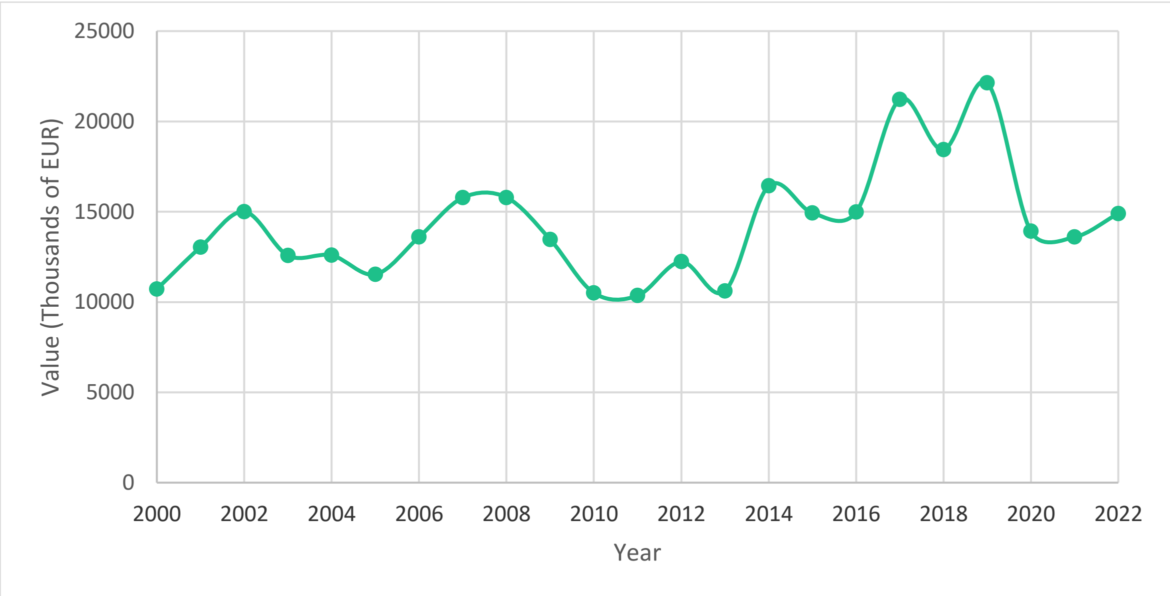

Figure 4. Economic Value of Fish Landings in Madeira from 2000 to 2022 (in Thousands of EUR) (Instituto Nacional de Estatística, 2023)

Tuna and black scabbardfish have predominantly dominated catches (Figure 5). Fish species like mackerel and horse mackerel, enjoyed popularity until the late '90s, before facing substantial drops. The catch numbers for tuna experienced a revival between 2017 to 2019, while black scabbardfish numbers dwindled in 2021 (Figure).

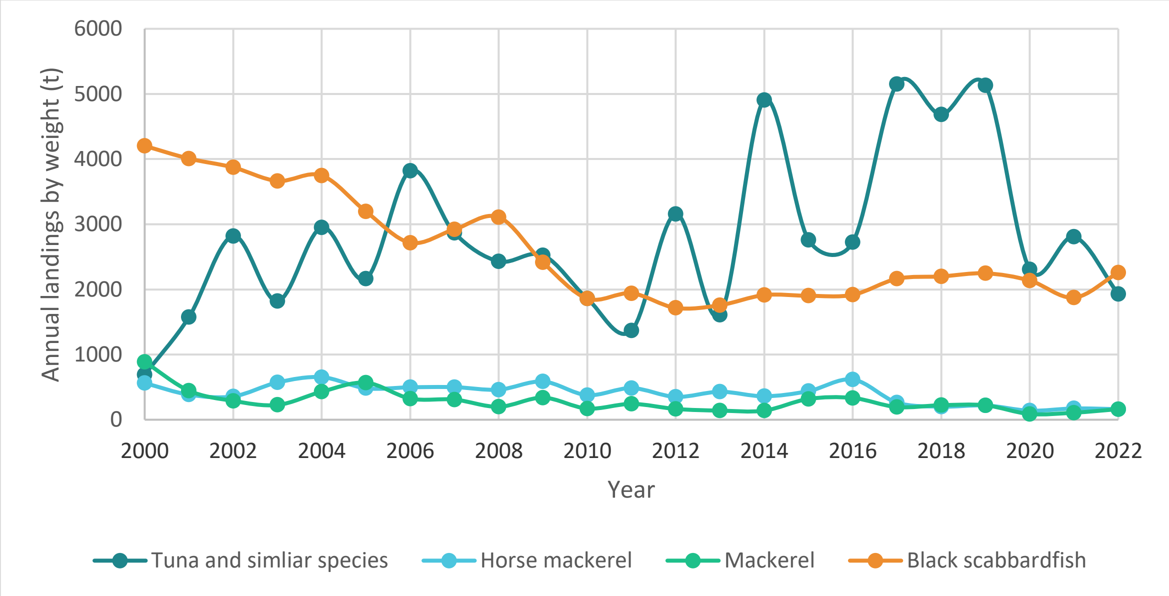

Figure 5. Annual landings by weight (t) for the four main target species in the Madeira Region: Tuna, mackerel, horse mackerel and black scabbard fish (Instituto Nacional de Estatística, 2023)

There has been a decrease in both fishing vessels and licenses from the mid-2000s, with licensed vessels declining from 145 in 2006 to 96 in 2021. Yet, the number of licenses issued in 2021 slightly surpassed the figures from 2010 (Instituto das Florestas e Conservação da Natureza, n.d.).

5.2 Stakeholder perceptions

There was little engagement with the majority of stakeholders identified and contacted. In this respect, despite numerous attempts at engagement, only two key stakeholders, representing the governmental authority and the fisheries sector, participated in the study. Twenty-one stakeholders did not provide any response. Of these, three of the contacted stakeholders mentioned holidays as the reason they were unavailable, with some hinting at possible participation in the future. Four stakeholders, understanding the intent of the study, advised contacting other individuals for more appropriate insights and chose not to participate. Three stakeholders visited the online questionnaire website but opted not to complete the questionnaire.

The two stakeholders who filled out the questionnaire exhibited a degree of scepticism regarding the immediate positive outcomes of the Selvagens Islands MPA on fisheries. The governmental authority stakeholder implied that the relatively recent implementation of the no-take MPA (2022), led to limited data on changes in fish abundance and species composition. Similarly, the fisheries sector stakeholder indicated that the establishment of the MPA has resulted in reduced catches and restricted fishing zones. Furthermore, this stakeholder also emphasized the economic challenges faced by local fishers due to restricted fishing zones within the MPA, shedding light on the practical complexities of implementing conservation measures. The fishers pointed out, *"We fish less and are more limited"* indicating the constraints imposed by the MPA. Similarly, the same stakeholder notes, *"The captures, essentially of small tuna species, ceased to exist"* showcasing the immediate impact on fishing activities within the MPA.

Notably, opinions diverged when considering the likelihood of spillover effects. The governmental authority stakeholder rates the likelihood as "Agree" for spillover from fully protected areas, while the fisheries sector stakeholder rates it as "Strongly Disagree". The governmental authority stakeholder expresses optimism, believing that the MPA will enrich biodiversity within and beyond the MPA. This stakeholder stated that "*the MPA works primarily as a conservation tool… it must also be a fisheries management tool*", emphasizing the potential dual role of the MPA. However, the fisher's perspective is more sceptical, expressing *"The type of fishing practised here is* *sustainable, catching fish one by one… it is not a conservation tool."* The fishers appear to suggest with this comment that the pole and line fishery targeting tuna, which was allowed before the creation of the recent no-take area, has a very low bycatch and high species selectivity, which is corroborated by several authors.

Different opinions were also observed regarding the collaborative initiatives between research groups, fishing communities, and management authorities. The governmental authority stakeholder considers such collaborations moderately successful, stating, *"The importance and advantages of reserves should be communicated… involving fishing communities should be prioritized."* Nonetheless, the fishers' representative is less convinced, mentioning, *"The MPA does not bring any benefit"* and highlighting the fishers' opposition to the MPA.

6 DISCUSSION

The Selvagens Islands MPA in the North Atlantic is of considerable historical, ecological, and geopolitical significance within the context of the Madeira Region. Nevertheless, the islands' remoteness and rough surrounding sea conditions have likely caused limitations to the extent of research activities being undertaken within the surrounding waters.

Friedlander's research underscores the Selvagens Islands MPA's ecological significance, revealing marked disparities in fish biomass and the abundance of commercially critical species compared to the Madeira mainland. Notably, the total fish biomass within the MPA is approximately 3.2 times that of the mainland, with top predator biomass exceeding tenfold. Additionally, species like groupers and jacks, often overfished regionally, were observed to be both common and larger in size within the MPA (Friedlander et al., 2017). These **findings highlight the MPA's crucial role in sustaining vital marine species, supporting both biodiversity and potential spillover effects** that could replenish fish stocks in neighbouring fishing areas. The presence of a healthy, diverse marine environment within the MPA indicates a strong potential for such spillover, emphasizing the need for future research to monitor and quantify these effects. Understanding the movement of species and the socio-economic impact on local communities will be critical in assessing the MPA's broader ecological and economic contributions.

In this work, we explored also the perceptions of the stakeholders involved with the Selvagens Islands MPA as well as the available ecological and fisheries literature focused on the MPA. In terms of the ecological implication of the MPA, **a consistent theme from both the literature and stakeholder responses is the preservation of biodiversity and the potential for ecological change both inside and outside the Selvagens Islands MPA (despite no data being available to test such changes)**. In this respect, the governmental authority stakeholders stated the belief that the MPA had the potential to enhance local and regional biodiversity. Importantly, they also stated that such biodiversity could be further enhanced with better MPA enforcement. Despite this, the implementation of the Selvagens Islands MPA has resulted in shifts in fishing patterns. This shift was criticised by the fisheries sector stakeholder, who focused on the reduction of available fishing areas and the negative effects on community livelihoods.

Notwithstanding the reported decline in catches, **MPAs such as the one in Selvagens Islands may be pivotal for preserving marine biodiversity**. Findings from M@rbis, the National Geographic Society and limited ecological research show that **the Selvagens Islands MPA may be important in preserving regionally threatened species and biodiverse marine ecosystems**. This is despite the lack of data on how the MPA has impacted the surrounding marine communities (aside from shielding them from fishing effects); it can be inferred from stakeholder feedback and existing research that MPAs may face a reduced range of anthropogenic threats, such as overfishing and pollution, showcasing their implied ecological importance.

Despite no quantitative data available, the limited stakeholder engagement indicated that at least one stakeholder group (government) believes that MPA designation may lead to ecological and fishery spillover. Despite this, stakeholder opinions diverge: while the governmental authority stakeholder expects a positive spillover effect, the fishers' representative strongly disagrees, suggesting the need for more context-specific research.

This study had limitations. The viewpoints shared by these two stakeholders offer just a fraction of the diverse perspectives needed to comprehensively grasp the intricacies of the Selvagens Islands MPA. Both previous studies and our qualitative work agree that **more targeted research**

is needed to better understand the so-called "spillover effects" in the Selvagens Islands MPA.

7 CONCLUSIONS

This study aimed to explore the perspectives of stakeholders and the available literature on spillover effects within and around the Selvagens Islands MPA. Importantly there is no research (either qualitative or quantitative) that has examined ecological or fishery spillover related to the Selvagens Islands MPA. Research has been primarily focused on surveying and assessing the abundance and diversity of marine communities between the Selvagens Islands MPA and MPAs within mainland Madeira. Therefore, the perspectives obtained from the stakeholders regarding the Selvagens Islands MPA, although limited, were useful in understanding the impact of the MPA on marine communities.

Interestingly, the perspectives varied significantly between stakeholders highlighting the complexities and challenges associated with managing the MPA (as well as the very limited stakeholder engagement). The single government official who responded to the questionnaire sees the MPA as a tool for conservation that could also benefit fishing through spillover effects. The single fisher that responded to the questionnaire, on the other hand, thought the MPA was a restriction to their work. In this respect, the MPA no-take policy has resulted in economic difficulties for the fishing community in the Madeira region, leading to scepticism about its immediate positive impact. In addition, the fisheries sector stakeholder's concerns regarding the immediate economic challenges posed by the MPAs no-take policy reflect the tangible impact of such measures on local fishing communities, a point supported by historical data indicating fluctuations in landed catch over the years. The fact that the opinions between government bodies and fishers diverged considerably emphasizes the need for comprehensive discussions on MPA management optimization. Such discussions should aim to harmoniously merge conservation initiatives with the tangible needs of local fishers.

Future research must adopt a comprehensive approach, integrating both qualitative insights and rigorous quantitative analyses, to elucidate the multifaceted impacts of the MPA. Although the qualitative data collected from a limited number of stakeholders has provided initial insights, it is imperative to expand our investigation through systematic quantitative methodologies. This includes conducting detailed ecological and socio-economic assessments, such as fish stock surveys, species movement tracking, and analysis of fisheries data, to quantitatively evaluate the spillover effects and socio-economic implications of the MPA.

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15..CASE STUDY REPORT:

LA GRACIOSA MARINE PROTECTED AREA

SPAIN – MACARONESIA

Analysis of potential spillover effects around the Marine Reserve of Graciosa Island and the Northern Islets of Lanzarote

Rupert Stacy

MRAG Europe

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LIST OF ABBREVIATIONS

Term	Description
BACI	Before-after control-impact
CPUE	Catch per unit effort
IEO	Spanish Institute of Oceanography
IUCN	The International Union for Conservation of Nature
MPA	Marine protected area
NGO	Non-Governmental Organisation
UVC	Underwater visual census

1 EXECUTIVE SUMMARY

The "Marine Reserve of Graciosa Island and the Northern Islets of Lanzarote" hereafter called La Graciosa Marine Protected Area (MPA), is a 707 km^2, category VI MPA, featuring a 12 km^2 fully protected area. With no commercial fleet active in the MPA since its establishment in 1995, artisanal and recreational fishing activity occurs within regulated zones outside of the fully protected area.

This case study utilised two research initiatives to obtain quantitative data on abundance and biomass of six fish species however only one was used as a major focus paper, due to providing more comprehensive data (Brito et al., 2006). Metrics of abundance, and to a lesser extent biomass, were collated from the latter study utilising underwater visual census surveys carried out before (1994) and after (2005) the establishment of the MPA. Sampling sites were located within the MPA, including the fully protected (integral) area, and outside of it, ranging 12-50 km. Data were assessed against a Before After Control Impact (BACI) design to determine whether data aligns with indicators of spillover effects. In total, six species were assessed using abundance data, while two of those six, also were assessed using biomass data.

Results suggest spillover indicators for three of the six species assessed after a 10-year period of protection. Two species identified as indicator species that are also targeted (*Sparisoma cretense* and *Serranus atricauda*) both indicate many potential spillover effects across reference sampling sites for both abundance and biomass, and in some cases are in agreement with each other (7 out of 13 comparisons). *S cretense* had more spillover effect indications within the MPA (<21km) than *S. atricauda*, which showed more spillover indications at sites outside of the MPA. Of the four non-indicator species assessed for abundance only, one indicated a potential spillover effect (*Mycteroperca fusca)* at two sites, both within the MPA (12 – 20 km). Neither of the two bycatch species studied were found to show indications of spillover effects. Furthermore, while *S. cretense* increased in abundance by 250%, its biomass increased only 2%, possibly alluding to ecological effects outside the scope of this case study.

The implications of these results suggest that when studied from the perspective of quantitative biomass and abundance data, spillover effects between species appear nuanced. Even species with similar life histories, and that are both targeted, show variation in response to protection. While some species seem to exhibit spillover effects, others do not, indicating varied species response to the level of protection afforded within the MPA. Reference sites within the MPA, within <20km of the fully protected area, had more indicators of potential spillover than outside it. These results may point to the greatest benefits being found close to the fully protected area, inside the MPA. This may be due to the overall large size of the MPA. Other explanations of the varied response could be the low level of fishing that occurred there in the years following establishment or the limited temporal sampling that was available (n=2 years). Unfortunately, no sampling was found from the partially protected buffer zone, which is missed opportunity to compare between, especially given their proximity.

Based on these findings, further examination of additional species is recommended, ideally incorporating biomass values relative to those where abundance values are already available. Furthermore, updated biomass and abundance estimates are now well overdue, and would not only add deeper level of understanding to the results presented by Brito *et al.,* (2005), but would shed light on the contemporary status of the MPA. The author also notes that in light of the variation in increases of abundance to biomass of *S. cretense*, that fishery spillover be investigated further (i.e. the proportion of this biomass that can be fished, taking into account regulations and accessibility).

2 BACKGROUND

Situated in the Azores, Canaries and Madeira ecoregion and found north of Lanzarote in the north-east of the Canary Islands, the Chinijo Archipelago hosts the marine protected area (MPA) "*Reserva Marina de la Isla Graciosa y de los Islotes del Norte de Lanzarote*", hereafter called "*La Graciosa*". Established by local and national authorities in a somewhat top-down approach (Chuenpagdee *et al*., 2013), La Graciosa was implemented in 1995 and contributes to Spain's national network of marine reserves, of which it is the largest (Goni *et al*. 2023).

La Graciosa marine reserve, is a category VI MPA in accordance with the IUCN Protected area categories (Rodríguez-Rodríguez *et al*. 2019), the primary objective of which is "*to protect natural ecosystems and use natural resources sustainably, when conservation and sustainable use can* *be mutually beneficial*" (Day *et al*. 2012). As well as being part of a national network of MPAs, the site is in part covered by the Natura 2000 sites "*Islotes del norte de Lanzarote y Famara*", designated in 1989 and "*Espacio marino del oriente y sur de Lanzarote-Fuerteventura*", designated in 2015, protected under the Birds Directive and Habitats Directive, respectively.

La Graciosa MPA is 70,764ha and covers a range of habitats including rocky shores, caves, maerl, seagrass beds, sandy substrates and open ocean environments that extend down to 1000m (Goni *et al*. 2023; Vandeperre *et al*, 2006). The MPA contains areas that are both fully protected and partially protected. There are further delineation of internal and external waters (Figure 1). These delineations represent shared management of the MPA as a whole, with the General State Administration (Spanish State) managing the external waters (60%) and the internal water managed locally by the Autonomous Community of the Canary Islands (40%) (Vandeperre *et al*, 2006).

The fully protected area (or integral reserve) is 1,225ha in size, represents less than 2% of the overall size, and is established within an area of circle that extends 1 mile from the centre on the island Roque del Este in the east of the Chinijo archipelago. The fully protected area restricts all activities, with any type of maritime fishing or extraction of marine living resources prohibited and access to the integral zone is authorised by the General Secretariat of Maritime Fisheries (BOE, 1995). The buffer zone, which extends 2 mile from the outer perimeter of the fully protected integral reserve area, is around 8,480ha and proportionately is 12% of the total marine reserve area. The buffer zone forbids recreational fishing but allows professional fishing with hook and line tackle, as well as traditional gears targeting *Sarpa salpa* and migratory species. The rest of the marine reserve, in both internal and external waters, regulates fishing activity by permitting only hook and line fishing, aimed at targeting *Sarpa salpa* and migratory species (Planes *et al*. 2008).

The MPA is zoned, with fisheries activity restricted across the whole reserve. The fully protected area (integral reserve) sits within a one mile circle radius of Roque del Este. The legal text that defines the restriction of fisheries activities is worded in a way that prohibits the extraction of marine flora and fauna, with certain exceptions (BOE, 1995). These are:

- The activity of professional sea fishing with hook tackle, and also with gears that have been traditionally used in the area for the capture of Salemas (*Sarpa salpa*) and migratory pelagic species;
- Fisheries activities from the aforementioned point must be conducted by vessels who's base port is from the island of La Graciosa, or by fisher that habitually fish in the MPA, which must be demonstrated/evidenced;
- The activity of recreational fishing using trolling methods targeting migratory pelagic species, which must not take place within 2nm from the outer perimeter of the fully protected area (integral zone) (essentially creating the buffer zone);
- Sampling marine flora and fauna for scientific purposes, which is authorised by the General Secretariat of Marine Fisheries.

According to Chuenpagdee *et al*. (2013), the designation of the MPA occurred in a top-down approach by national and regional government. The president of the local *cofradia*, initially in support of the MPA, then changed their mind and spoke against it. Local fishers were apparently sceptical about the plan, due to the lack of formal discussions and confusing information by the *cofradia*. The MPA was established anyway, through a decree stating the proposal had the support of the fisheries sector (BOE, 1995). One group affected by its establishment was the female shellfish gatherers who were not permitted to use the area - presumably as they were not included within at the design stage of the protected area. Chuenpagdee *et al*. (2013) also states that the establishment process was difficult due to resource competition between fishers and other users. The process was also entwined in a political struggle when local figures used the implementation of the MPA as a stage to confront with national government. As a result of these establishment issues, the MPA continued to be a source of contention. A socio-economic study found that professional fishers generally perceived the MPA negatively, despite having a generally positive perception that the MPA is good for the local economy (Alban *et al*., 2008). This same study also found that professional fishers displayed a majority of negative responses when asked about spillover effects.

The management body for the MPA, "Management and Monitoring Joint Commission" includes managers, political representatives and/or technical staff from the state, regional, and local fisheries administrations, a technician from IEO and representatives from the local fishers association ("*Cofradía de Pescadores*"). Running in parallel, there is also a "Scientific and Consultative Committee" made up of the manager from the Canary Government as well as representative from Canary research institutions (University of La Laguna, University of Las Palmas de Gran Canaria, Canary Institute of Marine Sciences) and IEO. However, the committee is referred to as a 'paper' committee, as it has never held a meeting (EMPAFISH consortium, 2008). Other shortcomings of the MPA include; non-participation of local representatives from the research institutions at Joint Commission meetings; public participation in the Commission; low frequency of Commission meetings; a lack of established monitoring programmes other than the IEO fisheries monitoring; insufficient funding for surveillance; and lastly, the largely failed role of the "*Cofradía de Pescadores*" which left fishers without sufficient representation and leadership on their behalf (EMPAFISH consortium, 2008).

No commercial vessels operate in the area since the 1990s, after the abundance of their target species decreased (Vandeperre et al., 2008). Since the MPA establishment only the artisanal fleet operate within the MPA. Allowed fisheries activities within the zones is documented within Article 4 of the establishing legal document published in 1995 (BOE, 1995). Subsequently, two Orders and a Resolution were passed in 1999, 2001 and 2022, respectively (BOE, 1999; BOE, 2001; BOE, 2022). The order of 1999 specifies regulations regarding diving, while the 2001 order adds an additional article, Article 8. Article 8 sets rules regarding recreational fishers being in possession of a relevant licence while in the MPA, as well as authorisation for the practice of recreational fishing, issued from the General Secretariat for Maritime Fisheries. Further limitations to the number of recreation vessels are stated – with 30 vessels per day simultaneously allowed access between May and October, and 15 per day between November and April. The most recent update to the management of La Graciosa MPA, is the 2022 Resolution.

The resolution was passed on December 7th 2022 by the General Secretariat of Fisheries, and updates the census of vessels authorised to carry out professional maritime fishing in the MPA. (BOE, 2022). This resolution states that the maximum number of boats permitted to be authorised to operate within the MPA is set at 50 vessels and they must come from a base port of Caleta del Sebo, Orzola, Arrecife or Puerto del Carmen (Figure 1). The 2001 list of authorised vessels had a maximum of 73 (Vandeperre *et al*., 2006). The 2022 resolution includes a requirement for vessels to also be registered on the General Registry of the Fishing Fleet – Spain's new national fleet register encompassing their outer territories. Exclusion criteria from La Graciosas authorised list of 73 vessels includes; a) removal from the General Registry of the Fishing Fleet; substitution by another vessel; selling capture through unauthorised first sale ports; change of base port to one other than listed as authorised; failure to provide catch information; do not carry out fishing activity within the scope of the marine reserve (with an exclusion clause for force majeure); and lastly, failure to comply with the rules of marine reserve or that the skipper or shipowner have firm administrative sanctions in the previous two years.

With only the artisanal and recreational fleet operating in the MPA, few gears are utilised and are mainly hook and line based, with purse and beach seining also occurring all year round. Of the 24 species targeted, *Sparisoma cretense*, *Merluccius merluccius,* and *Sarpa salpa* are the major species targeted (by weight), landing 25, 12 and 11 tonnes landed in 2005, respectively (Vandeperre et al, 2006). Details of the methods used, their seasonality, as well as the target and bycatch species can be seen in Table 1.

Since its establishment in 1995, the La Graciosa MPA has likely influenced the area's ecology, potentially leading to the recovery of fish populations and their subsequent spillover beyond the protection boundaries. Although monitoring efforts are in place, there is currently a lack of specific studies addressing ecological and/or fishery spillover. This research fills this gap by incorporating previous studies, monitoring data, and stakeholder insights to assess whether the La Graciosa MPA is indeed fostering spillover effects.

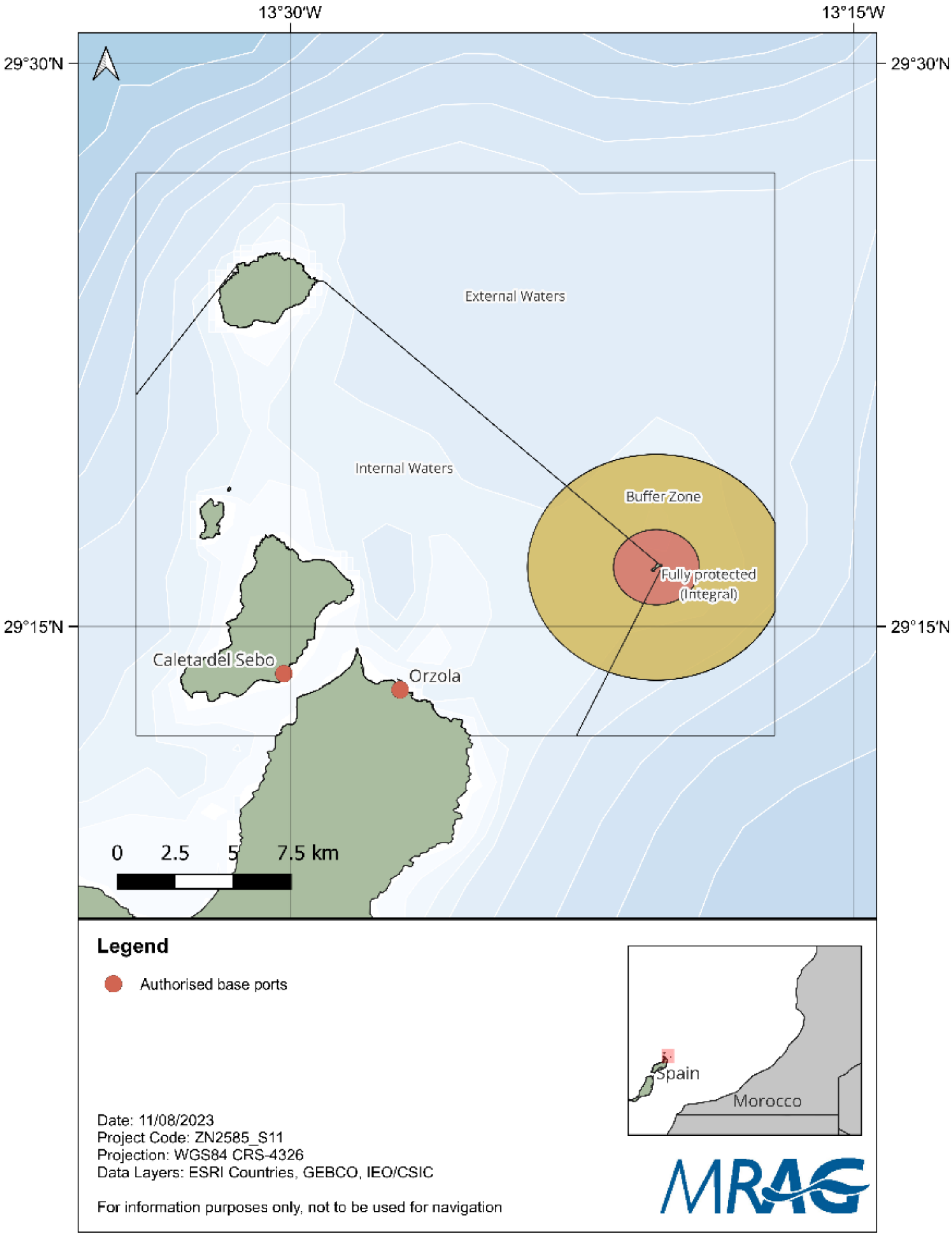

Figure 1. Map of the La Graciosa MPA, including ports of the islands included within authorised list of base/home port (Arrecife or Puerto del Carmen are not within scope of map).

Table 1. Table showing the gears, seasonality of their use, target and bycatch species caught within the zones of La Graciosa MPA (Vandeperre *et al*, 2006).

Area		Gear	Seasonality	Target species	Bycatch species
Interior (internal waters)	Fully protected	-	-	-	-
	Restricted Use	Handline	Depends on species	*Sparisoma cretense, Pagrus pagrus, Spondyliosoma cantharus, Serranus atricauda, Pagellus erythrinus, Epinephelus marginatus*	*Diplodus vulgaris, Phycis phycis, Scorpaena spp., Mycteroperca fusca, Balistes capriscus, Diplodus sargus, Bodianus scrofa, Pseudocaranx dentex, Pontinus kuhlii, Pagrus auriga, Diplodus cervinus, Parapristipoma octolineatum*
		Pole and line	April-Oct	*Sparisoma cretense*	-
		Pole and line with live bait	April-Nov	*Seriola spp., Mycteroperca fusca, Sphyraena viridensis, Dentex dentex*	-
		Jig	May-Oct	*Loligo vulgaris*	*Sepia officinalis*
		Purse seine	All seasons	*Sarpa salpa, Boops boops, Sardina pilchardus, Engraulis encrasicolus*	*Oblada melanura, Trachinotus ovatus, Sardinella spp., Belone belone*
		Beach seine	All seasons	*Atherina presbyter*	*Sardina pilchardus, Sardinella spp., Belone belone, Boops boops*
		Shellfish seeking	Mar-Nov	*Patella spp.*	*Osilinus spp.*
		Octopus long-handled tool	All seasons	*Octopus vulgaris*	-
Exterior (external waters)		Trap	Mar-Nov	*Scorpaena spp., Dentex spp., Phycis phycis, Pagrus pagrus*	*Muraena helena, Gymnothorax spp., Conger conger*
		Electric reel hook and line	All seasons	*Merluccius merluccius, Polyprion americanus*	*Pagellus bogaraveo, Schedophilus ovalis, Mustelus mustelus*

3 AIMS AND OBJECTIVES

The objective of this case study is to determine whether spillover may be occurring in the La Graciosa MPA. Established in 1995, having now 28 years of protection, the aim of this study is to test the assumption that the protection has allowed fish species within the MPA to recover/increase in comparison to when it was unprotected, and is now producing a net emigration of fish to the outside of the protected area, i.e., the MPA, and the protection it affords, is causing spillover effect.

To address whether spillover may or may not be occurring in La Graciosa, this case study aims to address the following specific objectives:

- Evaluate whether the perceptions of stakeholders indicate a likelihood of spillover effects occurring as a result of the MPA establishment;
- If and where appropriate, use a quantitative approach to evaluate the spillover effects that could be occurring, using metrics found through literature review;
- Provide recommendations for refining or improving the methodology for future spillover assessments.

4 METHODOLOGY

This case study uses both quantitative and qualitative methodologies to address the question of whether spillover might be occurring within the La Graciosa MPA. A combination of both desk-based research (literature review) and subsequent quantitative assessment of metrics found in the literature, and stakeholder interviews using an online questionnaire was used.

4.1 Literature review and data collection

Firstly, to collect background information and identify any quantitative sources of data a literature review was conducted. The literature review used a three-step assessment protocol which entails: (i) collation and screening; (ii) extraction; and (iii) critical appraisal. Searches were conducted using Google Scholar which has been shown to be useful for both peer-reviewed and grey literature, as well as broad searches to obtain information from government reports and competent authority websites. Searches used Boolean logic to combine terms for the La Graciosa and different topics. For example, "La Graciosa" OR "la Isla Graciosa y de los islotes del norte de Lanzarote" AND "spillover" OR "fish biomass" OR "fishery". This resulted in searches that provides literature relating to research conducted in the La Graciosa MPA focusing on changes in fish populations, fish community assemblages or impacts on the local fishery.

The resultant articles obtained from the literature search were then compiled and analysed to extract any data regarding spillover from the La Graciosa MPA. All literature were first screened by title, and then by abstract to ensure only relevant literature was assessed. Articles were omitted based on relevance of both title and abstract. Literature in Spanish was considered, but not fully translated as this would have taken too much time. Those articles with what appeared to be relevant information was translated as needed.

To perform a quantitative assessment of spillover, further criteria were added to the literature review to identify metrics that indicate whether spillover may be occurring. These data types and collection methods are highlighted in Table 2.

Table 2. Overview of main data types from which spillover effects could potentially be analysed, followed by the variety of methods with which these can be collected.

Fishery data type	Collection methods
Fish abundance / biomass	AIS/VMS data and/or logbook data
	Small-scale fisheries logbook data
	Visual detections (by transect)
	Capture-Recapture / Mark-Recapture
	Marine biological surveys
	(Light) traps
Larval biomass	Plankton samples
Fish size, weight, and age	Market sampling
	Marine sampling (surveys)
Fish movement	Acoustic telemetry network
	Tagging

Where literature contained information such as those indicated in Table 2, data from these articles were collated. Values were then compared against the framework highlighted in Table 3 (see the spillover assessment advisory protocol in Annex 5), which provides an indication of whether or not the data may indicate spillover based on a BACI (Before, After, Control, Impact) approach.

Table 3. This table provides an overview of the conclusions that can be drawn from the classic MPA BACI approach in assessing spillover. The examples presented are theoretical. The first two columns describe the difference in biomass before and after establishment of the MPA in the MPA site (Δ MPA) and in the reference site (Δ Ref). The potential combinations of changes in biomass were named in the column scenario name. The last three columns indicate whether a conclusion can be drawn from each scenario regarding the total biomass of the MPA and reference site, whether the MPA provides protection benefits, and whether the results indicate spillover.

Δ MPA	Δ Ref	Scenario name	Biomass?	Protection?	Spillover?
0%	0%	Stable	Consistent	No	No
0%	10%	Ref. site increased	Increase	No	No
10%	0%	MPA increased	Increase	Yes	No
10%	5%	Both increased, but MPA stronger	Increase	Yes	Potentially
5%	10%	Both increased, but ref. site stronger	Increase	No	Potentially
10%	10%	Mutual increased	Increase	Potentially	Potentially
-10%	0%	MPA decreased	Decrease	No	No
-10%	5%	Ref. site increased, but MPA decreased stronger	Decrease	No	No
-5%	10%	MPA decreased, but ref. site increased stronger	Increase	No	No
-10%	10%	MPA decreased as strong as ref. site increased	Consistent	No	No
0%	-10%	Ref. site decreased	Decrease	Yes	No
-10%	-5%	Both decreased, but MPA stronger	Decrease	No	No
-5%	-10%	Both decreased, but ref. site stronger	Decrease	Yes	No
-10%	-10%	Mutual decreased	Decrease	No	No
10%	-5%	Ref. site decreased, but MPA increased stronger	Increase	Yes	No
5%	-10%	MPA increased, but ref. site decreased stronger	Decrease	Yes	No
10%	-10%	MPA increased as strong as ref. site decreased	Consistent	Yes	No

4.2 Quantitative assessment of focal studies

Since before the establishment of the La Graciosa MPA the Ministry of Fisheries of the Government of the Canary Islands has been conducting monitoring and research alongside the University of La Laguna. Two studies, Salz (2015) and Brito et al., (2006) are the main sources of quantitative data used for this case study, as the reports provide abundance and or biomass data that could be used assess against. Additionally, Brito et al., (2006) provides Figure 2, providing locations of sampling sites for additional context.

Within a status review of Island Grouper (*Mycteroperca fusca)*, Salz (2015) references data published by Falcón et al. (2007), which is not publicly available online. Salz (2015) provides Figure 3 – mean density of island grouper per 100 m^2, within the integral reserve and two unknown reference sites across four years (1994, 1995, 2004 and 2005). The earlier years were treated as before and the latter two years as after the MPAs establishment. The data was collected via SCUBA using Underwater Visual Census (UVC) (Salz 2015). It is noted by the author here that it is likely that these data are based the same data as provided in Brito et al., (2006). Values were extracted from Figure 3 using 'Web Plot Digitizer' and were used to assess against the BACI assessment criteria shown in Table 3. 'Web Plot Digitizer' enables the accurate and precise estimation of values by calibrating graphical plots' axes within the tool and measuring bars, distances etc (Rohatgi, 2022).

The report by Brito et al., (2006) studies multiple fish populations, and is carried out "in-situ", with data collected using UVC. It's very likely that the methodology used is the same reported by Salz, (2015). The method uses a stationary visual count method from a fixed point, which is suitable for rocky bottoms of great heterogeneity (Harmelin-Vivien et al., 1985; Bohnsack and Bannerot, 1986). This technique was later modified by Falcón *et al*. (1993), whereby a diver is located in the centre of an imaginary circle that has a radius of 5.6 m (100 m^2 of surface area) which is marked by a rope, at which a diver positions themselves at the end of. After five minutes of counting the observer switches side and repeats, after which they spend some time looking for cryptic species that may have gone unnoticed. All fishes that enter the imaginary circle are counted; if a group of fish partially enters, all the fish of that group are counted; no groups/individuals that re-enter the circle are counted again (Brito et al., 2006). Both the number of specimens and their size are recorded for each species, as precisely as possible. Despite many replicates being conducted at each site, only six were chosen to conduct their analysis, as they were all collected by the same observer, reducing bias and improving power for comparison. Values are provided as a mean abundance, standardised as number of individuals per 100 m^2, for each sampling location (N= 12; Figure 2) for both 1994 and 2005. Sampling occurred within the No-take integral reserve (n=2), within the wider MPA (n=4) and outside of the MPA (n=6). Values of biomass are also recorded (presumably in grams, however the metric is not stated) for two species *S. cretense* and *S. atricauda*.

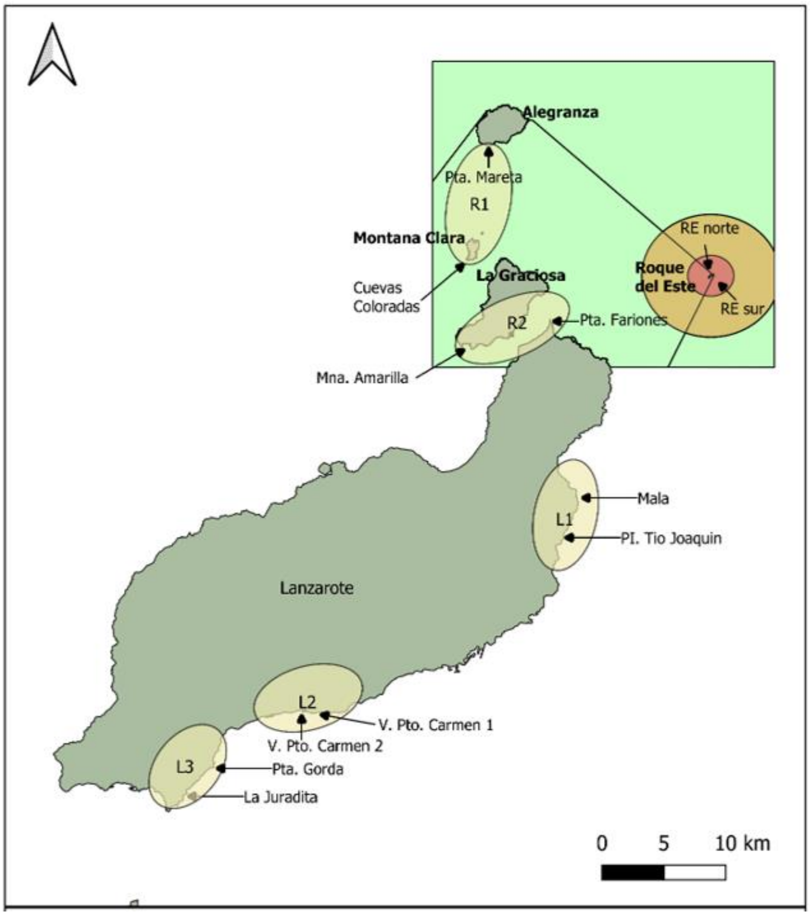

Figure 2. Sampling locations as provided in Brito et al., (2006)

4.3 Stakeholder survey

To address the topic of spillover at La Graciosa, an open-ended questionnaire was developed to capture stakeholder opinions on, for example, how aware the stakeholder was of the regulations and management measures of the MPA (see the questionnaire in Annex 4). The closed questions were statement-based and used Likert scale answer categories (such as: Strongly agree; Agree; Neutral; Disagree; Strongly Disagree) for the stakeholder to choose from.

The questions were grouped into four broad categories to encapsulate the key issues being studied. These included:

I. Respondent information. The first section required basic information from the respondent, including their name, institution and the type of stakeholder category they belonged to.

II. Background information. The second section of the questionnaire gathered background information from the stakeholder to understand more about the respondent and their use of the MPA. Questions included knowledge of when the MPA was established, the type of restrictions in place and how long the stakeholder has been associated with the MPA either through research, fishing or managing it.

III. Fishery impacts of MPAs. The third section explored the respondent's perceptions of the socio-economic impacts of spillover from the MPA. Stakeholders were asked to state whether the designation of an MPA / area where fishing is limited has led to an increase in revenues for fishers, whether the fishing community in the area feel their fisheries livelihoods are more secure after the MPA was established, and the extent to which they believe spillover from the MPA has influenced the catch composition in adjacent fishing grounds.

IV. MPAs as management tools. The fourth section of the questionnaire focused on the respondent's perceptions on whether MPAs are conservation or fisheries management tools. Stakeholders were asked to state whether their local MPA was acting as a conservation tool, a fisheries management tool or both. Other questions under this section required stakeholders to state their agreement/disagreement on whether the establishment of MPAs is an effective conservation strategy to support fish populations and commercial fisheries in their area. Respondents were also asked to indicate what factors they thought were contributing to spillover effects.

Four key stakeholder groups were targeted under this consultation including commercial and recreational fishers, fisheries managers and government authorities, scientists and environmental non-government organisations (NGOs). Therefore, while the four sections of the questionnaire where the same, specific questions were included for each of the four respondent groups. The questionnaire (in English) was translated into Spanish and set up as an online survey.

To gain details of stakeholders particular to the La Graciosa MPA, stakeholders were identified through speaking with team members from project partners (Spanish Institute of Oceanography (IEO)/Spanish National Research Council (CSIC)). Names, position, sector and contact details of stakeholders who have had previous or current experience of La Graciosa were provided. These contacts formed the base from which to target specific stakeholders. Additional stakeholders were contacted after it had become apparent the stakeholders contacted originally had not responded or provided any perceptions through the questionnaire. Initial requests to stakeholders were made in July 2023, with subsequent reminders sent twice in August.

5 RESULTS

5.1 Literature review and quantitative assessment of spillover effects

Quantitative assessment of abundance data presented in Salz (2015)

When compared against the framework for a BACI design in Table 3, these results do not conform to within the stated trends of change between 5 and 10%. However, taking these values as general trends and evaluating against the name/description does indicate that reference site R1 would fit against scenario name and descriptor of both increasing, but MPA increased stronger, potentially indicating a spillover effect (NT (no-take integral reserve) %Δ = 222; R1 %Δ = 277). This may also indicate a protective functioning of the MPA, as abundance is greater in the fully protected area than in the reference site R1. The other reference site, R2, would fit against the descriptor of both increasing, but MPA increasing stronger (R2 %Δ = 70), also potentially indicating a spillover effect.

Due to not having access to the raw dataset, it is unknown whether R1 and R2 are differing distances away from the fully protected area, as this information is not disclosed in Salz 2015. The study by Falcon et al. (2007), where this data originated, is not publicly available.

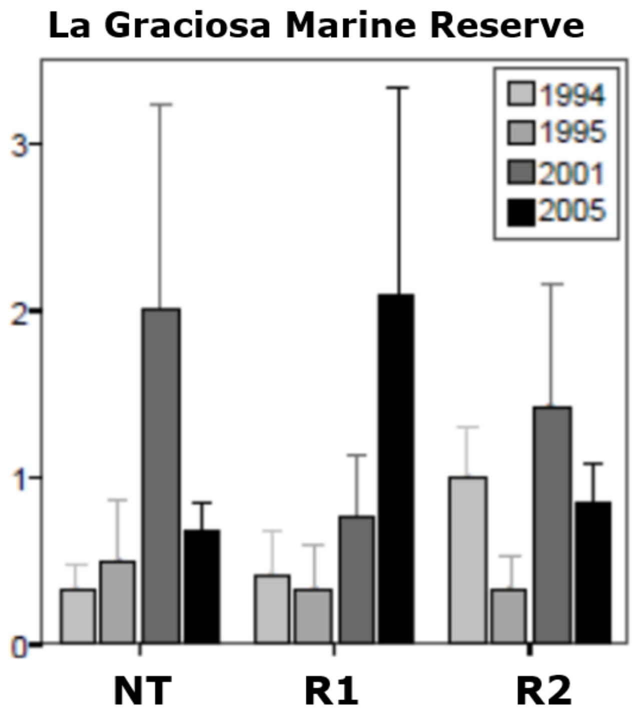

Figure 3. Mean density (±SE) of island grouper (fish/100m^2) recorded in years before (1994 and 1995) and after (2001 and 2005) reserve implementation in different management zones: NT = no-take integral reserve; R-based sites (R1 and R2) = traditional commercial gears, recreational shore fishing and SCUBA allowed (Source: Falcon et al., 2007). Based on restricted use zone/outside the buffer.

Table 4. Estimated values of fish/100m2 extracted from Figure 3 using 'Web Plot Digitizer' (Falcon et al., 2007; Salz 2015), included calculated average fish per 100m2 for before and after, percent change (%Δ) comparing before and after for each zone for M. Fusca.

Zone	Year	Period	fish/100m2	SE	Average fish / 100m2	%Δ	ΔMPA vs Δref Scenario
No take	1994	before	0.33	0.48	0.42	222.62	NA
No take	1995	before	0.51	0.87			
No take	2001	After	2.01	3.23	1.35		
No take	2005	after	0.69	0.86			
R1	1994	before	0.42	0.69	0.38	277.63	Both increased, but ref. site stronger - Potential Spillover indicator
R1	1995	before	0.33	0.61			
R1	2001	After	0.76	1.13	1.43		
R1	2005	after	2.09	3.34			
R2	1994	before	1.00	1.31	0.67	70.63	Both increased, but MPA stronger - Potential Spillover indicator and an indicator of protective functioning.
R2	1995	before	0.34	0.53			
R2	2001	After	1.42	2.16	1.14		
R2	2005	after	0.86	1.09			

Values taken from both Brito et al. (2006) and Salz, (2015), who both report on *M, fusca*, both indicate similar results. However, a question mark remains over the sampling locations reported in Salz (2015), but given results presented in Figure 5, its entirely plausible (and likely) the two sites R1 and R2 correspond to the sites Punta de la Mareta and Punta Fariones, respectively, given the similarity of results. Given these similarities, and without knowing reference locations of R1 and R2, these results will not be discussed further other than where the data is thought to match values presented by Brito et al. (2006).

Quantitative assessment of abundance and biomass data, Brito et al., (2006)

In total, data for six species were extracted and assessed against the standards provided in Table 3 using values provided in the Annex of Brito et al. (2006). The species selected for assessment against the BACI approach are *Sparisoma cretense*, *Diplodus cervinus*, *Centrolabrus trutta*, *Mycteroperca fusca*, *Sarpa Salpa*, and *Serranus atricauda*, as they provide a mix of trophic levels (Table 5). Two species which are not target species are also included as this can act as a control for other changes in the ecosystem (Table 5). Another factor in the choice of these species was data coverage across all sites and years, as for many species data was not available throughout. These species enabled a comprehensive coverage.

Results from this assessment are tabulated in a similar format as those in Table 4 and included in this case study as supplementary material. The results of the BACI assessment have been graphically plotted to present a comparison between the integral reserve and all the sites surveyed by Brito et al., (2006) (Figure 4 and Figure 5).

Table 5. Species, trophic level, whether or not the species is targeted in the region, as well as an indication of whether abundance and/or biomass data was extracted for a quantitative assessment of potential spillover (Froese and Pauly, 2023).

Species	Trophic level	Target	Biomass and/or abundance
Centrolabrus trutta	3.5 ± 0.4	Bycatch	Abundance
Diplodus cervinus	3.4 ± 0.1	Bycatch	Abundance
Mycteroperca fusca	4.3 ± 0.8	Target	Abundance
Sarpa Salpa	2.0 ± 0.0	Target	Abundance
Serranus atricauda	4.3 ± 0.6	Target	Abundance and Biomass
Sparisoma cretense	2.9 ± 0.3	Target	Abundance and Biomass

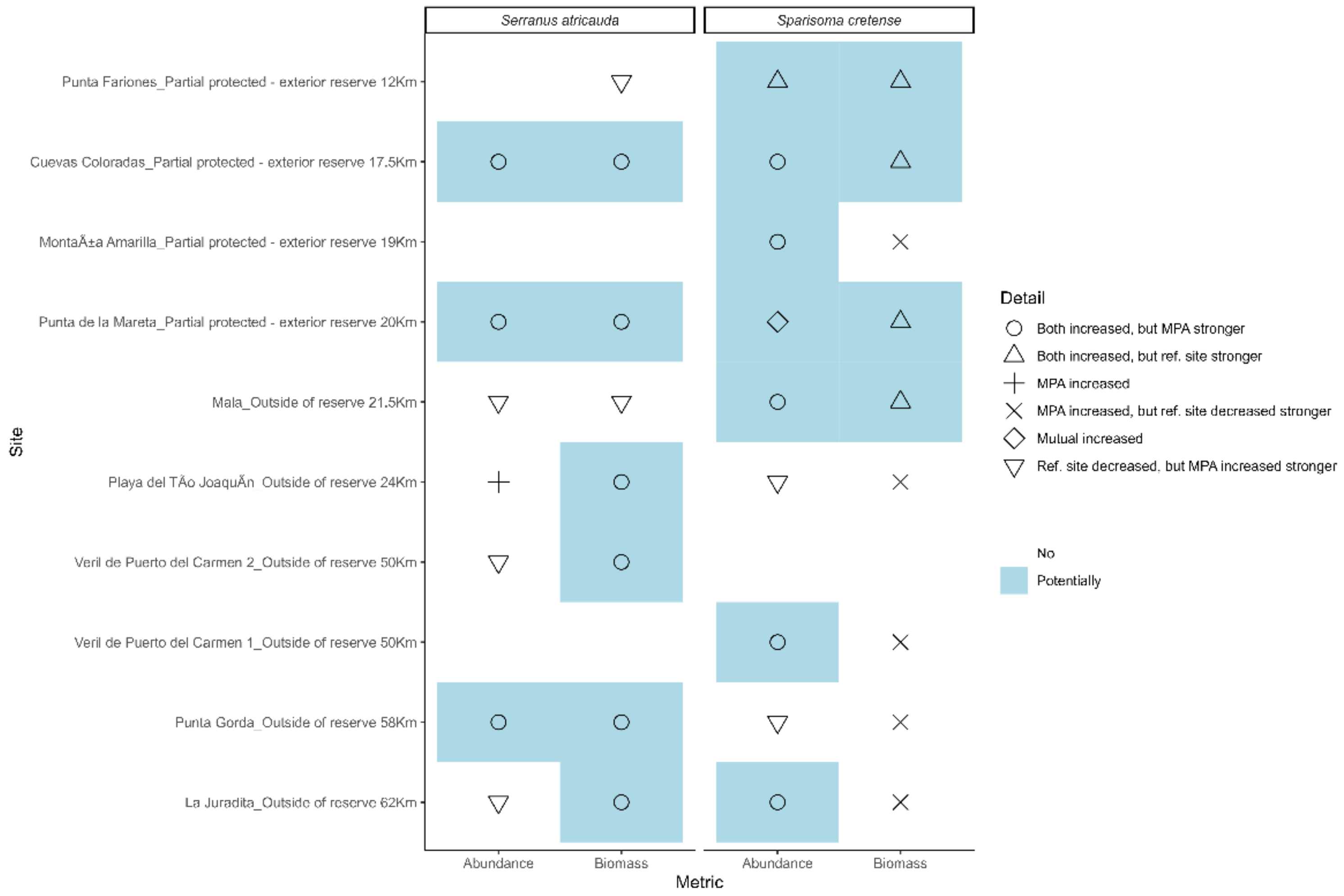

Figure 4. A tiled plot representing sites that indicate potential spillover when using a BACI approach to compare % Δ between the integral reserve and all other surveyed sites. Details included are a description of the scenario which fits the % Δ most appropriately and includes assessments of both abundance and biomass for two species. Empty cells occur when no values are present to be able to make an assessment. Sites are ordered based on distance from integral fully protected area.

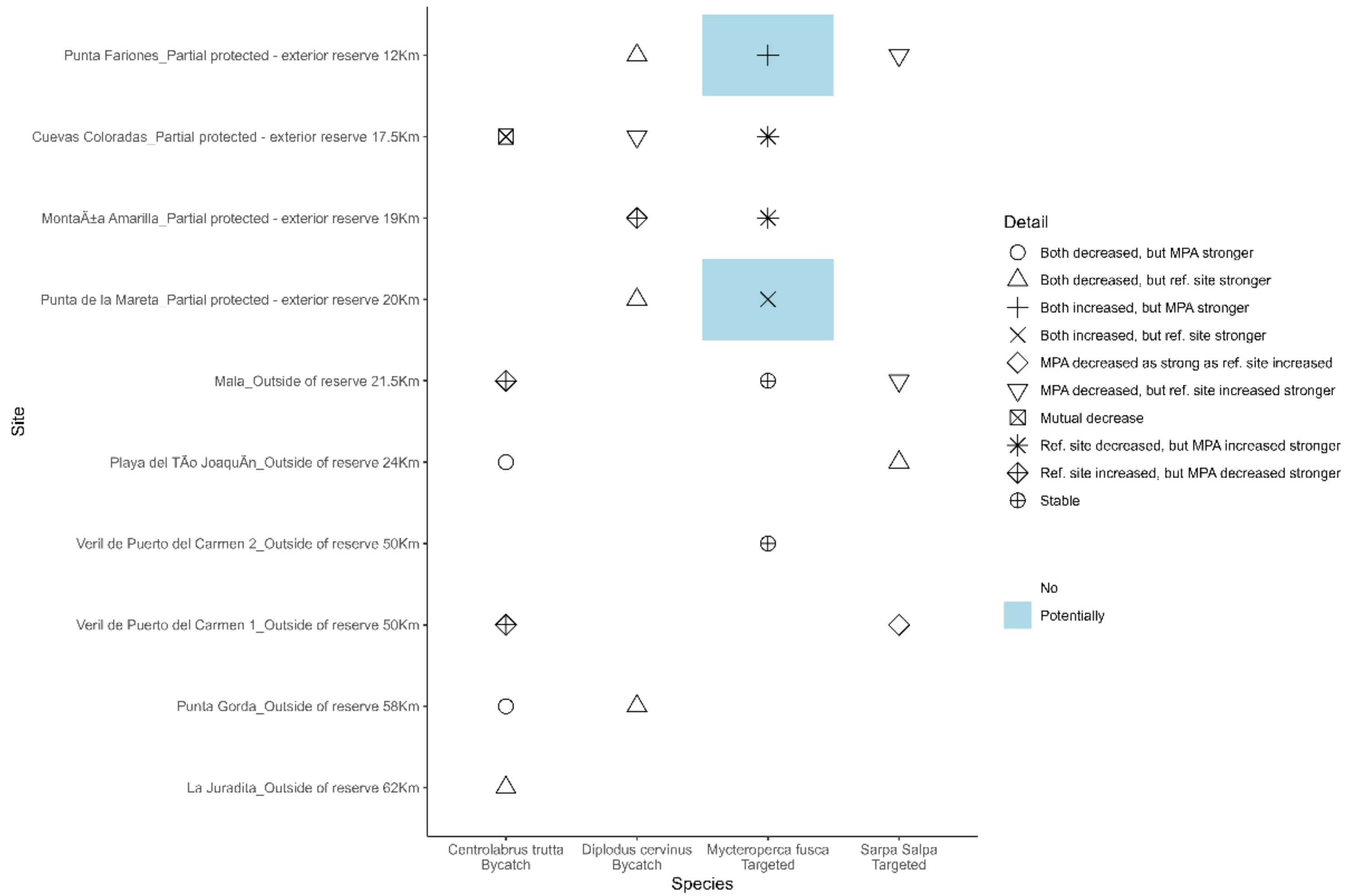

Figure 5. A tiled plot representing sites that indicate potential spillover when using a BACI aproach to compare % Δ between the Integral reserve and all other surveyed sites. Using only abundance, included are a description of the scenario which fits the %Δ most appropriately for four species. Empty cells occur when no values are present to be able to make an assessment. Sites are ordered based on distance from integral fully protected area

Population abundance indicator

Sparisoma cretense

The results presented in Figure 4 indicate that *S. cretense* had the highest number of potential spillover indicators based on percent change (% Δ) between the fully protected integral zone and all other sites sampled. Based on an average from the two sampling sites within the integral zones, the % Δ was 250. All sites from within the boundaries of the MPA indicate that spillover could be occurring (Punta Fariones %Δ = 908, Cuevas Coloradas %Δ = 233, Montaña Amarilla %Δ = 166 and Punta de la Mareta %Δ = 261), but do not suggest any kind of gradient based on detail descriptors and distance from integral reserve. Interestingly, where there is an indication of potential spillover from a site located outside of the MPA, detail descriptors indicate that while both increased, the MPA increased stronger in all cases. While within the MPA, all possible detail descriptors of potential spillover are indicated (Figure 4; Table 3). The fact the closest reference site to the integral reserve actually increased more than the integral reserve itself may indicate that density dependence within the integral reserve has been hit, and spillover has occurred into a more suitable habitat with a higher density dependence.

Serranus atricauda

For *S. atricauda,* results shown in Figure 4 point to fewer indicators of possible spillover based on abundance. Data provided allowed comparison of two reference locations within the MPA with the integral zone (Cuevas Coloradas and Punta de la Mareta). Where potential spillover is indicated in these two locations, both detail descriptors indicate that while both increased in abundance, the MPA saw a greater increase (IR%Δ= 757; Cuevas Coloradas %Δ= 366; Punta de la Lareta %Δ= 134). Outside of the MPA, five locations provided abundance metrics to compare against. These locations indicate that that three of five reference locations outside the MPA experienced a decrease in abundance for the reference site, while the MPA increased stronger (La Juradita %Δ =-34; Veril de Puerto del Carmen 2 %Δ = -48; Mala % Δ = -75).

Centrolabrus trutta

For *C. trutta*, average % Δ within the integral reserve was -87. Only one comparison between the integral reserve and reference points within the MPA could be made, finding no indication of spillover (Cuevas Coloradas %Δ = -90, a mutual decrease). A decrease within the integral reserve for a nontarget species indicates some sort of confounding variable, whether that might be ecological in terms of competition or local environment is unknown. But with a high resilience, and a population doubling time less than 15 months, an increase and/or an indication of spillover or protective functioning would otherwise be expected from a species with such parameters (Froese et al., 2017).

Mycteroperca fusca

In terms of the species with the highest frequency of spillover indicators, *M. fusca* would be ranked third, with two indications. Abundance metrics provided for *M. fusca* enabled comparison with all sites within the MPA boundary, with the integral reserve estimated to have experienced a %Δ of 100% (0.67 average fish/100 m^2 in 1994 versus 1.34 in 2005). Potential spillover for *M. fusca* is indicated at two sites within the wider reserve boundary - Punta Fariones (%Δ = 49) and Punta de la Mareta (%Δ = 1112), which are 12 and 20 km away from the integral reserve, respectively. In the case of Punta Fariones both increased, but the MPA increased stronger, while at Punta de la Mareta both increased, but the reference site increased stronger. The only two reference sites outside the MPA that were able to be assessed both indicate that *M. fusca* populations have remained stable at these locations when compared with the integral zone (Mala %Δ = 0; Veril de Puerto del Carmen 2 %Δ = 0).

Sarpa salpa

Values of abundance provided for *S. salpa* enabled comparison between the integral reserve and four reference sites, however only one was within the boundary of the MPA. None of these comparisons indicate potential spillover. The comparison between the integral reserve and Punta Fariones (12 km away from the IR) found that the MPA(IR) decreased (IR %Δ = -82) while the reference site increased stronger (Punta Fariones %Δ = 650). Mala, the next closest reference site, outside the MPA but 21 km away from the IR, had the same result. Mala, however, saw a 24,705 % change in abundance (0.17fish/100 m^2 in 1994 to 42.17 fish/100 m^2 in 2005). Playa del Tío Joaquín, situated very close to Mala (Figure 2) saw abundance decrease in both sites, but stronger in the reference site (Playa del Tío Joaquín %Δ = -100).

Diplodus cervinus

Values extracted allowed the comparison of the integral reserve to all four sites within the MPA, and one outside it (Figure 5). The integral reserve saw a decrease of – 36%, while the closest reference point, Punta Fariones also declined (%Δ = -66). Both sites decreasing, but the reference site decreasing more is a descriptor of potential protection. However, this assessment of protective functioning comes from both the integral reserve (-36%) and the reference site (-66%) decreasing in abundance, but the reference site decreasing more. This could suggest ecological effects, such as potential competition with *S. cretense*, which from data presented in this case study, appears to have hit a density dependence limit and could be having spillover effect in other parts within the MPA. However, the next closest reference site, Cuevas Coloradas, saw an increase of 194%, i.e. the MPA decreased but the reference site increased stronger.

Population biomass indicator

Sparisoma cretense

In total for *S. cretense* comparisons of %Δ of biomass was able to be conducted for nine reference sites, four of which are within the MPA (IR %Δ = 2). Of the four sites within the MPA, three indicate potential spillover and all display the same scenario descriptor – both increased, but the reference site increased stronger. These are Punta Fariones (%Δ= 504); Cuevas Coloradas (%Δ = 62); and Punta de la Mareta (%Δ = 137). Of the five reference sites outside the MPA that are compared, potential spillover is indicated in one (Mala %Δ = 4) where the same scenario descriptor is applicable as those above. The other reference sites that were able to be compared that do not indicate spillover all fit the descriptor of an increase within the MPA, but the reference site decreased stronger (Montaña Amarilla %Δ = -20; Playa del Tío Joaquín %Δ = -100; Veril de Puerto del Carmen %Δ = -4; Punta Gorda %Δ= -44; La Juradita %Δ = -30).

Serranus atricauda

For *S. atricauda*, comparison of %Δ of biomass was conducted for eight reference sites, three within the MPA, the other five outside the MPA. The IR itself is estimated to have had a %Δ of 766 (64 g/100 m^2 to 559 g/100 m^2). Comparisons made with the IR and reference sites within the MPA indicate potential spillover in two - Cuevas Coloradas (%Δ = 28) and Punta de la Mareta (%Δ = 23). For comparisons made with reference sites outside the MPA (n=5), four indicate possible spillover (Playa del Tío Joaquín %Δ = 425; Veril de Puerto del Carmen 2 %Δ = 27; Punta Gorda %Δ =277; La Juradita %Δ =407). Interestingly, of the eight comparisons made to the IR, all those that indicate spillover fit to the descriptor of both increasing biomass but the MPA increasing stronger. Similarly, all those points that do not indicate potential spillover but did contain data to compare exhibit the same descriptor of a reference site decreasing, but MPA increasing stronger (Punta Fariones %Δ = -3 and Mala %Δ = -47).

5.2 Stakeholder perceptions

Despite reminders via email and phone calls, the author notes difficulties in engaging stakeholders in this area throughout the stakeholder engagement period. Out of the 50 stakeholders contacted 14% responded with answers to the survey. The remaining contacts were Out-of-Office replies (18%), provided no reply (58%), indicated interest but did not respond to the survey (4%), or responded that the study was not applicable to them (6%). Given the low sample size (n = 7), the responses from this case study were combined with responses from another case study by Alban et al, (2008) and presented in the main report.

Among the seven responses gathered, four were deemed incomplete or unhelpful, while the remaining three encompass contributions from two fisheries management authority stakeholders and a single scientist. The limited number of responses, coupled with inconsistent provision of answers for each question, restricts the ability to compare perceptions across stakeholder groups for most questions. Notably, both fisheries management authority stakeholders indicate observed **changes in fishers' catches**, note **increases in catch per unit effort (CPUE) within the MPA**, and express moderate **agreement regarding spillover effects contributing to the recovery of overexploited fish populations in adjacent fisheries**. Conversely, the scientist presents a slightly divergent perspective, contending that there is **no discernible spillover of**

either fish or larvae from the MPA benefiting fisheries, citing concerns over the size and placement of the no-take integral reserve. Despite these disparities, both fisheries management authority and scientist stakeholders concur that the **MPA has elicited diverse biological responses in fish populations, leading to varied benefits for fisheries**, alongside acknowledging the economic advantages brought about by the MPA.

6 DISCUSSION

Using a BACI approach, an assessment was carried out using data provided in Salz (2015) and Brito *et al*., (2006) to assess whether their results indicate the potential occurrence of spillover.

6.1 Quantitative assessment

In total, six species of fishes were assessed against a BACI design for assessing spillover, using both abundance and biomass of fish per 100 m^2. Findings indicate that the response to 10 years of protection of biomass and abundance varies greatly between species and sites. Given the 10 years of protection this MPA has provided, some indications of spillover were expected, although no prior assumptions of which species or sites would yield more spillover effects were made. While the data point to being fairly certain that some species are displaying spillover indicators, this cannot be said for all species. **Results presented here point to potential spillover effects occurring for three out of six species assessed**, across a number of sites, both within the MPA, and to a lesser extent, outside it.

Species identified as indicator species by Brito et al., (2006) (*S. cretense* and *S. atricauda*) appear to be living up to their standard, as these two species produced more indications of potential spillover than all four of the other species combined when looking at abundance. *S. cretense* is a species of high local economic importance, with 25 tonnes landed in 2005 (Vandeperre et al., 2006) and methods allowing their capture (Handline and Pole & Line) written into the establishing legal text (traditional gears; BEO, 1995). It is possible to suggest that the MPA has a protective functioning that is potentially causing spillover effects for this species in particular. The author notes that this indication of potential spillover effects is largely indicated from within the MPA, from the integral zone to the reference zones within the MPA.

One potential confounding variable not taken into account is ecological effects caused by effects such as density dependence within the food web, which may explain the variation in effect responses between species. Both *S. atricauda and M. fusca* have similar trophic levels (Table 5). While *S. atricauda* had many positive spillover indications and had an increase in abundance of 757% at the integral reserve, *M. fusca* had much fewer, and abundance only rose 100%. This is despite almost identical trophic levels and exactly the same resilience (Low, minimum population doubling time 4.5 - 14 years, Froese et al., 2017). Whether this difference is related to fishing pressure, or other ecological effects is unknown but what is certain is that *M. fusca* has a slightly higher fishing vulnerability and fetches a higher price when compared with *S. atricauda* (Cheung et al., 2005; Sumaila et al., 2007). This provides an example of the confounding variables that may be occurring when assessing spillover indicators using metrics such as fish abundance or biomass.

Comparing the results between the two species where both abundance and biomass are assessed provides an interesting comparison. *S. atricauda* increased in 757% in abundance and 766% in biomass within the integral reserve. While *S. cretense* increased 250% in abundance and only 2% in biomass. This points to *S. cretense* increasing in number, but actually their overall biomass (size) has decreased, which would affect marketable catches for fishers. This data warrants further explanation as it may suggest that despite the spillover indicators, actual fishable spillover may not be occurring. Assessing the proportion of *fishery spillover* (i.e. the proportion of this biomass that can be fished, taking into account regulations and accessibility) relative to the spillover indicators may be more informative than from a fisheries perspective (Di Lorenzo *et al*., 2016). Unfortunately, no sampling was found from the partially protected area (buffer zone), which is missed opportunity to compare between, especially given their proximity and differences in regulated activities. Other studies found partially protected areas to be a useful tool (Sciberras et al., 2013), and collecting data to contribute towards the research behind partial protection areas would be beneficial. Additionally, it should be noted that this study used a fairly small sample sizes.

6.2 Stakeholder perceptions

The quantitative data from Brito et al. (2006) are now 18 years old, so when comparing these results to a socio-economic survey conducted around the same time, Alban et al, (2008) found that 48% of fishers 'fully disagree' when asked whether they think the MPA helps to enhance fish abundance outside the protected area i.e. spillover. While some fishers did 'fully agree' (29%) with this statement, which does align with some of the results presented here, it is interesting to note how the question is worded. "Outside the protected area" could mean outside of the MPA as a whole, or outside of the integral reserve. Given some professional fishers are permitted to fish within the MPA, but not the integral reserve, the "protected area" could mean the integral reserve to them, but to others could mean the MPA as a whole. Regardless of this uncertainty, fishers of La Graciosa largely disagree that the MPA help enhance abundance inside the protected area (29% rather disagree; 36% fully disagree). On the other hand, 36% do agree with this statement. Given these statements and results presented here, it would be interesting to know which fishers agree and disagree with these statements based on their chosen metier or target species. This would enable cross referencing and validation of the effects assessed here. Furthermore, Brito et al. (2006) indicates that poaching is likely occurring within the integral reserve due to an absence of *Epinephelus marginatus* in the 2005 survey, when previously they had been present. It's possible that many fishers don't feel that the MPA does protect species abundance, particularly when the most numerous metier is handline fishing that specifically target *E. marginatus*, amongst five others species (Vandeperre et al., 2006). The largely negative views of fishers towards the MPA are interesting in the context of the history referenced in the background of this case study, as 71% of fishers fully agree the MPA helps protect biodiversity. It appears **perceptions are split within the fisher community**, with a larger proportion of fishers believing the MPA is not functioning as it should in terms of providing elevated fish levels within and outside the MPA, but the majority believing it protects biodiversity. From a more contemporary view, stakeholder perceptions collected for this study tentatively suggest similar outcomes (albeit not from fishers), with the one scientist having opposing views to the two fisheries authority managers when it comes their perception of whether spillover is occurring or not. With that said, there is general agreement between these two stakeholder groups with regard to economic benefits provided by the MPAs protection, as well as varied biological responses with associated variation in catches.

6.3 Summary

These findings demonstrate a variation in ecological spillover responses that appear to depend on the species chosen to assess, as no site within the MPA seems to dominate where spillover indication occur. It is entirely possible these results could be confounded by species with preferences to habitat types found at different sites too. Nevertheless, both abundance and biomass seem to be in fairly similar agreement when compared for a species (Figure 4). These findings highlight the importance of continued monitoring of basic biological data. The author of this case study notes that it was very helpful to have stakeholder perceptions that were taken around the same time as the quantitative data was published. Having stakeholder perceptions to compare with the quantitative data taken at the same time enabled a useful contrast. These data are now more than 18 years old, with the MPA now providing nearly 30 years of protection. It would be very informative to have updated values for both abundance and biomass. If this was possible, coupled with contemporary stakeholder perceptions and further indicators such as those found Table 2, a much more comprehensive comparison of spillover indicators may be achieved. Failing this, a raw dataset for the values provided in Brito et al., (2006), with more values for biomass relative to those available for abundance, would allow a deeper understanding of spillover effects and possibly confounding variables such as those highlighted when comparing delta % of biomass and abundance between species. A further critique of the methods used here is the use of reference sites >50 km away from the fully protected area and whether spillover effects could be observed at this distance.

7 CONCLUSIONS

To answer the question of whether spillover could be occurring at the La Graciosa MPA, is not a straightforward question. **There is evidence to suggest spillover effects are occurring for both the indicator species *Serranus atricauda* and *Sparisoma cretense* based on indicators of increased biomass and abundance**. Only one non-indicator species showed indications of spillover - *Mycteroperca fusca* - occurring at two sites within the MPA but 20 km away from the fully protected area. Spillover effects are established with comparisons of metrics before and after the impact of MPA establishment from sites within and outside the protected area. In this case study potential spillover indications are limited to reference points largely within the MPA boundary itself, each separated by a minimum of 12 km from the fully protected (integral) area. For *S. cretense* spillover effects were more associated with sites within 25 km of the fully protected area, largely within the MPA. Fewer comparisons could be made for *S. atricauda* but still indicate spillover effects at 17 and 20 km to sites within the MPA. Given the size of La Graciosa (707 km^2) it is questionable whether comparison between sites more than 50 km away is justified, particularly when the highest level of protection is afforded to such a small portion of the total MPA site. The data used for the assessment is of good quality, but updated abundance values and corresponding values of biomass would provide a more balance view of spillover effects. Assessing more species may illude to which confounding variables such as competition, were responsible for the variation between responses of species to spillover effects.

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SUPPLEMENTARY INFORMATION

Site	Protection status	Distance to Integral (Km)	Trophic level	Species group	Species	Year	Abundance		Biomass		% Δ	ΔMPA vs Δref Scenario name	Spillover?
							Fish / 100 m^2	se	Fish / 100 m^2	se			
Roque del Este norte	Fully protected - Integral reserve	0	4.3 ±0.8	Targeted	*Mycteroperca fusca*	1994	0.5	0.55			34.00		
Roque del Este norte	Fully protected - Integral reserve	0	4.3 ±0.8	Targeted	*Mycteroperca fusca*	2005	0.67	0.52					
Roque del Este sur	Fully protected - Integral reserve	0	4.3 ±0.8	Targeted	*Mycteroperca fusca*	1994	0.17	0.41			294.12		
Roque del Este sur	Fully protected - Integral reserve	0	4.3 ±0.8	Targeted	*Mycteroperca fusca*	2005	0.67	0.82					
Roque del Este Average	Fully protected - Integral reserve	0	4.3 ±0.8	Targeted	*Mycteroperca fusca*	1994	0.67	-			100.00		
Roque del Este Average	Fully protected - Integral reserve	0	4.3 ±0.8	Targeted	*Mycteroperca fusca*	2005	1.34	-					
Punta de la Mareta	Partial protected - exterior reserve	20	4.3 ±0.8	Targeted	*Mycteroperca fusca*	1994	0.33	0.52			1112.12	MPA increased but ref site stronger	Potentially
Punta de la Mareta	Partial protected - exterior reserve	20	4.3 ±0.8	Targeted	*Mycteroperca fusca*	2005	4	5.62					
Cuevas Coloradas	Partial protected - exterior reserve	17.5	4.3 ±0.8	Targeted	*Mycteroperca fusca*	1994	0.5	1.22			-66.00	Ref. site decreased, but MPA increased stronger	No
Cuevas Coloradas	Partial protected - exterior reserve	17.5	4.3 ±0.8	Targeted	*Mycteroperca fusca*	2005	0.17	0.41					
Montaña Amarilla	Partial protected - exterior reserve	19	4.3 ±0.8	Targeted	*Mycteroperca fusca*	1994	1.33	1.21			-49.62	Ref. site decreased, but MPA increased stronger	No
Montaña Amarilla	Partial protected - exterior reserve	19	4.3 ±0.8	Targeted	*Mycteroperca fusca*	2005	0.67	1.03					

Site	Protection status	Distance to Integral (Km)	Trophic level		Species group	Species	Year	Abundance		Biomass		% Δ	ΔMPA vs Δref Scenario name	Spillover?
								Fish / 100 m²	se	Fish / 100 m²	se			
Punta Fariones	Partial protected - exterior reserve	12	4.3	±0.8	Targeted	*Mycteroperca fusca*	1994	0.67	0.82			49.25	Both increased, but MPA stronger	Potentially
Punta Fariones	Partial protected - exterior reserve	12	4.3	±0.8	Targeted	*Mycteroperca fusca*	2005	1	0.63					
Mala	Outside of reserve	21.5	4.3	±0.8	Targeted	*Mycteroperca fusca*	1994	0.33	0.82			0.00	Stable	No
Mala	Outside of reserve	21.5	4.3	±0.8	Targeted	*Mycteroperca fusca*	2005	0.33	0.52					
Veril de Puerto del Carmen 2	Outside of reserve	50	4.3	±0.8	Targeted	*Mycteroperca fusca*	1994	0.17	0.41			0.00	Stable	No
Veril de Puerto del Carmen 2	Outside of reserve	50	4.3	±0.8	Targeted	*Mycteroperca fusca*	2005	0.17	0.41					
Roque del Este norte	Fully protected - Integral reserve	0	2.9	±0.27	Targeted	*Sparisoma cretense*	1994	7.33	4.18			209.28		
Roque del Este norte	Fully protected - Integral reserve	0	2.9	±0.27	Targeted	*Sparisoma cretense*	2005	22.67	8.21					
Roque del Este sur	Fully protected - Integral reserve	0	2.9	±0.27	Targeted	*Sparisoma cretense*	1994	4.67	1.97			313.92		
Roque del Este sur	Fully protected - Integral reserve	0	2.9	±0.27	Targeted	*Sparisoma cretense*	2005	19.33	21.1					
Roque del Este Average	Fully protected - Integral reserve	0	2.9	±0.27	Targeted	*Sparisoma cretense*	1994	12				250.00		
Roque del Este Average	Fully protected - Integral reserve	0	2.9	±0.27	Targeted	*Sparisoma cretense*	2005	42						
Punta de la Mareta	Partial protected - exterior reserve	20	2.9	±0.27	Targeted	*Sparisoma cretense*	1994	0.83	1.6			261.45	Mutual increased	Potentially
Punta de la Mareta	Partial protected - exterior reserve	20	2.9	±0.27	Targeted	*Sparisoma cretense*	2005	3	2.52					
Cuevas Coloradas	Partial protected - exterior reserve	17.5	2.9	±0.27	Targeted	*Sparisoma cretense*	1994	1.5	1.76			233.33	Both increased, but MPA stronger	Potentially

Site	Protection status	Distance to Integral (Km)	Trophic level	Species group	Species	Year	Abundance		Biomass		% Δ	ΔMPA vs Δref Scenario name	Spillover?
							Fish / 100 m²	se	Fish / 100 m²	se			
Cuevas Coloradas	Partial protected - exterior reserve	17.5	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005	5	9.38					
Montaña Amarilla	Partial protected - exterior reserve	19	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994	1.5	3.21			166.67	Both increased, but MPA stronger	Potentially
Montaña Amarilla	Partial protected - exterior reserve	19	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005	4	8.37					
Punta Fariones	Partial protected - exterior reserve	12	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994	2	2.53			908.50	Both increased, but ref. site stronger	Potentially
Punta Fariones	Partial protected - exterior reserve	12	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005	20.17	17.71					
Mala	Outside of reserve	21.5	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994	0.83	0.75			221.69	Both increased, but MPA stronger	Potentially
Mala	Outside of reserve	22.5	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005	2.67	3.93					
Playa del Tío Joaquín	Outside of reserve	24	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994	2	4.43			-91.50	Ref. site decreased, but MPA increased stronger	No
Playa del Tío Joaquín	Outside of reserve	24	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005	0.17	0.41					
Veril de Puerto del Carmen 1	Outside of reserve	50	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994	1.5	0.84			88.67	Both increased, but MPA stronger	Potentially
Veril de Puerto del Carmen 1	Outside of reserve	50	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005	2.83	2.32					
Veril de Puerto del Carmen 2	Outside of reserve	50	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994							
Veril de Puerto del Carmen 2	Outside of reserve	50	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005	0.17	0.41					
Punta Gorda	Outside of reserve	58	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994	4.83	6.49			-24.02	Ref. site decreased, but MPA increased stronger	No
Punta Gorda	Outside of reserve	58	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005	3.67	3.5					
La Juradita	Outside of reserve	62	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994	0.67	1.21			23.88	Both increased, but MPA stronger	Potentially
La Juradita	Outside of reserve	62	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005	0.83	1.17					

Site	Protection status	Distance to Integral (Km)	Trophic level		Species group	Species	Year	Abundance		Biomass		% Δ	ΔMPA vs Δref Scenario name	Spillover?
								Fish / 100 m²	se	Fish / 100 m²	se			
Roque del Este norte	Fully protected - Integral reserve	0	2.9	±0.27	Targeted	*Sparisoma cretense*	1994			2705.64	1196.44	-27.40		
Roque del Este norte	Fully protected - Integral reserve	0	2.9	±0.27	Targeted	*Sparisoma cretense*	2005			1964.42	1413.55			
Roque del Este sur	Fully protected - Integral reserve	0	2.9	±0.27	Targeted	*Sparisoma cretense*	1994			1924.33	1499.09	43.58		
Roque del Este sur	Fully protected - Integral reserve	0	2.9	±0.27	Targeted	*Sparisoma cretense*	2005			2763.02	3072.8			
Roque del Este Average	Fully protected - Integral reserve	0	2.9	±0.27	Targeted	*Sparisoma cretense*	1994			4629.97	-	2.11		
Roque del Este Average	Fully protected - Integral reserve	0	2.9	±0.27	Targeted	*Sparisoma cretense*	2005			4727.44	-			
Punta de la Mareta	Partial protected - exterior reserve	20	2.9	±0.27	Targeted	*Sparisoma cretense*	1994			423.28	849.69	137.33	Both increased, but ref. site stronger	Potentially
Punta de la Mareta	Partial protected - exterior reserve	20	2.9	±0.27	Targeted	*Sparisoma cretense*	2005			1004.56	1007.35			
Cuevas Coloradas	Partial protected - exterior reserve	17.5	2.9	±0.27	Targeted	*Sparisoma cretense*	1994			839.29	1174.88	62.91	Both increased, but ref. site stronger	Potentially
Cuevas Coloradas	Partial protected - exterior reserve	17.5	2.9	±0.27	Targeted	*Sparisoma cretense*	2005			1367.25	3073.78			
Montaña Amarilla	Partial protected - exterior reserve	19	2.9	±0.27	Targeted	*Sparisoma cretense*	1994			778.54	1602.82	-20.73	MPA increased, but ref. site decreased stronger	No
Montaña Amarilla	Partial protected - exterior reserve	19	2.9	±0.27	Targeted	*Sparisoma cretense*	2005			617.12	1363.24			
Punta Fariones	Partial protected - exterior reserve	12	2.9	±0.27	Targeted	*Sparisoma cretense*	1994			549.54	922.73	504.35	Both increased, but ref. site stronger	Potentially

Site	Protection status	Distance to Integral (Km)	Trophic level	Species group	Species	Year	Abundance		Biomass		% Δ	ΔMPA vs Δref Scenario name	Spillover?
							Fish / 100 m²	se	Fish / 100 m²	se			
Punta Fariones	Partial protected - exterior reserve	12	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005			3321.17	2323.07			
Mala	Outside of reserve	21.5	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994			849.32	703.86	4.18	Both increased, but ref. site stronger	Potentially
Mala	Outside of reserve	22.5	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005			884.81	1939.79			
Playa del Tío Joaquín	Outside of reserve	24	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994			700.23	1601.67	-99.93	MPA increased, but ref. site decreased stronger	No
Playa del Tío Joaquín	Outside of reserve	24	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005			0.5	1.22			
Veril de Puerto del Carmen 1	Outside of reserve	50	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994			992.34	1057.79	-4.08	MPA increased, but ref. site decreased stronger	No
Veril de Puerto del Carmen 1	Outside of reserve	50	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005			951.86	605.82			
Veril de Puerto del Carmen 2	Outside of reserve	50	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994							
Veril de Puerto del Carmen 2	Outside of reserve	50	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005			111.1	272.13			
Punta Gorda	Outside of reserve	58	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994			1442.34	2599.78	-44.43	MPA increased, but ref. site decreased stronger	No
Punta Gorda	Outside of reserve	58	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005			801.53	658.95			
La Juradita	Outside of reserve	62	2.9 ±0.27	Targeted	*Sparisoma cretense*	1994			27.11	48.54	-30.21	MPA increased, but ref. site decreased stronger	No
La Juradita	Outside of reserve	62	2.9 ±0.27	Targeted	*Sparisoma cretense*	2005			18.92	24.39			
Roque del Este norte	Fully protected - Integral reserve	0	2.0 ±0.0	Targeted	*Sarpa Salpa*	1994	221.67	206.92			-95.34		
Roque del Este norte	Fully protected - Integral reserve	0	2.0 ±0.0	Targeted	*Sarpa Salpa*	2005	10.33	20.02					
Roque del Este sur	Fully protected - Integral reserve	0	2.0 ±0.0	Targeted	*Sarpa Salpa*	1994							
Roque del Este sur	Fully protected - Integral reserve	0	2.0 ±0.0	Targeted	*Sarpa Salpa*	2005	27.83	39.94					
Roque del Este Average	Fully protected - Integral reserve	0	2.0 ±0.0	Targeted	*Sarpa Salpa*	1994	221.67	-			-82.79		
Roque del Este Average	Fully protected - Integral reserve	0	2.0 ±0.0	Targeted	*Sarpa Salpa*	2005	38.16	-					

Site	Protection status	Distance to Integral (Km)	Trophic level	Species group	Species	Year	Abundance		Biomass		% Δ	ΔMPA vs Δref Scenario name	Spillover?
							Fish / 100 m²	se	Fish / 100 m²	se			
Punta de la Mareta	Partial protected - exterior reserve	20	2.0 ±0.0	Targeted	*Sarpa Salpa*	1994							
Punta de la Mareta	Partial protected - exterior reserve	20	2.0 ±0.0	Targeted	*Sarpa Salpa*	2005							
Cuevas Coloradas	Partial protected - exterior reserve	17.5	2.0 ±0.0	Targeted	*Sarpa Salpa*	1994							
Cuevas Coloradas	Partial protected - exterior reserve	17.5	2.0 ±0.0	Targeted	*Sarpa Salpa*	2005	51.67	126.56					
Montaña Amarilla	Partial protected - exterior reserve	19	2.0 ±0.0	Targeted	*Sarpa Salpa*	1994							
Montaña Amarilla	Partial protected - exterior reserve	19	2.0 ±0.0	Targeted	*Sarpa Salpa*	2005	50	122.47					
Punta Fariones	Partial protected - exterior reserve	12	2.0 ±0.0	Targeted	*Sarpa Salpa*	1994	1	2.45			650.00	MPA decreased, but ref. site increased stronger	No
Punta Fariones	Partial protected - exterior reserve	12	2.0 ±0.0	Targeted	*Sarpa Salpa*	2005	7.5	12.55					
Mala	Outside of reserve	21.5	2.0 ±0.0	Targeted	*Sarpa Salpa*	1994	0.17	0.41			24705.9	MPA decreased, but ref. site increased stronger	No
Mala	Outside of reserve	22.5	2.0 ±0.0	Targeted	*Sarpa Salpa*	2005	42.17	101.82					
Playa del Tío Joaquín	Outside of reserve	24	2.0 ±0.0	Targeted	*Sarpa Salpa*	1994	18.83	46.13			-100.00	Both decreased, but ref. site stronger	No
Playa del Tío Joaquín	Outside of reserve	24	2.0 ±0.0	Targeted	*Sarpa Salpa*	2005							
Veril de Puerto del Carmen 1	Outside of reserve	50	2.0 ±0.0	Targeted	*Sarpa Salpa*	1994	1.5	0.84			88.67	MPA decreased as strong as ref. site increased	No
Veril de Puerto del Carmen 1	Outside of reserve	50	2.0 ±0.0	Targeted	*Sarpa Salpa*	2005	2.83	2.32					

Site	Protection status	Distance to Integral (Km)	Trophic level	Species group	Species	Year	Abundance		Biomass		% Δ	ΔMPA vs Δref Scenario name	Spillover?
							Fish / 100 m²	se	Fish / 100 m²	se			
Veril de Puerto del Carmen 2	Outside of reserve	50	2.0 ±0.0	Targeted	*Sarpa Salpa*	1994							
Veril de Puerto del Carmen 2	Outside of reserve	50	2.0 ±0.0	Targeted	*Sarpa Salpa*	2005	0.17	0.41					
Punta Gorda	Outside of reserve	58	2.0 ±0.0	Targeted	*Sarpa Salpa*	1994							
Punta Gorda	Outside of reserve	58	2.0 ±0.0	Targeted	*Sarpa Salpa*	2005	2	4.9					
La Juradita	Outside of reserve	62	2.0 ±0.0	Targeted	*Sarpa Salpa*	1994							
La Juradita	Outside of reserve	62	2.0 ±0.0	Targeted	*Sarpa Salpa*	2005							
Roque del Este norte	Fully protected - Integral reserve	0	4.3 ±0.6	Targeted	*Serranus atricauda*	1994	0.33	0.82			454.55		
Roque del Este norte	Fully protected - Integral reserve	0	4.3 ±0.6	Targeted	*Serranus atricauda*	2005	1.83	1.47					
Roque del Este sur	Fully protected - Integral reserve	0	4.3 ±0.6	Targeted	*Serranus atricauda*	1994							
Roque del Este sur	Fully protected - Integral reserve	0	4.3 ±0.6	Targeted	*Serranus atricauda*	2005	1	1.1					
Roque del Este Average	Fully protected - Integral reserve	0	4.3 ±0.6	Targeted	*Serranus atricauda*	1994	0.33				757.58		
Roque del Este Average	Fully protected - Integral reserve	0	4.3 ±0.6	Targeted	*Serranus atricauda*	2005	2.83						
Punta de la Mareta	Partial protected - exterior reserve	20	4.3 ±0.6	Targeted	*Serranus atricauda*	1994	0.5	0.55			134.00	Both increased, but MPA stronger	Potentially
Punta de la Mareta	Partial protected - exterior reserve	20	4.3 ±0.6	Targeted	*Serranus atricauda*	2005	1.17	0.75					
Cuevas Coloradas	Partial protected - exterior reserve	17.5	4.3 ±0.6	Targeted	*Serranus atricauda*	1994	0.5	0.55			366.00	Both increased, but MPA stronger	Potentially
Cuevas Coloradas	Partial protected - exterior reserve	17.5	4.3 ±0.6	Targeted	*Serranus atricauda*	2005	2.33	0.52					

Site	Protection status	Distance to Integral (Km)	Trophic level		Species group	Species	Year	Abundance		Biomass		% Δ	ΔMPA vs Δref Scenario name	Spillover?
								Fish / 100 m²	se	Fish / 100 m²	se			
Montaña Amarilla	Partial protected - exterior reserve	19	4.3	±0.6	Targeted	*Serranus atricauda*	1994							
Montaña Amarilla	Partial protected - exterior reserve	19	4.3	±0.6	Targeted	*Serranus atricauda*	2005	1.33	0.52					
Punta Fariones	Partial protected - exterior reserve	12	4.3	±0.6	Targeted	*Serranus atricauda*	1994							
Punta Fariones	Partial protected - exterior reserve	12	4.3	±0.6	Targeted	*Serranus atricauda*	2005							
Mala	Outside of reserve	21.5	4.3	±0.6	Targeted	*Serranus atricauda*	1994	1.33	1.75			-75.19	Ref. site decreased, but MPA increased stronger	No
Mala	Outside of reserve	22.5	4.3	±0.6	Targeted	*Serranus atricauda*	2005	0.33	0.52					
Playa del Tío Joaquín	Outside of reserve	24	4.3	±0.6	Targeted	*Serranus atricauda*	1994	0.17	0.41			0.00	MPA increased	No
Playa del Tío Joaquín	Outside of reserve	24	4.3	±0.6	Targeted	*Serranus atricauda*	2005	0.17	0.41					
Veril de Puerto del Carmen 1	Outside of reserve	50	4.3	±0.6	Targeted	*Serranus atricauda*	1994							
Veril de Puerto del Carmen 1	Outside of reserve	50	4.3	±0.6	Targeted	*Serranus atricauda*	2005	0.33	0.52					
Veril de Puerto del Carmen 2	Outside of reserve	50	4.3	±0.6	Targeted	*Serranus atricauda*	1994	0.33	0.52			-48.48	Ref. site decreased, but MPA increased stronger	No
Veril de Puerto del Carmen 2	Outside of reserve	50	4.3	±0.6	Targeted	*Serranus atricauda*	2005	0.17	0.41					
Punta Gorda	Outside of reserve	58	4.3	±0.6	Targeted	*Serranus atricauda*	1994	0.17	0.41			194.12	Both increased, but MPA stronger	Potentially
Punta Gorda	Outside of reserve	58	4.3	±0.6	Targeted	*Serranus atricauda*	2005	0.5	0.55					
La Juradita	Outside of reserve	62	4.3	±0.6	Targeted	*Serranus atricauda*	1994	0.5	0.84			-34.00	Ref. site decreased, but MPA increased stronger	No
La Juradita	Outside of reserve	62	4.3	±0.6	Targeted	*Serranus atricauda*	2005	0.33	0.52					
Roque del Este norte -Biomass	Fully protected - Integral reserve	0	4.3	±0.6	Targeted	*Serranus atricauda*	1994			64.53	158.06	586.73		
Roque del Este norte -Biomass	Fully protected - Integral reserve	0	4.3	±0.6	Targeted	*Serranus atricauda*	2005			443.15	411.97			

Site	Protection status	Distance to Integral (Km)	Trophic level	Species group	Species	Year	Abundance		Biomass		% Δ	ΔMPA vs Δref Scenario name	Spillover?
							Fish / 100 m²	se	Fish / 100 m²	se			
Roque del Este sur - Biomass	Fully protected - Integral reserve	0	4.3 ±0.6	Targeted	*Serranus atricauda*	1994							
Roque del Este sur - Biomass	Fully protected - Integral reserve	0	4.3 ±0.6	Targeted	*Serranus atricauda*	2005			116.07	154.32			
Roque del Este Average - Biomass	Fully protected - Integral reserve	0	4.3 ±0.6	Targeted	*Serranus atricauda*	1994			64.53		766.60		
Roque del Este Average - Biomass	Fully protected - Integral reserve	0	4.3 ±0.6	Targeted	*Serranus atricauda*	2005			559.22				
Punta de la Mareta -Biomass	Partial protected - exterior reserve	20	4.3 ±0.6	Targeted	*Serranus atricauda*	1994			91.75	147.95	23.71	Both increased, but MPA stronger	Potentially
Punta de la Mareta -Biomass	Partial protected - exterior reserve	20	4.3 ±0.6	Targeted	*Serranus atricauda*	2005			113.5	144.03			
Cuevas Coloradas -Biomass	Partial protected - exterior reserve	17.5	4.3 ±0.6	Targeted	*Serranus atricauda*	1994			106.22	142.14	28.80	Both increased, but MPA stronger	Potentially
Cuevas Coloradas -Biomass	Partial protected - exterior reserve	17.5	4.3 ±0.6	Targeted	*Serranus atricauda*	2005			136.81	61.57			
Montaña Amarilla - Biomass	Partial protected - exterior reserve	19	4.3 ±0.6	Targeted	*Serranus atricauda*	1994							
Montaña Amarilla - Biomass	Partial protected - exterior reserve	19	4.3 ±0.6	Targeted	*Serranus atricauda*	2005			126.84	80.84			
Punta Fariones - Biomass	Partial protected - exterior reserve	12	4.3 ±0.6	Targeted	*Serranus atricauda*	1994			20	7.07	-3.35	Ref. site decreased, but MPA increased stronger	No
Punta Fariones - Biomass	Partial protected - exterior reserve	12	4.3 ±0.6	Targeted	*Serranus atricauda*	2005			19.33	5.13			
Mala -Biomass	Outside of reserve	21.5	4.3 ±0.6	Targeted	*Serranus atricauda*	1994			41.09	60.67	-46.99	Ref. site decreased, but	No

Site	Protection status	Distance to Integral (Km)	Trophic level	Species group	Species	Year	Abundance		Biomass		% Δ	ΔMPA vs Δref Scenario name	Spillover?
							Fish / 100 m²	se	Fish / 100 m²	se			
Mala -Biomass	Outside of reserve	22.5	4.3 ±0.6	Targeted	*Serranus atricauda*	2005			21.78	38.24		MPA increased stronger	
Playa del Tío Joaquín -Biomass	Outside of reserve	24	4.3 ±0.6	Targeted	*Serranus atricauda*	1994			6.14	15.05	425.41	Both increased, but MPA stronger	Potentially
Playa del Tío Joaquín -Biomass	Outside of reserve	24	4.3 ±0.6	Targeted	*Serranus atricauda*	2005			32.26	79.03			
Veril de Puerto del Carmen 1 - Biomass	Outside of reserve	50	4.3 ±0.6	Targeted	*Serranus atricauda*	1994							
Veril de Puerto del Carmen 1 - Biomass	Outside of reserve	50	4.3 ±0.6	Targeted	*Serranus atricauda*	2005			35.24	77.9			
Veril de Puerto del Carmen 2 - Biomass	Outside of reserve	50	4.3 ±0.6	Targeted	*Serranus atricauda*	1994			12.29	19.04	27.18	Both increased, but MPA stronger	Potentially
Veril de Puerto del Carmen 2 - Biomass	Outside of reserve	50	4.3 ±0.6	Targeted	*Serranus atricauda*	2005			15.63	38.3			
Punta Gorda - Biomass	Outside of reserve	58	4.3 ±0.6	Targeted	*Serranus atricauda*	1994			15.63	38.3	277.48	Both increased, but MPA stronger	Potentially
Punta Gorda - Biomass	Outside of reserve	58	4.3 ±0.6	Targeted	*Serranus atricauda*	2005			59	77.24			
La Juradita - Biomass	Outside of reserve	62	4.3 ±0.6	Targeted	*Serranus atricauda*	1994			9.44	15.59	407.42	Both increased, but MPA stronger	Potentially
La Juradita - Biomass	Outside of reserve	62	4.3 ±0.6	Targeted	*Serranus atricauda*	2005			47.9	80.64			
Roque del Este norte	Fully protected - Integral reserve	0	3.4 ±0.1	Bycatch	*Diplodus cervinus*	1994	1.83	2.86			-90.71		
Roque del Este norte	Fully protected - Integral reserve	0	3.4 ±0.1	Bycatch	*Diplodus cervinus*	2005	0.17	0.41					
Roque del Este sur	Fully protected - Integral reserve	0	3.4 ±0.1	Bycatch	*Diplodus cervinus*	1994							
Roque del Este sur	Fully protected - Integral reserve	0	3.4 ±0.1	Bycatch	*Diplodus cervinus*	2005	1	2.45					
Roque del Este Average	Fully protected - Integral reserve	0	3.4 ±0.1	Bycatch	*Diplodus cervinus*	1994	1.83				-36.07		
Roque del Este Average	Fully protected - Integral reserve	0	3.4 ±0.1	Bycatch	*Diplodus cervinus*	2005	1.17						
Punta de la Mareta	Partial protected -	20	3.4 ±0.1	Bycatch	*Diplodus cervinus*	1994	0.33	0.52			-48.48	Both decreased, but	No

Site	Protection status	Distance to Integral (Km)	Trophic level	Species group	Species	Year	Abundance		Biomass		% Δ	ΔMPA vs Δref Scenario name	Spillover?
							Fish / 100 m²	se	Fish / 100 m²	se			
	exterior reserve											ref. site stronger	
Punta de la Mareta	Partial protected - exterior reserve	20	3.4 ±0.1	Bycatch	*Diplodus cervinus*	2005	0.17	0.41					
Cuevas Coloradas	Partial protected - exterior reserve	17.5	3.4 ±0.1	Bycatch	*Diplodus cervinus*	1994	0.17	0.41			194.12	MPA decreased, but ref. site increased stronger	No
Cuevas Coloradas	Partial protected - exterior reserve	17.5	3.4 ±0.1	Bycatch	*Diplodus cervinus*	2005	0.5	0.84					
Montaña Amarilla	Partial protected - exterior reserve	19	3.4 ±0.1	Bycatch	*Diplodus cervinus*	1994	1.17	1.17			70.94	Ref. site increased, but MPA decreased stronger	No
Montaña Amarilla	Partial protected - exterior reserve	19	3.4 ±0.1	Bycatch	*Diplodus cervinus*	2005	2	2.19					
Punta Fariones	Partial protected - exterior reserve	12	3.4 ±0.1	Bycatch	*Diplodus cervinus*	1994	1.5	1.22			-66.67	Both decreased, but ref. site stronger	No
Punta Fariones	Partial protected - exterior reserve	12	3.4 ±0.1	Bycatch	*Diplodus cervinus*	2005	0.5	1.22					
Mala	Outside of reserve	21.5	3.4 ±0.1	Bycatch	*Diplodus cervinus*	1994	0.33	0.52					
Mala	Outside of reserve	22.5	3.4 ±0.1	Bycatch	*Diplodus cervinus*	2005	NA						
Playa del Tío Joaquín	Outside of reserve	24	3.4 ±0.1	Bycatch	*Diplodus cervinus*	1994	1	1.55					
Playa del Tío Joaquín	Outside of reserve	24	3.4 ±0.1	Bycatch	*Diplodus cervinus*	2005	NA						
Veril de Puerto del Carmen 1	Outside of reserve	50	3.4 ±0.1	Bycatch	*Diplodus cervinus*	1994	0.17	0.41					
Veril de Puerto del Carmen 1	Outside of reserve	50	3.4 ±0.1	Bycatch	*Diplodus cervinus*	2005	NA						
Veril de Puerto del Carmen 2	Outside of reserve	50	3.4 ±0.1	Bycatch	*Diplodus cervinus*	1994	NA						
Veril de Puerto del Carmen 2	Outside of reserve	50	3.4 ±0.1	Bycatch	*Diplodus cervinus*	2005	11.83	28.99					

Site	Protection status	Distance to Integral (Km)	Trophic level	Species group	Species	Year	Abundance		Biomass		% Δ	ΔMPA vs Δref Scenario name	Spillover?
							Fish / 100 m²	se	Fish / 100 m²	se			
Punta Gorda	Outside of reserve	58	3.4 ±0.1	Bycatch	*Diplodus cervinus*	1994	0.33	0.83			-48.48	Both decreased, but ref. site stronger	No
Punta Gorda	Outside of reserve	58	3.4 ±0.1	Bycatch	*Diplodus cervinus*	2005	0.17	0.41					
La Juradita	Outside of reserve	62	3.4 ±0.1	Bycatch	*Diplodus cervinus*	1994	0.67	0.82					
La Juradita	Outside of reserve	62	3.4 ±0.1	Bycatch	*Diplodus cervinus*	2005	NA						
Roque del Este norte	Fully protected - Integral reserve	0	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	1994	30.67	26.23			-89.14		
Roque del Este norte	Fully protected - Integral reserve	0	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	2005	3.33	3.27					
Roque del Este sur	Fully protected - Integral reserve	0	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	1994	26.83	30.62			-85.72		
Roque del Este sur	Fully protected - Integral reserve	0	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	2005	3.83	30.62					
Roque del Este Average	Fully protected - Integral reserve	0	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	1994	57.5				-87.55		
Roque del Este Average	Fully protected - Integral reserve	0	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	2005	7.16						
Punta de la Mareta	Partial protected - exterior reserve	20	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	1994							
Punta de la Mareta	Partial protected - exterior reserve	20	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	2005							
Cuevas Coloradas	Partial protected - exterior reserve	17.5	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	1994	9.17	5.64			-90.95	Mutual decrease	No
Cuevas Coloradas	Partial protected - exterior reserve	17.5	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	2005	0.83	2.04					
Montaña Amarilla	Partial protected - exterior reserve	19	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	1994							

Site	Protection status	Distance to Integral (Km)	Trophic level	Species group	Species	Year	Abundance		Biomass		% Δ	ΔMPA vs Δref Scenario name	Spillover?
							Fish / 100 m²	se	Fish / 100 m²	se			
Montaña Amarilla	Partial protected - exterior reserve	19	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	2005	0.17	0.41					
Punta Fariones	Partial protected - exterior reserve	12	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	1994	0.17	0.41			0.00		
Punta Fariones	Partial protected - exterior reserve	12	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	2005	0.17	0.41					
Mala	Outside of reserve	21.5	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	1994	3.17	5.46			26.18	Ref. site increased, but MPA decreased stronger	No
Mala	Outside of reserve	22.5	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	2005	4	6					
Playa del Tío Joaquín	Outside of reserve	24	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	1994	0.67	1.63			-50.75	Both decreased, but MPA stronger	No
Playa del Tío Joaquín	Outside of reserve	24	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	2005	0.33	0.82					
Veril de Puerto del Carmen 1	Outside of reserve	50	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	1994	0.5	0.84			34.00	Ref. site increased, but MPA decreased stronger	No
Veril de Puerto del Carmen 1	Outside of reserve	50	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	2005	0.67	1.03					
Veril de Puerto del Carmen 2	Outside of reserve	50	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	1994							
Veril de Puerto del Carmen 2	Outside of reserve	50	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	2005							
Punta Gorda	Outside of reserve	58	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	1994	0.83	2.04			-79.52	Both decreased, but MPA stronger	No
Punta Gorda	Outside of reserve	58	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	2005	0.17	0.41					
La Juradita	Outside of reserve	62	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	1994	0.33	0.52			-100.00	Both decreased, but ref. site stronger	No
La Juradita	Outside of reserve	62	3.4 ±0.1	Bycatch	*Centrolabrus trutta*	2005							

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