ORIGINAL RESEARCH

Effects of the establishment of marine protected areas on the Argentine Patagonian toothfish (*Dissostichus eleginoides*) fisheries

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ABSTRACT. At the beginning of the 1990s, the Argentine toothfish fishery gained prominence as a consequence of the rapid expansion of trawler and longliner fleets targeting this species. This fishing area covers the slope and shelf from 60° S to 37° S in the Argentine Exclusive Economic Zone. The main fishing ground is located in the southern area, bordering Namuncurá-Burdwood Bank II (NBBII) and Yaganes (Y) marine protected areas (MPA) established in 2018. In order to determine the impact generated by MPAs on effort distribution, 308 fishing trips carried out between 2010 and 2020, which reported 82% of the total fishing effort of Argentine toothfish declared in that period, were spatially analyzed. The Y-MPA sector categorized as National Marine Reserve and located to the south of Tierra del Fuego reported more than half (58%) of the toothfish catch recorded throughout that period, while the NBBII-MPA located to the east of Tierra del Fuego and south of De los Estados Island represented 17%. The NBBII-MPA sector established as a Strict National Marine Reserve and located to the south of the Burdwood Bank represented 25%. With the establishment of the MPAs, 7.11% of the international requirement has been met. At the moment, effects resulting from the creation of MPAs can only be speculated upon qualitatively, but should be quantified in the near future.

Key words: Effort distribution, management, impact, southwestern Atlantic Ocean, resources.

Efectos del establecimiento de las áreas marinas protegidas en la pesquería argentina de la merluza negra (*Dissostichus eleginoides*)

RESUMEN. A principios de la década de 1990, la pesquería de merluza negra argentina ganó protagonismo gracias a la rápida expansión de las flotas de arrastre y palangre que se dirigían a esta especie. Esta zona de pesca cubre el talud y plataforma desde los 60° S hasta los 37° S en la Zona Económica Exclusiva argentina. El principal caladero se encuentra en la zona sur, colindando con las áreas marinas protegidas (AMP) Banco Namuncurá-Burdwood II (NBBII) y Yaganes (Y), establecidas en 2018. Para determinar el impacto que generan las AMP en la distribución del esfuerzo, se analizaron espacialmente 308 viajes de pesca realizados entre 2010 y 2020, que reportaron 82% del total del esfuerzo pesquero declarado de merluza negra argentina en ese período. El sector Y-AMP categorizado como Reserva Nacional Marina y ubicado al sur de Tierra del Fuego, reportó más de la mitad (58%) de la captura de merluza negra registrada durante ese período, mientras que el NBBII-AMP ubicado al este de Tierra del Fuego y sur de la Isla de los Estados representaron 17%. El sector NBBII-AMP establecido como Reserva Nacional Marina Estricta y ubicado al sur del Banco Burdwood representó el 25%. Con el establecimiento de las AMP se ha cumplido 7,11% del requerimiento internacional. En la actualidad, los efectos resultantes de la creación de AMP solo pueden especularse cualitativamente, pero deberían cuantificarse en un futuro próximo.

Palabras clave: Distribución del esfuerzo, manejo, impacto, Océano Atlántico Sudoccidental, recursos.

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INTRODUCTION

Marine protected areas (MPAs) play an important role in the conservation and management of our oceans and coastal ecosystems. They are designated regions within marine environments which are legally protected and managed to safeguard and preserve their ecological integrity serving as refugees for marine biodiversity, protecting sensitive habitats, and contributing to the sustainable use of marine resources (IUCN 2013). The concept of MPAs has gained increasing recognition and importance due to the escalating threats facing marine ecosystems, including overfishing, habitat destruction, pollution, and climate change (Claudet et al. 2019; Duarte et al. 2020). Scientific research has provided substantial evidence of the benefits and effectiveness of MPAs in conserving marine biodiversity and restoring degraded ecosystems (Lester et al. 2009; Sala et al. 2021).

Patagonian toothfish (*Dissostichus eleginoides* Smitt, 1898) is a demersal-benthic fish of the Family Nototheniidae. It is a deep-sea, slow-growing (Collins et al. 2010), long-lived (Yates et al. 2018), mostly ichthyophagous predator with a high trophic level (Troccoli et al. 2020), which can reach more than 2 m total length (TL) and more than 100 kg weight (Nevinski and Kozlov 2002). It is widespread in the Atlantic, Pacific and Indian oceans, as well as in the northern region of the Antarctic Convergence (Fischer and Hureau 1985). Its distribution in the South Atlantic Ocean is influenced by the Malvinas Current and extends from 60° S to 37° S on the Argentine slope and shelf (Otero et al. 1982; Inada 1986). Highest concentrations of the species are found between the Burdwood Bank and De los Estados Island, to the south and northeast of the Malvinas Islands, and on the slope of Buenos Aires province (Prenski and Almeyda 2000; Martínez et al. 2001). This species exhibits a differential size distribution based on depth (Cotrina 1981; Cassia and Perrotta 1996; Prenski and Almeyda 2000), with largest specimens inhabiting up to 2,500 m (submarine canyons) and juveniles distributed within the water column up to 600 m (Cotrina 1981). Duhamel (1991) and Agnew et al. (1999) reported the same behavior for the species in the Kerguelen region and South Georgia Islands, respectively.

Patagonian toothfish fisheries in the Argentine Exclusive Economic Zone (EEZ) began at the early 1990s and gained prominence due to the rapid expansion mainly of trawler and longliner fleets, while a few vessels also used pots for a brief period. A set of management measures in accordance with the biological characteristics of the species were implemented in 2002 to prevent juvenile overfishing and ensure adequate recruitment for rational resource management. In addition to the establishment of the Commission for the Monitoring of Patagonian Toothfish Fishing Activity and the Subcommittee for Bycatch Control, the obligation to carry onboard observers proved to be crucial elements for management. As a result, the fishery is in a state of full exploitation tending to the sustainability of the resource and its fishery (Di Marco et al. 2019, 2020). Since 2021, the Argentine fishery has been engaged in an Improvement Program (PROME) that establishes short, medium and long-term objectives guided by recognized standards of the Marine Stewardship Council (MSC).

From the beginning of the fishery to the present, the predominance of one type of fishing gear over another has changed particularly in response to regulations and economic strategies of companies. Operating characteristics of the trawl and longline fisheries have determined areas of operation for each fleet type, with the longliner fleet having a much more extensive area of operation due to its ability to fish even on bottoms not suitable for trawling.

The Yaganes (Y) and Namuncurá-Burdwood Bank II (NBBII) MPAs were established in 2018.

Their establishment within the usual Patagonian toothfish fishing grounds will undoubtedly have an impact on the distribution of effort that must be taken into consideration, as well as the potential beneficial effects for the species and other conservation objectives. This paper examined potential effects of the establishment of the aforementioned marine areas on catches made by all fishing gear targeting this species between 2010 and 2020.

Brief review of Namuncurá-Burdwood Bank and Yaganes marine protected areas

The Namuncurá-Burdwood Bank I (NBBI-MPA) was the first MPA established in the southern zone created by National Act Nº 26875 in 2013 covering a total area of 28,000 km^2. This NBBI-MPA was later included into the framework of the National Act Nº 27037 by Decree Nº 888/2019, which established the MPAs' National System. The Burdwood Bank is a submarine plateau in the southwestern Atlantic located 150 km to the east of De los Estados Island and 200 km south of Malvinas Islands. Its steep edges produce vertical water movements bringing deep, nutrient-rich waters to the sea surface favoring primary production. It is a shallow area whose upper portion is not visited by either of the two toothfish fleets. It consists of the management categories National Marine Park and National Marine Reserve (Figure 1).

The National Act Nº 27490 was passed on December 2018 to establish two new southern

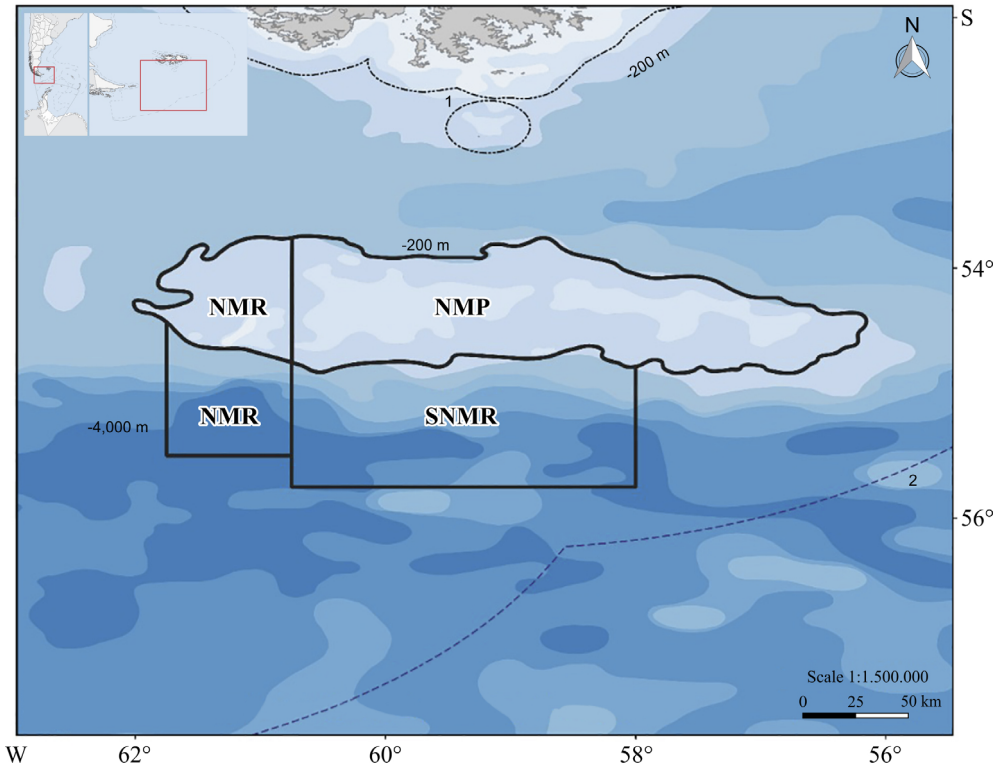

Figure 1. Namuncurá-Burdwood Bank marine protected area. The management categories are indicated. NMR: National Marine Reserve. SNMR: Strict National Marine Reserve. NMP: National Marine Park. 1: outer limit of the Argentine territorial sea. 2: outer limit of the Argentine Exclusive Economic Zone. Modified from https://www.argentina.gob.ar/parques nacionales/areasmarinas/namuncura-burdwood.

MPAs: Namuncurá-Burdwood Bank II (NBBII-MPA), which was added to the existing one, and Yaganes (Y-MPA) (Figures 1 and 2). The 32,336.3 km^2 NBBII-MPA consist of the management categories Strict National Marine Reserve (SNMR) and National Marine Reserve (NMR). The NMR category, located at the western end of the MPA, constitutes approximately one quarter of the total area. In contrast to the SNMR, which ban any productive activity, this category allows for the sustainable use of natural ecosystems. The Namuncurá-Burdwood Bank Marine Protected Area (NBB-MPA) is currently managed as a single conservation unit that encompasses the oceanic spaces of NBBI-MPA and NBBII-MPA; however, for the purposes of this document, reference will be made only to the NBBII-MPA, since it is the only one that reports depths greater than 800 m necessary for directed fishing of the species. A management plan that ensures the achievement of MPA objectives must be used to carry out the sustainable exploitation of fisheries, wildlife, tourism, and recreation altogether.

The first workshop of the NBB-MPA management plan was held in October 2019 with the participation of members from governmental and non-governmental organizations, as well as from private sectors of the civil society with interests in these MPAs. In it, the objective of 'conserving, investigating and monitoring the animal forest, the spawning and nursery areas of fish and populations of key species of food webs, the areas of

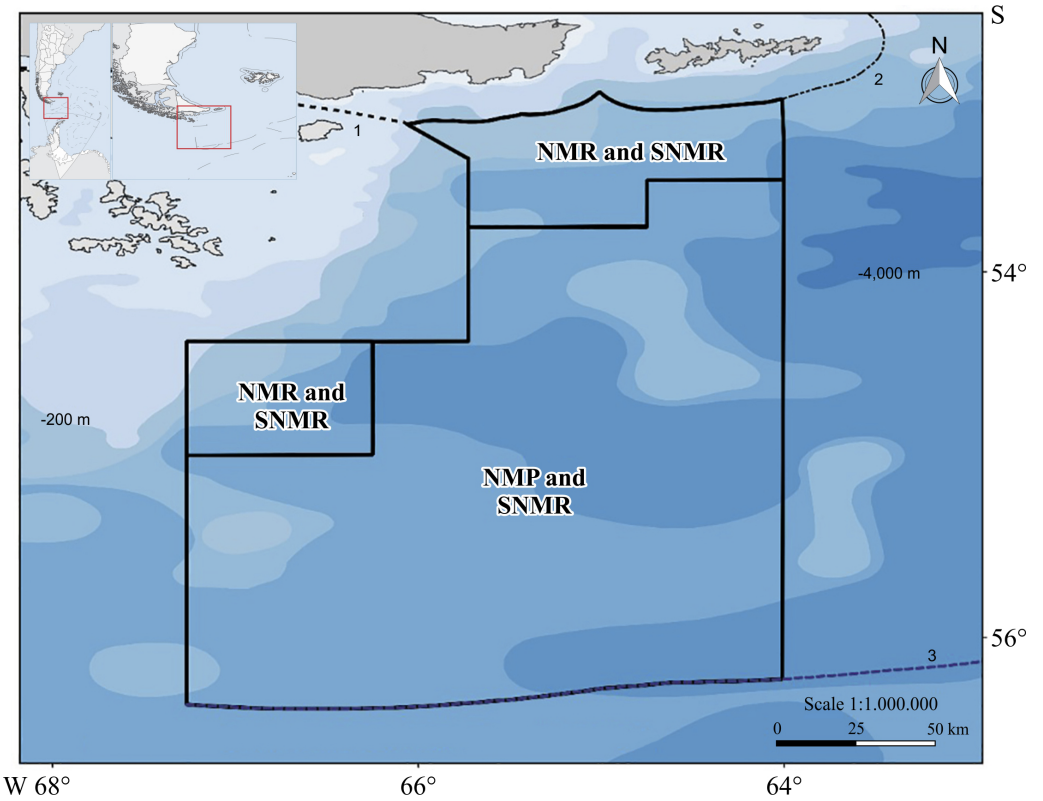

Figure 2. Yaganes marine protected area. The management categories are indicated. NMR: National Marine Reserve. SNMR: Strict National Marine Reserve. NMP: National Marine Park. 1: international limit. 2: outer limit of the Argentine territorial sea. 3: outer limit of the Argentine Exclusive Economic Zone. Modified from https://www.argentina.gob.ar/parquesnacionales/areasmarinas/yaganes.

use of top predators and the retention and upwelling processes of nutrients of the NBB-MPA' was drafted considering the following premises:

- Generation of knowledge through scientific research focused on the management and use of the MPA.
- Implementation of a monitoring program based on indicators and focused on all conservation objectives (CO).
- Prevention and mitigation of threats to COs.
- Sustainable use of fishing resources and conservation.
- Integrated administration of the management plan with different actors, particularly in the area of multiple uses.
- Application of adaptive management for the implementation, monitoring and improvement of the management plan.
- Inform society of the existence and importance of the MPAs.

The management plan for the NBB-MPA was finished in 2022 (APN 2022). This is the most important tool for strategic planning containing the necessary guidelines for the administration of the area, as well as for its monitoring and evaluation of progress. Several workshops with professionals and technicians from different institutions were held during the preparation stage to identify conservation objectives and management priorities. However, as of the time of preparing this document, a fisheries management plan necessary to enable fishing exploitation in the NMR has not yet been established.

Management categories of SNMR, National Marine Park (NMP), and NMR comprise the Yaganes MPA. As previously mentioned, MPAs are entirely within the Argentine EEZ and covers 68,834.31 km^2 (Figure 2). Seabed of the entire Yaganes MPA is under the category of SNMR, providing the highest degree of protection. However, within the framework of a management plan, the water column has been assigned the management category of NMR in two sectors.

In another much broader sector, the water column is under the management category NMP in order to guarantee controlled scientific, educational and recreational uses, admitting tourism as the only economic activity. Until now, the management plan for Yaganes have not been approved for any of the management categories established in the foundation act. The 129,170 km^2 surface area of the described MPAs is in or very close to important Patagonian toothfish fishing grounds for the Argentine fleet. The NBBII-MPA NMR covers 7,639 km^2 (approximately 6% of MPAs' bottoms) and was not historically a fishing area for the species. Depending on what is specified in the corresponding management plan, it is the only one that could engage in productive activities like bottom trawling for toothfish. Additionally, fishing in the water column will be allowed in the two NMR (20,643 km^2) of both NBB-MPA and Y-MPA, but it will be restricted to 16% of the entire area designated for southern MPAs of the Argentine EEZ. The Argentine toothfish fishery will undoubtedly be impacted by this restriction on productive activities, in this case trawl and longline fishing.

The Argentine Patagonian toothfish fishery: strategies and management measures applied

The Patagonian toothfish fishing gained prominence in Argentina at the beginning of the 1990s and quickly experienced significant growth due to the high commercial value of the species on international markets. In the early 2000s, catches from both trawl and longline fisheries consisted almost entirely of juveniles < 82 cm TL. As a consequence, INIDEP recommended taking precautions with the species' exploitation in particular due to a general trend in the fishery caused by the species' biological characteristics, such as its longevity, slow growth, large size, and age at first sexual maturity, which make the species easily suscepti-

ble to overfishing (Prenski and Almeyda 1997, 2000; Prenski 2000; Wöhler et al. 2001; Wöhler and Martínez 2002). In view of this, the Enforcement Authority implemented a series of resolutions between 2001 and 2002, including management elements covering different aspects of the fishery to avoid excessive capture of juvenile Patagonian toothfish, such as limits on the depth of the set, percentage of allowed juveniles per set, and hooks size, among others.

Resolution Nº 19/2002 from the Secretaría de Agricultura Ganadería y Pesca (SAGPyA) proved to be one of the most significant for fishery management, particularly in relation to the establishment of a Juvenile Patagonian Toothfish Protection Area (JPTPA) in geographic squares 5461, 5462 and 5463. The establishment of an Advisory Commission for monitoring the Patagonian toothfish fishing activity, comprising representatives of the business sector, scientists and the Enforcement Authority (Subsecretaría de Pesca y Acuicultura –SSPyA), together with the creation of the Subcommittee for the control of mixed landing made up of representatives of the business sector and the Enforcement Authority, were significant advances. Although both commissions aim to make it easier to control and monitor the resource, the first commission also advises on the development of the toothfish fishery and proposes new regulations or changes to existing ones to make the management plan for that fishery more efficient.

Resolution Nº 19/2002 also included additional measures for the management of the fishery. Among the most significant were the mandatory presence of an observer and inspector onboard of vessels targeting Patagonian toothfish, as well as the establishment of a limit of 15% for the proportion of juveniles allowed in sets specifically directed towards the species (equivalent to more than 3% of the total catch). The fishery management clearly evolved into adaptive management in light of the current regulatory environment. The evolution of the estimated percentage of juveniles was monitored on a quarterly basis based on the information collected by onboard observers on each fishing trip. Subsequently, the Individual Transferable Quota (ITQ) regime for the fishery was established by Resolution Nº 9/2007 of the Consejo Federal Pesquero (CFP) and Provision Nº 75/2010 of the National Fishery Control Agency (DNCP). Both acts helped effectively control catches and provided ship owners with greater predictability and transparency in their administration.

Due to the concentration of effort in the JPTPA, and the fact that the species reproduces in part of it, a reproductive ban has recently been implemented to safeguard the adult population during the main spawning season occurring during July, August, and September every year. Additionally, the percentage of juveniles permitted has been increased to 20% by CFP Resolution Nº 12/2019.

MATERIALS AND METHODS

Information was collected during the 2010-2020 period by observers from the Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP, Argentina) onboard of vessels with ITQ fishing for toothfish. Data included position, total catch and toothfish catch of each set per trip. Additionally, Patagonian toothfish were examined in both the Argentine EEZ and in established MPAs.

RESULTS AND DISCUSSION

A total of 31,834 sets corresponding to 308 fishing trips (231 trawlers and 77 longliners) were analyzed, reporting a catch of 32,063 t of Patagonian toothfish, which represented 82% of the 39,144 t total catches declared during that period (Tables 1 and 2).

Table 1. Bottom trawlers with Individual Transferable Quota (ITQ) fishing for toothfish and number of fishing trips with observers onboard from the 2010 to 2020 period.

Vessel/year	'Argenova XXII'	'Centurión del Atlántico'	'Echizen Maru'	'Esperanza del Sur'	'San Arawa II'	'Tai An'	'Viento del Sur'	Total
2010	-	7	6	3	6	5	5	32
2011	-	3	3	2	6	5	4	23
2012	1	4	4	-	8	5	-	22
2013	3	-	6	-	5	8	-	22
2014	1	4	5	-	7	7	-	24
2015	-	4	4	-	8	6	-	22
2016	-	3	4	-	2	7	-	16
2017	3	5	2	-	6	3	-	19
2018	4	3	5	-	6	4	-	22
2019	4	4	1	-	6	2	-	17
2020	2	3	4	-	3	-	-	12
Total	18	40	44	5	63	52	9	231

Fishing fleet activities with ITQ of the species in the Argentine EEZ between 2010-2020

Bottom trawl vessels

Operations of freezer fleet were restricted to the area south of 48° S because of a management measure to reduce the fishing effort for common hake (*Merluccius hubbsi*) established in 1999. Such displacement played a role in the fleet's decision to begin pursuing for Patagonian toothfish as a potential source of diversification due to its high commercial value. At the top of the fishery's expansion, around fifty vessels, including trawlers and longliners, reported catching Patagonian toothfish at the beginning of the 2000s. However, this number gradually decreased in early 2003 because of both the restrictive management strategy of fishing authorities and logistical reasons specific to each company, such as other nearby fisheries (Wöhler and Martínez 2017).

Over the last 10 years, the trawler fleet with ITQ for toothfish consisted of seven vessels (Troccoli and Martínez 2021), with five of them currently active (Table 1). Depending on the volume of catches, freezer vessels operating in the southernmost fishery in the Argentine EEZ primarily targeted hoki (*Macruronus magellanicus*). These vessels are typically large and possess significant operational capability to operate in that part of the Argentine EEZ. The main area of operation of this fleet is between 150-350 m deep; however, when directing their effort to toothfish they trawl at more than 800 m depths, since it is the minimum depth allowed for the capture of Patagonian toothfish.

Trawlers use different bottom gears depending on the target species to which they direct their effort. Most of the nets have a device called 'rock hopper' attached to the footrope. This device consists of 50 cm diameter steel balls joined by a 22 mm steel cable and protected by 60 cm diameter rubber discs. It causes the gear to roll and the net to jump on the bottom, preventing snags and allowing to fish on irregular bottoms.

When looking at all of the trawls that were recorded during this time period (29,045 hauls),

Table 2. Bottom longliners with Individual Transferable Quota (ITQ) fishing for toothfish and number of fishing trips with observers onboard from the 2010 to 2020 period.

Vessel/year	'Antartic III'	'Argenova XXI'	'Argenova XIV'	Total
2010	4	4	3	11
2011	6	7	3	16
2012	3	5	6	14
2013	4	4	4	12
2014	-	4	5	9
2015	-	4	3	7
2016	-	1	4	5
2017	-	-	1	1
2018	-	-	1	1
2019	-	-	1	1
2020	-	-	-	-
Total	17	29	31	77

we found that their durations ranged from less than 1 h to more than 10 h, with an average of 2 and 3 h. However, 38% of the species caught in the analyzed years came from sets that lasted less than 1 h, averaging 30 min (Table 3), a value that rises to 82% when considering trawls of less than 2 h. This shows that when targeting toothfish the duration of trawls decreases significantly compared to those when the vessel targets other species that constitute the southern fishery.

The area of operation of the toothfish trawling fleet holding ITQ fishing for southern species is located in high latitudes south of 50° S (Figure 3). The main fishing ground of this fleet fishing for Patagonian toothfish is located to the east of De los Estados Island. It is made up of three statistical grids: 5461, 5462 and 5463, all of which comprise the JPTPA. This area reports 97% of catches from the last ten years with respect to the total catches obtained by trawlers in that period (Table 4; Figure 4).

Table 3. Percentage of toothfish sets and catches of bottom trawl based on strata established according to the duration of fishing operations.

Duration (h)	Sets (%)	Catch (%)
Less than 1	10	38
1 to 2	17	44
2 to 3	18	10
3 to 4	18	4
4 to 5	17	2
5 to 6	10	0.70
6 to 7	5	0.40
7 to 8	2	0.10
8 to 9	1	0.09
9 to 10	0.60	0.01
More than 10	0.90	0.20

Bottom longline vessels

According to Martínez et al. (2002), numerous longline vessels targeting for toothfish joined the fishery at the beginning of the 1990s, resulting in the fleet's largest catch (close to 19,000 t). Spanish-type manual and automatic longline-operating vessels have gradually withdrawn from the

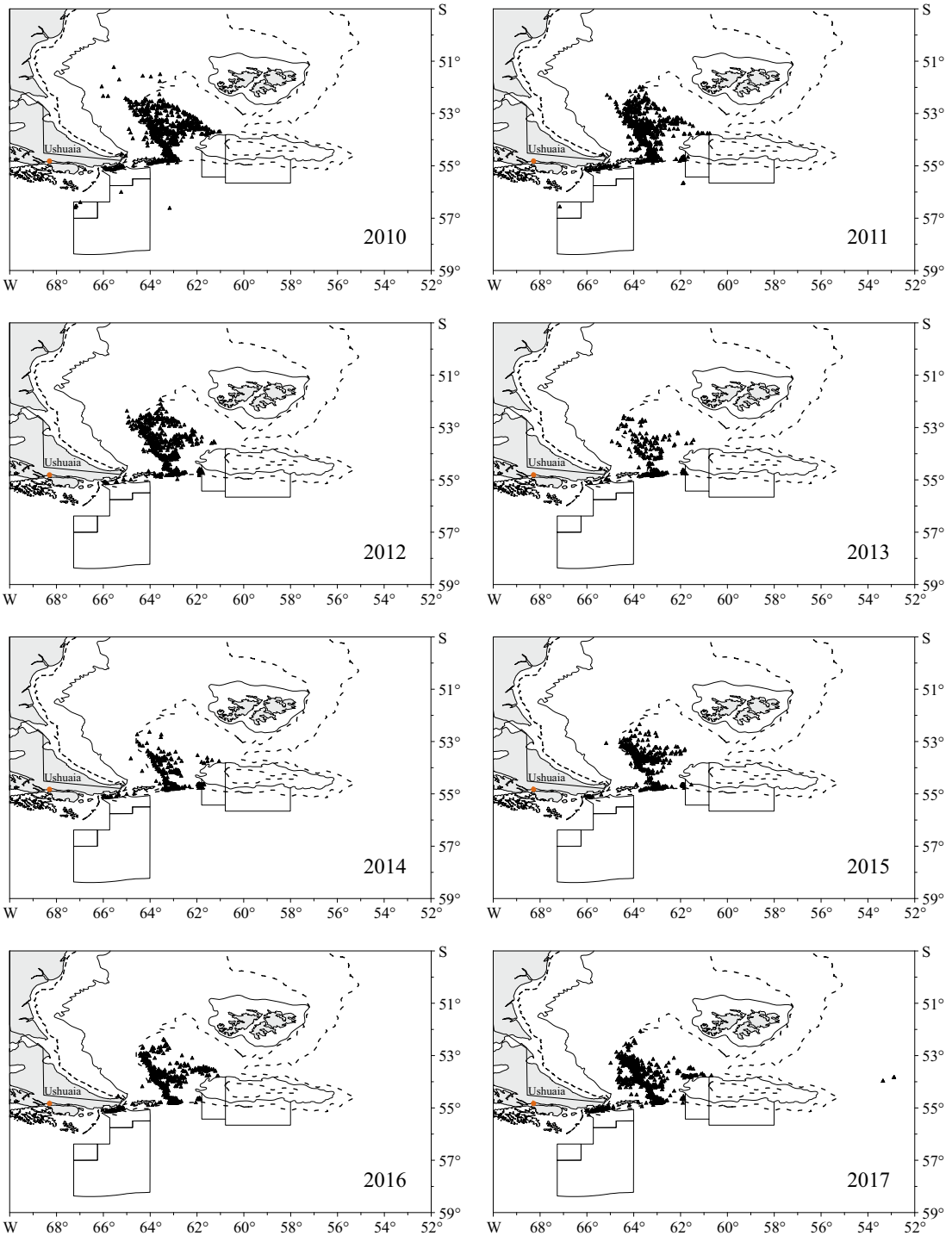

Figure 3. Geographical distribution of the effort (fishing hauls) made by the trawling fleet that fishes for toothfish in a directed manner, for each of the years of the period 2010-2020.

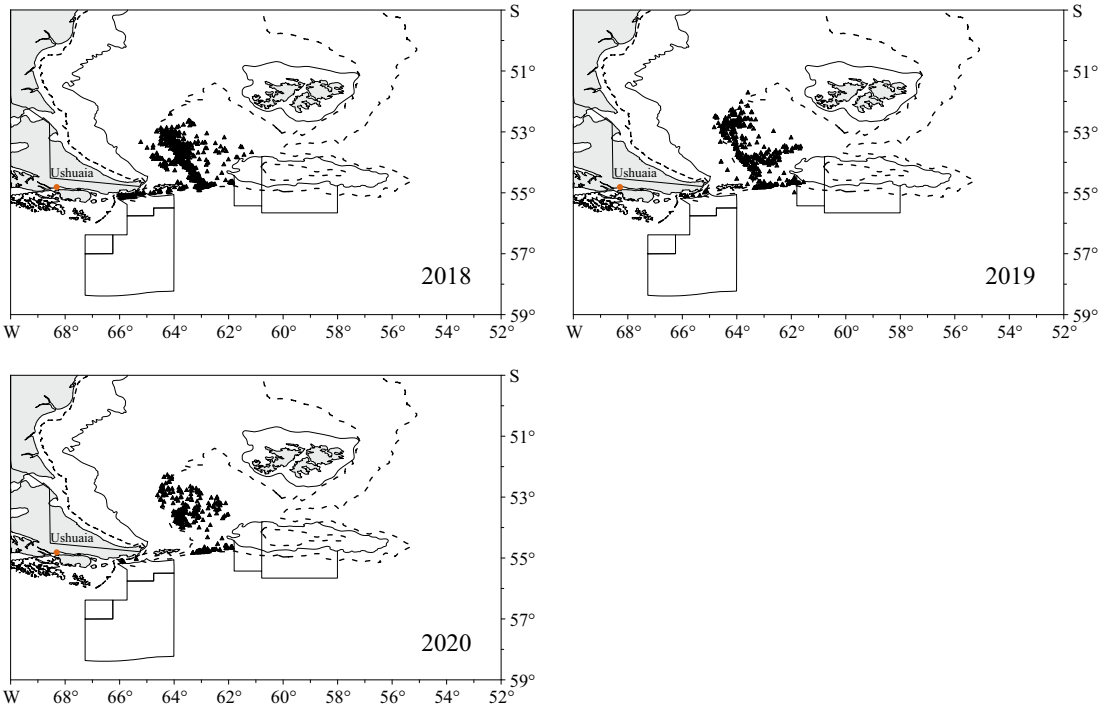

Figure 3. Continued.

Table 4. Patagonian toothfish catches (t) reported by scientific observers onboard trawlers in each Juvenile Patagonian Toothfish Protection Area (JPTPA) grid (squares 5461, 5462 and 5463) and the rest of the fleet operation area from 2010 to 2020.

Year/area	5461	5462	5463	Rest	Total
2010	0	22	879	33	934
2011	210	46	716	63	1,035
2012	506	260	821	39	1,626
2013	467	204	1,105	3	1,779
2014	684	634	2,035	7	3,360
2015	426	128	2,138	28	2,720
2016	304	269	1,670	56	2,299
2017	545	425	1,857	238	3,065
2018	1,220	360	2,173	60	3,813
2019	615	686	2,075	100	3,476
2020	190	1,484	867	14	2,555
Total	5,168	4,517	16,337	641	26,663
Percentage	19	17	61	3	100

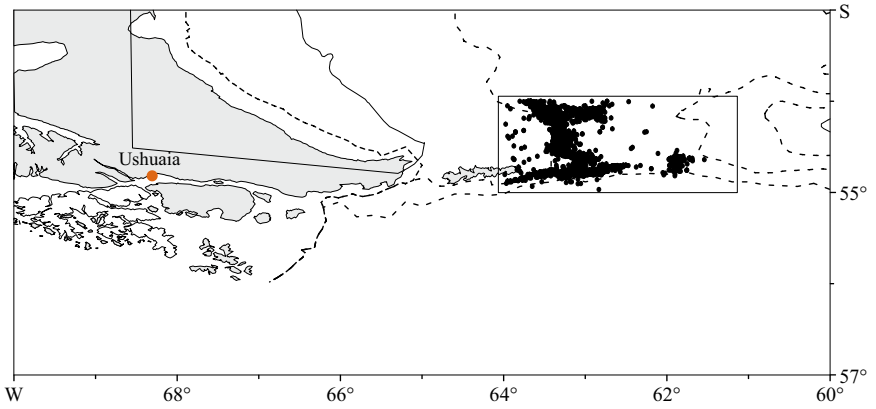

Figure 4. Geographic distribution of the effort (fishing sets) made by the trawling and longline fleets with Individual Transferable Quota (ITQ) of toothfish, in the Juvenile Patagonian Toothfish Protection Area (JPTPA) grid (squares 5461, 5462 and 5463) during the period 2010-2020.

fishery since transferable quota regime was established in 2010, with only the 'Argenova XIV' still in operation (Table 2). This vessel uses a manual longline with a main line of about 200 m long. Railings (12 m long), are attached to their respective nylon branch lines (1.60 m long) every 40 m apart. Each one of them has 2 bunches of 5 hooks and a dead weight made of stone bags weighing approximately 5 kg each used to anchor the gear to the bottom.

A device called 'umbrella system', designed to reduce interactions with marine mammals, particularly sperm whales, was incorporated into each branch line on some manual longliners beginning as for 2008. It is a conical sleeve with a 10-15 cm upper circle and a 70-74 cm lower circle joined by a 200-300 mm mesh size (Figure 5). When the line is tacked, the mesh moves and covers the six manually ingrown hooks that are located at the end of the branch line. In this way, the net is used to cover hooks during the process of hoisting the fishing gear onboard, serving to protect the toothfish from potential attacks of marine mammals. Additionally, heavier umbrella-equipped longlines sink faster preventing accidental bird capture. In certain hauls, depending on the depth or knowledge of the area, longlines can carry umbrella system with

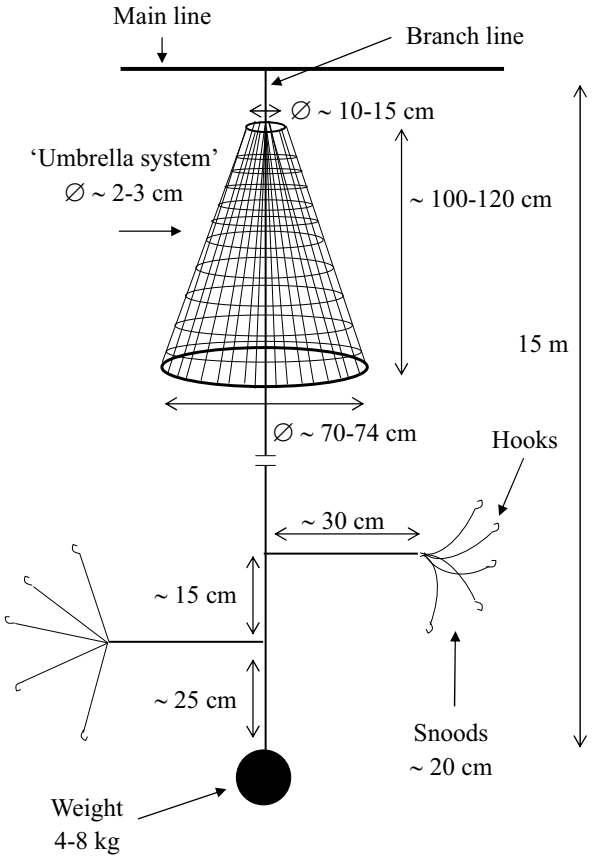

Figure 5. Detail of the device called 'umbrella system' used by the longline fleet (extracted from Moreno et al. 2008).

the railing in between or do without them and the heavier dead. The number of umbrellas by longline ranges from 250 to 300. The use of this device proved to be effective not only in reducing catch loss caused by marine mammal attacks, but also in increasing the efficiency of the gear by fishing as a bunch of hooks rather than an individual hook. Hooks are circular 'J' types, 6 cm long, 4 cm wide, manually incarnated typically with frozen squid discs as bait. Historically, the longline fleet's operation area in the Argentine EEZ was divided into two zones on the edge of the continental slope, 1,000 m apart, one to the north of 45° S and the other to the south of 54° S (Figure 6).

Although it is not the primary fishing ground for this species, the longline fleet has also made significant catches to the east of De los Estados Island. This fleet was conditioned to operate in productive areas where trawling was not possible by the type of bottom, avoiding a negative interaction with the trawling fleet. The bottom longline is an appropriate fishing gear for operating in areas of great difficulty for bottom trawling vessels because of its characteristics, including greater depths that can be reached with the longline, such as those found along the slope between 37° S and 47° S. Between 2010 and 2014, catches of bottom longliners operating in the three JPTPA grids reached approximately 50% of the total obtained using said fishing gear (Table 5). Due to changes in the composition of the fleet, all of the fish caught in 2014 came from grids outside the JPTPA, mostly south of 55° S and in areas that now incorporate the Y-MPA and NBB-MPA.

Potter vessels

The toothfish fishing industry made brief use of pots primarily between 2007 and 2008. At that time, Spanish-style longline companies went on several fishing trips with pots. Main areas of operation were at the east of De los Estados Island, deep waters of the slope between 41° S and 47° S, and south of Burdwood Bank. Only two trips with this kind of gear and one significant catch were recorded in 2011. Unfortunately, neither of those trips had an onboard observer from INIDEP. In order to collect information of the fishing area of this fleet, fishing trips carried out between 2007 and 2008 were used (Figure 7) (Martínez and Wöhler 2008, 2009).

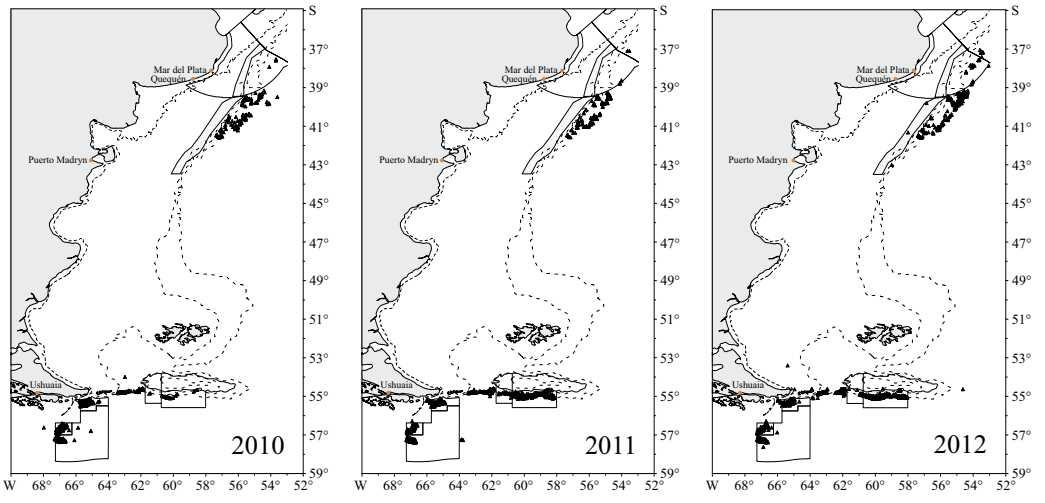

Figure 6. Geographical distribution of the effort (fishing sets) made by the longline fleet that catches toothfish in a directed manner, for each of the years of the period 2010-2020.

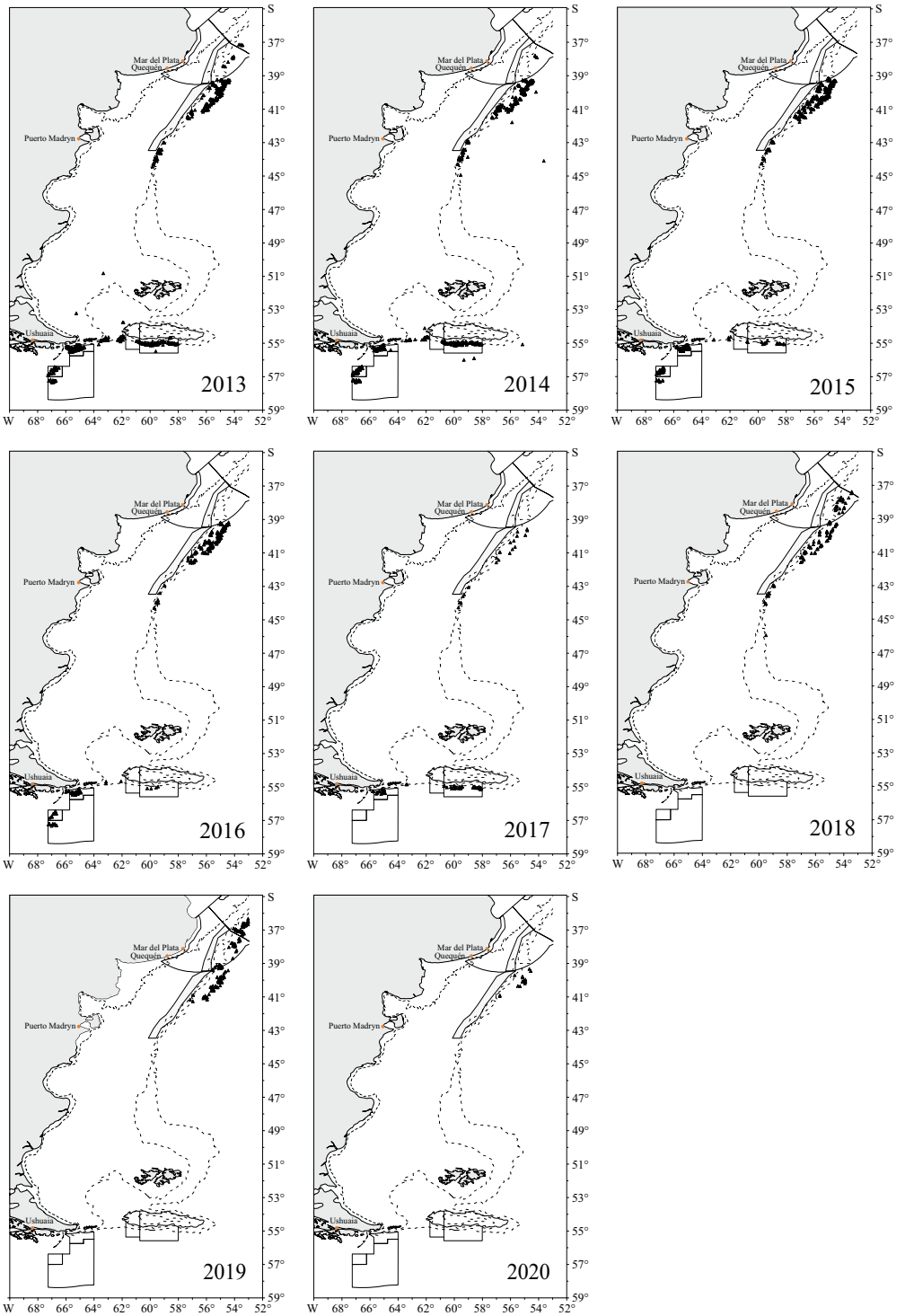

Figure 6. Continued.

Table 5. Patagonian toothfish catches (t) reported by scientific observers onboard longliners in each Juvenile Patagonian Toothfish Protection Area (JPTPA) grid (squares 5461, 5462 and 5463) and the rest of the fleet operation area from 2010 to 2020.

Year/area	5461	5462	5463	Rest	Total
2010	80	129	661	1,019	1,890
2011	119	321	497	981	1,918
2012	199	181	334	854	1,568
2013	106	84	739	664	1,593
2014	4	2	12	633	650
2015	-	1	1	712	714
2016	-	-	-	303	303
2017	-	-	-	98	99
2018	-	-	-	55	55
2019	-	-	-	82	82
2020	-	-	-	-	-
Total	508	718	2,246	5,401	8,872
Percentage	6	8	25	61	100

Observed and potential impacts of MPAs on toothfish catches in the southwestern Atlantic

Historical toothfish catches from areas that were later established as NBB-MPA and Y-MPA

Catches of Patagonian toothfish from NBB-MPA and Y-MPA during the 2010-2020 period were obtained only from bottom longlines. No catches from trawlers were registered (Table 6). As a result, the MPAs appear to have had no effect on the toothfish fishery, at least from the perspective of catches alone. It should be remembered that, due to the absence of management plans that would allow fishing in the MPAs, fishing is banned since the end of 2018 in both MPAs.

As previously stated, catches gathered by this kind of fleet were decreasing because of the gradual removal of longline vessels from the fishery and the transfer of quota to trawlers. This was reflected in catches from MPAs established in 2018, even reaching zero in 2019 as a result of the ban on fishing in that sector. The percentage of catch obtained by longliners in both MPAs with respect to the annual total caught in the years analyzed fluctuated between 14% and 65%, with a mean value of 33% for the entire period, with respect to the total obtained with bottom longline during 2010-2020 (Table 6).

Depending on catch locations in the MPAs, three sectors in which bottom longline fishing activities have been concentrated can be identified (Table 7; Figure 8). Sector 1 in the NBB-MPA, located in the SNMR, which since December 2018 does not allow the commercial exploitation of natural resources nor will it in the future. Sectors 2 and 3 correspond to the Y-MPA and are classified as SNMR in terms of the bed and subsoil and as a NMR in terms of the water column (Figure 8). Therefore, considering the historical areas of operation of the longline fleet since the establishment of management plans in the three MPAs, toothfish operations with bottom longlines could only be carried out in Sectors 2 and 3, if such plans consider it. In the case of the NBB-

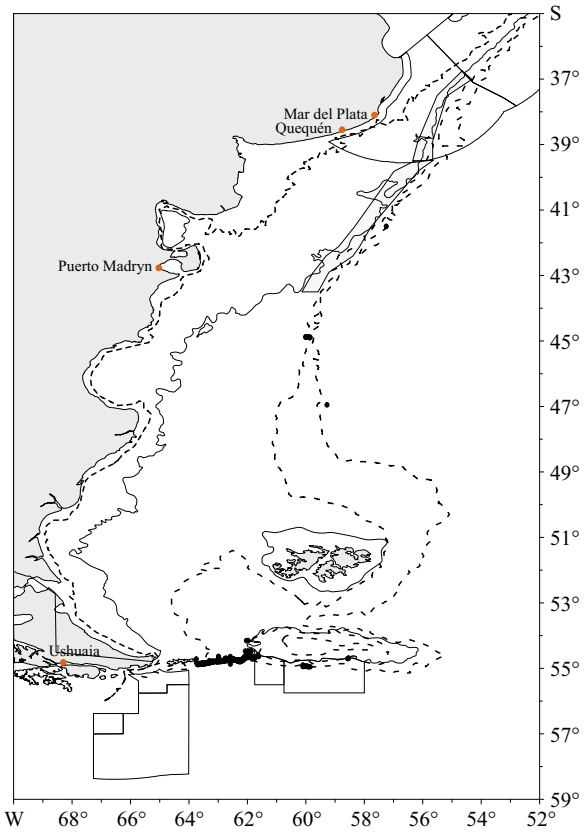

Figure 7. Geographical distribution of the effort (fishing hauls) made by the fleet that caught toothfish through the use of traps (pots) during the years 2007 and 2008.

MPA, there has been virtually no activity of toothfish trawlers and longliners in the last ten years in the geographical location of the NMR, where fishing activities are allowed. Even though the longline fleet only visited Sector 3 until 2016, it was responsible for more than half (58%) of all recorded catches during that time, while Sectors 1 and 2 were responsible for 25% and 17%, respectively (Table 7). However, Sector 1 reported catches between 31% and 57% of the total coming from the MPAs during the period 2011-2014, and between 9% and 17% if total catches from toothfish longline in the same years were considered. Consequently, it should also be considered as a relevant sector for the toothfish fishery.

Table 6. Total Patagonian toothfish catch reported by longliners from the total operation area and from Namuncurá-Burwood Bank and Yaganes MPAs, from 2010 to 2020.

Year	Total catch (t)	Catch from MPAs (t)	Catch from MPAs (% total catch)
2010	1,890	882	46.7
2011	1,918	545	28.4
2012	1,568	461	29.4
2013	1,593	357	22.4
2014	650	200	30.8
2015	713	294	41.2
2016	303	85	28.1
2017	99	65	65.7
2018	55	8	14.5
2019	-	-	-
2020	-	-	-
Total	8,789	2,897	33.0

It is reasonable to anticipate that the establishment of southern MPAs in Argentina will have a significant impact on the toothfish fishery in relation to what has been described. Even though trawling accounts for almost all of the species caught today, this was not always the case, and there is no guarantee that longline fishing will not increase in the future. Despite the fact that the establishment of the NBB-MPA and Y-MPA had very little effect on catches, this could change significantly if fishing methods were changed.

When analyzing the impact of the establishment of the southern MPAs on the Patagonian toothfish fishery in the Argentine EEZ, it should be considered not only the catches but also the direct effect that completely closed areas for fishing exploitation have on the toothfish population.

The 'spillover effect', which has been frequently mentioned and utilized by a number of authors in support of the establishment of MPAs as sup-

Table 7. Total Patagonian toothfish catch (t) reported by longliners from Sectors 1, 2 and 3, during the 2010 to 2020 period.

Year	Sector 1	Sector 2	Sector 3	Total
2010	45	120	717	882
2011	171	46	328	545
2012	181	53	227	461
2013	153	113	91	357
2014	114	25	61	200
2015	18	84	192	294
2016	2	30	53	85
2017	47	18	-	65
2018	8	-	-	8
2019	-	-	-	-
2020	-	-	-	-
Total	739	489	1,669	2,897

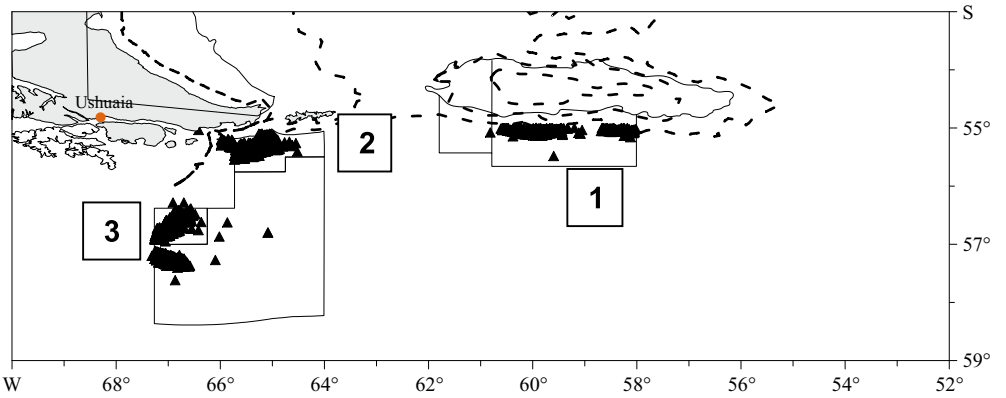

Figure 8. Location of the operating areas of the longline fleet in the period 2010-2020, differentiating between Sectors 1, 2 and 3 located in the Namuncurá-Burdwood Bank and the Yaganes MPAs.

posedly favor the increase in fish abundance and size, is another positive impact that could be generated on the toothfish stock. According to Hilborn et al. (2004), the yield obtained in nearby areas opened to fishing may rise in two ways. Firstly, because of an increase in the size of the fish that would be caught outside the MPA's boundaries. Secondly, as a result of an increase in the supply of eggs and larvae that would contribute to a growing biomass of spawners as a result of an increase in the fecundity of the fish by the increase in their size. Regarding the latter, the reproduction of the species in Sector 1 of the NBB-MPA occurs in winter months (Pájaro et al. 2005, 2009), and together with the area located east of NBBII-MPA, it constitutes the main reproductive area of the toothfish in the Argentine EEZ. On the other hand, a few authors (Halpern et

al. 2004; Hiddink et al. 2006; Greenstreet et al. 2009; Hilborn 2018) have criticized the positive effect of MPAs pointing out that those that prevent fishing (MPAs categorized as 'no take') actually move legal fishing to surrounding areas displacing fishing effort, and that there are few systematic studies in most areas allowing to evaluate whether an increase in egg production within the same area results in an increase in abundance outside of MPAs. An attempt to unravel this question in the future through the implementation of an exhaustive scientific research should be implemented. This plan should include studies inside and outside the MPAs in order to corroborate whether the sector, now closed to commercial exploitation due to the establishment of the NBB-MPA, will generate an increase in the biomass of the species outside those areas through the aforementioned 'spillover effect'. Based on tag-recapture studies conducted in the area, the evidence available indicates that, despite the fact that toothfish movements seem to be quite limited, the proximity of the MPA to the current trawlers and longliners fishing ground would allow this effect, since it is in the distance of detected movements in the area (Martínez et al. 2014; Waessle and Martínez 2018; Troccoli et al. 2022). In order to reveal such an important aspect, it would be advisable in the future to carry out intensive tagging experiences within the MPA, mainly of juvenile specimens, as has been done up to now in the program carried out by INIDEP.

In line with the above, Hilborn et al. (2004) expressed the possibility that MPAs serve as a useful tool for fisheries management, in addition to promoting biodiversity conservation. However, MPAs do not represent the total solution to the sustainability problems of fisheries on their own. Those authors also stated that a comprehension of the spatial structure of affected fisheries, ecosystems, and human communities is necessary for the success of MPAs. The use of marine reserves as well as other tools for managing fisheries can assist in achieving overall goals related to fisheries and biodiversity, but it will require careful planning and evaluation. If MPAs are implemented without a detailed analysis of their particularities and proper monitoring programs, there is a risk that expectations will not be met, disincentives will be created, and the credibility of what is potentially a valuable management tool will be lost (Claudet et al. 2019; Teschke et al. 2021).

A large majority of MPAs lack rigorous studies to evaluate their performance. Ojeda-Martínez et al. (2011) examined protection effects of a number of marine areas and discovered flaws in both objectives and evaluation process. The Before and After Control Impact sampling designs were utilized in very few instances. In the same vein, Gill et al. (2017) concluded that there is a dearth of useful research into whether in and under what circumstances MPAs boost fish abundance in a region. Similarly, no external effects are examined in the extensive meta-analysis within reserves. A clear explanation of what has been mentioned could occur in Sector 1 of the MPA-NBB, which has a considerable biomass of the resource, if the percentages of the total catch that said sector contributed in the past are taken into account. On the other hand, the Diego Ramírez Islands-Drake Passage Marine Park established in Chilean waters in 2018, borders Y-MPA and provides additional protection for the southern sea, which constitutes the natural habitat for toothfish and whose effect should also be analyzed (Figure 9).

CONCLUSIONS

Seventeen economic, social, and environmental goals of the 2030 Agenda for Sustainable Development were approved by UN member states, including Argentina, at the World Summit on Sustainable Development in 2015. The commitment to preserve at least 10% of the coastal and marine zones is derived from this, and it is based on the most up-to-date available scientific

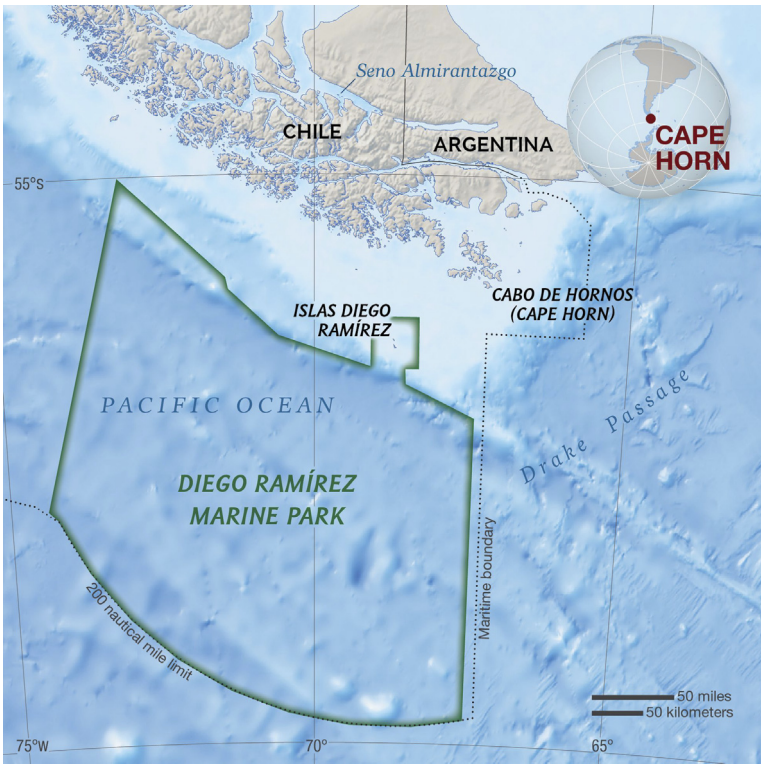

Figure 9. Geographical location of the Diego Ramírez Islands-Drake Passage Marine Park located in the Chilean EEZ and which complements the protection of the oceanic sector of the American southern cone together with the Namuncurá-Burdwood Bank and Yaganes MPAs, located in nearby areas, corresponding to the Argentine EEZ. Source: https://www.nationalgeographic.org/projects/pristine-seas/expeditions/cape-horn.

data. With the establishment of the NBB-MPA and Y-MPA at the end of 2018, Argentina met 7.11% of what is required by the 2030 Agenda.

Currently, the effects resulting from the creation of MPAs can only be speculated upon qualitatively. However, there is a potential for these effects to be quantified in the near future. Two types of impact derived from the establishment of the MPAs on the toothfish fishery were identified. The first one, which is short-term and can be considered negative, is the limitation of captures by the restriction to the operation of ships in areas that historically represented important fishing grounds of the species. Since the trawling fleet typically does not catch toothfish in these areas, this restriction would primarily apply to the longline fleet. This negative effect is insignificant for the time being because longline fishing is much less common in Argentina than it was in the past. However, if this type of fish fleet returns to the fishery, it could become very significant. In this instance, authorizing sectors of Namuncurá-Burdwood Bank I and II and Yaganes MPAs would help spread out the effort to catch the species.

The 'spillover effect' is other impact over the toothfish stock and would favor the increase in fish abundance and size. Even though several years have passed, there are no plans in place to begin evaluating the ecological and fishing impact of its implementation by monitoring the evolution of the fishing resources or biodiversity.

MPAs are only a tool and not a panacea. Many MPAs were created without clearly knowing what the social, environmental and economic impact

will be. This lack of foresight can give rise to political and economic problems compromising the survival of MPAs.

INIDEP contribution no. 2301.

Author contributions

Patricia A. Martínez: conceptualization, methodology, formal analysis, writing-original draft, writing-review and editing. Otto C. Wöhler: conceptualization, formal analysis, writing-review and editing. Gonzalo H. Troccoli: conceptualization, writing-review and editing. Emiliano J. Di Marco: writing-review and editing.

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