Chapter 2

Industrial fishing near West African Marine Protected Areas and its potential effects on mobile marine predators

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Abstract

Marine Protected Areas (MPAs) are increasingly implemented to facilitate the conservation of marine biodiversity and key habitats. However, these areas are often less effective in conserving mobile marine species like elasmobranchs (i.e., sharks and rays). Industrial fishing near MPA borders possibly impacts vulnerable species utilizing these protected areas. Hence, we aimed to study spatiotemporal patterns of industrial fisheries near MPAs in relation to the bycatch of elasmobranchs. Specifically, we analyzed the spatiotemporal fishing effort within the West African region, mapped fishing effort in the direct vicinity of the Parc National du Banc d'Arguin (Mauritania) and the Bijagós Archipelago (Guinea-Bissau) and compared the seasonal overlap between elasmobranch bycatch and fishing effort near these MPAs. We combined Automatic Identification System data and local fisheries observer data, determined fishing effort for each gear type and compared this with bycatch of elasmobranchs. We found that industrial fishing effort was dominated by trawling, drifting longlines and fixed gear types. Although no industrial fishing was observed within both MPAs, 72% and 78% of the buffer zones surrounding the MPAs were fished for the Banc d'Arguin and Bijagós, respectively. Within the Banc d'Arguin buffer zone, trawling and drifting longlines dominated, with longlines mainly being deployed in the fall. In the Bijagós buffer zone, trawling and fixed gears were most prevalent. Fisheries observer data for Mauritania showed that elasmobranch catches increased during the most recent sampling years (2016 to 2018). Elasmobranch catches within the waters of Guinea-Bissau peaked in 2016 and decreased in the following two years. Seasonal patterns in elasmobranch bycatch within the waters of both countries are likely caused by increased catches of migratory species. Catches of rays peaked in May and June for Mauritania and in October for Guinea-Bissau. Shark catches were highest in February and July in Mauritanian waters and in May and October in the waters of Guinea-Bissau. Our study indicates that industrial fisheries near the border of ecologically important MPAs may have potentially major implications for ecosystem functioning through the removal of (migratory) predatory species.

Introduction

To halt the degradation of marine ecosystems and to counter the overexploitation of marine resources, an increasing number of Marine Protected Areas (MPAs) have been implemented over the last two decades (Watson *et al.* 2014, McDermott *et al.* 2018). The majority of these implemented MPAs cover coastal areas, like vegetated wetlands and coastal reefs, which can be important for marine megafauna species (Fox *et al.* 2012, Sievers *et al.* 2019). Megafaunal species (e.g., sharks, rays, sirenians, cetaceans and sea turtles) frequently utilize coastal areas as nursery grounds in early life stages (e.g., Bangley *et al.* 2018) or as breeding areas (e.g., Waerebeek and Read, 2014), foraging areas (e.g., Eckert *et al.* 2006, Sievers *et al.* 2019) and predator-free refuge areas later in life (e.g., Heithaus *et al.* 2009). However, megafauna species generally have large home ranges and are often migratory (Lewison *et al.* 2016). They, therefore, only spend a limited but essential proportion of their life cycle in such areas. Within these coastal areas, megafaunal species exhibit essential ecological roles, including as (top) predators (Ferreira *et al.* 2017). In addition, due to their migratory nature, these species form important functional links (e.g., transferring nutrients) between coastal areas and other systems, such as the pelagic zone (Williams *et al.* 2018, Sievers *et al.* 2019).

Coastal areas like seagrass meadows, rocky shores, tidal flats, and mangroves also provide an essential nursery habitat for pelagic and commercial fish species (Stål *et al.* 2008, Binet *et al.* 2013, Honda *et al.* 2013). Designating such vital areas as MPAs can result in increased species richness and biomass of commercial fish species in surrounding areas, the so-called spillover effects (Stobart *et al.* 2009, Polunin and Roberts, 1993). Consequently, fisheries might be attracted to the borders of MPAs (Lorenzo *et al.* 2016). However, this phenomenon may not be problematic for highly productive species with small home ranges (i.e., small teleosts). Concentrated fishing activities might pose threats to vulnerable species with large home ranges, migratory behavior or species that only utilize the protected areas during a certain life stage (Burgess *et al.* 2013, Dulvy *et al.* 2014, Lewison *et al.* 2014).

Elasmobranchs (i.e., sharks and rays) are a species group susceptible to bycatch, and with their low recruitment rates, high maturity ages and other K-selected life history characteristics, many species of this group are particularly vulnerable to any non-natural mortality rates (MacKeracher *et al.* 2018). In addition, the status of many elasmobranch species remains unknown, and many species have wide home ranges, which challenges the effective conservation of this species group (MacKeracher *et al.* 2018, Dulvy *et al.* 2014).

As a consequence of stricter fishing regulations in many developed countries, distant-water fleets of these nations moved to the territorial waters of developing countries, including many countries in West Africa (Balmford *et al.* 2004, Worm *et al.* 2009). The high productivity of these waters, caused by the upwelling of the Canary Current, attracts fishing fleets from nations all over the world (Belhabib *et al.* 2019). Consequently, fishing effort within this region is among the highest in the world (Pauly and Christensen, 1995, Grecian *et al.* 2016). The region also contains highly diverse marine ecosystems that are threatened by habitat degradation, overexploitation and pollution (Tittensor *et al.* 2010, Stuart-Smith *et al.* 2013). Furthermore, the West African region is known for its data deficiency and high prevalence of endangered marine species, in particular species like hammerhead sharks (*Sphyrna spp.*), Lusitanian cownose rays (*Rhinoptera marginata*) and blackchin guitarfishes (*Glaucostegus cemiculus*).

There are two large intertidal MPAs of high ecological importance within the region: Parc National du Banc d'Arguin (PNBA) in Mauritania and the Bijagós Archipelago (BA) in Guinea-Bissau (Figure 2.1). Both areas are considered to play an important role as spawning and nursery areas for commercial fish species and for migratory species, including elasmobranchs (Jager, 1993, Valadou *et al.* 2006). Declines in the annual catch per unit effort of rays and sharks within the boundaries of these MPAs have sparked concerns among park managers, conservationists, scientists and the local communities about the status of these species groups within the region (Lemrabott *et al. unpublished data*, Leurs *pers. obs.*). Although fishing pressure through artisanal practices and bycatch rates within the MPAs are also substantial (Campredon and Cuq, 2001, Valadou *et al.* 2006, Diop and Dossa, 2011), fishing effort of industrial fleets at the borders of these MPAs could potentially have negative effects on the population status of marine megafauna utilizing these coastal areas (Guénette *et al.* 2014, Di Lorenzo *et al.* 2016). Herein we describe the industrial fishing activity within the West African region between 2012 and 2018 with three main objectives: (1) to analyze the spatiotemporal extent of gear-specific fishing efforts within the region, (2) to map fishing activity in the direct vicinity of the two largest West African MPAs, Parc National du Banc d'Arguin and the Bijagós Archipelago and (3) to link the industrial fishing effort with seasonal bycatch of elasmobranchs (i.e., sharks and rays) to estimate its effect on nature conservation goals of coastal MPAs.

Methods

Study area

We focused on the Eastern Central Atlantic (major fishing area 34 as defined by the Food and Agriculture Organization of the United Nations, FAO) as our main study area. This study site ranges from the territorial waters of Morocco in the north to the territorial waters of the Democratic Republic of Congo in the south (Figure 2.1). Geographical data on the EEZs of all nations within this region were extracted from the "MarineRegions" dataset (Lonneville *et al.* 2019). Areas outside of any EEZ were classified as the high seas.

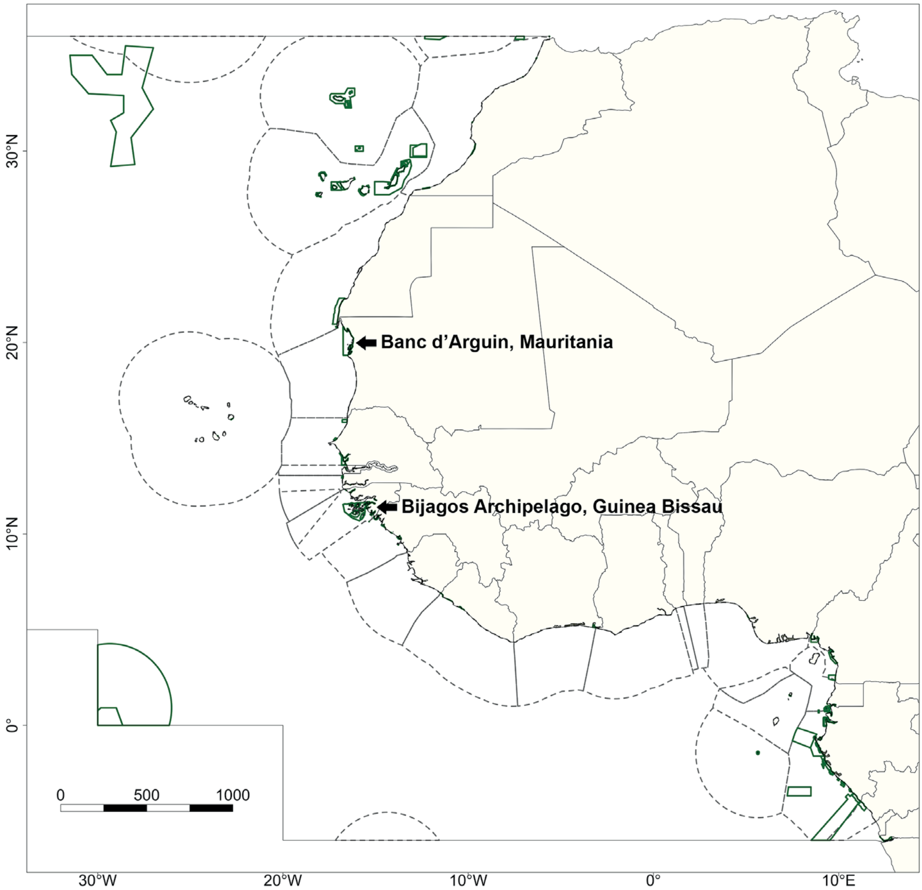

Figure 2.1 Defined study area indicating the Exclusive Economic Zones (EEZs; dashed lines) and Marine Protected Areas (MPAs; green lines) within the West African region. The inner gray border represents the northern and southern edges of the study area. The two focal MPAs, the Parc National du Banc d'Arguin (Mauritania) and the Bijagós Archipelago (Guinea-Bissau) are indicated.

Within our study area, we focused on two large MPAs: Parc National du Banc d'Arguin (PNBA; N20°14'5", W16°6'32") and the Bijagós Archipelago (BA; N11°15'0", W16°5'0") (Figure 1), for which spatial delineation was obtained from the World Database on Protected Areas (UNEP-WCMC and IUCN, 2019). The PNBA is the largest marine park in West Africa. It was designated as a RAMSAR site in 1982 and as a UNESCO World Heritage site in 1989. The entire national park is 12,000 km^2, of which 5,600 km^2 is marine (Binet *et al.* 2013). The area comprises a large variety of habitats, from bare tidal flats and intertidal seagrass meadows to extensive subtidal areas. The BA covers a 12,958 km^2 archipelago consisting of 88 islands and islets. The archipelago was designated as a UNESCO Biosphere Reserve in 1996 and as a RAMSAR site in 2014. The Bijagós contains dense mangrove forests, tidal flats, complex gully systems and extensive subtidal areas. Within the Bijagós Biosphere Reserve, the islands of Formosa, Orango, and João Vieira are designated as MPAs. Both MPAs are considered to be important for a large variety of (commercial) fish species, elasmobranchs and migratory shorebirds.

Data collection

Fishing effort data (2012 - 2018) was obtained from the Global Fishing Watch (GFW; www.globalfishingwatch.net), based on processed Automatic Identification System (AIS) transmissions of large vessels (Kroodsma *et al.* 2018). The GFW applied artificial neural network algorithms to the AIS data, which determined fishing activity and gear type used based on the speed and movement pattern of the vessel. As AIS is mandatory for all vessels above 300 gross tonnage, the dataset only includes large industrial vessels.

In total, 15 different gear categories within West African waters were identified, which we reclassified into six more general categories (Table 2.1). In addition, the GFW linked Maritime Mobile Service Identity (MMSI) information to the AIS transmissions, providing the flag state of registration for each vessel. The fishing effort, as the total number of fishing hours (in kilo hours, kh), was then determined per vessel, flag state, gear type and year for every 0.1° longitude/latitude grid cell over 2012-2018.

Fishery-dependent data was collected as part of fisheries observer programs by the national fisheries institutes Institut Mauritanien de Recherches Océanographique et de Pêches (IMROP) and Centro de Investigação Pesqueira Aplicada (CIPA), for Mauritania and Guinea-Bissau respectively. The data from the Mauritanian EEZ is based on logbook data documented and curated by the National Fisheries Institute IMROP. Data for this area was reported in the total catch per functional group, and the fishing effort was documented from 2012 to 2018. The data from Guinea-Bissau was collected by observers, who recorded the catch (in kg) per functional group (e.g., “Rays”, “Sharks”, “Diverse pelagics”). Observers also recorded the effort (in hours) for each vessel. The total catch per functional group and the total fishing effort was collected from 2012 to 2016 (CIPA, 2012, 2013, 2014, 2015, 2016). Vessel-based observer data was combined with fleet-wide landing data to extrapolate bycatch observations to the fleet level. No data on the survey effort was recorded for this data. The data presented thus reflects non-standardized survey efforts per month.

Table 2.1 New categories based on categories assigned by the Global Fishing Watch (GFW).

Category	GFW label
Trawlers	“trawlers”
Drifting longlines	“drifting longlines”
Fixed gear	“set longlines” “pots and traps” “set gillnets” “other fixed gears”
Purse seines	“tuna seines” “purse seines” “other seines”
Other gear	“pole and line” “dredge” “squid jiggers” “trollers” “other gears”
Unknown gear	“fishing”

Data processing

A 0.1° grid (±11x11 km near the equator) was superimposed on the study area, and industrial fishing effort was calculated per grid cell. The fished extent was determined as the proportion of fished grid cells relative to the total number of grid cells (n = 224,926). To determine and visualize the annual, gear-specific fishing effort in the direct vicinity of both MPAs, we created two buffer zones around each MPA of 1.5 and 2.0 times the surface area of the MPA. We also calculated the cumulative fishing effort over increasing distance from each MPA of each gear type specifically. Fishing effort based on the AIS data was not compared between years, as the number of vessels detected by the GFW algorithms increased every study year due to technological enhancements. For this reason, 2018 is reported for the most recent fishing effort calculations. For annual trends in fishing effort, we used the fishery-dependent data.

The fishery-dependent observer data contained information on both catches (in tons) and fishing effort (in fishing days). Catches were classified into functional groups, as limited information on species identification was available. From 2012 to 2015, both focal countries reported elasmobranch catches as part of diverse groups like “Diverse pelagic” or “Diverse demersal”. Since 2016, catches of sharks and rays have been reported separately (i.e., catches were not grouped together as elasmobranchs or grouped into other functional groups). Our data analysis only includes those catches reported as elasmobranchs, resulting in a conservative estimate of catches. Rays included all species labeled as “Raia”, and sharks included all species of hammerhead sharks (*Sphyrna spp.*), or species labeled as “Elasmobranchii” or “Caudo”. Fishing effort was registered as the number of hours that a vessel was actively fishing during a fishing expedition, separated per gear type. Seasonality of elasmobranch catches was investigated using catch recordings, for both countries separately. In addition, the total fishing effort was determined from the registered fishing effort and was subsequently compared to the AIS-based fishing effort of the GFW. For this, seasons were determined as winter (December-February), spring (March-May), summer (June-August) and fall (September-November).

Results

Spatiotemporal fishing activity off West Africa

A total of 5,449 kh (0.39 h^{-1} km^{-2}) of fishing effort by AIS-operating vessels were observed within the entire West African region, including the high seas, between 2012 and 2018 (Figure 2.2A, Appendix 2.3), with an average annual effort of 778 ± 466 kh (mean ± s.d.). Over the 6-year study period, at least 42.2 % of the West African region (5.9 x 10^6 km^2) was fished at least once (at our 0.1° resolution), with a mean annual extent of 21.9 ± 6.7% (3.9 ± 0.9 x10^6 km^2) (Appendix 2.1). Fishing effort concentrated in coastal waters (70% in EEZs compared to 30% in high seas), with the EEZs of Mauritania (10%), Western Sahara (8%), Morocco (8%) and Guinea-Bissau (7%) together containing over 36% of the total fishing effort (Appendix 2.3). The spatial distribution of the fishing effort peaked between the longitudes -18.45 and -15.45 (70.3 ± 56.6 kh) and off Sierra Leone between the latitudes 3.15 to 5.65 (27.2 ± 19.6 kh) (Figure 2.2). From the six gear types observed within the study area, trawlers (2,625 kh; 48.2%) and drifting longlines (1,901 kh; 34.9%) were the most deployed gear. The fishing effort of other gear types was relatively low (~200 kh combined; Appendix 2.3). Drifting longlines mainly operated on the high seas (80.3% of total effort by longliners). Trawlers were concentrated within the coastal zones and only covered 1.2 ± 0.3% of the entire region.

Over the entire study period, vessels from 60 flag states were observed within the West African region, although only ten flag states were responsible for 88% of the total fishing effort. The five most active flag states within the region were Spain (24%), China (15%), Japan (12%), Morocco (11%) and Ghana (6%).

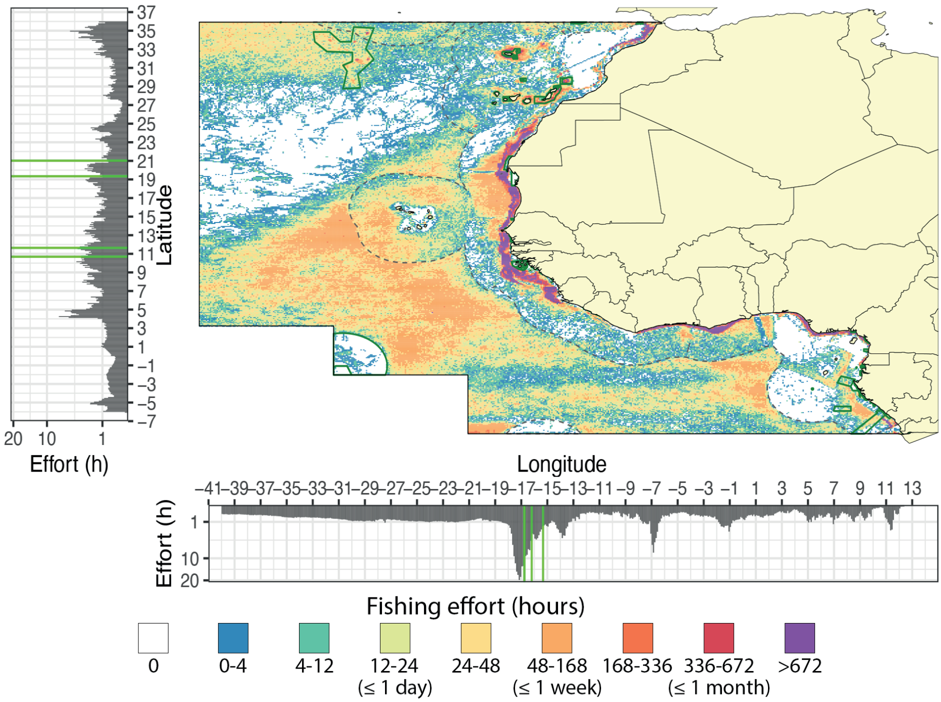

Figure 2.2 Total fishing effort off West Africa from 2012 to 2018. Color scale indicates the total hours of fishing within each grid cell (low = blue, moderate = yellow/orange, high = purple). Histograms on the axis show the total fishing effort in hours over the longitudinal and latitudinal range of the region. The longitudinal and latitudinal ranges of both MPAs are indicated with green lines.

Fishing activity near MPAs

Parc National du Banc d'Arguin (PNBA)

AIS-registered vessels showed a total of 560.7 kh fishing effort (3,2 h^{-1} km^{-2}) within the Mauritanian EEZ over the study period, covering 95.3% of the EEZ. Based on the fishery-dependent data, the fishing effort of the entire fleet operated within the Mauritanian EEZ ranged between 26.7·10^3 days in 2013 and 54.1·10^3 fishing days in 2018 (Figure 2.3A). No significant increase in fishing effort was found for the

Mauritanian EEZ. In total, 41 flag states operated within this EEZ during the study period, with Spain (36.4%), China (30.4%), and Mauritania (7.7%) being the dominant fleets (Appendix 2.3). Fishing vessels deployed all gear types, with trawlers as the most dominant gear type (353.3 kh; 63.0%). Because these trawlers mainly operated in coastal waters (Figure 2.4), the fished extent was relatively small (35.1% of the EEZ). Fishing effort increased over short distances from the PNBA, with trawlers showing the highest increase in efforts near the MPA and within the buffer zones (Appendix 2.2). Fishing effort within the 2.0x buffer zone around the PNBA was 117.5kh in 2018, with no industrial fishing observed within the boundaries of the PNBA. In 2018, 42.0% of the grid cells within the buffer zone were fished at least once, with trawlers dominating in both effort (89.3kh) and extent (33.2%).

The spatial distribution of trawlers was relatively constant throughout the year, while effort was highest in July (4.2 ± 3.8 kh) and December (4.4 ± 2.8 kh). There was a clear seasonal change in the spatial distribution of drifting longlines and fixed gears within the Mauritanian EEZ. Drifting longlines were constantly present but gradually increased from spring (3.3 kh) to fall (8.4 kh). Fixed gear types showed higher fishing effort in fall and winter (Figure 2.4). Overall fishing effort within the 2.0x-buffer zone peaked in the months of July, August and December (Figure 2.4C). Seasonal patterns in fishing effort between the AIS data (2.0x buffer zone) and the fishery-dependent data (Mauritanian EEZ) showed similar patterns (Figure 2.3C).

Traceable catches of sharks and rays were only documented in 2016, 2017 and 2018. Elasmobranch catches peaked at 85.8 tons in 2018, of which 55.5 tons were rays (64.7%) and 30.3 tons were sharks (35.3%) (Figure 2.3A). Ray catches were highest from April to July (8.4 ± 3.3 tons; mean ± se), whereas shark catches peaked in February (7.3 ± 3.4 tons) and July (6.0 ± 2.3 tons) (Figure 2.3B).

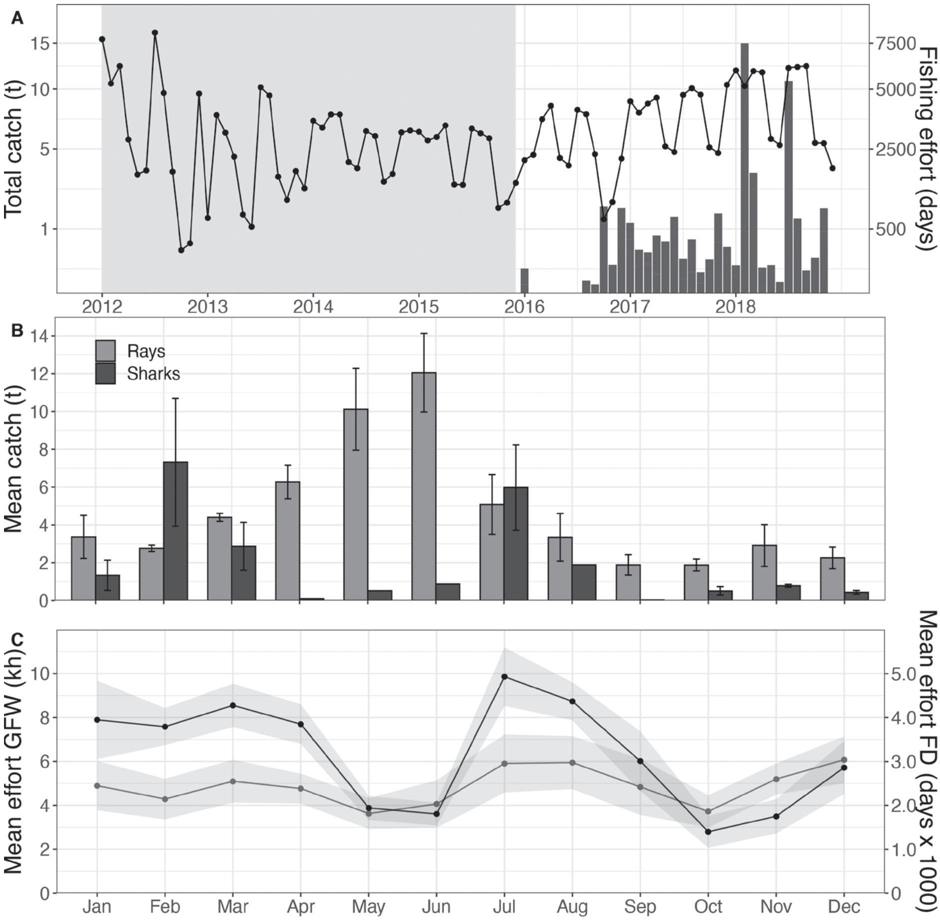

Figure 2.3 Total elasmobranch catches (bars) and fishing effort (line) within the Mauritanian EEZ, with no-data periods for elasmobranchs indicated in gray (A); with a close-up of the monthly mean catches, separated for sharks (black) and rays (grey), over the 2016-2018 period (B), in relation to fishing effort within the PNBA 2x buffer zone based on the AIS data (gray; in kh), and the total fishing effort in the Mauritanian EEZ as reported by the fisheries institute (black; in fishing days, FD) (C).

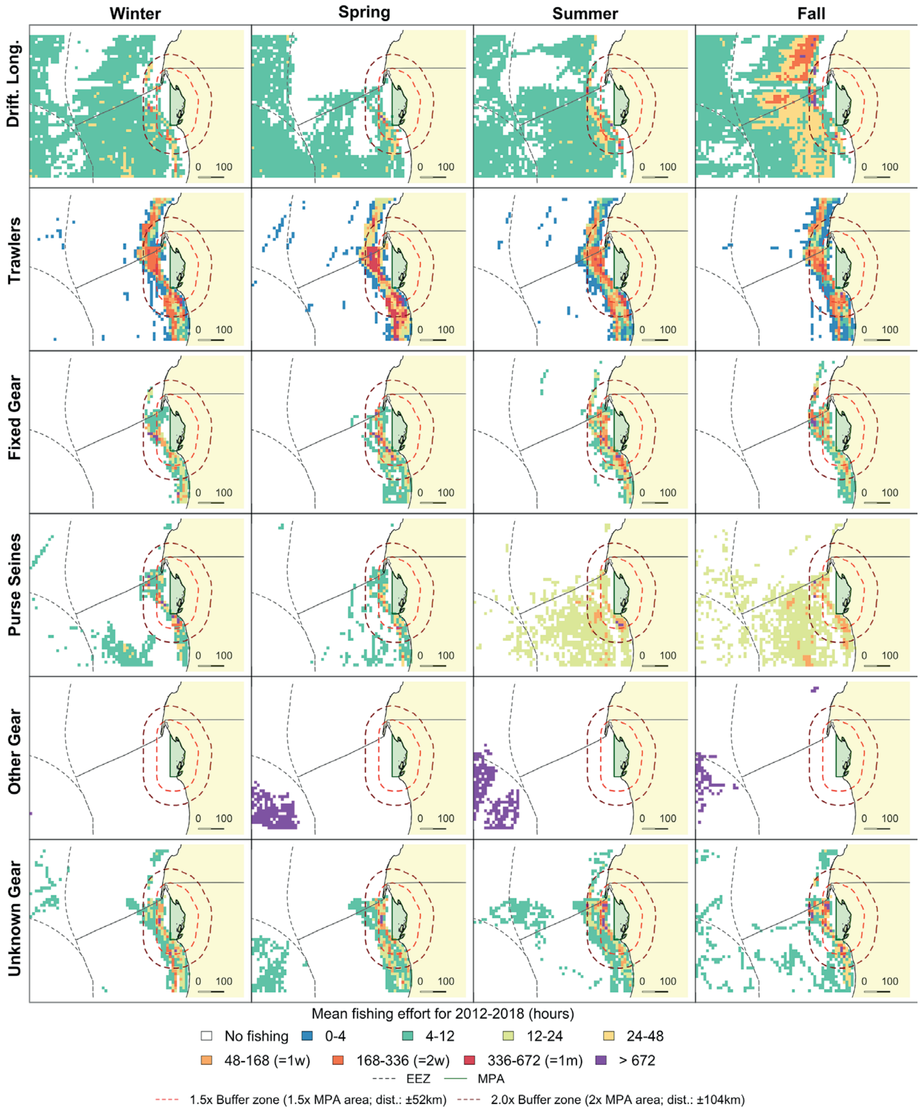

Figure 2.4 Fishing effort in the direct vicinity of PNBA (green) in Mauritania. Grid cell colors indicate seasonal mean fishing effort over the 2012 to 2018 period. Orange and red dashed lines represent 1.5x and 2.0x buffer zones of the PNBA. Exclusive Economic Zones (EEZ) are indicated as gray dashed lines.

Bijagós Archipelago (BA)

Fishing effort within the EEZ of Guinea-Bissau totaled to 386.0 kh (3.4 h^{-1} km^{-2}) in the study period, with a total fished extent of 73.5%. Based on fishery-dependent data, the fishing effort significantly increased (ß = 12.39, t = 5.05, $p < 0.01$) with 12.4 days per month from $10.4 \cdot 10^3$ days in 2013 to $27.8 \cdot 10^3$ fishing days in 2016 (Figure 2.5A). A total of 21 flag states were active within the EEZ, dominated by mainly Spain (34.3%), China (28.8%) and Senegal (9.8%) (Appendix 2.3). During the study period, all six gear types (Table 2.1) were observed. Trawlers showed the highest effort (374 kh; 96.9%), and were concentrated near the coast (48.4% of EEZ) (Figure 2.6). Unidentified gear types were the second most dominant, with a fishing activity of 8.7 kh (2.3%).

No industrial fishing effort was observed within the BA boundaries, but high effort was observed near the MPA borders (Appendix 2.2). Within the 2.0x buffer zone, fishing effort was 88.3 kh in 2018, with an extent of 42.9%. Trawlers were dominant in both effort (65.4%) and extent (41.2%) in 2018, based on AIS data. The fished extent within the buffer zone remained relatively constant throughout the year for all gear types, but fishing effort peaked in spring (Figure 2.5C, Figure 2.6). Seasonal patterns in fishing effort between the AIS data (2.0x buffer zone) and the fishery-dependent data (entire EEZ) showed similar patterns (Figure 2.5C).

Elasmobranch catches within the EEZ of Guinea-Bissau were reported separately in 2012 and from 2014 to 2018 (Figure 2.5A). In other years, catches were integrated into other functional groups and are therefore not included here. Reported catches were highest in 2016, with 262.92 tons, of which 18.97 tons (7.2%) were ray species and 243.95 tons (92.8%) were shark species. In the most recent year of the study (2018), total elasmobranch catches were 39.46 tons, with catches existing of 35.79 tons of rays (90.7%) and 3.68 tons of sharks (9.3%). Ray catches were highest in April and May, with 7.95 ± 3.04 (mean ± se) and 6.80 ± 1.13 tons, respectively (Figure 2.5B). Shark catches were also highest in October, with a mean weight of 23.74 ± 17.86 tons, and in May (23.49 ± 10.42 tons)

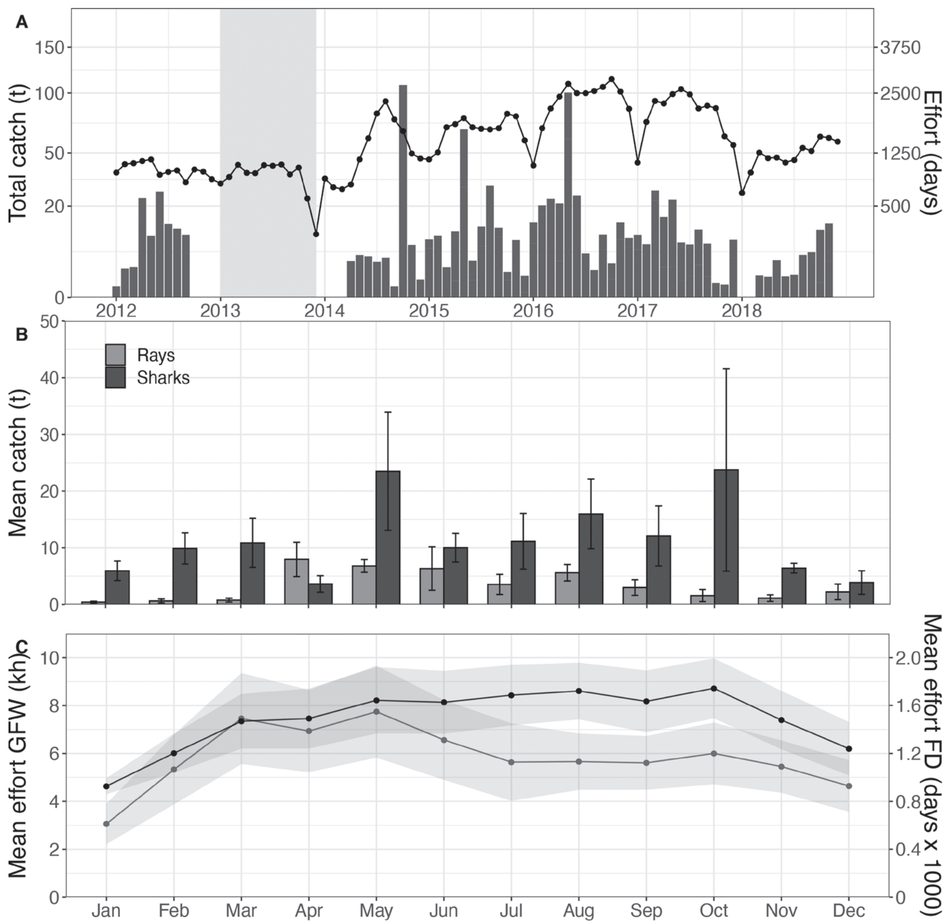

Figure 2.5 Total elasmobranch catches (bars) and fishing effort (line) within the Guinea-Bissau EEZ, with no-data periods for elasmobranchs indicated in gray (A), with a close-up of the monthly mean catches, separated for sharks (black) and rays (grey), over the 2014-2016 period (B), in relation to fishing effort within the BA 2x buffer zone based on the AIS data (gray; in kh), and the total fishing effort in the EEZ of Guinea-Bissau as reported by the fisheries institute (black; in fishing days, FD) (C).

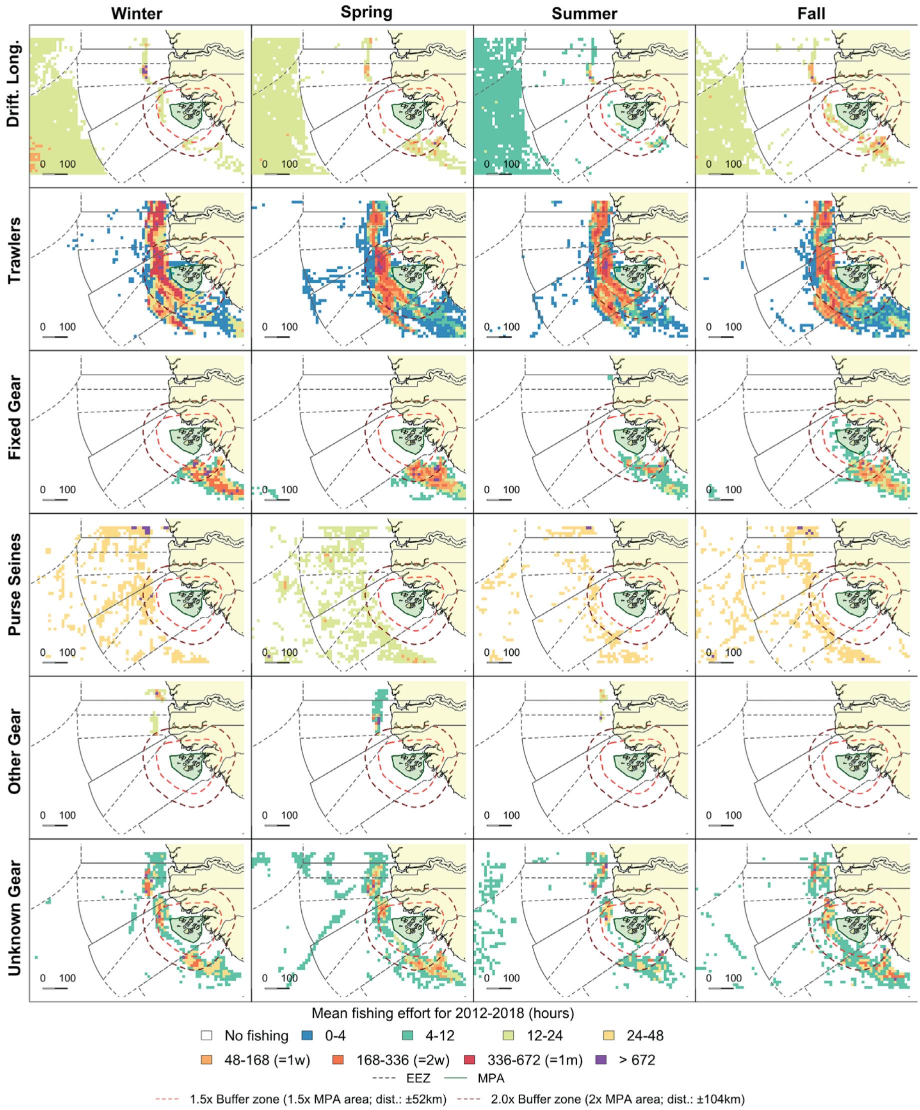

Figure 2.6 Fishing effort in the direct vicinity of the BA in Guinea-Bissau (in green). Grid cell colors represent seasonal mean fishing effort over the 2012 to 2018 period. Orange and red dashed lines indicate 1.5 and 2.0 buffer zones, respectively. Exclusive Economic Zones (EEZ) are indicated as gray dashed lines.

Discussion

In this study, we provide new insights into the recent (2012-2018) effort and spatiotemporal distribution of industrial fisheries in West Africa. In addition, we focused on fishing efforts in the vicinity of two large coastal MPAs. AIS records demonstrated that fishing activity is concentrated near the borders of MPA: Parc National du Banc d'Arguin (PNBA, Mauritania) and the Bijagós Biosphere Reserve (BA, Guinea-Bissau). Fishing effort within the Mauritanian EEZ was relatively stable, whereas effort within the EEZ of Guinea-Bissau increased significantly with 12 fishing days a month. Industrial fishing activity was mainly dominated by trawlers, drifting longlines and fixed gears. These gears mainly target mackerel (*Scomber* spp.), sardinella (*Sardinella* spp.), horse mackerels (*Trachurus* spp.) and cephalopods (Belhabib *et al.* 2013, Belhabib and Pauly 2015), but have bycatches of sharks and rays. In the waters from both Mauritania and Guinea-Bissau, the catches of elasmobranchs peaked in the most recent years of the study period. Seasonal peaks in industrial shark and ray catches were observed as well, but these did not coincide with seasonal maxima in industrial fishing efforts. We showed that industrial fisheries (especially trawlers) are concentrated within a thin belt surrounding both MPAs. This concentrated fishing effort could have potential effects on mobile marine predators such as elasmobranchs and other species that utilize coastal MPAs for a part of their life cycle only. Hence, fishing concentrations near MPA borders may impair the role of coastal MPAs for the protection of endangered, highly mobile marine megafauna. The inclusion of seasonal migration patterns and seasonal fishery bans near MPAs could aid in the conservation of mobile marine megafauna.

Although fishing efforts near the PNBA and BA showed a seasonal pattern, a similar pattern was not visible in reported elasmobranch catches from both EEZs. The observed peaks are probably explained by the higher temporal abundances of these species, indicating their migratory behavior. In Mauritania, sharks were caught most in February and July. These observations are congruent with those described by Zeeberg *et al.* (2006), who report the highest catches in August for hammerhead sharks and February for other shark species. The scalloped hammerhead shark (*Sphyrna lewini*), for instance, utilizes shallow coastal habitats during early life stages (e.g., mangrove areas) before it moves to more pelagic and deeper habitats (Hoyos-Padilla *et al.* 2014, Coiraton *et al.* 2020). The species migrates back to coastal, shallow habitats for parturition during the boreal summer (Capapé *et al.* 1998, Hazin *et al.* 2001). Recent findings suggest that scalloped hammerhead sharks are more dependent on coastal habitats than previously hypothesized (Coiraton *et al.* 2020). The PNBA is also hypothesized to be an important feeding and parturition site for the Lusitanian cownose ray (*Rhinoptera marginata*). Within the PNBA, ray catches by artisanal fishermen peak from November to the end of February (Lemrabott *in prep*.). A similar season (September to December) is reported for industrial fisheries and scientific surveys outside the PNBA (Hofstede 2001, Krakstad *et al.* 2004, Krakstad *et al.* 2005). Our study, on the other hand, shows that the catches of rays peak in April and July within the Mauritanian EEZ. Differences might be caused by the fact that the temporal scales of the studies do not overlap with the temporal scale of this study. Alternatively, annual differences in coastal upwelling events might cause changes in catches.

For Guinea-Bissau, we demonstrated increased catches of sharks and rays in May, October, and November. However, little information is available on elasmobranch abundance and habitat use. The scientific reports, based on observer data, additionally comprise limited species-specific information and have little consistency in registration. The actual numbers thus may be uncertain. However, the reported bycatch of elasmobranchs is supported by other studies (Belhabib and Pauly, 2015), sometimes showing much higher catch rates. We, therefore, argue that our estimates probably underestimate actual catches.

We demonstrated that trawlers were present during the whole year and dominated both fishing effort and spatial extent near the PNBA and BA. Drifting longlines were absent near BA but peaked near the PNBA in fall. Both gears generally have a high bycatch of sharks and rays (Zeeberg *et al.* 2006, Oliver *et al.* 2015). Drifting longlines were not present near BA, but the presence of this gear type near the PNBA peaked in fall. Trawlers have reported bycatch to mainly consist of pelagic teleosts (31%), hammerhead sharks (28%) and other shark species (19%) (Hofstede *et al.* 2001). Similarly, Zeeberg *et al.* (2006) reported that 42% of all bycatch for trawlers operating off Mauritania was hammerhead sharks, with other bycatch including large teleosts (i.e., sunfish *Mola mola* and billfishes; 26%), reef manta rays (*Manta birostris*; 9%), other sharks (9%), cetaceans (8%), benthic rays (5%) and sea turtles (1%). Bycatch of longline gear types within the region is characterized by species such as the Atlantic blue marlin (*Makaira nigricans*), blue sharks (*Prionace glauca*) and smooth hammerhead sharks (*Sphyrna zygaena*) (Coelho *et al.* 2015, Fernandez-Carvalho *et al.* 2015). Hence, trawlers and longliners surrounding the MPAs pose a conservation threat to elasmobranchs within the MPAs.

Our results show that the overall fishing effort was mainly concentrated near the borders of both MPAs. MPAs are known to increase local fish biomass, drawing fishing vessels to their borders to target the 'spillover' from these areas (Di Lorenzo *et al.* 2016). Another possible explanation for the concentrated fishing in this area is the local upwelling of the Canary Current, which makes the coast off the Western Sahara and Mauritania one of the richest fishing areas in the world (Goffinet, 1992). However, this does not explain why fishing effort is also concentrated near the Bijagós Archipelago, as it is located south of the upwelling's boundary (Goffinet, 1992). This upwelling is strongest during the short period from December to March (Cushing, 1971), which could result in elevated fishing activity due to higher local production. Indeed, it partly coincides with elevated fishing effort within the Mauritanian EEZ, but not with peaks in fishing effort in the waters of Guinea-Bissau, as migratory species utilize coastal areas for (parts) of their lifecycle and migrate between multiple habitats. For instance, American cownose rays (*Rhinoptera bonasus*) can migrate over distances of more than 1,500 km, and scalloped hammerhead shark movements could be traced at 684 km from coastal areas (Diemer *et al.* 2011, Ogburn *et al.* 2018). Our results from the 2.0x buffer zones around the PNBA and BA could indicate that this concentrated fishing activity might interfere with the migratory nature of these marine megafauna species.

In this study, we revealed spatiotemporal patterns of industrial fisheries in West Africa. We showed seasonal fluctuations but overall high concentrations of effort near the borders of the Banc d'Arguin National Park and the Bijagós Archipelago MPAs. Furthermore, we showed seasonal patterns in elasmobranch bycatch recordings within the EEZs of the corresponding countries, illustrating the migratory behavior of these species. We, therefore, conclude that the high concentration of fishing effort surrounding these important coastal areas conflicts with the migratory nature and vulnerability of elasmobranch species using these areas. This may lead to a further decrease of these vulnerable species in both pelagic and coastal habitats and their associated ecological role in linking these habitats. The increasing removal of predatory species from marine ecosystems can cascade through the ecosystem, with consequences for (both ecological and economic) ecosystem services (Martin *et al.* 2010, Barbier *et al.* 2011, Estes *et al.* 2011). For example, the removal of top predators like cod (*Gadus morhua*) is assumed to be the most likely explanation for the observed increase in mid-sized fishes, which in turn has caused increases in macro-algae recruitment (ecologic) or a weakening of the biological pump of nutrients from great depths, possibly negatively influencing productivity of fisheries (economic) (Sieben *et al.* 2011, Hammerschlag *et al.* 2019). The densely concentrated fishing activity near the border of such protected areas, therefore, not only undermines the conservation value of these areas for these megafauna species but might cascade into reduced functioning of coastal ecosystems and associated local livelihoods.

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