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Twenty years of monitoring reveal overfishing of bony fish stocks in the coastal national park Banc d'Arguin, in Mauritania

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Abstract

1. Along Africa's western coast, many local communities rely on the ocean for their livelihood. Over the last decades, introductions of new fishing techniques along with globalizing trade have strongly changed local fishing practices.
2. The Parc National du Banc d'Arguin (PNBA) in Mauritania had for centuries been subjected to an artisanal, low-impact, fishery. This fishing was exclusively oriented towards migratory bony fish species, mullet (*Mugil cephalus*) and meagre (*Argyrosomus regius*). Since the 1980s, these species have been replaced by illegal catches of internationally traded elasmobranchs (sharks and rays) and by non-migratory and relict species (resident) such as tilapias (*Sarotherodon melanotheron*) and catfishes (*Arius* sp.).
3. To date, most monitoring and management efforts have been dedicated to evaluating changes in elasmobranch populations and less focus has been on bony fish species. Data from a fishery monitoring programme are used to analyse the trends in effort, catch and catch per unit of effort of bony fish species by fitting non-parametric generalized additive models to capture changes in the fish community over the last 20 years.
4. Mullet and meagre became overfished early on, and the contribution of resident species (tilapias and catfishes) increased in the catches. Together with a pattern of increased effort on the traditionally targeted species, such a change in the catch could reflect a change in the fish community.
5. These results call for the implementation of sustainable fishing practices within PNBA. We propose the need to implement closures of fisheries during the species' breeding periods as well as the use of biological reference points such as the size at first capture and maximum sustainable yield targets for resident species.

KEYWORDS

fishery observers, Imraguen, overfishing, subsistence fishing, teleosts, West Africa

1 | INTRODUCTION

Artisanal and subsistence fishing are vital sectors for coastal populations in West Africa (Belhabib, Sumaila & Pauly, 2015). Subsistence fishing uses locally made, traditional nets and wooden boats and initially aims for local consumption, with few connections to regional and international markets (Lemrabott et al., in press). Such artisanal fisheries often use small boats with low engine power or sails and a limited number of gears and crew, and with limited cooling capacity and means of transport for the catches (Belhabib et al., 2018; Rousseau et al., 2019; Temesgen, Getahun & Lemma, 2019). Over the last decades, artisanal fisheries in West Africa have changed, with the modification of mesh sizes along with the length of the nets and the motorization of boats leading to considerable growth (Akpalu, 2010). These changes are probably driven by incentives stemming from the globalization of markets, and the associated increased trading of fish (Belhabib et al., 2018).

One major region with artisanal fisheries is the Parc National du Banc d'Arguin (PNBA, or Banc d'Arguin), in Mauritania, established in 1976 as the largest marine protected area in West Africa, and recognized since 1989 as a UNESCO World Heritage Site. The local people in Banc d'Arguin (called Imraguen, i.e. 'those who gather life') depend on fishing in the national park. Before its establishment as a protected area, Banc d'Arguin was an area of unmanaged fisheries. Imraguen fished seasonally and oriented their effort towards mullet (*Mugil cephalus*) near the shore, during their migration into Banc d'Arguin, and used simple and traditional fishing methods (Maigret & Abdallahi, 1976; according to Valentim Fernandez (1505), cited by Picon, 2002). With the introduction in the 1930s of lanches (traditional wooden sailing boats originating from the Canary Islands), fishers were able to reach deeper areas to fish seasonally migratory meagre (*Argyrosomus regius*; Maigret & Abdallahi, 1976). Since the establishment of PNBA in 1976, park authorities have regulated the fishing of bony fish species for subsistence only with the use of artisanal fishing methods and tools. Motorized boats and monofilament nets were prohibited and the park boundaries were policed against fishermen from outside who were not adhering to these regulations. Nevertheless, from the mid-1980s, increasingly the Imraguen have turned towards commercial fishing of a larger variety of species, including endangered rays and sharks, and their export to international markets such as tropical west Africa (dried and salted ray meat) and Asia (shark fins) (Boulay, 2013; Lemrabott et al., in press).

These changes and the internationalization of Imraguen fishing practices have raised concerns in different fora, including those of scientists, managers and conservation organizations. This has resulted in a call for better monitoring of the fishing activities within the Banc d'Arguin. For this, a joint collaborative programme was set up in 1997 between Banc d'Arguin and the Institut Mauritanien de Recherches Océanographiques et des Pêches (IMROP) with financial support from the International Foundation of the Banc d'Arguin (now merged in the MAVA Foundation) and the French foreign aid service. The monitoring has helped inform studies on the conservation status of non-targeted elasmobranch species (Ducrocq, Ould Sidi & Ould Yarba, 2004; Valadou, Brêthes & Inejih, 2006; Diop & Dossa, 2011) as well as some bony fish species (Bernardon & Mohamed Vall, 2004; Correia, Carneiro & Araújo, 2020), but the data stemming from this programme have not yet been analysed in an integrated way.

This paper describes the fishing system of the Imraguen and analyses the monitoring programme data as well as summarizing the fishing effort and catches for different bony fish groups per fishing net type. Catch per unit effort (CPUE) is used to explore potential overfishing of bony fish stocks and suggestions for future monitoring and management to ensure the conservation and protection of the fish in this protected national park are discussed.

2 | METHODS

2.1 | Study area

The Parc National du Banc d'Arguin covers 12,000 km^2 of shallow (<20 m deep) coastal shelf waters and islands including 500 km^2 of intertidal flats along the northern coast of Mauritania (Figure 1). The national park is situated on the western edge of the Sahara, bordering the Atlantic Ocean (from 20°50′ N, 16°45′ W to 19°20′ N, 16°28′ W). The intertidal flats have an extensive cover (>80%) of seagrasses, mostly *Zostera noltei* (Wolff & Smit, 1990; Folmer et al., 2012; van der Heide et al., 2012). The semi-diurnal tides have a tidal range of around 2 m. Seawater temperatures vary from ~20°C in January to ~30°C in September, and salinity ranges from 40 to 43‰ (Wolff & Smit, 1990; Lavaud et al., 2013; Clavier et al., 2014; Gutiérrez et al., 2015). The Banc d'Arguin receives hardly any freshwater inflow from rivers and with an annual rainfall of <20 mm (Yacoub & Tayfur, 2017), precipitation is limited to occasional thunderstorms, sometimes only occurring a few years apart (van der Geest et al., 2014). Instead of through riverine sediment inputs, the intertidal flats in this system keep up with sea-level rise owing to local aerial deposits of Saharan dust (Hanebuth & Lantzsch, 2008).

2.2 | Fishery monitoring programme and data collection

The Banc d'Arguin artisanal fisheries monitoring has been carried out since 1997 in the framework of a joint monitoring programme between IMROP and the PNBA. The programme is carried out by six scientific observers, who are assisted by six deputy members from the local community trained by IMROP. The scientific observers live permanently in the villages to ensure continuous data collection at the landing sites. The lanches' captains and the fishermen voluntarily agreed to share and allow observers to record fishing information.

In the period 1997–2005, fishing trips were single days only: the fishermen sailing out to sea in the morning and returning at the end of day to land their catches. Each day, upon the return of the vessels, each observer opened a 'work session' to record the fishing information from that day. The landings were investigated following a

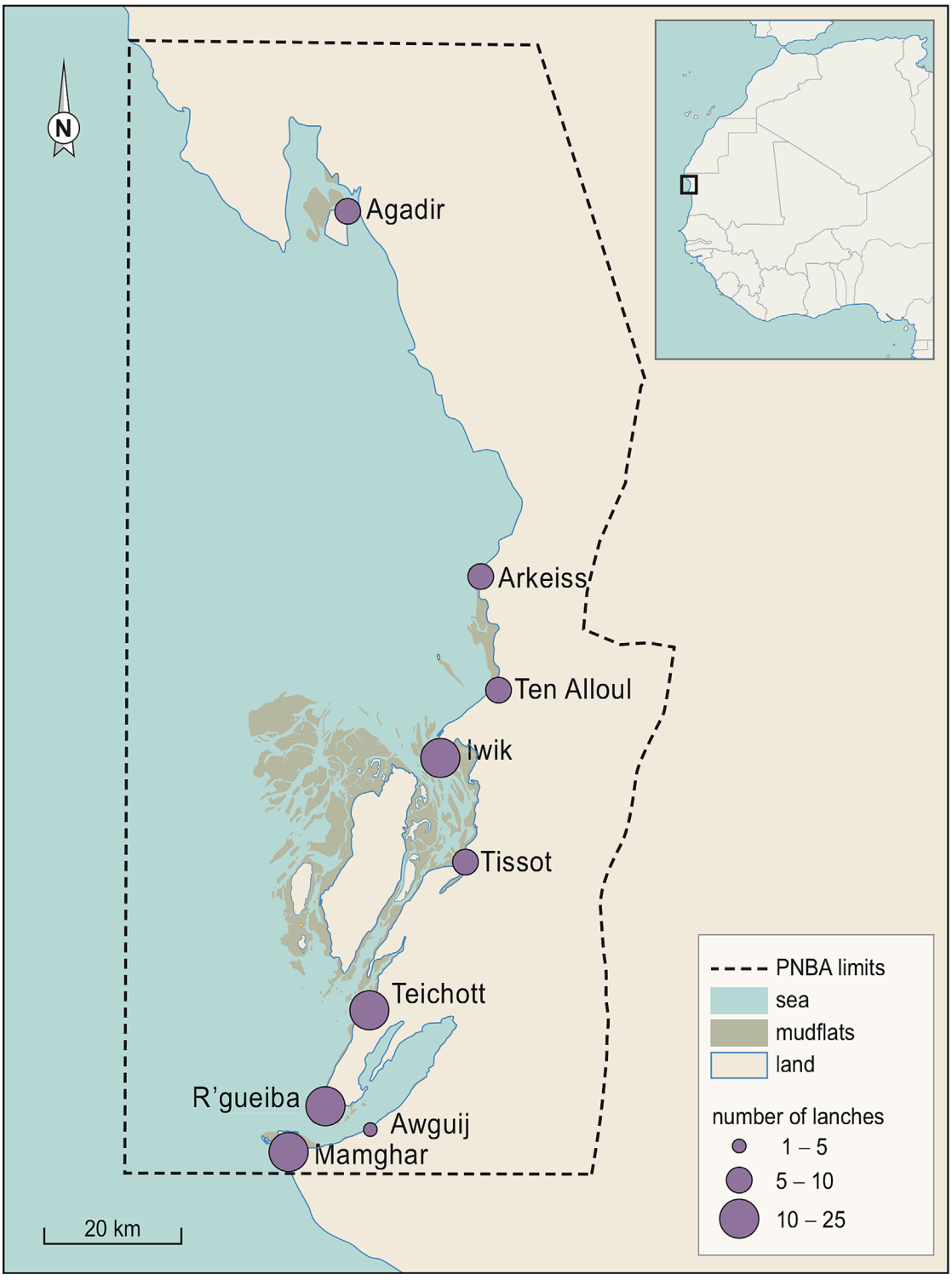

FIGURE 1 Study area showing the location of Imraguen villages. The dimensions of the bullets indicate the number of lanches operated from each village.

random sampling design, with the aim of surveying 80% of landings from the returning vessels that day. For each surveyed landing, the investigator inspected the catch. Depending on the species caught, the catch weight was estimated for smaller species (dorades, mullet and catfishes) while the actual weight was determined by the investigator for larger species (meagre, rays and sharks). During this period, fishing effort was calculated per gear by the number of vessels returning with that gear per day.

From 2006 onwards, there was a change in artisanal fishing strategy in Mauritania with the addition of extra fishing vessels and the appearance of so called 'pêche de marée' (i.e. fishermen staying at sea for several days). The sampling rate for the second period

remained at around 80% of the total observed daily returns, the investigators recording the weight of each catch as described above. In addition, to calculate the appropriate fishing effort, the length of the trip was recorded (Braham, 2017).

In both periods, two types of data sheets were filled in by the observers. The 'session' sheet summarized the daily fishing information (date, name of the village, start and end time of the session, catch composition, number of total landings, and the number of landings investigated). The 'returns' sheets contained the catch details collected directly by the observers for each returning vessel (date, fishing gears, number of fishing days per vessel, total weight and the weights in kilograms per species and per gear type, and fishing area). After the data collection, data sheets were verified by the programme supervisor before being entered in the computer. Each village and investigator was visited every 3 months by the programme supervisor to review the quality of the data collection.

2.3 | Data processing

The data have been curated as two time series: (1) effort (number of days at sea); and (2) species catches (in kilograms) aggregated monthly by type of fishing net for the time period 1997–2020. Based on the total observed catch the overall total catch was estimated following the formula:

$$\text{total catch (day)} = \text{weight (landings investigated)} \times \text{total landings/landings investigated.}$$

Initially, it was at times necessary to re-establish the monitoring programme according to consistent guidelines and to train the observers on data collection and bony fish species identification. Therefore, the data collected during the first 3 years of the programme were not used in the analyses. The exploration of the data showed that bony fish species at Banc d'Arguin were caught mainly by two types of fishing nets: (1) the emblematic mullet net (100–120 mm mesh size) used exclusively by Imraguen fishermen within Banc d'Arguin employing the traditional active encircling method (i.e. seine fishing); and (2) three types of standing rigging gill nets widely used from 2000 onwards, i.e. meagre net (>200 mm mesh size), a sole net and a dorade net, the latter two with mesh sizes of 100–120 mm. Six species groups of bony fish were selected for further analyses as they covered 97% of the total catch over the time period (full species composition is shown in Table S1). The fishing effort for each species group was calculated based on the dominant gear used to catch that species group (Table 1). Mullet is targeted by mullet nets. Meagre is targeted by meagre net. Law croakers were caught as bycatch by meagre nets. Dorades, tilapias and catfishes were caught as bycatch by mullet nets (note that the use of dorade nets stopped in 2012). The two main gear types, mullet net and meagre net, were further analysed for the assessment of the different species groups and the CPUE, as these account for the majority of effort and catches, on average 78 and 86% for effort and catch, respectively, over the study period.

2.4 | Changes in catch per unit of effort

Despite the shortcomings of CPUE as an indicator of the size of fish stocks (Harley, Myers & Dunn, 2001; Maunder et al., 2006; Kantoussan et al., 2014), without fishery-independent surveys, it is the only measure available to indicate changes in stock sizes of exploited fish (White et al., 2018). For the purpose of this analysis, CPUE per species group is defined as catch weight in kilograms reported per fishing day at sea with fishing gear predominantly catching that group (Table 1). Two groups were distinguished: (1) the emblematic and traditionally targeted migratory species of mullet and meagre (Bernardon & Mohamed Vall, 2004; Ould Taleb Sidi, 2013); and (2) the non-migratory species (residents), composed of law croakers, dorades, tilapias and catfishes.

2.5 | Statistical analyses

Changes over time in the effort, catch and CPUE were analysed by fitting non-parametric generalized additive models (GAMs) to the data. The GAM was selected because it provides a framework for flexible non-linear relationships in time series using non-parametric smoothers (Maunder & Punt, 2004; Cardinale et al., 2014; Yadav, Jahageerdar & Adinarayana, 2020). Moreover, GAMs offer the main advantage of being able to model non-linearity that often relates biological data to environmental factors (Cardinale, Nugroho & Hernroth, 2009). The GAMs were fitted using the gam() function of the 'mgcv' package with restricted maximum likelihood REML (Wood, 2017) in R, version 4.2.0 (R Core Team, 2022). REML criteria

Species groups	Mullet net	Meagre net	Dorade net	Sole net
Mullet	**11,100**	393	**755**	121
Meagre	154	**6,551**	38	**1,156**
Law croakers	271	**2,851**	67	135
Dorades	**545**	130	**347**	63
Tilapias	**5,412**	450	195	78
Catfishes	**6,367**	944	**624**	**1,818**
Other species	277	321	98	418
Percentage of top species	**97**	**81**	**81**	**79**

TABLE 1 Summary of average monthly landings (catch weight in kilograms) for the different net types used in the fishery over the time period 2000–2020. The values in bold indicate the top species and their percentages (bottom row) in the total catch of each net type.

TABLE 2 Summary table of generalized additive model (GAM) results for monthly effort by gear type in the fisheries in Banc d'Arguin over the period 2000–2020.

Gear types	Effective degrees of freedom	R^2 (adjusted)	Deviance explained (%)	*p*-Value
Mullet net	1	0.86	96	0.057
Meagre net	6.3	0.98	99	<0.0001

Significance level of *p*-value below alpha = 0.05.

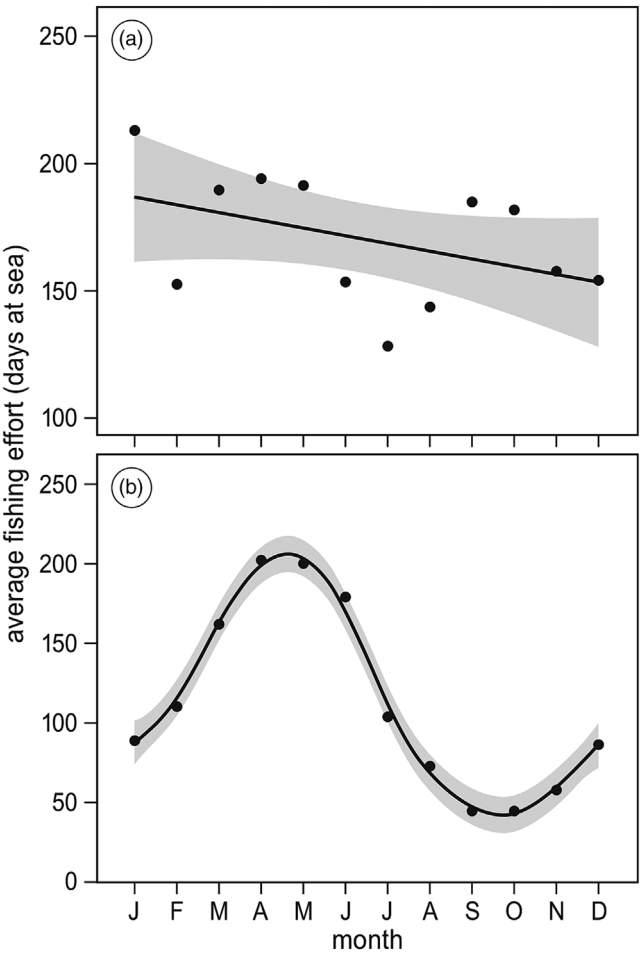

FIGURE 2 The year-round average fishing effort using mullet nets (a) and meagre nets (b) on bony fish species in Banc d'Arguin. The plots indicate a fitted trend through the data, with a 95% confidence interval of the fitted trend.

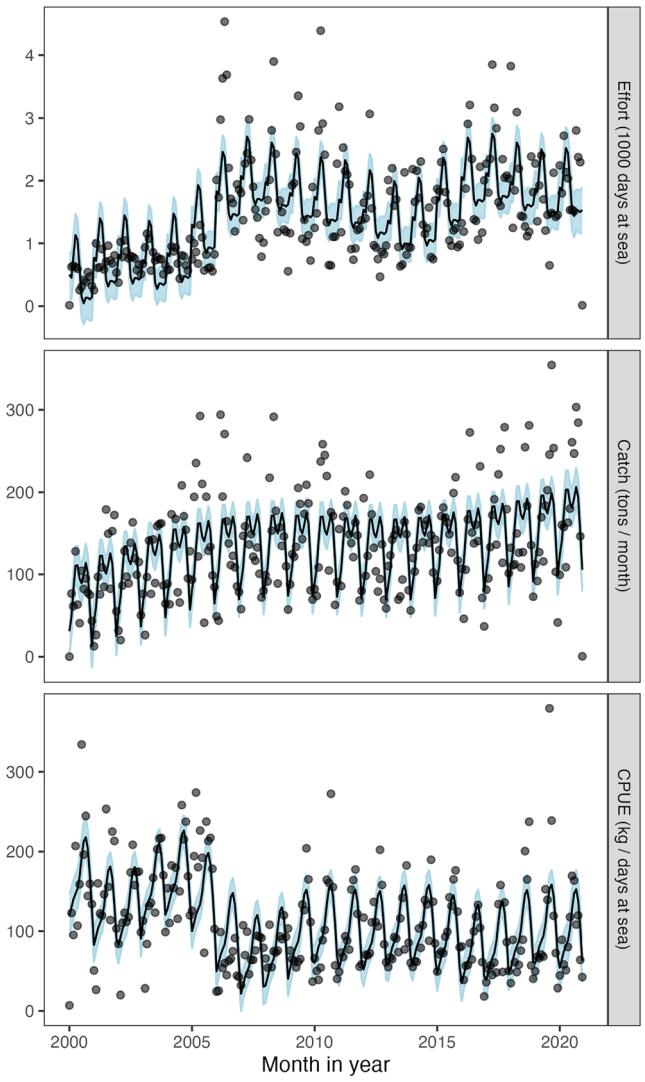

FIGURE 3 Overall trends in the yearly effort, catch, and catch per unit of effort (CPUE) of the fishery in Banc d'Arguin over the period 2000–2020. The plots indicate the fitted trends through the data, with a 95% confidence interval of the fitted trends.

were chosen as the default method in the model, because it is numerically stable (Wood, 2004), except for fitted models where 'family = poisson' was used.

Upon every vessel's return in the second period (2006–2020), the investigator also obtained from the captain a record of the geographic fishing area (assigned by a local name) in which the vessel had been fishing. As this information was not available for the earlier period, the spatial distribution of catches was only analysed from 2006 onwards. The total catch for migratory and resident species per fishing area was computed according to mullet nets and meagre nets. These data were then made spatially explicit by using digitized fishing area polygons within Banc d'Arguin using QGIS, version 3.24.2 (QGIS Development Team, 2022).

3 | RESULTS

3.1 | Seasonality of fishing effort

Traditional Imraguen fishing within Banc d'Arguin was synchronized with the migratory seasons of mullet and meagre using the specific gears targeting these species (mullet nets and meagre nets). Mullet were caught in the warm season from August to October, when the species entered Banc d'Arguin, and in the cold season, from December

to February, when the mullet migrated out of the area. Meagre were caught further offshore from February to June (Maigret & Abdallahi, 1976; Bernardon & Mohamed Vall, 2004; Lemrabott et al., in press). The data do not show significant seasonality in the effort of mullet nets throughout the year ($p = 0.057$, Table 2), but there is a decreasing trend towards the end of the year (Figure 2). Meagre nets show a clear significant seasonality ($p < 0.001$; Figure 2 and Table 2). This gear type was used mainly between October and July, with fishing effort peaking between April and June.

3.2 | Long-term trend of total effort, catch and CPUE

The total fishing effort and catch of bony fish species more than doubled between 2000 and 2020. The fitted GAM had significant non-linear trends ($p < 0.0001$, for total effort, total catch and CPUE, see Figure 3 and Table 3). Fishing effort initially increased fast, but seemed to saturate around 2005, while catches also stayed almost constant between 2005 and 2015, reflecting a minimum in the overall

TABLE 3 Summary table of GAM results for bony fish species effort (only for major gear types), catch and catch per unit of effort (CPUE) derived from the fishery monitoring programme (2000–2020) in Banc d'Arguin.

Level	Fishery	Response	R^2 (adj)	Deviance explained (%)	Smoother	edf	F (χ^2 in case of Poisson[a])	p value
Total fishery	Total	Effort	0.56	58	s(Year)	8.6	22.9	<0.0001
					s(Month)	6.8	14.8	<0.0001
		Catch	0.41	44	s(Year)	3.6	12.5	<0.0001
					s(Month)	6.4	16.3	<0.0001
		CPUE	0.53	56	s(Year)	8.8	13.1	<0.0001
					s(Month)	5.0	27.3	<0.0001
Gear type	Effort	Mullet net	0.49	52	s(Year)	8.3	23.5	<0.0001
					s(Month)	6.9	4.2	<0.001
		Meagre net[a]	0.62	66	s(Year)	3.8	17.8	<0.01
					s(Month)	4.2	50.1	<0.0001
Migratory species	Mullet	Catch[a]	0.85	88	s(Year)	8.9	529.8	<0.0001
					s(Month)	8.4	5347.5	<0.0001
		CPUE[a]	0.72	85	s(Year)	9.0	1595	<0.0001
					s(Month)	8.8	6207	<0.0001
	Meagre	Catch[a]	0.72	83	s(Year)	8.8	1302	<0.0001
					s(Month)	8.4	2177	<0.0001
		CPUE[a]	0.62	71	s(Year)	8.9	2495	<0.0001
					s(Month)	8.9	1738	<0.0001
Non-migratory species	Law croakers	Catch[a]	0.76	83	s(Year)	8.9	575.1	<0.0001
					s(Month)	8.0	1433.1	<0.0001
		CPUE[a]	0.51	64	s(Year)	8.8	390.4	<0.0001
					s(Month)	8.9	1870.1	<0.0001
	Dorades	Catch[a]	0.65	65	s(Year)	7.3	455.0	<0.0001
					s(Month)	8.3	382.5	<0.0001
		CPUE[a]	0.51	57	s(Year)	7.3	419.4	<0.0001
					s(Month)	4.6	278.3	<0.0001
	Tilapias	Catch[a]	0.51	57	s(Year)	7.6	928.1	<0.0001
					s(Month)	8.5	788.3	<0.0001
		CPUE[a]	0.24	32	s(Year)	8.4	277.4	<0.0001
					s(Month)	8.5	648.3	<0.0001
	Catfishes	Catch[a]	0.67	72	s(Year)	8.8	1142	<0.0001
					s(Month)	8.5	4074	<0.0001
		CPUE[a]	0.59	72	s(Year)	8.9	1914	<0.0001
					s(Month)	8.6	6835	<0.0001

[a]Models with *family = Poisson* setting.

CPUE trend (Figure 3 and Table 3). Towards the end of the study, the total annual effort and catch of the whole fisheries in Banc d'Arguin reached 22,000 fishing days at sea and about 2,000 tons, averaging 17,500 ± 1,470 fishing days at sea and 1,600 ± 67 tons (means ± SE) per year over the whole period.

The fishing effort with the two main gear types shows a linear increase of about three-fold in the case of the mullet nets and a similar increase for the meagre nets, followed by a decrease since 2009 for both the mullet net ($p < 0.001$) and the meagre net ($p < 0.01$) (Figure 4 and Table 3).

3.3 | Trends of the main bony fish species groups

For migratory species, the catch of mullet increased (smooth terms: $p < 0.0001$, Figure 5 and Table 3). For meagre, the catch increased initially until 2009, then decreased to almost zero over the remainder of the period (smooth terms: $p < 0.0001$, Figure 5 and Table 3). The CPUE shows an initial drop and slightly fluctuating trend at low values for mullet and was continuously decreasing for meagre (smooth terms: $p < 0.0001$ for mullet and meagre, Figure 5 and Table 3).

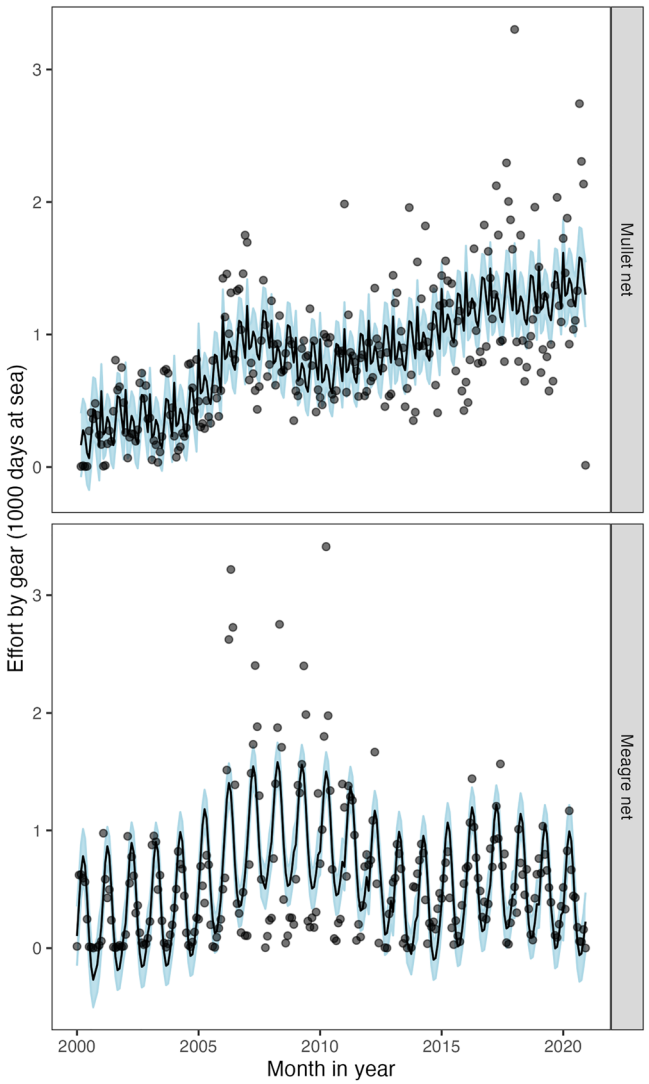

FIGURE 4 Trends in the total fishing effort of the two main gear types, mullet nets and meagre nets, used in fishing of bony fish within Banc d'Arguin. The plots indicate the fitted trends through the data, with a 95% confidence interval of the fitted trends.

The catches of all resident species, except for the law croakers, increased towards the end of the study period. The catch of law croakers increased initially, then dropped between 2009 and 2016 and modestly increased again in the final years (smooth terms: $p < 0.0001$, Figure 6 and Table 3). The catch of dorades was initially at a low level and increased from 2012 onwards (smooth terms: $p < 0.0001$, Figure 6 and Table 3). The catches and CPUEs of both law croakers and dorades were overall much lower than for tilapias and catfishes. The total catches of tilapias and catfishes increased linearly from almost zero in 2000 to 400 tons for tilapias and 600 tons for catfishes by 2020 (smooth terms: $p < 0.0001$, Figure 6 and Table 3). The trends in CPUE of law croakers and dorades reflect the same dynamics as the catches (smooth terms: $p < 0.0001$, Figure 6 and Table 3). The CPUE of tilapias saturated early in the time series and remained constant for catfishes (smooth terms: $p < 0.0001$, Figure 6 and Table 3).

3.4 | Fishing hotspots

The fishing areas which had the highest total catch for each species were explored, in the capture data for 2006–2020 (Figures S1 and S2). Mullet was mainly caught on the mudflats of the intertidal area in the central and southern parts of Banc d'Arguin (Figure S1). The highest catches were found in the fishing grounds to the north and south of Tidra island. Meagre was mainly caught in the north and in deeper areas, of which the highest catches were recorded close to Cap Tafarit (Figure S1). For the resident species, law croakers (Figure S2) were caught in the same fishing ground as meagre. The catches of dorades, tilapias and catfishes were rather more associated with the intertidal areas in the centre and the south of Banc d'Arguin (Figure S2).

4 | DISCUSSION

4.1 | Abundance and ecology of the main fish species in the catch

The results of two decades of fishing data from Banc d'Arguin show an overall increase in effort and catches of bony fish species. The declining CPUEs of the traditionally targeted migratory species (mullet and meagre) suggest non-sustainable overfishing of them. The declining captures of these species were compensated for by a shift towards non-migratory species (resident species), which do not show evidence of stock declines yet.

In the first years of the study, the traditional mullet and meagre nets targeted the migratory species and characterized the fisheries of

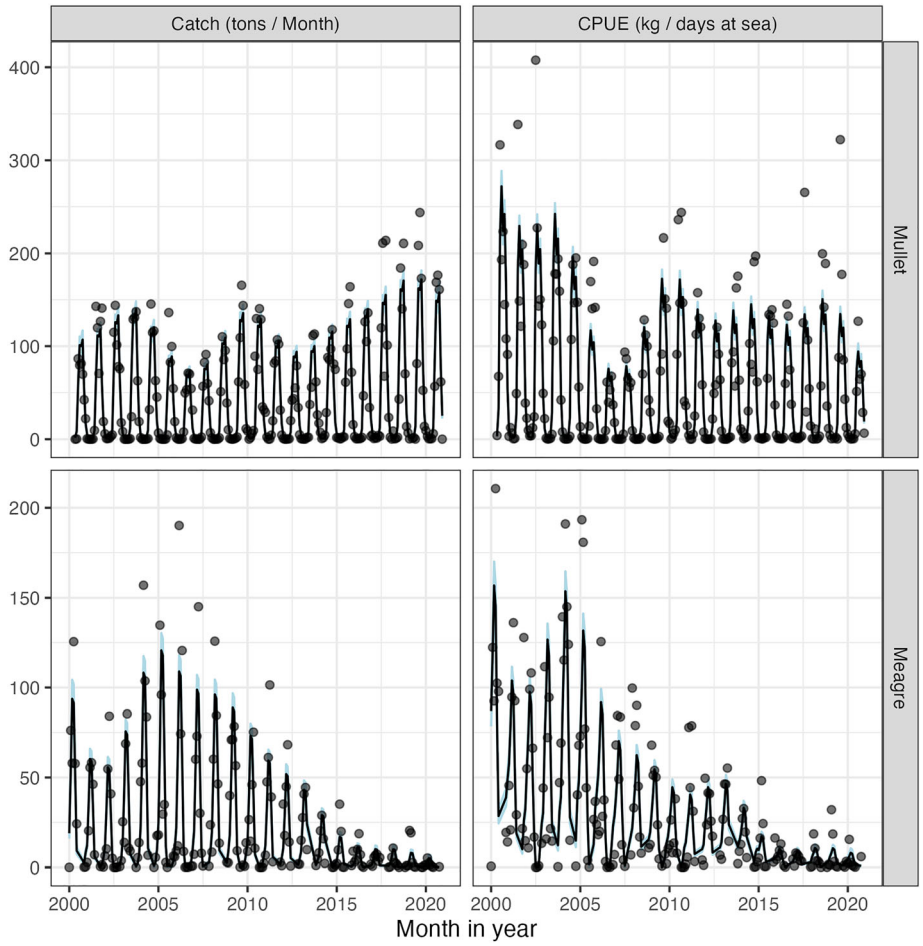

FIGURE 5 Trends in the total catch (left panels) and the catch per unit of effort (CPUE) (right panels) per year for the two migratory species mullet and meagre. The plots indicate the fitted trends through the data, with a 95% confidence interval of the fitted trends.

bony fish at Banc d'Arguin seasonally. At the end of the seasonal migrations, the mullet and meagre nets were used to fish other bony fish species. The low effort level of fishing with dorade nets and sole nets suggests that they were used as secondary gears. Since the small bony fish species can escape through the large mesh sizes of meagre nets, only the law croakers, which have sizes close to those of meagre, are also caught with meagre nets. The smaller species, such as dorades, tilapias, and catfishes, were caught by mullet nets.

Mullet enter the Banc d'Arguin during a period of its annual cycle for fattening up and are targeted by Imraguen fishery within Banc d'Arguin and by the artisanal fishery operating outside Banc d'Arguin along the migration route to their Senegal river spawning grounds (Bernardon & Mohamed Vall, 2004). Meagre is heavily targeted outside of Banc d'Arguin and faces a heavy fishing impact by offshore industrial fleets (Guénette, Meissa & Gascuel, 2014; Leurs et al., 2021). Moreover, inside Banc d'Arguin, shark and ray fishing developed as a new revenue model stimulated by external investors in the area. This is motivated by the demand for elasmobranch fins and dried meat for international markets as they are not eaten locally. The fishery has gone through a strong increase in overall effort since 2010 (Figure 3). Consequently, both mullet and meagre show declines in yield and abundances, with declining CPUEs, reflecting overfishing of these historical target species. Following this, fishermen shifted towards non-migratory bony fish species, such as tilapias and catfishes.

Towards the end of the study, the fisheries in the Parc National du Banc d'Arguin targeted the short-lived non-migratory bony fish with tilapias and catfishes comprising the majority of the catches. Tilapias have a small distribution range in Banc d'Arguin and are endemic in Banc d'Arguin (Severin-Reyssac & Bertrand, 1985), whereas catfishes have a large distribution within Banc d'Arguin and are characterized by a slow life-history strategy (Correia, Carneiro & Araújo, 2020; also see Figure S2). The fishing of these species emerged from the need to compensate for the decrease in yields of mullet and meagre and to keep up with increasing market opportunities for dried meat in other African countries (Boulay, 2013; Lemrabott et al., in press). Concomitant with the increasing fishing effort, catches of both tilapias and catfishes are increasing, suggesting that they are abundant and that their stocks are not yet currently overfished. However, management interventions may be required to prevent future overfishing of their stocks. This is important at several levels: (1) to promote the sustainable harvest of these two key species for their realized economic income in the light of the declines in traditional migratory species; and (2) to avoid a possible fishing rebound on sharks and rays when the catches of tilapias and catfishes could drop in the future.

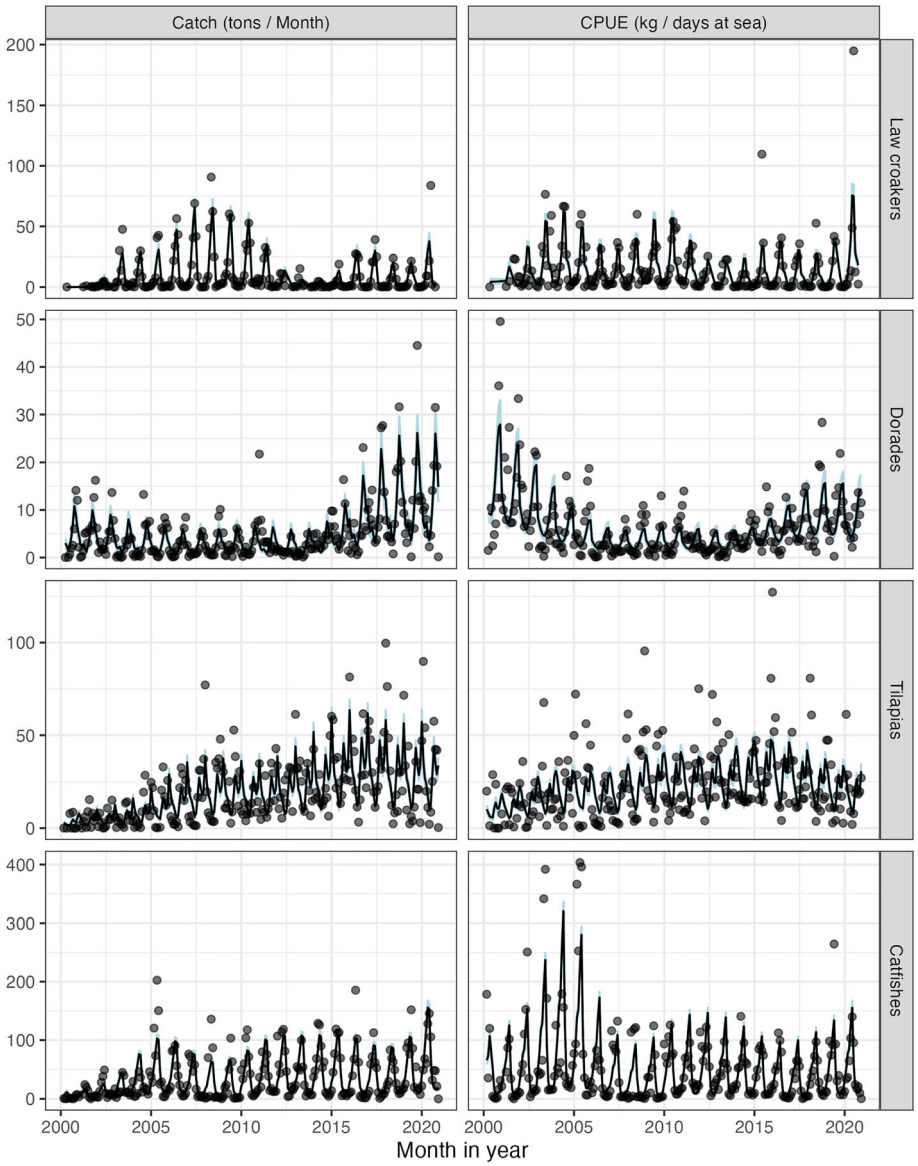

FIGURE 6 Trends in the total catch (left panels) and the catch per unit of effort (CPUE) (right panels) per year for resident species (law croakers, dorades, tilapias, and catfishes). The plots indicate the fitted trends through the data, with a 95% confidence interval of the fitted trends.

4.2 | Implications for fishery management and conservation

The Banc d'Arguin fishery is characterized by a diverse combination of gears and targets multiple species using different fishing strategies and relatively traditional fishing practices. In other regions worldwide, some common methods used in artisanal fisheries management to address problems of over-exploitation, over-capitalization and inefficient use of stocks include licences, gear restrictions, fishing effort restrictions and closed seasons (Selig et al., 2017). Emerging management approaches of community-based fisheries (co-management) with shared governance authority were developed as an alternative to the unsuccessful conventional management methods in artisanal fisheries (Albornoz & Glückler, 2020). In the context of a national park, it is especially relevant to look wider than the targeted fish species alone, and a holistic ecosystem-based management approach has become the main reference framework for fisheries governance which should be applied in this protected national park.

Already several management tools have been applied to the fisheries at the Banc d'Arguin, of which PNBA's declaration in 1996 explicitly mentions the commitment to sustainable fishing by the Imraguen fishermen. In later years this was followed by the establishment of the participative (co-management) approach, including fishers, scientists and managers to decide on fishing regulations. Additionally, the CPUE indices from the monitoring programme are annually analysed to guide managers in adjusting fisheries regulations, and to help with focused patrol of the Banc d'Arguin boundaries. However, such guidance should be based on the biological parameters of the fished species and the reliability of the data should be improved, as catch data from commercial fisheries alone cannot give the full picture. The management of migratory

species which spend a large part of their life outside Banc d'Arguin requires jurisdiction over their entire distribution (Guénette, Meissa & Gascuel, 2014). For the non-migratory species that are currently targeted (tilapias and catfishes), we propose the implementation of fisheries closures during the reproductive season (May–July) and a minimum body size based on size at first maturity (FL50), i.e. 35 cm fork length for *Carlarius parkii* and 40 cm fork length for *Arius latiscutatus* (Correia, Carneiro & Araújo, 2020).

The monitoring programme provides high-quality data on fishing within the Parc National du Banc d'Arguin for use by managers and scientists and highlights the need for a change to the unacceptable situation of overfishing in this marine protected area and World Heritage Site. Increasingly, the use of catch share programmes is argued for, using the economic tool of individual transferable quotas or ITQs (Scheld & Anderson, 2014; Acheson, Apollonio & Wilson, 2015). However, ITQs fail to address essential factors influencing stock sizes (Acheson, Apollonio & Wilson, 2015) and they are more suited as an instrument for quota sharing among fishermen rather than for setting a sustainable total quota from a fisheries management perspective. Furthermore, because quotas can be traded and end up in the hands of non-indigenous people (not with the local fishermen), this concept is ill-suited to the Banc d'Arguin system. The observed trends now call for a new type of fisheries management based on stock data and species' recovery capacity to avoid fish stocks falling to dangerously low levels. Fishing at Maximum Sustainable Yields would better fit the present case (Mkenda & Folmer, 2001; Abd El Barr, 2016); however, there may be a problem with strong differences in carrying capacity for different species caught with the same gear (e.g. fast-reproducing species, such as catfish, and slow-reproducing species, such as guitarfish, requiring different approaches). Another potentially useful tool to apply to this system is a 'catch-only' model (Ovando et al., 2022), which is based only on catch data to inform population stocks, even if there are often problems with reliability of the catches. This type of tool may be relevant for Banc d'Arguin as the sampling rate of the fisheries is high, the fishing effort is stable (capped at 114 boats) and all catches are landed (fishery with zero discards). Finally, in order to improve the information on population structure, we recommend placing observers onboard the lanches and implementing a control system to prevent landings at non-authorized sites. Any management policies should be appropriate to the specific context of the fishery and seek to implement management interventions designed to move fishing practices to a more sustainable state in accordance with the aims of stock renewal of target species.

AUTHOR CONTRIBUTIONS

Sidi Yahya Cheikhna Lemrabott, Han Olff, Theunis Piersma, El-Hacen Mohamed El-Hacen, Lemhaba Yarba Ahmed Mahmoud and Ebaye Sidina conceptualized the manuscript and the formal analyses. Amadou Abdarahmane Sall contributed to the data collection. Sidi Yahya Cheikhna Lemrabott conducted the data analyses with assistance from Anieke van Leeuwen, Theunis Piersma, El-Hacen Mohamed El-Hacen, and Han Olff. Sidi Yahya Cheikhna Lemrabott wrote the manuscript with input from Anieke van Leeuwen, Theunis Piersma, El-Hacen Mohamed El-Hacen, and Han Olff. All authors contributed significantly to the final draft.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest/competing financial interests that may have appeared to influence the work in this article.

DATA AVAILABILITY STATEMENT

Data associated with this article will be archived and made available in the Research Data Repository of the University of Groningen. (http://www.rug.nl/research/gelifes/research/data-management/repository?lang=en).

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