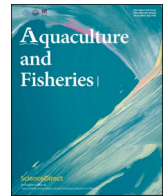


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The role of marine protected areas in sustaining fisheries: The case of the National Park of Banc d'Arguin, Mauritania

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ABSTRACT

Mauritania is characterized by fast-growing fisheries that have developed over the past several decades from low levels of fishing to intense fishing and have led to severe decreases in biomass and severe signs of over-exploitation. To ensure sustainable fisheries, a primary goal of science-based fisheries policy is to provide an adequate conservation status of marine habitats that are directly, or indirectly, fundamental for the lifecycle of fish populations of commercial interest. The National Park of Banc d'Arguin has been recognized for its nursery and fish biomass export functions. In this paper, we present the economic value of the fish provisioning service of marine coastal ecosystems of the protected area. We estimated the added value of artisanal fisheries, the spatial distribution of fishing activities, the contribution of the Park to the Mauritanian fisheries and the heritage value of artisanal fisheries.

Overall, the average added value for artisanal fisheries is about 43 million MRU (1 million euros) over the period 2006–2017. It mainly benefits to the ship-owners, which generates inequalities and threatens the livelihoods of the Imraguen. The spatial distribution of fishing activities and associated revenues shows high variability throughout the years, the seasons and the geographic areas, and reveals the high adaptability of Imraguen fishers. Fishing grounds are mostly located close to the shore, associated with seagrass beds, confirming the service of fish provisioning rendered by this ecosystem. Furthermore, the high productivity of seagrass beds contributes to the spill-over of biomass. The contribution of the Park to fishing activities that occur within the Mauritanian Exclusive Economic Zone is estimated to 15%, representing an added value creation of 3.2 billion MRU (71 million euros). The heritage value of the fisheries is assessed, through fishers' willingness to accept to stop their fishing activities, at 17.5 million MRU (0.4 million euros). Thus, this paper highlights the necessity of incorporating an ecosystem-based approach along with fishers' knowledge and adaptability into future conservation plan of the National Park of Banc d'Arguin and fisheries management at the local, national and regional scale.

1. Introduction

The National Park of Banc d'Arguin (PNBA), Mauritania, created in 1976, is the largest marine protected area in West Africa. The presence of a permanent upwelling zone at Cape Blanc maintains a supply of cold water. In contrast, the shoal zone of the Banc d'Arguin traps warm

water, thus constituting a unique hydrological regime that allows a diversity of rare biotopes on the West African coast (Ould Taleb, 2003; Sevrin Reyssac, 1983). It is inhabited by the indigenous Imraguen population who occupy nine villages distributed along the coast, with a total of approximately 1280 people, of which 341 are active fishers (Wagne & Sarr, 2018). As an indigenous population, the Imraguen are

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the only ones authorized to fish in the Park's waters for subsistence fishing, to meet the domestic needs of the communities. The Law 2000/24 on the PNBA enshrines several usage rights exclusively for the benefit of the Park's residents. It defines fishing, subsistence activities and, in particular, shore fishing, known as "Imraguen fishing" and fishing from a sailboat. Given its status of Marine Protected Area (MPA), the activities occurring in the PNBA are subject to strict compliance with the requirements for the conservation of ecosystems. Fishing is restricted to the use of 114 sailboats, who practice seasonal fishing using different types of nets. The Meagre net, Mullet net, Tollo net and Sole net, initially made to capture *Argyrosomus regius*, *Mugil* spp., *Mustelus* and *Solea* spp. respectively, are the most important ones in terms of captures within the PNBA. Ownership of sailboats and fishing rights are reserved exclusively for Imraguen.

However, over the last two decades, this supposedly subsistence fishery has turned into a commercial fishery and has resulted in increased pressure on the PNBA's marine resources (Failler, 2009, p. 145). The sustainability of fishing inside and outside the Park is compromised. The fishing in the PNBA takes place in an economic context where the use of sailboats is the essential axis of development for the Park. Still, the fisheries management system is faulty, illustrated by the sharks and rays fishing decree, implemented in 2003, despite which, landings have continued to increase over time (Failler et al., 2009).

In 2018, an extensive study on ecosystem services was performed for the National Park of Banc d'Arguin to demonstrate the importance of the Park, both ecologically and economically (Trégarot et al., 2018). In the framework of this valuation of ecosystem services, particular attention was paid to fisheries supply services, whether for artisanal coastal fishing or the contribution of the PNBA to industrial fisheries on the continental shelf of Mauritania, while emphasizing the social context of the Imraguen facing fishing regulations. First, this paper focuses on the economic evaluation of artisanal fishing, both on the distribution of fisheries catches in the PNBA and the economic performance of the main fishing categories. Secondly, this paper aims at valuing the contribution of the PNBA to the continental shelf fisheries using food web modelling. This model provides a basis for multispecies management considering the trophic activity of higher predators, namely humans, birds and marine mammals (Ould Taleb, 2003). Finally, in the third section, we performed a contingent evaluation to measure the heritage dimension of the fishery in the case of a fishing ban, a total or partial closure, or a redefinition of zoning in the PNBA.

This paper broadens the understanding of the importance of PNBA's marine coastal ecosystems in sustaining both artisanal and industrial fisheries. It shows the importance of concertation and collaborative work with fishers for MPA management (Di Franco et al., 2016). This paper is the first monetary valuation of the fishing supply service inside the PNBA, combined with the spatial distribution of fisheries catches based on the empirical knowledge of fishers, to highlight priority areas. This paper also updates the contribution of the PNBA to fisheries supply on the continental shelf from the previous assessment (Guenette et al., 2014). Here, the trophic functioning of the ecosystem was modelled over the period 2016–2018 using version 6.5 of the Ecopath with Ecosim (EWE) model (Christensen & Walters, 2004), considering the impact of fishing, the structure of the trophic network, and some aspects of the spatial distribution of species. Scenarios of additional fishing effort and habitat degradation inside the Banc d'Arguin allowed us to gain insight in its importance in the total production of the Mauritanian ecosystem and its links with the rest of the shelf. Finally, this paper put forward the role of fishers in the development of management strategies, considering their empirical knowledge, their position regarding fishing regulation, and their perception of alternative measures. The results of this paper should reinforce the case for the consequent role of PNBA's marine ecosystems on food security and social well-being. Furthermore, in the context of climate change and national adaptation policy, this paper should contribute to the development of equitable and sustainable management strategies, which are sorely lacking today.

2. Materials and methods

2.1. Study area

The National Park of Banc d'Arguin (PNBA) is a marine protected area located on either side of the 20th parallel (Fig. 1). It runs along 180 km of Mauritanian coast with an area of 12,000 km², composed almost equally of maritime (5400 km²) and continental (6600 km²) areas. The PNBA was created on June 24, 1976, by decree n° 76–147, and recognized as a wetland of international importance by the RAMSAR Convention in 1982. It was later declared a UNESCO World Heritage Site in 1989. The Law of January 24, 2000, defined the PNBA as a "national heritage" site. Its maritime area supports vast extents of mudflats and seagrass beds, as well as salt marshes and mangroves that both reach their distribution limits in the PNBA. The PNBA represents a valuable reserve for the reproduction and growth of many species of fish, molluscs (Jager, 1993), crustaceans (Schaffmeister et al., 2006) and marine mammals. But the reason for its creation concerns its vital role for millions of migratory birds as a site for feeding and breeding (Campredon, 2000).

The PNBA is partially closed to fishing; only the residents (the Imraguen), are allowed to fish using small wooden sailboat. Imraguen fishing has always aroused great interest because of its originality and age. The organization of Imraguen fishery was based on ancestral social rules which respected the rights and social rank of each individual. The fish were caught as they migrated along the Mauritanian coasts. It was consumed almost all year round thanks to adapted processing techniques. Confined between the desert and the sea, the survival of the community relies on each member's function and role. The population settled down in the Park and created the villages to flee the drought of the 1970s and take the new opportunities to exploit fishery resources.

Outside the PNBA, the Mauritanian Exclusive Economic Zone (EEZ) is also highly productive, enriched by an upwelling that is permanent near Cap Blanc but spanning only nine months around Nouakchott. Catches made by the Mauritanian fleet are very limited compared to those made by fleets from other countries, which have access to the fishery resources of the Mauritanian EEZ under fisheries agreements. Since the 1980s, landings have increased substantially, from 15,598 tonnes in 1980 to 952,707 tonnes in 2018 (FAO, 2020).

2.2. Assessment of artisanal fisheries in the National Park of Banc d'Arguin

To assess the artisanal fisheries catches in the PNBA and its revenue, we collected data on catches, landed prices and fishing effort (as the number of days) from the Monitoring System for Artisanal and Coastal Fisheries (SSPAC). To assess the intermediate consumption (daily cost for food and ice) and operating costs (crew share, access rights, repair and maintenance costs of boats and fishing gears) by each fishing category, we collected data from the socioeconomic databases of the Laboratory of Social and Economic Studies (LESE). All data were collected over the period 2006–2017. From these databases, we determined:

- The average annual active fleet per category of fishery
- The gross added value, calculated by subtracting from the revenues the intermediate consumption

with the revenues calculated by multiplying the average sale price (Pi) of each species (i) by the total quantity (Qi) landed by the fishing unit (j) per year, and the intermediate consumption calculated by multiplying the daily cost by the number of fishing days per year and by fishery category.

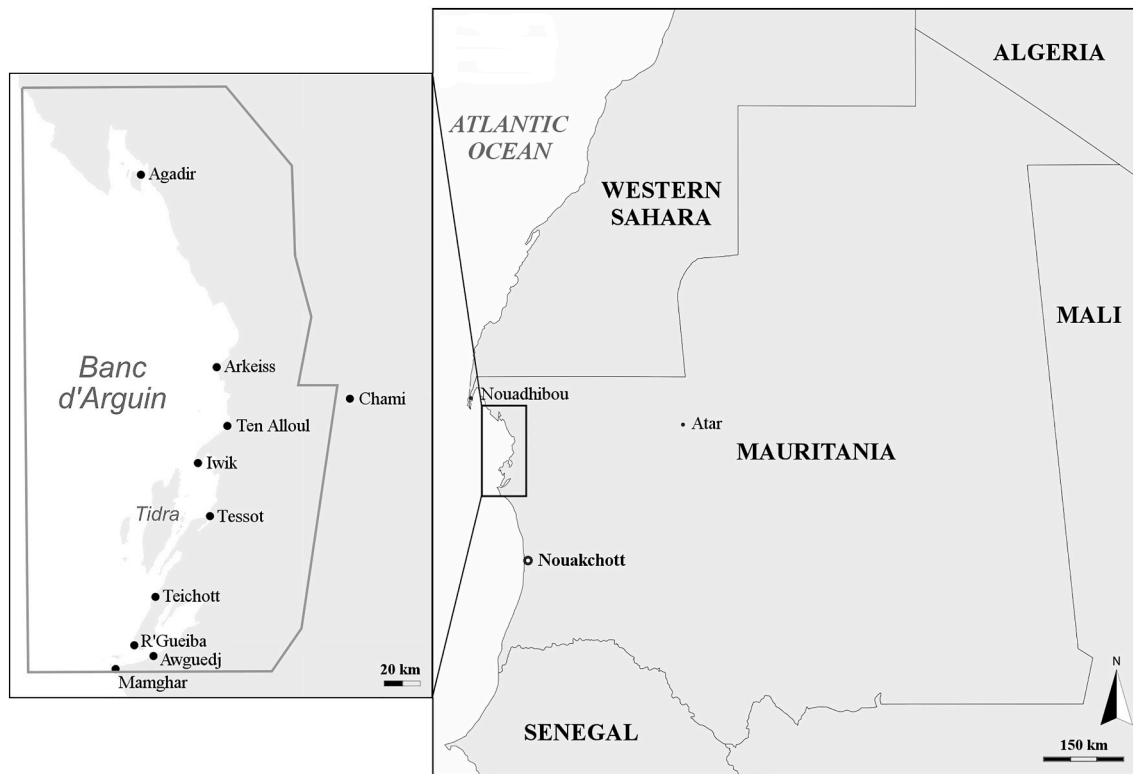


Fig. 1. Location of the National Park of Banc d'Arguin, Mauritania.

- The gross operating surplus, calculated by subtracting from the revenues, the operating charges (captain and crew salaries, repair costs and access rights).

Moreover, we analyzed the spatial distribution of the fishing activities in the PNBA, using the revenues of each fishing zone from 2014 to 2017. We used ArcGIS 10.2 for mapping the monetary value of the fishing zones.

2.3. Contribution of the National Park of Banc d'Arguin to industrial fisheries on the shelf and continental slope

The trophic functioning of the ecosystem was modelled over the period 2016–2018 using version 6.5 of the Ecopath with Ecosim (EWE) model. This model is an update of the Ecopath model previously built over the period 1991–2006 (Guénette et al., 2014), and therefore follows the same methodology. It took into consideration the impact of fishing, the structure of the trophic network, and some aspects of the spatial distribution of species. Ecopath allows you to understand the organization and trophic functioning of an ecosystem by considering it in its entirety. The entire ecosystem biomass is thus distributed between different boxes, arranged by trophic levels, defining the functional groups of the model (Christensen et al., 2005). This model covers the entire Mauritanian continental shelf from the coast to the 200 m isobaths, an area of 34,324 km². The main difference with the previous model is the addition of the bonga shad (*Ethmalosa fimbriata*) to the list of functional groups due to its strong dependence to the Banc d'Arguin and the importance of its catches (Table A1). The bonga shad was not included in Guénette et al. (2014) model since catches were negligible over the period 1991–2006. However, with the development of the fishmeal industry, this species has been fished in quantity since 2009 (Caillart, Leader, & Beyens, 2015; Corten et al., 2017).

2.3.1. Model calibration and update

We changed the fishing data with a more recent timeframe

(2016–2018), then we used stock assessment (Meissa & Gascuel, 2014) and assessed fishing mortality (catch/biomass). But often the biomass of the model is not consistent with the fishing data. Indeed, observed data from surveys do not necessarily reflect the actual status of population stocks. Quality of the model is, therefore, better when using population stock data rather than surveys data.

To calibrate the Mauritania model, we changed the biomass calculation method by correcting the catchability of groups whose behaviour and morphology facilitates or makes it difficult to capture them. For instance, we used a catchability of 0.1 for crustaceans instead of 0.5. The latter is usually used by default to estimate the effective biomass, thus increasing the biomass of this group. Catchability was recalculated so that the Yield/Biomass ratios were compatible with the fishing mortality resulting from the stock assessment.

Biomasses of *Octopus vulgaris*, mullets (*Mugil capurrii*, *M. cephalus*), meagre (*Argyrosomus regius*) were increased according to the output of the model by Meissa and Gascuel (2014) while mackerel's biomass (*Scomber colias*) was increased due to better assessment of mackerel's stocks using acoustic (FAO, 2019). Furthermore, to balance the model, we reduced the predation on groups with low biomass (algae) and increased it for more abundant groups in the ecosystem like small pelagics (sardines: *Sardina pilchardus* and sardinellas: *Sardinella aurita*, *S. maderensis*) and shelf crustaceans (shelf L – large – crustaceans, shelf crustaceans), provided that these groups appear in their diet. Finally, given the absence of diet studies for the bonga shad in Mauritania, we used the Ecopath model of Guinea (Gascuel, Guénette, Diallo, & Sidibé, 2009) to add this species to the diet matrix.

2.3.2. Scenario analyses

The Ecopath base model was used to simulate two scenarios, deriving from the current model. The first allows simulating the existence of a fictive fleet ($F = 0.8$) inside the Banc d'Arguin, by increasing fishing mortality on each exploitable functional group. The second allows simulating the destruction of habitat by increasing the mortality rate ($M = 0.02$) on benthic invertebrates (groups 33–38), plankton (groups

47–49) and seagrass beds (group 51) located inside the PNBA. This last scenario resulted in a ~40% decline in seagrass biomass and the extinction of the other nine groups.

2.3.3. Monetary valuation

To estimate the economic contribution of the PNBA to the fisheries operating in the Exclusive Economic Zone of Mauritania, we calculated the gross added value generated by the fleet categories whose species caught have a link with the PNBA (defined in the model as the contribution of the PNBA to the biomass of each species). For each type of fishery, an intermediate consumption ratio was applied to the revenue using the rates defined by IMROP Working groups (IMROP, 2014; Sidi et al., 2013) and those specified for the fishing vessels of the European fleet (Failler, 2015; Failler et al., 2018; Magnet, Defaux, & Failler, 2014). We used the average landed prices from the IMROP database and the working groups of the Mauritania-European Union joint commission (2018). Therefore, the added value generated by coastal marine ecosystems of the PNBA corresponds to the one generated by the fishing vessels operating on the continental shelf of Mauritania, weighted by the contribution's coefficient of the PNBA to the biomass of the species caught. We used economic data from the years 2016, 2017 and 2018.

2.4. Heritage value: willingness to accept in the face of fishing regulation

Considering the profound changes in the PNBA area, we deemed it necessary to use a contingent valuation to measure the heritage dimension of the fishery in the case of a fishing ban, a total or partial closure, or additional zoning in the PNBA that would directly concern the livelihood of Imraguen communities. We applied the contingent valuation method for estimating the value that an Imraguen fisher places to fisheries. The approach asked people to directly report their willingness to accept (WTA) – from the Mauritanian State – to stop their activities, due to the implementation of a fisheries management policy. The individuals interviewed anticipate the amount of money they should receive, assuming that individuals have perfect knowledge of the environmental goods and services available to them (Mbarek, 2016). A 21-day field mission was carried out within the PNBA in August 2018 to interview the Imraguen in all the villages of PNBA. Since we wanted to highlight the heritage value of the activity, we administered a questionnaire to fishing captains (13), fishers (7), former Imraguen fishers (11) and heads of households (10), for a total of 41 people out of 1283 inhabitants. The interviews lasted an average of 20 min per person. The relatively short questionnaire was possible with people who have a good understanding of their natural environment and choosing very experienced fishers who were present at the time of the moratorium on sharks and rays in 2003. A compensation for stopping targeted fishing for rays and sharks in the Park was attributed to fishers, by “purchasing their fishing nets” at the cost of 3.85 million MRU. Therefore, interviewees had a clear understanding of the compensation mechanisms and the concept behind the willingness to accept, and were very familiar with the issues and the laws in force in the PNBA. Some are heads of villages or representatives of tribes present in the PNBA.

To calculate the WTA per fishery category (Mullet, Meagre, Tollo, Sole), which refers to the specific use of nets as mentioned before, we multiplied the average WTA per interviewee associated to a fishery category by the number of sailboats targeting the fishery category.

3. Results

3.1. Monetary value of artisanal fisheries in the PNBA

During the 2006–2017 period, the number of active sailboats remained relatively constant (on average 96 sailboats). The duration of fishing trips was often less than 24 h, using several categories of fishing gear (Kane, Ball, Haidallah, & Fall, 2016). Wagne (2016) has identified an average of 12 different fishing categories annually based on the

combination of fishing gear, targeted species and artisanal fishing techniques (Isselmou et al., 2003). However, 97% of this effort is exerted by four fishing categories: the Mullet category (40.64%), Meagre category (38.46%), Tollo category (16.44%), and to a lesser extent, the Sole category representing about 1% of the fishing effort, and 0.75% of the total catches (Table 1). Therefore, we focused our analysis on those four categories. Table 1 summarizes the fishing effort of each fishing category, the revenue, intermediate consumption and gross added value and gross operating surplus. Note that those nets (Meagre, Mullet, Tollo and Sole) are not selective, and consequently, many other species are targeted beyond *Argyrosomus regius*, *Mugil* spp., *Mustelus* and *Solea* spp. (see Appendix B, Table B1 and Table B2).

The results of the economic analysis showed that the principal fisheries generated an average revenue of 47.91 million MRU per year, with an increase of 8% between 2006 (48 million MRU) and 2017 (52 million MRU). This revenue is divided between the following categories: Mullet (39.77%), Meagre (44.03%), Tollo (13.31%) and Sole (0.92%). The meagre (*Argyrosomus regius*) and the mullet (*Mugil cephalus*) are two essential species for the sales, and each represents 19% of the revenue of the Meagre and Mullet categories, respectively. The milk shark (*Rhizoprionodon acutus*) and the law croaker (*Pseudotolithus senegallus*) are the main targeted species with the Tollo net, representing respectively 5.92% and 2.16% of the revenue. Finally, the king mackerel, *Scomberomorus tritor* (0.27%) and the catfish *Arius laticulatus* (0.15% of revenue), despite their low revenue, contributed the most for the Sole category (Table B1). The intermediate consumption was estimated at 4.13 million MRU/year on average, representing approximately 9% of the total revenue, and varies according to the fishing category and the effort deployed. In 2017, the intermediate consumption was estimated at 4 million MRU. Since the sailboats do not use fuel, the economic weight is low and consist primarily of food (e.g. rice, flour, tea, bread, sugar, oil, water, ice, etc.). The resulting gross added value informs us about the wealth created by the direct use of sailboats during the period 2006–2017, with an average gross added value of 43.78 million MRU/year, and of 48.00 million MRU in 2017. With a gross added value of almost 20 million MRU/year, the Meagre category creates more wealth in the PNBA than any other fishing category, contributing to 42% of the revenues of the main fisheries. Out of the 43.78 million MRU of gross added value, 15.23% is returned to the captains and 30.43% to the crew, representing 22 million MRU in total. Another 9.45% and 0.22% of the added value are allocated to repair costs and access rights, respectively. The remaining 36% goes to the boat-owners.

Analyzing more precisely the species caught, it much depends on the season and the gear used. On average, 257 species were landed annually in the PNBA throughout the study. In term of value, the main species of interest are the rays (*Rhinoptera marginata* and *Rhinobatos cemiculatus*), the yellow mullet (*Mugil cephalus*), catfish (*Arius parkii*, *Arius laticulatus* and other *Ariidae*), the tilapia (*Saratherodon melanotheron*), sharks (*Rhizoprionodon acutus* and *Sphyrna lewini*), the meagre (*Argyrosomus regius*), the law croaker (*Pseudotolithus senegallus*), king mackerel (*Scomberomorus tritor*), the sea bream (*Diplodus sargus*). However, elasmobranchs remain among the most abundant species (almost 35% of the average catches of the leading fisheries (Table B2) despite the fishing regulation on sharks and rays implemented in 2003. As for the spatial distribution of the fishing effort, over the period 2014–2017, certain fishing grounds showed an increase in their annual value (Fig. 2). For instance, in *North West Tafarit* (Arkeiss) the amount increased from 2 million MRU in 2014 to 4 million MRU in 2017, the zone *El Hajra* (Agadir), was worth 150,000 MRU in 2014 against 877,000 MRU in 2017, and in *Eghewkert* the value increased from 196,000 MRU in 2014 to 406,000 MRU in 2017 with a peak in 2015 and 2016 approaching 2 million MRU. The zone *Chekcher* had seen its value increase substantially from 275,000 MRU in 2014 to 3 million MRU in 2017.

Fig. 3 shows the 124 fishing grounds in 2017 with their associated value per km². The annual and seasonal variation of fish catch influenced the number of fishing grounds over the years. They were 193 in

Table 1

Fishing effort, catches and economic indicators per fishing category, averaged over the period 2006–2017, in the National Park of Banc d'Arguin, Mauritania.

Fishing categories	Mullet	Meagre	Tollo	Sole	Total
Effort (days/year)	8177	7739	3308	190	19,414
	41%	38%	16%	1%	96%
Volume (tonnes/year)	1362.25	1084.18	442.12	22.65	2911.20
	45%	36%	15%	1%	97%
Revenue (MRU/year)	19,443,793	21,512,964	6,507,098	449,522	47,913,377
	40%	44%	13%	1%	98%
Intermediate Consumption food, ice etc. (MRU/year)	1,726,217	1,622,600	746,943	37,227	4,132,987
% Intermediate Consumption/Revenue	9%	8%	11%	8%	9%
Gross Added Value (MRU/year)	17,717,576	19,890,364	5,760,155	412,295	43,780,390
% Gross Added Value/Revenue	91%	92%	89%	92%	91%
% Gross Operating Surplus/Revenue	34%	34%	32%	44%	36%

2014, 170 in 2015, and 189 in 2016. Fishing grounds presenting the higher values were often close to the coast, associated with seagrass beds. Some fishing grounds are particularly productive such as *Nord Ouest Tafarit* and *Ouest Tafarit* from Arkeiss, and were constant over the years, each generating revenue between 1 and 4 million MRU/year each. The other areas like *Ekmech* and *Temdel* from Teichott, *Lekraa lebyedh*, *Techegmar* and *Vem Ezezi* from Iwik and *Eeyoun tissot* from Tissot provided substantial value only once over the period. Despite the lower number of fishing grounds in 2017, the revenue was not impacted, with the site *Eeyoun tissot* providing 7 million MRU in 2017.

3.2. Contribution of the PNBA to industrial fisheries on the continental shelf

The results show that most of the 32 groups depend on the Banc d'Arguin for their consumption, and consequently for their production (Fig. 4). In particular, 15 groups depend on the Banc d'Arguin for more than 30% of their total production (and more than 45% for eight groups), thus highlighting the role of the PNBA for many exploited species. We observed the highest levels of dependency for seabirds (73%), bonga shads (72%) and mullets (70%). In general, reliance on the PNBA is mainly due to the direct consumption of invertebrates living in the Banc d'Arguin, particularly in the case of coastal groups, including juveniles. Conversely, indirect consumption from the PNBA by more or less complex routes is essential for marine mammals, meagres, large pelagic and selacians. On average, 16% of the total consumption of the ecosystem comes directly or indirectly from the Banc. The PNBA's original consumption is the basis for 21% of the total production, including the primary producers (this high value being due to the vast extent of algae and seagrass beds from the Banc d'Arguin). For groups of coastal fish (including mullet and meagre), the overall consumption and production of the PNBA are higher than 40%. The degree of dependency is linked to the trophic level. The highest proportion of production from the PNBA (60%) is observed around the trophic level 2.3 (Guenette et al., 2014), mainly due to mullets, bonga shads, crustaceans and macrozooplankton, a group particularly abundant (and productive) in the Banc d'Arguin. The proportion decreases around the trophic level 2.8 represented by small pelagics.

The impact of the fictive fleet fishing in the Banc d'Arguin on any exploitable species would be a substantial decrease in the biomass of species of higher trophic levels (TL > 3), particularly the selacians, with a consequent release of predation on the lower trophic levels (Fig. 5).

On the other hand, habitat degradation in the PNBA would decrease the overall biomass at all trophic levels. Consequently, this habitat degradation would substantially impact the fishing sector which might lose between 15 and 18% of its total catches and more than 40% of artisanal and coastal catches, which is the primary sector of employment in Mauritania. These risks necessitate maintaining or even strengthening surveillance activities but more importantly, monitoring seagrass distribution and ecological state. Seagrass beds inside the PNBA provide food, shelter and support for the development of epiphytic algae and

associated microfauna (Ould Taleb, 2003). They support artisanal and coastal fisheries as well as industrial fisheries outside the Park.

Additional studies are still needed to improve the quality of the results obtained with this model due to the uncertainties weighing on specific data and basic settings. These uncertainties are mainly due to the lack of evaluation of the biomass of individual compartments of the ecosystem, in particular of lower trophic levels (phytoplankton, zooplankton and invertebrates). However, seagrass beds provide most of the productivity in the PNBA. Further modelling analysis on the contribution of PNBA would include fish movements, the proportion of juveniles developing in the PNBA reaching adult stocks, the geographic location of each fleet, including the Imraguen's fishery that we described.

Based on the current contribution of the PNBA to catches on the shelf and continental slope of Mauritania, we assessed its economic value (Table 2).

The average annual value (revenue) of the catches made by fleets operating along the shelf and continental slope of Mauritania during the period 2016–2018 was estimated at just over 52 billion MRU (Table 2). About 48% of the revenue is generated by the fishing fleets targeting small pelagics, consisting of a dozen species of sardinellas, horse mackerels and mackerels. Cephalopods (3 species) contribute nearly 35% of the revenue of fisheries, while demersal fisheries and crustaceans contribute to the remaining 15% (multiple species). The contribution of the PNBA corresponds overall to 15% of the gross added value generated by the fleets operating along the continental shelf of Mauritania. For the group of small pelagics and cephalopods, the PNBA contributes 13 and 10% respectively, and up to 31% for demersal species and crustaceans classified in the 'other species' category. The contribution of the PNBA, therefore, corresponds to 3.2 billion MRU per year (Table 2). This result shall be interpreted with caution given the various assumptions that were made for the Ecopath model.

3.3. Willingness to accept per sailboat and fishing category

Currently, the total number of active sailboats in the PNBA is 95 out of the 114 authorized to fish in the PNBA. However, throughout the year, one sailboat can target different fisheries depending on the seasons and the respective abundance of fish.

The WTA per fishing category in the PNBA varies between 2.5 and 6 million MRU (Fig. 6). With an average WTA of 0.067 million MRU/sailboat, the Meagre fishery reaches a total WTA of 4.96 million MRU with its 74 active sailboats. The Mullet category, composed of 59 sailboats with an average WTA of 0.10 million MRU, reaches a total WTA of 5.90 million MRU. A total of 18 sailboats form the Sole category, with an average WTA estimated at 0.22 million MRU per sailboat, the total WTA reaches 3.96 million MRU for this fishing category. The Tollo category is exercised by two sailboats with an average WTA of 1.25 million MRU per sailboat. The total WTA is 2.50 million MRU. It is clear that the lesser the number of sailboats per fishery, the higher the value per sailboat.

The Meagre category is the most important in terms of the number of

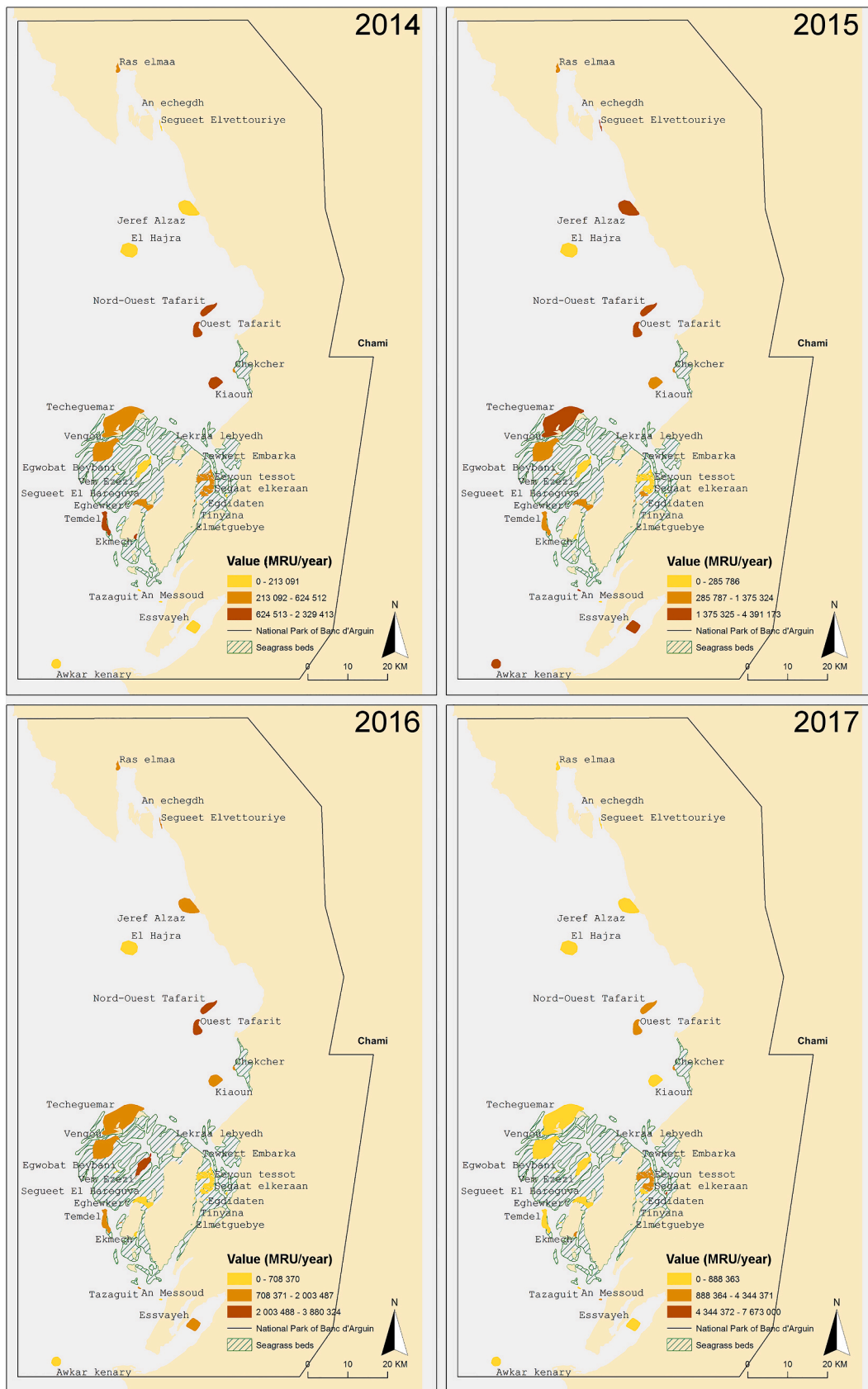


Fig. 2. Annual value per fishing grounds, all gears and targeted species combined, for the period 2014–2017 in the National Park of Banc d'Arguin, Mauritania.

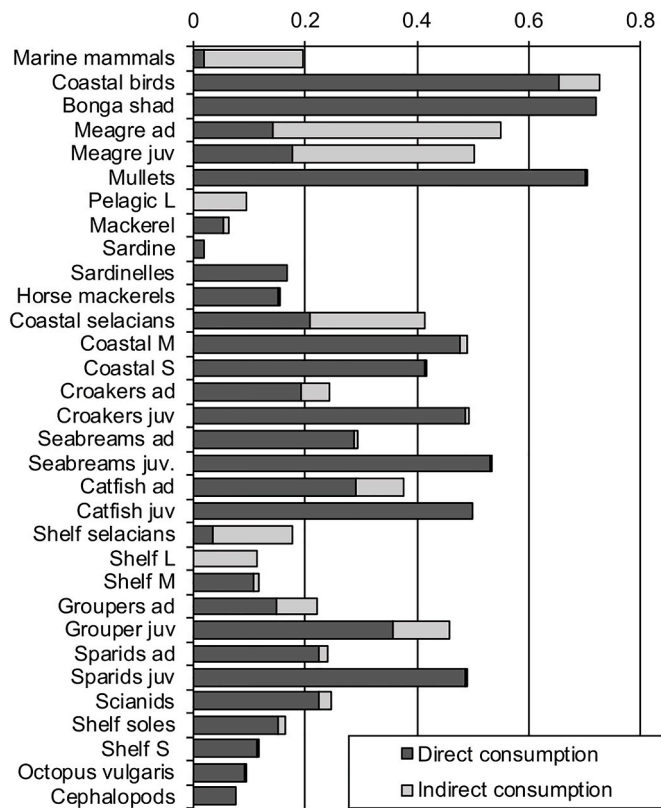


Fig. 4. Portion of the production originating from the National Park of Banc d'Arguin, through direct or indirect pathways, for the 32 Ecopath groups averaged over the period 2016–2018. Fish species have been grouped according to their size (small (S), medium (M) and large (L)) and, for six groups of coastal fish, into two phases: juveniles (juv, age 0–1 year) and adults (ad).

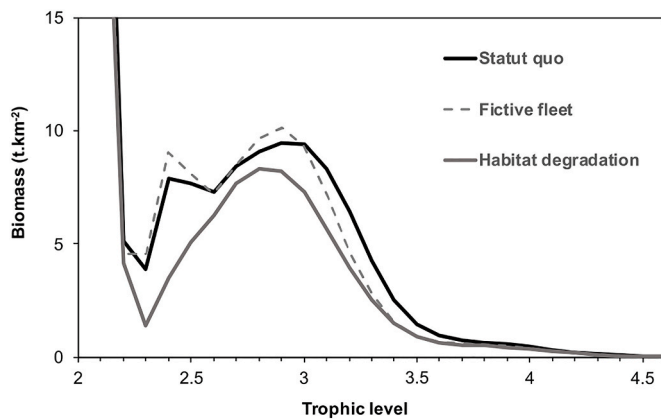


Fig. 5. Biomass spectra for the Base model (Statut quo) and scenario of additional fishing (Fictive fleet) in the National Park of Banc d'Arguin, and habitat degradation.

4. Discussion

4.1. From artisanal to commercial fisheries in the PNBA

The traditional management system for fishing activities is complex. It includes rules of preferential pre-sharing of zones: a sort of territorial limit between villages in the exploitation of mullets, a practice of alternating fishing zones, and the prohibitions of some behaviors in mullet fisheries, based on anthropomorphic grounds. The introduction of the sailboat since the 1960s enabled the Imraguen to improve their catches by going further away into the channels to look for schools of mullet, breaking the dependence of these fishers on the passage of schools of fish near the coast (Pelletier, 1986). The sailboat has become an essential tool in the Imraguen's fishing strategy by contributing to the profound economic and social change in the Banc d'Arguin area (Boulay, 2011; Fall 2014) and has been the determining factor in the extra-version of the Imraguen fishery, that has turned into a commercial fishery since the 1970s.

From 2006 to 2017, the annual catches in the PNBA averaged 2911 tonnes/year, but we observed an overall 42% increase between 2006 (2461 tonnes) and 2017 (3501 tonnes). The annual volume of fish for self-consumption in the PNBA reached on average 56 tonnes, worth 0.7 million MRU per year. It represents 1.87% of the total catches of sailboats and 1.4% of the total value. Despite its small share in production, it represents a significant part of the diet of PNBA populations, on average 43 kg/inhabitant/year, up to 55 kg/inhabitant/year in 2017. As a comparison, the national consumption ranges on average between 6 and 9 kg/inhabitant/year and estimated between 15 and 20 kg/inhabitant/year in the coastal cities of Nouadhibou and Nouakchott (IMROP, 2014). As a reminder, the total catch in 1997 was 500 tonnes in the PNBA. Our results confirm the increased pressure on the PNBA's marine resources.

It is no longer a situation of symbiosis between the Imraguen and their natural environment, nor a seasonal and subsistence harvesting system as described by Worms & Ould Eida, 2002, but a highly capitalistic market system within which most of the profits generated by the fisheries return to boat-owners. Within the Imraguen communities, there is a strong concentration of power in the hands of a minimal number of people. These are, at the same time, traditional and religious authorities, traders, vehicle owners, boat-owners and wholesalers. They also act as funders, making consumer loans, financing fishing operations or access to the means of production. Those multifunctional agents benefit the most from the fishing revenues. Some of them live within the PNBA, but we can safely say that the large margin benefits the outside world. The transfer of benefits out of the Park is all the more real because of the entry into the crews of non-native people whose income goes back to their villages of origin. PNBA fisheries generate an average Gross Operating Surplus of 17.25 million MRU/year. In other words, 36% of the revenue returns to boat-owners. In the PNBA, the captains seldom own the boat for which they are responsible, while a few boat-owners generally have several boats. This situation leads to significant differences in the shares recorded and, over time, leads to an increase in inequalities between fishers and boat-owners (Boulay, 2013). After the crew, it is the owners who profit from the economic value of the PNBA fishery.

Table 2

Economic indicators of industrial fisheries, averaged over the period 2016–2018, in the continental shelf and slope of Mauritania and contribution of the National Park of Banc d'Arguin.

MRU/year	Pelagics	Cephalopods	Other species	Total
Revenue (MRU/year)	27,823,071,010	16,460,450,050	8,029,433,955	52,312,955,014
Intermediate Consumption (MRU/year)	16,693,842,606	9,382,456,528	4,576,777,354	30,653,076,488
Gross Added Value (MRU/year)	11,129,228,404	7,077,993,521	3,452,656,601	21,659,878,526
Contribution PNBA	13%	10%	31%	15%
Gross Added Value PNBA (MRU/year)	1,449,887,399	705,855,624	1,066,781,450	3,248,981,779

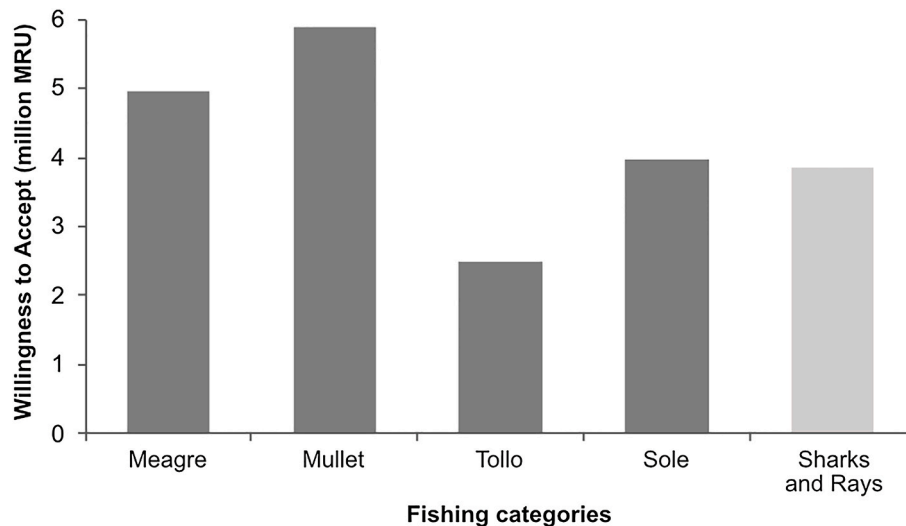


Fig. 6. Willingness to accept per fishing category in the National Park of Banc d'Arguin, Mauritania. The category 'Sharks and Rays' corresponds to the willingness to accept for the ban implemented in 2003.

4.2. Contribution of the park to fisheries in the EEZ

Beyond the added value generated by the PNBA, coastal countries in West Africa are heavily dependent on fisheries resources. Fish stocks in the highly productive EEZ of Mauritania are currently overfished with to this date no sign of recovery (Christensen et al., 2004; Failler et al., 2002; Gascuel et al., 2007; Meissa & Gascuel, 2014). They are highly dependent on the good functioning of the PNBA for their resilience. In addition to fishing pressure, the Mauritanian Institute of Oceanographic Research and Fisheries (IMROP) has observed a significant increase in temperature since 1970, correlated with a reduction in the intensity of the upwelling (Labrosse et al., 2010). These changes in temperature may explain the differences in latitudinal distribution observed for the meagre *Argyrosomus regius*, the cuttlefish *Sepia officinalis* and the ray *Raja straeleni* (Gascuel et al., 2007). Intense fishing activity combined with rapid climate change puts marine ecosystems in West Africa under severe pressure. With the PNBA contributing to 15% of the total added value from fisheries in the EEZ, the degradation of habitats in the PNBA (from climate change, pollution, and fishing practices) would threaten food security in this region despite the current network of marine protected areas in West Africa (RAMPAO) that includes the PNBA.

Yet, MPAs have been proven an effective tool for protecting marine resources against overexploitation and other anthropogenic pressures (Edgar et al., 2014; Kaplan, 2009; Mesnildrey et al., 2013). Our results confirm the benefits of MPAs to coastal fisheries and industrial fisheries. The PNBA protects, to some extent, fish stocks within its borders, and through density-dependent processes, contributes to fish catches in adjacent areas, the shelf and continental slope of Mauritania, as demonstrated elsewhere in other studies (Goñi et al., 2008; Murawski, Wigley, Fogarty, Rago, & Mountain, 2005; Russ et al., 2003). The role of MPAs in providing fisheries benefits is still debated because the results are often context-dependent (Hilborn et al., 2004; Hugues et al., 2016). After all, the spill-over effects can be very localized or limited by migration, and fish stocks could only benefit from protected areas of sufficient size (Colléter et al., 2014; Mesnildrey et al., 2013). Our results confirm that fish stocks in the EEZ of Mauritania benefit from the largest MPA of West Africa: the PNBA. Our results gave very similar dependency between the PNBA and the Mauritanian ecosystems. Over the period 1991–2006, the contribution of the PNBA was estimated at 18% (Guénette et al., 2014) while our updated model indicates 15%. More specifically, the slight decrease is observed for pelagics (13% instead of 16%) and cephalopods (10% instead of 14%). The groups that are most dependent on the PNBA according to the model are the meagre, the

mullet, the sardinellas and the horse mackerel. The decrease in the biomass of sardines and sardinellas (from 11.79 to 2.90 t/km² and from 18 to 9.35 t/km² respectively) was probably compensated by the increase in the biomass of mackerel and horse mackerels (from 1.45 to 6.79 t/km² and from 10 to 19 t/km² respectively) following the improvement of acoustic survey derived indices. The decrease in biomass for some groups are balanced by the increase for others (but see Table A1 and Guénette et al., 2014 for further comparisons). It could explain the similarity of the assessments obtained on the role of the reserve. The importance of the PNBA for the continental shelf and slope depends on the diet information and the assumptions made about their behaviour. As mentioned by Guénette et al. (2014), more information on benthos biomass and diet compositions at various times of the year, and locale could modify our findings.

The development of scenarios, here the increased fishing activity or the degradation of habitats in the Park, confirmed the findings of Guénette et al. (2014) and showed how local management strategies could have larger consequences at national and international scales. Allowing a higher fishery effort inside the PNBA would lead to a decrease in the mean trophic level of the catch. Even though the total biomass might increase inside the Park, the economic loss for industrial fisheries outside the PNBA would be greater. As a future research avenue, it would be interesting to develop more elaborate scenarios to determine the dependency of Mauritania fisheries with the PNBA and explore the linkages between the PNBA and the broader Mauritanian ecosystem. For instance, how the closure of sharks and rays fisheries could benefit PNBA trophic web and beyond could provide clearer evidence to fishers and support the development of adaptive management measures. Our Ecopath model provided an 'instantaneous' estimate of biomasses, trophic flows, and instantaneous mortality rates, for a 2016–2018 averaging window. This model assumes biomasses need not be at equilibrium for the reference year.

4.3. Fisheries management and conservation of habitats

The assessment of fishing supply services, among the other ecosystem services (Trégarot et al., 2018) can be seen as the willingness of the PNBA authorities to review the zoning to spatialize the restrictions and possible uses in the Park. Zoning makes it possible to confer a vocation on each zone of the Park according to its ecological importance to mitigate the external and peripheral threats (PNBA, 2014). The revision of the zoning, based on this work constitutes a mean of preserving the biodiversity of the PNBA, the cultural dimension of fishing

activities and the integration of the PNBA into national sectoral strategies for the development of fisheries in Mauritania. Compensation measures must be taken in favour of fishers, illustrated by their willingness to accept, if their activity should be set aside while helping them to develop alternative activities to reduce pressures on fishery resources (Alban & Boncoeur, 2004, pp. 185–204).

More importantly, the Imraguen should be part of the concertation process given their knowledge and adaptability over the years. The history of concertation in the PNBA reflects the complexity of managing a resource with multiple challenges. During the period 1999 to 2006, the Imraguen adhered progressively to the rules of management of the fisheries and gained awareness regarding the biological interest of preserving the selacians. The signing of a moratorium in 2003 was, without doubt, the most important and symbolic decision that the PNBA and its partners were able to obtain from the Imraguen. Without the financial compensation and the numerous local development projects in their favour, it would have been difficult, if not impossible, to foresee such a scenario of social acceptance of the rules of fisheries management. However, despite the conservation plan, the level of by-catch with other fishing gear was still high, and the Imraguen have continued to capture sharks and rays that currently constitute a large majority of the catches (Brahm, 2015). It is very difficult to avoid shark catches. Despite the repurchase of gears to fishers that specifically targeted sharks, which corresponds to the amount spent in 2004 to stop this fishery, other gears such as the Tollo and Meagre nets makes it possible to capture large quantities of sharks at the northern sites of the PNBA, from the villages of Ten Alloul, Arkeiss and Agadir (Brahm, 2015).

Although the Imraguen know the catch rules well, they take advantage of leeways in the regulations to get around the rules. The devices that capture in an untargeted way participate in these strategies. This situation recalls the façade consensus, described by some ethnologists and by many development experts, thus describing the villages as homogeneous and united communities, who would share the same vision of the world and would be cemented by a common tradition and culture (Bierschenk et al., 1998). The creation of a fisheries monitoring committee, a decision-making body supposed to establish rules for sustainable management of fisheries in a joint agreement with PNBA managers, in 2006, has proved unable to influence the fishing of selacians. The concertation workshops that followed between 2006 and 2017 also failed to restore the trends in catches of selacians before 2006 (Ly, 2018).

However, sharks have been captured essentially with the Tollo and Meagre nets since 2000. Moreover, a strong seasonality is observed in the capture of sharks, with 75% of annual capture of sharks occurring between May and June, over the period 2015–2019 (Brahm, 2020). One management option could be to limit the use of Tollo and Meagre nets between May and June. Moreover, additional zoning could be implemented if sharks are mostly captured in the northern sites of PNBA. This management option would require additional surveillance effort during this period.

The total WTA to stop the main fishing categories, estimated at 17.5 million MRU, represents the heritage value of the central Imraguen fisheries in the Banc d'Arguin National Park. Beyond the added value produced by the fishing, the WTA illustrate the attachment that the Imraguen have for their natural environment. A more in-depth survey with more elaborate scenarios and including a larger sample of interviewees would be a valuable addition to this preliminary result to estimating the willingness of Imraguen to accept further zoning or the limitation of fishing efforts between May and June for instance. The amount spent in 2004 to stop the sharks and rays' fishery was much higher than the WTA for the Tollo category, one of the most productive in the PNBA, revenue-wise.

While some species may have suffered from targeted fisheries in the past (i.e., sharks and rays for finning practices), further studies are required to investigate the sustainability of artisanal fisheries within the PNBA, as this activity became commercial-oriented. In addition to

protecting productive ecosystems like seagrass beds, the establishment of programs for the conservation of charismatic species (birds, turtles, sharks and rays, marine mammals, etc.) is required since they make it possible to direct efforts towards species located at the top of the trophic chain and thus give indications on the state of health of the environment. Despite the protection status of the PNBA and the low level of the human population on the coast, the populations of birds and selacians are decreasing, and the fish migration routes are changing. If the classic indicators of population abundance or specific wealth are commonly used, they do not provide information until too late about damage and damage to the environment. Other biodiversity indicators, based on the functional traits of the species, more sensitive to disturbances (Loiseau & Gaertner, 2015), should be used. The programs for the protection of emblematic species must, therefore, be supplemented by broader and long-term programs intended for the preservation of coastal and marine habitats.

5. Conclusion

Fishing is essential to the Mauritanian economy. It accounts for 10% of the Gross Domestic Product and between 35% and 50% of Mauritanian exports (Martín, 2010). However, this strong economic incentive has led to a situation of overfishing in the continental shelf, and within the National Park of Banc d'Arguin, an increased fishing pressure, environmental degradation, and social inequalities. The conservation and development policies carried out in the National Park of Banc d'Arguin are deadlocked. The result of this situation is threefold: the conservation actions of the PNBA are poorly received, with limited compliance by the fishers because suitable economic alternatives did not accompany them. The socio-economic conditions of the majority of Imraguen families are deteriorating. The economic resources generated in the Park are both highly dependent on external markets and almost systematically reinvested outside (the phenomenon of extraversion developed by Failler et al., 2010), and therefore do not benefit the improvement of living conditions in the Park (Boulay, 2011). An effective and efficient co-management of the protected area requires a rebalancing of powers, but also the training of young generations of inhabitants who would soon be able to actively participate in the management of the PNBA.

Given the transformation of the relations between the Imraguen and their ecological environment, marked by their insertion in the commercial circuits, estimating the value of the PNBA for fisheries aims at reaching a broader context by integrating the PNBA into national and regional policies of fisheries management and development. It is also essential to consider the "socio-ecosystem" (Collins et al., 2011) of the PNBA as one entity for implementing more integrated governance, and for creating a more reliable science, decision making, and practice interface (Bremer & Glavovic, 2013).

Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.aaf.2020.08.004>.

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