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Baited Remote Underwater Video (BRUV) surveys show threatened ichthyofauna associated with marine vegetation in the largest Marine Protected Area of West Africa, the National Park of the Banc d'Arguin



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Baited Remote Underwater Video (BRUV) surveys show threatened ichthyofauna associated with marine vegetation in the largest Marine Protected Area of West Africa, the National Park of the Banc d'Arguin

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ABSTRACT

Marine Protected Areas (MPAs) play a crucial role safeguarding marine ecosystems and their diversity. A major challenge in MPA management is efficient monitoring of biodiversity inside MPAs, and if it is linked local habitat structure. Diverse low impact ecosystem monitoring methods have been used in the recent decades, including underwater visual censuses, fishing surveys, and Baited Remote Underwater Video surveys (BRUVs). In the face of declining demersal fish populations, to understand their association to structural benthic habitats, this research undertakes a pioneering investigation within the Banc d'Arguin National Park (PNBA), Mauritania, employing BRUV surveys to comprehensively assess fish biodiversity and abundance across various habitats. A total of 62 fish species were identified, significantly more during daylight hours and in the autumn season, potentially linked to sampling effort and environmental factors. Vegetated habitats, particularly seagrass meadows, demonstrated higher fish abundance and diversity. The use of bait was needed to detect rare predatory species, but also induced biases towards carnivore-rich communities, preventing quantitative comparison of trophic level abundances. Most identified species are classified as Least Concern (IUCN), but local-scale assessments of potential population shifts are missing. Elasmobranchs featured prominently, emphasizing their conservation significance within this dynamic marine park, and their role in ecosystem stability. Finally, observed spatial differences in fish abundance and biodiversity suggested an influence of habitat type and protection level on demersal fish assemblages. This study thus contributes valuable insights into the ecology of demersal fish communities in the PNBA, emphasizing the need for adaptive conservation strategies and further research to ensure sustainable fisheries and species preservation in this critical marine environment.

Keywords: ichthyofauna identification, BRUVs, West Africa, MPA monitoring, endangered species, shark and ray conservation

RESUMO

As espécies de peixes demersais desempenham um papel crucial nos ecossistemas marinhos devido aos seus significativos benefícios socioeconômicos e importância ecológica. No entanto, estas espécies valiosas têm experimentado declínios alarmantes em escala global, levantando sérias preocupações quanto à sustentabilidade a longo prazo das suas pescas. A criação de Áreas Marinhas Protegidas (AMPs) emergiu como uma estratégia crucial para a gestão sustentável das pescas e a conservação da biodiversidade. Nos últimos anos, técnicas de monitorização alternativas, como transectos subaquáticos conduzidos por mergulhadores, amostragem de DNA ambiental (eDNA), pesquisas com vídeo remoto subaquático com isco (BRUVs), drones subaquáticos e *remote sensing*, têm surgido como metodologias não invasivas para monitorizar a abundância e biodiversidade de peixes.

Entre as mais importantes e sendo a maior das Áreas Marinhas Protegidas na África Ocidental, está o Parque Nacional do Banc d'Arguin (PNBA) localizado na Mauritânia. Foi criado em 1976 e este parque inclui habitats diversos e muito ricos em espécies, como as pradarias de ervas marinhas as quais cobrem por volta do 41% da superfície do Parque Nacional. Desempenham um papel vital na proteção das espécies de peixes demersais, atuando como importantes berçários, refugio, área de reprodução e de alimentação. Portanto, compreender a biodiversidade e abundância de peixes dentro do PNBA e nos seus diferentes habitats, torna-se crucial para o planeamento eficaz da conservação e gestão deste parque marinho. Os Imraguen são os únicos com autorização para praticar a pesca artesanal no Parque Nacional com os seus barcos de vela e técnicas tradicionais. No início a pesca praticada pelos Imraguen era de subsistência, mas virou para fins comerciais. Por causa do declínio na pesca de espécies muito importantes para eles como são as tainhas família Mugilidae e as corvinas-legítimas *Argyrosomus regius*, os pescadores tem começado a explorar outras espécies incluídas espécies em perigo de extinção de rayas e tubarões. Este estudo teve como objetivo comparar a biodiversidade e abundância de espécies de peixes em áreas vegetadas e não-vegetadas em diferentes locais do parque marinho ao longo de diferentes estações, identificar espécies de especial interesse, como elasmobrânquios ameaçados de extinção, e descrever como as espécies usam os diferentes habitats dentro do PNBA.

O estudo foi conduzido no Parque Nacional do Banc d'Arguin na Mauritânia, abrangendo diversas áreas, incluindo pradarias de ervas marinhas, áreas cobertas de algas e áreas de areia. O método de amostragem utilizado foi o sistema de vídeo submarino remoto com iscas (BRUV), que permitiu a identificação das espécies de peixes. Um total de 12 pontos diferentes foram selecionados, e os BRUVs foram implantados em transectos lineares em cada ponto, separados 250 metros entre si para evitar interações dos mesmos indivíduos em mais de um BRUV. A análise de vídeo foi realizada para quantificar a abundância de peixes usando o método MaxN, que representa o número máximo de peixes da mesma espécie observados em um único quadro da gravação.

Foram identificadas 62 espécies de peixes usando BRUVs, sendo a maioria delas encontrada em habitats vegetados, como pradarias de ervas marinhas. A análise revelou que a maioria das espécies identificadas eram carnívoras. Mais de três quartos das espécies identificadas foram classificadas como "Menos Preocupante" na Lista Vermelha da IUCN. No entanto, algumas espécies de elasmobrânquios e teleosteos foram identificadas, incluindo algumas em estado de ameaça, como " criticamente Em Perigo" e "Vulnerável".

A análise estatística mostrou diferenças significativas na abundância de peixes entre locais, com alguns locais tendo maior abundância do que outros. Além disso, foram identificadas diferenças significativas na

abundância de peixes entre diferentes locais, encontrando-se a maior abundância de peixes e a maior diversidade como é no caso de Cap Tagarit, Arkeiss, Arel e Moj Dahna, as quais são zonas com grandes extensões de pradarias de ervas marinhas. Isso destaca a importância de considerar a heterogeneidade do habitat na gestão e conservação do PNBA.

Não foram encontradas diferenças significativas na abundância de peixes entre diferentes estações do ano. Além disso, as pradarias de ervas marinhas foram os habitats com a maior abundância de peixes e maior biodiversidade.

Os resultados deste estudo demonstram que o método BRUV é eficiente para monitorar a biodiversidade de peixes em diferentes habitats do Parque Nacional do Banc d'Arguin. Foi observada uma maior diversidade de espécies em habitats vegetados, especialmente pradarias de ervas marinhas. No entanto, a presença de iscas nos BRUVs pode atrair predadores carnívoros, o que pode distorcer a composição das espécies observadas. A análise estatística revelou diferenças na abundância de peixes entre diferentes locais, destacando a importância de considerar a variação espacial na gestão de áreas marinhas protegidas. A identificação de espécies de elasmobrânquios em risco destaca a necessidade de medidas de conservação mais robustas para essas espécies.

Este estudo pioneiro de monitorização de peixes dentro do PNBA usando os BRUVs como método de amostragem, contribuiu para especificar uma lista de 62 espécies de peixe. É importante ressaltar que, embora muitas das espécies identificadas tenham sido classificadas como de "Menor Preocupação" pela Lista Vermelha da IUCN, a falta de informações atualizadas sobre as tendências populacionais locais e a exploração crescente das pescas na área enfatizam a necessidade de continuar a monitorização a curto e longo prazo para avaliar o estado real das populações de peixes no PNBA e garantir a sua conservação a nível local.

Em conclusão, este estudo fornece informações valiosas sobre a biodiversidade e abundância de peixes em diferentes habitats do Parque Nacional do Banc d'Arguin, na Mauritânia, usando o método BRUV. Os resultados destacam a importância das áreas vegetadas, como as pradarias de ervas marinhas, para a conservação de peixes demersais. Além disso, a identificação de espécies ameaçadas enfatiza a necessidade de medidas de conservação direcionadas. Este estudo pode servir como base para a gestão sustentável das pescarias e a conservação da biodiversidade marinha na região do PNBA com uma gestão conjunta com os pescadores Imraguen. Futuras pesquisas podem se concentrar em avaliar o impacto das AMPs e outras medidas de conservação na recuperação das populações de peixes e elasmobrânquios ameaçados.

Palavras chave: identificação de ictiofauna, BRUVs, Africa Topical do Oeste, monitorização, Areas Marinhas Protegidas, espécies em perigo de extinção, raias e tubarões

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ABBREVIATIONS

MPAs – Marine Protected Areas

CBD – Convention on Biological Diversity

UNEP – United Nations Environment Program

IUCN – International Union for Conservation of Nature

FAO – Food and Agriculture Organisation of the United Nations

PNBA – Parc National du Banc d'Arguin

Chl-a – Chlorophyll-a

BRUVs – Baited Remote Underwater Video surveys

URUVs – Unbaited Remote Underwater Video surveys

eDNA – Environmental DNA

MaxN – Maximum number of individuals for a certain species identified/counted in a single video frame

LC – Least Concern

NT – Near Threaten

VU – Vulnerable

EN – Endangered

CR – Critically Endangered

DD – Data Deficient

State-of-the-art

1. Marine Protected Areas (MPAs) for Conservation

1.1. Overview

In recent decades, the decline in ocean productivity has underscored the critical role of Marine Protected Areas (MPAs) in global conservation efforts (Smith et al., 2012; Grorud-Colvert et al., 2021). MPAs are designated areas strategically established to safeguard marine ecosystems, protect biodiversity, and promote sustainable use of marine resources (Hastings and Botsford, 2003; Lester et al., 2009). The significance of MPAs in conservation has been recognised internationally, leading to a growing number of MPA designations worldwide (Edgar et al., 2014; Davies et al., 2022).

Nevertheless, there is an urgent need for more enhanced conservation measures, and thus the global community has set ambitious targets to expand MPAs (Brander et al., 2020). The Convention on Biological Diversity (CBD), under the United Nations, aims to protect at least 30% of the global ocean by 2030 through the establishment of highly protected MPAs (CBD, 2021; Davies et al., 2022). This commitment, known as the "30x30" target, seeks to safeguard marine biodiversity, enhance ecosystem resilience, and support sustainable fisheries (Kubiak, 2020; O'Leary et al., 2021).

Efforts to expand MPAs have gained momentum through regional collaborations as well, which requires improvement in management and effectiveness (Muallil et al., 2019; Handayani et al., 2022). The United Nations Environment Program (UNEP) and the International Union for Conservation of Nature (IUCN) have partnered with various organisations to promote the implementation of MPAs at the regional level, such as the Caribbean Challenge Initiative and the Coral Triangle Initiative (UNEP and IUCN, 2013).

The importance of effective fisheries management within MPAs cannot be overstated (Weigel et al., 2014). Approximately 80% of the world's fish stocks are either fully exploited or overexploited, hence highlights the urge for sustainable fishing practices (FAO, 2020). By enforcing regulations within MPAs, such as fishing restrictions and habitat protection measures, the conservation goals of MPAs can be achieved while simultaneously supporting the recovery of fish populations and maintaining ecological balance (Halpern et al., 2019). Some recent studies show the recovery of certain fish stocks globally and give reason for optimism (Memarzadeh et al., 2019),

1.2. Importance of Fish Assemblages and Specific Ecosystems

Fish assemblages within MPAs provide very important ecological services (Chakraborty, 2017), holding both socioeconomic and ecological significance (Claudet et al., 2006). Demersal fish contribute to the overall health and functioning of marine ecosystems (Mumby et al., 2014). They support commercial and recreational fisheries, providing economic opportunities and food security for coastal communities (Allison et al., 2003). Ecologically, fish assemblages play a vital role in maintaining the stability of marine food webs and nutrient cycling (Pikitch et al., 2004). Furthermore, MPAs and no-take reserves are particularly important with species that are sedentary and do not have a dispersing larval stage (Di Lorenzo et al., 2016). Fish may use different habitats along their life-cycles (Gristina et al., 2017), so including different types of habitats when determining MPAs is crucial for a more efficient management (Honda et al., 2013).

Thereby, understanding the ecological importance of fish assemblages within MPAs (Claudet et al., 2006) and describing the habitat use of those species (Honda et al., 2013) helps to enhance conservation strategies.

1.2.1. Marine forests

Marine forests are crucial as ecosystem engineers and are extremely sensitive to changes in water quality, coastal development, and herbivore outbreaks (Gianni et al., 2013). Their conservation is fundamental for ensuring valuable socioeconomic resources, such as fisheries (Eger et al., 2021). However, they have faced numerous threats in the past decades and significant declining of their extensions has happened worldwide (Gibson et al., 2007). Climate change and the increase in the amount of extreme climatic events and their magnitude, poses a threat to these ecosystems (Smale et al., 2013). Establishing MPAs is crucial for ensuring the restoration of lost and degraded surfaces and for effective management of the different types of marine forests (Gianni et al., 2013).

1.2.1.1. Marine forests in the Parc National du Banc d'Arguin (PNBA)

Seagrass meadows

Seagrass meadows are formed by underwater flowering phanerogam plants, which are specific ecosystems within MPAs, that not only support the ecological resilience of fish populations but also serve as indicators of environmental health (Orth et al., 2006). Seagrasses appear at a global scale in all different latitudes, except in Antarctica (Kennedy and Björk, 2009), and there are around 60 species (Deguette et al., 2022). In temperate regions, there are fewer species of seagrass and there is a tendency to have a dominant species. In contrast, tropical regions contain greater species diversity and there is no clearly dominant species.

Seagrasses are of particular importance for reducing coastal erosion by buffering the wave impact (Ondiviela et al., 2014), for removing excess nutrients and pollutants from the water and for sequestering and storing carbon in the sediment, also known as blue carbon (Cheikh et al., 2023). By removing particles from the water, they allow more light to penetrate the water column optimizing photosynthesis rates for themselves and other photosynthetic species (Deguette et al., 2022). Seagrass meadows also serve as essential nursery habitats for numerous fish species, facilitating their reproduction, growth, and survival (Nordlund et al., 2018). By studying fish dynamics within seagrass habitats, valuable insights can be gained for effective fisheries management and conservation efforts of fish species and their populations (Honda et al., 2013). Their role is thereby undeniable even if they only cover around 0.1% of the worldwide seabed (Duarte, 2002), since they represent a very important percentage of the global NPP and carbon sequestration (Duarte and Krause-Jensen, 2017). In the case of the PNBA, the three seagrass species present are *Zostera noltei*, *Cymodocea nodosa* and *Halodule wrightii* (Chefaoui et al., 2021). Tregarot et al. (2021) estimated the intertidal seagrass area of the National Park in 67.400 ha using 518 Landsat image, what later Pottier et al. (2021) using Sentinel2 and Chefaoui et al. (2021) using a model calculated the seagrass meadows covered around 500.000 ha (the estimation included the top subtidal zone of the meadows). That means that seagrass meadows cover around 41% of the National Park (total area = 12 000 km²).

However, seagrass meadows are the most threatened ecosystems mainly due to eutrophication and changes in light incision, but also trawling (Krause-Jensen et al., 2021). Climate change and global warming have a

direct influence in the pH of the ocean, which has consequences in seagrass metabolism, affecting their resilience and thereby affecting their growth and recovery rates (Hughes et al., 2018).

Although seagrasses are not calcifying organisms, they live in direct interaction with many benthic calcifying species that live on their leaves and close by. All those organisms depend on a pH range to be able to calcify, so if the pH changes their calcifying capacity may be compromised. Bergstrom et al. (2019) have found that in acidifying oceans the seagrass species *Halodule wrightii* did not decrease its photosynthetic rates and its close proximity helped aid the seaweed *Halimeda cuneata* in calcification rate maintenance. Therefore, conservation efforts that have grown at a global scale in the past decades are not only important for seagrasses but also for all the organisms that depend on seagrass meadow ecosystems (Cullen-Unsworth and Unsworth, 2013).

2. PNBA as a Marine Protected Area (MPA)

2.1. Overview of the MPA

The Parc National du Banc d'Arguin (PNBA) is a huge coastal wetland located in Mauritania in West Africa, along the West African coast between Cap Blanc (20°46'N-17°02'W) and Cap Timiris (19°23'N-17°02'W) (Araujo and Campredon, 2016). Spanning approximately 12,000 square kilometres, it is one of Africa's largest and most important Marine Protected Areas (MPAs), which is delimited on the eastern side by the Sahara Desert (Médina et al., 2016). The last glaciation flooded the Gulf of Arguin, creating a freshwater lake which led to the occurrence of freshwater fish species (Araujo and Campredon, 2016). The presence of some species such as tilapia and catfish are direct indicators of the past brackish waters of an ancient estuarine environment.

Established in 1976, the PNBA is renowned for its rich biodiversity and serves as a critical habitat for a wide range of species. This includes an array of migrating and wintering bird species that breed on the sand banks (Wolff and Smit, 1990). It is also characterised by its unique ecological features, shaped by the deserted and remote conditions of the area, with remarkable sand and dust storms occurring year around and influencing the atmospheric particle density (Araujo and Campredon, 2016). This phenomenon also influences the particle density in the water, directly influencing the availability of nutrients coming from the sand desert (Herut et al., 2005). However, it can also lead to bad visibility conditions in the sea for certain visual analysis studies.

The park consists of shallower water of less than 10 m containing a series of sand islands, channels, mudflats, sandbanks, islands and islets, which are subject to the influence of tides, wind, and currents (Araujo and Campredon, 2016; El-Hacen et al., 2019). The PNBA has mainly soft sediments made of sandy and muddy areas, having only a few rocky places close to capes (Araujo and Campredon, 2016). That composition will affect the distribution of the different habitats present in the park. These dynamic processes contribute to the formation and maintenance of extensive seagrass meadows, which provide important feeding and breeding grounds for numerous marine species (Catry et al., 2023).

Regarding the general hydrology of the area, the PNBA has different current influences (Wolff and Smit, 1990; Araujo and Campredon, 2016). It is affected by the Canary Current from the north in the winter, the Equatorial Current from the south in the summer and cold-water upwelling throughout the year. When this

water is transported inside the PNBA, evaporation occurs and a salinity gradient appears from west to east, with the highest salinity waters around Iwik (El-Hacen et al., 2018). This may have an influence in the biodiversity occurrence, even at a macrobenthic level.

The PNBA has three main industrial threats: on the northwest off the city of Nouadhibou there are hundreds of international trawlers operating (Corten et al., 2017) and there are ongoing oil prospections; and in the eastern border there is a new gold mine (Araujo and Campredon, 2016). In the case of the trawlers, they provoke significant losses of bottom habitats like seagrass meadows (Meyer et al., 1999; Turschwell et al., 2021). Considering all of the previous ecological characterisations and human influences, including the threats, the species distribution will be directly conditioned in land and sea.

2.2. Fisheries in PNBA

The Imraguen (i.e., ‘those who gather life’) are a well-established local population in the PNBA (Araujo and Campredon, 2016; Lemrabott et al., 2023). They are an indigenous resident community of fishermen who practice subsistence fishing and are the only ones allowed to operate in the National Park, using sail boats (Trégarot et al., 2020). In addition, the only fishing techniques allowed are line fishing and net fishing, in which nets are done with natural materials such as linen or cotton but can never be monofilaments done with nylon or polyester (Lemrabott et al., 2023). However, the sustainability of their fisheries is in danger. What was once solely for subsistence has now expanded to include commercial purposes since the 80s (Lemrabott et al., 2023), increasing the total catches of fish per year (Ly and David, 2021).

Since the foundation of the National Park, 257 fish species have been identified (Trégarot et al., 2020), among which 39 occur exclusively within Mauritania (Araujo and Campredon, 2016). Commercially important fish species use the PNBA in their migration route, being the case of the Mugilidae family, or as a spawning area in the case of *Argyrosomus regius* (Araujo and Campredon, 2016). In most cases, the species of interest for the fishermen are rays (*Rhinoptera marginata* and *Rhinobatos cemiculus*), mullets (*Mugil cephalus*), catfish (*Arius parkii*, *Arius laticulatis* and other Ariidae), tilapia (*Sarotherodon melanotheron*), sharks (*Rhizoprionodon acutus* and *Sphyrna lewini*), meagre (*Argyrosomus regius*), law croaker (*Pseudolithus senegallus*), king mackerel (*Scomberomorus tritor*) and the sea bream (*Diplodus sargus*) (Trégarot et al., 2020). The catches of the traditional species (mullet and meagre) have declined, and that has driven the Imraguen to focus on other species (tilapia and catfish) in the case of bony fish but also in elasmobranchs (Lemrabott et al., 2023). Elasmobranchs have a high price in the international markets on other West African markets, so this provides an economical alternative to the local fishermen (Ly and David, 2021; Lemrabott et al., 2023). But this changes in fisheries may suppose a problem long term, so a collective management is essential for ensuring their livelihood and long-term sustainability of targeted fish species.

The most valuable fishing grounds are the ones closer to the shore, where there are seagrass meadows present (Trégarot et al., 2020), which enhances the importance of these ecosystems for the local economy and the conservation of many species. Habitat loss and degradation could mean a significant loss in artisanal and coastal fisheries, being the livelihood in the country (Ly and David, 2021).

2.2.1. Elasmobranchs

The PNBA supports a diverse array of marine species, including elasmobranchs, which encompass sharks and rays (Araujo and Campredon, 2016). These species play a crucial role in maintaining the balance and health of marine ecosystems (Ferretti et al., 2010; Worm et al., 2013). However, the conservation status of many elasmobranch species is a matter of concern nowadays, based on population assessments and conservation status classifications for species around the world (IUCN) (Catry et al., 2023).

It is important to note that the status of many elasmobranch species may have not been updated in terms of their IUCN assessments in the past decade, and thus, there is a need for updated information on their population (Dulvy et al., 2014; Simpfendorfer et al., 2020). Elasmobranchs are particularly vulnerable to overfishing and habitat degradation due to their slow growth, late maturity, and low reproductive rates (Dulvy et al., 2014). As a result, several elasmobranch species within the PNBA and globally are classified as critically endangered or threatened on the IUCN Red List (Chefaoui et al., 2021).

The significance of elasmobranchs in marine ecosystems cannot be understated (Cortés et al., 2008). They occupy various ecological roles, including apex predators, mesopredators, and bottom-dwelling species (Sreekanth et al., 2022). Elasmobranchs help regulate the populations of prey species, thereby maintaining the balance and biodiversity of marine food webs (Ferretti et al., 2010; Worm et al., 2013). Their presence also influences the behaviour and distribution of other species, shaping the structure and functioning of entire ecosystems.

Unfortunately, shark and ray populations are severely threatened by the practice of finning, which involves removing the fins from these animals and discarding the remainder of their bodies at sea (Schaper, 2012). The demand for these fins, primarily driven by the Asian market, has led to the overexploitation of shark and ray populations worldwide (Clarke et al., 2006; Clarke et al., 2013). Although the Asian market is the primary consumer, it is important to acknowledge that European fleets and countries may also be involved in shark and ray finning and serve as intermediaries in the exportation process (Hareide et al., 2007). Even if in the PNBA only the Imraguen were allowed to fish for subsistence purposes, the commercial purposes have increased in the last decades the landings of elasmobranchs (Trégarot et al., 2020). Elasmobranchs represent 35% of the fish landings being the most abundant species, despite the existing regulations since 2003.

Efforts to combat shark and ray finning and protect these vulnerable species have gained international attention (Iloulia, 2016). Various conservation organisations and regulatory bodies have implemented measures to reduce finning, such as requiring sharks to be landed with their fins naturally attached (Iloulia, 2016; Ferretti et al., 2020). However, further action is needed to enforce these regulations and address the underlying issues driving the demand for fins (Clarke et al., 2006; Clarke et al., 2013).

The PNBA is a very important area for elasmobranchs, since it is the only estuarine ecosystem between Europe and tropical Africa (Araujo and Campredon, 2016). Therefore, the park is of vital importance for species such as *Sphyrna* sp., *Glaucostegus cemiculus* and other guitarfish species. But given the conservation efforts done in the area populations of *Pristis* sp. that were very abundant before the establishment of the National Park, and whose populations could not be recovered since 1976.

2.3. Birds, marine mammals and turtles

Alike for fish species, the PNBA is a very important conservation site for turtles, marine mammals and sea birds (Araujo and Campredon, 2016; Hama et al., 2019; Trégarot et al., 2020). The National Park was declared after the importance the sand islands have for the birds (Araujo and Campredon, 2016). The sand banks in the PNBA are very important wintering grounds for different purposes (breeding, feeding...) for migratory birds, that spend the summer in Europe (Ens et al., 1990; Catry et al., 2023). Since the fifteenth century, huge colonies of seabirds and waders have been reported in the Gulf d'Arguin. Some species such as the Eurasian spoonbill, *Platalea leucorodia*, use the sand banks for breeding, and others such as *Egretta gularis* use the few mangrove trees present in them for nesting purposes (Araujo and Campredon, 2016). However, the bird populations present in the PNBA have decreased significantly in the past decades. Based on censuses done by Oudman et al., 2017 and Oudman et al., 2020 general bird count trends have decreased in the PNBA since the 80s. There may be different factors contributing to the decrease in bird numbers: changes in the food webs, effects of commercial fishing of some fish species, climate change effects on Arctic regions, and deterioration and disturbances along the migratory routes (Oudman et al., 2017; El-Hacen and Kidé, 2020). The reasons for that are yet to be understood (Araujo and Campredon, 2016; Oudman et al., 2020). Therefore, more precise long-term general and species-specific counting and studies to better understand changes in benthos assemblages, fish populations and possible changes in very important habitats for them like seagrass meadows are needed.

A few marine mammal species have been identified over the years in the PNBA, such as *Monachus monachus*, *Sousa teuszii*, *Orcinus orca* and *Tursiops truncatus* (Pinela et al., 2010). The distribution of the species changes, depending on the habitat. However, *S.teuszii* is the most abundant species inside the National Park (Araujo and Campredon, 2016). Both *M.monachus* and *S.teuszii* are coastal apex predators that are very important for ensuring trophic balances (Daskalov, 2002; Pinela et al., 2010), so their conservation should be a priority in the PNBA.

Four of the seven existing sea turtle species have been reported in Mauritania including green turtles (*Chelonia mydas*), leatherbacks (*Dermochelys coriacea*), loggerheads (*Caretta caretta*) and olive ridleys (*Lepidochelys olivacea*) (de la Hoz Schilling et al., 2023). All four species have been classified to some extinction threat level at a global scale by the IUCN Red List of Threatened Species (IUCN, 2022). Thereby the PNBA may play a crucial role in the conservation of the green turtles that feed in the extensive seagrass meadows present in Mauritania (Araujo and Campredon, 2016). However, both the industrial fisheries practiced out of the National Park and the artisanal fisheries practiced in the PNBA, have reported turtle bycatch in the past decades and are a threat to their population management (de la Hoz Schilling et al., 2023).

3. Methods for biodiversity estimation and conservation

3.1. Overview

Various monitoring methods have been employed to assess ichthyofauna biodiversity within MPAs, both to manage fishing stocks and for conservation (Pereira et al., 2017). These methods may include fishing surveys, visual underwater transects conducted by scuba divers, baited remote underwater video systems (BRUVs), underwater drones and satellite remote sensing (Guidetti et al., 2014; French et al., 2021). These

different monitoring methods provide complementary information about the ichthyofauna biodiversity within MPAs, allowing for a comprehensive assessment of fish populations and their associated habitats.

Fishing is a traditional method used to monitor fish populations within MPAs, which involves the use of fishing gear such as nets, traps, or hooks to capture fish (French et al., 2021). This method provides valuable information on species composition, abundance, and size distribution, especially on the slow-moving species that live in the seagrass canopies (Harmelin-Vivien and Francour, 1992). However, fishing has several limitations, including selectivity biases towards certain species, but also the potential for habitat damage, the disturbance or mortality of captured individuals and fish that avoid the nets due to boat sounds (Smith et al., 2017; Williamson et al., 2020; French et al., 2021). In addition, fishing techniques may have a limitation in estimating small size fish which play a very important role in populations and ecosystem dynamics (Guidetti et al., 2014). Understanding their abundance and distribution can provide valuable insights into the overall health and functioning of marine ecosystems. It must also be considered that the size of the MPA is crucial to determine how effective the conservation methods applied are (Pereira et al., 2017).

Underwater visual censuses (UVC) have been proven to be an effective method for estimating fish biodiversity in marine ecosystems too (Huveneers et al., 2019; Hill et al., 2020), which can be used just with scuba divers that perform a visual transect or scuba divers holding underwater video cameras (Schramm et al., 2020). The UVC is used for creating species inventories and biodiversity assessments (Watson et al., 2017; Harvey et al., 2021). This involves systematically swimming along predetermined transect lines and visually recording fish species, their abundance, behaviour, and interactions with the surrounding habitat. The data gathered is valuable for determining fish species composition, abundance, and distribution and recording their behaviour and their interactions with the surrounding habitat (Hill et al., 2020; Huveneers et al., 2019). This approach allows for non-destructive sampling, minimising disturbance to the underwater ecosystem (Watson et al., 2017; Harvey et al., 2021). However, it is labour-intensive and requires trained divers, limiting the spatial coverage and replicability of the surveys (Harborne et al., 2006; Babcock et al., 2010). Unless using an underwater video camera you will need experienced divers who can quickly and efficiently identify the fish to species level in situ (Harvey et al., 2004). Other disadvantages of the UVC are that there can be inter observer variations in the species identification, some fish may either avoid or be attracted to them (Dickens et al., 2011) and scuba divers will have depth and bottom time restrictions (Wickham and Watson, 1976; Cialoni et al., 2017). Using the underwater cameras helps solve some of those biases, since the videos can be later analysed and verified to identify the organisms more accurately to species level (Logan et al., 2017).

3.2. Use of baited camera techniques

Baited remote underwater video systems (BRUVs) and their different versions such as stereo-BRUVs and URUVs (Unbaited Remote Underwater Video surveys) have emerged as valuable tools for monitoring fish assemblages within MPAs (Harvey et al., 2012b). BRUVs provide non-invasive and standardised data collection, enabling researchers to assess fish abundance, species composition, and behaviour (Harasti et al., 2020). Long-term studies using BRUVs contribute to our understanding of population dynamics, the impacts of human activities, and the effectiveness of MPA management strategies (Hill et al., 2019). When applying

these methods, it is important to consider the economic and time costs associated with implementing BRUV studies, including equipment, maintenance, and data analysis (Harvey et al., 2012b).

BRUVs are a non-extractive nor invasive method (Schramm et al., 2020) which is very important when doing biodiversity monitoring in MPAs (Barret and Monk, 2021). This method has never been used before in the PNBA and implementing BRUVs in this remote area offers several advantages, including ease of application and relatively low-cost structure options (Harasti et al., 2020). Nevertheless, it has disadvantages: when visibility conditions are low (Unsworth et al., 2014), which may be the case in the PNBA due to the Sahara Desert. cameras and housing handle specific environment pressures, which may limit the deployment depth; with depth light penetration decreases limiting recording conditions for posterior identification of the species (Harvey et al., 2013); and bait may limit the type of fish and the species attracted to it (Langlois et al., 2010). Since it may attract with the bait more carnivorous species, it can lead to a mistaken interpretation of the biodiversity assemblages (Langlois et al., 2010) and it is not the best method for identifying cryptic species (Lowry et al., 2012).

In addition, inconsistencies in methodology, such as variations in bait quantity, recording time, and differences in colouring and illumination, can affect data comparability (Goetze et al., 2019; Harvey et al., 2020). However, BRUVs are an appropriate method that will attract predators to the bait and will allow the identification of larger predatory species, that may be compromised by the presence of scuba divers while doing transects (Schramm et al., 2020). On the other hand, the area that the bait plume covers and the distance at which species can be attracted is unknown (Taylor et al., 2013). Concerns also arise regarding the potential biases caused by larger fish and predators, as they may alter the behaviour of smaller fish (Goetze et al., 2019).

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Baited Remote Underwater Video (BRUV) surveys show threatened ichthyofauna associated with marine vegetation in the largest Marine Protected Area of West Africa, the National Park of the Banc d'Arguin

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ABSTRACT

Marine Protected Areas (MPAs) have a crucial role safeguarding marine ecosystems and their diversity. Diverse low impact ecosystem monitoring methods have been used in the recent decades, including underwater visual censuses, fishing surveys, and baited remote underwater video systems (BRUVs). In the face of declining demersal fish populations, this research undertakes a pioneering investigation within the Banc d'Arguin National Park (PNBA), Mauritania, employing BRUV surveys to comprehensively assess fish biodiversity and abundance across various habitats. A total of 62 fish species were identified, with significantly more species observed during daylight hours and in the autumn season, highlighting the potential influence of sampling effort and environmental factors. Moreover, while vegetated habitats, particularly seagrass meadows, demonstrated higher fish abundance and diversity, the presence of bait-induced biases in carnivore-rich communities underscored the importance of refining survey methodologies. Most identified species were classified as Least Concern by the IUCN, but local-scale assessments are necessary given potential population shifts. Elasmobranchs, vital to ecosystem stability, featured prominently, emphasizing their conservation significance within this dynamic marine park. Finally, spatial differences in fish abundance and biodiversity were observed, suggesting the influence of habitat type and protection level on demersal fish assemblages. This study thus contributes valuable insights into the ecology of demersal fish communities in the PNBA, emphasizing the need for adaptive conservation strategies and further research to ensure sustainable fisheries and species preservation in this critical marine environment.

Keywords: ichthyofauna identification, BRUVs, West Africa, MPA monitoring, endangered species, shark and ray conservation

1. Introduction

Demersal fish species play a crucial role in marine ecosystems due to their significant socioeconomic benefits and ecological importance (Smith et al., 2016). They contribute to the overall functioning and resilience of fish assemblages, influencing the stability and productivity of marine ecosystems (Claudet et al., 2010). However, these valuable fish species and populations have experienced alarming declines on a global scale, posing serious concerns for the long-term sustainability of their fisheries (Pauly et al., 1998). To address this pressing issue, the establishment of Marine Protected Areas (MPAs) has emerged as a crucial strategy for conserving fish biodiversity and ensuring the sustainable management of fisheries (Roberts et al., 2001). However, it is essential to monitor the biodiversity of MPAs in the long-term, to provide information for management, conservation and education initiatives.

Over the past few decades, alternative monitoring techniques, including underwater transects conducted by divers (Anderson et al., 2017), environmental DNA (eDNA) metabarcoding, Baited Underwater Remote Video surveys (BRUVs) (Stat et al., 2019), underwater drones (Landeo-Yauri et al., 2020) and remote sensing (Horning et al., 2010) among others, have emerged as non-invasive and non-extracting methodologies for monitoring fish abundance and biodiversity. These methods allow for sampling in diverse habitats and depths, reducing the ecological impact compared to traditional fishing techniques (Gaeta et al., 2011; Bayley et al., 2019).

BRUVs offer several advantages, including their non-destructive nature, the ability to sample rare species such as elasmobranchs, the provision of reviewable data to reduce interobserver errors, and the capacity to provide valuable information on habitat characteristics (Harvey et al., 2012). Additionally, the images captured during BRUV surveys can be effectively used for science communication purposes (Harvey et al., 2012). However, it is important to acknowledge that biases associated with bait, such as variation in bait plume dispersal and the differential sensitivity of fish species to different bait types, may influence the results obtained through BRUV surveys (Harvey et al., 2012). Moreover, certain cryptic and sedentary species may be under-represented in BRUV surveys and even dense canopies in seagrass meadows may not allow for a proper species identification and abundance estimation (Kiggins et al., 2018; French et al., 2021). Also, since it may attract with the bait more carnivorous species, it can lead to a mistaken interpretation of the biodiversity assemblages (Langlois et al., 2010).

Among the Marine Protected Areas (MPAs) in West Africa, the Banc d'Arguin National Park (PNBA) located in Mauritania, is the largest one and has held great importance since its establishment in 1976 (Lemrabott et al., 2023). Initially declared for the protection of migrating birds (Cornet et al., 2023), the PNBA covers a vast territory encompassing both marine and land areas, thus safeguarding a wide range of ecosystems and species (Guénette et al., 2014; Trégarot et al., 2020). This park includes diverse habitats, such as seagrass meadows, which play a vital role in supporting fish species, their populations, and the accurate prediction of fisheries dynamics (Iglésias et al., 2018). Meadows are essential ecosystems for marine demersal fish, serving as important nurseries (Hemminga and Nieuwenhuize, 1991; Trégarot et al., 2020). Consequently, gaining a comprehensive understanding of fish biodiversity and abundance within the PNBA becomes crucial for effective conservation planning and management of this marine park (Mora et al., 2013).

Particularly considering that different underwater habitats serve distinct purposes throughout the life cycle of fish species (Claudet et al., 2010).

This study aims to compare the biodiversity and abundance of fish species in both vegetated and non-vegetated areas at different points in the marine park across two different seasons, identify species of special interest such as elasmobranchs under extinction threat conservation status and describe how species use the different habitats inside the PNBA. The objective is to establish distinct protection areas that cater to the conservation of demersal fish species and support sustainable fisheries (Mallet et al., 2017).

2. Material and methods

2.1. Study site

The research was conducted within the Parc National du Banc d'Arguin in Mauritania (PNBA) (Figure 1), spanning from Cap Timiris ($19^{\circ} 23' 04''$ north, $16^{\circ} 32' 38''$ west) to Cap Alsaz ($20^{\circ} 25' 46''$ north, $16^{\circ} 22' 10''$ west). The Banc d'Arguin is a very large and shallow gulf that stretches along a desert coastline and includes sand banks forming islands, with an elevation not exceeding 5 m. Sampling was performed at depths ranging from 0.8 to 9.1 meters. To characterise the ichthyofauna present within the marine park, various habitats were analysed, including seagrass meadows, algae-covered areas, sand, and transition zones representing areas of transition between those habitats (Supplementary materials 'Figure I'). Seagrass meadows were predominantly composed of *Cymodocea nodosa*, while macroalgae areas were dominated by *Sargassum* sp..

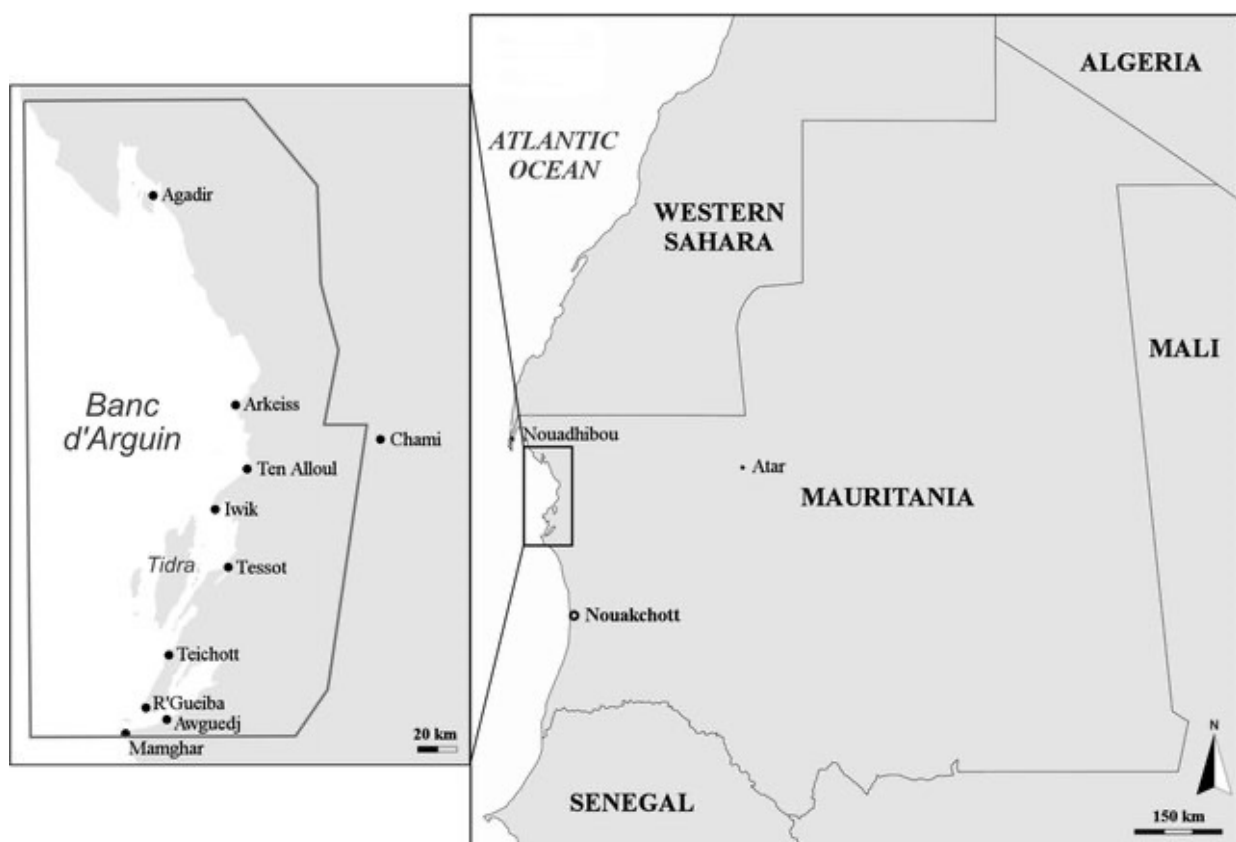


Figure 1. Map showing the location of Mauritania in Tropical West Africa on the right. On the left is shown the location of the Banc d'Arguin National Parc inside Mauritania where the research took part (Trégarot et al., 2021).

2.2. Sampling technique

A Baited Remote Underwater Video (BRUV) system was designed and constructed, replicated, specifically for use in the PNBA, to obtain video footage of present biodiversity underwater. The aim was to obtain images that could subsequently be used to identify species, with the help of taxonomy experts when needed. The BRUV design was adapted from Brooks et al. 2011 and Langlois et al. 2020. The sampling structures were constructed using 3 cm and 4 cm diameter PVC tubes, assembled to form a square pyramid (Figure 2a). This design allowed for a lightweight and cost-effective sampling structure. Atop each structure, a GoPro HERO 5 Black camera was mounted, set to record videos at 1080p resolution, 60 frames per second, and a medium field of view (FOV). The cameras were enclosed in SeaGIS waterproof housings (SeaGIS Pty Ltd <https://www.seagis.com.au/>), featuring acrylic faceplates, and positioned at a height of 40 cm, corresponding to the height of the pyramidal PVC tube structure. Bait, consisting of locally available fish species caught by fishermen, was placed 0.7 m in front of the cameras within wire-mesh bags attached to a PVC arm (Figure 2b). Each bait bag contained 3-4 chopped fish. The amount of bait added is in accordance with standard practices, i.e., 1kg of bait per sample hour (Harvey et al., 2007). The bait composition varied slightly between sampling events based on the availability of local catches. In May, *Sardinella* sp. and *Diplodus* sp. were used as bait, while in November, various species including *Coptodon guineensis*, *Diplodus* sp., *Carlarius* sp., *Dicentrarchus punctatus*, and some species from the Mugilidae family were utilised. Each BRUV deployment lasted approximately 1 hour and 15 minutes, which ensured 1 hour of recording analysis. The other 15 minutes are taken into an account during the deployment time (descent and ascent), to avoid boat sound influence, and can take some time to fish to detect the bait plume and approach the camera.

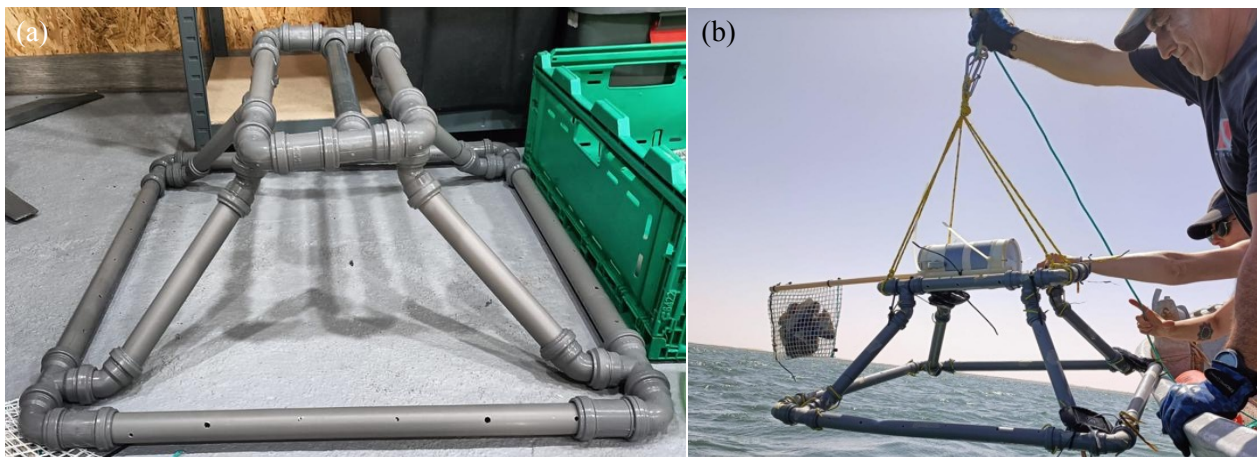


Figure 2. (a) Pyramidal PVC tube structure used for placing the cameras with the housing on the top. (b) BRUVs being deployed, where the plastic mesh bag with the bait is seen in front of the camera housing.

2.3. Experimental design

A total of 12 different points were selected across the southern and middle areas of the PNBA (Figure 3). Five points were sampled in spring (May), and seven points were sampled in autumn (November-December). In autumn, three different points were exclusively sampled during the day, while at four points, both day and night recordings were obtained. The selection of sites was based on consultation with local fishermen (Imraguen), to locate sites representative of various subtidal habitats of the PNBA.

For each point, three replicates were deployed in linear transects, with a minimum distance of 250 m between them to mitigate potential bait interference (Langlois et al., 2010). In total, 101 samples were collected, comprised of 28 samples in spring and 73 samples in autumn (Supplementary materials ‘Table I). Daytime samples were collected between 10 am and 5 pm, while nocturnal samples were set at 5 pm and 8 pm. For the sunset and night deployments a single white underwater Big Blue 4200 lumen torch was placed under the camera housing. The light was pointing at the bait mesh bag at a 50% intensity.

Once a BRUV was deployed, the point and time of deployment were noted, and the apparatus was recovered after 1 hour and 15 minutes of recording. When the cameras were submerged, a manual GPS was used for noting the coordinates of the points and a hand probe was used for recording the depth.

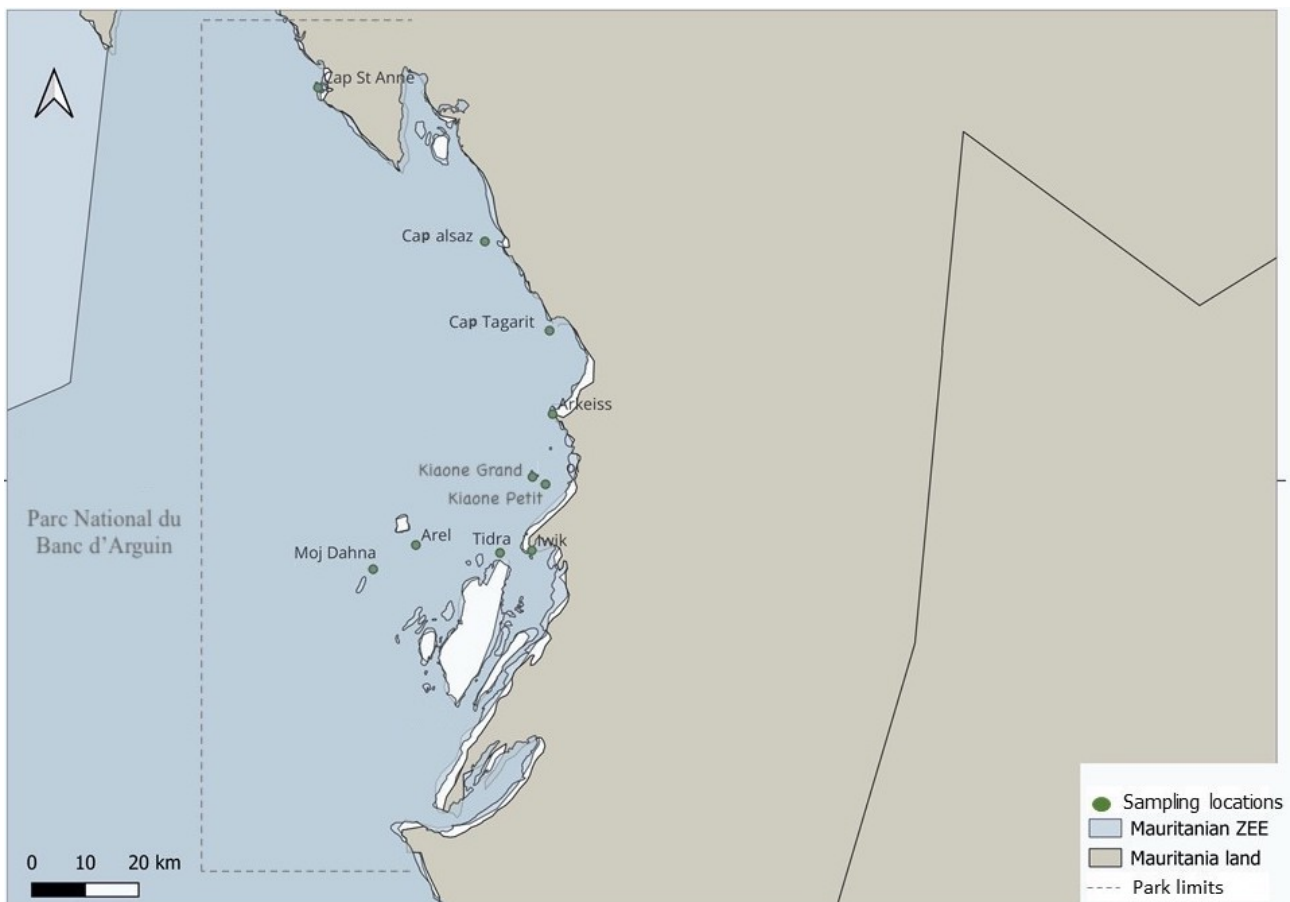


Figure 3. Map showing all the sampling sites where the BRUVs were deployed inside the PNBA.

2.2 Video analysis

The analysis was constrained by the limited field of view, influenced by oftentimes low visibility conditions caused by suspended sand particles from the desert. Visibility in the videos recorded in spring was around 1 m, while it improved in autumn with approximately 4 m in average, depending on the habitat type. Visibility was estimated visually using the images in the recorded videos. Additionally, in certain seagrass meadows covered by *Cymodocea nodosa*, the analysis was further restricted by the density of the canopy. Fish populations were quantified using the MaxN method, where MaxN represents the maximum number of fish of the same species observed within a single frame of the recording (Scott et al., 2015). The identification of the species was done using different identification books containing fish species from Mauritania (Maigret and Ly, 1986), the Atlantic Ocean (Debelius, 1997) and the Mediterranean Sea (Ballesteros, 2015). To ensure

accuracy in species identification, a specialist in fish identification from the Western Tropical Africa region was consulted to confirm species identifications of a subset of species to avoid potential misidentifications. The scientific names of all the species identified and the other taxonomic levels that they belong to were verified using WoRMS (WoRMS Editorial Board, 2023).

2.3 Statistical analysis

Initially, an Excel database was developed to organise the raw data systematically. FishBase was used as the main source for extracting biological and ecological data about the different fish species identified (Froese and Pauly 2000). That data that was extracted included information about family, order, diet, maximum depth at which the species can be found and conservation estate. This database served as a foundation for subsequent cleaning, formatting and analysis using Excel. The analysis was done using pivot tables to relate different variables among them (diet, vegetated and non-vegetated habitats, maximum abundances, sampling seasons and sampling points) and to calculate relevant ecological indexes:

Shannon

$$H = - \sum_{i=1}^s p_i \ln (p_i)$$

Simpson

$$D = 1 - \sum_{i=1}^N \frac{ni (ni - 1)}{N(N - 1)}$$

Evenness

$$E = \frac{hi}{H} \cdot 100$$

Statistical analyses were conducted using R version 4.2.3. (R studio, 2020). R was used to perform ANOVA, Kruskal-Wallis and Mann-Whitney U-tests, to test possible differences between the variables maximum abundance per season and per sampling point and ecological indexes per sampling point and per habitat.

QGIS version 3.30.3 was used to create the different geolocation and distribution maps.

3. Results

A total number of 62 species were identified with the BRUVs, including seven elasmobranch species and 55 teleosts among the three main habitats (algae, seagrass and sand) (Supplementary materials ‘Figure II’). The seven elasmobranch species belong to four families and the teleosts to 25 (Supplementary materials ‘Table II’ and ‘Table III’).

The species detected varied temporally, both with time of day and season. Among all the species, 81% were identified during the day and 19% of them at night (Figure 4a). Following that same trend, 13.5% of the total amount of species identified were seen in spring and 86.5% were identified in autumn (Figure 4b).

Vegetated habitats were widely used by fish species. Almost four times more species (75.84%) were identified in vegetated habitats, compared to the ones found in non-vegetated ones (21.69%) (Figure 5a). In the case of 10 species the habitat information could not be obtained due to a wrong positioning of the BRUV

underwater or very bad visibility. Some species were identified in both vegetated and non-vegetated habitats (28 species, 46.67%), and the number of species that exclusively used vegetated areas were almost ten times more (48.33%) than the ones using exclusively non-vegetated habitats (5%) (Figure 5b).

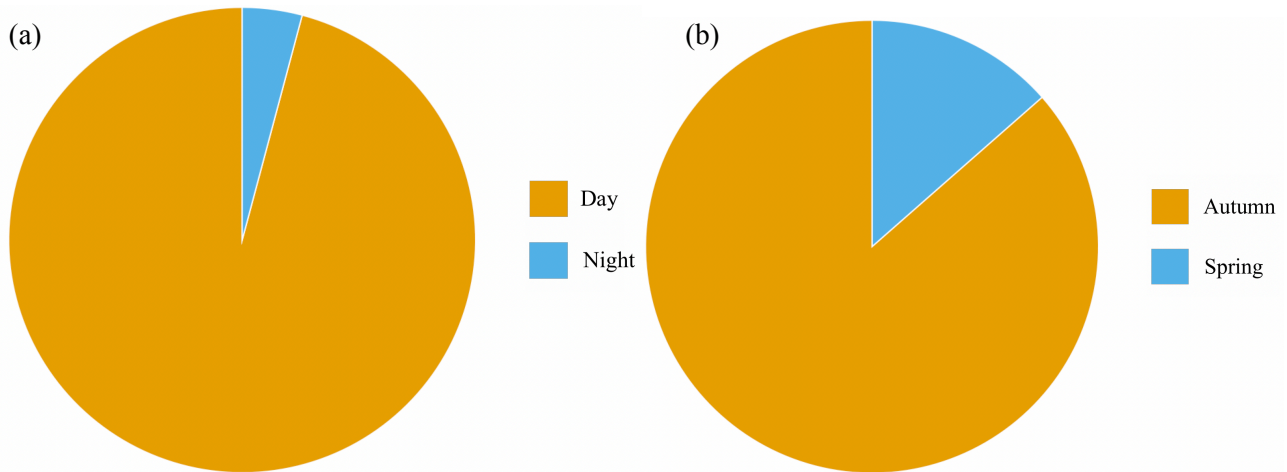


Figure 4. Pie charts showing (a) total number of species identified day and night; (b) total number of species identified in the two sampling periods, spring and autumn.

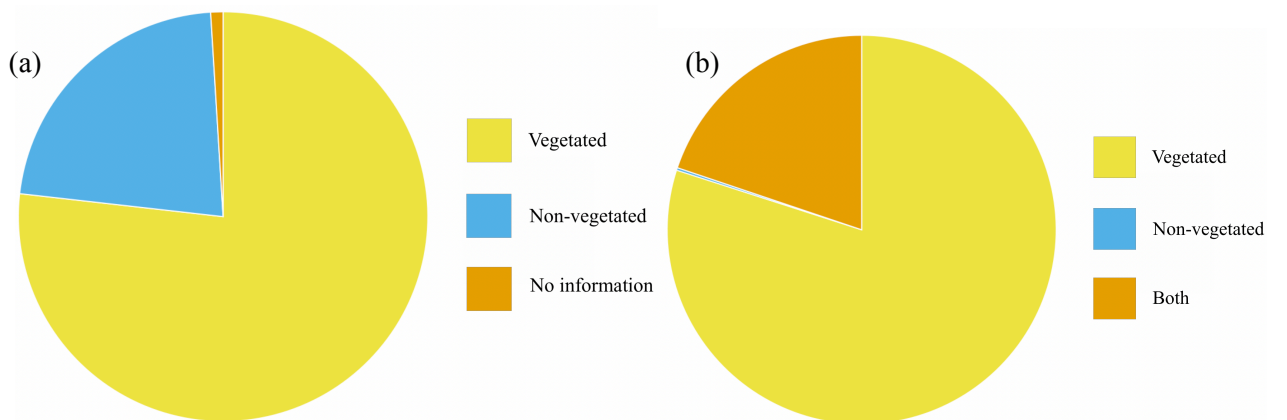


Figure 5. Pie charts showing (a) total number of species identified in vegetated and non-vegetated habitats; (b) total number of species identified in vegetated and non-vegetated habitats, considering some species appeared in both type of habitats.

The trophic level of the fish sampled was dominated by carnivores, as expected for baited sampling. From the total number of species identified, there were over four times more carnivore (67.91%) species than omnivores (15.60%) and only one herbivore species (Figure 6).

The species detected had several levels of conservation status. Over three quarters of the species identified are classified as LC (Least Concern) (79.96%) by the IUCN Red List of Threatened Species (reference) (Figure 7). Among the rest, 1.06% of the species are classified as CR (Critically Endangered), 0.18% EN (Endangered), 1.77% VU (Vulnerable), 2.65% NT (Near Threatened) and 1.24% DD (Data Deficient). Out of all the species threatened with extinction to some degree (VU, EN, CR), seven were elasmobranchs and four were teleosts (Figure 8), distributed through different points inside the PNBA.

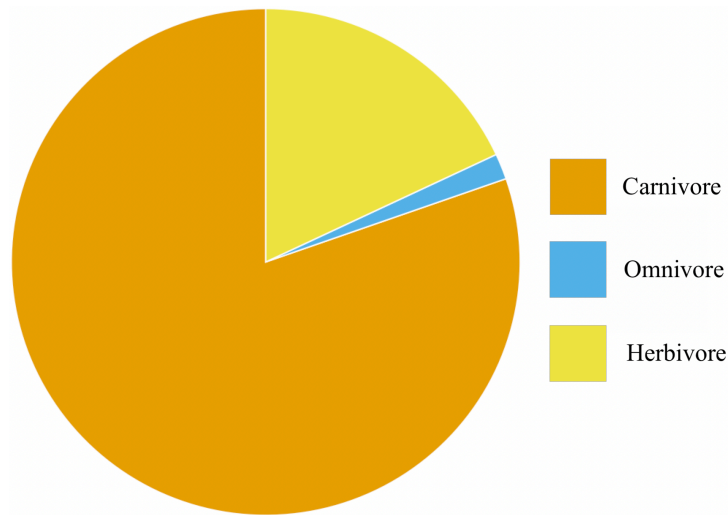


Figure 6. The pie chart shows how many of the species identified are carnivore, omnivore and herbivore based on their known dietary preferences.

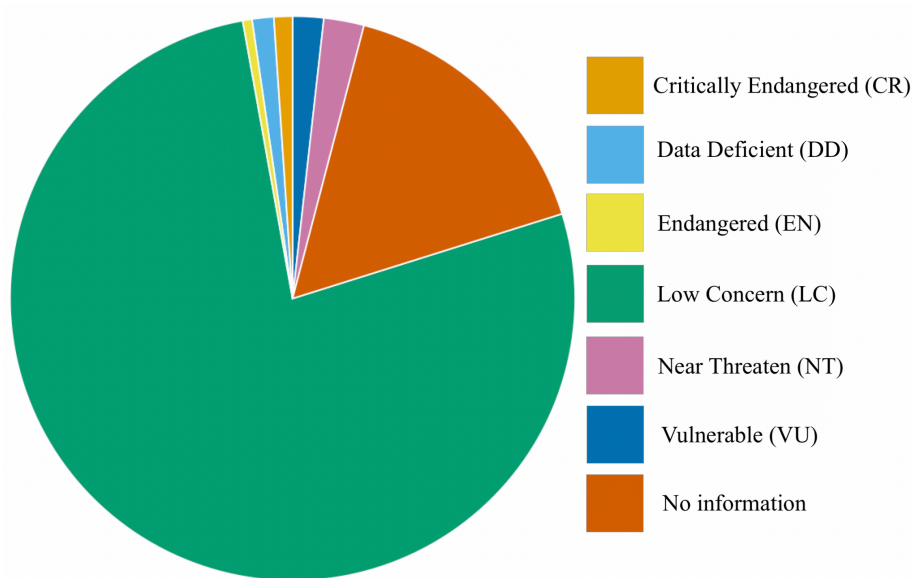


Figure 7. Pie chart that shows the percentages for the different conservation status categories of the species identified and based on the IUCN Red List of Threatened Species.

The distribution of species recorded among sites varied with season. The total abundance of fish was five times higher in autumn (5644 individuals) than in spring (1164 individuals) (Figure 9). In both sampling periods the location with the highest fish abundance was Arel, with 976 individuals counted in spring and 2737 individuals in autumn and the most abundant species were *Diplodus bellottii* (353 individuals in spring and 1330 in autumn) and *Spondylisoma cantharus* (328 individuals in spring and 186 in autumn). In spring, *Diplodus bellottii* was the most abundant species in Arel and Kiaone Grand and *Spondylisoma cantharus* was the most abundant one in Iwik both in spring and autumn. In autumn again *Diplodus bellottii* was the most abundant species in Arel and Kiaone Petit again and in Cap Alsaz. Instead, in Mojd Dakhna and Arkeiss, *Pagrus caeruleostictus* and *Mycteroperca rubra* were the most abundant species, respectively.

There were differences in fish abundance between the different points (p -value < 0.0001). The pairwise Mann-Whitney U-test revealed significant differences for Iwik – Arel ($p=0.013$), Iwik – Arkeiss ($p=0.041$) and Tagarit – Arel ($p=0.023$).

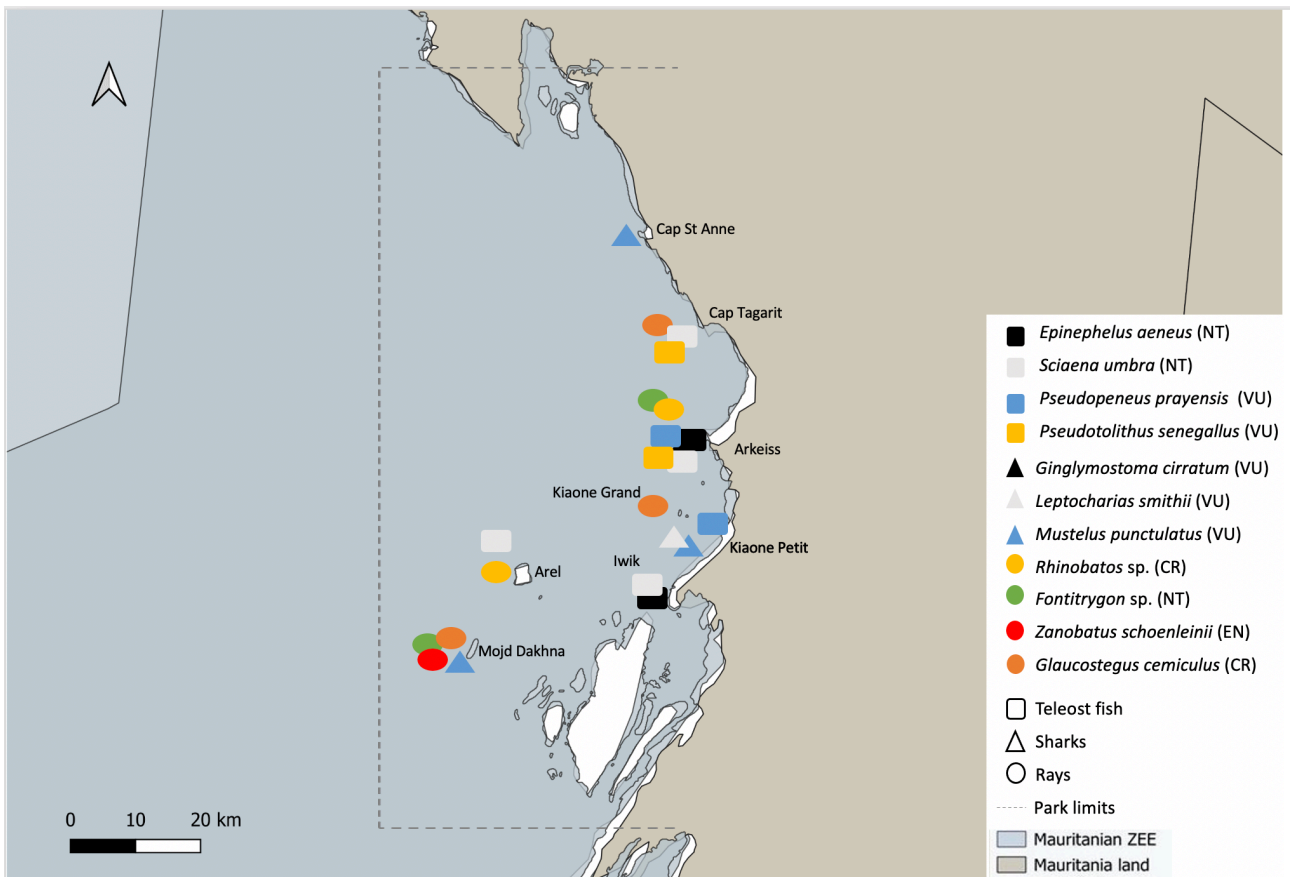
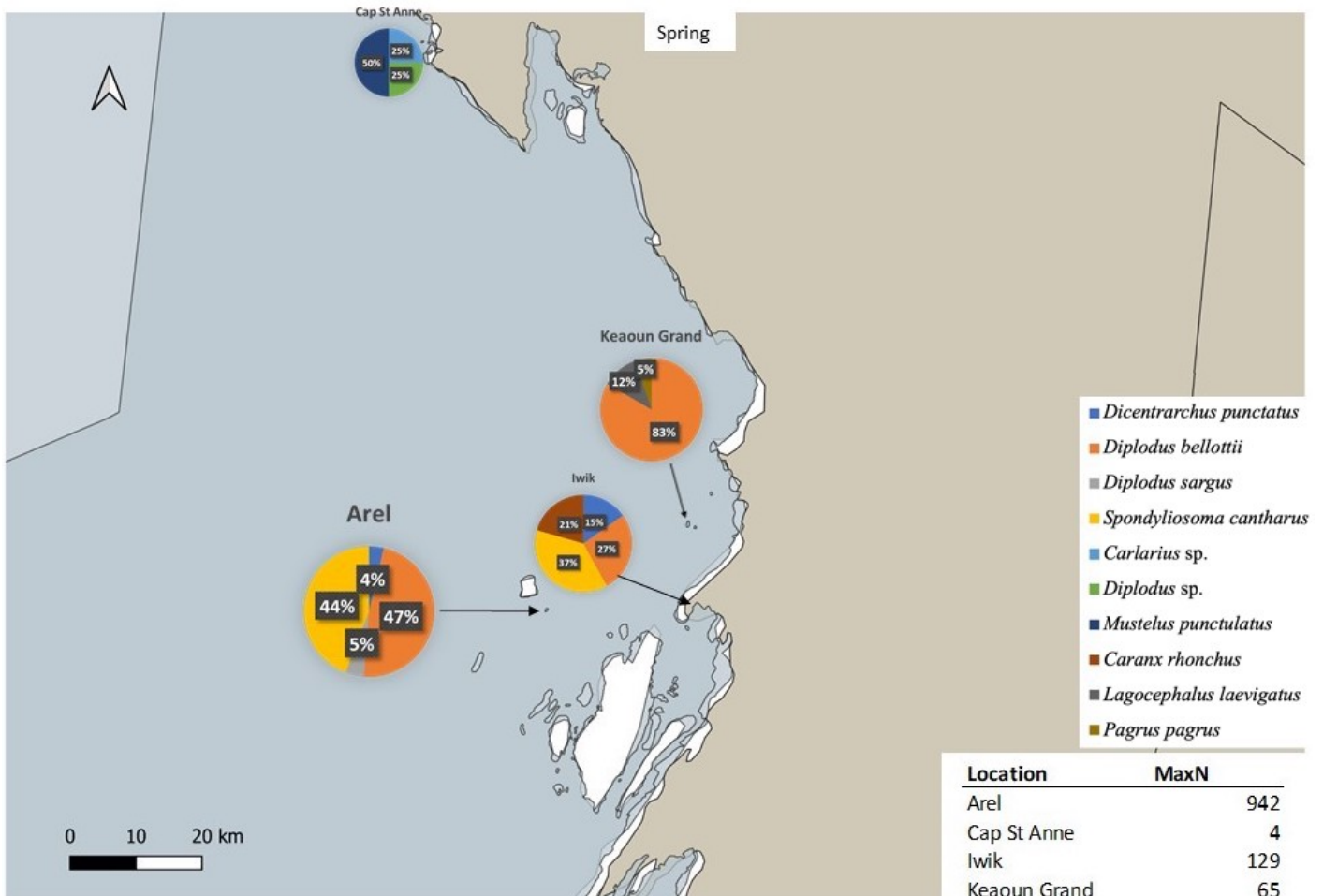


Figure 8. Map of the PNBA showing the points where the teleosts (squares) and elasmobranchs (sharks triangles and rays circles) were identified.



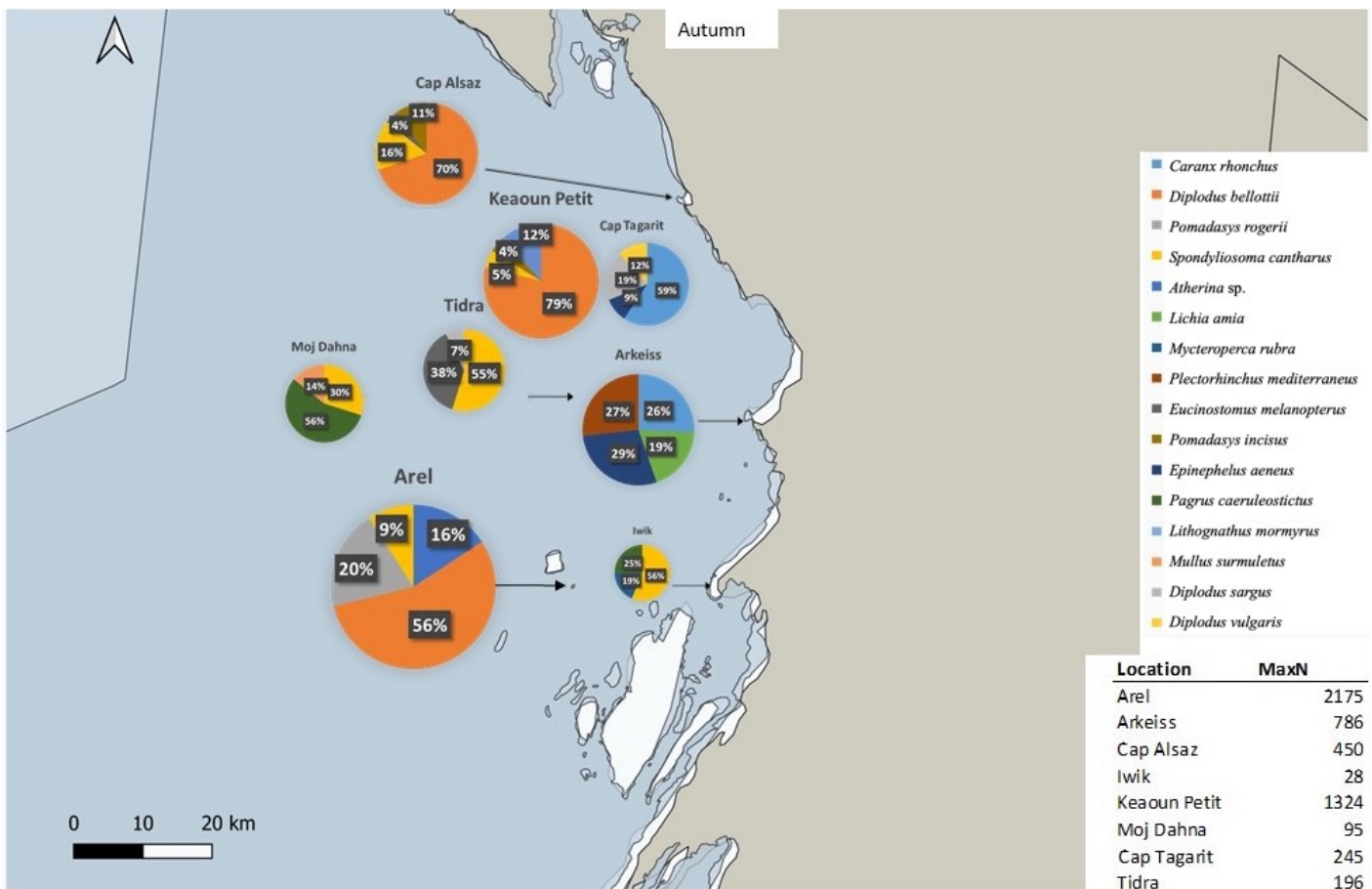


Figure 9 Map of the PNBA showing the abundances of the species identified in the different locations by sampling season, (a) in spring and (b) in autumn. The pie charts show the most abundant species and the size of the pie chart represents the total abundance of fish counted for each location.

The species abundance varied considerably with season. The habitat that had the highest abundance of fish counted in both seasons was seagrass with 1082 individuals in spring and 3198 in autumn. The most abundant species in both seasons (Figure 10) was *Diplodus bellottii* with 433 and 2447 individuals, respectively, and it was more abundant in the seagrass meadows. In the hypothesis test performed to find possible difference in fish abundance between the different BRUVs habitats, no significant differences were found (p-value = 0.07592).

Considering the abundance of fish (MaxN) identified in each habitat and classifying them depending on their diet (Figure 11), the habitats with the biggest fish abundance are the vegetated ones: seagrass (4277 individuals) and algae (382 individuals). In all the habitats the most abundant fish were carnivores (7568 individuals), followed by omnivores (1469 individuals) and both vegetated habitats were the ones with the biggest amount of carnivores.

Regarding the MaxN abundance of families found in the different habitats (Figure 12), the habitat with the biggest number of individuals was seagrass. Among all the habitats, the most abundant family were the Sparidae (4309 individuals) followed by the Haemulidae (684 individuals), Mugilidae (647 individuals) and the Carangidae (623 individuals).

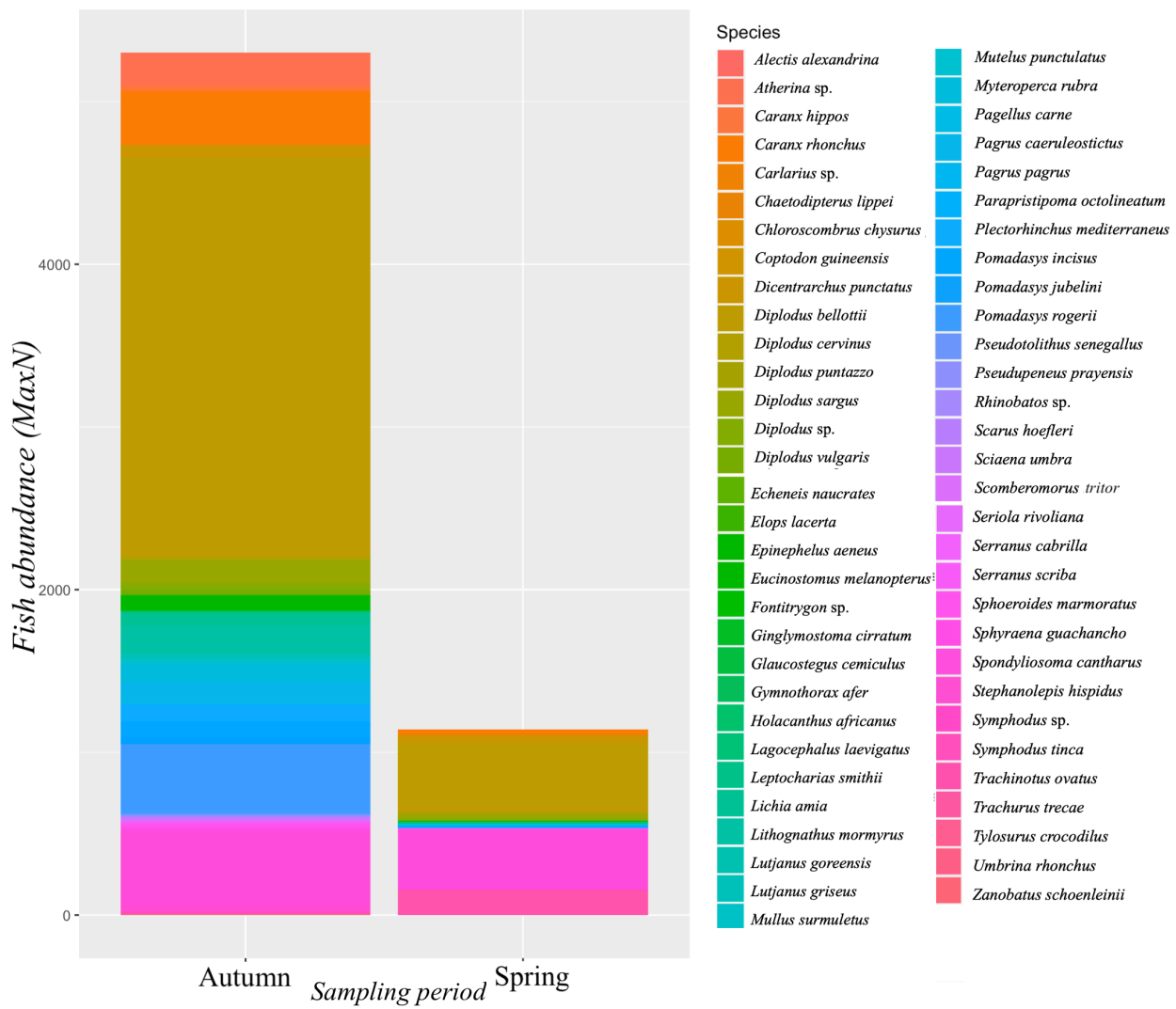


Figure 10. Ggplot bar graph showing the MaxN abundance of the different identified species per sampling period. MaxN is the maximum number of fish of the same species observed within a single frame of the recording.

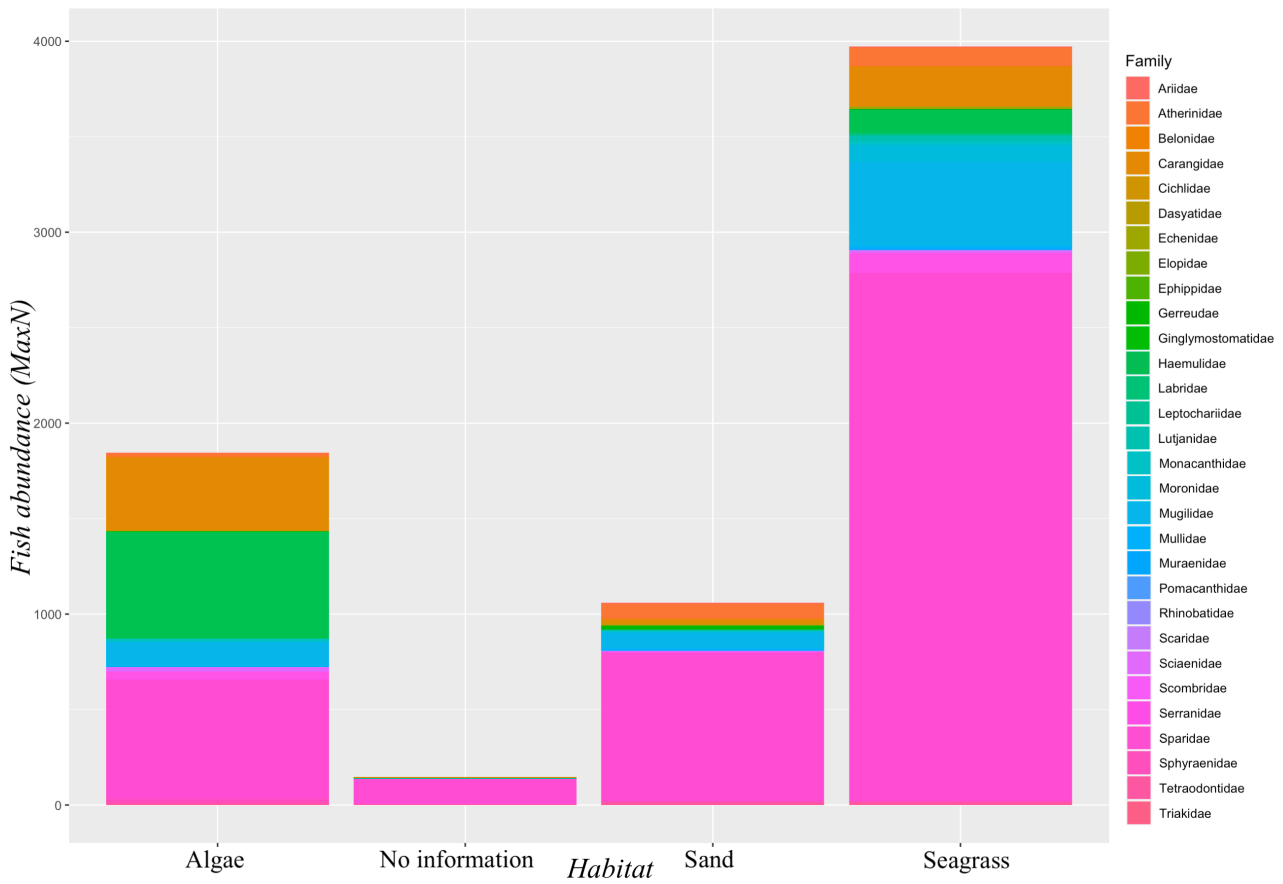


Figure 11. Ggplot bar graph showing the MaxN fish abundance per habitat and per diet. MaxN is the maximum number of fish of the same species observed within a single frame of the recording.

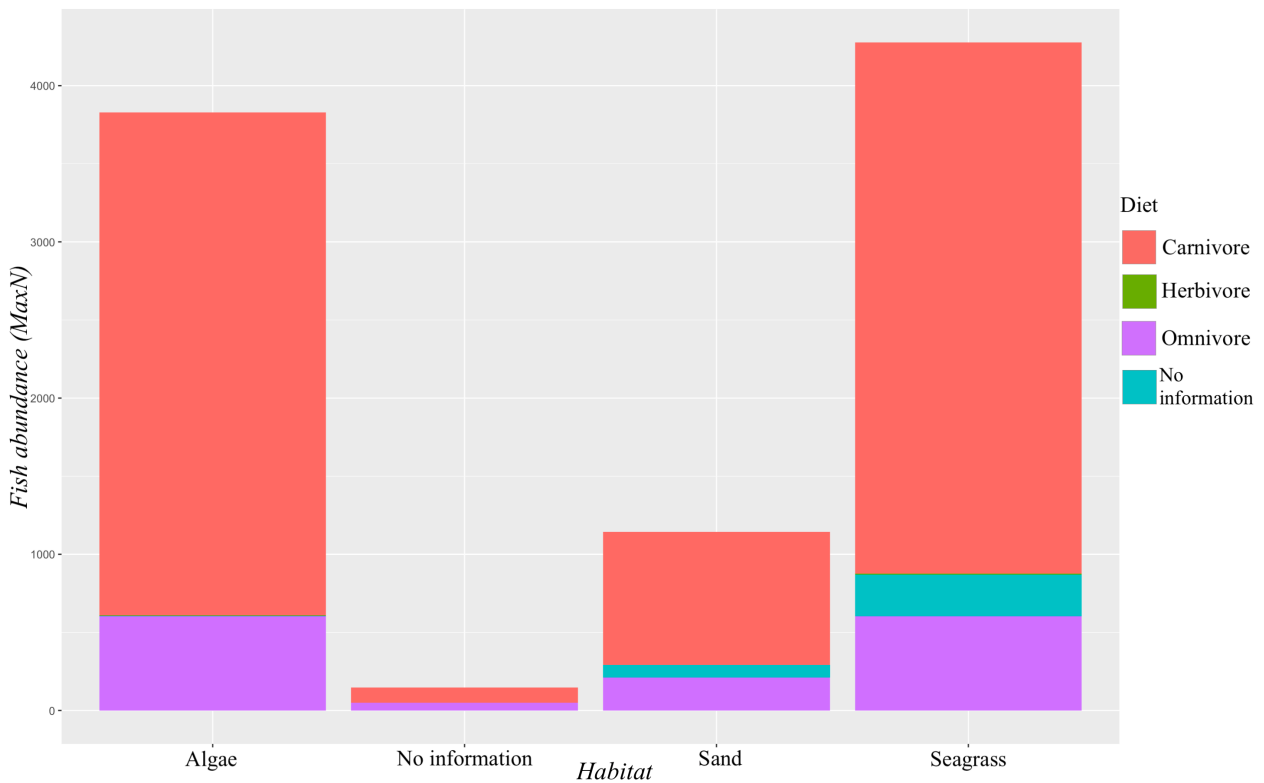


Figure 12. Ggplot showing the MaxN abundance grouped by families and by habitat. MaxN is the maximum number of fish of the same species observed within a single frame of the recording.

Three different ecological indexes were calculated for comparing the biodiversity of the different sampled points (Table 1a). The location with the highest Simpson and Shannon diversity is Arkeiss and the one with the lowest Kiaone Grand. Arel has the highest Evenness (Table 1b), and Cap St Anne the lowest. The non-parametric Kruskal-Wallis revealed no significant differences in ecological indexes between points and habitats, with p-values of 0.4373 and 0.3916 respectively.

Table 1. Table shows the values of the ecological indexes Simpson, Shannon and Evenness (a) for the different locations where the BRUVs were deployed in the PNBA; (b) for the different BRUV habitats.

(A) LOCATION	SIMPSON	SHANNON	EVENNESS
AREL	0.71622589	1.69396805	48.3630721
ARKEISS	0.92206165	2.87826777	12.1955004
CAP ALSAZ	0.54226173	1.23835134	6.98215671
CAP ST ANNE	0.62501	1.03972077	0.06206362
IWIK	0.81918131	2.12703545	2.4359969
KIAONE GRAND	0.39337278	0.90487407	1.00853375
KIAONE PETIT	0.40544423	0.9304514	20.5430566
MOJD DAKHNA	0.71933518	1.71609708	1.47401086
CAP TAGARIT	0.79310287	2.24850602	3.80139643
TIDRA	0.7358913	1.73300294	3.04111715
P-VALUE	0.4373	0.4373	0.4373

(B) HABITAT	SIMPSON	SHANNON	EVENNESS
ALGAE	0.86098842	2.4352817	26.4348361
SAND	0.67938326	1.80542113	16.3255886
SEAGRASS	0.67999517	1.88010984	54.9930759
N O INFORMATION	0.58069056	1.15604922	2.24649946
P-VALUE	0.3916	0.3916	0.3916

4. Discussion

This pioneer study using a novel non-invasive fish sampling method, provides an inventory of fish species, some of which with important conservation status, and revealed their association to structural subtidal habitats, inside the largest Marine Protected Area of West Africa, The National Park of the Banc d'Arguin. This was the first-ever use of non-invasive Baited Remote Underwater Video (BRUVs) to identify fish species and estimate their abundances in the different habitats of this MPA, revealing the occurrence of rare

threatened species that are typically difficult to monitor. The last previous exhaustive ichthyofauna species identification and description work in Mauritania was done by Maigret and Ly (1986), and later for the West African region by Simier et al. (2019). They identified and described species based on landings from fishermen or on their own samplings using purse seines. Using BRUVs now provides a new non-invasive way of monitoring different areas of the PNBA in the long-term, especially where threatened taxa like elasmobranchs were recorded. Furthermore, this method has the advantage of allowing objective comparison over long time series, as the images are stored for posterity, and allows us to know the habitat use of the species and identify critical habitats such as nursery areas, feeding and reproductive grounds of certain species (Zarco-Perello and Enríquez, 2019).

The high number of species identified in this study, a total of 62 species in different sites and habitats, confirms that BRUVs are an efficient non-extractive method for monitoring fish communities in MPAs (De Vos et al., 2014; Devine et al., 2019, La Mana et al., 2021). Our results provide an updated list of fish species in the PNBA, which can be useful to inform conservation strategies for different target species and habitats in this understudied field (De Vos et al., 2013; La Manna et al., 2021).

Day-Night patterns

Many more species were identified during daytime than at night. Fish have circadian movements which can be based on feeding or reproductive purposes (Harvey et al., 2012a). So BRUVs deployed before sunset are considered night BRUVs, since fish already show a change in their feeding behaviour (Helfman, 1986; Azzurro et al., 2007). However, diel habitat use of fish remains understudied (Harvey et al., 2012a). Furthermore, the species identified during the night did not show almost any interaction with the bait. Instead, plankton is attracted to the artificial light coming from the BRUVs structure (Watson et al., 2001), and zooplankton can attract carnivorous predators such as *Atherina* sp. (Quignard and Pras, 1986). *Atherina* sp. was the most abundant species in the night BRUVs, followed by *Spondylisoma cantharus* and *Dicentrarchus punctatus*, which visibly fed on suspended zooplankton showing erratic feeding movements. Other species that were attracted to the bait at night were *Gymnothorax afer* and *Ginglymostoma cirratum*. Both species are more active feeding at night and are presumed opportunistic feeders (González et al., 2021; Parton et al., 2023). Although during the day there was a bigger abundance of fish species and individuals, it is noted that there are significant differences in species composition and abundance during day and night and these may be associated to changes in feeding behaviour, predator avoidance and attraction to the light (Azzurro et al., 2007). Most species identified at night could potentially be found during the day, but since they are easily attracted to the light, their abundance and habitat use may be better described using night BRUVs.

The significant difference in species abundance between day and night can also be related to the sampling effort. Many more samples (N=62) were collected during the day ($n_{\text{day}}=59$) than during the night ($n_{\text{night}}=29$). The remote area and scarce lighting conditions make it more difficult to work at night in the PNBA. Therefore, doing late night deployments becomes complex and is not always feasible. It should also be considered that the days are shorter during the autumn time, with less time for deployments during the day; whereas in spring days are longer and sampling time effort would significantly increase. So, to have more comparable information about the number of species that appear at day and night, more sampling should be

done during the night in future campaigns, allowing for a more representative and complete list of fish species of the PNBA.

Seasonal patterns

More species were identified during autumn ($n_{\text{autumn}}=57$) than in spring ($n_{\text{spring}}=26$). Several hypotheses can be proposed based on these differences. First of all, differences caused by seasonality of presence caused by migratory patterns and other ecological factors. Second, because different sites were visited in each season, the seasonal differences observed could be spatial rather than temporal, influenced by different spatial use of the PNBA sites by the species. Among the locations with the richest species diversity sampled in autumn, only Arel was also sampled in spring.

Finally, the environmental conditions were different between seasons. In springtime there were worse ocean conditions created more complex sampling conditions and the BRUVs were sometimes not deployed exactly where it was planned due to logistic challenges. In springtime winds were much stronger and visibility conditions were much worse, too. That may be due to a higher Chl-a concentration in the water and more suspended sand particles (Figueroa-Pico et al., 2020). Based on Ocean Color data collections, Pradhan et al. (2006) concluded in their research that there was an inter-annual variation in Chl-a concentrations in the PNBA. Those variations depend on the Canary current influence and wind seasonality (Vázquez et al., 2023), which condition the upwelling influence and dust deposition from the Sahara Desert. The dust deposition from the Sahara is very rich in iron and other nutrients, which enriches the water, increasing its productivity (Rizzolo et al., 2017). In the case of the elasmobranch species identified, only one species was identified in spring (*Mustelus punctulatus*) and all the other species were identified in autumn. Lower visibility and higher particle concentrations in the water make fish species detection more difficult during those periods of the year.

Only four species were exclusively identified in spring (*Holacanthus africanus*, *Pagellus acarne*, *Pagrus pagrus* and *Trachinotus obatus*), the rest were seen again in autumn, and 37 new species were identified only in the autumn samplings. Some species in the PNBA are migratory bony fish species, which is the case of the *Mugil cephalus*, and others are resident (Lemrabott et al., 2023). Mulletts were identified in both seasons and, although in this study mulletts couldn't be identified to species level just with the recording and based on morphological characteristics, the number of individuals from the family mugilidae counted in autumn was much bigger ($n= 623$) than in spring ($n= 24$), in agreement with the seasonal migration of the species (Bernardon and Vall, 2005). The migration is related to the reproductive cycle of the species and starts before the summer. The individuals stay in the PNBA for a few months while they grow, and end of November they head towards the south. Accordingly, we counted greater abundances of mulletts in the end of November and beginning of December.

Habitat patterns

More than three quarters of the identified species were found in vegetated habitats such as seagrass meadows. It is well known that seagrass meadows play a crucial role for the conservation of lots of ichthyofauna species and their community structure (Espino et al., 2011), using them as nursery grounds and to hide from predators, being habitats with big species richness and fish abundance (Guidetti, 2000;

Nagelkerken et al., 2001; Gilby et al., 2018). However, most fish species used vegetated habitats but also non-vegetated ones, and only very few species used exclusively non-vegetated sand areas. It is known that some species have clear shifts between different habitat types in their ontogenetic cycle (King, 2004). It would be easier to provide further evidence how some species in the PNBA use the different habitat types by applying stereo-BRUVs, which allow for the length of the recorded individuals to be determined, potentially giving an indication of state of maturity (or life-cycle state) for certain large-bodied species (Galaiduk et al., 2017; Grimmel et al., 2020). But using stereo-BRUVs in this type of remote areas is difficult, since the set BRUV structure used should not be disassembled during the whole sampling period after the calibration of the cameras, which allows for precise measuring of the fish (Langlois et al., 2020). An alternative to that could be to use a scale in the camera or close to it and using a laser with two dots that get the length of the individuals (Rochet et al., 2006). So, without those length and biomass data, it is yet uncertain if the species recorded and identified using both vegetated and non-vegetated habitats use them at different growth stages and for different functional stages or not.

Trophic patterns

In the vegetated habitats where most species were observed, the most abundant species were *Diplodus bellottii* and *Spondylisoma cantharus* which are carnivorous and omnivorous, respectively (Froese and Pauly, 2000). Although herbivores are not attracted to the bait, the fish movement that is created around the cameras has been proven to attract them (Colton and Swearer, 2010). But the carnivores attracted to the bait of the BRUVs likely account for the absence of herbivore species living on the vegetated habitats due to predator-prey dynamics, potentially leading to a misrepresentation of the ecological assemblages present (Van Looijengoed, 2014). To solve that bias, Ghazilou et al. (2016) used two different types of baits: tuna for some cameras and plant-based powder for others. They proved that more carnivores were attracted to the BRUVs containing tuna and more herbivores were present in the plant-based ones, better representing the demersal fish assemblages present in the area. Another alternative method to verify the influence of the bait on the attraction of carnivores is removing the bait and doing URUVs (Unbaited Remote Underwater Video surveys) (Cousins et al., 2017; French et al., 2021). This allows to record the habitats with their natural assemblages and without bait biases. The variation of the type of BRUV used will depend on the purpose of the research.

The bait used in both sampling periods had different fish species, and (bait) species composition changed slightly even between different sampling days, potentially influencing the species attraction (Jeunen et al., 2020). Another attraction bias to consider is related to the bait quantity (Dorman et al., 2012; Hardinge et al., 2013; Wraith et al., 2013). The bait quantity will affect the plume size and thereby the distance it can reach and at which it can be detected by predators (Taylor et al., 2013), although tides and currents should also be taken into consideration (Jones et al., 2021).

Spatial patterns

Significant differences were found between different locations in fish abundance: Iwik – Arel, Iwik - Arkeiss and Cap Tagarit – Arel. Instead, significant differences were not found between the different locations per season. In Arel and Arkeiss we recorded mainly vegetated habitats and in Iwik and Cap Tagarit non-vegetated ones. Considering vegetated habitats with algae and seagrass had higher ecological indexes

confirmed that vegetated habitat has higher abundance of fish and host a higher number of species being more diverse and richer (Dunne et al., 2023). The location with the richest biodiversity and fish abundance was Arkeiss. This is an area surrounded by pronounced sandstone cliffs and lots of rock blocks in the water, same as in Cap Tagarit. That creates a more complex rocky habitat that creates refuge places for fish, giving natural protection to the species there (Hall and Kingsford, 2021). Those places were followed in abundance and biodiversity by Mojd Dakhna and Arel, which are the furthest sampling locations. Based in the findings from Lemrabott et al., 2023, all those four areas are fishing hotspots Imraguen, since they are places that have high abundance of migrating and resident species.

Conservation status

Over three quarters of the species identified with the BRUVs have been classified as LC ($n_{LC}=47$) in the IUCN Red List. Furthermore, many of the species identified in the BRUVs and classified as LC, haven't been updated since 2008-2014 (IUCN, 2022) possibly leading to a misinterpretation of the status of those species nowadays (Hayward et al., 2015). In addition to the lack of updated information of current population trends, the conservation status of most species is assessed at a global or broad regional scale by the IUCN. That means that at a local scale in Mauritania the identified fish populations may have changed and their trends are unknown; this plays a crucial role for prioritizing the conservation of the species at a local scale (Bachman et al., 2019; Miqueleiz et al., 2020). For example, Meissa and Gascuel (2014) state that from the 22 fish stocks they analysed in Mauritania since 1982 their total biomass had decreased by 75%. Using BRUVs and other methods for quantifying the status of fish species and their distribution in the PNBA with short and long-term research is essential for assessing their populations.

Nevertheless, some of the species identified in the BRUVs are classified with some threat level by the IUCN. Some examples are *Sciaena umbra*, *Pseudolithus senegallus* and *Glaucostegus cemiculus* which were found in bigger abundances in Arkeiss, Cap Tagarit and Mojd Dakhna respectively. *P.senegallus* was already classified as Vulnerable in the IUCN Red List in the assessment from 2015 and the population trend as decreasing (Nunoo, 2021). Both artisanal and industrial fisheries have increased in the PNBA and Mauritania respectively, causing a decline in the fisheries of the mullets and meagre in the last two decades (Ly and David, 2021; Lemrabott et al., 2023). Therefore, the Imraguen have started to target other species (Lemrabott et al., 2023), such as the white grouper *Epinephelus aeneus* (NT), flathead mullet *Mugil cephalus* (LC), spotted sea bass *Dicentrarchus punctatus* (LC) and rubberlip grunt *Plectorhinchus mediterraneus* (DD) (Meissa and Gascuel, 2015). Although most of those newly targeted species don't show official declines in their populations yet (Meissa and Gascuel, 2015), the number of trawlers and pirogues have increased in numbers in the past decades in Mauritania. That significantly increases the fishing pressure of some species not only outside where the industrial fisheries happen, but also inside the PNBA (Gascuel et al., 2007; Touron-Gardic et al., 2022; Lemrabott et al., 2023). All those newly targeted species have been identified in this research. Even if their conservation states do not mean a big threat yet to the species, knowing their exploitation has increased (Meissa and Gascuel, 2015), is important to identify their habitat areas and use for their conservation and protection (Gristina et al., 2017). Ensuring resilience to the fish stocks is not only a benefit for the PNBA and the Imraguen livelihood, but also for ensuring resilience to the species outside the

National Park, since they may use the National Park as a refuge in their early life stages (Mesnildrey et al., 2013; Meissa and Gascuel, 2015).

Final considerations

Considering that global fish stock assessments show worrying numbers, the follow up of the fish stock at a local scale is very important for conservation but also socio-economically (Smith et al., 2016; Pereira et al., 2017). Most fish species identified here are considered as Least Concern by the IUCN at a global scale (IUCN, 2020) but little is known about their population trends in Mauritania and the PNBA. Furthermore, regulations have been established with the aim of improving the state of some species like sharks and rays, but numbers do not seem to improve (Lemrabott et al., 2023). This study facilitates a first updated list of ichthyofauna diversity within the PNBA done in the last decades and for the first time with a low-impact method, the BRUVs. The applied technique has been demonstrated to work as a long-term monitoring strategy that will help the National Park better their demersal fish stocks, that are crucial as livelihoods for the Imraguen.

The results of this study indicate that this pioneer fish monitoring method in the PNBA, can be an efficient strategy for long-term monitoring of fish communities especially for the goal of detecting rare threatened predatory species. BRUVs have been applied for a long time as a sporadic tool for identifying habitats and fauna that are challenging to sample otherwise, and can be effectively used for monitoring and conservation purposes. However, it is also a strong tool for doing long-term monitoring, especially in MPAs, as the existence of video footage allows independent verification of the observation records over time by different specialists. Here, this approach has been successfully applied in the PNBA for the first time as a method for identifying ichthyofauna. This will help not only future estimations of biodiversity and abundance of fish species but also to monitor changes in very important habitats like the seagrass meadows. Species in risks of extinction like elasmobranchs were found in some locations, so those places may be of vital importance for their conservation.

The main conclusions of this study are i) there are differences in abundance and distribution of fish species associated to the subtidal habitats inside the marine park. Seasonal differences were detected, possibly associated to seasonal migratory patterns but further studies need to be done aiming at spatio-temporal analyses. ii) This technique provides a low cost/ low impact method for efficient monitoring in the PNBA. The results highlight the presence of certain species with extinction conservation status that could not be observed in other ways. iii) Our approach has improved the knowledge about the habitat biodiversity and the spatial occurrence of endangered species in the largest Marine Protected Area of West Africa, providing information for management, conservation and education.

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Supplemental materials

Figure I. Each picture shows one of the variables categories used for classifying the fish species: (a) *Cymodocea nodosa* seagrass meadow at 1.5 metres depth in Kiaone Petit; (b) a transition habitat at 5 metres depth between a *Cymodocea nodosa* seagrass meadow and *Sargassum* sp. forest in Cap Tagarit; (c) a sand habitat at 5 metres depth in Cap Tagarit; (d) a night BRUV at 3 metres depth in Arkeiss; (e) and (f) show images of BRUVs in which the habitat was classified as ‘No information’, due to very low visibility conditions and a bad positioning of the BRUV structure respectively.

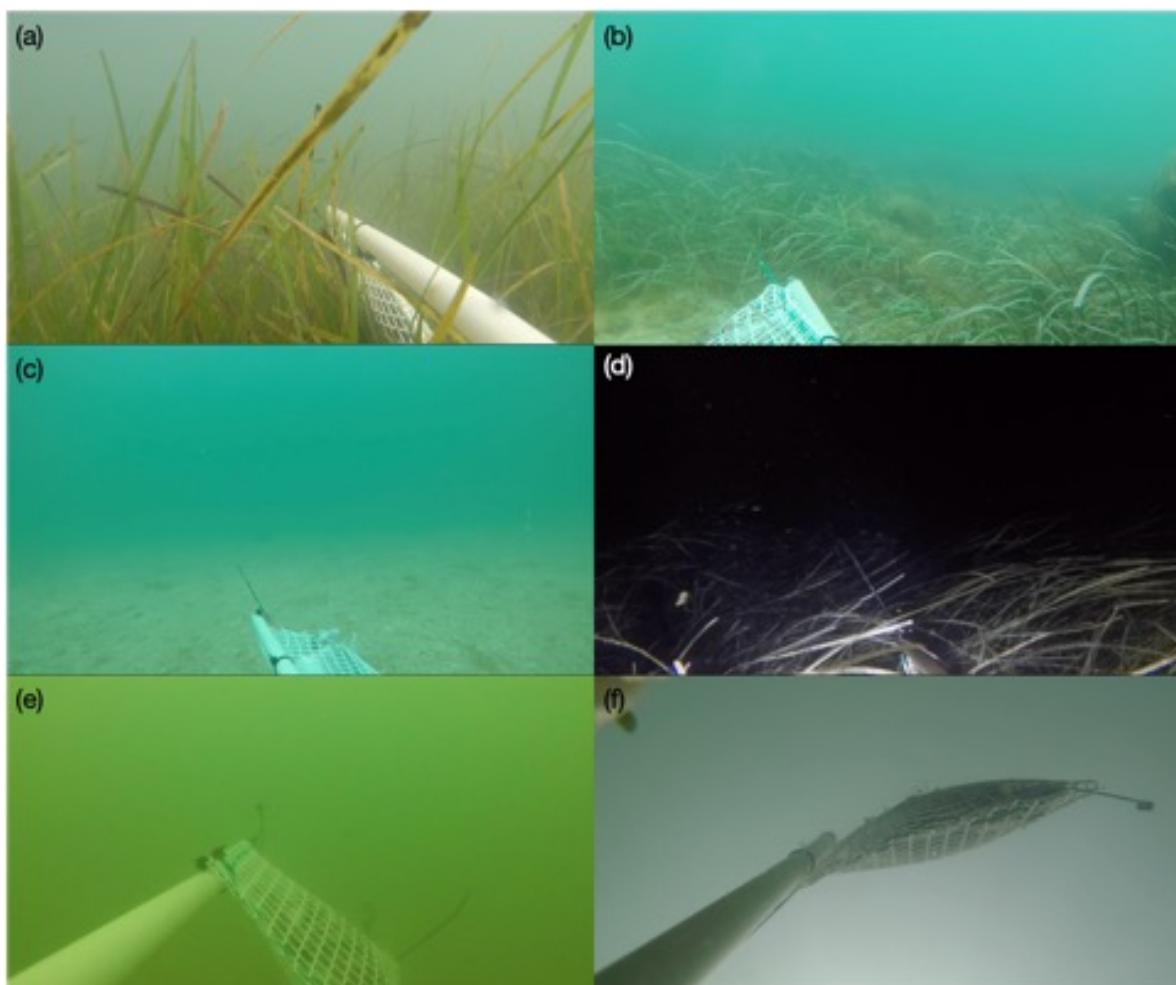


Table I. Table contains the metadata of the BRUVs done in both sampling periods (spring and autumn) with details on location data, type of habitat, depth, temperature and time of analysis. In the BRUV code the first letter corresponds to the sampling period (M – May and N – November), the B with the first number is the BRUV number of that day and the D and the number is the sampling day for each season.

BRUV code	BRUV name	Latitude	Longitude	Location	Habitat	Depth (m)	Temp. (°C)	Analysis time (min)	Deployment
1	M B 1D1	19,8758	-16,2964	Iwik	Sand	5,5	19	61,06	Day / spring

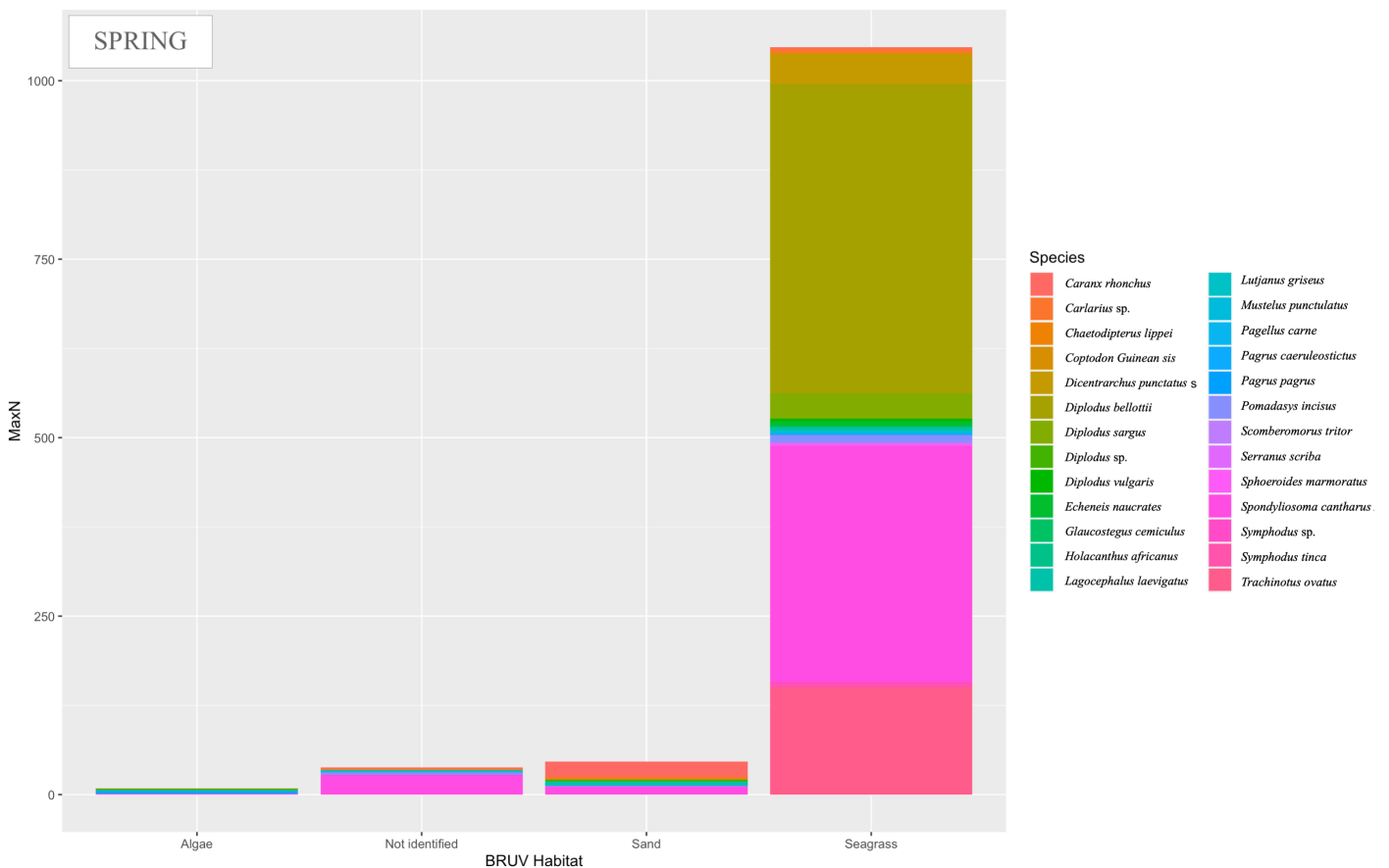
2	M B 2D1	19,8756	-16,2971	Iwik	Sand	5,5	19	60,68	Day / spring
3	M B 3D1	19,8755	-16,2980	Iwik	Sand	9	19	65,76	Night / spring
4	M B 1D2	20,0076	-16,3014	Kiaone Grand	Seagrass	3	19	68,95	Day / spring
5	M B 2D2	20,0065	-16,2987	Kiaone Grand	Seagrass	1,5	19	67,74	Day / spring
6	M B 3D2	20,0064	-16,2959	Kiaone Grand	Seagrass	2,5	19	63,95	Day / spring
7	M B 3D2	20,0159	-16,2987	Kiaone Grand	AlgSand	5	19	55,21	Day / spring
8	M B 5D2	19,8738	-16,2904	Iwik	Sand	5,5	19	56,17	Night / spring
9	M B 6D2	19,8729	-16,2874	Iwik	Sand	4	19	58,04	Night / spring
10	M B 7D2	19,8718	-16,2842	Iwik	Sand	6	19	61,08	Night / spring
11	M B 1D3	20,6973	-16,6741	Cap St Anne	Seagrass	3	19	63,11	Day / spring
12	M B 2D3	20,6902	-16,6826	Cap St Anne	Rock	5	19	63,17	Day / spring
13	M B 3D3	20,6993	-16,6779	Cap St Anne	Unknown	4	19	50,45	Day / spring
14	M B 4D3	20,7124	-16,6774	Cap St Anne	Unknown	5	19	59,72	Day / spring
15	M B 5D3	20,7144	-16,6772	Cap St Anne	Unknown	4	19	60,37	Night / spring
16	M B 6D3	20,7162	-16,6766	Cap St Anne	Unknown	4	19	61,59	Night / spring
17	M B 1D4	19,8879	-16,5004	Arel	Seagrass	3	19	61,31	Day / spring
18	M B 2D4	19,8866	-16,5019	Arel	Seagrass	1,5	19	63,39	Day / spring
19	M B 3D4	19,8852	-16,5036	Arel	Seagrass	2	19	63,86	Day / spring
20	M B 4D4	19,8920	-16,4977	Arel	Seagrass	1,5	19	83,03	Day / spring
21	M B 5D4	19,8935	-16,4960	Arel	Seagrass	1,5	19	84,47	Day / spring
22	M B 6D4	19,8950	-16,4934	Arel	Seagrass	3	19	84,27	Day / spring
23	M B 1D5	19,8764	-16,2827	Iwik	Sand	4	19	13,88	Day / spring
24	M B 2D5	19,8719	-16,2811	Iwik	Seagrass Unknown	1,5	19	70,62	Day / spring
25	M B 3D5	19,8786	-16,2828	Iwik	Unknown	4	19	71,3	Day / spring
26	M B 4D5	19,8839	-16,2909	Iwik	Sand	5	19	59,53	Day / spring
27	M B 5D5	19,8863	-16,2894	Iwik	Sand	5	19	55	Day / spring
28	M B 6D5	19,8896	-16,2879	Iwik	Sand	4	19	52,36	Day / spring
29	NB1 D1	20,3547	-16,4363	C a p Tagarit	Sand	6	20	72,92	Day / autumn
30	NB2 D1	20,3155	-16,4544	C a p Tagarit	Sand	6	20	92,31	Day / autumn
31	NB3 D1	20,3330	-16,4444	C a p Tagarit	Sand	6,2	20	77,68	Day / autumn

32	NB4 D1	20,39	-16,3827	C a p Tagarit		5,4	20	67,22	D a y / autumn
33	NB5 D1	20,1736	-16,3783	C a p Tagarit	SeagAlg	4,4	20	82,63	D a y / autumn
34	NB6 D1	20,1736	-16,3783	C a p Tagarit	Sand	5,5	20	80,79	D a y / autumn
35	NB7 D1	20,3005	-16,4086	C a p Tagarit	Sand	4,6	20	58,81	D a y / autumn
36	NB8 D1	20,3252	-16,4030	C a p Tagarit	SeagAlg Sand	4,2	20	58,74	D a y / autumn
37	NB9 D1	20,3013	-16,4094	C a p Tagarit	SeagAlg	3,9	20	62,33	D a y / autumn
38	NB1 OD1	20,2775	-16,4097	C a p Tagarit	Sand	4,1	20	63,88	Night / autumn
39	NB1 1D1	20,3127	-16,4158	C a p Tagarit	Seagrass	5	20	56,77	Night / autumn
40	NB1 2D1	20,295	-16,4188	C a p Tagarit	Algae	4,5	20	67,66	Night / autumn
41	NB1 D2	20,3375	-16,3963	Arkeiss	Seagrass	3,5	20	55,38	D a y / autumn
42	NB2 D2	20,3477	-16,4094	Arkeiss	AlgRock Sand	4,5	20	59,65	D a y / autumn
43	NB3 D2	20,3508	-16,4383	Arkeiss	Seagrass	4,6	20	56,2	D a y / autumn
44	NB4 D2	20,3222	-16,4661	Arkeiss	Seagrass	4,6	20	71,77	D a y / autumn
45	NB5 D2	20,2733	-16,4880	Arkeiss	Sand	4,6	20	74,15	D a y / autumn
46	NB6 D2	20,2986	-16,4813	Arkeiss	Sand	4,8	20	72,74	D a y / autumn
47	NB7 D2	20,2086	-16,4961	Arkeiss	AlgSand	3,5	20	42,99	D a y / autumn
48	NB8 D2	20,1619	-16,4872	Arkeiss	SeagSan d	3,1	20	104,83	D a y / autumn
49	NB9 D2	20,1819	-16,4955	Arkeiss	SeagSan d	3,4	20	108,45	D a y / autumn
50	NB1 OD2	20,34	-16,4469	Arkeiss	Seagrass	4,8	20	136,82	Night / autumn
51	NB1 1D2	20,3125	-16,4669	Arkeiss	Seagrass	4,6	20	77,53	Night / autumn
52	NB1 2D2	20,3283	-16,4586	Arkeiss	Seagrass	4,8	20	98,47	Night / autumn
53	NB1 D3	20,015	-16,2880	Kiaone Petit	Seagrass	2,6	20	79,49	D a y / autumn
54	NB2 D3	20,0911	-16,3613	Kiaone Petit	Seagrass	2,3	20	86,28	D a y / autumn
55	NB3 D3	20,0575	-16,3133	Kiaone Petit	Seagrass	1,6	20	73,48	D a y / autumn
56	NB4 D3	20,1272	-16,3991	Kiaone Petit	Seagrass	2,8	20	53,44	D a y / autumn
57	NB5 D3	20,1744	-16,44	Kiaone Petit	Seagrass	2,8	20	84,61	D a y / autumn
58	NB6 D3	20,1444	-16,4094	Kiaone Petit	Seagrass	2,5	20	88,01	D a y / autumn
59	NB7 D3	20,2116	-16,4955	Kiaone Petit	SeagSan d	2,6	20	90,65	D a y / autumn
60	NB8 D3	20,1886	-16,4772	Kiaone Petit	*	3,6	20	77,48	D a y / autumn
61	NB9 D3	20,1605	-16,4572	Kiaone Petit	SeagSan d	3,6	20	85,1	D a y / autumn

62	NB1 D4	19,9197	-16,6455	Arel	Sand	6,9	20	73,75	Day / autumn
63	NB2 D4	19,9111	-16,675	Arel	Sand	9,1	20	77,5	Day / autumn
64	NB3 D4	19,9052	-16,7108	Arel	Sand	6,2	20	78,65	Day / autumn
65	NB4 D4	19,9436	-16,6613	Arel	Seagrass	3,4	20	66,75	Day / autumn
66	NB5 D4	19,955	-16,6380	Arel	SeagSand	3,9	20	18,23	Day / autumn
67	NB6 D4	19,9747	-16,6119	Arel	SeagSand	2,9	20	70,88	Day / autumn
68	NB7 D4	20,0444	-16,5225	Arel	Seagrass	3,4	20	60,27	Day / autumn
69	NB8 D4	20,0202	-16,5483	Arel	SeagAlg	4,4	20	59,62	Day / autumn
70	NB9 D4	20,0069	-16,5663	Arel	AlgSand	3,4	20	57,47	Day / autumn
71	NB1 D5	20,055	-16,7094	M o j d Dakhna	AlgSand	2,1	20	67,89	Day / autumn
72	NB2 D5	20,0683	-16,7213	M o j d Dakhna	AlgSand	2,1	20	71,66	Day / autumn
73	NB3 D5	20,0744	-16,7161	M o j d Dakhna	AlgSand	2,3	20	73,64	Day / autumn
74	NB4 D5	19,8844	-16,6872	M o j d Dakhna	AlgSand	3,2	20	57,57	Day / autumn
75	NB5 D5	19,8952	-16,6719	M o j d Dakhna	Sand	3,4	20	62,46	Day / autumn
76	NB6 D5	19,9019	-16,6463	M o j d Dakhna	Sand	3,8	20	64,62	Day / autumn
77	NB7 D5	20,0530	-16,8258	M o j d Dakhna	SeagSand	1,5	20	54,72	Day / autumn
78	NB8 D5	20,0697	-16,8113	M o j d Dakhna	Seagrass	1,5	20	56,67	Day / autumn
79	NB9 D5	20,0894	-16,8063	M o j d Dakhna	SeagAlg	1,5	20	58,98	Day / autumn
80	NB1 D6	19,8997	-16,3944	Iwik	AlgSand	7,9	20	107,76	Day / autumn
81	NB2 D6	19,885	-16,3963	Iwik	Sand	7,7	20	72,7	Day / autumn
82	NB3 D6	19,9394	-16,4205	Iwik	Sand	6,3	20	72,8	Day / autumn
83	NB4 D6	20,0294	-16,4019	Tidra	AlgSand	3,6	20	74,17	Day / autumn
84	NB5 D6	20,0547	-16,4238	Tidra	Sand	3,6	20	73,51	Day / autumn
85	NB6 D6	20,0805	-16,4452	Tidra	Sand	3,9	20	71,77	Day / autumn
86	NB7 D6	20,0991	-16,4616	Tidra	Sand	3,5	20	76,65	Day / autumn
87	NB8 D6	20,1102	-16,4783	Tidra	Seagrass	1,1	20	77,68	Day / autumn
88	NB9 D6	20,1291	-16,4808	Tidra	Sand	5,1	20	79,65	Day / autumn
89	NB1 OD6	20,0358	-16,3758	Iwik	Sand	7,3	20	54,48	Night / autumn
90	NB1 1D6	20,0333	-16,3525	Iwik	Sand	8	20	54,51	Night / autumn
91	NB1 2D6	20,0347	-16,3138	Iwik	Sand	7,5	20	52,64	Night / autumn

92	NB1 D7	19,5738	-16,5047	C a p Alsaz	Sand	1,3	20	149,28	Day / autumn
93	NB2 D7	19,5688	-16,5177	C a p Alsaz	Sand	1,7	20	81,45	Day / autumn
94	NB3 D7	19,5616	-16,5308	C a p Alsaz	Sand	1,5	20	81,72	Day / autumn
95	NB4 D7	19,5433	-16,5441	C a p Alsaz	Seagrass	2,5	20	74,03	Day / autumn
96	NB5 D7	19,5330	-16,5419	C a p Alsaz	Seagrass	1,8	20	106,19	Day / autumn
97	NB6 D7	19,5313	-16,5391	C a p Alsaz	Seagrass	1,1	20	104,82	Day / autumn
98	NB7 D7	19,5241	-16,5480	C a p Alsaz	Seagrass	2,1	20	78,34	Day / autumn
99	NB8 D7	19,5152	-16,5408	C a p Alsaz	Seagrass	1,7	20	71,53	Day / autumn
100	NB9 D7	19,4969	-16,5202	C a p Alsaz	Seagrass	1,4	20	71,62	Day / autumn
101	NB1 OD7	20,1188	-16,2614	Arkeiss	SeagSand	0,8	20	67,19	Night / autumn
102	NB1 1D7	20,1183	-16,2601	Arkeiss	Seagrass	1	20	21,47	Night / autumn
103	NB1 2D7	20,1190	-16,2625	Arkeiss	Seagrass	1,1	20	54,21	Night / autumn

Figure II. Ggplots showing the MaxN abundance for the different species identified. Each graph belongs to a different sampling period and species abundance has been classified per habitat, spring season above and autumn season below.



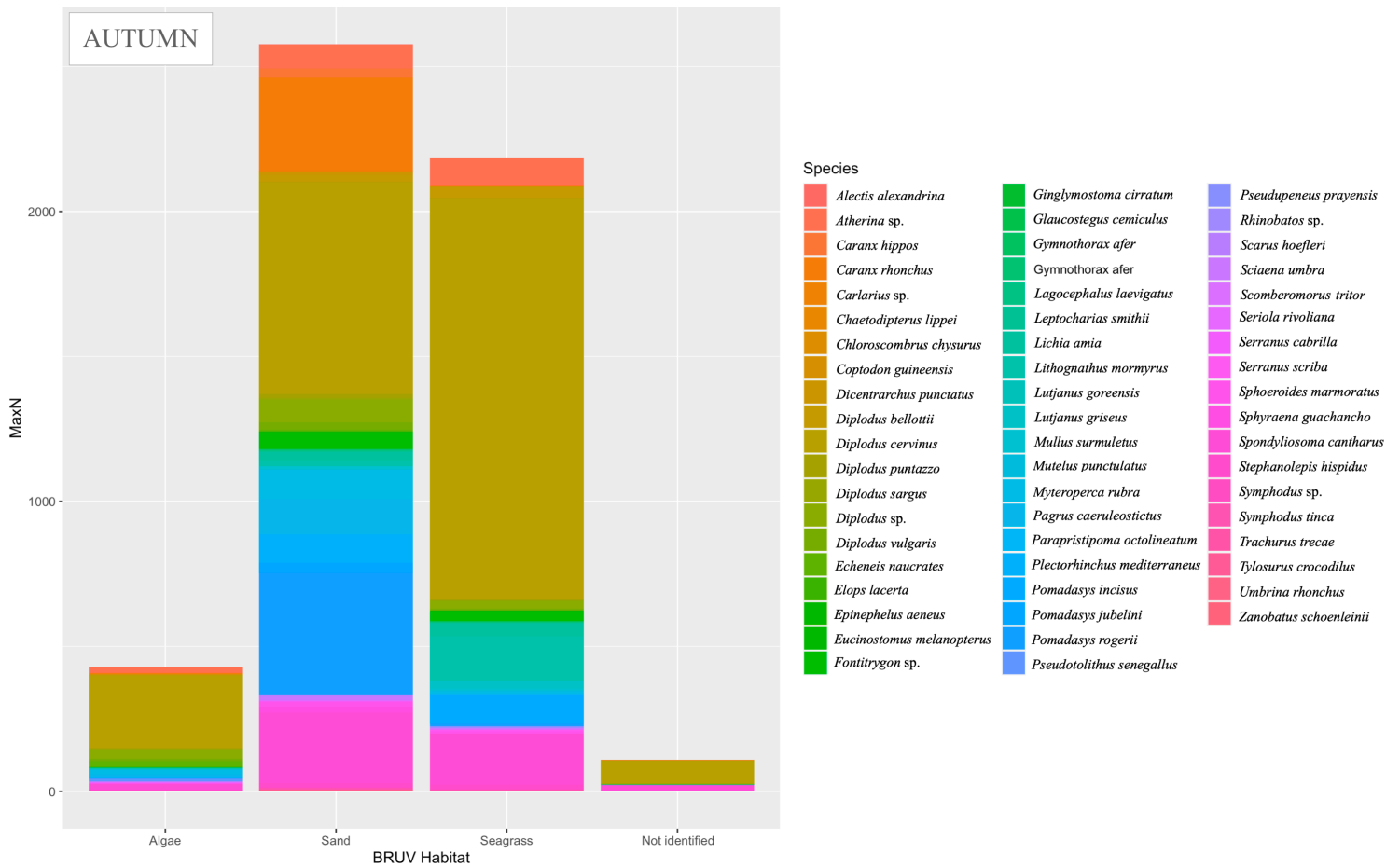


Table II. List of the species identified with the BRUVs in the different points sampled along the PNBA in Mauritania. Some species were identified to a species level and a few could only be identified into genus level, due to bad visibility conditions or the individual being in a not proper positioning in the image to identify it. The table content includes different variables including species name and family verified with WoRMS (WoRMS Editorial Board, 2023); diet, habitat and maximum depth at which the species can be found extracted from FishBase (Froese and Pauly 2000); and the conservation state and population trend extracted from IUCN (IUCN, 2022).






Species	Family	Diet	Habitat	Max. depth	Conservation state / Population trend
<i>Alectis alexandrina</i>	Carangidae	Carnivore	Non-vegetated	70	LC / Stable
<i>Atherina</i> sp.	Atherinidae	Carnivore	Both		LC / Unknown
<i>Caranx hippos</i>	Carangidae	Carnivore	Vegetated	350	LC / Stable
<i>Caranx rhonchus</i>	Carangidae	Carnivore	Both	200	LC / Stable
<i>Carlarius</i> sp.	Ariidae	Carnivore	Both		LC Unknown
<i>Chaetodipterus lippei</i>	Ephippidae	Omnivore	Both	50	LC / Unknown


Chloroscombrus chrysurus	Carangidae	Omnivore	Non-vegetated	110	LC / Stable
Coptodon guineensis	Cichlidae	Omnivore	Both		LC / Unknown
Dicentrarchus punctatus	Moronidae	Carnivore	Both		LC / Unknown
Diplodus bellottii	Sparidae	Carnivore	Both	100	LC / Unknown
Diplodus cervinus	Sparidae	Omnivore	Both	300	LC / Decreasing
Diplodus puntazzo	Sparidae	Omnivore	Vegetated	150	LC / Unknown
Diplodus sargus	Sparidae	Carnivore	Both	50	LC / Unknown
Diplodus sp.	Sparidae	Omnivore	Both		LC
Diplodus vulgaris	Sparidae	Carnivore	Vegetated	160	LC / Unknown
Echeneis naucrates	Echeneidae	Carnivore	Both	85	LC / Stable
Elops lacerta	Elopidae	Carnivore	Vegetated	50	LC / Unknown
Epinephelus aeneus	Epinephelidae	Carnivore	Both	200	NT / Decreasing
Eucinostomus melanopterus	Gerridae	Omnivore	Both	25	LC / Unknown
Fontitrygon sp.	Dasyatidae	Carnivore	Vegetated		VU, NT
Ginglymostoma cirratum	Ginglymostomatidae	Carnivore	Vegetated	130	VU / Decreasing
Glaucostegus cemiculus	Rhinopristiformes	Carnivore	Both	100	NT / Decreasing
Gymnothorax afer	Muraenidae	Carnivore	Vegetated	801	LC / Unknown
Holacanthus africanus	Pomacanthidae	Omnivore	Vegetated	40	LC / Stable
Lagocephalus laevigatus	Tetraodontidae	Carnivore	Both	180	LC / Unknown
Leptocharias smithii	Leptochariidae	Carnivore	Vegetated	75	VU / Decreasing
Lichia amia	Carangidae	Carnivore	Both	50	LC / Unknown



Lithognathus mormyrus	Sparidae	Carnivore	Vegetated	150	LC / Stable
Lutjanus goreensis	Lutjanidae	Carnivore	Vegetated	50	DD / Unknown
Lutjanus griseus	Lutjanidae	Carnivore	Vegetated	180	LC / Unknown
Mullus surmuletus	Mullidae	Carnivore	Both	409	LC / Unknown
Mustelus punctulatus	Triakidae	Carnivore	Vegetated		VU / Decreasing
Mycteroperca rubra	Serranidae	Carnivore	Vegetated	200	LC / Unknown
Pageillus acarne	Sparidae	Omnivore	Both	500	LC / Unknown
Pagrus caeruleostictus	Sparidae	Carnivore	Both	200	LC / Unknown
Pagrus pagrus	Sparidae	Carnivore	Vegetated	250	LC / Unknown
Parapristipoma octolineatum	Haemulidae	Carnivore	Vegetated	60	LC / Unknown
Plectorhinchus mediterraneus	Haemulidae	Carnivore	Vegetated	180	DD / Unknown
Pomadasys incisus	Haemulidae	Carnivore	Vegetated	100	LC / Unknown
Pomadasys jubelini	Haemulidae	Carnivore	Vegetated	100	LC / Unknown
Pomadasys rogerii	Haemulidae	Carnivore	Vegetated	90	LC / Unknown
Pseudotolithus senegallus	Sciaenidae	Carnivore	Vegetated	150	VU / Decreasing
Pseudupeneus prayensis	Mullidae	Carnivore	Vegetated	300	VU / Decreasing
Rhinobatos sp.	Rhinobatidae	Carnivore	Both	100	CR / Decreasing
Scarus hoefleri	Scaridae	Hervivore	Vegetated	15	LC / Unknown
Sciaena umbra	Sciaenidae	Carnivore	Both	200	NT / Decreasing
Scomberomorus tritor	Scombridae	Omnivore	Vegetated	40	LC / Unknown







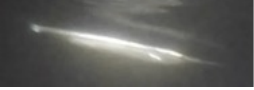


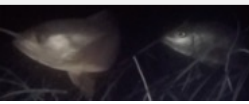
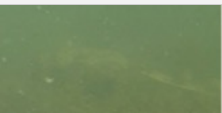
S e r i o l a rivoliانا	Carangidae	Carnivore	Vegetated	245	LC / Stable
S e r r a n u s cabrilla	Serranidae	Carnivore	Vegetated	500	LC / Stable
S e r r a n u s scriba	Serranidae	Carnivore	Both	150	LC / Stable
Sphoeroides marmoratus	Tetraodontidae	Carnivore	Both	100	LC / Unknown
Sphyraena guachancho	Sphyraenidae	Carnivore	Vegetated	100	LC / Unknown
Spondylisoma cantharus	Sparidae	Omnivore	Both	300	LC / Unknown
Stephanolepis hispidus	Tetraodontidae	Carnivore	Both	293	LC / Unknown
Symphodus sp.	Labridae	Carnivore	Both		LC / Stable
Symphodus tinca	Labridae	Carnivore	Both	50	LC / Stable
Trachinotus ovatus	Carangidae	Carnivore	Vegetated	200	LC / Unknown
Trachurus trecae	Carangidae	Carnivore	Vegetated	100	LC / Stable
Tylosurus crocodilus	Beloniformes	Carnivore	Vegetated	13	LC / Unknown
U m b r i n a ronchus	Sciaenidae	Carnivore	Both	200	DD / Unknown
Zanobatus schoenleinii	Zanobatidae	Carnivore	Non-vegetated	100	VU / Decreasing

Table III. The table contains the list of species identified with the BRUVs showing in one column their accepted scientific name and the picture used for their identification.

Species	Picture	Species	Picture
Alectis alexandrina		Mustelus punctulatus	
Atherina sp.		Mycteroperca rubra	
Caranx hippos		Pagellus acarne	-

<i>Caranx rhonchus</i>		<i>P a g r u s caeruleos tictus</i>	
Carlarius sp.		<i>P a g r u s pagrus</i>	-
<i>Chaetodi p t e r u s lippei</i>		<i>Parapristi p o m a octolineat um</i>	
<i>Chlorosc ombrus chrysuru s</i>		<i>Plectorhin c h u s mediterraneus</i>	
<i>Coptodo n guineens is</i>		<i>Pomadasy s incisus</i>	
<i>Dicentrar c h u s punctatu s</i>		<i>Pomadasy s jubelini</i>	
<i>Diplodus bellottii</i>		<i>Pomadasy s rogerii</i>	
<i>Diplodus cervinus</i>		<i>Pseudotol i t h u s senegallus</i>	
<i>Diplodus puntazzo</i>		<i>Pseudupe n e u s prayensis</i>	
<i>Diplodus sargus</i>		<i>Rhinobato s sp.</i>	
<i>Diplodus sp.</i>	-	<i>S c a r u s hoefleri (female)</i>	

Diplodus vulgaris		Sciaen umbra	
Echeneis naucrates		Scomberomorus tritor	
Elops lacerta		Seriola rivoliana	
Epinephelus aeneus		Serranus cabrilla	
Eucinostomus melanopterus		Serranus scriba	
Fontitrygon sp.		Sphoeroides marmoratus	
Ginglymostoma cirratum		Sphyraenaguachancho	
Glaucostegus cemiculus		Spondyliosoma cantharus	
Gymnothorax afer		Stephanolepis hispidus	
Holacanthus africanus		Symphodus sp.	

Lagocephalus laevigatus			Symphodus tinca	
Leptocharisma smithii			Trachinotus ovatus	-
Lichia amia			Trachurus trecae	
Lithognathus mormyrus			Tylosurus crocodilus	
Lutjanus goreensis			Umbrina ronchus	
Lutjanus griseus			Zanobatus schoenleinii	
Mullus surmuletus	