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Biodiversity and community assemblage of shallow habitats of the National Park of Banc d'Arguin (Mauritania): influence of habitat, season and site

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Supervisors:

Ester Serrao

Co-supervisor

Karim Erzini

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Declaração de autoria de trabalho

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This thesis took place in the Centre of Marine Sciences (CCMAR) of the University of Algarve (Faro, Portugal) with the collaboration of the PNBA (Parc National du Banc d’Arguin)and the IMROP (Institut Mauritanien de Recherches Océanographiques et de Pêches) to perform the sampling campaigns.

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Abstract (Resumo Portuguese)

O Banc d'Arguin, localizado ao longo da costa da Mauritânia, é uma zona húmida costeira de mais de 10.000 km2 com águas rasas, grandes leitos de ervas marinhas e planície de maré. Esta região que hospeda uma das maiores MPA da África, chamada Parc National du Banc d'Arguin, é um dos ecossistemas mais abundantes e diversificados do mundo, sustentando uma alta produção primária. Uma forte ressurgência de água rica em nutrientes no norte causa elevada produção primária de fitoplâncton nas áreas do norte do Banc. Na parte sul e sudeste, grandes planícies de marés e tapetes de ervas marinhas criam um ecossistema distinto associado a produção primária bentónica subtidal e intertidal. O Banc d'Arguin, é conhecido por hospedar um grande e diversificado painel de espécies, raras e ameaçadas de extinção de grande importância ecológica. O clima e os fatores abióticos encontrados nesta região, são únicos, com a presença de espécies temperadas, subtropicais e tropicais encontradas dentro de um mesmo ecossistema. Uma grande biodiversidade de espécies bentónicas, peixes, camarões, elasmobrânquios e pássaros são conhecidos por estar presentes nesta área onde a atividade pesqueira é estritamente controlada. Nesta área protegida estão autorizados apenas os Imraguens, pescadores locais espalhados por aldeias por todo o litoral, utilizando técnicas milenares para pescar dentro do PNBA. A presença de peixes de valor económico é conhecida e bem documentada na região. No entanto, a diversidade e composição do habitat costeiro de águas rasas, composto por grandes tapetes de ervas marinhas e bancos de areia, onde a maioria desses peixes e outras espécies amadurecem e recrutam, permanece parcialmente desconhecida. Esses habitats representam um fator chave para entender a grande biodiversidade encontrada no Banc d'Arguin. É importante ter um melhor entendimento da importância desses habitats e as consequências das possíveis mudanças que podem ocorrer.

A biodiversidade de habitats de ervas marinhas e habitats de areia localizados em habitats de águas rasas do Banc d'Arguin foram amostradas com uma rede de arrasto em 3 locais, durante duas missões de amostragem em dezembro e abril. A rede permitiu-nos recolher amostras das áreas rasas intertidais e subtidais nos primeiros metros de água onde se encontram os tapetes de ervas marinhas. Os 3 locais de amostragem foram determinados com um habitat de ervas marinhas e um habitat de areia, amostrados dentro da mesma área geográfica. O local A presente no sul do Banc d'Arguin em Mamghar era uma baía costeira. O site B ficava em Iwik, na parte sudeste do Banc e era um local costeiro exposto.

O local C ficava nas ilhas de Kiji e Nair, localizadas nas lagoas rasas a oeste de Iwik. Os 3 locais diferentes foram amostrados durante o inverno e a primavera para comparar os resultados entre as estações. Alguns locais de amostragem extras foram adicionados durante a amostragem da primavera, mas não usados na análise estatística. Essas amostragens extras em tapetes de ervas marinhas foram realizadas a fim de avaliar com mais precisão a composição de espécies desses habitats.

Os objetivos deste estudo foram testar se a comunidade era diferentes entre os habitats, em termos de abundância, diversidade de espécies e estrutura, e o efeito da estação e do local. A comunidade era muito diferente entre os habitats em termos de abundância, diversidade de espécies e estrutura da comunidade. Os habitats de ervas marinhas compostos por *Zostera noltei*, *Cymodocea nodosa* e *Halodule wrightii* suportaram um maior número de indivíduos, espécies e diversidade do que a areia nua. Ambos os habitats foram dominados em abundância por *Atherina boyeri* e outras espécies encontradas em todos os habitats. No entanto, as espécies de ervas marinhas e areia associadas eram muito diferentes e explicavam as diferenças na estrutura da assembleia. Na verdade, o grande campo de ervas marinhas oferece um abrigo para muitas espécies, explicando a maior diversidade encontrada nesses habitats. A família e as espécies associadas às ervas marinhas eram espécies de: camarões; *Stephanolepsis hispidus*; *Nicholsina usta*; *Fistularia tabacaria*; Sepiidae; Sparidae; Tetraodontidae; Syngnathidae; Labridae; Lutjanidae e Serranidae. No entanto, as espécies de areia eram muito diferentes, com uma composição principalmente de espécies de peixes planos, como *Citharichthys stampflii*; *Pegusa lascaris*; *Pegusa triophthalma*; *Psettodes belcheri; Solea senegalensis*; *Synaptura lusitanica*, bem como várias espécies de raia, como *Dasyatis margarita*, *Glaucostegus cemiculus* ou *Rhinobatos rhinobatos*.

O fator sazonalidade apenas apresentou diferenças no número de espécies, diversidade e estrutura da comunidade de peixes. A temporada de primavera suportou um maior número de espécies, supostamente correlacionado com o aparecimento de juvenis de um grande número de espécies, chegando a habitats protegidos rasos para se desenvolverem e partirem na temporada para águas mais profundas. No inverno algumas espécies estiveram presentes, como *Eucinostomus melanopterus* e não foram encontradas na primavera, ao contrário de *Atherina boyeri* e um maior número de outras espécies encontradas principalmente na primavera. Uma estratégia ecológica diferente explica as diferenças, no entanto, o maior número de espécies que aparecem na primavera é explicado por padrões sazonais, principalmente devido a diferenças nos fatores abióticos

que ocorrem entre as estações. O fator local mostrou diferenças em termos de abundância e diversidade de espécies, entre Mamghar e os outros locais, mas não para a estrutura da comunidade. Supõe-se que a maior abundância e diversidade de espécies em Mamghar é devido a uma área mais protegida de fortes fatores abióticos, bem como uma disponibilidade de presas pode ser maior na zona. A quase totalidade dos indivíduos capturados eram jovens (98,7%), confirmando a função de berçário desses habitats rasos do Banc d'Arguin, especialmente no habitat de ervas marinhas onde a comunidade mais abundante e diversa é encontrada. Esta observação enfatizou a importância crucial dessas zonas para sustentar uma biodiversidade saudável e diversa em toda a região. No entanto, os estudos mais recentes mostram que essas áreas de berçário do Banc d'Arguin estão em perigo, com uma redução progressiva e, eventualmente, o desaparecimento dos grandes tapetes de ervas marinhas e planícies de maré devido ao aquecimento global e elevação do nível do mar. Potenciais eventos abióticos extremos com mais frequência, bem como as mudanças gerais que ocorrerão nestas décadas, podem alterar profundamente a comunidade nos habitats do Banc d'Arguin e afetar os padrões de sazonalidade atualmente observados.

Palavras-chave: Seagrass; Mauritânia; Berçário; Banc d'Arguin; Assembléia da comunidade

Abstract (English)

The biodiversity and community assemblages of seagrass and sand habitats located in shallow water habitats of the Banc d'Arguin were sampled with a beach seine at 3 sites, during two sampling missions in December and April. The objectives were to test if the community assemblages in term of abundance, species diversity and assemblage structure were different between habitats, as well as the effect of the season and the site. The community assemblage was found to be very different between habitats in term of abundance, species diversity and community assemblage structure. Seagrass habitats composed of *Zostera noltei*, *Cymodocea nodosa* and *Halodule wrightii* supported a larger number of individuals, species and diversity than bare sand. Both habitats were dominated in abundance by *Atherina boyeri* and other species found in all habitats. However, the seagrass and sand associated species, were very different and accounted for the differences in the assemblage structure. The large canopy of seagrass offers a shelter for a lot of species explaining the higher diversity found in these habitats. The season factor only showed differences in the number of species, diversity and fish assemblage structure. The spring season supported a larger number of species, supposedly correlated to the appearance of juveniles of a large number of species coming to nurseries in shallow protected habitat before leaving later in the season to deeper waters. The site factor showed differences in terms of abundance and species diversity only between Mamghar and the other sites, but not for the community assemblage structure. Almost all individuals caught were young juveniles (98.7%). It confirms the nursery function of the shallow habitats of the Banc d'Arguin, specially in seagrass habitat where the most abundant and diverse community is found. This work confirm that these large seagrass beds are essential in the development of the high biodiversity known to be found in the Banc d'Arguin.

Key words: Seagrass; Mauritania; Nursery; Banc d'Arguin; Community assemblage

1. **Introduction**

The Banc d'Arguin, located along the coast of Mauritania is defined as a coastal wetland, with shallow water, large sea grass beds and tidal flats (Schaffmeister et al., 2006). The Banc d'Arguin represents an area of over 10 000km^2 (Wolff et al., 1993). It extends from Cap Blanc (20°460 N – 17°020 W), representing the Northern part of the zone, to Cap Timiris (19°230 N– 17°020 W), the southern border (Araujo & Campredon, 2016). The coast is shallow, and presents different aspects along it and in the gulf d'Arguin with mudflats, channels, sand banks, and islands of variable sizes (Araujo & Campredon, 2016).

In 1976, the Parc National du Banc d'Arguin (PNBA), one of the biggest MPA in Africa, and registered in the UNESCO World Heritage List (Trégarot et al., 2019; Araujo & Campredon, 2016) was created with an area of more than 12 000 km^2. This area, covering coastaland marine ecosystems with shallow water, tidal flats along with a continental part (Sahara Desert) represents the most important fish nursery area in Mauritania and is essential to maintain sustainable fish stocks (Jager 1993; Campredon and Cuq, 2001; Correia et al., 2021).

Because of its location, the Banc d'Arguin is subject to upwelling events coming from the Canary upwelling system, one of the biggest in the world (Arístegui et al., 2009). Due to this, a high primary production is associated with this region, resulting in large stocks of fishes, shrimps, and other species relying on high levels of primary production (Carlier et al., 2015; Araujo and Campredon, 2016). Several species of endangered turtles can be found in the Banc d'Arguin, the most abundant being *Chelonia mydas* (Cardona et al., 2009) known to feed on the large seagrass beds covering the gulf (Godley et al., 2003; Catry et al., 2009). Moreover, a large number of endangered species of rays and sharks are found in the Banc (Leurs et al.,2021). Moreover, the Gulf d'Arguin represents a winter refuge for millions of migrating shorebirds every year (Altenburg et al., 1983; Araujo & Campredon, 2016). However, many studies consider that the southeastern tidal flat region covered by seagrasses represents a distinct ecosystem from the northern one. Indeed, the food web is supported mainly by local benthic primary production, and not by the upwelling system present in the Northern part of the Banc d'Arguin (Sevrin-Reyssac, 1983; Boudouresque et al.,1988; Calier et al., 2015).

The seagrass meadows present in the Banc d'Arguin represent a very large nursery area for a lot of marine species (Schaffmeister et al., 2006; Jager, 1993). The presence of a dense seagrass meadows canopies in the subtidal shallow zones with epiphytes provides a protection and a shelter from predators (Stoner, 1983; Orth et al., 1984; Pollard, 1984; Bell and Pollard, 1989; Ribeiro et al. 2006). Seagrass habitat provide higher food diversity and availability for the small individuals maturing inside these nursery zones (Burchmore et al., 1984; Connolly, 1994; Nakamura 2012) in opposition with unvegetated habitats.

The large seagrass beds are composed of three main species (Wolff et al., 1993):

- *Zostera noltii* a temperate seagrass, where the Banc d'Arguin is close to the Southern limit of the species. *Z. noltei* is found in large quantities and forms meadows with very high density. This species is known to be found in the intertidal zone. The average leaves width and length (maximum length 19.6 ± 2.5 cm) are found to be higher than *H.wrightii* but smaller than *C.nodosa* (Chefaoui et al., 2021).

- *Halodule wrightii* where the Banc d'Arguin represents the northern limit of the species (Green & Short, 2003). This tropical species has a smaller habitat structure with short thin leaves (maximum length (14.7 ± 1.8 cm) and low shoot densities. This species is known to be found mixed with *C. nodosa* and in the first meters of the subtidal part of the banc d'Arguin (Chefaoui et al., 2021).

- *Cymodocea nodosa* where the Banc d'Arguin is considered as the southern limit of the species (Alberto et al., 2008). This temperate species is found in large quantities in the first meters of the subtidal zones. Presenting less shoot density than the two other species, the long (maximal leaf length 38.4 ± 7.9 cm) and width leaves of this seagrass present very dense zones of vegetation (Chefaoui et al., 2021).

Cymodocea nodosa and *Halodule wrightii* can be found along all the coast of Mauritania. Moreover, *Cymodocea nodosa* has been reported to be found along with *Zostera noltii* in sandy habitats (Cunha & Araújo, 2009). Furthermore, field observations report that *Cymodocea nodosa* and *Halodule wrightii* have been found to be mixed in some habitats.

Within the PNBA many species of fish of economic values are found and are caught by the Imraguens, being the only ones allowed to fish. The Imraguens are local and resident fishermen spread in eight different villages along the coast of the PNBA (Araujo & Campredon, 2016). They use traditional and ancient techniques, targeting some species such as *Argyrosomus regius* and *Mugil cephalus* with nets and small sailing boats (Trégarot et al., 2019). The Imraguens are dependent on these fisheries and rely on them to survive (Campredon and Cuq, 2001; Araújo and Campredon, 2016). As a result, they are the only ones allowed to fish, using non-motorized boats called “lanches”. There are 114 of these sailing boats allowed access to fish in the PNBA (Correia et al., 2021; Trégarot et al.,2019). As the only fishermen allowed within the PNBA, the Imraguens represent a precious source of information regarding the fish stocks, the abundance and distribution of other species, and all the different changes occurring within the MPA. As a result of this fishing activity, the presence of fishes of economical values are known and well documented in the region. However, the diversity and composition of the coastal shallow water habitat, composed of large seagrass beds and sand banks, where most of these fishes but also all of the other species that do not have economic values are maturing and recruiting, remains partly unknown. These habitats represent a key factor to understand the high biodiversity found in the Banc d’Arguin. It is important to have a better understanding of the importance of these habitats and the consequences of potential changes that could occur.

Indeed, only a few studies have assessed the species composition of the inshore habitat. The arid and very remote conditions encountered in these Banc d’Arguin coastal and sandbanks habitats are one of the reasons. However, Gushchin and Fall (2012), in a similar study investigated the fish community composition of some shallow habitats with 91 species recorded. Some of the species known to be found in all locations are designated as “background species” such as: *A. presbyter, C. labrosus, D. punctatus, D. bellottii, D. sargus, E. melanopterus, L. mormyrus, L. dumerili, M. capurrii, M. cephalus, P. perotaei, S. maderensis and S. senegalensis.* Gushchin and Fall (2012), obtained almost exclusively juvenile fishes (97.9–99.7% of their catch) as a result, we expected to find mostly juveniles and immature in our samples (Jager et al, 1993).

Jager (1993) assessed the composition of the juvenile fishes found in this area and particularly in the north of Tidra where part of our sampling occurred, with a beam trawl. The outcome was the presence of three main species and groups: *Stephanolepsis hispidus*, *Diplodus bellottii* and *Gobidae.*

In addition to fishes, three main species of crabs are known to be present in the zone, with *Uca tangeri*, *Callinectes marginatus*, and the crab *Panopeus africanus* representing the three main species (Wolf and Smit, 1990). Shrimp species are also part of the diverse marine species encountered in these habitats with more than 11 species identified by Schaffmeister et al. in 2006.

No studies have assessed the effect of the habitat on community assemblages in the Banc d'Arguin. However, it has been assessed in some other habitats in the world having characteristics similar to those of the Banc d'Arguin, such as coastal nearshore shallow waters and shallow water lagoons and estuaries (Weinstein and Brooks, 1983; Heck et al.,1989; Connolly, 1994; Grey et al. 1996; Arrivillaga and Baltz,1999; Travers and Potter, 2002).In these studies the species diversity as well as the abundance of individuals were higher in seagrass habitats than unvegetated ones. Moreover, seagrass habitats are known to sustain the most biomass (Jenkins et al. in 1997 and Hughes in 2002).

The community assemblage structure is also known to be strongly influenced by the habitat type (Jenkins et al. 1997; Gray et al., 1998; Ribeiro et al. 2006; Ribeiro et al. 2012; Midwood and Chow-Fraser, 2012).

The season factor plays an important role in the species community assemblage (Ribeiro et al., 2006) with various patterns observed linked to the recruitment of juveniles of certain species of fish and shrimps (Schaffmeister et al., 2006). Gushchin and Fall (2012) sampled every month and showed strong variations in term of abundance and species diversity throughout the year with no strong pattern identified. However, studies in other part of the world such as in the south of Portugal (Algarve) showed differences between winter and spring in the community assemblage. Indeed Ribeiro et al. (2006) found a higher abundance in spring than in winter and Ribeiro et al. (2012) found the opposite. However, both studies found a higher number of species in spring. Migration of species into shallow areas in order to mature around spring as well as spawning events of resident species around this time are explaining the higher number of species found in spring (Ribeiro et al.,2006; Ribeiro et al., 2012). Indeed, the species assemblage fluctuate between seasons due to sequential immigration and emigration of certain species (Hyndes et al.,1999; Thiel and Potter, 2001).

Species leave the area to the adjacent coastal waters later in the year. This seasonal pattern has been observed for fishes, shrimp species (Schaffmeister et al.,2006) and Sepiidae (Darmaillacq et al., 2008).

The location within the Banc d'Arguin seems to play an important role given the result of various studies sampling the fish communities (Jager, 1993; Gushchin and Fall, 2012). In these studies, the fish abundance as well as the species diversity fluctuated a lot between locations and as a result it was important to sample different areas to assess any possible community assemblage differences. The presence of two distinct ecosystems driven by different primary resources is also to take into account in the Banc d'Arguin. Indeed, the upwelling phytoplankton driven ecosystem present in the North (Berghuis et al., 1993) is different from the Southern-east intertidal flats ecosystem (Carlier et al., 2015). This ecosystem sampled in our study and driven mainly by a local benthic primary production have not been investigated in the past with a particular focus on the shallow tidal flat regions. No previous studies have assessed the differences in terms of community assemblage structure in the Banc d'Arguin between habitats, and no studies focused on the whole marine community instead of only the fish.

For these reasons the aim of this study was to investigate the differences in terms of community assemblage in the shallow vegetated and unvegetated habitats present in the tidal flat region of the Banc d'Arguin between habitats, season and site. The aim was also to highlight the importance of these zones for the development of the various species sustaining a large and rare biodiversity found in the region.

2. Material and method

2.1 Study area

This study was carried out in the east to south-eastern part of the Banc d'Arguin between Iwik and Mamghar (**Fig. 2.2**). These areas are known to present large seagrass beds and tidal flats. Three main sites were chosen in this study following 3 main criteria:

-Zone of seagrass beds and zone without, within the same geographic area

-Accessibility of the sampling zone

-Possibility to sort and analyze the samples in lab directly after the sampling

Within each site, two sampling locations were investigated with one presenting a bare sand bottom with any vegetation, and one presenting seagrass beds covering the totality of the sampling area. The sand locations as well as the seagrass ones needed to have a low slope allowing to perform the beach seine sampling with an average 70cm to and 1m depth. Regarding the vegetated habitats, the seagrass coverage area needed to be large enough to sample 3 times in the same site. Indeed, a patchy coverage of the seagrass could induce a sand bottom part sampled and can bias the results. We tried to have a seagrass density as even as possible between each replicate.

The three species of seagrass found to compose the seagrass habitat with *Zostera noltii*, *Halodule wrightii* and *Cymodocea nodosa* were sampled. These species are found at different depth ranges and locations throughout the littoral (**Fig. 2.1**).

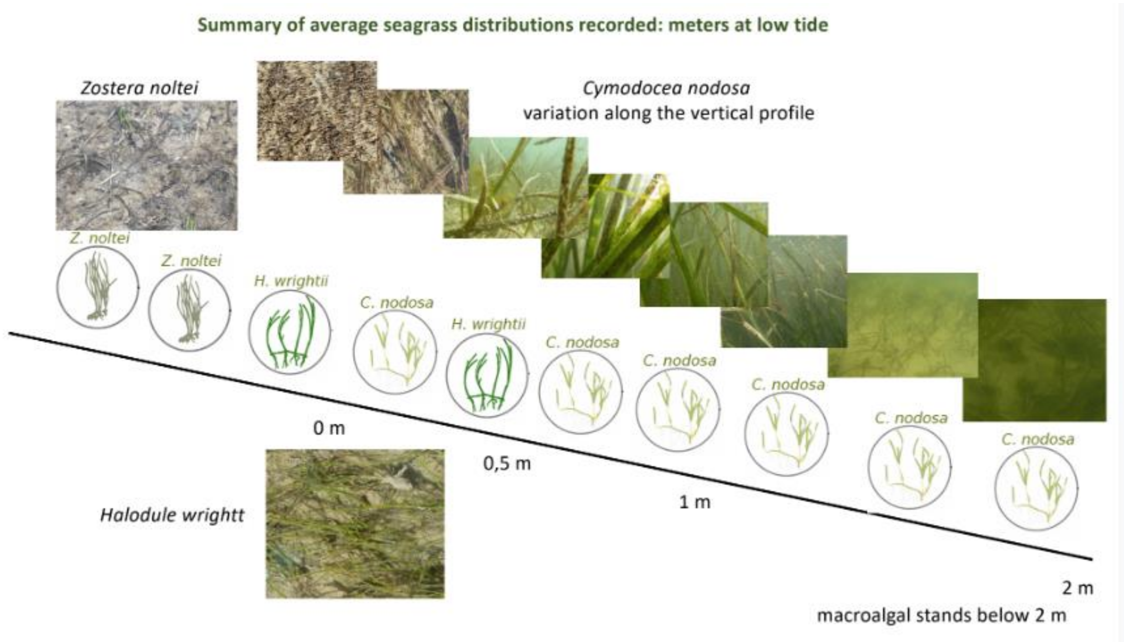


Fig. 2.1 Field observations of the seagrass distribution (with depth recorded at low tide (Ester Serrao,2020)

The three study sites were:

-Mamghar(A): This location accounting for the site A presents large zones of seagrass beds but also zones without seagrass, all of this within the same geographic area (**Fig. 2.2**). Unvegetated habitats were sampled near Cap Timiris at the entrance of a small mangrove system however presenting a large habitat of bare sand (19°22’16”N 16°31’52”W). The vegetated location situated on the eastern part of Mamghar in the Baie de Saint-Jean, has large seagrass beds following all this coast of the bay (19°25’09”N 16°22’23”W).

-Iwik(B): This location accounting for the site B was also located near a PNBA research center (**Fig. 2.2**). This location has large seagrass beds up north form Iwik (19°53’00”N 16°17’34”W) as well as large shallow sand banks in front of the Iwik marine center (19°54’18”N 16°18’35”W).

-Islands and channels on the west of Iwik(C): This location accounting for the site C, is found within Banc d'Arguin channels, mostly covered by seagrass banks. This site allowed to sample outside of the coast, in order to see if the species composition were different in these Channel Islands (**Fig. 2.2**). The vegetation habitat was found in Kiji, a large island of several kilometers presenting very dense and extended seagrass beds all around the area (19°43'19"N 16°30'05"W). The islands being highly vegetated and hard to access for the majority of them, the non-vegetative area was found in the small island of Nair (**Fig.1**). Situated North-East from Kiji (19°52'07"W 16°23'29"N) this location is known to be an important breeding ground for a lot of birds (Veen et al., 2018).

Other areas were sampled in the spring. All of these new sampled areas were vegetated and as a result the comparison of vegetated and unvegetated habitats could not be carried out. Moreover, it was not possible for these extra zones to be compared with the results of December. As a result, we did not take them into account for the statistical analysis.

The extra zone was:

- The island of Agnefour (19°51'42"N 16°24'36"W).

- The island of Muzan (19°54'01"N 16°30'11"W).

- Iwik center extra zone (19°53'25"N 16°17'20"W

A number was assigned to each sampling zone, as follows:

Littoral type:

1 Mamghar (mangrove) Sand
2 Mamghar (baie saint jean) Vegetation
3 Iwik (center) Vegetation
4 Iwik (center) Vegetation
5 Iwik (center) sand
6 Muzan Vegetation
7 Kiji Vegetation
8 Nair Sand
9 Agnefour Vegetation

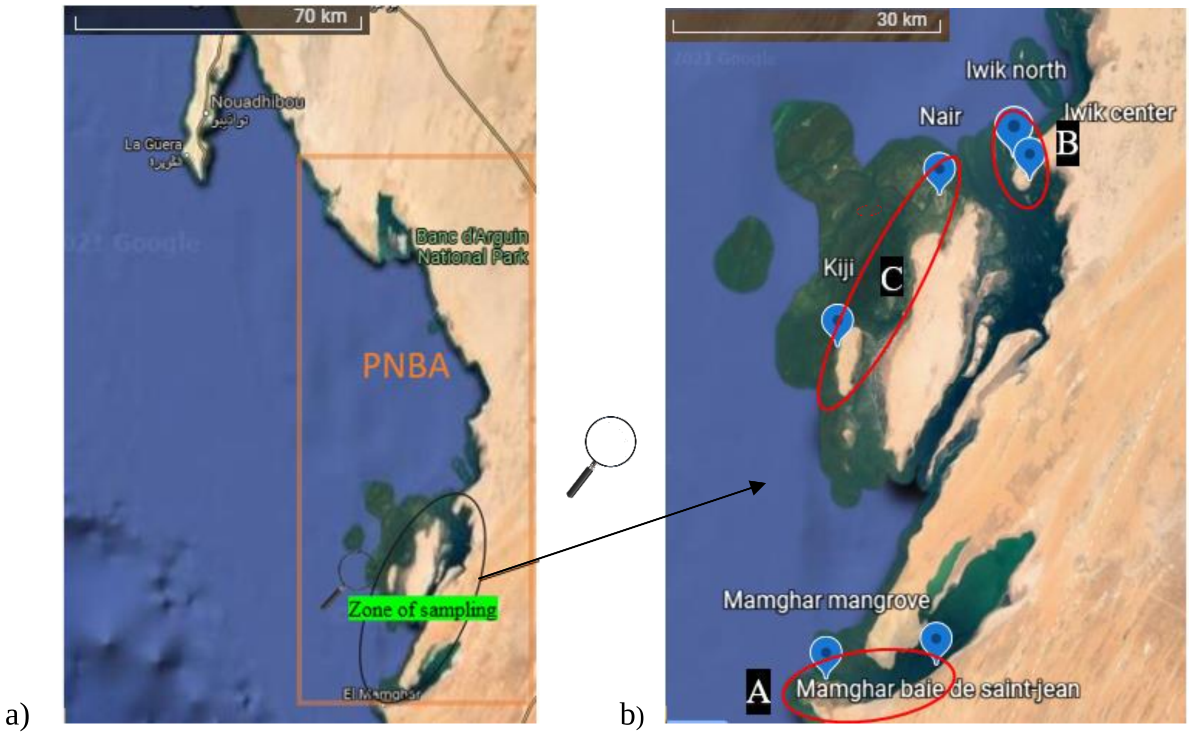


Fig. 2.2 Map of the Banc d'Arguin and zone of sampling within the PNBA borders (a) with a zoom on the 3 sites sampled (b).

2.2 Sampling design

Marine fauna was collected using a 17m, 9mm mesh size beach seine net. The net was dragged perpendicular to the shore with an equal open area between replicates. The sampling was done around low tide. The net was placed around 30m from the shore in order to have a sampling depth between 70cm to 1m. The net was dragged for 50m. The distance of 50m refers to the study of (Lombardi et al., 2014) showing that a 50m tow seems to have better results than a greater beach seine towing distance. After this, the two-handling people were slowly « closing » the net as they head to the shore. The bottom of the net needs to be in contact with the bottom all the time; to do it, it is important to ensure that the speed of the towing is slow. The sampling was performed with a downward to parallel dragging force to the ground. If the dragging is performed with an upward force, then the net is probably going to lift, and the species can escape. Moreover, keeping a similar opening area of the net for all of the samplings performed is essential.

For the sampling part occurring in the islands, an Imraguens sailing boat was used to reach them (**Fig. 2.3**). Moreover, sampling with a beam trawl was supposed to be performed. However due to the poor maneuverability of the boat it was impossible to do so.

Fig. 2.3 Sailing boat ("Lanche") used to go to the sampling locations in the islands

The sampling method was identical as possible between all replicates. Three replicates were performed at each location as a minimum. Some more were performed when the catches varied a lot within each treatment.

Measurements were then performed on the individuals caught, taking the weight (g) and total length (cm). Later in the lab the identification was performed. Regarding the big specimens,the measurements were taken directly on the sampling spot followed by a picture and an immediate release in order to keep them alive. For each species, the total length (TL) of every individual was measured to the nearest mm.

Figure. 2.4 Illustration of the beach seine net deployed during sampling

2.3 Data analysis

The first step was to analyses the samples in order to determine the different species present. As a result, a direct determination of the species could be done directly after the samplings, with the direct inspection of all the following morphological features. Following Teletchea (2009) fish identification was mainly based on the external morphological appearance such as body shape, pattern of colors, scales size and number of them, position and shape of the fins, number of rays on the fins (Strauss and bond, 1990).

Regarding other species such as shrimps, the identification relied on external morphological features such as color or body shape, but with a particular focus on the appendices, rostrum or antennae.

For crabs we looked at the color, shape but specially the claws and the carapace. The size of the animal also helped to determine the species.

In order to identify the species, identification keys and literature based on the fishes known to be found in Mauritania were used (Bonnet, 1969; Serret and Opic, 1990; Vakily et al., 2002) The expertise of IMROP (Mauritanian institute of fisheries) agents was of great help. Some determination websites were also used such as “www.fishbase.org”, where the extensive list of all the fish species recorded in Mauritania can be found.

In order to infer about the nursery effect of the sampled habitats, the size of each species compiled allowed us to calculate the density of juveniles based on the length at first maturity (L50) for each species (Veiga et al., 2006) using the website “Fishbase”.

The different results were compiled in a table with the species name, the total length, and number of individuals for each sample location. We also added the total weight of each species as well as the proportion of juveniles found and the Shannon-Diversity index.

The Shannon-Wiener diversity index (H’) (Shannon & Wiener 1949) was calculated following the formula:

$$H' = -\sum_{i=1}^{R} p_i \ln p_i$$

pi = proportion of total sample represented by species i.

The eveness have also been calculated using: S = number of species

Evenness = H’/Hmax with Hmax =ln(S) = Maximum diversity possible

In order to test if the differences obtained in the number of species, number of individuals and the diversity indices, were significant between each factor, a 3-way factorial analysis of variance (ANOVA) was performed.

For this we considered the three factors: (site, habitat and month) fixed (Ribeiro et al.

2012). The differences were considered as significant when the P-value was $P \leq 0.05$. When significant differences in abundance, number of species or Shannon-Weiner index for a factor or interacting factors were found, bar plots were generated in order to give a visual interpretation of these results.
If significant effects were detected by the ANOVA analysis, and in order to see which mean was differing, an HSD (Tukey's Honestly Significant Difference) test was done. This test was performed with a level of significance set to $P \leq 0.01$. According to Underwood (1981) this level of significance is set in order to avoid Type I errors.
In order to assess the differences in term of species composition for each factor, a table of the 10 most abundant species found for each variable of the factor was generated. In addition, a table of the 10 species with the highest biomass for each variable of the factors was also generated.
An indicator species analysis was used in order to see if some species were associated to any of the variables of the different factors (Bakker, 2008) using 10000 permutations and a significance value of $P \leq 0.05$.

In order to assess if the species assemblage structure was differing between each factor a pairwise ANOSIM (Analysis of similarities) was performed using the abundance and presence/absence data. The abundance data were square-root transformed in order for each species to contribute evenly to each analysis (Clarke and Green, 1988). This analysis was followed by a non-metric multi-dimensional scaling (nMDS) for the significant factors in order to create two-dimensional ordination plots and visualize the differences (Field et al.,1982; Clarke, 1993; Ribeiro et al., 2006). All analyses were performed in RStudio environment version 1.4.1717 (Rstudio team, 2020). Pairwise ANOSIM comparisons were made between all groups, using 10 000 simulations in each case. When the P-value was $P \leq 0.05$ the differences were considered as significant.

3. RESULTS

3.1. Number of species and individuals

A total of 4653 individuals weighing 37125 g were caught over the two sampling campaigns. The result of 6 sampling locations in December and 9 in April were compiled (Table 2-4). Over sampling 30 species were caught in December and 46 in April, for a total of 53 species and 32 families (**Table 3.1**).

All species found were fish with the exception of a Portunidae crab species (*Callinectes marginatus*), a Sepiidae species (*Sepia officinalis*) and several shrimps species (*Hippolyte inermis; Palaemon elegans; Penaeus spp.; Sicyonia carinata).* The proportion of fish in the total number of individuals is 96% and 89% of the total number of species. As a result, the results are essentially based on fishes.

The crab-*Callinectes marginatus* individuals were present in large numbers in all the sampling locations and were extremely hard to quantify and measure. As a result, this species counted for the overall number of species found in this work but is removed form statistical analysis.

In April, 9 sampling locations have been recorded, representing 3 more than December. However, these extra sampling locations have not been taken in consideration to perform statistical analysis in order to be able to compare the December and April results.

Taking into consideration these six sampling locations, divided in Sites A, B and C, the overall number of individuals was higher in the vegetated habitats (2112 individuals; 64% total) than in the unvegetated (1196 individuals; 36% total) (Annex 11). The same tendency is also observed with the species number, with 44 species in vegetated habitat and 23 for unvegetated (Annex 11). A total of 24 species were found only in vegetated habitats, 3 only in unvegetated and 20 were found in both. The 6 species left from the 53 found in total were present in the 3 sampling locations added in the April sampling mission. These species are: *Cynoglossus senegalensis; Cynoponticus ferox; Epinephelus guaza; Ethmalosa fimbriata; Lutjanus dentatus* and *Pagellus bellottii*. All of these species have been found in a vegetated habitat.

Regarding the number of individuals and species per site, 47% of the individuals were found in site A, 27% in site B and 26% in site C. A total of 15 species were only found in site A, 3 only in site B and 3 only in site C with 26 being found in at least two of the sites (**Table 3.2-3.3;** Annex 12).

Regarding the number of individuals and species per season: the spring sampling represented 53% of the individuals caught and 47% for the winter. A total of 17 species were only found in spring, 8 only in winter and 23 were common to both seasons (Tables 2-3). The size range and the average size of the species caught for each location both showed that species assemblages were almost exclusively formed by juveniles and YOY (young of the year). The proportion of juveniles between locations range from 95.2% to 99% with an average of 98.7% (**Tables 3.2-3.3**; Annex 13)

Table 3.1 List of the families and species caught during the sampling

Atherinidae	*Atherina boyeri*
Batrachoididae	*Halobatrachus didactylus*
Blennidae	*Blennidae*
Cichlid	*Coptodon guineensis*
Clupeidae	*Ethmalosa fimbriata*
Cynoglossidae	*Cynoglossus senegalensis*
Dasyatidae	*Dasyatis margarita*
Fistulariidae	*Fistularia tabacaria*
Gerreidae	*Eucinotomus melanopterus*
Gobiidae	*Gobiidae*
Hippolytidae	*Hippolyte inermis*
Labridae	*Symphodus bailloni*
	Symphodus cinereus
	Symphodus tinca
Lutjanidae	*Lutjanus dentatus*
	Lutjanus goreensis
Monacanthidae	*Stephanolepsis hispidus*
Moronidae	*Dicentrarchus punctatus*
Mugilidae	*Liza aurata*
	Mugil capurrii
	Liza dumerili
	Liza ramada
Muraenesocidae	*Cynoponticus ferox*
Palaemonidae	*Palaemon elegans*
Paralichthyidae	*Citharichthys stampfilii*
Penaeidae	*Penaeus spp.*
	Sicyonia carinata
Pomadasyidae	*Pomadasys incisus*
	Pomadasys rogerii
Portunidae	*Callinectes marginatus*
Psettodidae	*Psettodes belcheri*
Rhinobatidae	*Glaucostegus cemiculus*
	Rhinobatos rhinobatoss
Scaridae	*Nicholsina usta*
Sepiidae	*Sepia officinalis*
Serranidae	*Epinephelus aeneus*
	Epinephelus guaza
	Epinephelus marginatus
	Rypticus saponaceus
	Serranus scriba
Soleidae	*Pegusa lascaris*
	Pegusa triophthalma
	Solea senegalensis
	Synaptura lusitanica
Sparidae	*Diplodus bellottii*
	Diplodus sargus
	Lythognathus mormyrus
	Pagellus bellottii
	Spondyliosoma cantharus
Syngnathidae	*Hippocampus spp.*
	Syngnathus spp.
Tetraodontidae	*Epiphion guttifer*
	Sphaeroides spengleri

Table 3.2 Number of individuals, Total length and Total Weight per species caught over each sampling location with mean Shannon-Weiner index, evenness and % of adult species over the winter sampling period

No.	Species	Littoral type 1 n	1 TL	1 TW	2 n	2 TL	2 TW	3 n	3 TL	3 TW	5 n	5 TL	5 Tw	7 n	7 TL	7 TW	8 n	8 TL	8 TW	n-total	TW-Total
1	Atherina boyeri																				0
2	Blennidae										1				7.1	18				1	18
3	Callinectes marginatus																				0
4	Citharichthys stampfilii																				0
5	Coptodon guineensis				1	12.7	37	1	12.1	28										2	65
6	Cynoglossus senegalensis																				0
7	Cynoponticus ferox																				0
8	Dasyatis margarita																1 l: 21,1 ;L :22,2		472	1	472
9	Dicentrarchus punctatus	23	12.1	418	2	10.8	20							23	7.82	304				48	742
10	Diplodus bellottii																				0
11	Diplodus sargus																				0
12	Epinephelus aeneus																				0
13	Epinephelus guaza																				0
14	Epinephelus marginatus																				0
15	Epiphion guttifer							6	9.7	71				13	8.2	184				19	255
16	Ethmalosa fimbriata																				0
17	Eucinotomus melanopterus	249	6.6	816	191	7.1	770	74	6.7	236				35	6	102	42	6.5	104	591	2028
18	Fistularia tabacaria	1	83.5	275	2	32.2	15													3	290
19	Glaucostegus cemiculus																1 l :39 ; L:12,5		200	1	200
20	Gobidae spp.				18	8.1	114	7	8.2	19										25	133
21	Halobatrachus didactylus				14	10.6	304	11	9.3	143				14	10.8	380				39	827
22	Hippocampus sp.																				0
23	Hippolyte inermis													1	1.8	1				1	1
24	Liza dumerilii	84	9.2	683	1	15.4	35	44	5.5	68	172	5	367				17	12.8	341	318	1494
25	Liza aurata				5	11.5	68													5	68
26	Liza ramada	2	10.3	15																2	15
27	Lutjanus dentatus																				0
28	Lutjanus goreensis				2	10.2	29													2	29
29	Lythognathus mormyrus													7	3.3	14				7	14
30	Mugil capurii	1	10.8	13	2	10.7	26	2	6.9	11				1	2.8	1				6	51
31	Nicholsina usta																				0
32	Pagellus bellottii																				0
33	Palaemon elegans																				0
34	Pegusa lascaris				3	12.2	39													3	39
35	Pegusa triophthalma																				0
36	Penaeus spp.				5	6.2	5	12	6.7	6				9	5.6	11	2	5.5	1	28	23
37	Pomadasys incisus	38	8.2	247	9	8.9	76	33	8.18	101										80	424
38	Pomadasys rogerii	1	8	3	12	8.6	79													13	82
39	Psettodes belcheri																				0
40	Rhinobatos rhinobatoss																				0
41	Rypticus saponaceus																				0
42	Sepia officinalis				1	17.5	126													1	126
43	Serranus scriba				3	12.9	88													3	88
44	Sicyonia carinata							2	7.8	7				3	6.3	7				5	14
45	Solea senegalensis	13	9.8	132										1	14.2	26				14	158
46	Sphoeroides spengleri	1	8.8	13	13	9.1	127	16	10.8	212				58	10.3	1267				88	1619
47	Spondyliosoma cantharus																				0
48	Stephanolepsis hispidus				71	5.7	347	10	4	24				17	4.5	32				98	403
49	Symphodus bailloni																				0
50	Symphodus cinereus				2	9.5	24													2	24
51	Symphodus tinca																				0
52	Synaptura lusitanica																				0
53	Syngnathus spp.													3	12.7	8				3	8
	TOTAL	413			357			218			173			185			63			1409	
	Species total	11			20			13			2			15			6				
	Total Weight			2615			2329			926			367			2355			1118		9710
	% adult species	0.2			0.3			0.5			0			3.2			1.58			(96,2% - 99,9%)	
	Shannon-Wiener index	1.20			1.8			1.94			0.03			1.92			0.86				
	Evenness	0.52			0.61			0.78			0.04			0.77			0.54				

Table 3.3 Number of individuals, Total length and Total Weight per species caught over each sampling location with mean Shannon-Weiner index, evenness and % of adult species over the spring sampling

No.	Species	Littoral type																	
		1			2			3			4			5			6		
		n	*TL*	*TW*	*n*	*TL*	*TW*	*n*	*TL*	*TW*	*n*	*TL*	*TW*	*n*	*TL*	*TW*	*n*	*TL*	*TW*
1	Atherina boyeri				95	5.3	99	700	5.1	748	39	4.5	28	335	3.59	38			
2	Blennidae				25	6	55										12	5	6
3	Callinectes marginatus																		
4	Citharichthys stampfilii	13	14.4	334															
5	Coptodon guineensis				5	13.8	239				1	26.8	380						
6	Cynoglossus senegalensis																19	7.3	76
7	Cynoponticus ferox																1	50	67
8	Dasyatis margarita							2	l:21,6 ; L: 23,	917							4	l:20,2 ; L:20,8	414
9	Dicentrarchus punctatus	9	17.2	512	19	10.5	292	24	13.9	628							1	17	50
10	Diplodus bellottii				10	10.6	191												
11	Diplodus sargus				133	5.1	342	75	3.5	55	69	3.8	37				3	4.3	5
12	Epinephelus aeneus				7	13.6	228	1	20.2	110	1	11.5	24						
13	Epinephelus guaza																		
14	Epinephelus marginatus				5	14.2	234												
15	Epiphion guttifer				2	51	1850	1	12.5	44	1	15	76				1	17.4	92
16	Ethmalosa fimbriata										1	6	1						
17	Eucinotomus melanopterus							1	10	10									
18	Fistularia tabaccaria				3	80.1	475												
19	Glaucostegus cemiculus																		
20	Gobidae spp.				5	6.5	13	5	5.8	14	19	3.6	9				52	4	52
21	Halobatrachus didactylus				4	9.2	53												
22	Hippocampus sp.				1	4	1												
23	Hippolyte inermis																		
24	Liza aurata	1	19.5	72	4	17	165												
25	Liza dumerilii																		
26	Liza ramada																		
27	Lutjanus goreensis																		
28	Lutjanus dentatus				1	10.1	15												
29	Lythognathus mormyrus																		
30	Mugil capurii				69	6.7	147	47	6.4	107	4	5.2	7						
31	Nicholsina usta							13	5.9	34									
32	Pagellus bellottii										2	5.3	3						
33	Palaemon elegans							1	5.3	1									
34	Pegusa lascaris							1	6.1	8	3	5.4	5						
35	Pegusa triophthalma	6	6.5	14															
36	Penaeus spp.	4	5.3	4	12	6.2	21	34	7.8	118	23	7.1	79				84	5.5	37
37	Pomadasys incisus	16	8.4	138	20	6.6	64				10	5.9	30						
38	Pomadasys rogerii	1	16.5	53	3	11.8	69												
39	Psettodes belcheri																7	8.1	42
40	Rhinobatos rhinobatos							2	l:37 ; L:12,5	542	1	l: 31 ; L: 10,1	201						
41	Rypticus saponaceus				2	16.75	167												
42	Sepia officinalis							5	7.2	88	5	5.4	29				2	7.25	29
43	Serranus scriba				16	12.6	847												
44	Sicyonia carinata																		
45	Solea senegalensis	8	21.2	681				9	8.1	57	1	10.1	10	19	7.3	74	5	5.5	46
46	Sphaeroides spengleri	4	10.5	80	24	10.8	540	4	10.4	81	4	10.6	85						
47	Spondyliosoma cantharus				3	4.8	6												
48	Stephanolepsis hispidus				5	9.5	72												
49	Symphodus bailloni				2	7.4	10												
50	Symphodus cinereus																		
51	Symphodus tinca				1	3	1				5	3.9	3						
52	Synaptura lusitanica				3	20.4	259	1	8	4									
53	Syngnathus spp.							4	17.9	28	8	11.2	12				5	14.1	15
	TOTAL	62			479			930			197			354			196		
	Species total	11			28			20			19			3			14		
	Total Weight			1888			6455			3594			1019			112			931
	% adult species	4.8			1.3			1.6			1.5			0.3			0.5		
	Shannon-Wiener index	1.93			2.37			1.06			2.06			0.21			1.69		
	Evenness	0.88			0.72			0.36			0.71			0.3			0.66		

Table 3.3 (Contd.). Number of individuals, Total length and Total Weight per species caught over each sampling location with mean Shannon-Weiner index, evenness and % of adult species over the spring sampling

No.	Species	Littoral type 7			8			9			n-total	TW-Total	BEAM TRAWLING		
		n	*TL*	*TW*	*n*	*TL*	*TW*	*n*	*TL*	*TW*			*n*	*TL*	*TW*
1	Atherina boyeri										1169	913			
2	Blennidae										37	61			
3	Callinectes marginatus											0			
4	Citharichthys stampfilii										13	334			
5	Coptodon guineensis							8	18.8	1260	14	1879	26	12.5	923
6	Cynoglossus senegalensis										19	76			
7	Cynoponticus ferox										1	67			
8	Dasyatis margarita				5	l: 18,2; L:20,2	2053				11	3384			
9	Dicentrarchus punctatus				27	5.3	48				80	1530			
10	Diplodus bellottii										10	191			
11	Diplodus sargus				4	8	193	68	6.1	271	352	903	1	5.5	3
12	Epinephelus aeneus										9	362			
13	Epinephelus guaza										0	0	1	17	70
14	Epinephelus marginatus										5	234			
15	Epiphion guttifer							8	13.2	575	13	2637			
16	Ethmalosa fimbriata										1	1			
17	Eucinotomus melanopterus										1	10			
18	Fistularia tabaccaria										3	475			
19	Glaucostegus cemiculus											0			
20	Gobidae spp.										81	88			
21	Halobatrachus didactylus							16	14.5	1158	20	1211	6	17.8	515
22	Hippocampus sp.										1	1			
23	Hippolyte inermis											0			
24	Liza aurata				9	8.8	63				14	300			
25	Liza dumerilii	1	7.7	11	7	4.6	9				8	20			
26	Liza ramada											0			
27	Lutjanus goreensis											0			
28	Lutjanus dentatus										1	15			
29	Lythognathus mormyrus											0			
30	Mugil capurii	338	6.41	745	39	6.3	89	10	5.5	14	507	1109			
31	Nicholsina usta										13	34			
32	Pagellus bellottii										2	3			
33	Palaemon elegans										1	1			
34	Pegusa lascaris										4	13			
35	Pegusa triophthalma										6	14			
36	Penaeus spp.	1	4.5	1							158	260	48	8.9	223
37	Pomadasys incisus				28	6.1	71				74	303			
38	Pomadasys rogerii										4	122			
39	Psettodes belcheri				2	20.1	228				9	270			
40	Rhinobatos rhinobatos				1	l:32 ; L:13,5					4	743			
41	Rypticus saponaceus										2	167			
42	Sepia officinalis							11	11.87	460	23	606	14	7.4	331
43	Serranus scriba							7	19.2	1667	23	2514			
44	Sicyonia carinata											0			
45	Solea senegalensis				5	10.8	86				47	954			
46	Sphaeroides spengleri							93	11	1913	129	2699	9	12.1	261
47	Spondyliosoma cantharus							57	4.8	87	60	93	2	4.8	11
48	Stephanolepsis hispidus							110	10.5	2188	115	2260	4	8.4	41
49	Symphodus bailloni							36	6.6	149	38	159	6	6.8	22
50	Symphodus cinereus											0			
51	Symphodus tinca										6	4			
52	Synaptura lusitanica	3	6.7	12	4	5.4	2				11	277			
53	Syngnathus spp.							11	21.1	64	28	119			
	TOTAL	343			131			435			3127		117		
	Species total	5			12			13					11		
	Total Weight			769			2842			9806		27416	2400		
	% adult species	0.3			0.8			2.1		95,2%-99,7%			4.3		
	Shannon-Wiener index	0.09			1.92			2.05							
	Evenness	0.06			0.8			0.82							

The 3-way ANOVA showed that both Site and Habitat were responsible for significant differences in the number of individuals but not the Season. The interaction Site-Habitat; Site-Season; Habitat-Season and all 3 factors combined were also significant (**Table 3.4**; **Fig. 3.1**; Annex 1-3).

Table 3.4 F values and significance levels for the 3-way ANOVA of number of individuals, number of species and mean Shannon-Wiener index (H'), testing for differences between Habitat, Site, and Season.

Effects	df	Number of individuals		Number of species		Shannon-Wieiner	
		F	p	*F*	p	*F*	p
Site	1	18.83	<0.001	17.64	<0.001	35.44	0.027
Habitat	2	47.71	<0.001	232.66	<0.001	20.69	0.046
Season	1	0.46	0.503	22.54	<0.001	4.53	0.167
Habitat x Site	2	8.69	0.001	2.21	0.131	3.84	0.206
Site x Season	1	13.2	<0.001	0.26	0.777	6.55	0.125
Habitat x Season	2	17.65	<0.001	6.38	0.019	5.48	0.154
Habitat x Site x Season	2	14.03	<0.001	3.56	0.044	2.83	0.145

The Tukey's HSD results allows to see the differences among and within each interacting factors. The results of the test confirmed that vegetated habitats had significantly higher number of individuals than unvegetated (**Fig. 3.1**). Moreover, there is a significant difference between sites A: B and A:C but not between B:C (Annex 9, **Fig. 3.1**). The graphical representation of the significant interactions between factors allows to see the combined effect of the Site and Habitat on the number of individuals as well the Site x Season interaction and Season x Habitat (Annex 1-3).

Regarding the season effect between each site, it was only significant for site C where the number of individuals was significantly higher in spring than in winter (Annex 2). The result of the Tukey HSD test for the Season-Habitat interactions showed that there was only a significant higher number of individuals in seagrass habitat in spring (Annex 9).

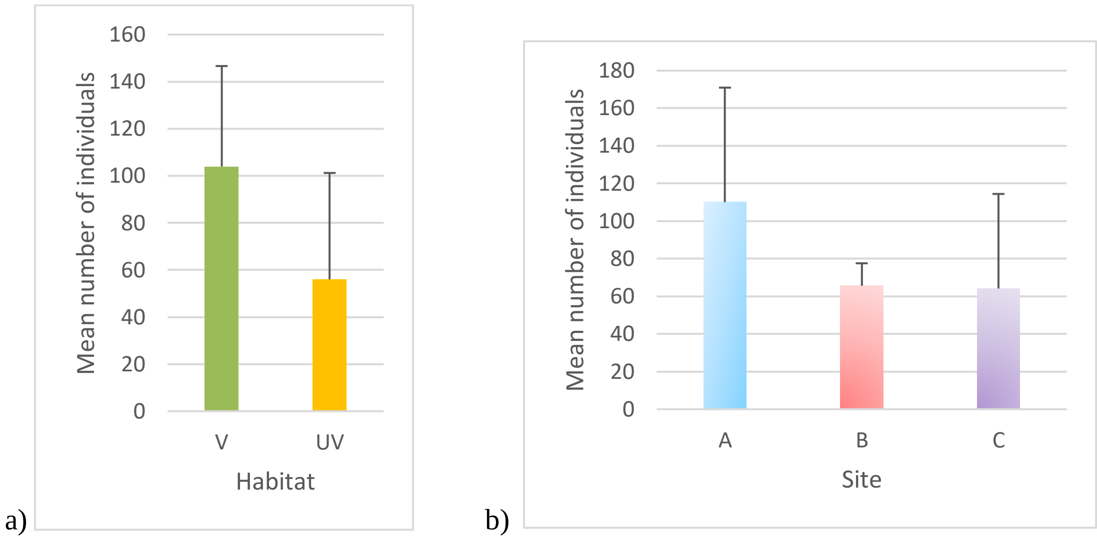
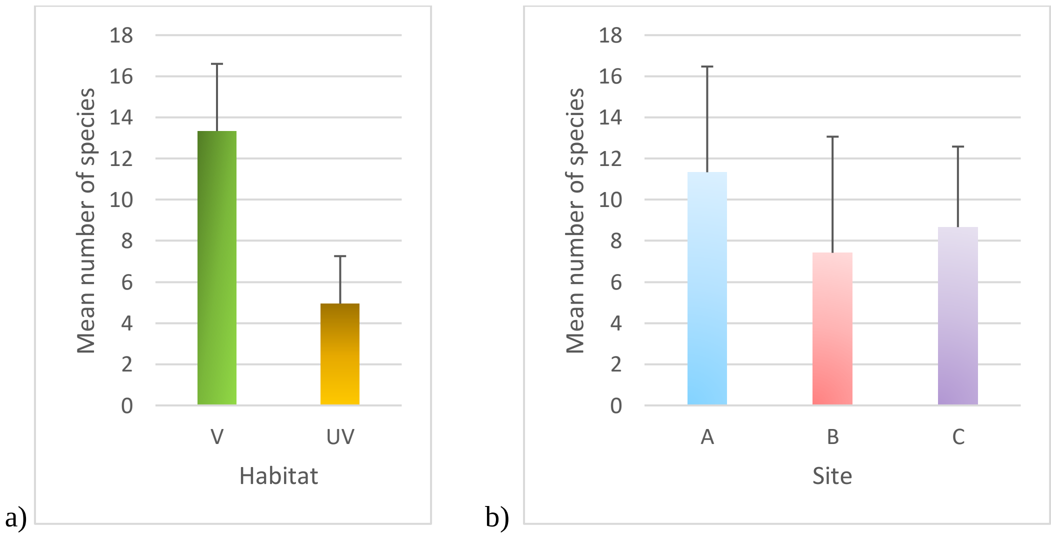
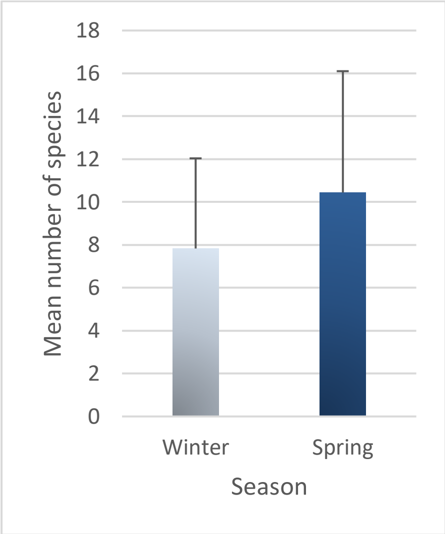


Fig. 3.1 Mean number of individuals caught for each significant factor: (a) Habitat; (b) Site + standard errors

The 3-way ANOVA results of the species showed that all three factors were responsible for significant differences in the number of species as well as the interaction Habitat-Season and the interaction of all 3 factors (Table 4).

Tukey's HSD tests confirmed that vegetated habitats have significantly higher number of species than unvegetated (Annex 8 **Fig. 3.2**) and significantly higher in spring than in winter (Annex 8; **Fig. 3.2**). Moreover, same as for the individuals there is a significant difference between site A: B and A:C but not between B:C (Annex 8). Regarding the interaction between Season and Habitat, Tukey's HSD revealed a higher number of species found in vegetated habitats in winter and in spring (Annex 3; Annex 8).



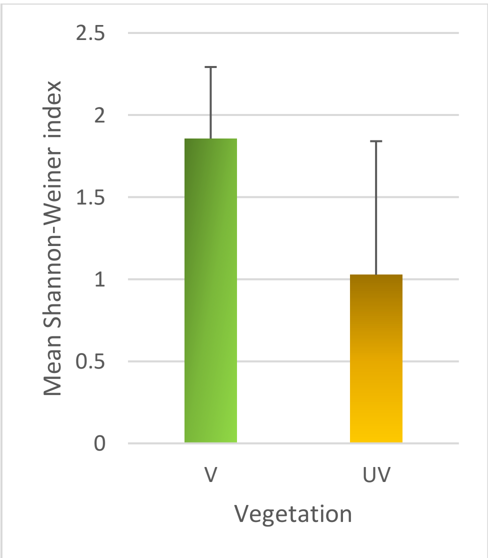


c)

Fig. 3.2 Mean number of species for each significant factor: (a) Habitat; (b) Site; (c) Season + standard errors

For the Shannon-Wiener index ANOVA results, Habitat and Site were the only two factors having significant differences in the number of species (Table 4). For the Habitat the Tukey HSD test results showed that the vegetated locations had higher index value than the non-vegetated ones (Annex 10; **Fig. 3.3**). Regarding the Site factor, Tukey's HSD results only showed a significant difference between site A and B with a higher diversity index for site A than for site B (Annex 10, **Fig. 3.3**).

a)



b)

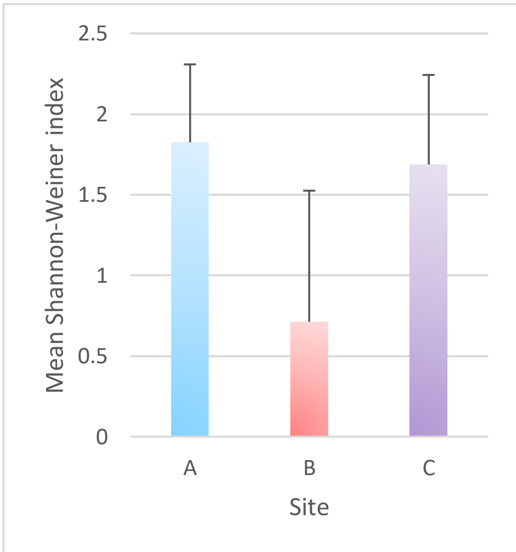


Fig. 3.3 Mean Shannon-Weiner index for each significant factor: (a) Vegetation; (b) Site + standard errors

3.2. Species composition

The sampling locations were dominated in term of occurrence by the crab *Callinectes marginatus* (Portunidae), found in very large quantities for every net tow and location. However, the abundance, Total Length and Total Weight of individuals could not be reported. Indeed, crabs were too abundant and the measures on site were impossible due to the difficulties to immobilize them all in order to carry out the measurements.

The most abundant species was *Atherina boyeri*, representing more than 25% of the total fish caught for this study. However, this species was only caught during the spring sampling (**Table 3.5**) making the relative abundance of this species for the spring sampling going up to 37.4% (**Table 3.7**). Three species (*Atherina boyeri; Eucinostomus melanopterus* and *Mugil capurrii*) accounted for more than 50% of the catches of the study and the 10 most abundant species represent 85% of the total individuals caught. The biomass results showed a more dispersed distribution among species with 50% and 71% of the total biomass accounted for by 6 species and 10 species respectively (**Table 3.5**)

If we look at the Habitat factor, in the vegetated habitats almost 76% of the total number of catches was represented by only three species which is not the case for the unvegetated habitat where the species distribution of the fish caught is more evenly distributed, with 16% of the catch being species outside of the top 10 most abundant (**Table 3.6**)

By looking at the variation between season in term of the most abundant species (**Table 3.7**) we can see that the three most abundant species for both seasons are different with respectively *E. melanopterus, L. aurata* and *S. hispidus* in December *and A. boyeri, M. capurrii and D. sargus* in April. We can also note that only two species account for more than 64% of all the individuals catches in winter. In spring the distribution within species of the catch is more dispersed. Indeed, to have more than 64% of the individuals caught we need to take into consideration the first 5 most abundant species.

Regarding the site effect (**Table 3.8**), we can see that for sites A and C the distribution of the abundance is more spread than for site B where *Atherina boyeri* account for 57% of the total caught. We can also see for site A and C a more dispersed distribution of the abundance between species, with respectively more than 15% and 17% of the number of catches represented by other species than the top 10 most abundant ones. (**Table 3.8**).

If we look at the biomass results, we can see that the species accounting for the most are different from the abundance data ones, such as *Dasyatis margarita*, *Epiphion guttifer*, *Serranus scriba or Coptodon guineensis* (**Table 3.6 - 3.7**). This difference in term of species distribution between abundance and biomass data can be seen for all of the three factors Habitat, Season and Site (Annex 4).

Table 3.5 List of the 10 most represented species in the community with (a) abundance data and (b) biomass data

a)

Rank	Specie	Abundance	relative abundance (%)
1	Atherina boyeri	1169	25.77
2	Eucinostomus melanopterus	592	13.05
3	Mugil capurii	513	11.31
4	Diplodus sargus	352	7.76
5	Liza aurata	332	7.32
6	Sphaeroides spengleri	217	4.78
7	Stephanolepsis hispidus	213	4.70
8	Penaeus spp.	186	4.10
9	Pomadasys incisus	154	3.40
10	Dicentrarchus punctatus	128	2.82
	Others:	680	14.99

b)

Rank	Specie	Biomass	relative biomass (%)
1	Sphaeroides spengleri	4318	11.63
2	Dasyatis margarita	3856	10.39
3	Epiphion guttifer	2892	7.79
4	Stephanolepsis hispidus	2663	7.17
5	Serranus scriba	2602	7.01
6	Dicentrarchus punctatus	2272	6.12
7	Halobatrachus didactylus	2038	5.49
8	Eucinostomus melanopterus	2038	5.49
9	Coptodon guineensis	1944	5.24
10	Liza aurata	1794	4.83
	Others:	37126	28.85

Table 3.6 List of the 10 most abundant species in (a) unvegetated habitats (b) vegetated habitats

a)

Rank	Specie	Abundance	Relative abundance (%)
1	Atherina boyeri	335	28.01
2	Eucinotomus melanopterus	291	24.33
3	Liza aurata	283	23.66
4	Pomadasys incisus	82	6.86
5	Dicentrarchus punctatus	59	4.93
6	Solea senegalensis	45	3.76
7	Mugil capurii	40	3.34
8	Citharichthys stampflii	13	1.09
9	Liza dumerilii	7	0.59
10	Dasyatis margarita	6	0.50
	Others:	35	2.93

b)

Rank	Specie	Abundance	Relative abundance (%)
1	Atherina boyeri	834	24.97
2	Mugil capurii	473	14.16
3	Diplodus sargus	348	10.42
4	Eucinotomus melanopterus	301	9.01
5	Stephanolepsis hispidus	213	6.38
6	Sphaeroides spengleri	212	6.35
7	Penaeus spp.	180	5.39
8	Gobidae	106	3.17
9	Pomadasys incisus	72	2.16
10	Dicentrarchus punctatus	69	2.07
	Others:	532	15.93

Table 3.7 List of the 10 most abundant species in (a) winter (b) spring

a)

Rank	Specie	Abundance	relative abundance (%)
1	Eucinostomus melanopterus	591	41.94
2	Liza aurata	318	22.57
3	Stephanolepsis hispidus	98	6.96
4	Sphaeroides spengleri	88	6.25
5	Pomadasys incisus	80	5.68
6	Dicentrarchus punctatus	48	3.41
7	Halobatrachus didactylus	39	2.77
8	Penaeus spp.	28	1.99
9	Gobiidae	25	1.77
10	Epiphion guttifer	19	1.35
	Others:	75	5.32

b)

Rank	Specie	Abundance	relative abundance (%)
1	Atherina boyeri	1169	37.38
2	Mugil capurrii	507	16.21
3	Diplodus sargus	352	11.26
4	Penaeus spp.	158	5.05
5	Sphaeroides spengleri	129	4.13
6	Stephanolepsis hispidus	115	3.68
7	Gobiidae	81	2.59
8	Dicentrarchus punctatus	80	2.56
9	Pomadasys incisus	74	2.37
10	Spondyliosoma cantharus	60	1.92
	Others:	402	12.86

Table 3.8 List of the 10 most abundant species in (a) site A; (b) site B; (c) site C

a)

Rank	Specie	Abundance	relative abundance (%)
1	Eucinotomus melanopterus	440	33.56
2	Diplodus sargus	133	10.14
3	Atherina boyeri	95	7.25
4	Liza aurata	90	6.86
5	Pomadasys incisus	83	6.33
6	Stephanolepsis hispidus	76	5.80
7	Mugil capurii	72	5.49
8	Dicentrarchus punctatus	53	4.04
9	Sphaeroides spengleri	42	3.20
10	Blennidae	25	1.91
	Others:	202	15.41

b)

Rank	Specie	Abundance	relative abundance (%)
1	Atherina boyeri	1074	57.37
2	Liza aurata	216	11.54
3	Diplodus sargus	144	7.69
4	Eucinotomus melanopterus	75	4.01
5	Penaeus spp.	69	3.69
6	Mugil capurii	53	2.83
7	Pomadasys incisus	43	2.30
8	Gobidae	31	1.66
9	Solea senegalensis	29	1.55
10	Dicentrarchus punctatus	24	1.28
	Others:	114	6.09

c)

Rank	Specie	Abundance	relative abundance (%)
1	Mugil capurii	388	28.68
2	Sphaeroides spengleri	151	11.16
3	Stephanolepsis hispidus	127	9.39
4	Penaeus spp.	96	7.10
5	Eucinotomus melanopterus	77	5.69
6	Diplodus sargus	75	5.54
7	Spondyliosoma cantharus	57	4.21
8	Gobidae	52	3.84
9	Dicentrarchus punctatus	51	3.77
10	Symphodus bailloni	36	2.66
	Others:	243	17.96

During this sampling 12 species were found in very low abundance (>3 individuals): *Cynoponticus ferox; Ethmalosa fimbriata; Epinephelus guaza; Glaucostegus cemiculus; Hippocampus sp.; Hippolyte inermis; Liza ramada; Lutjanus dentatus; Lutjanus goreensis; Pagellus bellottii; Rypticus saponaceus; Symphodus cinereus* (**Table 3.2- 3.3**).

Two "hotspots" of rays have been identified in site B and C with respectively Iwik center and the island of Nair. These two locations accounted for the totality of the rays caught during the sampling.

The results of the indicator species analysis showed that there was a statistical significance only for Habitat and Season. Indeed, for the Habitat factor, *Sphaeroides spengleri* and *Mugil capurrii* were statistically associated to the vegetated habitat (**Table 3.9**). For the Season factor, *Diplodus sargus* was associated to the spring season. For the winter season *Eucinostomus melanopterus* and *Liza dumerili* were associated (**Table 3.9**). Finally, no species have been significantly associated to any site.

Table 3.9 Results of the indicator species analysis for each factor with R-statistic and P-value

Factor		Species associated	R-statistic	P-value
Habitat	Vegetated	*Sphoeroides spengleri*	0.661	0.030
		Mugil capurrii	0.648	0.003
	Unvegetated	/	/	/
Season	Winter	*Eucinostomus melanotperus*	0.756	0.017
		Liza dumerili	0.621	0.027
	Spring	*Diplodus sargus*	0.627	0.017
Site	A	/	/	/
	B	/	/	/
	C	/	/	/

3.3 Community assemblage structure

The nMDS ordination plot using the “presence/absence” data clearly showed a separation between Vegetated and Unvegetated samples (**Fig.3.4**). The nMDS using the squared-rooted abundance also show the same pattern (**Fig.3.4**). The seagrass samples are more tightly grouped, than the sand ones. This indicates higher similarities within the sample, while the sand samples are more dispersed, inducing a lower similarity. For the Season factor we can see a clear separation between spring and winter for both “presence/absence” data and square-root abundance data (**Fig. 3.4**).

The result of the ANOSIMs revealed an overall significant Habitat and Seasonal effect on the species assemblage structure for both absence/presence data and square-root transformed abundance data. There is no significant effect of both factors combined (**Table 3.10**). It can be seen with the two graphs representing the two factors combined (**Fig. 3.5**) where no clear pattern can be seen.

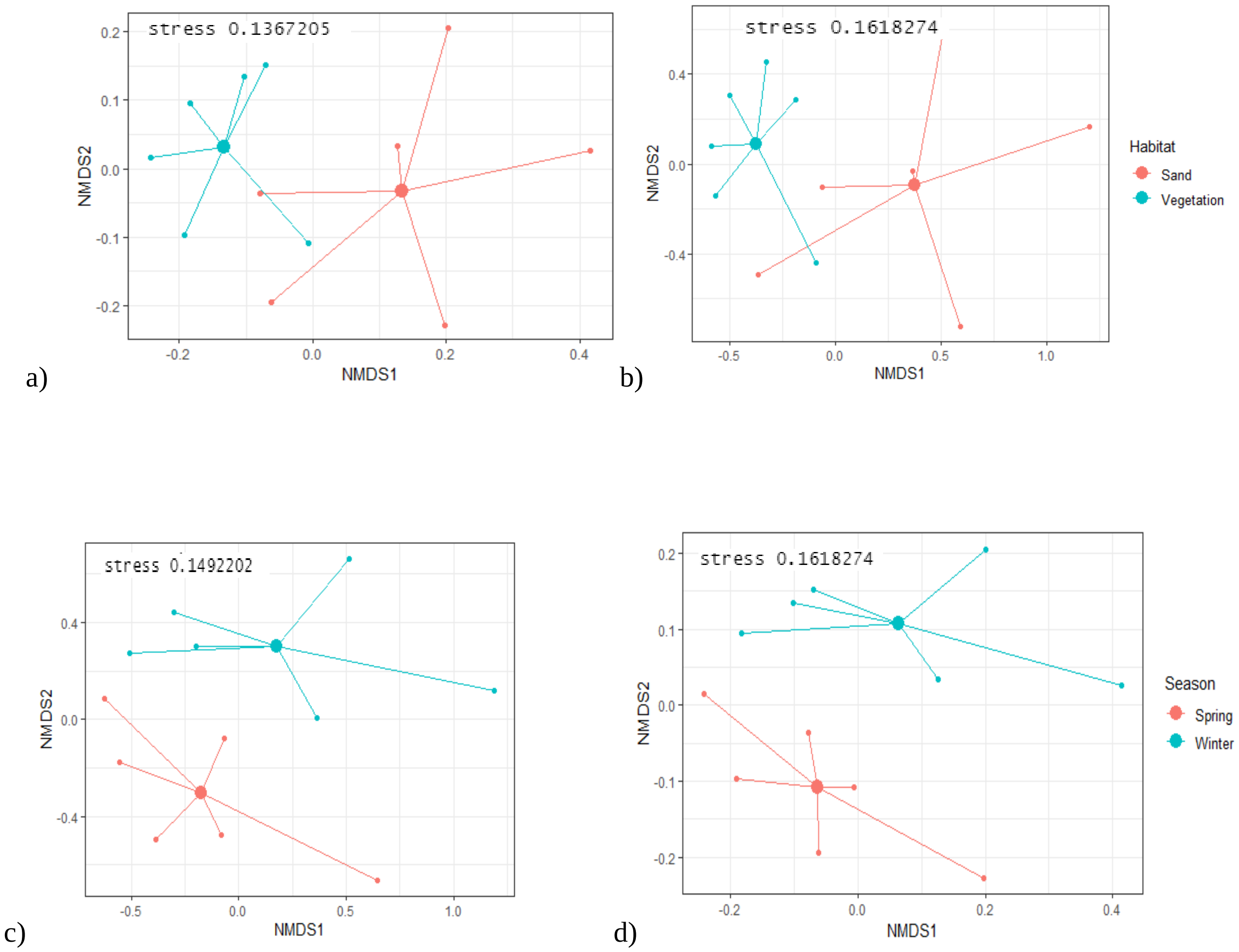


Fig. 3.4 nMDS ordination plot of the presence/absence data (a) and sqrt abundance data (b) for the Habitat factor; and of the presence/absence data (c) and sqrt abundance data (d) for the Season factor

Table 3.10 R-stat and Significance values of the ANOSIM for each significant factors and interactions between them

Data	Factor	*R-Stat*	*P*
Abundance	Habitat	0.268	0.030
	Season	0.488	0.002
	Site	0.053	0.629
	Vegetated:Season	0.740	0.100
	Unvegetated:Season	0.778	0.100
Prensence/ Absence	Habitat	0.376	0.007
	Season	0.249	0.037
	Site	0.008	0.258
	Vegetated:Season	0.389	0.100
	Unvegetaed:Season	0.407	0.200

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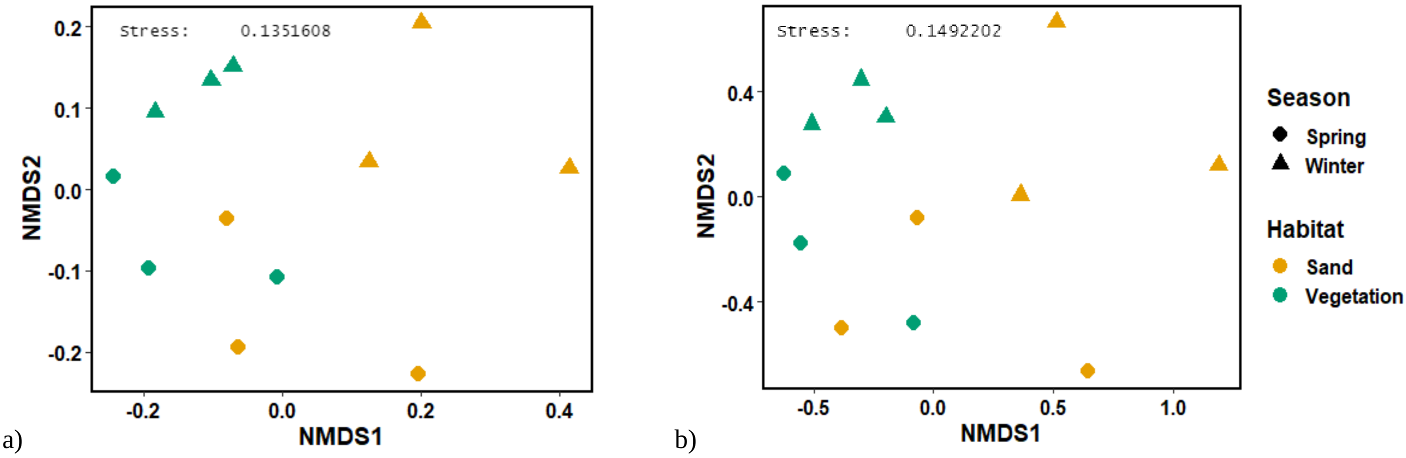

Fig. 3.5 nMDS plot of the two factors Habitat and Site combined for square-root abundance data (a) and presence/absence data (b

4. DISCUSSION:

4.1 Habitat differences

In this study the results showed a higher number of species in seagrass habitats than sand, and a more diverse community. The number of individuals was also higher in seagrass than in sand habitat and was in agreement with the results of prior studies (Weinstein and Brooks, 1983; Heck et al.,1989; Connolly, 1994; Grey et al. 1996; Arrivillaga and Baltz,1999; Travers and Potter, 2002). The community assemblage structure was also different between habitats and are in good agreement with literature on the subject (Jenkins et al. 1997; Gray et al., 1998; Ribeiro et al. 2006; Ribeiro et al. 2012). The vegetation has a key role in the community assemblage structure as Midwood & Chow-Fraser (2012) stated. In this study they showed that the changes in the vegetation of the habitats and especially the loss of vegetation in shallow waters induces a decline in species richness and a more homogeneous assemblage as we observed in this study. Moreover, Jenkins et al. (1997) and Hughes (2002), showed that the vegetation habitats sustain the most biomass.

The differences observed on the community diversity and abundance of species could be explained by a higher structural complexity of the seagrass habitat and a higher productivity (Ribeiro et al., 2006). The presence of a dense seagrass meadows of *Zostera notlei* in the intertidal zones turning into a mix of *Halodule wrightii* and *Cymodocea nodosa* dense canopy in the subtidal shallow zones provides protection and a shelter from predators, with epiphytes creating a dense zone to hide (Stoner, 1983; Orth et al., 1984; Pollard, 1984; Bell and Pollard, 1989; Ribeiro et al. 2006). Seagrass habitat also provide higher food diversity and availability (Burchmore et al., 1984; Connolly, 1994; Nakamura 2012) in comparison with unvegetated ones.

If we look at the species composition for the Habitat factor, *Atherina boyeri* was the most abundant species for both habitats. This species, is not dependent on any habitat being a planktivorous fish (Guidetti and Bussotti, 2002) and is as a result present in large quantities in vegetated and unvegetated shallow waters areas. (Keskin, 2007; Embarek et al. 2017).

In the unvegetated habitat a different habitat composition can be observed with *Eucinostomus melanopterus* being the most abundant. This species was present in both habitats and is known to be common in shallow water habitats (Raz-Guzman and Huidobro, 2002, Solari et al., 2010). This species has a clear ontogenetic shift among habitats and ecosystems and is not seagrass or sand dependent, presenting a more generalist habitat association (Reis-Filho et al., 2019). A high abundance of *Liza aurata* was found over sand and is in accordance with the observations of Ribeiro et al. in 2012, associating this species to unvegetated habitats where is seems to be more adapted for schooling. *Dasyatis margarita* has also been associated with unvegetated habitat. The individuals caught were juveniles and are known to be found in mudflat habitats where they have a high small prey availability and switch to deeper zone when they are mature (Lim et al., 2019). As expected, unvegetated habitat supported different flat fish species known to be associated with mudflat and sand habitats*: Citharichthys stampflii; Pegusa lascaris; Pegusa triophthalma; Psettodes Belcheri; Solea senegalensis; Synaptura lusitanica*; (Van der Veer et al.,1995; Martinho et al., 2010).

If we look at the vegetated habitat *Mugil capurri* was found in high numbers and was significantly associated to seagrass habitats. However, this species is not vegetation dependent and is found everywhere in the Banc d'Arguin (Gushchin and Fall, 2012). *Diplodus sargus* have been found in high numbers over seagrass habitat like Guidetti (1999). The Sparidae family is known to be found in vegetated habitats specially during the development of the young of the year (YOY) (Guidetti, 2000; Verdiell et al. 2007; Gushchin and Fall, 2012). As a result, it explains the presence in our study of Sparidae species (*Diplodus bellottii; Diplodus sargus; Lythognathus mormyrus; Pagellus bellottii; Spondyliosoma cantharus)* in vegetated areas. Some other species found are known to be associated with seagrass habitats such as Tetraodontidae species, (Kochzius, 1997; Aziz et al, 2006); *Stephanolepsis hispidus* , which is known to be strongly dependent of it being a direct consumer of seagrass (Sevrin-Reyssac, 1983) or Syngnathidae species. Indeed, this family is known to use these habitats to hide from predators (Pollard, 1984; Howard and Koehn, 1985; Kendrick and Hyndes, 2003) and is considered as a flagship group for the species living in seagrass habitats. Indeed, investigating their presence is essential in order to assess the conservation status of a seagrass habitat. Other species and families found in this study are also known to be dependent on the seagrass habitats such as the Labridae (Leis & Hay, 2004; MacArthur & Hyndes, 2007), Lutjanidae (Nagelkerken et al., 2000; De La Morinière et al., 2003), Serranidae (Koenig & Colin, 1999; Tuya et al., 2014); *Nicholsina usta* (Arrivillaga & Baltz, 1999; Fodrie et al. 2010) and *Fistularia tabacaria* (Fodrie et al., 2010), considered as threatened in the red list of the IUCN (Carpenter et al., 2015).

Shrimp population caught in this study, were found in vegetated habitats. It is in accordance with the literature saying that shrimps are using these sheltered areas to grow and move offshore later as adults (Schaffmeister et al., 2006).

Sepiidae, known to be present in the Banc d'Arguin (Jagger et al., 1993; Vonk, 2001) were also caught over seagrass and are known to use the vegetation as a nursery and shelter from predators (Koulouri et al., 2016; Forsey, 2019).

4.2 Season differences

The season results showed that there was not a significant difference in the number of individuals caught between the two season even if the number of individuals was higher in spring for the 6 locations. The Shannon-Weiner diversity index results didn't show a significant difference between season, as Ribeiro et al. in 2012 obtained. However, the season factor turned out to be significantly different in the number of species found. Moreover, a significant difference in community assemblage structure between the two seasons was clearly identified.

The non-significance of the differences in abundance was also observed by Ribeiro et al. (2012) and Gushchin and Fall (2012). Indeed, the high abundance of few species is hiding the possible abundance differences for the rest of the species between season.

The number of species caught between seasons was significantly higher for spring than for winter following the results of Dahlberg and Odum, 1970; Ribeiro et al. 2006; Masuda, 2008. Moreover, almost all the indivduals caught were juveniles (98.7%). We hypothesis that the changes in species diversity as well as community assemblage observed between months are similar to the ones occurring in others shallow intertidal habitats. The early life stages of migrant species coming in these habitats, induce a higher species diversity found, and a different community structure (Hannan and Williams,1998; Guidetti and Bessotti, 2000; Ribeiro et al. 2006 and 2012). Indeed, some Serranidae; Sparidae; Labridae; Cichlids and Soleidae species are recruiting to these shallow tidal flats with seagrass. Being protected from predators and having a high prey abundance availability, they leave to deeper waters in adjacent coastal waters as juveniles or maturing adults later in the year (Yoklavich, et al., 1991).

The other resident species, found all year in the Banc d'Arguin also follow a seasonal pattern of spawning events, linked to abiotic factors and food availability being more favorable in the warm seasons (Ribeiro et al., 2006). As a result, we expect to see strong differences in term of community assemblages, species diversity and abundance for the other seasons that could not be sampled in this study.

Regarding the species composition, the most abundant species in spring (*Atherina boyeri*), is known to have a maximum peak of spawning period between March and April (Fernandez-Delgado et al., 1988) just before our spring sampling. Indeed, the small size of individuals caught in this study indicates an early life stage for the individuals. Some other species such as *Diplodus sargus* have been strongly associated to the spring season in our study as ot was the case in Ribeiro et al. (2012). It is explained in the literature by a spawning season beginning in January in similar geographic areas (Mouine et al., 2007) and that could explain the high presence of very small individuals in spring.

The abundance and species diversity of shrimps was higher in spring. The shrimp species are known to spawn offshore and mature in coastal waters (Schaffmeister et al., 2005) and this higher abundance and diversity is probably due to a spawning event between December and April.

The high presence of *Eucinostomus melanopterus* young of the year only in December could be explained by a recruiting and maturing of the population in winter to leave the shallow areas later in the season for deeper waters. Other species have been associated to the winter season such as *Liza dumerilli* that is known to have a spawning season from December to February (Van der Horst and Erasmus, 1981) and that could explain the high presence of juveniles. The same observation can be made for *Liza aurata*, with a spawning season between October/December (Mehanna, 2006; Ghaninejad et al., 2010).

4.3 Site differences

The results of the community assemblage structure did not show any statistically significant differences between the sites. The higher abundance and diversity found in Site A was also observed by Gushchin and Fall (2012). Located in Mamghar and separated in two sampling locations: “Mamghar mangrove”, an unvegetated location, and “Baie Saint-Jean”, a vegetated one these two locations have been sampled by Gushchin and Fall (2012) and a higher species diversity was also found

To understand why site A accounted for more individuals than the other sites, we can look at *Eucinostomus melanopterus* which was the most abundant species found in winter, and mainly found in site A. Moreover, in spring *Diplodus sargus* which was also caught in high abundance was found mainly in site A too. These two species as a result can explain partly the highest number of individuals. Adding to that we found more species in the site A and as result it could explain an overall higher number of individuals.

Regarding the reason why the number of species was higher in site A, some hypothesis could be made. The "Baie de Saint Jean" location being protected from strong wind, current and waves, could constitute a safer area for the species to grow as juveniles. The seagrass is dense and covers a big area making this place a safe spot for a lot of species to mature. If we look at the second sampling location of the site A (Mamghar mangrove), this place is also protected from the wind and creates a perfect shelter for some sand related species. This location acting like a small mangrove system, could explain why the number of individuals and species are higher in this location than for the two other sites, being known the role of mangroves as nursery sites (Robertson and Duke, 1987). However even if the Site A was more diverse and abundant than the other sites, no significant difference in the community assemblage for the site factor was found.

If we look at the species composition, each site had a predominant species in term of abundance. The site A was dominated by *Eucinostomus melanopterus* as found in Gushchin and Fall (2012).

For the site B, the most abundant species was *Atherina boyeri*. This over presence of *Atherina boyeri* in the site B is hard to explain but could be due to a large school present in the area, the day of the sampling. This species known as a truly resident species, is found in high abundance in shallow habitats (Pombo et al.,2005) and a high presence in the zone of sampling could strongly influence the abundant results. This species is known to be strongly associated to nearshore coastal waters (Andreu-Soler et al., 2003; Gürkan et al., 2013). As a result, it would explain why we found this species in site A and B being coastal sites but not in site C, a site made of islands further from shore.

For the site C, the *Mugil capurrii* was the most abundant species. This species known as a background species in the Banc d'Arguin (Gushchin and fall, 2012) was present in almost all the locations in every site. However, most of the individuals have been caught during a single sampling in Kiji island accounting for site C. This over representation in this location could be explain by the presence of a big school of this species during the sampling.

4.4 General composition and observations

By looking at the size of the individuals we caught over this study, we can clearly see that almost all of the individuals were juveniles (98.7% of the catches). These results confirm the importance of the Banc d'Arguin as a nursery and shelter habitat for most of the species (Wolff et al., 1993; Heck, 1997; Schaffmeister et al., 2006; Van Etten 2002; Gushchin and Fall, 2012; Trégarot et al.,2020). The seagrass meadows with a high food availability constitute the best option for a lot of species to grow and then execute an ontogenetic shift to deeper waters and habitats to feed on larger food items (Nakamura et al, 2012).

If we compare our study to the one from Guschchin and Fall in 2012 we can see that most of the species known as background species in the Banc d'Arguin were found (*Dicentrarchus punctatus, Diplodus bellottii, D. sargus, Eucinostomus melanopterus, Lithognathus mormyrus, Liza dumerili, Mugil capurrii, Solea senegalensis*). The other background species that have not been caught during this study could be explained by the difference in term of locations and time of sampling with less locations sampled in our study and with only two months of sampling. Of our 53 species found 32 were also found in the Gushchin and Fall study, the difference being mostly due to Shrimps, Crabs, Sepiidae and Rays species.

During our sampling the presence in two sites of endangered ray species caught our attention. Indeed 17 rays belonging to 2 endangered species (IUCN;2020) (*Glaucostegus cemiculus*; *Rhinobatos rhinobatos* and 1 vulnerable *(Dasyatis margarita*) have been caught in two zones of samplings (Iwik center and Nair Island). The reason of the high concentration of rays in this location should be assessed by further investigations and the Iwik center marine base being close to the Iwik site constitute a perfect place to do so.

The only species that has been found in a large quantity in every location over this study is the Portunidae crab (*Callinectes marginatus*). This crab is known to be present in the Banc d'Arguin in high abundance (Zwartz, 1990; Wolff et al.,1993; Vonk, 2001), specially on the infra-littoral Dahdouh-Guebas (2001). However, this species was the only crab species caught in our study and to our knowledge, no studies assessed the ultra-domination of this species over the others and the evolution of this population In Kiji thousands of individuals have been video recorded by night predating on small juvenile fishes and it would be interesting to assess the impact of this species on the population of other crabs and on the population of juvenile fishes of the area.

During this study several species of shrimps have been recorded (*Penaeus* spp., *Hippolite inermis, Sicyona carinata, Palaemon elegans*). All of this species has been recorded in the Banc d'Arguin by Schaffmeister et al. in 2006. It is hard to interpret the abundance of each species due to absence of a cone end to our beach seine. Moreover, the conformation of the net and the mesh size was allowing them to escape, jumping out of the net or going thru it for small individuals. However, the results are interesting in order to confirm the role of seagrass as a nursery for shrimp species (Blanco-Martínez et al., 2020).

It is also important to highlight that in our study, the sampling was done in the south inshore ecosystem of the Banc d'Arguin, that has been proved to be different form the Northern one in the Cape Blanc region. Indeed, the temperature and salinity in the Banc d'Arguin vary between seasons (Bernikov, 1969) as well as the wind inducing a southward flow in the Banc d'Arguin (Peters, 1976). The upwelling system of the Banc d'Arguin bringing cold nutrient-rich water between January and April (Sevrin-Reyssac 1993) was known to be the driven factor of community abundance and diversity by inducing a high primary production (Minas et al. 1982 and Aristegui et al.,2009). However, studies only focused on offshore ecosystem. As a result, Carlier et al. (2015) investigated the importance of this upwelling system hitting the continental shell on the littoral ecosystems and the tidal flats of the banc d'Arguin present more in the south where our study was carried. The study showed that due to the shallow conformation of the Banc d'Arguin there was almost no connectivity between the North nutrient-enriched waters and the south in term of community assemblage. The intertidal habitats with seagrass beds present in the south, and sampled in this study, were relying on a local benthic primary production promoted by nutrient enrichment coming from the Sahara more than upwelling nutrient-enriched water. Moreover, there is a weak connectivity between northern community assemblage and southern where our study occurred. As a result, it would be interesting to investigate the differences between the two assemblage structures in further studies.

5. CONCLUSION

In this study, the effect of the habitat, season and site have been assessed on the community assemblage of the shallow coastal water habitats of the Banc d'Arguin. Clear differences in the assemblage structure have been obtained for the Habitat and Season factor. However, no clear difference has been obtained in the community assemblage structure for the Site factor.

A higher abundance, number of species and diversity have been observed in seagrass habitat. A different species composition could also be observed between habitats, seasons and sites. Indeed, some species and families are seagrass dependent in their development such as, *Nicholsina usta; Fistularia tabacaria*; *Stephanolepsis hispidus, Sepia officinalis,* Syngnatidae, Sparidae, Labridae; Lutjanidae; Serranidae and shrimps. On the other hand, some other species were associated with unvegetated habitats such as rays or flat fish species. A third category of so called "background" species was found to be present in every habitat and not strictly dependent of one.

The season factor in our study showed a significantly higher number of species found in spring. This observation is probably due to the immigration of young juveniles recruiting in the shallow habitat where they can find prey availability and a shelter to mature over spring and summer. After maturing these juveniles will move to deeper waters inducing a very different species composition of the ecosystem community between seasons.

The site factor did not show a different community assemblage but a higher abundance and number of species were found in Mamghar. This area represents a more protected area from abiotic factors such as strong wind in comparison to Iwik and the Islands (Kiji; Nair). The density of seagrass canopy and distribution could also play a big role in the diversity and abundance of species.

The Banc d'Arguin intertidal and subtidal littoral is almost exclusively composed of young individuals (98.7% in our study). Indeed, a various number of species (53 in our study) are using these shallow habitats in order to grow and be protected from predators. The importance of the vegetation for a large number of species living in the Banc d'Arguin is essential to keep a healthy and abundant biodiversity in this MPA. However, with the upcoming changes that the Banc d'Arguin estimations are made that 78% of the seagrass coverage could disappear by 2100. Moreover 2 of the 3 seagrass species presents are expected to disappear. In a very new study about to be published (Chefaoui et al., 2021) predictions are made that both *Zostera noltei* and *Cymodocea nodosa* will disappear from the Banc d'Arguin by 2050 letting *Halodule* Wrighti the only seagrass species in the region. As a result, the intertidal zones composed of large *Zostera noltei* sea grass beds will be replaced by unvegetated tidal flats inducing a strong impact on the fish assemblage structure of the region as well as the biodiversity. The loss of large and dense canopy of *Cymodocea nodosa* replaced by *H. wrightii*, a small and less dense patchy seagrass species, will induce probably even bigger changes in the composition of these nursery areas. These changes in seagrass density will most likely have a strong impact on the intertidal and subtidal juveniles of the Banc d'Arguin, and eventually on the whole ecosystem of the Banc d'Arguin. This region representing one of the biggest seagrass beds in the world supporting a large variety of rare and endangered species of fishes, elasmobranchs, turtles and birds is of particular concern given the expectation that it will be strongly affected by climate changes occurring this century.

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Annexes:

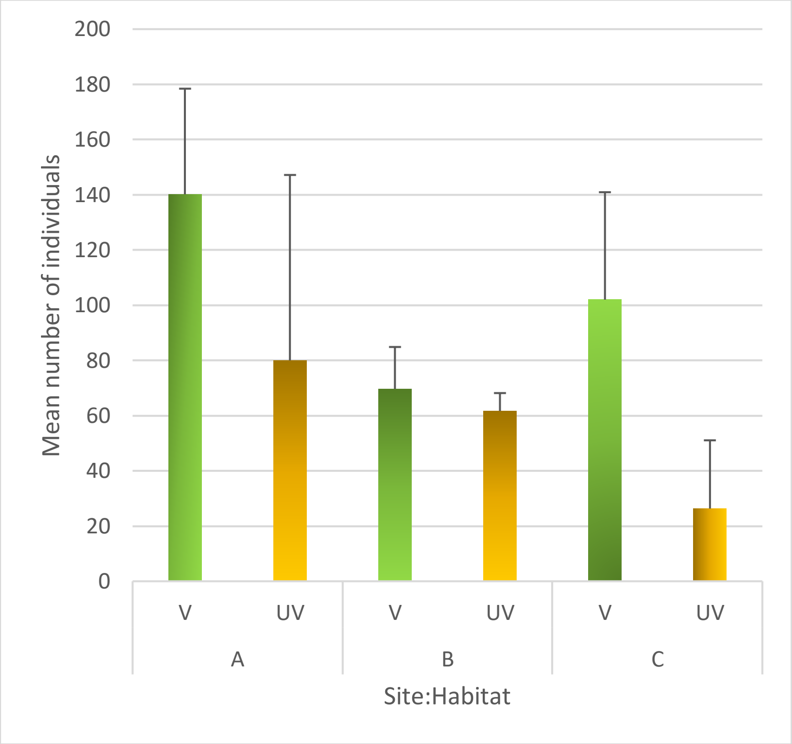


Fig. A1 Mean number of individuals caught for the significant interaction between Site and Habitat + standard errors

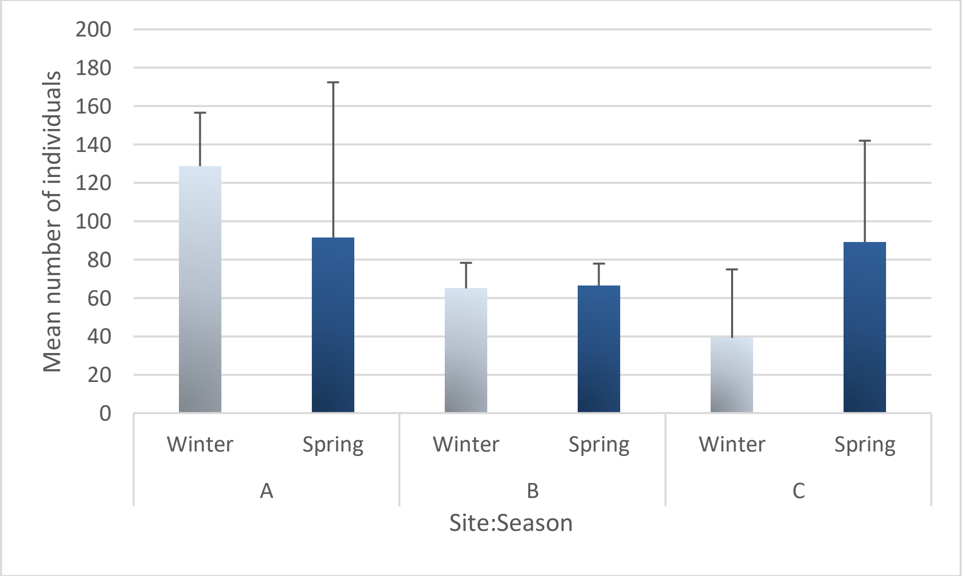


Fig. A2 Mean number of individuals caught for the significant interaction between Site and Season + standard errors

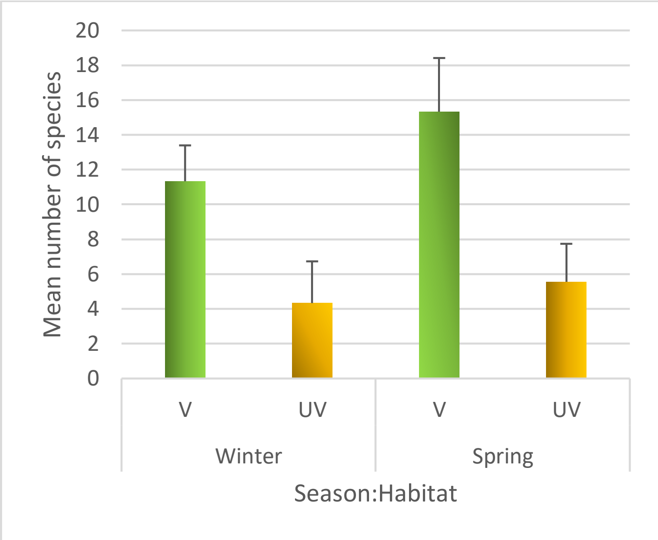


Fig. A3 Mean number of species caught for the significant interaction between Season and Habitat + standard errors

Table A1. List of the 10 species with the highest biomass in unvegetated habitats

Rank	Specie	Biomass	relative biomass (%)
1	Dasyatis margarita	2525	28.24
2	Liza aurata	1526	17.07
3	Dicentrarchus punctatus	978	10.94
4	Solea senegalensis	973	10.88
5	Eucinotomus melanopterus	920	10.29
6	Pomadasys incisus	456	5.10
7	Citharichthys stampfilii	334	3.74
8	Fistularia tabaccaria	275	3.08
9	Psettodes belcheri	228	2.55
10	Glaucostegus cemiculus	200	2.24
	Others:	527	5.89

Table A2. List of the 10 species with the highest biomass in vegetated habitats

Rank	Specie	Biomass	relative biomass (%)
1	Sphaeroides spengleri	4225	14.99
2	Epiphion guttifer	2892	10.26
3	Stephanolepsis hispidus	2663	9.45
4	Serranus scriba	2602	9.23
5	Halobatrachus didactylus	2038	7.23
6	Coptodon guineensis	1944	6.90
7	Dasyatis margarita	1331	4.72
8	Dicentrarchus punctatus	1294	4.59
9	Eucinotomus melanopterus	1118	3.97
10	Mugil capurii	1058	3.75
	Others:	7019	24.90

Table A3. List of the 10 species with the highest biomass during the winter beach seine sampling

Rank	Specie	Biomass	relative biomass (%)
1	Eucinostomus melanopterus	2028	20.89
2	Sphaeroides spengleri	1619	16.67
3	Liza aurata	1494	15.39
4	Halobatrachus didactylus	827	8.52
5	Dicentrarchus punctatus	742	7.64
6	Dasyatis margarita	472	4.86
7	Pomadasys incisus	424	4.37
8	Stephanolepsis hispidus	403	4.15
9	Fistularia tabaccaria	290	2.99
10	Epiphion guttifer	255	2.63
	Others:	1156	11.91

Table A4. List of the 10 species with the highest biomass during the spring beach seine sampling

Rank	Specie	Biomass	relative biomass (%)
1	Dasyatis margarita	3384	12.34
2	Sphaeroides spengleri	2699	9.84
3	Epiphion guttifer	2637	9.62
4	Serranus scriba	2514	9.17
5	Stephanolepsis hispidus	2260	8.24
6	Coptodon guineensis	1879	6.85
7	Dicentrarchus punctatus	1530	5.58
8	Halobatrachus didactylus	1211	4.42
9	Mugil capurrii	1109	4.04
10	Solea senegalensis	954	3.48
	Others:	7248	26.43

Table A5. List of the 10 species with the highest biomass in site A

Rank	Specie	Biomass	relative biomass (%)
1	Epiphion guttifer	1850	13.92
2	Eucinotomus melanopterus	1586	11.94
3	Dicentrarchus punctatus	1242	9.35
4	Liza aurata	955	7.19
5	Serranus scriba	935	7.04
6	Solea senegalensis	813	6.12
7	Fistularia tabaccaria	765	5.76
8	Sphaeroides spengleri	760	5.72
9	Pomadasys incisus	525	3.95
10	Stephanolepsis hispidus	419	3.15
	Others:	3437	25.87

Table A6. List of the 10 species with the highest biomass in site B

Rank	Specie	Biomass	relative biomass (%)
1	Dasyatis margarita	917	15.24
2	Atherina boyeri	814	13.53
3	Rhinobatos rhinobatos	743	12.35
4	Dicentrarchus punctatus	628	10.44
5	Liza aurata	435	7.23
6	Coptodon guineensis	408	6.78
7	Sphaeroides spengleri	378	6.28
8	Eucinotomus melanopterus	246	4.09
9	Penaeus spp.	203	3.37
10	Epiphion guttifer	191	3.17
	Others:	1055	17.53

Table A7. List of the 10 species with the highest biomass in site C

Rank	Specie	Biomass	relative biomass (%)
1	Sphaeroides spengleri	3180	17.84
2	Dasyatis margarita	2939	16.49
3	Stephanolepsis hispidus	2220	12.46
4	Serranus scriba	1667	9.35
5	Halobatrachus didactylus	1538	8.63
6	Coptodon guineensis	1260	7.07
7	Epiphion guttifer	851	4.78
8	Mugil capurii	849	4.76
9	Sepia officinalis	489	2.74
10	Diplodus sargus	469	2.63
	Others:	2359	13.24

Table A8. Outcome of the Tukey HSD test for the Number of species data with Pvalues (V=vegetated; U=unvegetated; Sites=A, B, C; Season= winter and spring)
)

Data	Significant Factors or interations	Comparison levels	*P*
Number of species	Habitat	V-U	0.0000004
	Site	B-A	0.0000001
		C-A	0.0004855
		C-B	0.0049839
	Season	Winter-Spring	<0.0000001
	Habitat:Season	V:Spring-U:Spring	0.0000004
		U:Winter-U:Spring	0.0000433
		V:Winter-U:Spring	0.0000423
		U:Winter-V:Spring	0.0000000
		V:Winter-V:Spring	0.0000000
		V:Winter-U:Winter	0.0006061

Table A9. Outcome of Tukey HSD test for the number of individuals data with Pvalues (V=vegetated; U=unvegetated; Sites=A, B, C; Season= winter and spring)

Data	Significant Factors or interations	Comparison levels	*P*
Number of individuals	Habitat	V-U	0.0000004
	Site	B-A	0.0000679
		C-A	0.0000436
		C-B	0.9829969
	Site:Habitat	V:A-U:A	0.0005273
		U:B-U:A	0.6524441
		V:B-U:A	0.9525104
		U:C-U:A	0.0020036
		V:C-U:A	0.4666700
		U:B-V:A	0.0000128
		V:B-V:A	0.0000636
		U:C-V:A	0.0000000
		V:C-V:A	0.0418041
		V:B-U:B	0.9841287
		U:C-U:B	0.0691667
		V:C-U:B	0.0280201
		U:C-V:B	0.0158242
		V:C-V:B	0.1144563
		V:C-U:C	0.0000225
	Habitat:Season	V:Spring-U:Spring	0.0000003
		U:Winter-U:Spring	0.0871476
		V:Winter-U:Spring	0.0010205
		U:Winter-V:Spring	0.0000922
		V:Winter-V:Spring	0.0104234
		V:Winter-U:Winter	0.2493803
	Site:Season	B:Spring-A:Spring	0.3237940
		C:Spring-A:Spring	0.9999564
		A:Winter-A:Spring	0.0500718
		B:Winter-A:Spring	0.2724007
		C:Winter-A:Spring	0.0026300
		C:Spring-B:Spring	0.4266260
		A:Winter-B:Spring	0.0003377
		B:Winter-B:Spring	0.9999973
		C:Winter-B:Spring	0.2488834
		A:Winter-C:Spring	0.0327263
		B:Winter-C:Spring	0.3659923
		C:Winter-C:Spring	0.0042222
		B:Winter-A:Winter	0.0002568
		C:Winter-A:Winter	0.0000015
		C:Winter-B:Winter	0.2973800

Table A10. Outcome of Tukey HSD test for the Shannon-Weiner index data with Pvalues (V=vegetated; U=unvegetated; Sites=A, B, C; Season= winter and spring)

Data	Significant Factors or interations	Comparison levels	*P*
Shannon-Weiner index	Habitat	V-U	0.0269614
	Site	B-A	0.0493753
		C-A	0.7370159
		C-B	0.0650176

Table A11. Repartition of the species between habitats

No.	Species	Littoral type					
		Sand (A)	Veg (A)	Veg (B)	Sand (B)	Veg (C)	Sand (C)
1	Atherina boyeri		95	700	335		
2	Blennidae		25		1		
3	Callinectes marginatus						
4	Citharichthys stampfilii	13				26	
5	Coptodon guineensis		6	1			
6	Cynoglossus senegalensis						
7	Cynoponticus ferox						
8	Dasyatis margarita			2			6
9	Dicentrarchus punctatus	32	21	24			27
10	Diplodus bellottii		10			1	
11	Diplodus sargus		133	75			4
12	Epinephelus aeneus		7	1		1	
13	Epinephelus guaza						
14	Epinephelus marginatus		5				
15	Epiphion guttifer		2	7			
16	Ethmalosa fimbriata						
17	Eucinotomus melanopterus	249	191	75			42
18	Fistularia tabaccaria	1	5				
19	Glaucostegus cemiculus						1
20	Gobidae spp.		23	12		6	
21	Halobatrachus didactylus		18	11			
22	Hippocampus sp.		1				
23	Hippolyte inermis					1	
24	Liza aurata	85	5	44	172		26
25	Liza dumerilii		5				7
26	Liza ramada	2					
27	Lutjanus dentatus						
28	Lutjanus goreensis		3				
29	Lythognathus mormyrus					7	
30	Mugil capurii	1	71	49			39
31	Nicholsina usta			13			
32	Pagellus bellottii						
33	Palaemon elegans			1			
34	Pegusa lascaris		3	1			
35	Pegusa triophthalma	6				48	
36	Penaeus spp.	4	17	46			2
37	Pomadasys incisus	54	29	33			28
38	Pomadasys rogerii	2	15				
39	Psettodes belcheri						2
40	Rhinobatos rhinobatos			2			1
41	Rypticus saponaceus		2			14	
42	Sepia officinalis		1	5			
43	Serranus scriba		19				
44	Sicyonia carinata			2			
45	Solea senegalensis	21		9	19	9	5
46	Sphaeroides spengleri	5	37	20		2	
47	Spondyliosoma cantharus		3			4	
48	Stephanolepsis hispidus		76	10		6	
49	Symphodus bailloni		2				
50	Symphodus cinereus		2				
51	Symphodus tinca		1				
52	Synaptura lusitanica		3	1			4
53	Syngnathus spp.			4		3	
	Total	475	836	1148	527	128	194

	V	UV	
Number of inidviduals found in habitat:	2112	1196	
	V	**UV**	**Common**
Number of species only found in habitat:	24	3	21

colour code:

found in extra samples
found only in vegetated habitats
found only in unvegetated habitats
common to both habitats
crab (not counted)

Table A12. Repartition of the species between Sites

No.	Species	Site A	Site B	Site C
1	Atherina boyeri	95	121	
2	Blennidae	25	1	
3	Callinectes marginatus			
4	Citharichthys stampfilii	13		
5	Coptodon guineensis	6	1	
6	Cynoglossus senegalensis			
7	Cynoponticus ferox			
8	Dasyatis margarita		2	6
9	Dicentrarchus punctatus	53	24	50
10	Diplodus bellottii	10		
11	Diplodus sargus	133	75	4
12	Epinephelus aeneus	7	1	
13	Epinephelus guaza			
14	Epinephelus marginatus	5		
15	Epiphion guttifer	2	7	13
16	Ethmalosa fimbriata			
17	Eucinotomus melanopterus	440	75	77
18	Fistularia tabaccaria	6		
19	Glaucostegus cemiculus			1
20	Gobidae spp.	23	12	
21	Halobatrachus didactylus	18	11	14
22	Hippocampus sp.	1		
23	Hippolyte inermis			1
24	Liza aurata	90	216	26
25	Liza dumerilii	5		8
26	Liza ramada	2		
27	Lutjanus dentatus			
28	Lutjanus goreensis	3		
29	Lythognathus mormyrus			7
30	Mugil capurii	72	49	388
31	Nicholsina usta		13	
32	Pagellus bellottii			
33	Palaemon elegans		1	
34	Pegusa lascaris	3	1	
35	Pegusa triophthalma	6		
36	Penaeus spp.	21	46	12
37	Pomadasys incisus	83	33	28
38	Pomadasys rogerii	17		
39	Psettodes belcheri			2
40	Rhinobatos rhinobatos		2	1
41	Rypticus saponaceus	2		
42	Sepia officinalis	1	5	
43	Serranus scriba	19		
44	Sicyonia carinata		2	3
45	Solea senegalensis	21	28	6
46	Sphaeroides spengleri	42	20	58
47	Spondyliosoma cantharus	3		
48	Stephanolepsis hispidus	76	10	17
49	Symphodus bailloni	2		
50	Symphodus cinereus	2		
51	Symphodus tinca	1		
52	Synaptura lusitanica	3	1	7
53	Syngnathus spp.		4	3
	Total	1311	761	732

	A	B	C	
Number of inidviduals found in site:	1311	761	732	

	A	B	C	common
Number of species only found in site:	15	3	3	27

colour code:

(none)	found in extra samples
green	found only in site A
blue	found only in site B
yellow	found only in site C
red	common to both seasons
grey	crab (not counted)

Table A12. Repartition of the species between Season

No.	Species	Season: Spring	Season: Winter
1	Atherina boyeri	469	
2	Blennidae	25	1
3	Callinectes marginatus		
4	Citharichthys stampfilii	13	
5	Coptodon guineensis	6	2
6	Cynoglossus senegalensis		
7	Cynoponticus ferox		
8	Dasyatis margarita	5	1
9	Dicentrarchus punctatus	55	48
10	Diplodus bellottii	10	
11	Diplodus sargus	206	
12	Epinephelus aeneus	8	
13	Epinephelus guaza		
14	Epinephelus marginatus	5	
15	Epiphion guttifer	3	19
16	Ethmalosa fimbriata	1	
17	Eucinotomus melanopterus		591
18	Fistularia tabaccaria	3	3
19	Glaucostegus cemiculus		1
20	Gobidae spp.	24	25
21	Halobatrachus didactylus	4	39
22	Hippocampus sp.	1	
23	Hippolyte inermis		1
24	Liza aurata	14	318
25	Liza dumerilii	8	5
26	Liza ramada		2
27	Lutjanus dentatus		
28	Lutjanus goreensis	1	2
29	Lythognathus mormyrus		7
30	Mugil capurii	450	6
31	Nicholsina usta		
32	Pagellus bellottii	2	
33	Palaemon elegans		
34	Pegusa lascaris	3	3
35	Pegusa triophthalma	6	
36	Penaeus spp.	40	28
37	Pomadasys incisus	74	80
38	Pomadasys rogerii	4	13
39	Psettodes belcheri	2	
40	Rhinobatos rhinobatos	2	
41	Rypticus saponaceus	2	
42	Sepia officinalis	5	1
43	Serranus scriba	16	3
44	Sicyonia carinata		5
45	Solea senegalensis	33	14
46	Sphaeroides spengleri	32	88
47	Spondyliosoma cantharus	3	
48	Stephanolepsis hispidus	5	98
49	Symphodus bailloni	2	
50	Symphodus cinereus		2
51	Symphodus tinca	6	
52	Synaptura lusitanica	10	
53	Syngnathus spp.	8	3

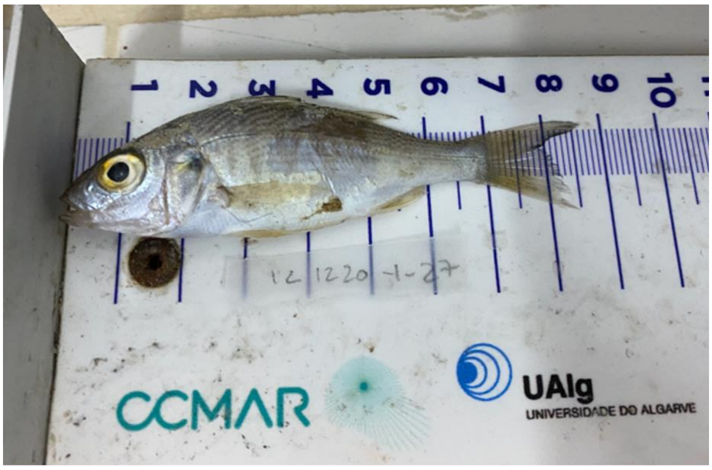
	Spring	Winter	
Number of individuals in:	1566	1409	

	winter	spring	common
Number of speices only found in	8	17	23

colour code:

found in extra samples
found only in spring
found only in winter
common to both seasons
crab (not counted)

Extra photos: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