First data on the diversity and functional structure of fish assemblages in the Sidi Moussa Lagoon (Atlantic Morocco)

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Abstract. Lagoons are critical ecological zones in coastal ecosystems, providing diverse habitats for many species and serving as essential nurseries and feeding grounds for fish. The Sidi Moussa lagoon, a valuable Moroccan ecosystem, faces significant environmental stress from human activities like intensive agriculture, industrial pollution, and tourism. These pressures threaten biodiversity and risk disrupting the ecosystem's balance. Analyzing fish assemblages and taxonomic biodiversity provides valuable insights into ecosystem functioning. This study presents the first comprehensive inventory of the ichthyological community in the Sidi Moussa Lagoon (Atlantic Morocco) in 2023, focusing on its use of shallow habitats by fish fauna. Sampling was conducted in April and November 2023, during the rainy and dry seasons, respectively, using a beach seine net at 8 stations covering most of the lagoon. The analysis considered taxonomic and functional aspects, including ecological and trophic guilds. A total of 187 individuals from 13 species across 9 families were collected. Regarding the composition of the fish assemblages at the sampling sites in terms of ecological guilds, marine species were consistently, the most represented, in both species number and fish abundance. Of the 13 species, 8 were marine straddlers (61%), 4 were residents (31%), and one was a diadromes (8%). The composition of the fish assemblage in Sidi Moussa lagoon based on dietary preference guilds indicates the dominance of detritivores and omnivores species, in the lagoon in terms of species number. This study seeks to enhance the ecological value of the lagoon and support its conservation efforts, however further research is needed to deepen the understanding of the spatiotemporal dynamics of the fish fauna and its interactions with local and global factors.
Key Words: ecology, biodiversity, ichthyofauna, conservation, lagoon.

Introduction. Estuaries and lagoons, transitional environments between land and sea, are inland water bodies, usually located parallel to coastlines. These ecosystems are connected to the sea through one or more channels and are generally shallow (de CA Frischknecht et al 2023). Tides, river discharge, wave action, and coastal current regimes mainly influence the physical and environmental characteristics of coastal lagoons. Additionally, meteorological factors such as wind and rain affect the dynamics of these environments (Franco et al 2007; de CA Frischknecht et al 2023).

These nutrient-rich transitional ecosystems provide critical ecological functions, serving as refuges, feeding grounds, and breeding areas for juvenile aquatic species. They offer suitable habitats, particularly for the early life stages of fish and invertebrates, and act as migratory pathways for anadromous and catadromous species (Ferreira et al 2017). However, due to their location in marginal shallow areas, coastal lagoons are highly susceptible to anthropogenic pressures. Activities such as agriculture, tourism, industry, and urbanization significantly affect these ecosystems (Akin et al 2005; Pérez-Ruzafa & Marcos 2012; Bouchkara et al 2021). Fish communities in coastal lagoons play a vital ecological role in transferring energy across trophic levels. Due to their sensitivity to environmental variations, they are widely considered bio-indicators (Soto-Galera et al

1998; Barrella & Petrere 2003). The structure, distribution, and abundance of fish assemblages in these ecosystems depend on balancing marine and freshwater inputs (Kara & Quignard 2019). Furthermore, their spatial and temporal dynamics are influenced by daily and seasonal environmental variations (Teodósio et al 2016). Fish assemblages can also be characterized based on water characteristics (Faunce et al 2004; Embarek et al 2017; Kara & Quignard 2019) and substrate type (Pérez-Ruzafa et al 2011). Colonization history, biological processes such as predation and competition, along with abiotic factors, can all influence the composition of fish communities within coastal lagoons (Pérez-Domínguez et al 2012).

The Moroccan Atlantic and Mediterranean coast hosts diverse transitional ecosystems including five lagoons - Nador Lagoon, Moulay Bousselham Lagoon, Sidi Moussa Lagoon, Oualidia Lagoon, and Khnifis Lagoon- along with estuaries and bays, spanning over 200,000 hectares (El Himer et al 2013). These lagoons provide multiple ecosystem services, such as aquaculture, tourism, and fishing. However, increasing human activities around these ecosystems have degraded their environmental quality, exposing them to threats similar to those in other Mediterranean regions (Maanan et al 2004). In 1980, Morocco ratified the RAMSAR convention for the protection of wetlands, and currently, around 20 sites, including the Oualidia-Sidi Moussa wetland complex (Ramsar site no. 1474), are listed under this agreement (Tamadouni et al 2017).

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To enhance our understanding of the environmental status and functioning of the Sidi Moussa lagoon, this initial study on ichthyological diversity complements previous research focused on pollution impacts (El Himer et al 2013; Latifa et al 2013; Jayed et al 2017; Benmhammed et al 2021b; Khbaya et al 2023). Sedimentary and morphodynamic processes (Hilmi et al 2005; Latifa et al 2013), macrobenthic taxa (Chaouti et al 2019), and bivalve culture projects (Rzama et al 2002; Jayed et al 2017; Doukilo et al 2021; El Hamoumi et al 2022; Khbaya et al 2023).

Considering the relevance of this topic and the lack of studies in the Sidi Moussa lagoon, the primary objectives of this study are to describe the specific composition and abundance of the fish community, as well as to analyze their taxonomic and functional characteristics. This knowledge will be useful to assist the decision-making process towards the sustainable management of local natural resources in Sidi Moussa lagoon.

Material and Method

Description of the study sites. Sidi Moussa Lagoon is located on the Moroccan Atlantic coast (32°52′0′′N–8°51′05′′W) between the cities of El Jadida and Safi about 15 km south of the Jorf Lasfar industrial complex (Latifa et al 2013). This lagoon is characterized by an elongated shape imposed by the morphology of the inter-dune depression between consolidated continental and coastal dunes (Figure 1). It lies in a straight strip parallel to the coastline, measuring 5.5 km long and 0.5 km wide on average. The total surface area is estimated at 420 ha with a maximum depth of 2.5 m (Maanan et al 2004). The lagoon and peripheral marshes are covered with plant formations typical of wetlands (reedbeds and salt meadows) and cultivated areas in the plain (El Himer et al 2013).

The lagoon is part of the Oualidia – Sidi Moussa complex, ranked by the Ramsar Convention (site N°1474) as a wetland of biological and ecological importance primarily serving as a habitat for migratory bird protection. It is also a valuable environment for a wide variety of plants, fish, mollusks, crustaceans, polychaetes, tunicates, and cnidarians (Zidane et al 2019), and other wildlife (Makaoui et al 2018).

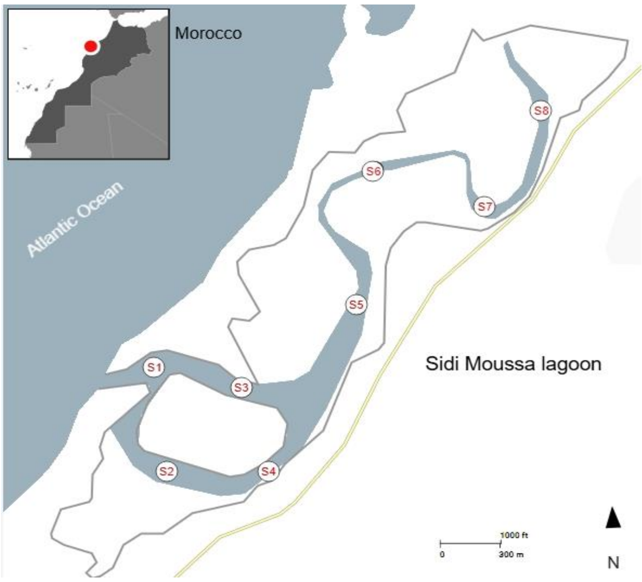

Figure 1. Map illustrating the geographical location of the Sidi Moussa Lagoon (Moroccan Atlantic) and the fish sampling stations (S1-S8).

The lagoon is separated from the ocean by a cordon of consolidated dunes, which ensures stable lagoon-ocean communication via two unequal channels at the downstream end of the lagoon: a narrow mouth that provides a permanent connection with the Atlantic Ocean; and a substantial sand deposit located just inland of the mouth. In addition, secondary channels wind through the lagoon, surrounded by mudflats and Salicornia meadows, while the main channel (maximum depth of 5m), runs across a shoreline with numerous secondary channels (maximum depth of 2m), decreasing in depth upstream where it is limited by salt marsh. Freshwater inputs to the lagoon are relatively small, derived from rainfall (run-off from the surrounding lands), the groundwater table, which has a net flow of seawards, and freshwater resurgences from the Plio-Quaternary aquifer that outcrops along the lagoon's edges (El Himer et al 2013). The tidal regime at Sidi Moussa Beach is semi-diurnal, with two high tides and two low tides approximately every 25 hours, with a tidal range fluctuating between 2 m and 4 m (Hilmi et al 2005).

The climate of the lagoon is classified as hot temperate. It is characterized by an oceanic influence, with an average annual temperature of around 18.7°C and an average yearly rainfall of 317 mm.

As reported in previous studies, measurements of physicochemical parameters in Sidi Moussa Lagoon indicate that the lowest water temperature recorded was 13.4±1.1°C, observed in January 2019. In contrast, the highest temperatures were recorded in April and August 2018, reaching 25.8±0.4°C. Salinity levels peaked at 33.1 psu in July and October 2018 (Doukilo et al 2021), while dissolved oxygen concentration ranged between 5.81 mg L^{-1} and 13.17 mg L^{-1} in the seam period (Kaddioui et al 2018).

The hydraulic regime of the lagoon is subject to the semi-diurnal tidal rhythm; with the maximum tidal amplitude being approximately 2m (spring tide) and 0.5m (neap tide) (Hilmi et al 2005).

The distribution of the sedimentary facies within the lagoon is governed, mainly, by the marine dynamics. This situation separates the lagoon into two areas: an area with an essentially marine influence, made up of sandy facies which is poor in metallic elements and organic matter but rich in biogenic carbonates; and a second area under a typically lagoonal influence characterized by silty to silty–muddy facies with high concentrations of heavy metallic elements and organic matter, but poor in carbonates (Maanan et al 2004). An important agricultural area borders the lagoon of Sidi Moussa. Fishing remains a traditional and seasonal activity, whilst aquaculture is also developing. Although Sidi Moussa is not a major resort, there is a significant tourist influx, especially during the summer season.

Sampling methods and laboratory treatment. Samples were collected from the lagoon during two key periods in 2023: April, reflecting the predominant influence of the wet season, and October, representing established dry season conditions. Sampling was conducted according to a systematic design (Figure 1) involving 8 stations (S1 to S8) distributed throughout the lagoon. Given the limited prior knowledge about the structure of the lagoon's ichthyological community, this approach is the most effective way to address the spatial heterogeneity of the community (Cochran 1953). Fishing was carried out using a beach seine 20 meters long and 3 meters wide with a mesh size of 10 mm, a method recognized for its effectiveness in sampling fish in shallow waters, particularly in coastal lagoon ecosystems (Franco et al 2022).

At each station, the seine was dragged over a distance of 50 m, corresponding to an estimated fishing effort of 500 m² per station. As this fishing gear covers the entire water column from the bottom to the surface, both juveniles and adults of pelagic and benthic-demersal species were captured. The captured fish were placed in labeled plastic bags, kept cool in thermo-insulated enclosures, and transported to the laboratory for species-level identification. In the laboratory, all fish specimens were identified to species level using standardized taxonomic keys. However, some individuals of the family Mugilidae were only identified at the family level due to their small size and the difficulty in distinguishing species-specific morphological features at early life stages. To ensure the accuracy and reliability of the identifications, both the scientific and common names of all species were checked and cross-referenced using FishBase, a comprehensive global information system on fishes. The specimens were counted, weighed (wet weight in grams) using a precision balance (0.01 g), and measured to the nearest millimeter (total length). When a species exceeded 30 individuals in a seine haul, a random sample of 30 fish was measured; excess individuals were only counted to determine the total number and calculate the total biomass.

Functional pre-treatment. To describe the functional structure of the fish assemblage in the Oualidia Lagoon, captured species were grouped into ecological groups (resident, R; migratory marine, including euryhaline species, M; occasional marine, including stenohaline diadromous species, D). And trophic groups (strictly benthivorous, Bv; detritivores, DV; herbivores, HV; planctivores, PL; hyperbenthos-zooplanktonic fish, HZ; species with a diet that can change from zooplanktonic hyperbenthos to hyperbenthos; HZ-HP or from microbenthos to HP, Bmi-HP; omnivores, Ov). The assignment of fish species to functional groups was based on the literature for European estuaries and lagoons (Franco et al 2008a; Franco et al 2008b; Zucchetta et al 2010; Elliott et al 2022).

Data analysis. Abundance and biomass were calculated at each station and expressed as catch per unit effort (CPUE= individuals/500 m²). Diversity indices, including the Shannon-Wiener index (log base 2), were employed to assess species diversity and evenness. These analyses were conducted using PRIMER© (Plymouth Routines In Multivariate Ecological Research) software (Clarke & Warwick 1994). Diversity indices were compared across seasons using the Wilcoxon-Mann-Whitney test ($p<0.05$), conducted with RStudio (version 1.1.463) and R (version 3.6.3).

Results

Taxonomic diversity. A total of 187 individuals were collected in the Sidi Moussa lagoon during the two campaigns, represented by 13 fish species belonging to 9 distinct families. Mugilidae exhibited the highest species richness, with three species. Gobiidae, Sparidae and come in second with 2 species each. The remaining families are represented by just a single species each: Labridae, Atherinidae, Blenniidae, Batrachoididae, Serranidae, and Syngnathidae (Table 1).

Table 1

Fish species sampled in the Sidi Moussa lagoon, with allocation to family

Family	*Species*	*Common names (FAO)*	*EG*	*TG*	*Habitat*	*Total abundance*	*N % Total*
Atherinidae	*Atherina boyeri* (Risso, 1810)	Big-scale sand smelt	R	HZ	P	17	9.13
Mugilidae	*Chelon auratus* (Risso, 1810)	Golden grey mullet	M	DV	BD	28	15,05
	Chelon saliens (Risso, 1810)	Leaping mullet	D	DV	BD	50	26.88
	Mugil sp	-	-	-	BD	5	2.68
Gobiidae	*Gobius niger (*Linnaeus, 1758)	Black goby	R	Bmi,HP	BD	15	8.06
	Pomatoschistus norvegicus (Collett, 1902)	Norway goby	R	BV	BD	19	10.21
Labridae	*Symphodus bailloni* (Valenciennes, 1839)	Baillon's wrasse	M	BV	BD	1	0.53
Sparidae	*Diplodus sargus* (Linnaeus, 1758)	White seabream	M	OV	BD	17	9.13
	Pagellus acarne (Risso, 1827)	Axillary seabream	M	OV	BD	1	0.53
Batrachoididae	*Halobatrachus didactylus* (Bloch & Schneider, 1801)	Lusitanian toadfish	M	HP	BD	13	6.89
Blenniidae	*Parablennius sanguinolentus* (Pallas, 1814)	Rusty blenny	M	BV	BD	4	2.15
Syngnathidae	*Syngnathus acus (*Linnaeus, 1758)	Greater pipefish	R	BV	BD	16	8.60
Serranidae	*Epinephelus caninus* (Valenciennes, 1843)	Dogtooth grouper	M	OV	D	1	0.53

Trophic group (TG), ecological group (EG), Habitat (P: pelagic; BD: bentho-demersal), Percentage of total abundance (N %).

Ecological guilds (EG). D-Diadromes; M-Marines; R-Residents. Feeding guilds (FG): BV- strictly benthivores; DV- detritivores; HV-herbivores; HZ hyperbenthos-zooplankton feeders; HP- hyperbenthos-fish feeders; Bmi-HP- fish showing an ontogenetic change in feeding preference from microbenthos to HP; OV- omnivores.

Numerically, the Mugilidae family dominated the total abundance over the two study periods, contributing by 44.61% of the total catch represented by, *Chelon saliens* and *Chelon auratus* stand out as the most abundant species, with percentages of 26.88% and 15.05% respectively of all catches. Followed by the Gobiidae (18.27%) represented by *Pomatoschistus norvegicus and Gobius niger* with a percentage of 10.21%, and 8.06% respectively.

Three families accounted for 72.04% of the total abundance: Mugilidae (44.62%), Sparidés (9.67%), and Gobiidae (18.27%). Moreover, these families and four additional ones represented almost 97% of the total abundance: Atherinidae (9.13%), and Syngnathidae (8.60%). Batrachoididae (6.98%), and Atherinidae (2.06%), Mugilidae was the dominant family in terms of abundance over the two study periods. Fish abundance is higher at shallower stations than at deeper stations.

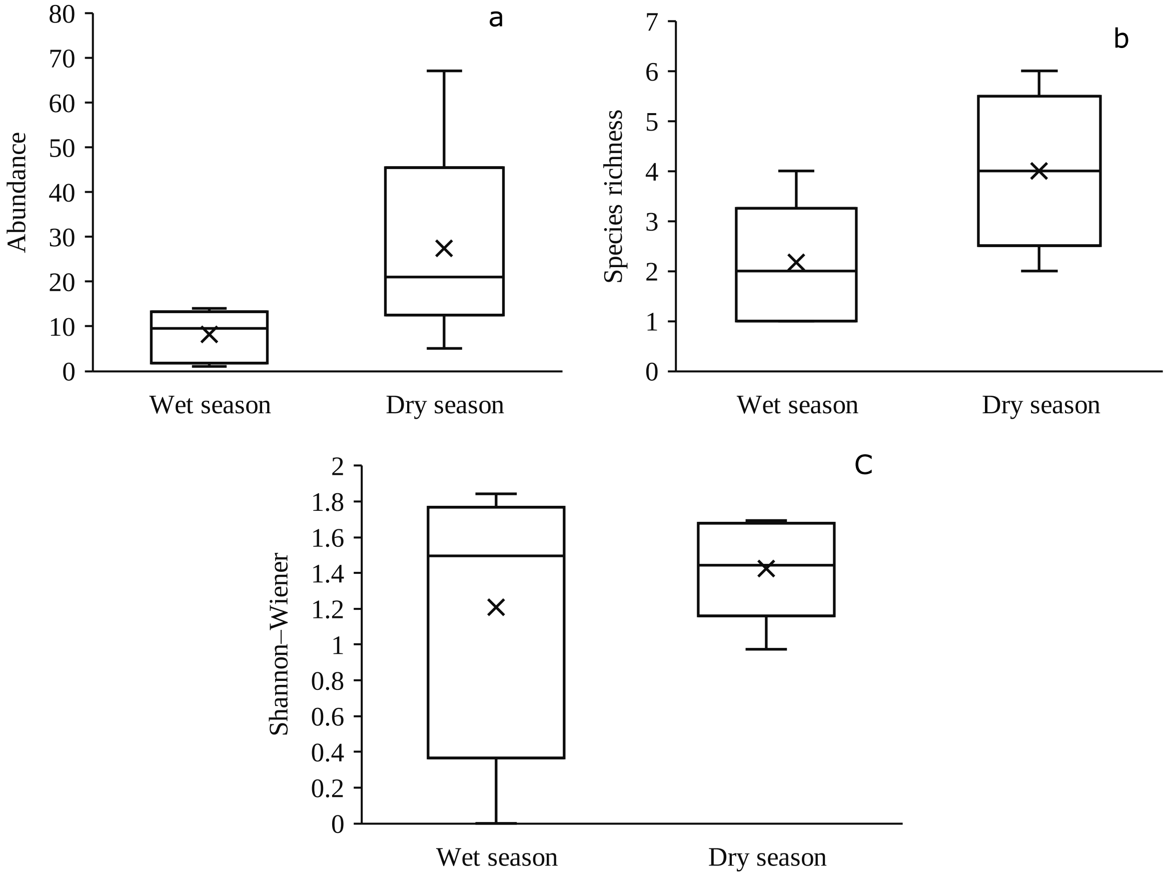

Figure 2. Temporal and spatial variations of the total number of fishes sampled at Sidi Moussa Lagoon in mean (a) abundance, (b) species richness, and (c) Shannon-Wiener index (Moroccan Atlantic), (× average values).

The species richness during the wet season of all captures reached a maximum of 13 species (Table 1) (*Atherina boyeri, Chelon auratus, Chelon saliens, Gobius niger, Pomatoschistus norvegicus, Mugil sp, Symphodus bailloni, Diplodus sargus, Pagellus acarne, Halobatrachus didactylus, Parablennius sanguinolentus, Epinephelus caninus, Syngnathus acus*) belonged to 8 families in the lagoon. Whereas this richness barely exceeds 9 species (*Atherina boyeri, Chelon saliens, Symphodus bailloni, Diplodus sargus, Halobatrachus didactylus, Pomatoschistus norvegicus, Gobius niger, Syngnathus acus*) belonging to 9 families during dry season (Figure 2).

The results of the Wilcoxon-Mann-Whitney tests ($p>0.05$) showed no significant differences between the wet and dry seasons for the diversity indices studied. Species richness (S), abundance (A), and Shannon's diversity index (H) in the Sidi Moussa Lagoon.

Functional diversity: ecological guilds. The distribution of identified species according to their ecological guilds (figure 3a) reveals a marked dominance of marine-affinity species, constituting 61% of the total species richness, equivalent to 8 species. Resident species represented 31% (4 species), while diadromous species accounted for 8%. In terms of abundance (Figure 3b), Resident species were the dominant guild, comprising 67 individuals, or more than 37% of the total catch. Marine affinity followed with 65 individuals, representing 36%, and Diadromous species contributed 27% with 50 individuals.

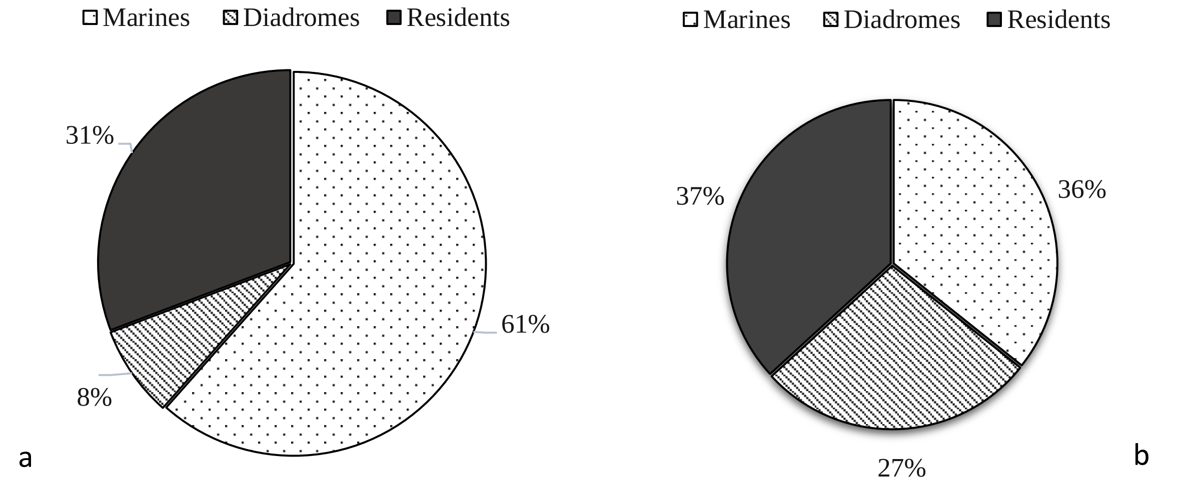

Figure 3. Ecological guilds in terms of species richness (a), and abundance (b) of the Sidi Moussa Lagoon's (Moroccan Atlantic) fish fauna. D-Diadromes; M-Marines; R-Residents.

Functional diversity: Feeding guilds. The fish community in the Sidi Moussa Lagoon can be categorized into six guilds. Among these, benthivores (BV) and omnivores (OV) were the most diverse, constituting 30.77% of each of the fish species (four species). Additionally, there were detritus feeders fish (DV), accounting for 15.38% of the fish community (two species). Notably, more than half of the recorded fish fauna in the lagoon was strictly or partially benthivorous (9 species, totaling 52%) (Figure 4a).

The other feeding guilds included, which have shown an ontogenetic shift in feeding preference from microbenthos to hyperbenthos-fish (Bmi-HP), hyperbenthos-fish-eaters (HP) and hyperbenthos-zooplankton-eating species (HZ) each represented by one species (7.69% each), within the ichthyofaunal diversity recorded in Sidi Moussa lagoon (Figure 4a).

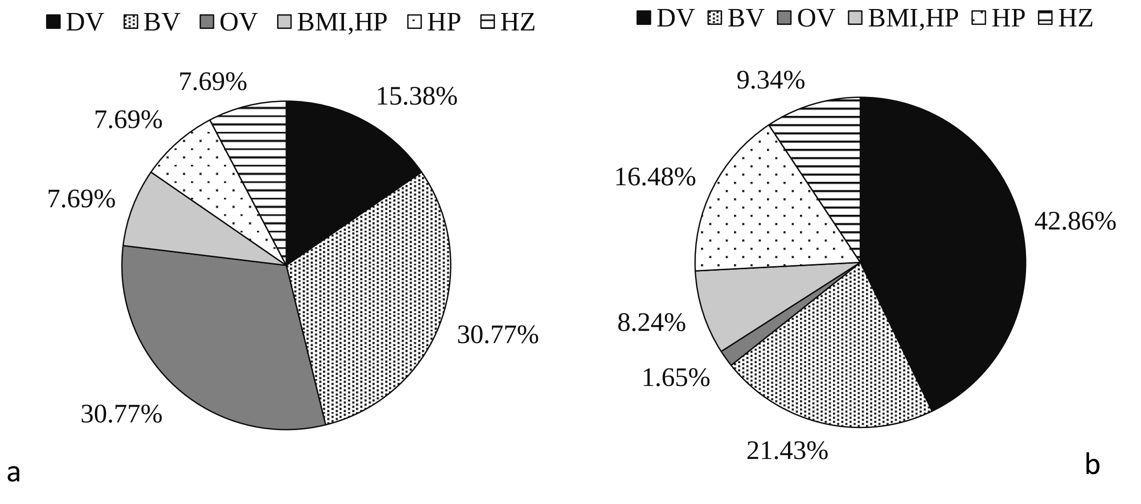

Figure 4. Feeding guilds in terms of species richness (a), and abundance (b) of the Sidi Moussa Lagoon's fish fauna. BV- strictly benthivores; DV- detritivores; HV-herbivores; HZ hyperbenthos-zooplankton feeders; HP- hyperbenthos-fish feeders; Bmi-HP- fish showing an ontogenetic change in feeding preference from microbenthos to HP; OV- omnivores.

In terms of abundance (Figure 4b), detritivores (DV) represented the largest number of fish, with 78 individuals, accounting for over 42.86% of the total fish captured. This high prevalence can be attributed to the abundant presence of Mugilidae species. Benthivores (BV) followed, representing 21.43% with more than 39 individuals, and hyperbenthos-zooplankton-eating species (HZ) accounted for 16.48%. Other feeding guilds included hyperbenthos fish-eaters (HP), Omnivores (OV), and fish species exhibiting an ontogenetic shift in feeding preference, transitioning from microbenthos to hyperbenthos fish (Bmi-HP), which was a smaller group with less than 10% of the fish community.

Discussion. The present study is the first to compile a list and analyze the structure and diversity of fish assemblages in Sidi Moussa Lagoon. Notably, no rivers discharge into the lagoon and the small size of this ecosystem may be responsible for this reduced fish species diversity (only 13 species) in this environment relative to the average found in the other European and Mediterranean lagoons (Malavasi et al 2004; Chaoui & Kara 2006; Franco et al 2006). The number of species and the structure of the fish community in shallow lagoons such as the Sidi Moussa Lagoon are strongly influenced by site characteristics and by several abiotic factors, such as temperature, salinity, dissolved oxygen, ocean connection, type of vegetation, and substratum (Elliott & Dewailly 1995; Pérez-Ruzafa & Marcos 2012).

Species richness in the Sidi Moussa Lagoon exhibited notable variability across sampling stations, ranging from 1 to 4 species during the wet season, with an average of 1.62. In contrast, during the dry season, species richness increased significantly, exceeding 9 species from 5 families, with an average of 2.5 species per station. The maximum number of species recorded during this period was 6, while the minimum was 2. Despite this relatively low diversity, the findings align with those reported in other Mediterranean lagoons. For instance, studies on 40 Atlantico-Mediterranean lagoons (Pérez-Domínguez et al 2012) revealed species richness ranging from 6 to 48, with an average of 23.4 species (Pérez-Ruzafa et al 2011). Similarly, in the African Mediterranean region, diversity varied between 13 and 26 species including 19 species in Merja Zerga (Morocco), 26 in Ghar El Melh (Tunisia), 19 in Lake Manzala (Egypt) (Kraïem et al 2009), 13 in Ichkeul lagoon (Tunisia) (Sellami et al 2010), and 13 in Drana Lagoon (Greece) (Koutrakis et al 2009). Other studies using similar methods, such as beach netting, reported 18 species in Nador Lagoon (Bouchereau et al 2000) and 15 species in the same lagoon between 2012 and 2014 (Jaafour et al 2015). Notably, an extensive inventory carried out between 2015 and 2016 in Marchica Lagoon (Selfati et al 2019) identified 86 fish species, underscoring significant seasonal and annual variations. The observed variation in fish diversity among the different lagoons can be attributed to the specific characteristics of each lagoon, including geographic location (latitude and longitude), geomorphology (e.g., surface area and heterogeneity of habitats), the degree of connection with freshwater (salinity) and the number and extent as well as the length, width, of maritime openings (Elliott et al 2022). Additionally, these variations can also be influenced by the sampling effort and the type of fishing gear used. Beach netting, used in this study, is a particularly effective technique for sampling in shallow waters, especially in lagoon ecosystems (Franco et al 2022).

During this study, the assemblage was dominated by eight species belonging to the fourth family, Mugilidae (44.61%), which occurred in both seasons and dominated in abundance and biomass. Followed by the Gobiidae (18.27%), and Sparidae (9.66%), represented by Diplodus sargus and Pagellus acarne, respectively. All of them are native species that occur in other similar environments on the Atlantic coast of Morocco.

The Shannon–Wiener diversity index is a valuable tool for characterizing fish biodiversity in transitional ecosystems. In the present study, this index varied slightly in Sidi Moussa lagoon between the two seasons when average values ranged from 0.97 to 1.69. This result reflects a moderately diversified community, and it is comparable with the study in the Nador Lagoon (Selfati et al 2023) while the Shannon–Wiener diversity index varies from 0.02 to 2.72, with a mean value of 1.41. In addition, in the study of (Jaafour et al 2015) this diversity index spanned from 1.24 in winter to 1.84 in summer in the Nador Lagoon.

The analysis of species caught showed three ecological guilds. The high presence of marine species in the two seasons influenced the general composition of the assemblages in the Sidi Moussa Lagoon. Of the 13 species recorded in the Lagoon, 8 were marine straddlers (61%), 4 residents, and 1 diadromes were marine-lagoon-dependent fish species spawning in the sea and migrating into the lagoon during their life cycle. The high occurrence of marine species in this lagoon indicates the importance of these areas as breeding, feeding, and growth sites and refuges from predation, serving as possible nursery habitats for numerous fish species (Pihl et al 2002; Franco et al 2007; de CA Frischknecht et al 2023) that is supported by the presence of juvenile individuals of many fishes species. This trend was also observed in previous studies in Mediterranean lagoons, in Morocco, Marchica Lagoon (Jaafour et al 2015), and European lagoons (Akin et al 2005; Manzo et al 2016; Scapin et al 2019).

As regards the composition of the fish assemblages in terms of the dietary preference guilds, the detritivores and omnivores species were the most highly represented groups in terms of the number of species, which represented four species (30.77%) each. Moreover, concerning fish abundance, detritivores presented by three species of Mugilidae quantitatively dominate (42.86% of total abundance) of this fish assemblage.

Mugilidae species are detritivores and known by filtration and ingesting of large quantities of sediment (Manzo et al 2016), should prefer muddy sediments (Ruitton et al 2000; Elliott et al 2002), this was consistent with the crucial role of detritus in the food webs of coastal lagoons (Franco et al 2008a). This contributes significantly to the ecological functioning of these systems as they directly use and transfer primary production (Ruitton et al 2000).

Instead, the contribution of the benthivores to the fish community was important in the study period, with a mean relative abundance of 21.43%. Whereas the contribution of the omnivore species exceeds barely 1.65% in terms of fish abundance. The food webs of aquatic systems with moderate river flows, such as Mediterranean coastal lagoons, are often dominated by local detrital sources (Elliott et al 2002). The high presence of detritivorous and omnivorous fish in Sidi Moussa (no rivers discharge into the lagoon) could be explained by the predominance of autochthonous detrital sources, generally derived from submerged macrophytes and salt marshes.

The high prevalence of infrequent species observed in this study is a common feature of coastal lagoons and estuaries in the region, as documented in previous research (Goren 2014; Kara & Quignard 2019; Selfati et al 2023). Either the low occurrence of certain species, such as Symphodus bailloni, Halobatrachus didactylus, Syngnathus acus, and Parablennius sanguinolentus, may be attributed to the population dynamics within this specific environment or the sampling methodology employed (Franco et al 2012). Among the species studied, Chelon saliens, belonging to the Mugilidae family, stands out due to its high abundance during both wet and dry seasons compared to other species. This species is commonly found in coastal waters and exhibits migratory behavior, moving between freshwater, estuarine, and marine environments for spawning purposes (Malavasi et al 2004). Chelon saliens is widely distributed across the Mediterranean basin as well as the black Sea and the Sea of Azov (Facca 2020), highlighting its adaptability to a diverse range of aquatic habitats. In the Atlantic, it has been reported from the coast of Morocco to the Bay of Biscay (Franco et al 2008b).

Species richness in the Sidi Moussa Lagoon exhibited notable variability across sampling stations, ranging from 1 to 4 species during the wet season, with an average of 1.62. In contrast, during the dry season, species richness increased significantly, exceeding 9 species from 5 families, with an average of 2.5 species per station. The maximum number of species recorded during this period was 6, while the minimum was 2. Despite this relatively low diversity, the findings align with those reported in other Mediterranean lagoons. For instance, studies on 40 Atlantico-Mediterranean lagoons (Pérez-Domínguez et al 2012) revealed species richness ranging from 6 to 48, with an average of 23.4 species (Pérez-Ruzafa et al 2011). Similarly, in the African Mediterranean region, diversity varied between 13 and 26 species including 19 species in Merja Zerga (Morocco), 26 in Ghar El Melh (Tunisia), 19 in Lake Manzala (Egypt) (Kraïem et al 2009), 13 in Ichkeul lagoon (Tunisia) (Sellami et al 2010), and 13 in Drana Lagoon (Greece) (Koutrakis et al 2009). Other studies using similar methods, such as beach netting, reported 18 species in Nador Lagoon (Bouchereau et al 2000) and 15 species in the same lagoon between 2012 and 2014 (Jaafour et al 2015). Notably, an extensive inventory carried out between 2015 and 2016 in Marchica Lagoon (Selfati et al 2019) identified 86 fish species, underscoring significant seasonal and annual variations. The observed variation in fish diversity among the different lagoons can be attributed to the specific characteristics of each lagoon, including geographic location (latitude and longitude), geomorphology (e.g., surface area and heterogeneity of habitats), the degree of connection with freshwater (salinity) and the number and extent as well as the length, width, of maritime openings, (Elliott et al 2022).

Previous studies have shown that the species composition of shallow coastal ecosystems is strongly influenced by species-specific preferences for abiotic conditions and their ability to withstand frequent fluctuations in these parameters (Akin et al 2005; Elliott et al 2022). In particular, temperature and salinity are widely recognized as critical factors that determine the spatial and temporal structure of fish assemblages (Akin et al 2005; Franco et al 2007; Pérez-Ruzafa et al 2011; Manzo et al 2016). However, a notable limitation of the current study is the exclusion of these abiotic factors, which may have influenced the observed patterns of species distribution and abundance. In addition, despite the use of beach nets - a technique known to be particularly effective for sampling in shallow waters, especially in lagoon ecosystems (Franco et al 2022) - the fish sampling methodology may still introduce biases. Factors such as the mesh size of the net and whether the net was dragged along the bottom of the water body can significantly affect the results. For example, benthic species, which inhabit the bottom layers of the water column, are often under-represented in samples because they are difficult to capture using standard netting techniques.

Our investigation into the relationship between fish assemblage structure and environmental factors, such as substrate type and proximity to the marine inlet, revealed a correlation between these elements. However, no clear relationship was found between the spatiotemporal distribution of fish and key environmental conditions, such as temperature, salinity, and dissolved oxygen. This suggests that while environmental factors undoubtedly influence fish communities, their effects may be indirect or mediated by complex biotic and abiotic interactions. For instance, spatial variability in diversity and abundance was observed between downstream stations (stations 1,2,3 and 4), which are influenced by proximity to the marine inlet, strong hydrodynamic dynamics, and sandy substrates, and upstream stations (stations 5,6,7 and 8) exhibited greater fish diversity, characterized by low hydrodynamic dynamics, muddy substrates, and macrophyte presence.

The Sidi Moussa Lagoon is significantly affected by human activities, including intensive modern agriculture in surrounding areas. These practices contribute to organic pollution and nutrient enrichment, potentially leading to eutrophication and subsequent oxygen depletion in the lagoon. The mineral pollutants produced by salt production, artisanal fishing, tourism, and the expansion of the phosphate industry in the region can bioaccumulate in fish tissues, causing physiological stress, reduced reproductive success, and changes in trophic interactions and fish community composition, often favoring more resilient species over those that are ecologically sensitive. Consequently, further research is needed to elucidate the underlying mechanisms driving these patterns, which could provide a more comprehensive understanding and clarify the relationship between environmental conditions and fish distribution in the Sidi Moussa Lagoon. By addressing these gaps, we can enhance our understanding of the complex factors shaping coastal ecosystems and improve conservation and management strategies.

Conclusion. This study represents the first comprehensive inventory and analysis of fish assemblages in the Sidi Moussa Lagoon, revealing a relatively low species diversity of 13 species, likely due to the lagoon’s small size and lack of river inflows. Species richness varies seasonally with higher diversity during the dry season (up to 9 species) compared to the wet season (1-4 species). The fish community was dominated by marine species, particularly Mugilidae (44.61%), Gobiidae (18.27%), and Sparidae (9.66%), reflecting the lagoon’s role as a nursery and feeding ground. The Shannon-wiener diversity index indicated moderate biodiversity (0.97-1.69), consistent with other Mediterranean lagoons. Ecological guilds analysis showed a predominance of marine straddlers (61%), with detritivores and omnivores dominating dietary guilds, highlighting the importance of detrital was linked to environmental factors such as substrate type and proximity to the marine inlet, with greater diversity observed in vegetated, upstream areas. These findings underscore the ecological significance of the Sidi Moussa Lagoon and emphasize the need for further surveillance and protection efforts to ensure sustainable management of this ecosystem, particularly fish diversity. From a scientific perspective, the Sidi Moussa lagoon requires long-term monitoring to assess the impact of environmental changes and human activities. Continuous and systematic surveillance integrating abiotic and biotic factors to better understand the dynamics of this ecosystem, including fluctuations in water quality, biodiversity, and sediment composition. This monitoring will make it possible to identify trends, detect the first signs of deterioration, and assess the effectiveness of conservation measures. It will also provide valuable data for developing sustainable management strategies and mitigating the adverse effects of anthropogenic pressures. By prioritizing long-term monitoring, stakeholders can ensure the preservation of this ecologically important lagoon while supporting its resilience in the face of current environmental challenges.

Acknowledgements. The authors are grateful and would like to thank local artisanal anglers for their participation and assistance during the field trips in Sidi Moussa Lagoon.

Conflict of interest. All authors declare no conflicts of interest.

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Received: 31 January 2025. Accepted: 03 April 2025. Published online: 03 April 2025.
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How to cite this article:
Erbib A., Selfati M., Doukilo I., Bazairi H., Fahde A., 2025 First data on the diversity and functional structure of fish assemblages in the Sidi Moussa Lagoon (Atlantic Morocco). AACL Bioflux 18(2):771-784.