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Updated and comprehensive checklist of the fish fauna of the Marchica Lagoon (Alboran Sea, Morocco), following hydraulogical intervention

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ABSTRACT

This study was conducted on the Marchica lagoon, a designated Ramsar site regionally recognized for its biological, ecological and socio-economical value. Intensive Ichthyofaunal inventories carried out during the post-stabilization of the inlet (after 2011), mainly between 2015 and 2016, documented 86 teleostean fish including 55 earlier reported species and 31 newly recorded ones. Consequently, the updated checklist of the Marchica lagoon's ichthyofauna (1908-2016), increased to 112 species, belonging to 33 families. Sparidae (17 species) is the richest family. Out of the updated checklist, 89 (79.46%) and 19 (16.96%) were categorized as marine and resident species respectively indicating that the Marchica lagoon is largely typified by nursery-dependent species. More than half of the fish fauna recorded in the lagoon is strictly or partially benthivores. The checklist also documents 10 threatened species under different categories of conservation status. According to the functional approach, ichthyological evolution before (1908-2011) and after hydraulogical intervention (2011-2016) is marked in terms of the ecological guild by an increase in the number of marine species. This fact is supported by management actions implemented after 2011, particularly the opening of the new large pass, allowing a large variety of marine species to enter the lagoon. Regarding the trophic guilds, the most remarkable changes before and after 2011, concerned the strictly or partially benthivorous species. This is supposed a significant evolution within the Marchica lagoon benthic habitats, following the opening of the artificial inlet since 2011. Recent concerns about global environmental changes suggested that a similar study of long-term population changes is required including not only the presence of species or families but also the total diversity, biomass, and population dynamics, as growth, reproduction, mortality and productivity.

INTRODUCTION

Currently, there is a global concern about biodiversity, especially its loss due to human impacts, as well as its effects on ecosystems goods and services **(Díaz *et al.*,**

2006; Cardinale *et al*., 2012). Recent studies have suggested that the biodiversity decrease might reduce ecosystems services through feedback mechanisms **(Worm *et al*., 2006)**, with potentially important socio-economic consequences **(Costanza *et al*., 1997)**. Indeed, the high degree of human dependence on biodiversity is formally recognized by the United Nations, through the Convention on Biological Diversity, the Millennium Development Goals, and the Aichi Strategic Plan for Biodiversity 2011–2020 **(CBD, 2010)**.

Worldwide, coastal lagoons represent 13% of the coastline **(Knoppers, 1994)** and together with other coastal ecosystems contribute to a large part of the ecological richness of the biosphere **(Costanza *et al*., 1997)**. Owing to their position between terrestrial, freshwater and marine interfaces, coastal lagoons belong to the Critical Transition Zones **(Levin *et al*., 2001)** that provide essential ecosystem services such as shoreline protection, water quality improvement, fisheries resources, habitat and food for migratory and resident animals and recreational areas for human populations **(Levin *et al*., 2001)**. These habitats have historically been of great interest to humans because of their high biological productivity **(Alongi, 1998)**, and their functioning as nursery areas and feeding grounds for opportunistic marine estuarine fishes, most of which are of real or potential fishing interest **(Yáñez-Arancibia and Nugent, 1977; Clark, 1998; Elliott *et al*., 2002)**.

Coastal lagoons are known as natural lentic water bodies distributed along the continental shoreline and can be permanently open or intermittently isolated from the adjacent sea by sand barriers **(Kjerfve, 1994; Duck and da Silva, 2012)**. Thus, the degree of isolation is the main environmental factor responsible for the structure of coastal lagoon fauna communities **(Barnes, 1994)**. Seawater renewal, depending on the degree of enclosure of the lagoon, affects most environmental variables and has a prominent role in the organization of biological communities. Natural instability leads to wide variations in species diversity. The recurring pattern of species richness, decreasing from the marine regions to the inner parts of the lagoon, has been widely documented **(Guelorget and Perthuisot, 1983; Lardicci *et al*., 1993; Koutsoubas *et al*., 2000; Bazaıri *et al* 2003; Reizopoulou and Nicolaidou, 2004)**. A strong relationship is documented between diversity and confinement **(sensu Guelorget and Perthuisot, 1992)**, as environmental instability increases in relation to the degree of isolation from the marine influence **(Reizopoulou and Nicolaidou, 2004)**. **Elwany (2011)** described that the closure of the inlet affects the lagoon biology as follows: firstly, the lagoon system begins to deteriorate rapidly, in the second step, the loss of habitat is observed for commercial fish species, and ultimately, the increase of freshwater leads to habitat change. Interruption of water exchanges by siltation at inlet leads to low flushing and flooding, which in turn is responsible for the reduction in salinity, biodiversity, productivity, and overall deterioration of the ecosystem. Furthermore, the degree of communication between the lagoons and the sea determines lagoon heterogeneity, species diversity, the colonization of marine species and the fishing activity **(Perez-Ruzafa *et al*., 2005, 2007)**.

Because of the ecological and economic value of coastal lagoons and their vulnerability, human hydraulic interventions in open coastal systems are common throughout the world **(Mehta, 1996)**, to deal with frequent changes within the system **(Osterblom *et al*., 2010)** and to promote the exchange of seawater, stabilize water levels, and hopefully encourage the recruitment of desirable fishes. Currently, in the most managed lagoons, hydraulic management consists in the opening/closure of communications with the sea through sluice gates to control the water flow inside the coastal lagoon and thus partly regulate environmental parameters such as temperature, dissolved oxygen, salinity and nutrient content, in particular during periods of freshwater input **(Cataudella *et al*., 2015)**.

The fish fauna is one of the most important components of lagoon ecosystems, providing many ecosystem services to human societies such as food supply and job creation **(Lopes and Videira, 2013; Newton *et al*., 2014)**. In addition, they provide a number of ecological processes that are essential for the functioning and resilience of lagoon ecosystems **(Koutrakis *et al*., 2005; Franco *et al*., 2006; Aliaume *et al*., 2007)**. Ichthyological knowledge can therefore provide a better understanding of the ecological challenges and functioning of lagoon ecosystems.

Although there are suggestions that artificial openings are widely practiced **(Bally, 1987; Pollard, 1994a; Griffiths and West, 1999)**, little is known of their impacts on fish assemblages. **Kok and Whitfield (1986)** suggested that lagoon openings promote the recruitment of fishes that spawn at sea, while **Griffiths and West (1999)** warned of the possible dangers of artificial lagoon openings to resident fishes, which may be less tolerant of the higher salinities that often persist after lagoon openings.

The Mediterranean region hosts around 400 coastal lagoons, covering a surface of over 641 000 ha and differing in both their typology and use **(Cataudella *et al*., 2015)**. More than 199 of fish are present in coastal lagoons in the Atlanto-Mediterranean region **(Pérez-Ruzafa *et al*., 2010)**. However, the complexity of interactions at the lagoon scale makes them particularly vulnerable to anthropogenic pressures that threaten their ecological integrity and sustainability, but also to natural changes, which would affect the abundance, distribution and diversity of fauna and flora **(Kennish and Paerl, 2010; De Wit, 2011)**.

The Marchica Lagoon, also called Nador Lagoon, is an important ecosystem in the southern side of the Western Mediterranean owing to its extent, its biological, ecological and socio-economic value. It has been designated as a Site of Biological and Ecological Interest since 1996 and RAMSAR site since 2005. Artisanal fishing is the main socio-economic activity in the Marchica lagoon, with about 390 boats constituting 14% of the artisanal fleet of the whole Moroccan Mediterranean, and provides direct employment for

887 people, representing about 11% of the total job offers generated by artisanal fishing in the Moroccan Mediterranean **(Malouli, 1999; Najih *et al*., 2015).** The fishing fleet spreads over sixteen sites around the lagoon and provides an estimated total production of 1157 tons/year **(Najih *et al*., 2015)**. In terms of added value, artisanal fishing activity in the Nador lagoon produces a positive economic effect for the nation in general and especially for the Nador region where it plays an important role in both socio-economic and cultural aspects of the people of coastal communities **(Malouli *et al*., 2002)**.

This ecosystem has undergone in the past a natural stress (storms, floods and tsunamis) which materialized by limited periods of communication with the sea and a change in the position of the pass on the lido over time **(Fig. 1)**. From 1907 to 1910, the Marchica lagoon was totally isolated from the sea thus becoming an evaporitic basin with a reduced water surface. In 1910, communication with the sea was re-established by dredging and this pass was for a long time the only navigable access to Nador. This pass, undergoing a gradual silting, was clogged and a natural older pass was in turn dredged in 1941. After a total closure of the lagoon since 1977 (obstruction date of the previous pass), the Bocana pass was opened in 1979 because of a storm event. In 1993, the pass was almost clogged by marine sediment input **(Inani, 1995)**. These conditions had a strong influence on the Marchica lagoon ecosystem. Indeed, the phenomenon of eutrophication has invaded this ecosystem, as stipulated by **Zerrouqi *et al*. (2013)**. This situation required the development of a channel with the construction of two jetties and an opening of 250 m wide and 3 m deep in 2004.

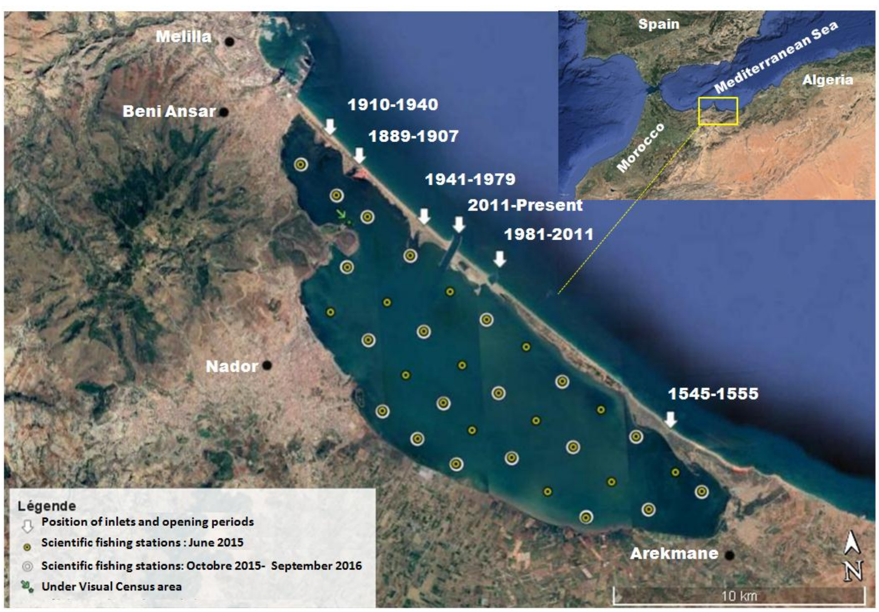

Fig. 1. Study area with pass history (modified from **Raji *et al.*, 2013**) and localization of sampling stations during 2015-2016.

In addition, the lagoon has been subject to various environmental modifications of physical, chemical and biological nature due to on site and land-based human activities. Studies have identified significant changes in sedimentation rates, concentrations of inorganic pollutants **(Ruiz *et al*., 2006)**, and eutrophication **(MATEE, 2005)**, making this area a good example of an impacted coastal lagoon. In 2009, the Marchica lagoon was classified as a "Hotspot" for pollution in the Mediterranean by the Action Plan for the Mediterranean due to its deteriorated state of health **(UNEP/MAP, 2012)**.

It became imperative to carry out an hydrological intervention in order to increase the self-cleaning capacity of the lagoon and improve its fisheries and bioresources for the greater benefit of the communities depending on them. This was achieved by opening a new sea inlet in 2011, replacing the old and smaller one (Bocana; 1981-2011), along with additional management measures as for example the treatment of the catchment waters discharged in the lagoon. The opening of the new pass led to a rapid improvement of the quality of the lagoon waters **(Aknaf *et al*., 2015)** and an increase of the fish catches from this system than ever before **(Najih *et al*., 2015)**.

The present work aimed to provide an updated checklist of the fish fauna of the Marchica Lagoon under the new inlet opening (after 2011). An updated and comprehensive list of all fish species recorded from the Marchica lagoon is also presented and discussed. Then, fish fauna was compared before and after the opening of the new pass in 2001 to evaluate the effects of this hydrological intervention on the taxonomic and functional composition of fish fauna.

MATERIALS AND METHODS

1. Study area

The Marchica lagoon (35°09'25 N / 002°50'43 W), also called Nador Lagoon, is the second largest (115 km², 25 km long and 7.5 km wide) lagoon in northern Africa and the unique coastal lagoon lying on the Mediterranean coast of Morocco **(Fig. 1)**. This lagoon has a maximum depth of approximately 8 meters. It is separated from the Mediterranean Sea by a 25 km long sandbar, with one artificial opening (300 m wide and 6 m deep) which assures a renewal of water in 15 days instead of 57 days under the configuration of the old pass (**Maicu *et al.*, 2021**). The water balance of the lagoon is expressed by three sources: the marine waters passing through the artificial pass and which are still dominant, a fresh water contribution from two large groundwater and temporary flows of fluvial **(Jeyar *et al*., 2015)**.

The climate of the region is Mediterranean: a hot and dry summer, spreading from June to October with an average temperature of 20°C, and a cool and rainy period from November to May, with average temperatures of 12°C. Annual precipitation ranges from 224 mm to 390 mm with an average of 300mm / year **(El Yaouti *et al*., 2009; Re, 2010)**. General wind regime is WSW (24.8%) from November to May, and ENE (32.9%) from May to October with average intensities varying from 3.8 to 6.2 m/s **(Tesson, 1977; Hilmi, 2005)**.

2. Data sources and treatments

The updated fish inventory of the Marchica lagoon is based on an extensive spatial and systematic sampling conducted on 32 stations during June 2015 as well as on a monthly survey performed on 20 stations between October 2015 and November 2016 **(Fig. 1)**. The fishing gear was a purse seine of about 110 m in length and 11 m in height, with a mesh size of 6 mm. As this fishing gear covers the entire water column from the bottom to the surface, both juveniles and adults of pelagic and bentho-demersal species were captured. The inventory was enriched by visual underwater monitoring data and by the data of the periodical daily tide with autochthones fishermen. In total, our inventory is the result of 343 shots of seine, 43 visual underwater monitoring and 10 professional fishing tides. In addition, the unique study conducted by **Jaafour *et al*. (2015)** on Marchica lagoon fish fauna after 2011 was also taken into consideration.

The comprehensive list of all fishes reported in the Marchica lagoon from 1908 to 2016 (108 years) was established based on published data until the year 2016 **(Oden, 1914; Lozano Cabo, 1953; Aloncle ,1961; Bouchereau *et al*., 2000; Jaafour *et al*., 2015** and **present study)**. Species names were checked and updated to current nomenclature according to World Register of Marine Species (*http://www.marinespecies.org*) and the classification adopted mainly follows **Nelson's (2006)** classification system for taxonomic categories, with order, family, genera and species. The conservation status of all fish species was determined based on the International Union for Conservation of Nature Red List categories **(IUCN** Red List of Threatened Species **2019)**: (1) extinct (EX), (2) extinct in the wild (EW), (3) critically endangered (CR), (4) endangered (EN), (5) vulnerable (VU), (6) near threatened (NT), (7) least concern (LC), (8) data deficient (DD), and (9) not evaluated (NE). Two additional categories, Regionally Extinct (RE) and Not Applicable (NA), are used in regional Red List assessments. Species are classed as threatened if they fall within the categories EX, RE, EW, CR, EN, VU or NT. Taxa that are not identified to species level are not considered.

The functional structure of the fish in the lagoon was described by allocating species to functional groups. These included the ecological guilds (residents, R; marines; M (marine migrants, MM; marine stragglers, MS) and diadromous; D) and feeding groups (strictly benthivores, Bv; detritivores, DV; herbivores, HV; planktivores, PL; hyperbenthos-zooplankton feeders, HZ; hyperbenthos-fish feeders, HP; fish showing an ontogenetic change in feeding preference from HZ to HP, HZ-HP, or from microbenthos to HP, Bmi-HP; omnivores, Ov). The allocation of the fish species to the functional groups was based on the literature for European estuaries and lagoons **(Elliott and Dewailly, 1995; Garcia Charton and Perez Ruzafa, 2001, 2004; Franco *et al*., 2008a, 2008b, 2012; Selfati *et al.*, 2019)**, with additions and adjustments for species not listed in those papers and accounting for specific fish use and adaptations in the lagoon of

Marchica (based on local knowledge from monthly monitoring conducted between October 2015 and September 2016). Available information on the trophic level was also used as obtained from Fishbase **(Froese and Pauly, 2016)**.

Fish data prior to the opening of the new inlet (before 2011; 1908-2010) correspond to four inventories. These are the first one realized by **Oden (1914)**, followed by that of **Lozano Cabo (1953), Aloncle (1961)** and **Bouchereau *et al*. (2000)**. For the post-hydrological intervention (after 2011; 2011-2016), it is mainly our inventory enriched by only two species from **Jaafour *et al*. (2015)** namely *Atherina presbyteras* Cuvier, 1829 as a new recorded species and *Pomatoschistus marmoratus* (Risso, 1810) as an earlier reported one.

RESULTS AND DISCUSSION

1. Taxonomic diversity

While compiling the checklist, some taxonomical corrections were made. For example: *Ariosoma bulearica* (Delaroche, 1809) appearing in **Aloncle (1961)** is considered here as *Ariosoma balearicum* (Delaroche, 1809). However, a difficulty was encountered to retain a valid scientific name for *Sciaena ronchus* (Valenciennes, 1836) that was recorded by **Aloncle (1961)**. This species was cited by **Collignon (1959)** as *Umbrina ronchus* (Valenciennes, 1843). The latter author mentioned the recommendation of **Dardignac (1961)** that *Sciaena ronchus* (Valenciennes, 1836) must be replaced by *Sciaena fusca* (Dardignac, 1956), but finally the name that appeared in the book of the latter was *Umbrina fusca* (Dardignac, 1958). This last nomenclature has been retained and the corresponding updated scientific name is Umbrina ronchus (Valenciennes, 1843).

The overall list of fishes reported from the Marchica lagoon **(Table 1)** before 2011 (1908–2010) and after 2011 (2011–2016) included a total of 112 valid species. They belong to nine orders, 33 families, and 70 genera. The Perciformes are largely the richest order (67 species, 39 genera and 17 families) followed by Pleuronectiformes (15 species, 11 genera and 3 families). The number of fish fauna species recorded in the Marchica lagoon represented approximately 56% of the 199 known species from coastal lagoons of the Atlanto-Mediterranean Europe **(Pérez-Ruzafa *et al*., 2010)**.

The fish fauna belonged to 33 families largely dominated by the Sparidae (17 species), followed by Gobiidae and Soleidae (10 species each), Labridae (9 species), Serranidae (8 species), Mugilidae and Syngnathidae (6 species each). These families as considered as characteristic of ichthyological communities in warm, temperate and semi-tropical coastal lagoons and estuaries **(Potter *et al*., 1990; Elliott & Dewailly, 1995; Costa *et al*., 2002; Kara and Quignard, 2018)**. Bothidae, Carangidae and Clupeidae were represented by 4 species each; and 3 species each accounted for both Sciaenidae and

Trachinidae. Seven families are represented by two species each. The remaining 14 families are represented only by one species each **(Table 1, Fig. 2)**.

After the opening of the new pass since 2011, the fish fauna of the Marchica lagoon is composed of a total of 86 species (84 species from our study and two species from **Jaafour *et al*. (2015)** from which 55 were earlier reported species and 31 newly recorded **(Table, 1** and **Fig. 2)**. Our inventory, resulting from monitoring conducted in 2015-2016, is highly diversified (84 species) that those of **Aloncle (1961)**, **Oden (1914)** and **Lozano Cabo (1953)** with 52, 40 and 26 species, respectively. The inventories of **Bouchereau *et al*. (2000)** (16 species) and **Jaafour *et al*. (2015)** (15 species), based on samples from the shallow margins of the lagoon, are the least-diversified ones. The higher number of our inventory is due to the important sampling effort, diversity of sampling technics and potentially to the ecorestoration measures implemented after 2011.

Table 1. Checklist of fishes reported from Marchica lagoon (1908–2016).

TAXON	EG	FG	IUCN
ORDER: ANGUILLIFORMES			
FAMILY: ANGUILLIDAE			
(*)*Anguilla anguilla* (Linnaeus, 1758) **[1,3,4,6]**	D	HP	EN
FAMILY: CONGRIDAE			
Ariosoma balearicum (Delaroche, 1809) **[3]**	M	Bmi,HP	LC
(**)*Conger conger* (Linnaeus, 1758) **[6]**	M	Bmi,HP	LC
FAMILY: OPHICHTHIDAE			
(**) *Dalophis imberbis* (Delaroche, 1809) **[6]**	M	Bmi,HP	LC
ORDER: ATHERINIFORMES			
FAMILY: ATHERINIDAE			
(*) *Atherina boyeri* Risso, 1810 **[1,4,6]**	R	HZ	LC
(**) *Atherina presbyter* Cuvier, 1829 **[5]**	M	PL	LC
ORDER: BELONIFORMES			
FAMILY: BELONIDAE			
(*) *Belone belone* (Linnaeus, 1761) **[3,6]**	M	HP	LC
FAMILY: HEMIRAMPHIDAE			
(**) *Hemiramphus far* (Forsskål, 1775) **[6]**	M	HV	NA
(*) *Hyporhamphus picarti* (Valenciennes, 1847) **[1,5,6]**	M	HV	LC
ORDER: CLUPEIFORMES			
FAMILY: CLUPEIDAE			
Alosaalosa (Linnaeus, 1758) **[1]**	D	PL	RE
(*) *Sardina pilchardus* (Walbaum, 1792) **[1,6]**	M	PL	LC
(*) *Sardinella aurita* (Valenciennes, 1847) **[1,6]**	M	PL	LC
(*) *Sardinella maderensis* (Lowe, 1838) **[3,6]**	M	PL	LC
FAMILY: ENGRAULIDAE			
(*) *Engraulis encrasicolus* (Linnaeus, 1758) **[1,2,3,4,6]**	M	PL	LC
ORDER: MUGILIFORMES			
FAMILY: MUGILIDAE			
(*) *Chelon labrosus* (Risso, 1827) **[3,6]**	M	DV	LC
(*) *Chelon auratus* (Risso, 1810) **[2,3,5,6]**	M	DV	LC

TAXON	EG	FG	IUCN
(*) *Chelon ramada* (Risso, 1827) **[2,3,6]**	D	DV	LC
(*) *Chelon saliens* (Risso, 1810) **[1,6]**	D	DV	LC
(*) *Mugil cephalus* Linnaeus, 1758 **[1,2,3,6]**	M	DV	LC
Oedalechilus labeo (Cuvier, 1829) **[2,3]**	M	DV	LC
ORDER: PERCIFORMES			
FAMILY: APOGONIDAE			
(**) *Apogon imberbis* (Linnaeus, 1758) **[6]**	M	Bmi,HP	LC
FAMILY: BLENNIIDAE			
(*) *Salaria pavo* (Risso, 1810) **[3,4,5,6]**	R	OV	LC
FAMILY: CALLIONYMIDAE			
(**) *Callionymus risso* Lesueur, 1814 **[6]**	R	BV	LC
FAMILY: CARANGIDAE			
(*) *Caranx rhonchus* Geoffroy Saint-Hilaire, 1817 **[1,6]**	M	Bmi,HP	LC
Lichia amia (Linnaeus, 1758) **[3]**	M	HP	DD
(*) *Trachinotus ovatus* (Linnaeus, 1758) **[3,6]**	M	Bmi,HP	LC
(*) *Trachurus trachurus* (Linnaeus, 1758) **[1,3,6]**	M	Bmi,HP	LC
FAMILY: CENTRACANTHIDAE			
(**) *Spicara smaris* (Linnaeus, 1758) **[6]**	M	HZ	LC
FAMILY: GOBIIDAE			
(*) *Aphia minuta* (Risso, 1810) **[2,3,6]**	M	PL	LC
(*) *Deltentosteus quadrimaculatus* (Valenciennes, 1837) **[6]**	M	BV	LC
Gobius bucchichi Steindachner, 1870 **[4]**	R	BV	LC
(*) *Gobius cobitis* Pallas, 1814 **[4,6]**	R	Bmi,HP	LC
(**) *Gobius cruentatus* Gmelin, 1789 **[6]**	M	OV	LC
(*) *Gobius niger* Linnaeus, 1758 **[1,2,5,6]**	R	Bmi,HP	LC
(*) *Gobius paganellus* Linnaeus, 1758 **[4,6]**	R	Bmi,HP	LC
(*) *Pomatoschistus marmoratus* (Risso, 1810) **[4,5]**	R	BV	LC
Pomatoschistus microps (Krøyer, 1838) **[4]**	R	BV	CR
(**) *Pomatoschistus minutus* (Pallas, 1770) **[6]**	M	BV	VU
FAMILY: HAEMULIDAE			
(**) *Parapristipoma octolineatum* (Valenciennes, 1833) **[6]**	M	BV	DD
(*) *Pomadasys incisus* (Bowdich, 1825) **[1,6]**	M	BV	LC
FAMILY: LABRIDAE			
(**) *Coris julis* (Linnaeus, 1758) **[6]**	M	BV	LC
(**) *Labrus viridis* Linnaeus, 1758 **[6]**	M	Bmi,HP	VU
(**) *Symphodus tinca* (Linnaeus, 1758) **[5,6]**	R	BV	LC
(*) *Symphodus cinereus* (Bonnaterre, 1788) **[2,3,4,5,6]**	R	BV	LC
(*) *Symphodus mediterraneus* (Linnaeus, 1758) **[2,3,6]**	M	BV	LC
(**) *Symphodus melops* (Linnaeus, 1758) **[6]**	M	BV	LC
(*) *Symphodus ocellatus* (Linnaeus, 1758) **[2,3,6]**	R	BV	LC
Symphodus roissali (Risso, 1810) **[3]**	R	BV	LC
(**) *Thalassoma pavo* (Linnaeus, 1758) **[6]**	M	BV	LC
FAMILY: MORONIDAE			
(*) *Dicentrarchus labrax* (Linnaeus, 1758) **[1,3,4,6]**	M	HZ-HP	NT
(*) *Dicentrarchus punctatus* (Bloch, 1792) **[1,3,5,6]**	M	HZ-HP	LC
FAMILY: MULLIDAE			
(*) *Mullus barbatus barbatus* Linnaeus, 1758 **[1,3,5,6]**	M	BV	LC
(*) *Mullus surmuletus* Linnaeus, 1758 **[1, 2, 3, 6]**	M	BV	LC

TAXON	EG	FG	IUCN
FAMILY: POMATOMIDAE			
Pomatomus saltatrix (Linnaeus, 1766) **[3]**	M	HP	LC
FAMILY: SCIAENIDAE			
Sciaena umbra Linnaeus, 1758 **[1,3]**	M	HP	VU
Umbrina cirrosa (Linnaeus, 1758) **[1,3]**	M	BV	VU
Umbrina ronchus (Valenciennes, 1843) **[3]**	M	BV	DD
FAMILY: SCOMBRIDAE			
Scomber colias Gmelin, 1789 **[1]**	M	HZ-HP	NT
FAMILY: SERRANIDAE			
Epinephelus aeneus (Geoffroy Saint-Hilaire, 1817)	M	HP	NT
(**) *Epinephelus caninus* (Valenciennes, 1843) **[6]**	M	HP	DD
(**) *Epinephelus costae* (Steindachner, 1878) **[6]**	M	HP	DD
Epinephelus itajara (Lichtenstein, 1822) **[3]**	M	HP	VU
(*) *Epinephelus marginatus* (Lowe, 1834) **[2,6]**	M	HP	EN
(*) *Mycteroperca rubra* (Bloch, 1793) **[2,3,6]**	M	HP	LC
(**) *Serranus hepatus* (Linnaeus, 1758) **[6]**	M	Bmi,HP	LC
(*) *Serranus scriba* (Linnaeus, 1758) **[3,6]**	M	HP	LC
FAMILY: SPARIDAE			
(*) *Boops boops* (Linnaeus, 1758) **[1,2,3,6]**	M	OV	LC
Dentex dentex (Linnaeus, 1758) **[3]**	M	HP	VU
(*) *Diplodus annularis* (Linnaeus, 1758) **[1,2,3,6]**	M	OV	LC
(*) *Diplodus sargus* (Linnaeus, 1758) **[1,2,3,4,6]**	M	OV	LC
(**) *Diplodus cervinus*(Lowe, 1838) **[6]**	M	OV	DD
(*) *Diplodus puntazzo* (Walbaum, 1792) **[1,2,6]**	M	OV	LC
(*) *Diplodus vulgaris* (Geoffroy Saint-Hilaire, 1817) **[2,3,6]**	M	OV	LC
(*) *Lithognathus mormyrus* (Linnaeus, 1758) **[1,2,3,6]**	M	BV	LC
(*) *Oblada melanura* (Linnaeus, 1758) **[1,2,3,6]**	M	OV	LC
(*) *Pagellus erythrinus* (Linnaeus, 1758) **[1,3,6]**	M	OV	LC
(*) *Pagellus acarne* (Risso, 1827) **[3,6]**	M	BV	LC
(**) *Pagrus auriga* Valenciennes, 1843 **[6]**	M	BV	DD
Pagrus caeruleostictus (Valenciennes, 1830) **[2,3]**	M	Bmi,HP	DD
(*) *Pagrus pagrus* (Linnaeus, 1758) **[1,2,3,6]**	M	Bmi,HP	LC
(*) *Sarpa salpa* (Linnaeus, 1758) **[1,3,6]**	M	HV	LC
(*) *Sparus aurata*Linnaeus, 1758 **[1,2,3,6]**	M	BV	LC
(*) *Spondyliosoma cantharus* (Linnaeus, 1758) **[1,6]**	M	OV	LC
FAMILY: SPHYRAENIDAE			
(*) *Sphyraena sphyraena* (Linnaeus, 1758) **[1,3,6]**	M	HP	LC
FAMILY: TRACHINIDAE			
Trachinus araneus Cuvier, 1829 **[1]**	M	Bmi,HP	LC
Trachinus draco Linnaeus, 1758 **[1,3]**	M	Bmi,HP	LC
Trachinus radiatus Cuvier, 1829 **[3]**	M	Bmi,HP	LC
ORDER: PLEURONECTIFORMES			
FAMILY: BOTHIDAE			
Arnoglossus laterna (Walbaum, 1792) **[1]**	M	Bmi,HP	LC
(**) *Arnoglossus rueppelii* (Cocco, 1844) **[6]**	M	Bmi,HP	LC
(**) *Arnoglossus thori* Kyle, 1913 **[6]**	M	Bmi,HP	LC
(*) *Bothus podas* (Delaroche, 1809) **[2,3,6]**	M	Bmi,HP	LC
FAMILY: SCOPHTHALMIDAE			

TAXON	EG	FG	IUCN
Scophthalmus rhombus (Linnaeus, 1758) **[1]**	M	HP	LC
FAMILY: SOLEIDAE			
(**) *Buglossidium luteum* (Risso, 1810) **[6]**	M	BV	LC
Dicologlossa cuneata (Moreau, 1881) **[1,2,3]**	M	BV	DD
Microchirus theophila (Risso, 1810) **[3]**	M	BV	DD
Microchirus variegatus (Donovan, 1808) **[2,3]**	M	BV	LC
(**) *Monochirus hispidus* Rafinesque, 1814 **[6]**	M	BV	DD
(*) *Pegusa lascaris* (Risso, 1810) **[1,4,6]**	M	BV	DD
(*) *Solea solea* (Linnaeus, 1758) **[4,5,6]**	M	BV	LC
(**) *Solea senegalensis* Kaup, 1858 **[6]**	M	BV	DD
(**) *Synaptura lusitanica lusitanica* de Brito Capello, 1868 **[6]**	M	BV	DD
Synapturichthys kleinii (Risso, 1827) **[2]**	M	BV	DD
ORDER: SCORPAENIFORMES			
FAMILY: DACTYLOPTERIDAE			
(**) *Dactylopterus volitans* (Linnaeus, 1758) **[6]**	M	Bmi,HP	LC
FAMILY: SCORPAENIDAE			
(**) *Scorpaena porcus*Linnaeus, 1758 **[6]**	M	Bmi,HP	LC
FAMILY: TRIGLIDAE			
Chelidonichthys lucerna (Linnaeus, 1758) **[1]**	M	Bmi,HP	LC
(*) *Chelidonichthys lastoviza* (Bonnaterre, 1788) **[1,6]**	M	BV	DD
ORDER: SYNGNATHIFORMES			
FAMILY: SYNGNATHIDAE			
(*) *Hippocampus guttulatus* Cuvier, 1829 **[3,6]**	R	BV	NT
(**) *Hippocampus hippocampus* (Linnaeus, 1758) **[6]**	R	BV	NT
(*) *Syngnathus abaster* Risso, 1827 **[4,5,6]**	R	BV	LC
(**) *Syngnathus acus* Linnaeus, 1758 **[6]**	R	BV	LC
(**) *Syngnathus rostellatus* Nilsson, 1855 **[6]**	R	HZ	DD
(*) *Syngnathus typhle* Linnaeus, 1758 **[4,5,6]**	R	HZ	LC

IUCN Red List Status: **CR**-Critically Endangered; **VU**-Vulnerable; **NT**-Near Threatened; **LC**-List Concern; **DD**-Data Deficient; **NE**-Not Evaluated; **EN**- Endangered.

Ecological guilds (EG): **D**-Diadromes; **M**-Marines; **R**-Residents.

Feeding guilds (FG): **BV**- strictly benthivores; **DV**- detritivores; **HV**-herbivores; **PL**-planktivores; **HZ**-hyperbenthos-zooplancton feeders; **HP**- hyperbenthos-fish feeders; **HZ-HP**- fish showing an ontogenetic change in feeding preference from **HZ** to **HP**; **Bmi-HP**- fish showing an ontogenetic change in feeding preference from microbenthos to **HP**; OV- omnivores.

Post-hydrological intervention inventory: (*): Earlier reported; (**): New records.

Record reference: 1: **Oden (1914)**, 2: **Lozano Cabo (1953)**, 3: **Aloncle (1961)**, 4: **Bouchereau *et al.* (2000)**, 5: **Jaafour *et al.* (2015)**, 6: present study.

Versus the high influx (31) of species to the lagoon after 2011, 26 species belonging to 16 families were not recorded **(Fig. 2)**. The most affected family by species disappearance was that of Soleidae (4 species) known to be dependant on sandy substrate, the same for Scophthalmidae (1 species) and Trachinidae (3 species). This could be related to changes in the nature of the lagoon substrate after the opening of the new pass, where there is a tendency towards siltation and regression of the sandy substrate **(Najih *et al.*, 2016)**. This limiting factor appears true for trachinidae especialy for Trachinus draco, which have a high affinity for sandy substrates **(Deniel, 1975; Giakoumi and Kokkoris,**

2013). This latter species was abundant and frequent during our survey in the sandy adjacent area (open sea) but not collected inside the lagoon

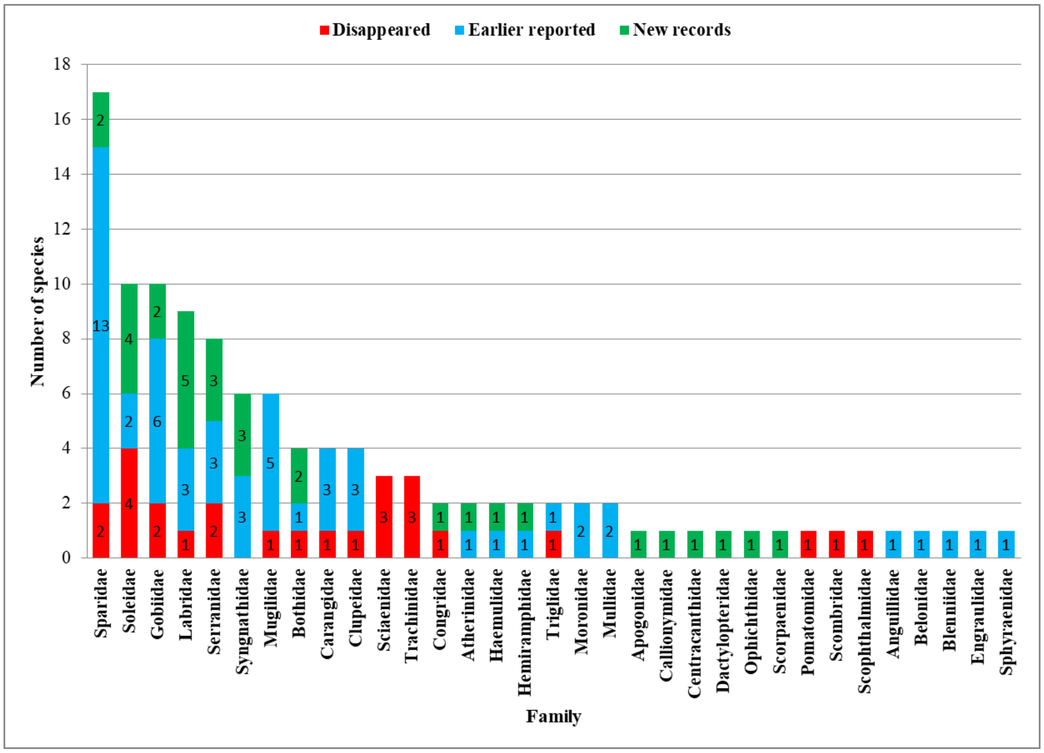

Fig.2. Specie's occurrence status by family recorded in the Marchica lagoon.

2. Functional diversity: ecological guilds

Out of the total 112 species, 89 (79.46%) and 19 (16.96%) were categorized as marine and resident species respectively. The diadromous were represented only by 4 species (3.58%) **(Fig. 3)**.

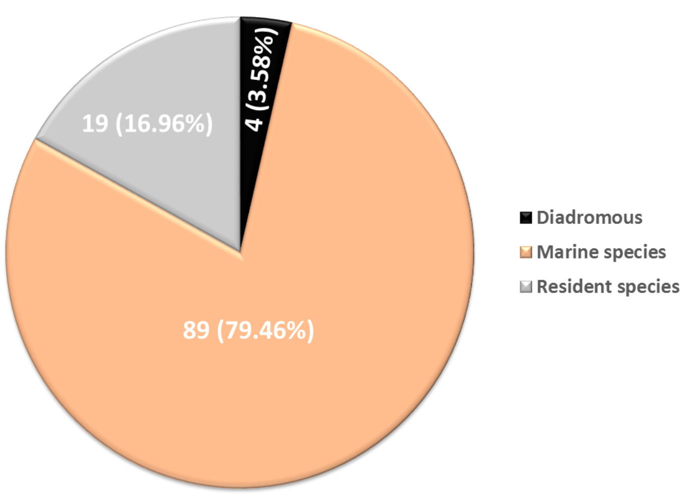

Fig. 2. Ecological status of the Marchica lagoon's fish fauna.

The higher number of marine species in fish composition of Mediterranean coastal lagoon is common and is perhaps due to their using of the lagoon as nursery, where they find optimal conditions for their survival and growth **(Franzoi *et al*., 2010; Franco *et al*., 2006, 2008b, 2012)**. However, the dominance of species of marine origin in the Marchica lagoon (79.64% of species) is higher than the average of marine species (66%) recorded in other Mediterranean lagoons **(Franco *et al*., 2008b)**.This is likely associated with the increased connectivity between lagoon and sea following the opening of a bigger sea inlet in 2011, and the resulting marinization of the lagoon **(Mostarih *et al*., 2016)**.

Comparison between before and after 2011 in terms of ecological guilds **(Fig. 4)**, revealed an increase in the number of marine species (5 more species). This fact can be explained by the management measures implemented after 2011, particularly the opening of the new large pass (300m in large and 6 m in depth), allowing a large variety of marine species to enter the lagoon, and resultant improvement in water quality **(Aknaf *et al*., 2015)** and also an increase in water renewal rate **(Hilmi *et al*., 2015; Maicu *et al*., 2018)**. The same pattern has been observed for resident species that have gained two more species after restoration. However, the only negative pattern has been recorded for diadromous species with one species less; it is *Alosa alosa* wich was once recorded from Marchica lagoon **(Oden, 1914)** but the species has never been recorded thereafter

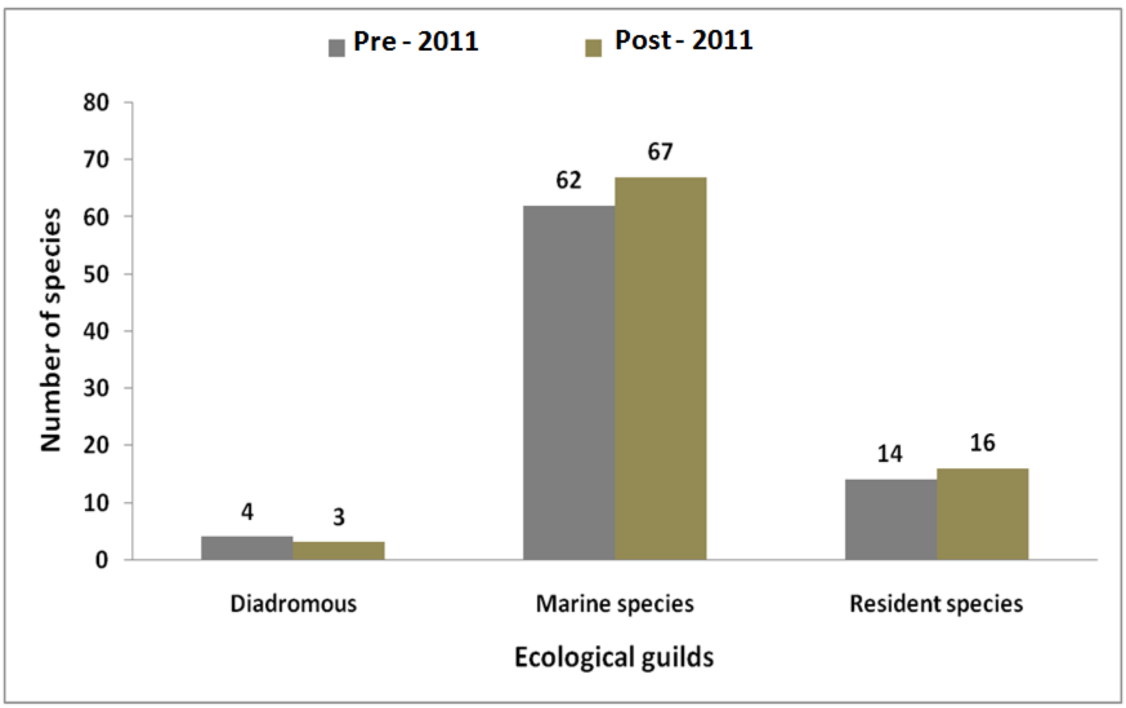

Fig. 3. Ecological situation of the lagoon's fish fauna before and after the opening of the new inlet since 2011.

3. Functional diversity: Feeding guilds

The trophic structure of fish assemblages in the lagoon, including all the inventories, was represented by nine feeding guilds. The most diverse trophic guilds are benthivores (BV) and fish showing an ontogenetic change in feeding preference from microbenthos to hyperbenthos-fish feeders (Bmi-HP). More than half of the fish fauna recorded in the lagoon are strictly or partially benthivores (63 species, 55.75%) **(Fig. 5)**. This is accordance with the characteristics of the other Mediterranean lagoons, where the microbenthivory was the dominant mode among fishes feeding **(Franco *et al*., 2008b)**.

The hyperbenthos-fish feeders (HP) and the omnivores (OV) constitute respectively 13% (15 species) and 10 % (11 species) of the ichtyofaunal diversity recorded in the Marchica lagoon. The remaining guilds constitute together about 20 % of the ichtyofaunal diversity.

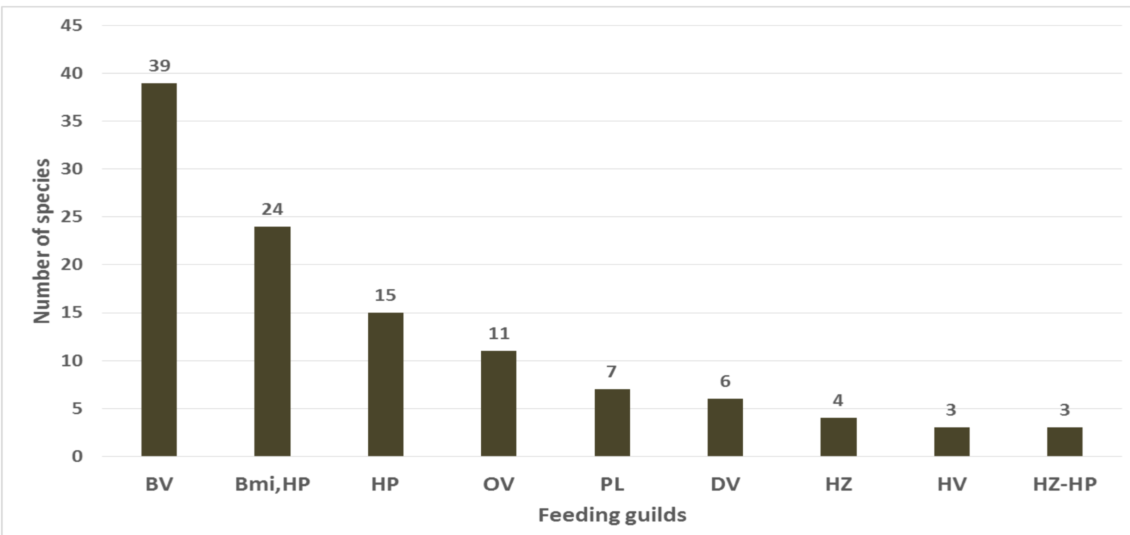

Fig. 4. Trophic diversity of the Marchica lagoon's fish fauna.Feeding guilds: BV- strictly benthivores; DV- detritivores; HV-herbivores; PL-planktivores; HZ-hyperbenthos-zooplancton feeders; HP- hyperbenthos-fish feeders; HZ-HP- fish showing an ontogenetic change in feeding preference from HZ to HP; Bmi-HP- fish showing an ontogenetic change in feeding preference from microbenthos to HP; OV- omnivores.

Comparison of trophic categories before and after 2011 highlighted that the most trophic groups affected were benthivores (BV), fish showing an ontogenetic change in feeding preference from microbenthos to hyperbenthos-fish feeders (Bmi,HP) and hyperbenthos-fish feeders (HP). 16 species strictly or partially benthivorous (BV or Bmi, HP) recorded before 2011 were not recorded in recent inventories. In return, 23 species of the same trophic categories (14 BV and 9 Bmi, HP) were newly recorded **(Fig. 6)**. This act pleads for a significant change in the trophic quality of the benthic substrate, which was consistent with the conclusion of **Najih *et al*. (2016)**, who mentioned a regression of the mud-sandy substrate in favor of the mud substrate.

However, a negative trend has been recorded for hyperbenthos-fish feeders (HP). This group, feeding on fish and mobile invertebrates living over the bottom **(Franco *et al*., 2008b)**, was characterized by a negative balance (7 disappearance against 2 new records). Decrease in species diversity of this feeding group (HP), which characterize species of large body and high trophic level **(Pinnegar *et al*., 2002; Keppeler et al., 2020)**, let us hypothesize a gradual transition from long-lived high trophic level piscivorous fish towards short- lived invertebrates and planktivorous fishes at lower trophic levels as has been observed worldwide **(Pauly *et al*., 1998 & 2000)**.

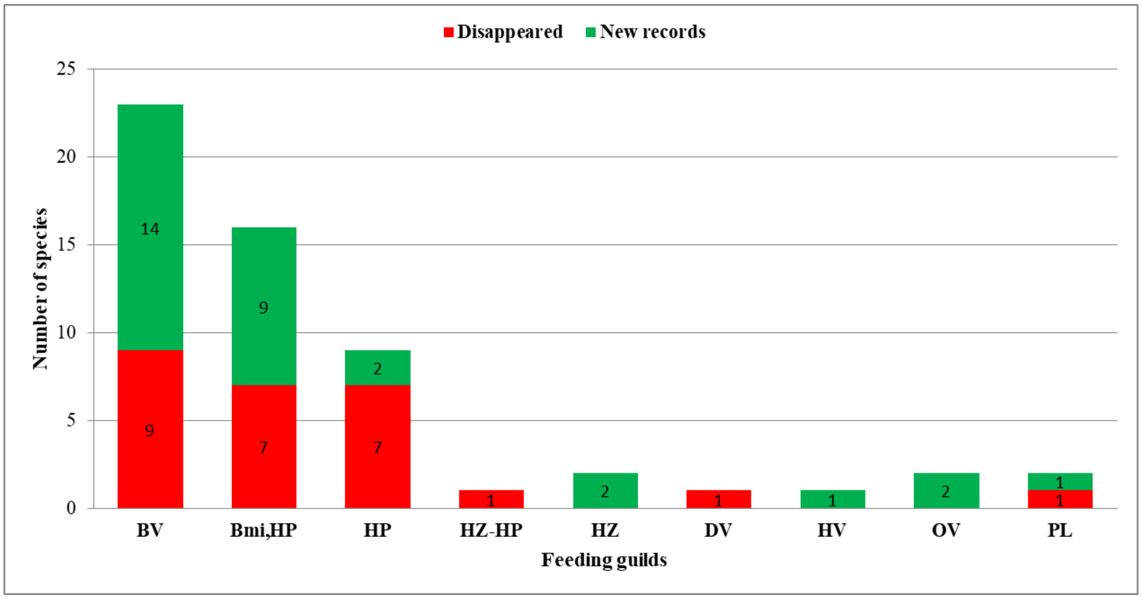

Fig. 5. Trophic dynamics of the lagoon's fish fauna pre and post restoration.Feeding guilds: BV- strictly benthivores; DV- detritivores; HV-herbivores; PL-planktivores; HZ-hyperbenthos-zooplancton feeders; HP- hyperbenthos-fish feeders; HZ-HP- fish showing an ontogenetic change in feeding preference from HZ to HP; Bmi-HP- fish showing an ontogenetic change in feeding preference from microbenthos to HP; OV- omnivores.

4. Biodiversity status and threatened species.

Literature review on the biodiversity status of fish from the Marchica Lagoon, based on IUCN criteria, revealed a total list of 111 evaluated species.The evaluation is, however, Not Applicable (NA) for only one exotic species, namely *Hemiramphus far*.

In total, 10 species (9%) were recorded as threatened and categorized under Regionally Extinct (RE : 1 species ; i.e. 0.9%), Critically Endangered (CR : one species ; i.e. 0.9%), Endangered (EN : 2 species ; i.e. 1.8%) and Vulnerable (VU : 6 species ; i.e. 5.4%) **(Table 2)**. Further, 13 additional species are listed as Near Threatened (NT) that need conservation measures unless they may move to threatened category very soon. The high proportion, 71.17 % (79 species) of fish of Marchica lagoon were categorized as Least Concern (LC), whereas 17 species (15.31%) were documented as Data Deficient (DD).

Table (2). Assessment of biodiversity status of Marchica fishes (Categorization of threatened and non-threatened species with conservation status)

Family	Threatened species						Non-threatened species			Total species assessed
	RE	CR	EN	VU	NT	Total	LC	DD	Total	
Anguillidae			1			1				1
Apogonidae							1		1	1
Atherinidae							2		2	2
Belonidae							1		1	1
Blenniidae							1		1	1
Bothidae							4		4	4
Callionymidae							1		1	1
Carangidae							3	1	4	4
Centracanthidae							1		1	1
Clupeidae	1					1	3		3	4
Congridae							2		2	2
Dactylopteridae							1		1	1
Engraulidae							1		1	1
Gobiidae		1		1		2	8		8	1
Haemulidae							1	1	2	2
Hemiramphidae							1		1	1
Labridae				1		1	8		8	9
Moronidae					1	1	1		1	2
Mugilidae							6		6	6
Mullidae							2		2	2
Ophichthidae							1		1	1
Pomatomidae							1		1	1
Sciaenidae				2		2		1	1	3
Scombridae					1	1				1
Scophthalmidae							1		1	1
Scorpaenidae							1		1	1
Serranidae			1	1	1	3	3	2	5	8
Soleidae							3	7	1	1
Sparidae				1		1	13	3	16	17
Sphyraenidae							1		1	1
Syngnathidae					2	2	3	1	4	6
Trachinidae							3		3	3
Triglidae							1	1	2	2
Total	1	1	2	6	5	15	79	17	96	111
% To Total Assessment of Species	**0.9**	**0.9**	**1.8**	**5.4**	**4.5**	**13.5**	**71.17**	**15.31**	**86.48**	**100**

In the Marchica lagoon, the common threats to the biodiversity of fishes, could be resulted from at least four main external forcing factors: (1) fishing activities, especially through illegal practices (personal observation), (2) pollutants **(Zerrouqi *et al.*, 2013 ; Matoir *et al.*, 2015)**, habitat degradation **(Selfati *et al.*, 2018)** and biological invasions **(Selfati *et al.*,2017; Chartosia *et al.*, 2018; Oussellam et al., 2021)**.

CONCLUSION

There is a lack of structured quantitative data of the ichthyological component (density, biomass and sampling network), and a lack on the characteristics of the lagoon especially for the prerestoration period (physical-chemical conditions, anthropogenic influence). When this problem is combined with the absence of information or difference between the sampling methods, it is difficult to explain fully the differences between periods with respect to the fish assemblage. It is also important to point out that sampling errors and possible different methodology, not only in the field but also in the laboratory, using different taxonomic keys, probably generate such differences **(Elliott et Hemingway, 2008)**. Despite this, the available data contribute tothe knowledge of the presence or absence of each fish species within the 20th century in the Marchica lagoon, a complex system experiencing a large variety of environmental changes. Given the degree of changes identified in the present study, it seem that both benthic habitats and column water were impacted. This is consistent with other hydrological, sedimentological and biological studies **(Chair *et al*., 2018; Najih *et al*., 2016; Bocci et *al*., *2016;* Maicu et al., 2021)**. It is also concluded that fish data have an important role in ecological monitoring and lagoon management.

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