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Biodiversity Studies for Sustainable Lagoon: Thermophilic and Tropical Fish Species vs. Endemic Commercial Species at Mellah Lagoon (Mediterranean, Algeria)

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Abstract: Lagoons play an important socio-economic role and represent a precious natural heritage at risk from fishing pressure and chemical and biological pollution. Our research focused on better understanding the discrimination of fish biodiversity, the detection of non-indigenous species, and the valorization of commercial indigenous species at Mellah lagoon (Algeria). Taxonomic characterization and barcoding for all fish species and Inkscape schematic drawings for the most common species are provided. A total of 20 families and 37 species were recorded. The thermophilic species *Coris julis*, *Thalassoma pavo*, and *Aphanius fasciatus* and tropical species such as *Gambusia holbrooki* and *Parablennius pilicornis* were identified. Numerous Mediterranean species of socio-economic importance are highlighted, and detailed information is summarized for the lagoon's sustainability. This short-term evaluation goes hand in hand with long-term programs documenting the interaction between indigenous and non-indigenous species in the lagoon and will allow the development of a provisional relationship model for future studies. Thermophilic and tropical species patterns in the Mellah lagoon are presented. Taken together, we provide useful data that can guide future investigations and may become a potential management tool for achieving the Sustainable Development Goals and protecting species with large socio-economic roles from potential thermal stress impact.

Keywords: Mediterranean biodiversity assessment; taxonomic characterization; barcoding; biological pollutants; fish morphological schematic drawing; sustainable lagoon; sustainable development goals (SDG); SDG 14 "Life under water"; SDG 13 "Climate action"; SDG1 "Poverty"

1. Introduction

Climate change and natural resource management are mutually interrelated [1,2]. Addressing these problems for economic purposes and specifically for human health requires knowledge of resources and estimation of their variability over time [3–5]. This study presents a specific perspective that bridges environmental, social, and economic gaps in an effort to allow for effective implementation of the sustainable development of coastal areas [6] by informing policies adopted in the Mediterranean for coastal area management [7,8]. These management policies are now starting to also be considered applicable to Mediterranean lagoons. Since the 17th century, a lagoon has been defined as a "marine water body separated from the open sea where sea water mixes with continental fresh water". The most studied lagoons in the Mediterranean are located in Albania, Algeria, Egypt, France, Greece, Italy, Montenegro, Morocco, Spain, Tunisia, and Turkey, as reported by Cataudella et al. [9]. Their value is that of providing ecosystem services that contribute to the well-being of the human population for many ecological, cultural, and medical uses [10]. Their stressors, as in lagoons around the world, include overexploitation [11], pollution [12–14], climate change, and biological invasions [5,15–18], often co-occurring in time and space and having cumulative effects. Such ecosystem changes can have large consequences on species abundance, biodistributions, and ecosystem functioning and services [5,19,20]. Therefore, it is of primary importance to protect lagoons. They contribute to the overall productivity of coastal waters by supporting a variety of habitats and to the reduction in poverty (Agenda 2030, SDG1) by providing natural resources [21]. We focused our attention on the Mellah lagoon, which is located near the city of Kala, Wilaya El Tarf, Algeria. The lagoon appears to have rich biodiversity, as per the research carried out by Chaoui et al. [22] and Embarek et al. [23]. However, the discrimination of fish, which is often carried out with the help of fishermen, does not report a taxonomic description of characteristics linked to families, genera, and species. Further, identification has never been made using molecular techniques to confirm the discrimination. The era of climate change requires careful planning that takes into account thermophilic and tropical species to adequately contain or limit the entry of voracious fish capable of destroying long-standing balances in the lagoon [5,24]. These goals will eventually lead to the optimization of available resources while minimizing environmental impacts on biodiversity conservation and sustainability. Our main interest in this research centers on the evaluation of biodiversity and its conservation. Our central research goals at Mellah lagoon were to: establish criteria for fish identification and monitoring, describe the common patterns of thermophilic and tropical fish species in Mediterranean lagoons, and report their common socio-economic value. These results could provide some indications of the sustainability of Mediterranean resources.

2. Materials and Methods

2.1. Site Study and Fish Collection

Fishes were collected at Mellah lagoon (collection station: 36°53′39.5″ N, 8°19′29.6″ E, Figure 1) in April of 2018 and 2021. This lagoon is an ovoid-shaped coastal lake of approximately 864 hectares and 4.79 km long, located near the city of El Kala, Wilaya El Tarf, Algeria. Its maximum width is 2.60 km in the northern half, the minimum width is 0.62 km in the southern half, and the perimeter is 13.53 km. The maximum depth is 6.4 m; the average depth is 2.7 m [9]. The lagoon connects to the Mediterranean via a channel that is 0.87 km long and was artificially modified. Fishing is practiced only in the peripheral belt of the lagoon up to 4 m deep, because catches are rare at the bottom of the central part, probably due to the lack of oxygen [9]. In the present study, the different fish species (total number = 705 in 2018; 656 in 2021) were recovered by professional fishermen by trammel net (length = 20 m, height = 1.50 m).

A floating fishing net was used, consisting of three nets: middle, slightly stretched net with small meshes of 12 mm on each side is included between two other nets that are rather tight, with a mesh wider than 7–8 cm on each side. After photograph collection, external anatomical examination, and morphological identification, tissue aliquots of 100 mg were prepared.

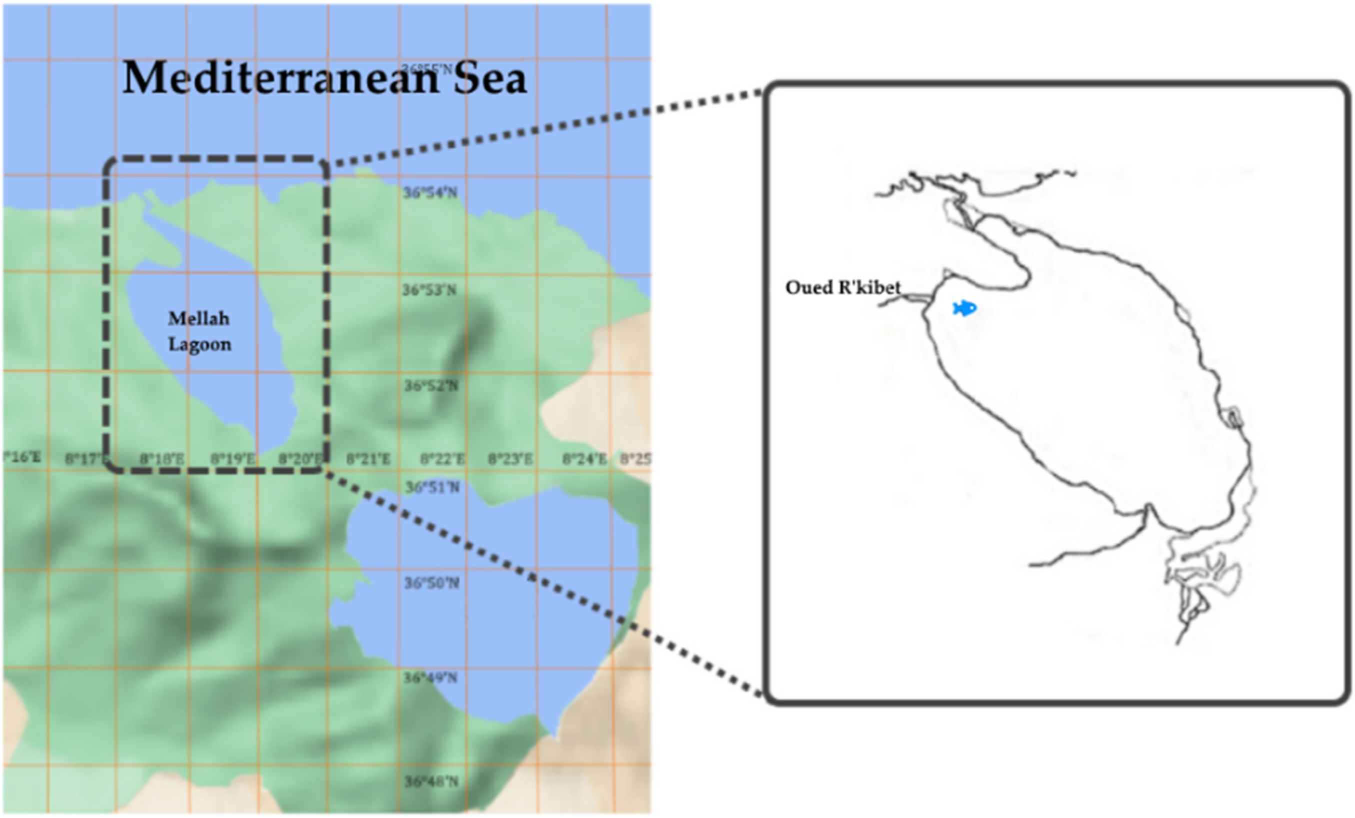

Figure 1. Study site at Mellah lagoon, El Kala, Wilaya El Tarf, Algeria, by Google Maps. The fish symbol indicates location of the collection station (coordinates: 36°53′39.5″ N, 8°19′29.6″ E).

Aliquots were obtained from fillets (*n* = 10 specimens) of each species or from whole bodies of small fish (*n* = 2 pool) (Table S1 of Supplementary Materials) and stored at −20 °C until molecular investigations.

2.2. Fish Discrimination in Mellah Lagoon

Taxonomic identification procedures were applied as reported by Tramice et al. [25]. The family, genus, and species levels were discriminated on the basis of features of the head; body shape and color; eye diameter and position; opercle; lateral line; the number, position, and form of the fins; the size and shape of the scales; the shape and position of the mouth; and the type of teeth. Subsequently, starting from photos of each of the most prevalent species, schematic images were created by the Inkscape software [26], and anatomical keys for identification were recorded.

Molecular identification was also performed for all fish specimens on 100 mg of tissue using the barcoding method reported by Di Finizio et al. [27] and the following primers: COI_UP (5′-ACTTCAGGGTGACCGAAGAATCAGAA-3′) and COI_DW (5′-ATCTTTGGTGCATGAGCAGGAATAGT-3′), as utilized in previous studies [5,25,28]. To confirm the identification, the fragments of COI tRNA sequences obtained after amplification, purification, and sequencing were then compared with COI rRNA sequence data in GenBank [29] belonging to the identified species examined using FASTA [30].

2.3. Mediterranean Lagoon Fauna, Fauna Identification, Bioinvasion, and Lagoon Fauna Socio-Economic Value: Data Sources

The search keywords that were used, both singly and in combination, were as follows: the name of the Mediterranean lagoon, including synonyms of lagoon such as “lagoon, lake, lac, lagune”, and country. The keys used for species and their identification were found in WORMS ID [31], Fishbase [32], and FAO [33], and information about conservation status according to IUCN [34] and socio-economic use of fish [35–38] were obtained. The main biogeographic lagoon distribution was identified starting with Google Earth and using graphic software paint.net [39] and icons [40]. Data relating to fish species for halieutic use (i.e., fishing for human consumption), use in aquariums, use for restocking, medical use, aquaculture and valliculture use, as well as data on bioinvasion of non-indigenous species (NIS) and provisional models of bioinvasion and dynamics between loser and winner species, were found in web-based searches using Web of Knowledge (ISI Web of Science), Science Direct (Scopus), Fishbase, Wikipedia, Google Scholar, and Google searches. Searches were restricted to the last two decades to focus on the most recent and relevant publications.

The search words were applied in English, French, and Arabic. There is also substantial literature in Italian, Arabic, and French that was consulted for socio-economic importance, but this is not listed in the References except when applicable to Mellah lagoon or to highlight the socio-economic value of native and non-native species.

3. Results

3.1. Fish Biodiversity at Mellah Lagoon

3.1.1. Morphological Identification

An example of the process of applying the adopted taxonomic criteria from family to species for fish identified with high population density is as follows: fishes that lack scales and with heads usually having cirri or fleshy flaps on eyes, long dorsal and anal fins, spines that are usually flexible, dorsal fin that is occasionally high anteriorly, fewer spines than segmented (soft) rays, and two spines in the anal fin were categorized as members of the Blennidae family. Of these, specimens in which we detected a lateral line forming a continuous anterior tube with regularly spaced, short transverse branches were identified as belonging to the genus *Parablennius*. The possession of 20–22 segmented dorsal-fin rays, 22–24 segmented anal-fin rays, and 28–30 caudal vertebrae are additional characteristics used to indicate that the fish assigned to the genus *Parablennius* belongs to the species *pilicornis*, which is illustrated in Figure 2.

A similar analysis was performed for all specimens with high population density collected in the present study. The fish drawings created and their schematic taxonomic characteristics are described in Table S2 of the Supplementary Materials.

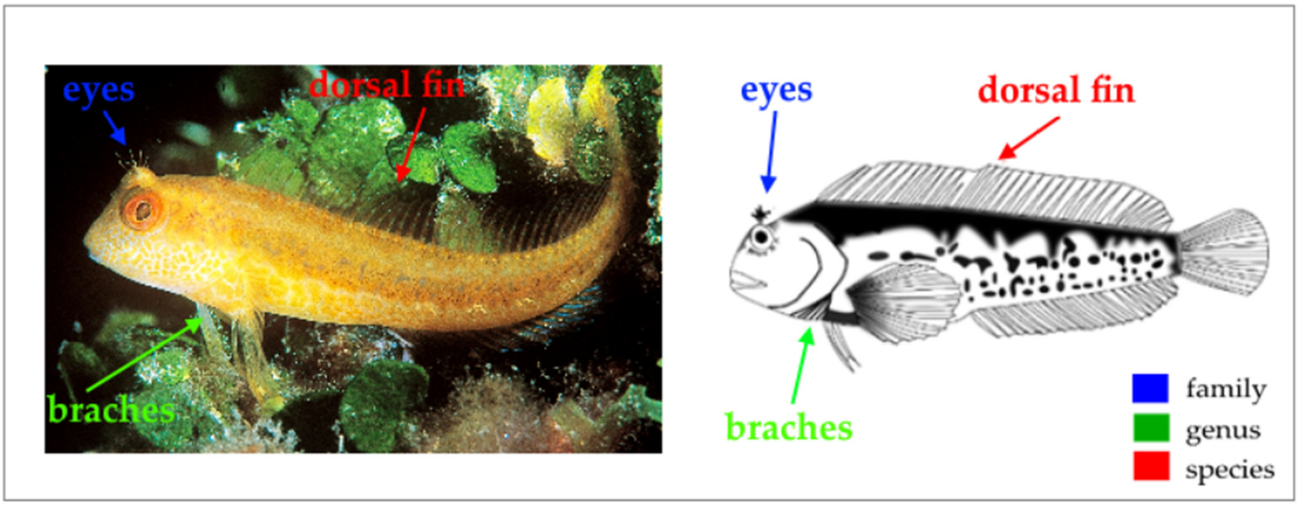

Figure 2. Photograph and drawing of *Parablennius pilicornis* (female). The colored arrows indicate the main anatomical distinguishing characteristics pertaining to family, genus, and species as detailed in Supplementary Table S1. Photograph by Adriano Madonna; drawing created by Sara Inglese.

3.1.2. Barcoding

The primers utilized amplified the corresponding fragment of the mitochondrial region of cytochrome oxidase 1 (COI) in all specimens examined. The PCR products were subsequently sequenced. Each sequence obtained was then subjected to FASTA searches against the NCBI DNA database (GenBank) and classified according to the sequence with which it aligned with the highest identity. This allowed the unambiguous identification of 37 species belonging to 20 families (Table 1).

Table 1. Common names (Arabic and English), taxonomy, and relative GenBank accession number of the COI barcode sequence for fish species discriminated at Mellah lagoon.

	Common Name (Arabic and English)		**Identified Species Taxonomy (Genus, Species, Family)**	**COI Genbank Accession Number**
Thoaban elbahr eloroby	ثعبان البحر الأوروبي	European eel	*Anguilla anguilla* Anguillidae	KX870840.1
Samaket cardinal elbahr elabyad elmotawasit	سمك كاردينال البحر الأبيض المتوسط	Mediterranean cardinalfish	*Apogon imberbis* Apogonidae	KY176390.1
Samak elkharman (elhaqul)	سمك الخرمان (الحاقول)	Garfish	*Belone belone* Belonidae	KJ768216.1
Hasaas elbahr elabyad elmotawasit alramlia	حُساس متوسّطيّ (حساس البحر الأبيض المتوسط الرملي)	Big-scale sand smelt	*Atherina boyeri* Atherinidae	KM538220.1
Sarsaran	صرصران	Leerfish	*Lichia amia* Carangidae	JF493771.1
Blenny halqy elraqaba	حلقي الرقبةبليني	Ringneck blenny	*Parablennius pilicornis* Blenniidae	KY176597.1
Kanjir thoaban elbahr	كونجر ثعبان البحر	Conger eel	*Conger conger* Congridae	KJ709742.1
kilifish elbahr elmotawasit	كيليفيش البحر المتوسط	Mediterranean killifish	*Aphanius fasciatus* Cyprinodontidae	MH410032.1
Jubi eimlaq	جوبي عملاق	Giant goby	*Gobius cobitis* Gobiidae	JF935262.1
Jubi bwkish	بوكيش جوبي	Bucchich's goby	*Gobius bucchichi* Gobiidae	MT884415.1
Jubi aswad	جوبي أسود	Black goby	*Gobius niger* Gobiidae	MT670248.1
Jubi elsakhr	الصخر جوبي	Rock goby	*Gobius paganellus* Gobiidae	MT670258.1
Quris muqazah motawasity (Arisa)	قورس مقزح متوسطي (عريسة)	Mediterranean rainbow wrasse	*Coris julis* Labridae	KJ709510.1
Ellibrus eltaawws	اللبروس الطاووس	Peacock wrasse	*Simphodus tinca* Labridae	KJ768310.1
Ellibrus elmuzakhrafa	اللبروس المزخرفة	Ornate wrasse	*Thalassoma pavo* Labridae	MT216188.1
Elqarus	سمك القاروص	Sea bass	*Dicentrarchus labrax* Moronidae	KC5000512.1
Samak elburi samik elshafa	سمك البوري سميك الشفة	Thichlip mullet	*Chelon labrosus* Mugilidae	EU715474.1
Elburi elzahabi	البوري الذهبي	Golden mullet	*Chelon aurata* Mugilidae	KC500832.1
Elburi raqiq elshafa	البوري رقيق الشفة	Mowel	*Chelon ramada* Mugilidae	KY683175.1
Elburi elsaghir	البوري الصغير	Small mullet	*Liza saliens* Mugilidae	Y683176.1
Samak elburi elmuntashir	السمك البوري المنتشر	Common mullet	*Mugil cephalus* Mugilidae	KJ205081.1
Elburi elmukhatat ahmar	البوري المخطط أحمر	Surmullet	*Mullus surmuletus* Mullidae	KJ768264.1
Elshiq elmotawasity (thoban elbahr)	الشيق المتوسطي (ثعبان البحر)	Mediterranean moray	*Muraena helena* Muraenidae	LC163889.1

Table 1. *Cont.*

	Common Name (Arabic and English)		Identified Species Taxonomy (Genus, Species, Family)	COI Genbank Accession Number
Samakat elbaeud	سمكة البعوض	Eastern mosquitofish	*Gambusia holbrookii* Poeciliidae	MT456153.1
Aqrab elbahr elbirazilii	عقرب البحر البرازيلي	Orange scorpionfish	*Scorpaena scrofa* Scorpaenidae	JN312316.1
Samak elshaykh	الشيخ	Comber	*Serranus hepatus* Serranidae	KM538559.1
Samak mousa	سمك موسى	Senegalese sole	*Solea senegalensis* Soleidae	KC501568.1
Samak muza	سمك موزة	Bogue	*Boops boops* Sparidae	KM538238.1
Eldunis shibshid	الدنيس شيبشيد	Sheephead bream	*Diplodus puntazzo* Sparidae	KJ012350.1
Eldunis elabyad	الدنيس الأبيض	White seabream	*Diplodus sargus* Sparidae	MT943711.1
Om jiwa	أم جواء	Twoband bream	*Diplodus vulgaris* Sparidae	KJ012360.1
Eldunis ehmukhatat	الدنيس المخطط	Sand steenbras	*Lithognathus mormyrus* Sparidae	JF493795.1
Shalba	شلبة	Goldline	*Sarpa salpa* Sparidae	JF494424.1
Eldunis (eldunis mozhab elraasa)	دنيس (الدنيس مذهب الرأس)	Gilthead bream	*Sparus aurata* Sparidae	KF280323.1
Eldunis Elmusraj (minuraa)	المسرج الدنيس (منورى)	Saddle bream	*Oblada melanura* Sparidae	HQ945848.1
Hosan elbahr	حصان البحر	Seahorse	*Hippocampus ramulosus* Syngnathidae	GQ502143.1
Elsamakat elanbobia zat elkhutut elsawda	السمكة الأنوبية ذات الخطوط السوداء	Blackstripe pipefish	*Syngnathus abaster* Syngnathidae	KY176665.1

3.2. *Patterns of Non-Indigenous Mellah Lagoon Fish in Mediterranean Lagoons*

Table 2 reports the pattern of non-indigenous Mellah lagoon fish in other Mediterranean lagoons or in relation to coasts or caves when no lagoon data were available, whereas Figure 3 shows their biodistribution pattern graphically. The thermophilic species *Coris julis* has been reported in only the following lagoons: Mellah lagoon in Algeria ([22,23] and the *present study*), Dalyan Lagoon in Turkey [41] ([22,23] and the *present study*), Messolonghy lagoon in Greece [42], and Marchica Lagoon in Morocco [43]. However, as reported in Table S2, sightings of *Coris julis* have also been reported along the coasts of Tunisia [44], Egypt [45,46], Albania [47], Italy [48], France [49,50], and Spain [51]. Data were unavailable for Montenegro. The only reported lagoon sightings of *Thalasoma pavo* were in the Mellah lagoon in Algeria ([22,23] and the *present study*), in the lagoon of Mar Menor in Spain [52], and in Marchica Lagoon in Morocco [43], whereas *Thalasoma pavo* sightings have been reported along the coasts of Tunisia [53], Egypt [46], Turkey [54], Greece [55], Albania [47], Italy [56,57], and France [58]. Data were unavailable for Montenegro. *Aphanius fasciatus* has been observed at Mellah lagoon in Algeria ([22,23]and the *present study*), Ghar El Melh Lagoon in Tunisia [9,59,60], Bardawil Lagoon in Egypt [61], Beymelek Lagoon in Turkey [62,63], Agiasma Lagoon in Greece [9,64–66], Butrinti Lagoon in Albania [9,67], Tivat salina Lagoon in Montenegro [9], Venice Lagoon in Italy [9,66,68–70], Bieux salins lagoon in France [66], Mar Menor lagoons in Spain [68], and Marjia Zerga Lagoon in Morocco [59]. Data were unavailable for Montenegro. Among the tropical species, *Gambusia holbrookii* sightings have been reported in lagoons of Algeria ([22,23] and the *present study*), Tunisia and Egypt [59], Turkey [63], Greece and Albania [71], Italy [68,72], and France [73], Spain [74], Morocco [75]. Data were unavailable for Montenegro. Further, *Parablennius pilicornis* was found in Mellah lagoon in Algeria ([22,23] and the *present study*), in Mar Menor Lagoon in Spain [52], and in Marchica Lagoon in Morocco [23]. In bays, this species has been identified in Tunisia [76], Egypt [46], Italy [28,77], and France [77]. Data were unavailable for Turkey, Greece, Albania, and Montenegro.

Table 2. Mediterranean biodistribution of thermophilic and tropical Mellah lagoon fish (lagoon literature; * coast literature).

Country	Thermophilic Species			Tropical Species	
	Coris julis	*Thalassoma pavo*	*Aphanius fasciatus*	*Gambusia holbrookii*	*Parablennius pilicornis*
Algeria	Chaoui et al. [22]; Embarek et al. [23]; *present study*	Chaoui et al. [22]; Embarek et al. [23]; *present study*	Chaoui et al. [22]; Embarek et al. [23]; *present study*	Chaoui et al. [22]; Embarek et al. [23]; *present study*	Chaoui et al. [22]; Embarek et al. [23]; *present study*
Tunisia	* Milazzo et al. [53]; Zarrad et al. [44]	* Milazzo et al. [53]	Kraïem et al. [59]; Sellami et al. [60]; Cataudella et al. [9]	Kraïem et al. [59]	Otero et al. [77]
Egypt	* Akel [45]; Akel and Karachle [46]	* Akel and Karachle [46]	Lotan and Ben-Tuvia [61]	Kraïem et al. [59]	* Akel and Karachle [46]
Turkey	Ayaz et al. [41]	* Karachle and Stergiou [54]	Acarli et al. [62]; Innal [63]	Innal [63]	n.d.
Greece	Costa et al. [42]	*Papadakis et al. [55]	Nicolaidou et al. [64]; Kottelat et al. [65]; Cataudella et al. [9]; Facca et al. [66]	Kalogianni et al. [71]	n.d.
Albania	* Soldo and Bakiu [47]	* Soldo and Bakiu [47]	Peja et al. [67]; Cataudella et al. [9]	Kalogianni et al. [71]	n.d.
Montenegro	n.d.	n.d.	Cataudella et al. [9]	n.d.	n.d.
Italy	* Guidetti et al. [48]	* Azzurro et al. [56]; * Encarnação et al. [57]	Franco et al. [68]; Cataudella et al. [9]; Valdesalici et al. [69]; Facca et al. [66]; Zucchetta et al. [70]	Franco et al. [68]; Locatello et al. [72]	* Pastor and Francour [77]; * Madonna et al. [28]
France	* Lejeune [49]; Bray and Bartoli [50]	* Sala [58]	Facca et al. [66]	Le Direach et al. [73]	* Pastor and Francour [77]
Spain	* Crec'hriou et al. [51]	Pérez-Ruzafa et al. [52]	Franco et al. [68]	Srean et al. [74]	Pérez-Ruzafa et al. [52]
Morocco	Selfati et al. [43]	Selfati et al. [43]	Kraïem et al. [59]	Kraïem et al. [59]; Taybi et al. [75]	Embarek et al. [22]

3.3. Mediterranean Lagoon Fish and Socio-Economical Use Analysis

The identified species of Mellah lagoon reported in the other Mediterranean lagoons are listed in Table 2. The potential socio-economic uses of Mellah lagoon fish fauna are categorized in Table 3, while detailed information on their use for human food, restocking, aquaculture and valliculture, aquariology, animal feeding, and medical studies are reported in detail in Table S3. Figure 3 depicts identified areas in the Mediterranean where each species, including thermophilic and tropical species, has socio-economic potential. All species were evaluated for their human food use. The utilization of species reported in Table 3 is well documented in the literature. No information has been found on the indigenous species *Gobius bucchichi* and *Syngnathus abaster*, nor for the thermophilic species *Thalassoma pavo* or the tropical species *Gambusia holbrooki and Parablennius pilicornis*. Halieutic use is not recommended for the thermophilic species *Aphanius fasciatus* or for the indigenous species *Hippocampus ramulosus.* Restocking information has been reported for the species: *Anguilla anguilla*, *Aphanius fasciatus*, *Apogon imberbis*, *Atherina boyeri*, *Chelon labrosus*, *Conger conger*, *Coris julis*, *Dicentrarchus labrax*, *Diplodus sargus*, *Diplodus vulgaris*, *Gambusia holbrooki*, *Mugil cephalus*, *Mullus surmulentus*, *Muraena helena*, *Oblada melanura*, *Sarpa salpa*, *Scorpaena scrofa*, *Symphodus tinca*, *Solea senegalensis*, *Sparus aurata*, and *Syngnathus abaster.* Aquaculture and valliculture are adopted for the species: *Anguilla anguilla*, *Atherina boyeri*, *Belone belone*, *Chelon labrosus*, *Dicentrarchus labrax*, *Diplodus puntazzo*, *Diplodus sargus*, *Liza aurata*, *Liza ramada*, *Liza saliens*, *Mugil cephalus*, *Solea senegalensis*, and *Sparus aurata.* Aquariology is the main use for the thermophilic and tropical species *Aphanius fasciatus*, *Coris julis*, *Gambusia holbrooki*, *Parablennius pilicornis*, *Thalassoma pavo*, and a few indigenous species, such as *Apogon imberbis*, *Gobius bucchichi*, *Gobius niger*, *Gobius paganellus*, *Serranus hepatus* and *Symphodus tinca*. Use in animal feed has been reported for indigenous species such as

Anguilla nguilla, *Atherina boyeri*, *Belone belone*, *Boops boops*, *Chelon labrosus*, *Gobius bucchichi*, *Liza aurata*, *Liza ramada*, *Liza saliens*, and *Mugil cephalus.* Medical use of the species *Belone belone*, *Boops boops*, *Dicentrarchus labrax*, *Lichia amia*, *Mugil cephalus*, *Mullus surmulentus*, *Oblada melanura*, *Scorpaena scrofa*, and *Sparus aurata* has also been extensively reported in the literature. *Sparus aurata* and *Mugil cephalus* represent fish species that have had successful, and potentially multi-valued, applications in all of the Mediterranean lagoons due to their wide distribution, whereas *Hippocampus ramulosus* is a species designated as near threatened, according to the International Union for Conservation of Nature (IUCN), and thus, its socio-economic potential cannot be considered.

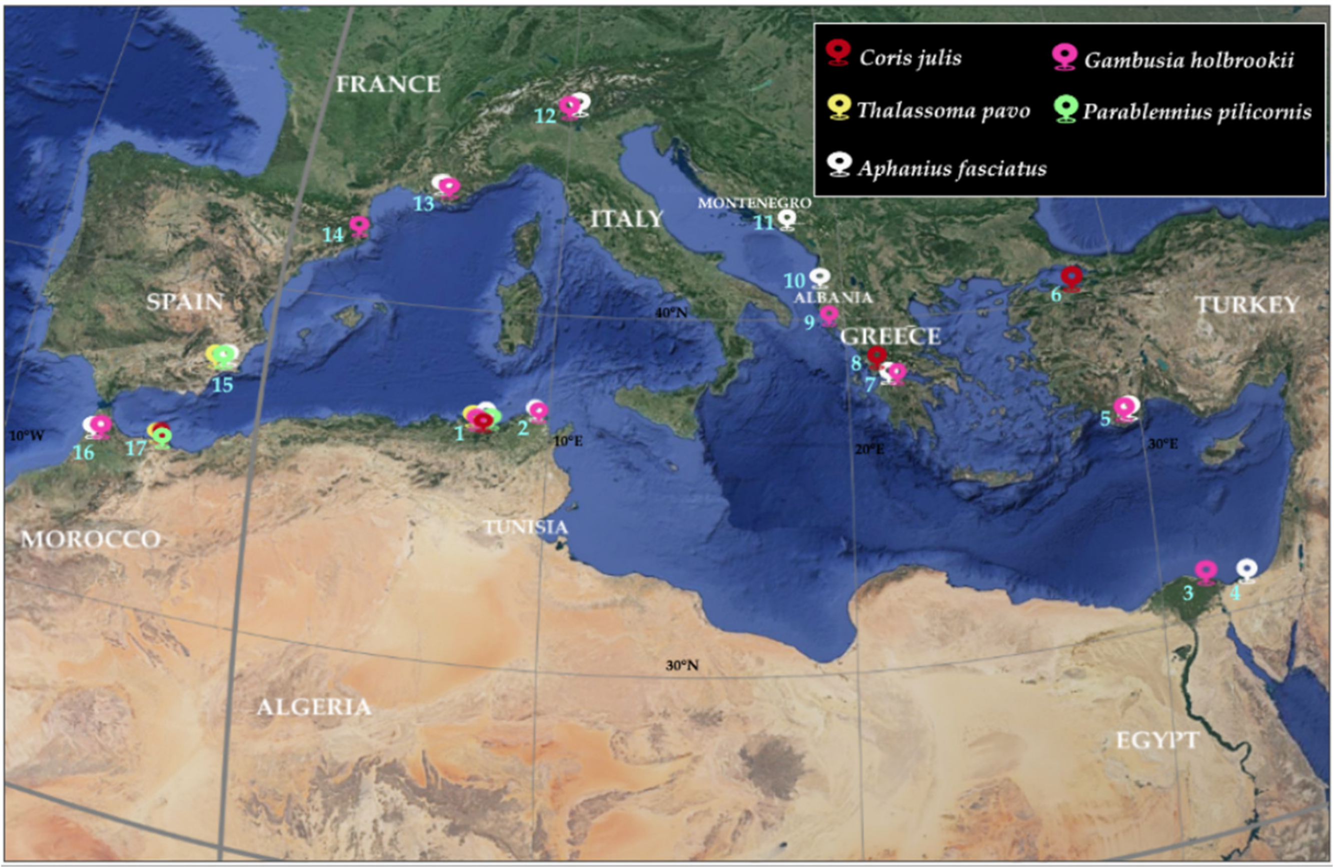

Figure 3. Main biogeographic lagoon distribution of thermophilic and tropical species found at El Mellah lagoon, Algeria. Image by Google Earth. 1. Algeria: Mellah lagoon; 2. Tunisia: Ghar El Melh Lagoon; 3, 4. Egypt: Lake Manzala, Bardawil Lake; 5, 6. Turkey: Beymelek Lagoon, Dalyan Lake; 7, 8. Greece: Prokopos Lake, Messolonghy; 9, 10. Albania: Butrint Lagoon, Narta; 11. Montenegro: Tivat salina; 12. Italy: Venice Lagoon; 13. France: Bieux salins Lagoon; 14, 15. Spain: Ter Vell, Mar Menor lagoons; 16, 17. Morocco: Merja Zerga Lagoon, Marchica Lagoon.

Table 3. Socio-economic use of examined lagoon fish.

Fish Species	Socio-Economic Use				
Syngnathus abaster	Restocking				
Lithognathus mormyrus	Human food				
Thalassoma pavo	Aquariology				
Gobius cobitis	Human food				
Parablennius pilicornis	Aquariology				
Sarpa salpa	Human food	Restocking			
Diplodus vulgaris	Human food	Restocking			
Diplodus puntazzo	Human food	Culture			
Serranus hepatus	Human food	Aquariology			
Gambusia holbrookii	Aquariology	Restocking			
Muraena helena	Human food	Restocking			
Gobius paganellus	Human food	Aquariology			
Gobius niger	Human food	Aquariology			
Gobius bucchichi	Aquariology	Animal Feeding			
Aphanius fasciatus	Aquariology	Restocking			
Conger conger	Human food	Restocking			
Lichia amia	Human food	Medical			
Apogon imberbis	Aquariology	Restocking			
Solea senegalensis	Human food	Restocking	Culture		
Oblada melanura	Human food	Restocking	Medical		
Diplodus sargus	Human food	Restocking	Culture		
Boops boops	Human food	Animal Feeding	Medical		
Scorpaena scrofa	Human food	Restocking	Medical		
Mullus surmuletus	Human food	Restocking	Medical		
Liza saliens	Human food	Culture	Animal Feeding		
Liza ramada	Human food	Culture	Animal Feeding		
Liza aurata	Human food	Culture	Animal Feeding		
Symphodus tinca	Human food	Restocking	Aquariology		
Coris julis	Human food	Restocking	Aquariology		
Chelon labrosus	Human food	Restocking	Culture	Animal Feeding	
Dicentrarchus labrax	Human food	Restocking	Culture	Medical	
Belone belone	Human food	Culture	Animal Feeding	Medical	
Atherina boyeri	Human food	Restocking	Culture	Animal Feeding	
Anguilla anguilla	Human food	Restocking	Culture	Animal Feeding	
Sparus aurata	Human food	Restocking	Culture	Medical	
Mugil cephalus	Human food	Restocking	Culture	Animal Feeding	Medical

4. Discussion

Lagoons of the Mediterranean as well as the Mediterranean itself are at risk. High fishing pressure, pollution, and climate change are strongly affecting biota and marine ecosystems, mainly due to significant increases in temperature [5,15–18]. Climate change is responsible for this area becoming a global hotspot of non-native species, particularly the "southernization" and "tropicalization" of the northern and southern sectors, respectively, mainly due to the northward expansion of indigenous thermophilic species and the introduction of tropical species through the Suez Canal and the Strait of Gibraltar. Non-indigenous species in particular have been reported by the Intergovernmental Platform for Biodiversity Science and Policy as one of the top five global causes of negative effects on nature worldwide [78]. The alerting, monitoring, and valorization of coasts and lagoons can be a challenge for the maintenance of sustainability [79].

4.1. An Updated Overview on Fish Biodiversity at Mellah Lagoon

Through the investigation of morphological and barcoding discrimination carried out in April 2018 and April 2021 at Mellah lagoon (El Tarf, Algeria), we were able to assign the genus and species for 37 species, of which 3 are thermophilic and 2 are tropical species, as reported in Table 1. As is known, barcoding is defined as the use of a standardized short DNA region for species discrimination, which, for fish, is typically the COI region of mitochondrial DNA. Furthermore, Inkscape schematic drawings for the most common species have been provided, and anatomical keys for identification were recorded (see Table S2) to enable the fast, accurate, and cost-effective identification of fishery products. A similar approach was previously utilized in our studies for samples from the Tyrrhenian Sea (Italian Mediterranean coast) [80] and the Egyptian coast [5,81], as well as for Atlantic species [27] and Asian species [25]. The present work of species discrimination at Mellah lagoon is an update of the most recent overview of this lagoon's biodiversity conducted by Chaoui et al. [22] and by Embarreket et al. (in 2017) [23] and confirms the taxonomic data of widely distributed species that were present in 2006. In fact, in 2006, Chaoui and coworkers showed a species pattern in the Mellah lagoon similar to the one that we discriminated morphologically and by barcoding. What varies for some species is the population density. Therefore, in the alternate summary Table S4, we indicate the population densities reported in the studies by Chaoui and coworkers [22] and by Embarek and coworkers [23], as well as those relating to our studies conducted in 2018 and 2021. It is noted that many species not reported in 2017 were present in 2006, April 2018, and April 2021. However, in the quantitative studies by Embarek and coworkers [23], the species examined were linked to the number of samplings and seasonality. Our data, therefore, verify the presence of high biodiversity. Furthermore, our visual census, our collection samples, and the local knowledge highlighted a decrease in the density of thermophilic species such as *Aphanius fasciatus* and tropical species such as *Gambusia holbrookii*. In our studies, the population density for *Atherina boyeri*, *Lithognatus mormyrus*, and *Spaurus aurata* is also shown to have decreased. For other species, such as *Conger conger*, *Chelon ramada*, *Diplodus puntazzo*, and *Syngnathus abaster*, the population density seems to have increased. Additional monitoring is necessary to validate the density of populations with innovative systems to implement SDG 14, Life under water, and SDG 13, Climate action effects [82].

4.2. Pattern of Thermophilic and Tropical Fish Mellah Lagoon in Other Mediterranean Lagoons

The data that we collected from the literature reveal a clear distribution pattern of the thermophilic and tropical species found in Mellah lagoon in the Mediterranean.

Most of these species have already been reported and extensively studied in the lagoons of Algeria, Tunisia, Egypt, Turkey, Greece, Albania, Montenegro, Italy, France, Spain, and Morocco [9]. When lagoon data did not exist, the species distribution pattern was defined by country-specific coastal data instead. Thermophilic species such as *Coris julis* have been reported in a few lagoons. They have been found in Algeria, Turchia, Greece, and Morocco. *Thalasoma pavo* has been reported in Algeria, Spain, and Morocco, whereas *Aphanius fasciatus* was already known to have a wide distribution in all lagoons examined. The tropical *Gambusia holbrooki* has been observed in 10 of 11 lagoon countries that were more extensively examined, except for Montenegro, whereas *Parablennius pilicornis* has been detected only in Spain, Morocco, and Algeria. We suppose that these incomplete distribution patterns can be related to limited literature in international journals. Further, proper taxonomy and identification have been major limiting factors in the ability to detect

NIS fishes. This is compounded by the lack of updated local fauna inventories and the lack of taxonomic expertise and local knowledge in some Mediterranean areas. Data presented in this updated review can therefore be very useful in providing further evidence that biological pollution has been one of the top five global causes of negative changes in nature worldwide since 1970 [78]. In fact, studies on alien species have shown that they have led to substantial changes in the distribution of species [83,84], resulting in a significant loss of biodiversity [85], the spread of disease, and the impairment of economic activities [86]. The current attention to lagoons is linked to and supplements the evidence of the effects of bioinvasion, which has already been reported [87,88], especially in systems where water availability can be a limiting resource [89,90]. Thermophilic and alien species induce competition with native species when they simultaneously have an active demand for the same resource (e.g., food, nesting site, and/or space) [91]. The effects are much more evident between native species and invasive species [91,92]. The results of our analyses confirm the hypothesis that *Thalassoma pavo* and *Coris julis*, being present in the same lagoons, utilize the habitat in different ways. *Thalassoma pavo* feeds on turf algae, while *Coris julis* feeds on bushy algae. In the present study, as tropical species, we identified *Gambusia holbrooki and Parablennius pilicornis. Gambusia holbrooki* is an invasive and omnivorous species native to America's northern and central waters, intentionally introduced around the world for the control of mosquito populations, and it has become one of the most successful invasive fish in the world. It is a voracious species that preys on insects and other prey. The female is viviparous and "gives birth" from three to six times a year with up to 100 completely formed young [93]. *Gambusia holbrooki* is very competitive with the thermophilic species *Aphanius fasciatus,* which is endemic to the central-eastern Mediterranean in Cyprus as well as many other Mediterranean lagoons [88]. Further, *Gambusia* tolerates a wide range of salinity concentrations; it is even able to survive in oxygen-poor waters characterized by a salinity higher than that of sea water (hypersaline waters). Behavioral and competitive interactions between *Gambusia holbrooki* and *Aphanius fasciatus* could be mediated by salinity. Studies by Monti et al. [94] highlighted that when setting default salinity concentrations in aquariums, *Gambusia* showed reduced aggressiveness. *Aphanius fasciatus* is known to be a eurythermic and euryhaline fish species; it has a widespread distribution among Mediterranean lagoons, as does *Gambusia*, although increasing anthropogenic activity has caused a general decline in numbers, and for this reason, *A. fasciatus* is considered to be a species that is "dying out".

4.3. Mediterranean Lagoon Sustainability

In terms of their use for human consumption, many endemic fish species examined at Mellah lagoon are appreciated for the quality of their meat, as is the case for the garfish *Belone belone*; the thichlip mullet *Chelon labrosus*; the sea bass *Dicentrarchus labrax*; the white bream *Diplodus puntazzo*, *Diplodus sargus*, and *Diplodus vulgaris*; the leerfish *Lichia amia*; the sand steenbras *Lithognathus mormyrus*; the common mullet *Mugil cephalus*; the surmullet *Mullus surmuletus*; the saddle bream *Oblada melanura*; the sea bream *Sparus aurata*; the Senegalese sole *Solea senegalensis*; and the European eel, *Anguilla anguilla* [34–36,95–98]. Others have less commercial value and are mainly intended for the preparation of fish soups or fried foods, for example, the big-scale sand smelt *Atherina boyeri*; the bogue *Boops boops*; the conger eel *Conger conger*; the Mediterranean rainbow wrasse *Coris julis*; the gobies *Gobius cobitis*, *Gobius niger*, and *Gobius paganellus*; several mullets: *Liza ramada*, *Liza saliens*, and *Liza aurata*; the orange scorpionfish *Scorpaena scrofa*; the comber *Serranus hepatus*; and the peacock wrasse *Symphodus tinca* [35,36,96,99,100]. Human consumption of the thermophilic species *Aphanius fasciatus* and the indigenous species *Hippocampus ramulosus* is not recommended (because this species is listed as near threatened; therefore, its capture has been forbidden). Further, of fundamental importance for socio-economic purposes is the application of different species for the purpose of restocking marine environments, where, as is well known, there is a depletion of resources as a result of overfishing or biological pollution. This is the case for *Anguilla anguilla,* which is a critically endangered species [101], as is *Aphanius fasciatus* [102], *Apogon imberbis*, *Conger conger*, *Coris julis*, *Diplodus vulgaris Mullus surmulentus*, *Muraena helena*, *Oblada melanura*, *Sarpa salpa* and *Symphodus tinca* [103], *Atherina boyeri* [34], *Chelon labrosus* [104], *Dicentrarchus labrax* [96], *Diplodus sargus* [105,106], *Gambusia holbrooki* [107], *Mugil cephalus* and *Sparus aurata* [105], *Scorpaena scrofa* [108], *Solea senegalensis* [109], and *Syngnathus abaster* [110]. Some species find possible applications in different fields, such as: valley farming and aquaculture farming. Examples of species for this application are: *Anguilla Anguilla*, *Dicentrarchus labrax*, *Mugil cephalus*, *Sparus aurata* [111], *Atherina boyeri*, *Chelon labrosus*, *Liza aurata*, *Liza saliens* [104], *Belone belone* [112], *Diplodus puntazzo*, *Diplodus sargus*, and *Liza ramada* [113], and *Solea senegalensis* [97]. Species such as *Aphanius fasciatus* and *Gambusia holbrooki* [114], *Apogon imberbis*, *Coris julis* and *Parablennius pilicornis* [37], *Gobius bucchichi*, *Gobius niger*, *Gobius paganellus*, *Serranus hepatus*, *Symphodus tinca*, and *Thalassoma pavo* [35] are utilized for aquariology. In some cases, they are used as live feed or as fish meal, as occurs with *Anguilla anguilla* [115], *Atherina boyeri* [116], *Belone belone, Gobius bucchichi* [35], *Boops boops* [117], *Chelon labrosus, Liza aurata*, *Liza ramada*, *Liza saliens*, and *Mugil cephalus* [113]. Furthermore, there are studies that have emphasized the importance of some of the species considered for their benefits for human health if introduced to an individual's diet. The garfish, *Belone belone*, is rich in proteins and vitamins that are important for metabolic activities, as well as monounsaturated fatty acids and omega-3, which are important for cardiovascular health; however, it also has high cholesterol levels. According to experts, however, consuming the right doses of these nutrients can be an important measure for keeping heart rate under control and reducing cardiovascular risks [38]. From research conducted by Lassoued et al. [118], it is deduced that the bogue, *Boops boops*, has a positive role in the reduction in effects such as cardiovascular diseases caused by the high-fat diet characteristic of our time. Moreover, this species is rich in vitamins of group B and group A, potassium, iron, calcium, and phosphorus, which are important for metabolic activities, the immune system, cardiovascular health, the prevention of anemia, and bone health and teeth, respectively. The sea bass *Dicentrarchus labrax* has multiple benefits for human health, such as the control of triglyceride levels and blood pressure, by providing omega-3, and its high concentrations of phosphorus are supportive for the development of bones and teeth but also for memory. This fish is also strongly recommended for pregnant women, as its folic acid levels are able to reduce the risk of congenital malformations in newborns by 70% [38]. In addition, nutritional studies highlighted that regular human consumption of sea bass reduces cancer and particularly prostate cancer mortality by 64% and 50%, respectively [38]. The leerfish *Lichia amia* is particularly known for its lipid profile, which is rich in monounsaturated and polyunsaturated fats, making it potentially important for cardiovascular health, but like *Belone belone*, it is a source of cholesterol, and therefore, it is necessary to consume the right amount to obtain positive health effects in this case as well [38]. Studies carried out on *Mugil cephalus* have paid particular attention to the importance of omega-3s in preventing colon cancer [119]. They are valid adjuvants of 5-fluorouracil, an anti-cancer drug [119]. Minimum levels of cholesterol are present in the surmullet *Mullus surmulentus*, which, on the other hand, shows high concentrations of vitamins of groups B and A but also of important minerals, such as zinc, which is important for processes involved in growth, tissue repair, and sexual development, and selenium, essential for its antioxidant and anti-cancer properties [38]. Like the mullet, the saddle bream *Oblada melanura* is also characterized by low concentrations of carbohydrates and an abundance of minerals such as potassium, which is important for maintaining water balance and blood pressure, and iron, which is essential for tissue oxygenation and prevention of anemia [38]. The orange scorpionfish, *Scorpaena scrofa*, has been indicated for the prevention of heart disease, hypertension, diabetes, arthritis, cancer, multiple sclerosis, and various autoimmune diseases thanks to its omega-3/omega-6 ratio [100]. Finally, the sea bream *Sparus aurata* has been recommended not only for its contribution of omega-3, calcium, phosphorus, and iron but also for its iodine levels, which are essential in the regulation of thyroid hormones [38].

4.4. Mediterranean Lagoon Fish Conservation and Management: Thermophilic and Tropical Species vs. Endemic Commercial Species

To preserve the sustainability and natural richness of lagoons, it is necessary to intervene and regulate the pathways of greatest risk both with regulatory tools that are reinforced and with self-regulation tools such as codes of good practice. Adequate corrective management measures to conserve sensitive species are required with research involvement. Studies should be encouraged to understand what promotes the coexistence of invaders and native species, such as the study carried out by Monti et al. [94], which highlighted that defined salinities affect the voracity of *Gambusia*. Furthermore, another question that would be important to answer is, as pointed out by Ho et al. [120], how the role of abiotic factors guides the space–time dynamics of animal communities. Among the strategies for better/smart regulation and sustainability of the lagoons, increasing awareness, sharing information, preventing new invasions, adopting control measures, promoting information campaigns, and long-term planning are highlighted. It is for this purpose that they must be conceived and implemented for ecosystem monitoring, models, and ecological forecasts [20]. Monitoring by local ecological knowledge (LEK) has generated a very useful cumulative body of practices and beliefs. In fact, it has been applied as a tool for the monitoring and management of the environment and many marine resources [94], being cheap, feasible, and extremely useful, to complement traditional sampling surveys performed on a large geographical scale [121]. Further, ecosystem modeling software is currently being successfully applied. The most commonly used is Ecopath with Ecosim, which has been widely applied to model aquatic food webs [122]. In this context, Moullec et al. [123,124], using a high-resolution regional climate model [125], a regional biogeochemistry model [126], and a food web model [123], described how to calculate the potential effects of climate change on biomass. Furthermore, Libralato et al. [24] developed temporal simulations to explore the effects of the arrival of invasive species, changes in primary production, and sea warming in the Adriatic Sea. The process of improving regulation (better/smart regulation and better lawmaking) through model studies could gain increasing importance for more coordinated strategies and for the simplification of regulatory frameworks, taking into account the knowledge on a single species, their alimentary habits, and their tolerance [66]; however, in this case, more focused research is also necessary.

5. Conclusions

Based on the socio-economic resources of identified lagoon species, this work focused on the development of guidelines for a sustainable lagoon. Over time, they should facilitate and promote the verification of the species present through Inkscape schematic drawings and verification through the alignment of the obtained sequences with sequences present in GenBank, the accession numbers of which are shown in an organized table. The presence of thermophilic and tropical species is specifically emphasized, and a possible method that is already in use is presented to monitor the effects of the climate and to protect endemic species using a provisional model, as discussed. During our study, we encountered obstacles, such as the small number of published articles reporting the real damage inflicted by these species and on the possible natural methods to counter their harmful voracity, unlike the well-documented case linked to the *Gambusia* species. Further, we were able to provide an overview of the biodistribution of thermophilic and tropical species detected at Mellah lagoon that are also present in many other Mediterranean lagoons. The results of the current research can therefore represent the first careful examination of the fauna of Mellah lagoon and be used for further analyses over time to safeguard biodiversity and promote Agenda 2030 milestones.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w14040635/s1, Table S1: Number and total length range (cm) of fish species caught in April 2018 and April 2021. Table S2: Identification of species with high population density in Mellah lagoon. Table S3: Applications of Mediterranean fish for Sustainable Development Goals. Table S4: Fish conservation status of Mellah lagoon and population density through the years (2006, 2017, 2018, and 2021).

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