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A Risk Screening of Potential Invasiveness of Alien and Neonative Marine Fishes in the Mediterranean Sea: Implications for Sustainable Management

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Abstract: Biological invasions have posed a major threat to global and regional biodiversity. The Mediterranean Sea, one of the major biodiversity hotspots in the world, has long suffered multiple and frequent invasion events. This paper represents the screening results of the potential invasiveness of 23 introduced marine fish species, which are classified as neonative and alien. To predict the invasiveness potential of species under current and predicted climate conditions, the Aquatic Species Invasiveness Screening Kit (AS-ISK) is applied. Thresholds have been constituted to classify low, medium and high-risk species by receiver operative characteristic curve analysis (ROC). The calibrated basic and climate-change threshold assessment scores used to classify species from low, to medium to high risk were computed between 27.5 and 33.0 respectively. Based on these thresholds, under current climatic conditions, 15 species were high risk, while the remaining species were medium risk, and the *Chaetodipterus faber* and the *Holocentrus adscensionis* switched from the medium-risk to the high-risk group under future climatic conditions. The highest score belonged to *Fistularia petimba*, followed by *Siganus fuscescens*, *Abudefduf* spp., *Acanthurus monroviae* and *Lutjanus argentimaculatus*. This study focused on the species that have not been assessed for their invasiveness potential, and the results can provide important insights into their sustainable management in the future.

Keywords: biological invasion; AS-ISK; non-native species; the Suez Canal; the Gibraltar Strait

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1. Introduction

Whether in terrestrial or freshwater and marine ecosystems, management of invasive non-native species has been a difficult challenge for scientists and public authorities. These species directly cause the extinction of other species while indirectly causing changes in ecosystem functioning [1].

In terms of management strategy, aquatic ecosystems are more disadvantaged than terrestrial ecosystems. Since humans are terrestrial mammals, they perceive changes in their own habitats more quickly; management strategies and action plans have tended to be developed mostly for terrestrial ecosystems. This tendency hinders the development of management strategies against aquatic invasive species [2]. However, there are some difficulties in implementing actions against biological invasions in aquatic ecosystems (especially marine ecosystems) compared to terrestrial ecosystems, which are as follows: (a) multiple connectivity through the water mass, (b) the size of the recipient area and (c) the inherent ability of the invader. A series of lags (in detection, arrival, establishment, geographical expansion and human response) caused by the aforementioned obstacles prevent control of a biological invasion in the marine environment [3]. The success of measures and approaches such as eradication depends on the rapid detection of the invader in the novel environment [4]. In terms of the size of the marine environment, a maintenance management approach that simply controls the population at acceptably low levels is more realistic than eradication [5]. Maintenance management practices have been accelerated to reduce the negative environmental impacts of lionfish and pufferfish throughout the

Mediterranean. Although joint action plans and approaches against invasive species that have common traits seem to be advantageous, invasive control strategies should be fundamentally species-specific [6]. It is essential that action plans against invasive species should constitute multiple comprehensive approaches; however, in the sustainable management of invasive species, there are both ecological and socioeconomic components. Therefore, a series of pragmatic solutions (e.g., AS-ISK, EICAT, SEICAT, etc.) were developed to determine the ecological and socio-economic impacts of invasive species.

These risk assessment applications are mainly used to aid the implementation of the requirements of the European Regulation 1143/2014 for the prevention and management of the introduction and spread of invasive alien species [7]. One successful application of ecological risk screening for non-native species was for invasive freshwater fish, and is known as the Fish Invasiveness Scoring Kit (FISK) [8]. Similarly, several successful risk assessment studies have been carried out globally or regionally for screening freshwater and marine ecosystems against non-native species [9–18]. The FISK tool was later developed to cover plants and animals in marine, brackish and freshwater systems, and is now known as the Aquatic Species Invasiveness Screening Kit (AS-ISK).

Risk-screening applications, the keystone of risk-assessment systems, are used to determine potential invaders that may colonize a new environment and enable the prediction of the possible effects that these may cause in the recipient environment [19]. Risk-screening protocols are based on the bioecological features of the target organism and a comparison of the characteristics of the biogeographical region in which it exists [20]. The main features of the risk-screening methods are as follows: a simple information scan (a question-and-answer format), adaptivity to common computer programs, high reliability estimates and flexibility of the application for many different taxonomic groups [19,20]. Although risk-scanning tools have wide areas of usage and application strategies, all of them aim to discriminate between invasive and noninvasive species in a fast and effective way [21]. Another advantage of risk-screening tools is that they give scientists the chance to test the quality and reliability of data in the published literature [22]. Regarding the AS-ISK studies for non-native marine fishes in the Mediterranean, risk-screening outputs incline mostly towards the established species known as veteran Lessepsian fishes. There is clearly an existing gap in the literature caused by the risk screening of alien species that are still rare in the Mediterranean, as well as non-native species considered as alien species (neonative).

In this context, the present study relates to sustainable management, aiming to assess the probability of invasion, based on present and future climatic conditions, of the alien and neonative fish observed in the Mediterranean. This screening was carried out to provide useful data both for the sustainable management of non-native fish and the conservation of native fish in the Mediterranean.

2. Materials and Methods

A total of 23 species, classified as alien and neonative, were chosen, and their potential invasiveness in the RA was assessed by the AS-ISK (version 2.3, downloaded from www.cefas.co.uk/nns/tools/, accessed on 2 June 2021). This classification is simply made according to the introduction pathway being human-mediated (alien) or considered as a range-expansion (neonative) of the species. Different criteria were considered in the selection of the screened species. These were: (a) reported in the Mediterranean and (b) not previously screened for in the Mediterranean Sea. These species were as follows (in alphabetical order): *Abudefduf* spp.; *Acanthopagrus bifasciatus* (Forsskål, 1775); *Acanthurus chirurgus* (Bloch, 1787); *Acanthurus coeruleus* (Bloch and Schneider, 1801); *Acanthurus gahhm* (Forsskål, 1775); *Acanthurus monroviae* (Steindachner, 1876); *Acanthurus sohal* (Forsskål, 1775); *Chaetodipterus faber* (Broussonet, 1782); *Chrysiptera cyanea* (Quoy and Gaimard, 1825); *Fistularia petimba* (Lacepède, 1803); *Holacanthus ciliaris* (Linnaeus, 1758); *Holocentrus adscensionis* (Osbeck, 1765); *Lutjanus argentimaculatus* (Forsskål, 1775); *Lutjanus fulviflamma* (Forsskål, 1775); *Lutjanus sebae* (Cuvier, 1816); *Paracanthurus hepatus* (Linnaeus, 1766); *Paranthias furcifer* (Valenciennes, 1828); *Pomacanthus imperator* (Bloch, 1787); *Pomacanthus maculosus* (Forsskål, 1775);

Siganus argenteus (Quoy and Gaimard, 1825); *Siganus fuscescens* (Houttuyn, 1782); *Zebrasoma flavescens* (Bennett, 1828) and *Zebrasoma xanthurum* (Blyth, 1852).

AS-ISK determines the invasiveness of non-native species based on the response to 55 questions. The first 49 questions are related to a Basic Risk Assessment (BRA), which is associated with the bio-geographical and biological aspects of target species. The remaining 6 questions, known together as the Climate Change Assessment (CCA), enable evaluation of how and at what level the BRA will be affected by future predicted climate conditions [9]. Validation of screening was based on the response and justification of the assessor and their level of confidence in the response. Responses should mainly be based on the relevant literature. If the assessor uses personal opinion, the confidence level of the response will be at a level (low or medium) to keep the screening results from being valid. After screening, BRA (from −20 to 68) and BRA + CCA (composite) scores (from −32 to 80) were assigned to target species. Eventually, the AS-ISK classified species that had a score lower than 1 as low risk, while higher score values than 1 were classified as a medium-risk or high-risk invasive species. Discrimination between high and medium risk levels was determined by a threshold value that was associated with RA area-specific calibration. Assessors can assign 4 different levels of confidence (low, medium, high, very high) to each question-related response. These confidence levels were recommended by the International Programme on Climate Change [23,24].

Data Processing and Statistical Analysis

Firstly, the scientific name of each screened species was updated via Eschmeyer's Catalog of Fish [25] and the Fishbase database [26]. For the CCA, climate classification provided by [27] was used, and the native habitats of non-native species were separated in the present study as temperate marine or tropical marine.

After the computation of the BRA and CCA scores, the prediction skill of the AS-ISK in discriminating between the non-native fish species being a medium or high risk in terms of invasiveness was tested by Receiver Operating Characteristic (ROC) analysis. However, implementation of the ROC curve analysis is dependent on the a priori categorization of species in terms of their documented invasiveness (i.e., noninvasive or invasive). For this purpose, global and regional databases were used, such as the Global Invasive Species Database (GISD: http://issg.org/database/species/List.asp, accessed on 2 June 2021), the Invasive Species Compendium (CABI: www.cabi.org/isc, accessed on 2 June 2021), the European Alien Species Information Network (EASIN: https://easin.jrc.ec.europa.eu/easin, accessed on 2 June 2021), the European Network on Invasive Species (NOBANIS: https://www.nobanis.org/, accessed on 2 June 2021) and the Ellenic Network on Aquatic Invasive Species (ELNAIS: https://elnais.hcmr.gr/, accessed on 2 June 2021). If no information was available on these databases, then the relevant literature, including keywords or the running titles 'invasive', 'invasiveness' and 'impact' (including the scientific name of the species) was searched on Google Scholar. In the case of a match, the available literature was accepted as confirmation to categorize the species as a priori invasive or noninvasive.

The confidence factor (CF) that depends on the confidence level (CL) assigned to each answer was computed as below:

$$\mathrm{CF} = \sum(\mathrm{CQi})/(4 \times 55)\ (\mathrm{i} = 1, \ldots, 55)$$

where $\mathrm{CL}_{\mathrm{QI}}$ is the confidence level for the *i*th Question (Qi), 4 is the maximum achievable value of confidence and 55 is the total number of questions.

The $\mathrm{CL}_{\mathrm{BRA}}$ and $\mathrm{CL}_{\mathrm{CCA}}$ were also computed (out of the $\mathrm{CL}_{\mathrm{Total}}$ for all 55 Q_{S}) via the 49 Q_{S} comprising the BRA and the 6 Q_{S} comprising the CCA.

Statistical differences between the mean $\mathrm{CL}_{\mathrm{BRA}}$ and $\mathrm{CL}_{\mathrm{CCA}}$ and between the mean $\mathrm{CF}_{\mathrm{BRA}}$ and $\mathrm{CF}_{\mathrm{CCA}}$ were found using a permutational (univariate) analysis of variance (PERANOVA) derived from a one-factor design (consisting of two levels: BRA and CCA). This analysis was based on the normalized data and the Bray–Curtis dissimilarity measure, with 9999 unrestricted permutations of the raw data [28], and with statistical effects evaluated at $\alpha = 0.05$.

3. Results

The ROC curves for the BRA resulted in an Area Under the Curve or AUC of 0.9389 (0.8401 to 1.000 95% CI), and for the BRA + CCA it resulted in an AUC of 0.9333 (0.8234 to 1.000 95% CI) (Figure 1).

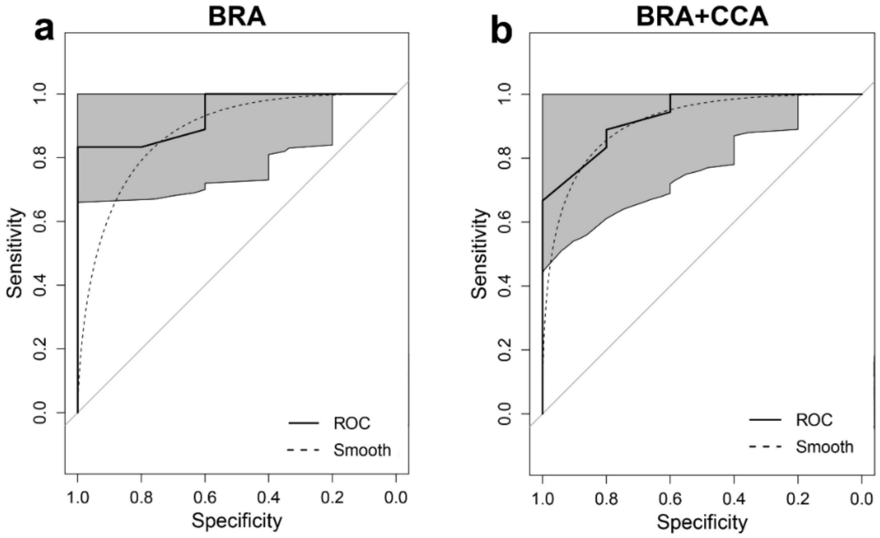

Figure 1. (**a**) Receiver Operating Characteristic (ROC) curve (solid line) for the Basic Risk Assessment (BRA) on the alien and neonative fish species screened with the Aquatic Species Invasiveness, Screening Kit (AS-ISK) for the Mediterranean Sea (see also Table 1); smoothing line and confidence intervals of specificities are also provided; (**b**) Same for the Climate Change Assessment (CCA).

The Area Under the Curve (AUC) measures the accuracy of the calibration analysis and provides the ability to differentiate between non-invasive and invasive Indo-Pacific (alien) and Atlantic fish (neonative) in the RA area. The AUC data interpretation classification was as follows [29]: acceptable discriminatory power ($0.7 \leq \text{AUC} < 0.8$), excellent ($0.8 \leq \text{AUC} < 0.9$) and outstanding ($0.9 \leq \text{AUC}$).

Youden's J calibration of the AS-ISK risk outcomes provided a threshold of 27.5 for the BRA and a threshold of 33.0 for the BRA + CCA. According to the BRA threshold, species with scores within the interval 1 to 27.5 were classified as medium risk, and species with scores within 27.5 to 68.0 were classified as high risk. These scores on the BRA + CCA threshold were calculated within 1.0 to 33.0 and 33.0 to 80 for medium-risk species and high-risk species, respectively. Finally, species classified as low-risk were those with BRA scores between −20 and 1.0 and BRA + CCA scores between −32 and 1.0. Concerning both the BRA and BRA + CCA thresholds, 15 (65.2%) of the 23 screened species were classified as high-risk and 8 (34.8%) were classified as medium-risk, while no species were found in the low-risk group. All 15 species categorized a priori as invasive were (correctly) classified as high-risk, and no a priori invasive species were classified as low-risk (cf. false negatives). A family-specific description of all species screened in this study is represented in the Supplementary Materials.

For the BRA and BRA + CCA, the highest threshold scores belonged to *Fistularia petimba*, *Siganus fuscescens*, *Abudefduf* spp., *Acanthurus monroviae* and *Lutjanus argentimaculatus* (Table 1). The CCA outputs caused an increase in the BRA score for all the screened species. The highest possible (positive) change in score was calculated to be 12 for 8 species, whereas the delta value ranged from 6 to 10 (Table 1) for the remaining 15 species.

The mean CL (for all Qs) was 2.387 ± 0.041 SE, the CL_{BRA} 2.390 ± 0.038 SE and the CL_{CCA} 2.358 ± 0.089 SE, and no statistically significant difference was found between the CL_{BRA} and CL_{CCA}. The mean values for CF (0.596 ± 0.010 SE) and CF_{BRA} (0.596 ± 0.009 SE) were lower than the mean value for the CF_{CCA} (0.599 ± 0.028 SE). In all cases, the narrow standard errors indicated an overall similarity in CLs and CFs across the species assessed (due to the two indices being related).

Table 1. Extant non-native species in the Mediterranean Sea via the Suez Canal (Red Sea) and the Strait of Gibraltar (Atlantic Ocean) or via ballast water, a priori categorization (NI = noninvasive; Y = invasive), categorization depending on introduction (A = Alien; N = Neonative). Basic Risk Assessment (BRA), and BRA plus Climate Change Assessment (BRA + CCA) scores and corresponding risk outcomes, difference (Delta) between BRA + CCA and BRA scores, Confidence Level (CL) and Confidence Factor (CF) (see text for explanation) for all questions (Total) and separately for the BRA and CCA components of the risk assessment. Risk outcomes are based on a threshold of 27.5 for the BRA (Low: score within interval [−20, 1[; Medium: [1, 27.5[; High: [27.5, 68]) and of 33.0 for the BRA + CCA (Low: [−32, 1[; Medium: [1, 33.0[; High: [33.0, 80]) (note the reverse bracket notation indicating in all cases an open interval).

Species Name	Inv.	Cat	Assessment Component					Confidence					
			BRA		BRA + CCA			CL			CF		
			Score	Outcome	Score	Outcome	Delta	Total	BRA	CCA	Total	BRA	CCA
Abudefduf spp.	Y	A	35	High	47	High	12	2.49	2.49	2.50	0.62	0.62	0.63
Acanthopagrus bifasciatus	NI	A	25	Medium	31	Medium	6	2.82	2.80	3.00	0.70	0.70	0.75
Acanthurus chirurgus	Y	A	34	High	44	High	10	2.08	2.08	2.00	0.52	0.52	0.50
Acanthurus coeruleus	Y	A	34	High	44	High	10	2.31	2.35	2.00	0.58	0.59	0.50
Acanthurus gahhm	Y	A	32	High	42	High	10	2.09	2.10	2.00	0.52	0.53	0.50
Acanthurus monroviae	Y	A	35	High	45	High	10	2.44	2.49	2.00	0.61	0.62	0.50
Acanthurus sohal	Y	A	32	High	42	High	10	2.36	2.41	2.00	0.59	0.60	0.50
Chaetodipterus faber	NI	A	27	Medium	37	High	10	2.60	2.67	2.59	0.65	0.65	0.67
Chrysiptera cyanea	NI	A	14	Medium	26	Medium	12	2.45	2.39	3.00	0.61	0.60	0.71
Fistularia petimba	Y	A	45	High	57	High	12	2.47	2.47	2.50	0.62	0.62	0.63
Holacanthus ciliaris	Y	A	29	High	37	High	8	2.47	2.51	2.17	0.62	0.63	0.54
Holocentrus adscensionis	Y	N	25	Medium	35	High	10	2.05	2.08	1.83	0.51	0.52	0.46
Lutjanus argentimaculatus	Y	A	35	High	47	High	12	2.53	2.49	2.83	0.63	0.62	0.71
Lutjanus fulviflamma	Y	A	31	High	43	High	12	2.36	2.29	3.00	0.59	0.57	0.75
Lutjanus sebae	Y	A	28	High	40	High	12	2.35	2.29	2.83	0.59	0.57	0.71
Paracanthurus hepatus	NI	A	18	Medium	28	Medium	10	2.35	2.43	1.67	0.59	0.61	0.42
Paranthias furcifer	NI	N	13	Medium	19	Medium	6	2.33	2.37	2.00	0.58	0.59	0.50
Pomacanthus imperator	Y	A	31	High	37	High	6	2.31	2.33	2.17	0.58	0.58	0.54
Pomacanthus maculosus	Y	A	31	High	37	High	6	2.33	2.37	2.00	0.58	0.59	0.50
Siganus argenteus	Y	A	33	High	45	High	12	2.78	2.63	2.83	0.70	0.66	1.00
Siganus fuscescens	Y	A	36	High	48	High	12	2.56	2.53	2.83	0.64	0.63	0.71
Zebrasoma flavescens	NI	A	18	Medium	28	Medium	10	2.15	2.20	2.00	0.51	0.54	0.42
Zebrasoma xanthurum	NI	A	21	Medium	31	Medium	10	2.24	2.20	2.50	0.56	0.55	0.63

4. Discussion

The semi-enclosed Mediterranean Sea is considered to be one of the earth's most biodiverse aquatic hotspots, showing high rates of endemism. The Mediterranean Sea hosts approximately 17,000 species, and 30% of these are endemic species classified as endangered, threatened or vulnerable [30]. Diversity difference between the western and the eastern basin has reached almost sixfold so far [31]; however, endangered, threatened or vulnerable species have mainly existed in the western Mediterranean basins [30]. As for the eastern Mediterranean, called the Levantine Sea, it has been faced with invasion by Indo-Pacific species since the opening of the Suez Canal in 1869. Today, approximately 165 non-native fish marked as alien or neonative have been reported in the Mediterranean Sea [32–35].

According to the AS-ISK results, alien fishes (*Fistularia petimba*, *Siganus fuscescens*, *Abudefduf* spp., *Acanthurus monroviae*, and *Lutjanus argentimaculatus*) were the top threshold scores species while neonatives determined medium-risk. It is determined that the highest-scoring species gather around similar traits. They are (i) resource exploitation, (ii) invasiveness elsewhere and (iii) a dispersal mechanism.

Considering the AS-ISK applications that have been implemented successfully for screening invasive alien marine organisms on a global and regional scale [9–18,36–42], there is a study that used the previous version of the AS-ISK application (FISK) for risk assessment of ornamental fish [42]. However, no study exists in which the risk assessments of the species screened in this study have been compared (except for *Pomacanthus maculosus* and *Zebrasoma flavescens*). In [42], the authors screened the invasion risk of freshwater fish in Malaysia and found the high, medium and low invasion risk of screened species to be 30.43% (seven species), 34.78% (eight species) and 34.78% (eight species), respectively. In [16], they evaluated *Pomacanthus maculosus* and *Zebrasoma flavescens* in the coastal waters of South Korea and found them to be false negatives (meaning a priori invasive species classified as noninvasive). Contrary to this, the BRA and BRA + CCA screening classified them as medium-risk species. The AS-ISK aims to accurately distinguish between invasive and noninvasive spreading (present or future) in the RA sector. In particular, in the event of screening less-studied species and/or of scant literature available, responses to AS-ISK questions and, hence, the output reflect the level of expertise amongst assessors. Moreover, the low percentage of false negatives (0% in the present study) indicated the accuracy of these findings. As mentioned above, the screening of the same horizon species (that are not currently existence in the RA area but have the potentual to arrive in the future) might have differed among studies conducted in different RA areas due to several reasons (e.g., a lack of literature and dissimilar climatic conditions between the Risk Assessment (RA) area and the taxon's native habitat).

The main introductory factor for most of the screened species in the present study is considered to be the link to the aquarium trade [43]. The aquarium trade is responsible for the translocation of species outside their native range and around the world, and for European seas is recognized as the fourth most significant factor in the introduction of fish, invertebrates and plants [43,44]. Unfortunately, the threat caused by the aquarium trade to coastal ecosystems cannot yet be determined due to the scarcity of scientific evidence on the matter; however, declaring findings of non-native species by public authorities could help to increase public awareness of the importance of reducing the release of non-native ornamental freshwater/marine fish species. Apart from intentional introductions related to aquarium releases, the Suez Canal is the main factor for the accidental introduction of alien species in the Mediterranean Sea.

Comparing the effects of invasions via the Suez Canal and the Strait of Gibraltar, the Lessepsian invasion originating from the Suez Canal has caused mainly negative ecological (competition, hybridization, habitat modification, contamination with new diseases, etc.) and socioeconomic impacts (economic losses, post-consumption neurotoxic effects and traumatic amputation) [45]. In support of this, the invasiveness potential of alien species is found to be greater than that of neonatives, based on the published literature and the outcomes of the present study. (Table 1). In point of fact, this is to be expected, because when environmental conditions are suitable, neonative species firstly colonize areas adjacent to their historic range. In contrast to neonatives, alien species can occur in and invade unexpected areas due to human-mediated effects that facilitate the overcoming of dispersal barriers [46].

Thus, the veteran Lessepsian invaders, such as rabbitfish (*Siganus luridus* and *Siganus rivulatus*), lionfish (*Pterois miles*) and cornet fish (*Fistularia commersonii*), are well established and have caused drastically negative changes to pelagic and benthic habitats throughout the Mediterranean Sea [47]. In this study, congeners of some of the aforementioned species in the eastern Mediterranean were screened, and the BRA and BRA + CCA results of these species were found to be closely similar [10]. CCA, which included climate change projections, increased the BRA score of all screened species. Unfortunately, as the CCA scores indicated, these ongoing changes in physiochemical conditions in the Mediterranean Sea provide alien and neonative species with an introduction, as well as an opportunity to spread. Based on reports of the introduction of newcomers and the range expansion of extant non-native species [48], the effects of these ongoing changes are already observed throughout the Mediterranean. Specifically, the remodeling of sea currents (especially the Levantine Surface Water (LSW) and Levantine Intermediate Water (LIW) in association with the eastern Mediterranean Transient (EMT)) in the Mediterranean Sea removes dispersal barriers, and so alien species (relatively lower in neonatives) are easily introduced, invading colder sectors (e.g., the northern Aegean Sea, the Adriatic Sea and the Sicilian coast) without needing to undergo a temperature-dependent integration phase during invasion [49,50]. Additionally, crossing the Suez Canal is one of the major steps for the introduction of Indo-Pacific species and their establishment in the Mediterranean Sea; however, the dynamics of the Suez Canal play an important role as much as the inherent abilities of species in the Lessepsian invasion processes. In [51], the authors stated that seasonal strong resultant currents throughout the Suez Canal caused the enhanced introduction and dispersal of Lessepsian species into the Mediterranean Sea, while forming a restrictive physical barrier on the movement of organisms from the Mediterranean to the Suez Canal. Hence, there is a strong and non-negligible relationship between the Lessepsian migration and the seasonal changes in the Suez Canal currents. Because the widening and deepening of the Suez Canal in 2015 caused reduced sea-level differences between the Red Sea and the Mediterranean Sea, this reduction has resulted in an asymmetrical migration between the Red Sea and the Mediterranean Sea [51].

High-resolution ocean model studies have shown that the salinity and temperature of the surface-water masses of the Mediterranean Sea will be affected by climate change. This influence will not only be limited to the Mediterranean basin, it will also have an impact on the Atlantic Ocean. According to circulating model studies [52–56], at the Strait of Gibraltar, the net water transport will not change significantly, but the Mediterranean Overflow Water (MOW) layer that flows outside the Mediterranean Sea into the Atlantic will become saltier (~0.36 psu), warmer (1.8 °C) and lighter (–0.1 kg/m^3). Therefore, this future change will affect the position and the characteristics of the Mediterranean Waters flowing into the Atlantic Ocean, and consequently the Atlantic Meridional Overturning Circulation (AMOC). Accordingly, if these are depended on to predict the status of the Mediterranean Sea in future climate projections, veteran alien species that have already invaded the western Mediterranean could be introduced to the Atlantic Ocean, while new subtropical and tropical neonative species from the Atlantic Ocean could be more easily introduced into the Mediterranean.

5. Conclusions

The risk-assessment screening proposed in this study highlighted the potential impacts of previously underestimated alien and neonative species in the Mediterranean Sea, some of which are in fact listed in the global invasive database. However, while the tools of the RA method are valid and offer an initial screening of potentially invasive species, the invasion process depends on interactions in the receiving ecosystem (i.e., is context-dependent). Therefore, future site-specific and detailed studies are needed to better define whether the species screened in this study are truly invasive or not. However, it is necessary to consider the classification of alien and neonative species, because these species, which differ in terms of introduction pathways, also differ from each other in the ecological and socio-economic effects they cause in the novel environment. These differences have been proved by bio-ecological studies and pragmatic solutions in the literature. Additionally, these differences will directly affect the precautions taken in sustainable ecosystem management and will thus affect the success of these precautions.

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