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The non-indigenous isopod *Paracerceis sculpta* Holmes, 1904 invasion of the Marchica lagoon (Moroccan Mediterranean Coast)

Reda El Kamcha [1*], Soilam Boutoumit [1,2], Oussama Bououarour [1] and Hocein Bazairi [1,3]

1. BioBio Research Center, BioEcoGen Laboratory, Faculty of Sciences, Mohammed V University in Rabat, 4 Avenue Ibn Battouta, B.P. 1014 RP, 10106, Rabat, Morocco
2. University of Nantes, LETG UMR 6554, Nantes, France
3. Institute of Life and Earth Sciences, University of Gibraltar, Europa Point Campus, Gibraltar GX11 1AA

***Corresponding Author: redaelkamcha@gmail.com**

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ABSTRACT

The non-indigenous *Paracerceis sculpta* (Holmes, 1904) is native to the Pacific coast of North and Central America and has widely invaded several areas of the Mediterranean. The current study was conducted to examine the first and extended record of *P. sculpta* in the Marchica lagoon in the Mediterranean coast of Morocco (southern Alboran Sea). The species is well established in the lagoon and its presence and abundance are clearly associated with vegetated habitats. Shipping activity was the most likely vector for the introduction of *P. sculpta* into Marchica lagoon.

INTRODUCTION

Biological invasions of non-indigenous species (NIS) are the second main cause of biodiversity loss that represent a major environmental and economic threat to biodiversity in coastal marine ecosystems **(Nentwig, 2007; Katsanevakis *et al.*, 2014a; Canning-Clode, 2015; Roy *et al.*, 2019)**. The Mediterranean Sea is one of the marine basins most affected by NIS. The rate of introduction of marine invasive species has greatly increased during the last years **(Katsanevakis *et al.*, 2013; Galil *et al.*, 2016; Zenetos *et al.*, 2017)**, making the Mediterranean Sea a global hotspot for bioinvasions **(Galil *et al.*, 2017)**. In marine environment, the main vector of the introduction of NIS worldwide is attributed to intense maritime traffic **(Petrocelli *et al.*, 2019; Sardain *et al.*, 2019)**. In this context, opening artificial channels **(Galil, 2006, Galil *et al.*, 2017)** and aquaculture farming **(Savini *et al.*, 2010)** has also been recorded.

The non-indigenous sphaeromatid isopod *Paracerceis sculpta* (Holmes, 1904) is considered as the most widely distributed species within the genus **(Ulman *et al.*, 2017; Martínez-Laiz *et al.*, 2018)**. Originally described from the North and Central American Pacific Coast, *Paracerceis sculpta* has also been recorded from several biogeographical regions **(Marchini *et al.*, 2017)**. In the Mediterranean Sea, it was noticeably been reported for the first time in Tunisia in 1978 **(Regiz, 1978)**.

Up-to-now, many non-indigenous species have been recorded in the Marchica lagoon in the Mediterranean coast of Morocco **(Selfati *et al.*, 2017; Oussellam & Bazairi *in* Chartosia *et al.*, 2018; Selfati *et al.*, 2019; El Kamcha *et al.*, 2020)**. In the present paper, the first occurence of *Paracerceis sculpta* in the Marchica lagoon was profoundly studied to spotlight the relation between its abundance and the environmental variables. Furthermore, the current study was conducted to revise and update the Mediterranean distribution and spreading of that NIS.

MATERIALS AND METHODS

1. Sampling site

The Marchica lagoon, also called Nador lagoon, is located in the Moroccan Mediterranean coast (35° 09′ 39″ N; 2° 50′ 57″ W) (Fig. 1). With a surface area of 115 km^2, it has been recorded as the largest lagoon in Morocco. Besides its biological, ecological, and economic interest, the lagoon has been encountered with an abundant stressing factors released by many anthropogenic activities **(Najih *et al.*, 2017).**

The sampling approach included 28 stations (Fig. 1). In each station, macrozoobenthos samples were collected in three replicates using a Van Veen grab (0.1 m^2 covering area). The samples were collected in February, May, August, and November 2015. In addition, water temperature and salinity were measured *in situ*, using a portable multiparameter (HI 9828, HANNA Instrument).

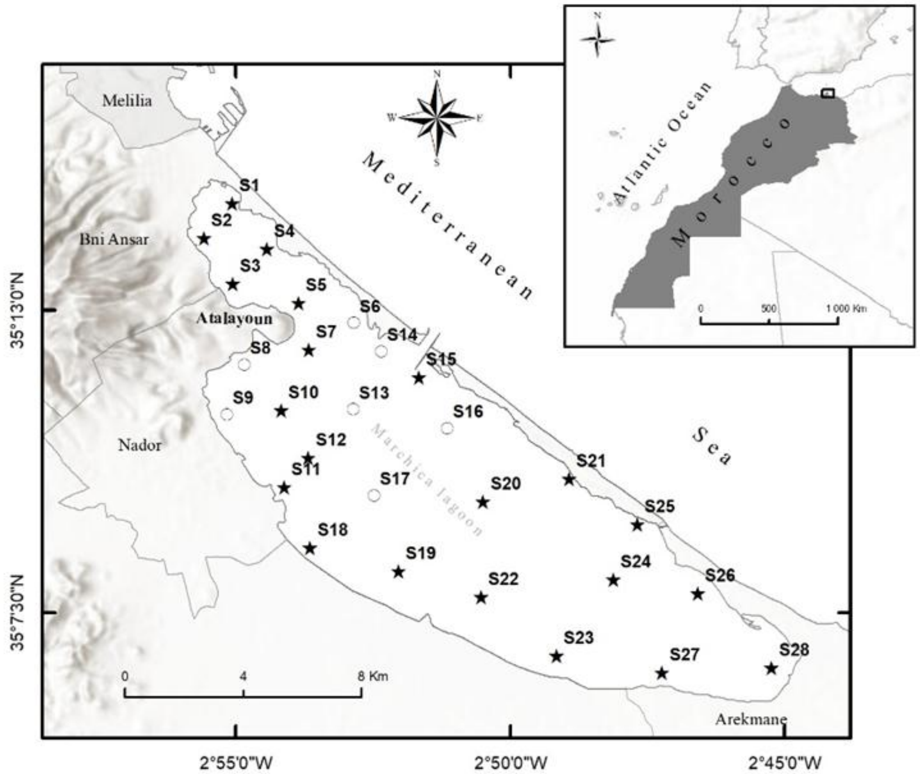

Fig. 1. Map of the Marchica lagoon showing the locations and sampling design (stations 1 to 28). *Star symbols* indicate the stations where *Paracerceis sculpta* was recorded during 2015.

2. *Literature analysis*

To outline the actual distribution of *P. sculpta* in the Mediterranean Sea, an extensive literature search was performed. Concerning the date of records, the year of the first collection was considered. In case the collection date was not recorded in literature, the species were noted to be found before the publication date.

3. *Data analysis*

The relationship between environmental and biological data was explored using the biotic and environmental linking (BIOENV) procedure from the Primer v6 software (**Clarke & Gorley, 2006**). The BIOENV analysis computed a Spearman rank correlation between the Bray–Curtis similarity matrix of abundances and the similarity matrix of transformed and normalized environmental variables based on Euclidean distance. The influence of the season and the type of habitat (bare habitat vs vegetated habitat) on the isopod abundance was investigated using two-way analysis of variance (ANOVA) and STATISTICA software (StatSoft, Inc.).

RESULTS AND DISCUSSION

The crustacean isopod *Paracerceis sculpta was* identified according to the morphological character provided by **Menzies (1962**), **Espinosa-Pérez and Hendrickx (2002)** and **Marchini *et al.* (2017)**. The adult male (Fig. 2 a) is characterized by three projective longitudinal hairy ridges on pleotelson (the central is bigger than the others), very lengthly, extended and pointed exopod, and a shape of a pleotelson apex that extends into a broad notch, with a central anterior tooth and a large curved lateral tooth at each side. On the other hand, the adult female (Fig. 2 b) has three short hairy ridges on pleotelson, two flattened uropods that are similar in length, and a concave apex of pleotelson.

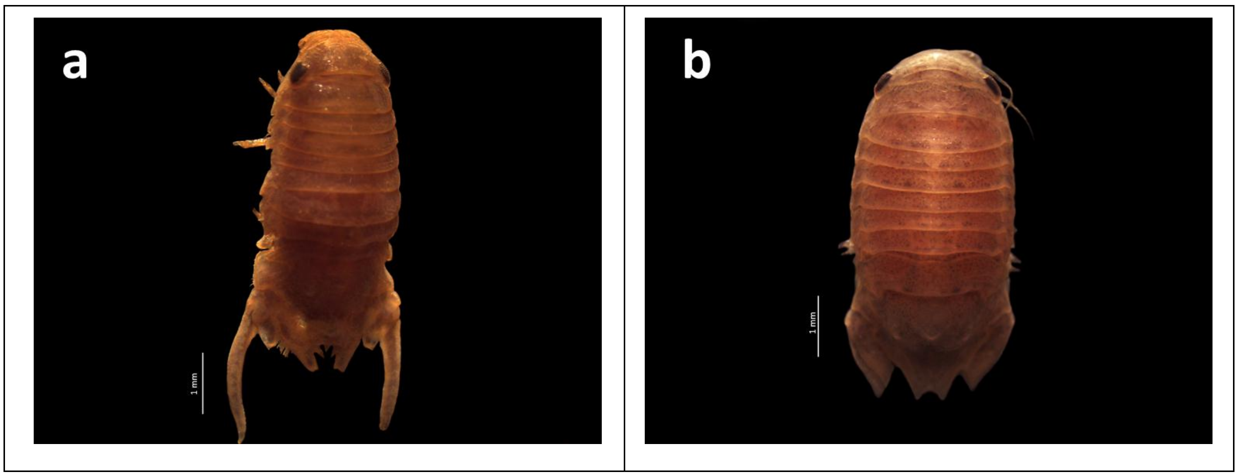

Fig. 2. *Paracerceis sculpta* (Holmes, 1904) from Marchica lagoon. (**a)** male specimen; (**b)** female specimen (Photos by Reda El Kamcha).

In the Marchica Lagoon, a total of 4353 individuals of *P. sculpta* were collected in 21 out of the 28 sampling stations during the study period. The species was very abundant, representing about 38% of the total sampled Peracarida. The abundance of *P. sculpta* in terms of seasons is summarized in Figure (3). The mean abundance was 129.55 ± 22.22 ind/m^2 with the highest value recorded in summer (232 ind/m^2).

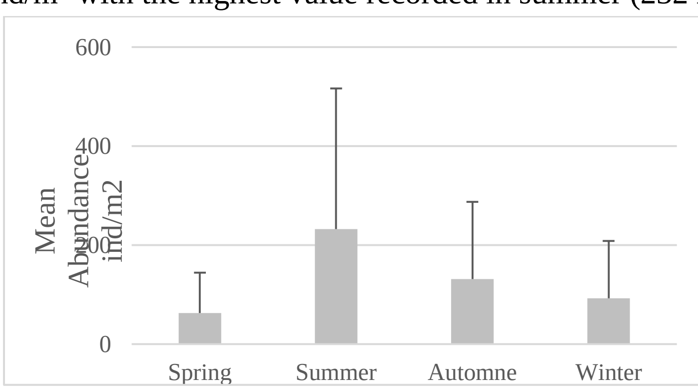

Fig. 3. Seasonal variation in mean abundance (± standard deviation) of *Paracerceis sculpta* in the Marchica lagoon**.**

Table (1) represents the results of linking environmental to biological data (BIOENV procedure). The best combinations of the maximum correlation (p = 0.467) occurred for the "Mean Biomass vegetation". Moreover, the abundance of the species differed markedly among the habitats (ANOVA; $p<0.05$) (Table 2). Similar results were obtained from a study at the Bizerte Lagoon (Tunisia), confirming the effect of vegetation biomass on the temporal distribution of those species **(Zaabar *et al.*, 2017)**.

Table 1. Biotic and environmental linking (BIOENV) analysis displaying the three highest Spearman rank correlations using square root quantitative data of *Paracerceis sculpta*, collected from February to November 2015. Bold type indicates the best combination overall.

Variables	Correlations	Selections
1. Mean Biomass vegetation ($g.m^{-2}$)	**0.467**	1
2. Mean Biomass *C. nodosa* ($g.m^{-2}$)	0.365	1;3
3. Mean Depth (m)	0.342	1;4
4. Mean Temperature (°C)	0.305	1;3;4
5. Mean Salinity (Psu)	0.233	1;3;5

Table 2. ANOVA of the influence of the type of substrate (vegetated) on the abundance of *Paracerceis sculpta* among seasons (*$p > 0.05$)

	F	P
Intercept	14.68720	0.000218
Season	0.67825	0.567290
Vegetation	10.11860	**0.001935***
Season*Vegetation	1.33100	0.268353
Error		

Paracerceis sculpta is a relatively resistant organism with wide environmental tolerances **(Hewitt & Campell, 2001; Espinosa-Pérez & Hendrickx, 2006)**. It inhabits a wide range of habitats, coasts and lagoons of subtropical to temperate regions **(Martínez-Laiz *et al.*, 2018)**. Additionally, it is able to live in a large variety of substrata, such as soft and hard bottoms, algae, sponges and bryozoans **(Pires, 1981; Castelló & Carballo, 2001; Ariyama & Otani, 2004; Marchini *et al.*, 2015)**. In the present samples, *P. sculpta* was mainly associated with seagrass beds; *Cymodocea nodosa* (Ucria) Ascherson, 1870; *Ruppia maritima* Linnaeus, 1753 and algae *Caulerpa prolifera* (Forsskål) J.V. Lamouroux, 1809; *Chaetomorpha linum* (O.F. Müller) Kützing, 1845; and other non-identified algae.

Recently, the invasive isopod *Paracerceis sculpta* has widely extended its geographic distribution in the Mediterranean Sea. It has been reported from 11 Mediterranean countries: Algeria, Cyprus, Egypt, Spain, Gibraltar, Greece, France, Malta, Morocco, Slovenia, and Tunisia (Table 3& Fig. 4). The higher invasive potential and the large plasticity of the species appear to provide an additional reason for its large worldwide distribution **(Katsanevakis *et al.*, 2014b)**. In Morocco, the species was first recorded in Smir and M'diq Marinas in 2011/2012 **(Martínez-Laiz *et al.*, 2018)** and has recently extended its range to the Marchica lagoon.

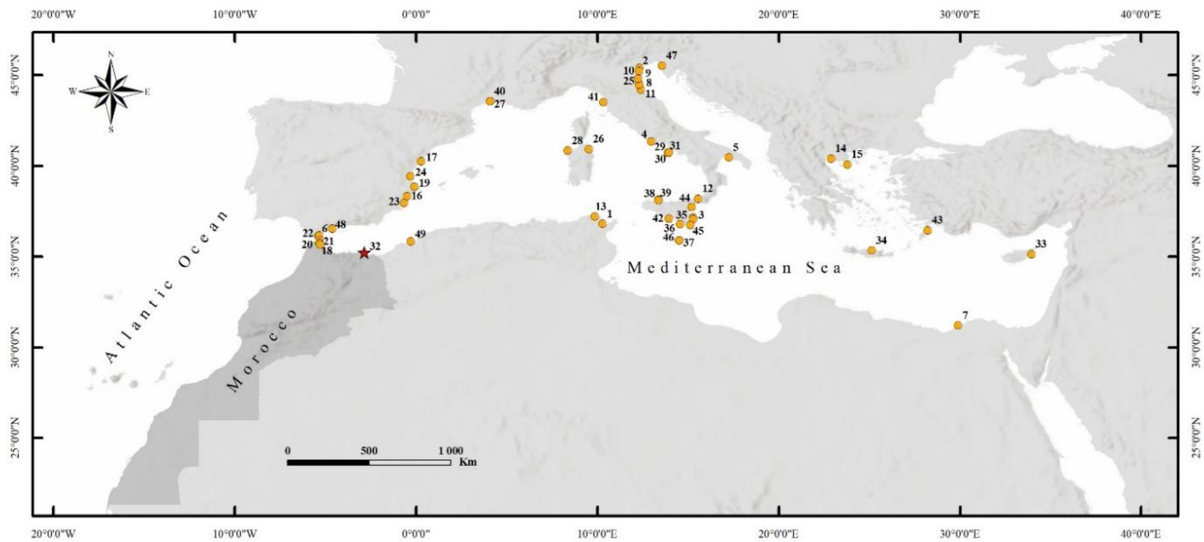

Fig. 4. Known distribution of *Paracerceis sculpta* in the Mediterranean Sea. Red star (present study). Numbers of records refer to Table (3).

The invasion of that isopod in the Marchica lagoon is most probably due to human introduction via ship transport either as bio-fouling or in ballast waters, because Marchica hosts a yachting marina (Atalayoun) (**El Kamcha *et al.*, 2020)**. Another plausible explanation is the surrounding harbors and marinas (Beni Ansar harbor and the Melilla marina) that could act as a potential site for the introduction in Marchica lagoon **(El Kamcha *et al.*, 2020)**. Accordingly, ports and marinas constitute an important site for the introduction of species carried by international shipping **(Ferrario *et al.*, 2017; Ulman *et al.*, 2017; Zenetos & Galanidi 2020)**. Remarkably, marinas are considered as hot-spots for NIS, and with a certain level of maritime traffic, these can be a potential vector for the spread and establishment of marine NIS in other localities **(Clarke Murray *et al.*, 2014; Ulman *et al.*, 2019)**. *Paracerceis sculpta* is well established that has become the most abundant peracarida in the Marchica Lagoon. The present findings recorded an increase in the number of NIS found in the Marchica Lagoon to five species; namely, *Bursatella leachii* Blainville, 1817 **(Selfati *et al.*, 2017)**, *Callinectes sapidus* Rathbun, 1896 **(Oussellam & Bazairi *in* Chartosia *et al.*, 2018)**, *Hemiramphus far* Forsskål, 1775 **(Selfati *et al.*, 2019)**, *Caprella scaura* Templeton, 1836 **(El Kamcha *et al.*, 2020)** and *P. sculpta* in the present study.

Table 3. Records of *Paracerceis sculpta* in the Mediterranean Sea ordered by year of record. The asterisk indicates the first Mediterranean record.

Record no.	Country	Locality	Latitude (N)	Longitude (E)	Habitat	Sampling date	Reference
1	Tunisia	Lake of Tunis	36.808°	10.275°	Lagoon	1978	Regiz, 1978
2	Italy	Venice	45.405°	12.317°	Lagoon	1981	Forniz and Sconfietti, 1983
3	Italy (Sicily)	Golfo di Augusta	37.211°	15.207°	Marina	1983	Forniz and Maggiore, 1985
4	Italy	lago di Caprolace	41.356°	12.975°	Marina	1983	Forniz and Maggiore, 1985
5	Italy	Mar Piccolo di Taranto	40.465°	17.234°	Marina	1983	Forniz and Maggiore, 1985
6	Gibraltar	Gibraltar	36.136°	-5.361°	Marina	1991	Castelló and Carballo, 2001
7	Egypt	Eastern Harbour of Alexandria	31.208°	29.894°	Marina	1995	Ramdan *et al.*, 1998
8	Italy	Cesenatico (Onda Marina)	44.204°	12.397°	Marina	2004	Savini *et al.*, 2006
9	Italy	Chioggia (Sporting club)	45.225°	12.292°	Marina	2004	Savini *et al.*, 2006
10	Italy	Goro (Nautica Mondo)	44.803°	12.254°	Marina	2004	Savini *et al.*, 2006
11	Italy	Marina di Ravenna	44.490°	12.288°	Marina	2004	Savini *et al.*, 2006
12	Italy (Sicily)	Faro coastal lake (Messina)	38.195°	15.563°	Marina	< 2009 (date of publication)	Cosentino *et al.*, 2009
13	Tunisia	Bizerte Lagoon	37.202°	9.847°	Marina	from October 2009 to September 2010	Zaabar *et al.*, 2017
14	Greece	Thermaikos	40.406°	22.893°	Marina	2009 and 2010	Katsanevakis *et al.*, 2014b
15	Greece	Toroneos	40.087°	23.789°	Marina	2009 and 2010	Katsanevakis *et al.*, 2014b
16	Spain	Marina Alicante	38.34°	-0.485°	Marina	2011/2012	Martínez-Laiz *et al.*, 2018
17	Spain	Marina Benicarló	40.249°	0.288°	Marina	2011/2012	Martínez-Laiz *et al.*, 2018
18	Spain	Marina Ceuta	35.895°	-5.317°	Marina	2011/2012	Martínez-Laiz *et al.*, 2018
19	Spain	Marina Dénia	38.85°	-0.11°	Marina	2011/2012	Martínez-Laiz *et al.*, 2018
20	Spain	Marina La Línea	36.16°	-5.36°	Marina	2011/2012	Martínez-Laiz *et al.*, 2018
21	Morocco	Marina M'Diq	35.684°	-5.313°	Marina	2011/2012	Martínez-Laiz *et al.*, 2018
22	Morocco	Marina Smir	35.75°	-5.34°	Marina	2011/2012	Martínez-Laiz *et al.*, 2018
23	Spain	Marina Torrevieja	37.971°	-0.681°	Marina	2011/2012	Martínez-Laiz *et al.*, 2018
24	Spain	Marina Valencia	39.43°	-0.33°	Marina	2011/2012	Martínez-Laiz *et al.*, 2018
25	Italy	Pialassa Baiona	44.493°	12.292°	Lagoon	2012	Vincenzi et al. 2013
26	Italy (Sardinia)	Olbia	40.927°	9.526°	Marina	2014	Ferrario *et al.*, 2017
27	France	Port de la Grande-Mote	43.553°	4.083°	Marina	2014	Marchini *et al.*, 2015
28	Italy (Sardinia)	Porto Torres (Marina Turritana)	40.845°	8.364°	Marina	2014	Ferrario *et al.*, 2017
29	Italy	Ischia Island (Marina di Casamicciola)	40.75°	13.908°	Marina	2015	Ulman *et al.*, 2017
30	Italy	Ischia Island (Marina di Sant'Angelo)	40.696°	13.894°	Marina	2015	Ulman *et al.*, 2017
31	Italy	Ischia Island (Porto d'Ischia)	40.745°	13.94°	Marina	2015	Ulman *et al.*, 2017
32	Morocco	Marchica lagoon	35.168°	-2.858°	Lagoon	From February to November 2015	Present study
33	Cyprus	Famagusta (Famagusta Port)	35.134°	33.938°	Marina	2016	Ulman *et al.*, 2017
34	Greece	Heraklion (Old Venetan Harbour)	35.347°	25.145°	Harbor	2016	Ulman *et al.*, 2017
35	Italy (Sicily)	Licata (Marina di Cala del Sole)	37.091°	13.939°	Marina	2016	Ulman *et al.*, 2017
36	Italy (Sicily)	Marzamemi (Marina di Marzamemi)	36.733°	15.121°	Marina	2016	Ulman *et al.*, 2017
37	Malta	Msida (Msida Yacht Marina)	35.9°	14.504°	Marina	2016	Ulman *et al.*, 2017
38	Italy (Sicily)	Palermo (Marina Villa Igiea)	38.127°	13.371°	Marina	2016	Ulman *et al.*, 2017
39	Italy (Sicily)	Palermo (Porto La Cala)	38.121°	13.369°	Marina	2016	Ulman *et al.*, 2017
40	France	Port de la Grande-Mote	43.554°	4.08°	Marina	2016	Ulman *et al.*, 2017
41	Italy	Port of Livorno	43.55°	10.291°	Marina	2016	Tempesti *et al.*, 2020
42	Italy (Sicily)	Porto Turistco Marina di Ragusa	36.781°	14.547°	Marina	2016	Ulman *et al.*, 2017
43	Greece	Rhodes (Mandraki Port)	36.45°	28.226°	Marina	2016	Ulman *et al.*, 2017
44	Italy (Sicily)	Riposto (Porto dell'Etna)	37.731°	15.21°	Marina	2016	Ulman *et al.*, 2017
45	Italy (Sicily)	Siracusa (Porto Grande)	37.063°	15.282°	Marina	2016	Ulman *et al.*, 2017
46	Malta	Valleta (Grand Harbour Marina)	35.892°	14.514°	Marina	2016	Ulman *et al.*, 2017
47	Slovenia	Harbour of Piran	45.526°	13.567°	Harbor	2017	Ferrario *et al.*, 2018
48	Spain	Marina Fuengirola	36.54°	-4.617°	Marina	2017	Martínez-Laiz *et al.*, 2018
49	Algeria	Arzew port	35.849°	-0.298°	Marina	December 2018 and April 2019	Bensari *et al.*, 2020

CONCLUSION

The increasing number of NIS in the Marchica Lagoon confirms that that coastal ecosystem is facing a threat due to biological invasions (**El Kamcha *et al.*, 2020**). Accordingly, researches on the effects and risks of invasive species in the Marchica lagoon should be conducted to evaluate their invasive potential impact and to assist the development of management plans to control those species.

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