Mediterranean Marine Science

Vol 25, No 1 (2024)

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doi: 10.12681/mms.35846

Review Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available on line at http://www.medit-mar-sc.net
www.hcmr.gr
DOI: http://doi.org/10.12681/mms.35846

Updating the national list of marine alien species in Morocco

Bilal MGHILI[1], Imane LAMINE[2, 3], Mohamed RAMI LAAMRAOUI[4], Mustapha AKSISSOU[1] and Marika GALANIDI[5]

[1] LESCB, URL-CNRST N° 18, Faculty of Sciences, Abdelmalek Essaadi University, Tetouan, Morocco
[2] Laboratory of Aquatic Systems: Marine and Continental Ecosystems, Department of Biology, Faculty of Sciences, Ibn Zohr University, BP 8106, Agadir, Morocco
[3] Higher Institute of Nursing Professions and Technical Health, Errachidia, Morocco
[4] Laboratory of Research and Development in Engineering Sciences, Faculty of Science and Technology Al-Hoceima, Abdelmalek Essaadi University, Tetouan, Morocco
[5] ÜEE LLC, Marine Ecology Division, Teknopark Izmir A1/49, 35437 Urla, Türkiye

Corresponding author: Bilal MGHILI; b.mghili@uae.ac.ma

Contributing Editor: Argyro ZENETOS

Received: 13 November 2023; Accepted: 31 March 2024; Published online: 30 April 2024

Abstract

This study provides an updated list of alien marine species that have been introduced to Morocco by analyzing both previous data and new findings. A total of 46 marine alien and 15 cryptogenic and crypto-expanding species were recorded in Moroccan waters. Alien species are more abundant in the Mediterranean (35 species) than in the Atlantic (16 species) waters. The number of records of introductions increased in recent years in Moroccan waters. Macrophyta ranked first in terms of the number of species (19 species), followed by Mollusca (8 species), Crustacea (7 species), Cnidaria (5 species), Pisces (3 species), and Tunicata (2 species), while Nematoda and Annelida each contain only one species. The finding of *Phyllorhiza punctata*, a new species recorded for the first time in the Moroccan Mediterranean waters, is described. The Moroccan Mediterranean harbors more established species (77%) than the Atlantic (69%), contrary to casual records (25% in the Atlantic and 20% in the Mediterranean). Within Moroccan waters, 12 species have been identified as either invasive or potentially invasive: *Rugulopteryx okamurae*, *Sargassum muticum*, *Asparagopsis armata*, *Asparagopsis taxiformis, Caulerpa cylindracea, Codium fragile*, *Agarophyton vermiculophyllum, Artemia monica*, *Callinectes sapidus, Caprella scaura, Microcosmus squamiger*, and *Branchiomma luctuosum.* The Transport-Stowaway pathway accounted for 23 and seven records in the Mediterranean and Atlantic, respectively. In the Mediterranean, the second most frequent pathway was Transport-Contaminant (6 species), while in the Atlantic was Escape (4 species). This list serves as a starting point for management measures and for selecting invasive alien species to assess their impact.

Keywords: Biological invasions; Checklist; Non-Indigenous Species; Invasive species; Mediterranean; Morocco.

Introduction

The Mediterranean Sea stands out as a region of exceptional marine biodiversity, yet it is also among the most vulnerable areas in the world to a wide range of anthropogenic activities such as pollution, climate change effects, habitat loss, and biological invasions (Azzurro *et al.*, 2019; Mghili *et al.*, 2020). More than 1000 alien species have been documented to date in the Mediterranean Sea, of which more than half are classified as established and spreading (Galanidi & Zenetos, 2022; Zenetos *et al.*, 2022a, b). The introduction of alien species into ecosystems can produce fundamental changes in the structure of native communities and ecosystem functioning (e.g., Peyton *et al.*, 2019; Howard *et al.*, 2019) with losses in native biodiversity (e.g., García-Gómez *et al.*, 2020; Bellard *et al.*, 2016; Tsirintanis *et al.*, 2022). According to Bellard *et al.* (2016), biological invasions have been involved in the extinction of 62% of amphibians, reptiles, birds, and mammals just in the last century. The impacts of biological invasions can have profound effects on ecosystem services (Tsirintanis *et al.*, 2022). Moreover, the presence of invasive species poses a significant threat to human health through a range of mechanisms, including pathogen transmission, envenomation, and intoxication (Galil, 2018; Peyton *et al.*, 2019; Tsirintanis *et al.*, 2022). Habitat disturbance, climate change, and increased global trade are predicted to play a significant role in biological invasions and the future movement of alien species (Bellard *et al.*, 2018; Azzurro *et al.*, 2019). The most successful method to control biological invasions is the prevention of novel introductions by managing their main

pathways. When an alien species has been established in a novel ecosystem, its elimination is very costly and sometimes impossible (Turbelin *et al.*, 2022). Collecting data on the biology and ecology of newly introduced species and on the pathways of introduction is essential to prevent further introductions (Zenetos *et al.*, 2017). Comprehensive lists of alien species and their invasiveness in the different regions of the Mediterranean are crucial in this regard. Therefore, there is an urgent need to collect and report data on alien species in the different Mediterranean countries. Despite the ecological importance of the southern basin of the Mediterranean Sea, research on non-native species in this region has been relatively scarce compared to the northern basins, highlighting the need for further endeavors to enhance our understanding of non-native species in this particular area (Zenetos *et al.*, 2022a).

Situated at the northwestern extremity of the African continent, Morocco occupies a highly strategic location between the Mediterranean Sea and the Atlantic Ocean, with a shoreline of more than 3500 km (Mghili *et al.*, 2020): the Atlantic coast extends more than 3000 km while the Mediterranean coast extends for more than 500 km. The Strait of Gibraltar is a point of connection between the Mediterranean Sea and the Atlantic Ocean and is considered a vital maritime route. This area is also heavily impacted by human impacts (Mghili *et al.*, 2020; Bouzekry *et al.*, 2022). Thus, Morocco is a transition region between the Atlantic and the Mediterranean basins, under the influence of the Strait of Gibraltar, and therefore a key region for understanding the influx of alien species into the Mediterranean Sea from the Atlantic. At this time, data concerning alien species in Moroccan waters are rare and fragmentary (Menioui, 2021), with most studies not specifically focusing on alien species. The majority of Mediterranean countries have now established a list of alien species (e.g., Ounifi-Ben Amor *et al.*, 2016; Grimes *et al.*, 2018; Servello *et al.*, 2019; Zenetos *et al.*, 2020; Băncilă *et al.*, 2022; Massé *et al.*, 2023; Png-Gonzalez *et al.*, 2023). This is not the case for Moroccan waters, which have received little attention compared to other Mediterranean countries.

The objective of our study was to draw up a list of alien marine species introduced into the Moroccan marine environment, and to discuss their dynamics, their distribution, their impact, the current status of their populations, and also their main pathways of introduction and propagation.

Materials and Methods

Data were compiled for the Moroccan coastline, including both the Mediterranean and the Atlantic parts. In our study, we gathered data on introduced species in Moroccan coastal areas from various sources, including scientific and grey literature such as PhD and MSc theses, technical reports, unpublished observations, and databases on alien species and biodiversity. We used a range of databases, including the MAMIAS database (UNEP/MAP, 2017), Global Invasive Species Database (GISD), FishBase, Global Invasive Species Information Network (GISIN), CIESM Atlas, Global Biodiversity Information Facility (GBIF), and Mediterranean Marine Invasive Species information system (MedMIS) managed by IUCN. Our analysis includes information on animals and plants, and we identified new records of introduced species in Moroccan waters. We recorded the year of first record, natural range, pathway of introduction, and potential ecological and economic impacts for each alien species, and used the World Register of Marine Species (WoRMS) nomenclature. The year of first record for each species is given for the Moroccan coastline, even if earlier records exist in Ceuta, Melilla, or the Chafarinas Islands (Spain). In the absence of data concerning the observation date, the publication date was considered as the first registration date. The geographical distribution of the species reported in this study were collected from studies conducted on these species in Moroccan waters.

Alien species were classified into four categories in terms of establishment success, namely established, casual, questionable records, and species of unknown establishment (Zenetos *et al.*, 2020). Species with at least two occurrences in the study area (three occurrences for fish) spread over space and time, indicating self-sustaining populations, are categorized as established species, while those having been observed only once with no indication of self-sustaining populations, are listed as casual species. Species with uncertain or unverified identification (lack of sufficient description, illustration, or unverified citizen scientist observations) are referred to as questionable records and are not included in the calculations for alien species total numbers but they are, however, listed for future reference and to bring attention to material in need of validation. Species records in Ceuta/Melilla/Chafarinas were combined with Moroccan records to determine establishment success. Among established species, those impacting biodiversity, socio-economics, and human health are classified as invasive alien species. Establishment success was assessed separately for the Mediterranean and Atlantic species in this study. Particular attention was paid to the biogeographical status (alien or cryptogenic) of the cited species in relation to their original distribution based on the literature. Cryptogenic and crypto-expanding species are listed separately in this study.

The main pathways of introduction into Moroccan waters were evaluated using the six main categories of the Convention on Biological Diversity (CBD) classification (Harrower *et al.*, 2018), as further refined in Pergl *et al.* (2020):

1. "Release in nature" (REL) relates to the intentional introduction of living alien species for the purpose of human use in the natural environment (i.e., fishery in the wild—including game fishing, intentional release in the wild of species kept in domestic aquaria and other intentional release);
2. "Escape from confinement" (EC) refers to the accidental escape of live species from confinement (i.e., aquaculture/mariculture, botanical gardens/zoos/

aquaria -excluding domestic aquaria-, live food and live bait);
3. "Transport-contaminant" (TC) refers to species transported by host/vector, including contaminant on animals, contaminant on plants, and parasites on animals;
4. "Transport-stowaway" (TS) refers to the transport of live species associated to the transporting vessels and equipment (ship/boat hull fouling, ship/boat ballast water, hitchhikers on ship/boat, angling/fishing equipment, organic packing material, and other means of transport);
5. "Corridor" (COR) (interconnected waterways/basins/seas);
6. "Unaided" (UNA) (natural dispersal across borders of invasive alien species that have been introduced through all other pathways).

Finally, when calculating temporal trends in alien species introductions, we followed the 6-year assessment periods of the Marine Strategy Framework Directive (EC, 2008) and the Integrated Monitoring and Assessment Programme for the Mediterranean (UNEP/MAP, 2017), in order to facilitate comparisons with marine non-indigenous species trends in other countries and larger geographic divisions of the Mediterranean.

Results

A new record of an alien species in Morocco

One new alien species is herein reported for the first time in Morocco. An individual of *Phyllorhiza punctata* von Lendenfeld, 1884 was photographed near the coast of Nador (35.171389 º N / 2.927500 º W) on August 3, 2017. The species was sighted and photographed by scuba divers and the individual was not collected. Later, a single individual was stranded in the same area (Fig. 1). The individual was quickly identified by experts as *P. punctata* based on its distinctive coloration and bell shape. This is the first report of this alien species in Moroccan waters. Its native distribution includes the central Indo-Pacific and temperate Australasia (Tsiamis *et al.*, 2018). The appearance of *P. punctata* in the Moroccan Mediterranean is not surprising, since it has already been indicated in neighboring countries such as in Tunisia (Gueroun *et al.*, 2015).

Taxonomic identity and status

A total of 46 marine alien species were recorded in Moroccan waters. Records of alien species in the marine environment in Morocco are given in Tables 1 and 2, separately for plants and animals in the Mediterranean and Atlantic coasts. The repartition between the kingdoms is significantly unbalanced: 59% belonging to animals and 41% to plants and are presented in eight broad taxa groups (Table 1 and Table 2). Macrophyta (containing Chlorophyta, Ochrophyta, and Rhodophyta) have the highest richness amongst alien species (19 species, 41% of all species), followed by Mollusca (8 species, 17%), Crustacea (7 species, 15%), Cnidaria (5 species, 11%), Pisces (3 species, 6.5%), and Tunicata (2 species, 4%). Nematoda and Annelida each contain only one species (Figs. 2A, B). Of the total species, 34 taxa (74%) were well established in Moroccan waters with self-sustaining, and some of them invasive (Fig. 3), populations in at least one of the sites in the study area, while ten taxa were listed as casual (22%). In each group, the ratio of established/casual alien species ranged considerably between

Fig. 1: Australian spotted jellyfish, *Phyllorhiza punctata*, observed on the coast of Nador, 3 August 2017.

Table 1. Alien and cryptogenic Macrophyte and animal species recorded in the Moroccan Mediterranean, including origin, locality, year of first observation, author, and vector of introduction (TS: Transport Stowaway, TC: Transport Contaminant, COR: Corridor, EC: Escape from Confinement, REL: Release into Nature, UNA: Unaided, UNK: Unknown).

Taxa	Species	Status of the species	Establishment success of the species	Origin	Year	Pathway	Locality	References
Rhodophyta	*Asparagopsis armata* Harvey, 1855	Alien	Invasive	SW Pacific	1984	TS	Saïdia, Al Hoceima, Jabha, Tamernoute, M'diq, Cabo Negro, Jbel Moussa, Ksar-Sghir	González-García & Conde Poyales (1994)
	Asparagopsis taxiformis (Delile) Trevisan de Saint-Léon, 1845	Alien	Invasive	Indo Pacific and Atlantic	1993	TS	Cap trois fourches, Jbel Moussa	Altamirano (1999)
	Antithamnion amphigeneum Millar, 1990	Alien	Established	SW Pacific	1989	TS	Saïdia, Nador, Al Hoceima, Cala Iris, Jabha, M'diq	González-García & Conde Poyales (1994)
	Bonnemaisonia hamifera Hariot, 1891	Alien	Established	Indo-Pacific	1989	TS	Saïdia, Al Hoceima, Cala Iris, Jabha, Tamernoute, M'diq, Cabo Negro, Ksar-Sghir	González García & Conde Poyales (1994)
	Hypnea spinella (Agardh) Kützing, 1847	Alien	Established	Pantropical	2012	TS	Cala Iris, Al Hoceima, Tala Youssef	Moussa *et al.* (2018)
	Melanothamnus harveyi (Bailey) Díaz-Tapia & Maggs, 2017	Alien	Casual	NW Pacific	2012	TS	Al Hoceima	Moussa *et al.* (2018)
	Diplothamnion jolyi van den Hoek, 1978	Alien	Established	Atlantic and Pacific	2012	UNK	Cala Iris, Al Hoceima, Tala Youssef	Moussa *et al.* (2015)
	Spongoclonium caribaeum (Børgesen) M.J. Wynne, 2005	Alien	Casual	W Atlantic	2012	UNK	Al Hoceima	Moussa *et al.* (2018)
	Lophurella stichidiosa (Funk) Díaz-Tapia comb. nov.	Alien	Established	Australia	1989	UNK	Al Hoceima	González-García & Conde Poyales (1994)
	Lophocladia trichoclados (Montagne) F. Schmitz, 1893	Alien	Established	Indo-Pacific	2019	TS	Al Hoceima	Bazairi *et al.* (2020)
	Womersleyella setacea (Hollenberg) R.E. Norris 1992	Alien	Casual	Indo-Pacific	2019	TS	Al Hoceima	Bazairi *et al.* (2020)
	Polysiphonia atlantica Kapraun & J.N. Norris, 1982	Cryptogenic	Casual	Unknown	1989	TS	Al Hoceima, Tamernoute, M'diq, Cabo Negro, Ksar-Sghir	González-García & Conde Poyales (1994)
	Chondria coerulescens (J. Agardh) Falkenb, 1901	Cryptogenic	Established	Unknown	1989	TC	Saïdia, Nador, Cala Iris, Al Hoceima, Jabha, Tamernoute, M'diq, Cabo Negro, Ksar-Sghir	González-García & Conde Poyales (1994)
	Antithamnionella elegans (Berthold) Price & John, 1986	Cryptogenic	Established	Unknown	1989	TS	Saïdia, Nador Al Hoceima, Cala Iris, Jebha, M'diq	González-García & Conde Poyales (1994)
	Antithamnionella boergesenii (Cormaci & G. Furnari) Athanasiadis, 1996	Cryptogenic	Casual	Unknown	2012	TS	Al Hoceima, Cala Iris, Jebha	Moussa *et al.* (2018)
	Antithamnionella spirographidis Wollaston, 1968	Cryptogenic	Established	Unknown	1989	UNK	Saïdia, Jabha, M'diq	González-García & Conde Poyales (1994)

Continued

Table 1 continued

Taxa	Species	Status of the species	Establishment success of the species	Origin	Year	Pathway	Locality	References
	Anotrichium furcellatum (J. Agardh) Baldock, 1976	Cryptogenic	Casual	Unknown	1989	UNK	Tamernoute, Cabo Negro, Ksar Sghir	Benhissoune *et al.* (2003)
	Champia compressa Harvey, 1838	Cryptogenic	Established	Unknown	2012	UNK	Cala Iris, Torres, Al Hoceima	Moussa *et al.* (2015)
	Tiffaniella gorgonea (Montagne) Doty & Meñez, 1960	Cryptogenic	Established	Unknown	2013	TS	Al Hoceima	Salhi *et al.* (2019)
	Vertebrata fucoides (Hudson) Kuntze 1891	Cryptogenic	Casual	Unknown	1989	TS	Nador, Al Hoceima, Tamernoute, M'diq, Cabo Negro, Ksar-Sghir	González-García & Conde Poyales (1994)
Chlorophyta	*Codium fragile* (Suringar) Hariot, 1889	Alien	Invasive	NW Pacific	1989	TC/TS	Nador, Karia Arkemanne, Cala Iris, Al Hoceima, Jebha, Jbel Moussa	González-García and Conde Poyales (1994)
	Caulerpa cylindracea Sonder, 1845	Alien	Invasive	Indo Pacific	2014	EC/TS	Tanger, Jbel Moussa	Bazairi *et al.* (2016)
	Caulerpa taxifolia (M.Vahl) C. Agardh, 1817	Alien	Questionable record	Indo Pacific	1987	EC/TS		Riadi (1998)
	Caulerpa chemnitzia (Esper) J.V. Lamouroux, 1809	Cryptogenic	Casual	Indo Pacific	2019	UNK	Al Hoceima	Bazairi *et al.* (2020)
	Acetabularia calyculus J.V. Lamouroux, 1824	Cryptogenic	Casual	Unknown	1989	UNK	Nador	González García & Conde Poyales (1994)
Ochrophyta	*Rugulopteryx okamurae* (E.Y. Dawson) Hwang *et al.* 2009	Alien	Invasive	Pacific	2017	TS	Nador, Al Hoceima, Stehat, Fnideq, M'diq, Jbel Moussa	El Aamri *et al.* (2018)
	Colpomenia peregrina Sauvageau, 1927	Alien	Established	Indo Pacific	1989	TC/TS	Al Hoceima, Jabha, M'diq, Ksar-Sghir	González-García & Conde Poyales (1994)
	Cutleria multifida (Turner) Greville, 1830	Alien	Casual	Indo Pacific	1989	EC/TS	Al Hoceima, Jabha	González-García & Conde-Poyales (1994)
	Sargassum muticum (Yendo) Fensholt, 1955	Alien	Invasive	NW Pacific	2019	UNK	Al Hoceima	Bazairi *et al.* (2020)
Mollusca	*Magallana/Crassostrea* sp./spp.	Alien	Established	NW Pacific	1999	EC	Mar Chica lagoon, M'diq, Marina Smir, Jbel Moussa	Chaouti and Bayed (2005)
	Crepidula fornicata Linnaeus, 1758	Alien	Unknown	NW Atlantic	1987	TC/TS	Mar Chica lagoon	Menioui (1987)
	Bursatella leachii Blainville, 1817	Cryptogenic	Established	Circumtropical	2016	TS	Mar Chica lagoon	Selfati *et al*. (2017)
Crustacea	*Penaeus japonicus* Spence Bate, 1888	Alien	Established	Indo-Pacific	1987	EC	Mar Chica lagoon, Moulouya estuary	Menioui *et al.* (2021)
	Artemia monica Verrill, 1869	Alien	Invasive	Americas	2000	TC	Mar Chica lagoon	Amat *et al.* (2005)
	Caprella scaura Templeton, 1836	Alien	Invasive	Indo-Pacific	2011	TS	Mar Chica lagoon, Marina Smir	Ros *et al.* (2014)

Continued

Table 1 continued

Taxa	Species	Status of the species	Establishment success of the species	Origin	Year	Pathway	Locality	References
	Paracerceis sculpta Holmes, 1904	Alien	Established	Indo-Pacific	2011	TC/TS	Mar Chica lagoon, Marina Smir, M'diq	Martínez-Laiz *et al.* (2018)
	Callinectes sapidus Rathbun, 1896	Alien	Invasive	W Atlantic	2017	UNA	Ksar-Sghir, M'diq, Martil, Al Hoceima, Mar Chica lagoon, Moulouya estuary	Oussellam & Bazairi in Chartosia *et al.* (2018)
	Laticorophium baconi (Shoemaker, 1934)	Alien	Established	Pacific	2011	TS	Tangier, Kabila, M'diq	Guerra-García *et al.* (2023)
	Merhippolyte ancistrota Crosnier & Forest, 1973	Crypto-expanding	Casual	E Atlantic	1980	UNK	Alboran Sea off the coast of Morocco	d'Udekem D'acoz & Duriš (1996)
Tunicata	*Microcosmus squamiger* Michaelsen, 1927	Alien	Invasive	Circumtropical	1991	TS	Nador	Zibrowius (1992)
	Polyandrocarpa zorritensis (Van Name, 1931)	Alien	Casual	E Pacific	2023	TS	Saïdia	El bouchikhi (2023a)
	Styela plicata Lesueur, 1823	Alien	Questionable record	N Pacific	2024	TS	Saïdia	El bouchikhi (2024c)
	Botrylloides niger Herdman, 1886	Alien	Questionable record	W Atlantic	2024	TS	Saïdia	El bouchikhi (2024a)
Annnelida	*Branchiomma luctuosum*, Grube, 1870	Alien	Invasive	Indo-Pacific	2021	TS	Saïdia	Mabrouki *et al.* (2021)
Nematoda	*Anguillicola crassus* Kuwahara *et al.*, 1974	Alien	Established	N Pacific	1998	TC	Moulouya estuary	Rahhou *et al.* (2001)
Bryozoa	*Tricellaria inopinata* d'Hondt & Occhipinti Ambrogi, 1985	Alien	Questionable record	N Pacific	2024	TS	Saïdia	El bouchikhi (2024b)
Fish	*Etrumeus golanii* Di Battista *et al.*, 2012	Alien	Established	Indo-Pacific	2018	UNA	Fnideq	Tamsouri *et al.* (2019)
	Hemiramphus far Rüppell, 1838	Alien	Established	Indo-Pacific	2015	UNA	Mar Chica lagoon	Selfati *et al.* (2019)
	Fundulus heteroclitus Linnaeus, 1766	Alien	Established	Atlantic	2017	UNK	Moulouya estuary	Taybi *et al.* (2020)
Cnidaria	*Clytia linearis* Thorneley, 1900	Alien	Established	Circumtropical	1984	TS/UNA	Alboran Sea off the coast of Morocco	Ramil & Vervoort (1992)
	Eudendrium carneum Clarke, 1882	Alien	Casual	Circumtropical	2023	TS	Saïdia	El bouchikhi (2023b)
	Phyllorhiza punctata von Lendenfeld, 1884	Alien	Casual	Circumtropical	2017	TS	Nador	**Present study**
	Oculina patagonica de Angelis D'Ossat, 1908	Cryptogenic	Casual	Unknown	2013	UNK	Cap des Trois Fourches	Bazairi *et al.* (2014)

Table 2. Alien and cryptogenic Macrophyte and animal species recorded in the Moroccan Atlantic.

Taxa	Species	Status of the species	Establishment success of the species	Origin	Year	Pathway	Locality	References
Rhodophyta	*Asparagopsis armata* Harvey, 1855	Alien	Invasive	SW Pacific	1984	TS	Tangier, Assilah, Larache, Temara, Bouznika, Mohammedia, Casablanca, El Jadida, Oualidia lagoon, Agadir, Sidi Ifni, Tan Tan	Werner (1948)
	Agarophyton vermiculophyllum (Ohmi) Gurgel, J.N. Norris et Fredericq, 2018	Alien	Invasive	Pacific	2023	UNK	Oualidia lagoon	Nadri *et al.* (2023)
Ochrophyta	*Undaria pinnatifida* (Harv.) Suringar, 1873	Alien	Unknown	Pacific	1987	TC	Rabat	Menioui (1987)
	Sargassum muticum (Yendo) Fensholt, 1955	Alien	Invasive	NW Pacific	2012	TC/EC	Doukkala, Oualidia lagoon, El Jadida	Sabour *et al.* (2013)
	Rugulopteryx okamurae (E.Y.Dawson) Hwang *et al.*, 2009	Alien	Invasive	Pacific	2020	TS	Larache, Assilah, Casablnaca, El Jadida	**Present study**
Mollusca	*Magallana gigas* Thunberg, 1793	Alien	Established	NW Pacific	1950	EC	Cintra bay, Oualidia lagoon, Dakhla bay, Bousselham lagoon	Shafee (1985)
	Magallana angulata Lamarck, 1819	Alien	Established	Pacific	1952	EC	Dakhla bay, Oualidia lagoon	Shafee (1985)
	Patinopecten yessoensis Jay, 1857	Alien	Casual	Pacific	1995	EC	Oued Eddahab, Imsouane Bay, Khnifiss lagoon	Catanzano (1999)
	Favorinus ghanensis Edmunds, 1968	Alien	Casual	Tropical Atlantic	2012	TS	Agadir	Tamsouri *et al.* (2014)
	Polycera hedgpethi Marcus, 1964	Alien	Established	Eastern Pacific	2009	TS	Agadir	Cervera *et al.* (2010)
	Godiva quadricolor Barnard, 1927	Alien	Established	Eastern Pacific	2008	TS	Agadir	Cervera *et al.* (2010)
	Polycerella emertoni Verrill, 1880	Alien	Established	Unknown	2011	TS	Agadir	Tamsouri *et al.* (2014)
	Mya arenaria Linnaeus, 1758	Cryptogenic	Established	Unknown	1987	TS/EC	El Jadida	Menioui (1987)
Crustacea	*Callinectes sapidus* Rathbun, 1896	Alien	Invasive	W Atlantic	2021	TS	Daraa estuary, El Jadida, Casablanca, Rabat, Bouselham lagoon, Larache, Assilah, Tangier	Chaouti *et al.* (2022)
	Sphaeroma walkeri Stebbing, 1905	Alien	Casual	Indian Ocean	1982	UNA	Tangier	Jacobs (1987)
Cnidaria	*Tridentata marginata* Kirchenpauer, 1864	Alien	Established	Circumtropical	1970	UNK	-	Patriti (1970)
	Eudendrium merulum Watson, 1985	Alien	Established	Circumtropical	2007	UNK	Tangier	Iazza *et al.* (2013)

some groups (Fig. 4). The dominant groups (Macrophyta, Mollusca, and Crustacea) all displayed a high percentage of established alien species (Fig. 4). The groups with the largest number of casual alien species are Macrophyta (4 species), Cnidaria (2 species), and Mollusca (2 species).

At the species level, the blue crab (*Callinectes sapidus* Rathbun, 1896) was the most widespread species (Table 1), being registered in several regions. Seven more alien species (*Rugulopteryx okamurae* (E.Y.Dawson) I.K.Hwang, W.J.Lee & H.S.Kim, 2009, *Asparagopsis armata* Harvey, 1855, *Asparagopsis taxiformis* (Delile) Trevisan de Saint-Léon, 1845, *Bonnemaisonia hamifera*

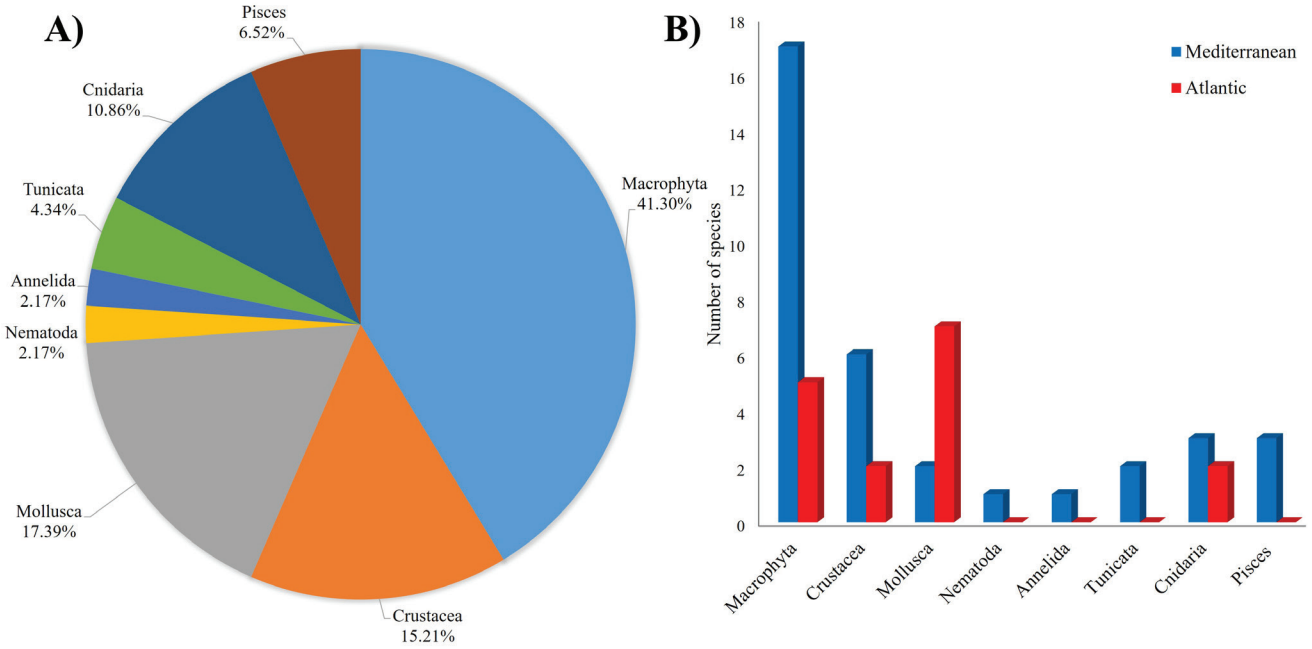

Fig. 2: Percentage of alien species in Moroccan waters by taxonomic group (A) and spatial distribution of species numbers (B).

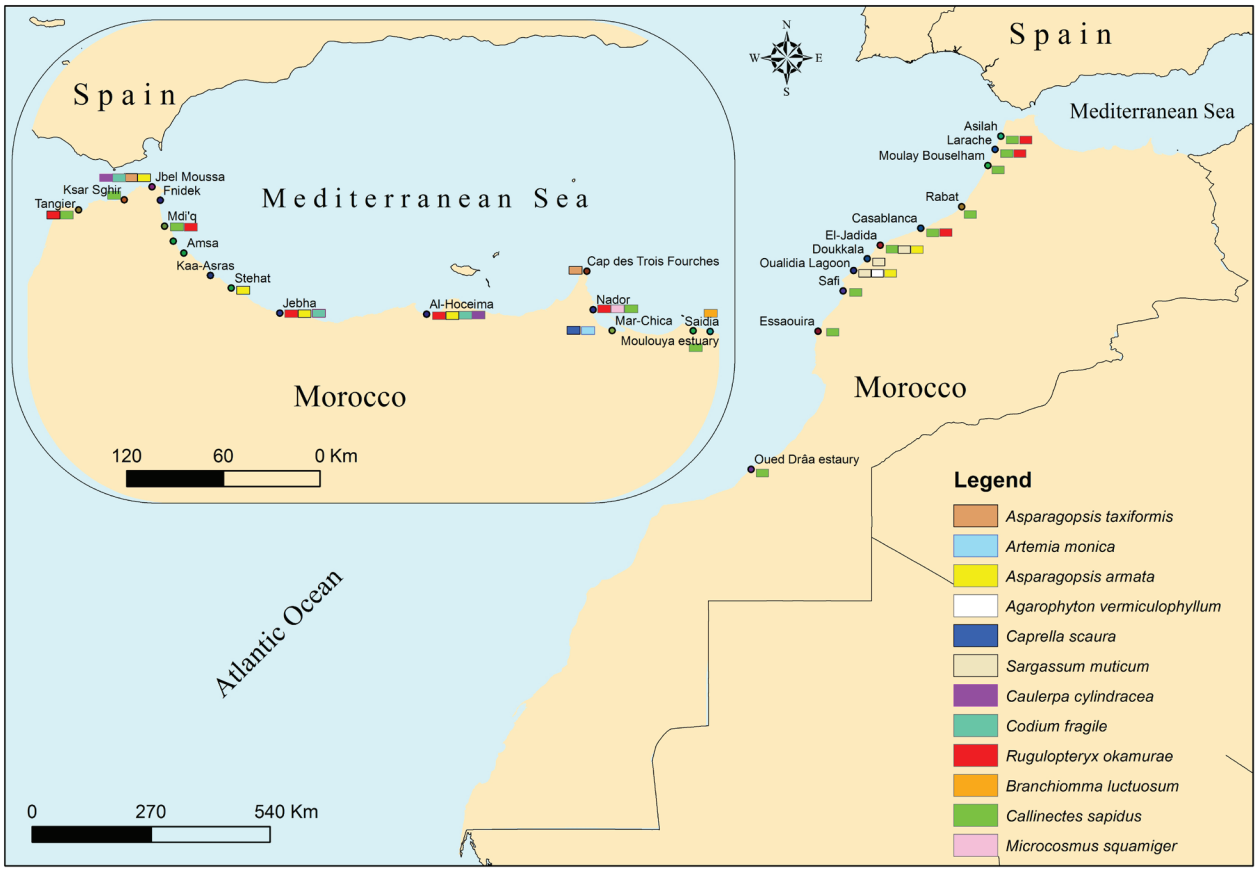

Fig. 3: The distribution of invasive species on both Moroccan coasts.

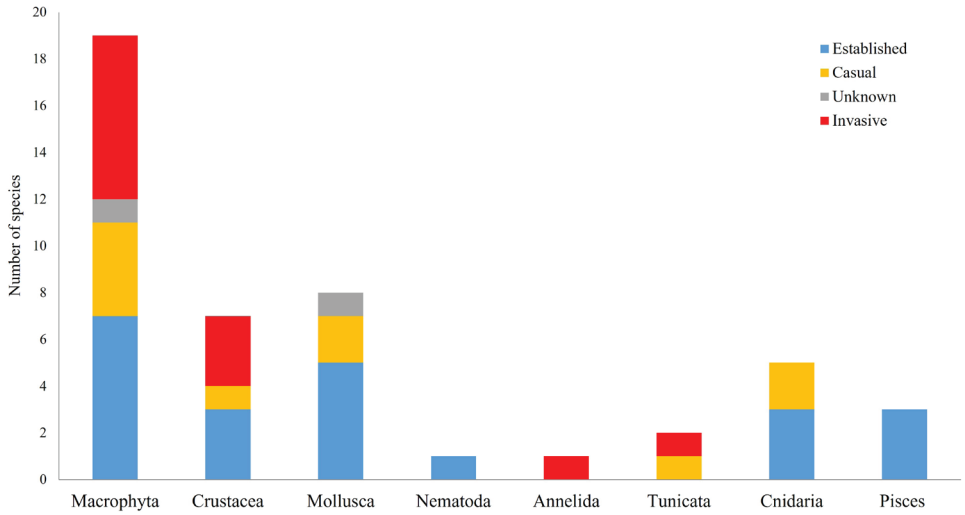

Fig. 4: Number of alien species per taxa group recorded in Moroccan waters according to the establishment success of the species.

Hariot, 1891, *Codium fragile* (Suringar) Hariot, 1889, *Caulerpa cylindracea* Sonder, 1845, and *Paracerceis sculpta* (Holmes, 1904)) were registered in most of the sites in Moroccan waters, while the vast majority of taxa were registered in only one site (Fig. 3). Based on their impacts, 12 alien species are considered to be invasive in Moroccan waters. Macrophyta occupied the first place in the numbers of invasive species (7 species), followed by Crustacea (3 species), Annelida (1 species), and Tunicata (1 species). These include the macroalgae *Rugulopteryx okamurae*, *Sargassum muticum* (Yendo) Fensholt, 1955, *Asparagopsis armata*, *Asparagopsis taxiformis, Caulerpa cylindracea, Codium fragile, Agarophyton vermiculophyllum* (Ohmi) Gurgel, J.N.Norris et Fredericq, 2018; the Crustacea *Artemia monica* Verrill, 1869*, Caprella scaura* Templeton, 1836, and *Callinectes sapidus*; the Annelida *Branchiomma luctuosum* Grube, 1870 and the Tunicata *Microcosmus squamiger* Michaelsen, 1927.

This study revealed 14 cryptogenic and one crypto-expanding species belonging to four groups (Tables 1, 2). The group with the highest number of species was Macrophyta (11 species) followed by Mollusca (2 species), while Cnidaria and Crustacea with one species each (Fig. 5).

Temporal and spatial trends

The very first record of an introduction is that of the mollusk *Magallana/Crassostrea* sp./spp. which was observed in the Moroccan Mediterranean in 1950 (Shafee, 1985). Due to the lack of a national marine non-native monitoring network in Morocco, providing precise information on the exact dates of introduction and describing the current distributions of these alien marine species is challenging. The rate of species introduction into Moroccan waters is showing an upward trend since the beginning of 1982 (Fig. 6). More than 18% of the species were recorded between 1988-1993. These recordings were associated with scientific campaigns carried out on algae. From the beginning of 2000 until the end of 2005, the rate of introduction of novel alien species was very low in both Moroccan coasts (Fig. 6). More than 53% of the reports were documented after 2010. During the last decade, the majority of the novel records were recorded in the Mediterranean. Notably, alien algae presented the

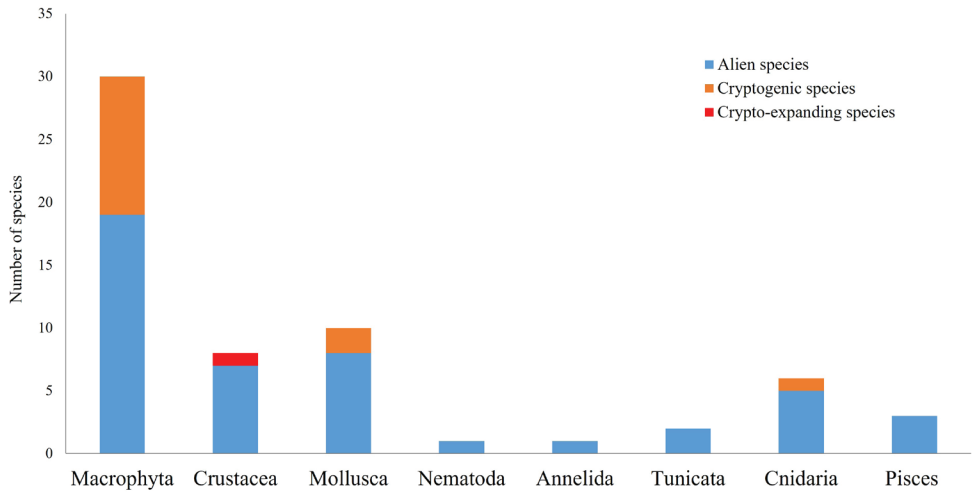

Fig. 5: The number of alien, cryptogenic, and crypto-expanding species in each taxa group.

greatest number of sightings in the late 1980s and early 2000s, as well as during the period 2012-2014. The same trend was observed for Mollusca, where most cases were recorded between 1950 and 2009, while Pisces records peaked in the last years (2015- 2018). During the last decade (2012-2022), alien algae have increased by ten new species, Pisces by three new species, mollusks and cnidarians by two new species and crustaceans and tunicates by one new species.

Of the 61 species, 49 (80%) were recorded along the Moroccan Mediterranean coast (35 alien species, 13 cryptogenic species, and one crypto-expanding species), of which 44 are found only in the Mediterranean region (Table 1). These 35 alien species belong to the animal (51%, 18 species) and plant (49%, 17 species) kingdoms and are distributed in eight taxon groups (Table 1). Macrophyta rank first in terms of the number of alien species in the Mediterranean (17 species, 49%), followed by Crustacea (6 species, 17%), Cnidaria (3 species, 8.6%), Pisces (3 species, 8.6%), Mollusca (2 species, 5.7%), and Tunicata (2 species, 5.7%), while all other taxa were represented by one species only (Nematoda and Annelida). The greater proportion of them are well established (46%) or casual (20%), and 31% (11 species) are invasive in the Moroccan Mediterranean. Macrophyta (13 species), Crustacea (6 species), and Pisces (3 species) have the highest number of established species on the Mediterranean coast. Macrophyta (4 species) and Cnidaria (2 species) were characterized by the highest number of casual species. Approximately 14% (5 species) of the alien species are shared between the Mediterranean and the Moroccan Atlantic coasts. The distribution of alien species reported along the Moroccan Mediterranean coasts varies considerably among regions. Al Hoceima is the region with the highest number of alien species in the Moroccan Mediterranean (16 species), followed by the lagoon of Mar Chica (Nador, 13 species). The port of Saïdia recorded six alien species. The inventory of alien species in marine protected areas (Al Hoceima and Jbel Moussa) in Morocco comprised a total of 15 species belonging to two taxon groups, most of which had already established reproductive populations in the zones surveyed and a low number presented an invasive behavior (7 species).

In the Moroccan Atlantic coast, 17 of the 61 species (28%) were documented (16 alien species and one cryptogenic species), with 12 being specific to the Atlantic region. The alien species of the Moroccan Atlantic belong to the animal (69%, 11 species) and plant (31%, 5 species) kingdoms and are grouped in four taxa groups (Table 2). The Mollusca (7 species, 44%) and Macrophyta (5 species, 31%) have the highest number of species in the Atlantic (Fig. 2B). Along this coast, four species are casual and 11 alien species are well established, of which five species are identified as invasive. Regarding alien species in the Atlantic, Oualidia lagoon recorded the highest number of species (5 species), followed by Agadir marina (4 species).

Probable vectors of introduction

All potential vectors for the introduction of alien species into Moroccan waters are presented in Figure 7. The pathway of introduction of seven species is unknown. Transport-Stowaway (28 species), Transport-Contaminant (7 species), Escape (6 species), and Unaided (5 species) were the major introduction pathways into Moroccan waters. Of the 46 alien species recorded in Moroccan waters, seven are considered as having entered via multiple vectors and pathways. In the Mediterranean, the most common pathway is Transport-Stowaway, with 23 alien species having been likely introduced through two vectors, hull fouling, or ballast water. The second most frequent pathway was Transport-Contaminant with six species introduced by this pathway in the Mediterranean. Four of the species arrived in the Mediterranean via the Suez Canal and then spread to Moroccan Mediterranean waters presumably via natural dispersal (pathway Unaided). Similarly, Transport-Stowaway was the dominating probable pathway of introduction of species in the Atlan-

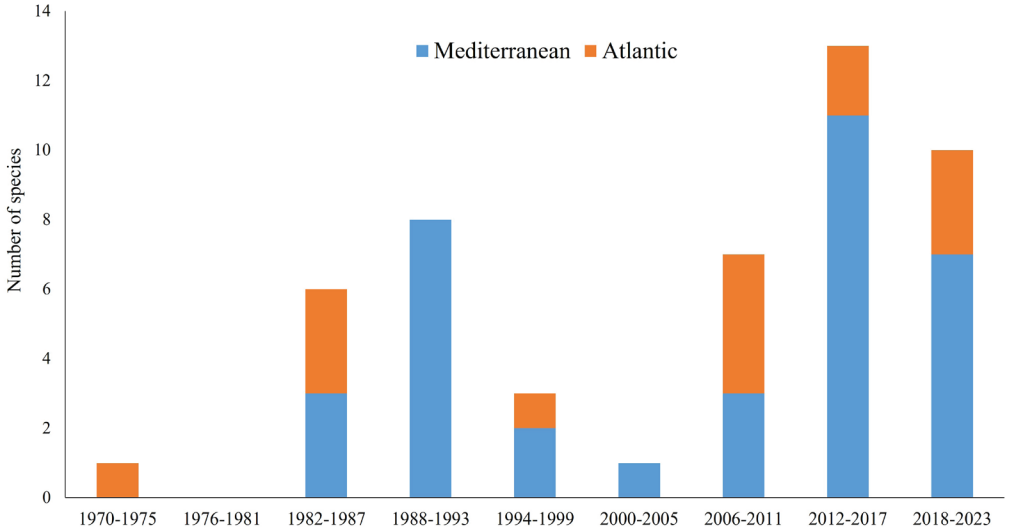

Fig. 6: Temporal trends of introduced species along the two Moroccan coasts.

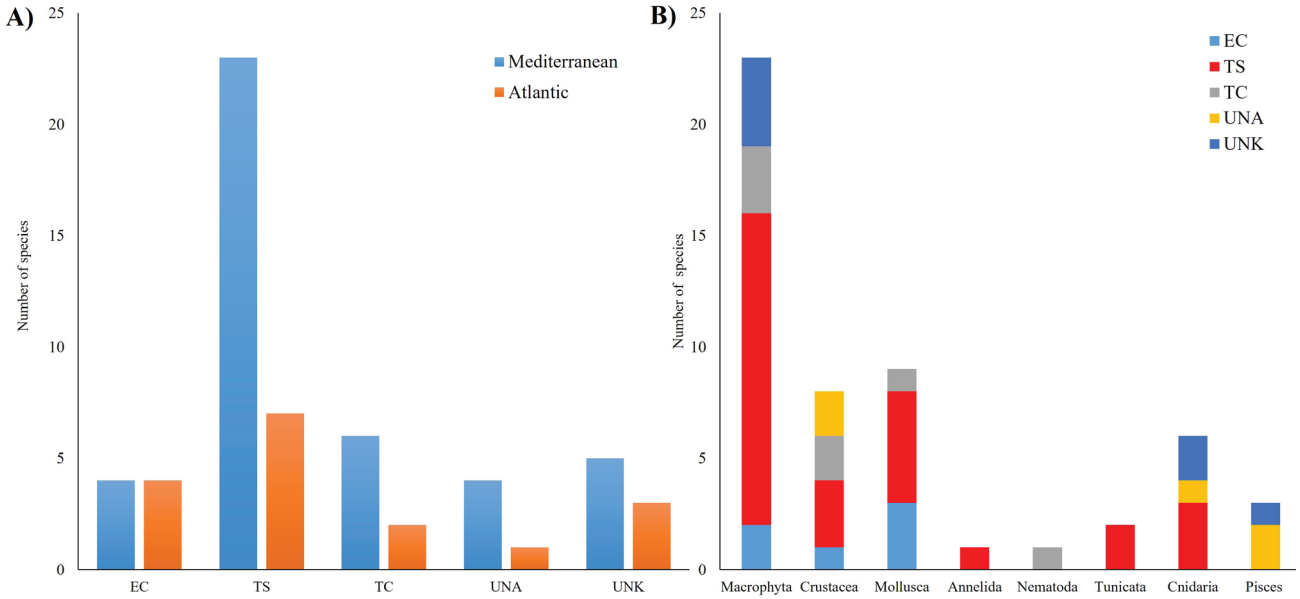

Fig. 7: Contribution of various introduction pathways to the introduction of alien species on the two Moroccan coasts (A) and by taxon group (B).

tic (7 species). Escape is more prevalent in the Moroccan Atlantic (25% species) than in the Mediterranean (11% species), albeit with the same absolute number of species for each region (4 species). Temporal variation in introduction pathways of alien species in the Moroccan Mediterranean revealed that Transport-Stowaway (10 species) and Transport-Contaminant (6 species) were the principal pathways in the early years (1950-2000), while Escape was represented by five introduced alien species. However, changes in introduction pathways were observed in recent years (2001-2023), where Transport-Stowaway (18 species) was the dominant pathway followed by Unaided (3 species). Within taxonomic groups, Escape was the predominant introduction pathway for mollusks, while Pisces were primarily introduced to Morocco through natural dispersal, after having entered the Mediterranean through the Suez Canal. Algae and Crustacea were mainly introduced via Transport-Stowaway and Transport-Contaminant. The other taxonomic groups in the Moroccan Mediterranean are associated with different pathways of introduction.

The majority of recorded alien species in the Atlantic were sourced from the Pacific Ocean (63%). In the Moroccan Mediterranean, introduced species from the Indo-Pacific Ocean (37%), the Pacific Ocean (31%), and the Atlantic Ocean (20%) were more frequent.

Discussion

Morocco occupies a strategic position at the north-western end of the African continent, with coasts on both the Atlantic Ocean and the Mediterranean. The Moroccan basin holds a crucial position due to its proximity to the Strait of Gibraltar, which makes it an area of significant importance. This study is the first comprehensive compilation and analysis of existing data on alien species in Moroccan waters and highlights that the Moroccan coastline is undergoing a major biological invasion. This list serves as a starting point for management measures and for selecting invasive alien species to assess their impact. Despite the increase in the number of alien species in Moroccan waters, this figure is most likely underestimated. In total, the number of marine alien species in Moroccan waters is much lower than in many other regions of the Mediterranean and the proximal east Atlantic, such as Spain (412 species, Png-Gonzalez *et al.*, 2023), France (342 species, Massé *et al.*, 2023), Italy (265 species, Servello *et al.*, 2019), Tunisia (163 species, Sghaier *et al.*, 2015; Ounifi-Ben Amor *et al.*, 2016), and Portugal (133, Chainho *et al.*, 2015). However, the number recorded in this study is very close to the alien biota in Algeria (39 species in Galanidi *et al.*, 2023). This significant difference from the majority of countries is probably due to several reasons, such as (i) the length and regularity of dedicated research efforts (ii) the number of different ecoregions within the country, (iii) the varying intensity of specific introduction routes, (iv) and the length of the shoreline.

Update, trends, and impacts of alien species in the Mediterranean

The present study lists a total of 35 alien species for Moroccan Mediterranean waters. The number of species reported from the Mediterranean coast is higher than for the Atlantic. Png-Gonzalez *et al.* (2023) observed similar results on the Atlantic and Mediterranean coasts of Spain. Globally, the Mediterranean Sea is the most invaded by alien species in recent years, due to environmental pressures and climate change (Zenetos & Galanidi, 2020; Zenetos *et al.*, 2022a, b, c; Massé *et al.*, 2023; Png-Gonzalez *et al.*, 2023). Macrophyta (particularly Rhodophy-

ta), Mollusca, and Crustacea are the most common alien taxa in Moroccan Mediterranean waters. At the western Mediterranean level, Macrophyta are the predominant alien group, representing 27% of all alien species, while alien Mollusca account for 22%, with crustaceans, polychaetes, and fishes constituting approximately 19%, 10%, and 13% of alien taxa each, respectively (Galanidi *et al.*, 2023). Our study is in general congruence with the findings of Galanidi *et al.* (2023) in terms of ranking order, but the relative representation of taxonomic groups differs substantially. The predominance of alien algae in this analysis appears to be linked to the above-mentioned surveys concentrated specifically on these taxa, and may also be partly attributed to limitations of expertise on the other taxonomic groups. Macrophytes are also the group with the highest number of cryptogenic species due to their taxonomic complexities, species complexes, and difficulties in pin-pointing species origins (Galanidi *et al.*, 2023).

Patterns in the introduction of non-native species demonstrated that there has been an overall increase in the number of species introduced into Moroccan waters in recent years. This increase may be the result of the rapid development of aquaculture and maritime transport in recent years, but may also be directly associated to the interest of the scientific community in the impact of introduced species. Since the early 1980's, there has been a growing trend in the number of alien species recorded in Mediterranean waters, albeit with considerable fluctuations. These results should be interpreted with caution, as they sometimes reflect discreet sampling events. For example, the high peak in the years 1983-1993 is the consequence of an intensive survey of benthic algae conducted in 1988-1993, during which most alien algae were documented for the first time in the Moroccan Mediterranean (González-García & Conde Poyales, 1994). Previous research assessing the dynamics of introduction of alien species in the Mediterranean also revealed that the number of recently recorded alien species during the last century is growing in the aquatic environment (Zenetos *et al.*, 2022a; Servello *et al.*, 2019; Massé *et al.*, 2023; Png-Gonzalez *et al.*, 2023). This growth partly reflects the growing interest in invasive species and their impacts in the Moroccan Mediterranean. As more targeted surveys emerge and with the forthcoming implementation of the National Monitoring Programme of Morocco (SPA/RAC – ONU Environnement/PAM, 2017) within the context of the Integrated Monitoring and Assessment Programme of the Mediterranean Sea (IMAP) (UNEP/MAP, 2017) the number of alien species in Moroccan Mediterranean waters would certainly be expected to rise in the future. Several species with earlier records in Chafarinas Islands/Melilla/Ceuta (Spain) appeared later in Morocco and are now well established (Conde Poyales, 1984). For example, *Asparagopsis armata* was first reported in 1980 from the Chafarinas Islands (Conde Poyales, 1984) but the first Moroccan sighting took place during a series of surveys between 1989-1993, when the species was already widespread all along the Moroccan coastline (González-García & Conde Poyales, 1994). The same trend was observed for other species such as *Asparagopsis taxiformis*, *Codium fragile*, and *Eudendrium merulum* Watson, 1985 (Altamirano, 1999; Peña Cantero & García Carrascosa, 2002). The position of these two regions (Chafarinas Islands and Melilla) at the east end of the Moroccan Mediterranean has certainly contributed to the increase in early detection rates of alien species in these regions. The early detection in both regions through monitoring also contributed to the increased numbers of species reported for the first time in these regions compared to Moroccan waters. Two alien species (*Lagocephalus sceleratus* Gmelin, 1789 and *Tridentata marginata* Kirchenpauer, 1864) recorded so far only in the region of Ceuta and Chafarinas Islands in the Mediterranean (Gonzalez-Duarte *et al.*, 2013; Azzurro *et al.*, 2020) and those resulting from modelling predictions (e.g., *Fistularia commersoni* Rüppell, 1838*,* Azzurro *et al.*, 2013) could be future alien species in Moroccan Mediterranean waters.

In the Mediterranean Sea, increasing sea surface temperatures may also promote range expansion of subtropical and tropical eastern Atlantic species into this sea via the Strait of Gibraltar. The high percentage of alien and cryptogenic species may therefore be a result of the general warming trend in Mediterranean Sea in recent years (Azzurro *et al.*, 2019; Galanidi & Zenetos, 2022). In fact, the western Mediterranean is already experiencing an increased penetration of warm water alien species whose primary introduction occurred in the eastern and central Mediterranean, particularly Lessepsian species (Galanidi *et al.*, 2023).

Approximately two thirds of the alien species recorded (74%) in this study were established on the Moroccan Mediterranean coast. The percentage of established taxa in our study is similar to that recorded in the waters of neighboring countries such as Spain (Png-Gonzalez *et al.*, 2023), Algeria (Grimes *et al.*, 2018), Tunisia (Ounifi-Ben Amor *et al.*, 2016), France (Massé *et al.*, 2023), and Italy (Servello *et al.*, 2019). In the absence of systematic monitoring programs in Moroccan waters, established populations of alien species are more probable to be observed than casual introduced taxa due to the higher abundance of these species in space and time (Zenetos *et al.*, 2017). The number of species for which the status is casual is relatively high in Morocco (20%), underlining the importance of carrying out more targeted studies on this group that might reveal previously overlooked populations. Consequently, the number of casual species in this study may be slightly overestimated. Casual species should not be neglected in terms of management, as they may expand and become invasive in the near future. Zamora-Marín *et al.* (2023) recommended the importance of increasing monitoring efforts on these species.

Moroccan coastal lagoons tend to harbor the greatest number of alien species due to deteriorated environmental conditions and few competitors that facilitate establishment by invasive species (El Kamcha *et al.*, 2021). These lagoons are also hosts to numerous anthropogenic activities that facilitate secondary dispersal (Selfati *et al.*, 2017). The Mar Chica lagoon is the most important area for the introduction of invasive alien species in Morocco

(Selfati *et al.*, 2017, 2019). Marinas, tourists, commercial ports, and aquaculture are reasons that have led to the classification of this lagoon as a "sink but also a source" for the spread of invasive alien species (Selfati *et al.*, 2017; El Kamcha *et al.*, 2021). Three species, namely the crab *Callinectes sapidus* and the brine shrimp *Artemia monica* and amphipod *Caprella scaura* demonstrate invasive behavior in this lagoon. Several alien species reported in the Moroccan Mediterranean were first detected in the Mar Chica lagoon (Amat *et al.*, 2005; Selfati *et al.*, 2017; El Kamcha *et al.*, 2021). Marine protected areas in the Moroccan Mediterranean have not escaped biological invasion (Al Hoceima and Jbel Moussa) and have long been impacted by the introduced invasive species that threaten aquatic biodiversity. However, very little is known about alien species, their densities, distributions, and ecological and economic impacts in marine protected areas.

Despite the relatively low number of alien species in the Moroccan Mediterranean, a considerable proportion of them (31%) are species that have been classified as invasive in some part of their introduced range, having significant impact on native biodiversity and ecosystem functioning. In Morocco, the impact of alien species has been poorly examined due to the recent introduction of most species, except for some alien species which quickly demonstrated an impact on the receiving environment. It is also possible that these species have not been extensively researched or remain poorly understood in the region, although some studies have reported negative ecological and economic damage caused by alien species.

The most recent and most extensive invasion of Moroccan Mediterranean waters is that of the blue crab *Callinectes sapidus*. According to Chaouti *et al.* (2022), the blue crab is very abundant in the Moroccan Mediterranean. Fishermen cited the blue crab as the species primarily interacting with fishing activities, with the major issue being net damage, catch reduction, and health risk (Oussellam *et al.*, 2021). The brown alga *Rugulopteryx okamurae*, one of the invasive species documented in Moroccan waters, was found to be widely distributed across multiple regions in the area (El Aamri *et al.*, 2018). After its arrival in 2016 and within just a few years, this alga became the most common species in the Jbel Moussa and Ceuta region in only one year, occupying more than 90% of the seabed between 10 and 20 m depth (García-Gomez *et al.*, 2021). This species has caused significant changes in the structure of the coralligenous community and a regression of the bioindicator species *Mesophyllum expansum* (Philippi) Cabioch & M.L.Mendoza, 2003 and *Paramuricea clavata* (Risso, 1827) (Sempere-Valverde *et al.*, 2021). Additionally, hundreds of tons of this algae stranded on Moroccan beaches, becoming a nuisance with repercussions for tourism. Mass strandings also lead to significant clean-up costs and substantial economic losses. Local fishers have also indicated that this alga clogs fishing nets resulting in a significant decrease in their ability to capture fish (personal communication to the authors). Also, fishers need to expend additional time to get the fishing net operational. In order to mitigate the economic losses, additional fishing trips were necessary. Recently, aquaculture also suffers from the impact of this invasive species (Fig. 8). Recent studies indicate that *Artemia monica* is a threat to *Artemia* biodiversity worldwide because it is substituting native *Artemia* species (Amat *et al.*, 2007). Additionally, non-native algae species such as *Codium fragile* and *Asparagopsis armata* have caused the elimination of native algae populations, particularly those already under stress (Menioui, 2021). The ecological impacts of some invasive species in Moroccan waters have been correlated with strong economic impacts.

Despite the fact that assessing the pathways of introduction of alien species is essential for defining management priorities in Moroccan waters, pathway assignments are often educated guesses based on species biology, previous association with specific vectors and location of the findings (Bailey *et al.*, 2020). In addition, numerous introduction pathways are possible for many alien species due to the multitude of human activities taking place in or near the site of the first sighting (Massé *et al.*, 2023; Png-Gonzalez *et al.*, 2023). The introduction of alien species in the Moroccan Mediterranean was performed through all the major marine introduction pathways, but three dominant pathways were clearly identified: Transport-Stowaway, Transport-Contaminant, and Escape. These predominant pathways have been also recognized as the main vectors of introduction of marine alien species by previous studies in Italy, Spain, France, Tunisia, and other Mediterranean countries (Servello *et al.*, 2019;

Fig. 8: Mass stranding of *Rugulopteryx okamurae* on beaches and its impact on aquaculture in Moroccan waters (Photo credit: Mohamed Rami Laamraoui).

Png-Gonzalez *et al.*, 2023; Massé *et al.*, 2023), as well as on global scale (Turbelin *et al.*, 2022). The importance of shipping vectors is due to the Moroccan Mediterranean position as a transition zone between the Mediterranean and the Atlantic, and its proximity to major shipping routes and port facilities. The earliest record of a ship-mediated introduction is that of *Asparagopsis armata* (Conde Poyales, 1984). Since then, introductions by shipping have progressively increased over the last years.

Although Morocco is located in the western end of the Mediterranean basin, with the opening of a Suez Canal a significant number of species have been able to traverse the distance across the Mediterranean and reach our coasts through a variety of secondary spread pathways, including natural dispersal (pathway Unaided). In Morocco, for example, two fish species were likely introduced unaided, *Etrumeus golanii* DiBattista, Randall & Bowen, 2012 (Tamsouri *et al.*, 2019) and *Hemiramphus far* Forsskål, 1775 (Selfati *et al.*, 2019). Not surprisingly, a large number of alien species are from the Atlantic, the majority of which have arrived in Morocco as ship stowaways. Mghili *et al.* (2022) have already shown the role of marine litter in the transport of alien species in the Moroccan coasts. Although none of the recorded species were invasive, their occurences indicate the potential for marine litter to act as a vector for alien species in the Moroccan Mediterranean.

Update, trends, and impacts of alien species in the Atlantic

Sixteen alien species are currently registered in Atlantic waters. Our data indicate that studies on Morocco's Atlantic coast have still only been partially revealed: very few data are available on the presence of alien species in Moroccan Atlantic waters and this number is rather low compared to adjacent areas (e.g., 133 in Portugal; Chainho *et al.*, 2015), which can be explained by several reasons. The first is that the issue of alien species has not received sufficient attention in the Atlantic compared to the Mediterranean, and the second is linked to the length of the Atlantic coastline, which extends over 3,000 km, making it difficult to track the presence of alien species. Mollusca and Macroalgae were the most numerous alien species records in the Moroccan Atlantic, as also observed in neighboring Atlantic countries (Chainho *et al.*, 2015). This dominance of Mollusca seems to be linked to aquaculture. Most of these species were introduced with the aim of increasing the cultivation of species and aquaculture in Morocco (Menioui, 2021). Marine aquaculture began in Morocco in the 1950s. Oyster farming was the first , initially conducted in Oualidia lagoon on the Moroccan Atlantic coast, and later extended to other coastal regions such as Khnifiss lagoon and Dakhla Bay (Shafee, 1985; Catanzano, 1999). Several species have been introduced for aquaculture purposes, notably the oyster *Magallana gigas* (Thunberg, 1793) in the lagoon of Oualidiya (Shafee, 1985; Menioui, 1987) and the Yesso scallop (*Patinopecten yessoensis* Jay, 1857), first introduced in Morocco in the 1980s (Catanzano, 1999). As in the Mediterranean region, Transport-Stowaway is a major vector of introduction into the Atlantic. The Moroccan Atlantic is an extremely important maritime route and is a major trading point between Africa and Europe. Domestic freight vessels and fishing and recreational vessels can present a risk for the transport of alien species in this region. Many alien species in the Atlantic are well-established algae. The four most frequently documented species in the Atlantic were the algae *Sargassum muticum*, *Rugulopteryx okamurae, Asparagopsis armata*, and the crab *Callinectes sapidus*. These species are among the most widespread alien species in the Atlantic and also in the Mediterranean, and their negative impacts are well documented.

Sources of uncertainty

This study reveals certain points of concern, especially with the confirmation of the presence of some species and their status (introduced or cryptogenic). In this study, *Saccharina japonica* Areschoug, 1851 and *Mnemiopsis leidyi* Agassiz 1860, previously identified as alien in the study by Menioui (2021), have been excluded from the list of alien species of Morocco because their occurrence has not been subsequently confirmed in Moroccan waters and does not have appropriate illustration or description in the articles to enable a positive identification. The presence of *Caulerpa taxifolia* (M.Vahl) C.Agardh, 1817 in the Moroccan Mediterranean is now considered an unconfirmed record. Riadi *et al.* (1998) had reported the presence of this species in Moroccan waters, but no details were provided. As no confirmation was ever reported by the researchers, we list it here as an unconfirmed record. Some species need taxonomic expertise or even genetic analyses to be adequately identified. This is well exemplified by *Magallana angulata Lamarck,* 1819, and *M. gigas*, which are cultured in Morocco on both coasts. Moreover, a number of recent records from Saidia marina, sourced from iNaturalist, are included herein as questionable records until their identity is confirmed and verified with quality control processes of the platform, namely *Botrylloides niger* Herdman, 1886*, Tricellaria inopinata* d'Hondt & Occhipinti Ambrogi, 1985, and *Styela plicata* (Lesueur, 1823) (El Bouchikhi, 2024a, b, c). On the other hand, "research grade" observations from iNaturalist pertaining to *Polyandrocarpa zorritensis* (Van Name, 1931) and *Eudendrium carneum* (Clarke, 1882) are herein accepted as valid records (El Bouchikhi, 2023a, b).

Two changes in alien status are worth highlighting; the pantropical mollusk *Bursatella leachii* (Blainville, 1817), long believed to have entered the Mediterranean Sea through the Suez Canal (e.g., Selfati *et al.*, 2017), is now considered cryptogenic. Moroccan and other Mediterranean populations have been shown using molecular methods to be closer genetically to Atlantic specimens, indicating that the species has reached Morocco through the Gibraltar Strait (Bazzicalupo *et al.*, 2020; Córdoba González *et al.*, 2023). Another species that was classi-

fied as alien by Menioui (2021), *Mya arenaria* Linnaeus, 1758, is currently considered as cryptogenic. Many species have not been included in the current list because they involved range expansion. The position of the Moroccan Mediterranean coast close to the Strait of Gibraltar facilitates the entry of Atlantic species without human assistance. This indicates that certain species present in the Moroccan Mediterranean, such as *Leathesia marina* (Lyngbye) Decaisne, 1842 and *Psenes pellucidus* Lutken, 1880, could be classified as naturalized in the zone as part of a range expansion process (see Benhissoune *et al.*, 2002; Maurin, 1962 for each species record, respectively). At the same time, crypto-expanding species of tropical east Atlantic origin/distribution such as *Merhippolyte ancistrota* Crosnier & Forest, 1973, as well as *Calappa pelii* Herklots, 1851 and *Percnon gibbesi* Milne Edwards, 1853 (the last two only found in the Chafarinas Islands - Galil *et al.*, 2002; Sánchez-Tocino *et al.*, 2014) may have used the Strait of Gibraltar as their gateway into the Mediterranean, so that their populations in Morocco and adjacent waters warrant further investigations, ideally with molecular methods, that could help differentiate between range expansions or true introductions.

Finally, some records lack geographic precision. In the Moroccan Atlantic, *Tridentata marginata* is mentioned among the alien species without any details on distribution (Patriti, 1970). Similarly, *Clytia linearis* Thorneley, 1900 was also recorded in the Alborán Sea off the coast of Morocco in the sampling surveys conducted by Ramil & Vervoort (1992). These authors did not provide precise details of the distribution of this species. It is also important to consider older records that may have not been subjected to such scientific rigor in the past such as *Undaria pinnatifida* (Harv.) Suringar, 1873. As well as adding new alien species, future work should also be directed at reexamination of older records in Moroccan waters in order to minimize ambiguity.

What next?

The historical overview indicates a strong trend in the increase of number of alien species in Moroccan marine waters in recent years. Indeed, this trend is parallel to the degree of scientific interest. However, the alien species inventory appears to be far from complete. The lack of scientific interest and limited availability of taxonomists for certain groups are the main factors contributing to the disparity on introduced species in Morocco, particularly in comparison to Spain, Algeria, Tunisia, and Libya. This review highlights the need for increased attention and documentation on this issue in Morocco to address the current knowledge gap. The total number of alien species in the marine environment is expected to be much higher than reported in this study and we can reasonably suppose the presence of several alien species reported from neighboring countries (Spain and Algeria).

Managing invasive species is a big challenge for Morocco. As early as 1997, the National Biodiversity Study and the first National Biodiversity Strategy and Action Plan identified alien species as a significant threat to the preservation and optimal utilization of Morocco's biological heritage (Menioui, 2021). Recently, Morocco adopted the national plan for the prevention of the introduction of novel non-indigenous marine species by managing their pathways and to attenuate their negative impact. Within the IMAP framework linked to the National Monitoring Program (SPA/RAC– ONU Environnement/PAM, 2017), Morocco has begun monitoring non-indigenous species. Early detection monitoring is particularly demanding for alien species in Moroccan waters, especially in the Mediterranean. To enhance our understanding of introduced species in Moroccan marine waters, additional investigations on various taxonomic groups such as Bryozoa, Tunicata, Cnidaria, Anthozoa, Echinodermata, Turbellaria, Sipuncula, and pelagic phytoplankton and zooplankton taxa are required. Moreover, it is crucial to conduct further research on fish and macroalgae to gain a comprehensive understanding of the scope of introduced species in Moroccan marine ecosystems. To improve knowledge of introduced species, it is essential to enhance and strengthen national capacities related to taxonomy. This study documents a significant number of alien species in the lagoon of Mar Chica, which covers only a small portion of Moroccan marine waters. Given that lagoons are considered as areas of refuge for alien species (Selfati *et al.*, 2017), they deserve greater attention in research. Presently, there is limited research on alien species and their impact in Moroccan marine waters. It is crucial to prioritize the evaluation of alien species impacts in marine conservation efforts in Morocco, as there is a lack of data on this issue. The Strait of Gibraltar is a frontier more permeable to Atlantic species which naturally expand their range. Therefore, some of the species recently recorded in the Mediterranean and considered to have extended their geographical range may be in fact introduced. Conducting surveys in the Moroccan Mediterranean is necessary to determine the status of these species and facilitate effective management strategies. Early detection is considered as essential in the management of invasive species due to the extreme difficulty of eradicating these species once they are established and naturalized in the marine environment. Risk assessment, monitoring, and control of existing populations are also strongly recommended in Moroccan waters.

Conclusions

Our study provides a reliable and up-to-date record of non-indigenous species present in Moroccan marine waters. This information is critical in evaluating future threats and devising conservation and management strategies for the Moroccan Mediterranean. The presented data are especially valuable in establishing priority lists of invasive alien species detected in Moroccan marine ecosystems. Nevertheless, it is essential to note that the actual number of non-native species in Moroccan waters may well exceed the documented count in this report. Furthermore, the findings of this paper open new research

directions, including the impacts of invasive species. Our study shows that the monitoring of alien species in different regions is unequal, indicating the need to study the overall distribution of alien species in Moroccan marine waters. It is important to put in place biosecurity measures to prevent the introduction of alien species into new areas in Moroccan waters, and rapid intervention measures to monitor and eradicate alien species that could become invasive.

Declaration of competing interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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