

REVIEW

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Mediterranean non indigenous species at the start of the 2020s: recent changes

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Abstract

The current amendments to the Mediterranean marine Non-Indigenous Species (NIS) inventory for the period 2017-2019 are the result of a continuous literature search and update of the Hellenic Centre for Marine Research (HCMR) offline database. They take into account recent findings, previously missed records, back-dated records based on the re-examination of existing material or phylogenetic studies and changes in nomenclature. During the period 2017-2019, 70 new species were added to the inventory of established species, 25 that had escaped our attention in the past and 23 newly introduced, which have already established self-sustaining populations. Meanwhile, 22 species previously known only with casual records have established viable populations and a total of 36 species have expanded their distribution into new Marine Strategy Framework Directive regions, primarily the Central Mediterranean and the Adriatic Sea. Intensified research efforts, prompted by the reporting obligations created by recent legislation, complemented by ever expanding networks and initiatives involving citizen scientists have certainly contributed to higher rates of discovery of alien species presences. However, the expansion of tropical and sub-tropical species into the cooler waters of the Aegean, the Adriatic and the western Mediterranean indicates that the warming of Mediterranean waters due to climate change is also facilitating the geographic expansion of NIS in the region. The rate of new introductions in this 3-year period is 8 species per year for the whole Mediterranean, without taking into account casual records or species with reporting lags. Only 4 species per year enter through the Suez Canal, while a considerable number of species are introduced through shipping vectors and the aquarium trade. Acknowledging the dynamic nature of invasions and the uncertainty inherent in compiling check lists, we consider the present work as the most accurate and up-to-date NIS list to inform policy, management and decision-making.

Keywords: Alien species, Mediterranean inventory, Updates, Range expansion

Introduction

Alien species inventories constitute a fundamental first step and a very important tool for the implementation of relevant policies and the delineation of management approaches (Vanderhoeven et al. 2017). They inform prioritization processes, e.g. Horizon Scanning (Roy et al. 2015; Tsiamis et al. 2020), the assessment of trends in introduction pathways (Korpinen et al. 2019) and the evaluation of existing management practices through the

calculation of suitable indicators (Armon and Zenetos 2015; Rabitsch et al. 2016).

As management efforts/policy initiatives to tackle alien and invasive species are intensified at the global and regional level (CBD (Convention on Biological Diversity) 2011; IMAP 2017), it is imperative that such inventories are regularly updated and remain current, especially since the introduction rate of new alien species globally does not appear to level off (Seebens et al. 2017 but see Zenetos 2019 for the Mediterranean), while their spread into new areas is facilitated by increasing volumes of trade and global transport networks (Latombe et al. 2017; Seebens et al. 2015).

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The inclusion of alien species descriptors and indicators in policy instruments has created reporting obligations at the national level (e.g. see Tsiamis et al. 2019) and triggered a surge of scientific activity dedicated to their detection, quantification, the exploration and mitigation of their impacts. Indicatively, the financial investments for alien species research and management have increased significantly in Europe since the early 1990s (Scalera 2010) and national monitoring schemes that cover NIS are in place in many Member States (ICES 2019). Additionally, Citizen Science (i.e. the involvement of the public in the production of scientific data – McKinley et al. 2017) has emerged as a powerful contributor to the early detection of new alien species as well as the surveillance of established invaders (Groom et al. 2019; Giovos et al. 2019) and novel genetic methods are more routinely employed, helping to clarify uncertainties with respect to species' identities and geographic origins (Bayha et al. 2017; Simon et al. 2019; Viard et al. 2019). As a result of this, the time lag between the first detection of a new alien species and the publication of the corresponding record has decreased in recent years, largely aided by the willingness of scientific journals to publish such biodiversity observations (Zenetos et al. 2019). The development of open data infrastructures, such as the European Alien Species Information Network (EASIN) (<https://easin.jrc.ec.europa.eu/easin>), that assure quality control of alien species information (Tsiamis et al. 2016) further enhances accessibility and analysis of the available information. The above notwithstanding, there are still information gaps and validation problems with alien species lists, that can only be overcome with the collaboration of local and taxonomic experts and the continuous update of regional/national databases. One such effort for Mediterranean marine alien species resulted in the critical revision and massive update of the alien species inventory for the Mediterranean Sea (Zenetos et al. 2017). In the current review, we build on that study and report recent changes in the marine Mediterranean xenodiversity since 2016, aiming to present a comprehensive and up-to-date NIS checklist at the closing of the previous decade.

Methodology

The work of Zenetos et al. (2017), including the published species list as well as the underlying database (HCMR offline database), forms the baseline for the current work. Updates are based on an extensive literature search, complemented by personal communications with local experts where needed, to verify alien status and establishment success.

Updates presented herein include:

- i). records of new alien species (AS) for the Mediterranean, reported after 2016;
- ii). records of alien species published in the scientific literature but missing from comprehensive lists for the Mediterranean (including from the Zenetos et al. 2017 paper);
- iii). species for which new literature until December 2019 (complemented by expert knowledge) reveals a change in their establishment success, most commonly from casual to established but also the reverse.
The terminology used in Zenetos et al. (2017) is also employed here, i.e. 'casual' denotes species reported once or twice on the basis of single individuals, whereas 'established' is used for species with multiple records, spread over time and place, regardless of evidence of reproductive success. Locally established species, i.e. species with established populations in one location only were also included in this category, with the rationale that they can constitute source populations for further expansion;
- iv). species that have expanded their distribution into new areas [sensu MSFD: Marine Strategy Framework Directive (EC (European Commission) 2008)] since 2016;
- v). species that, on the basis of genetic studies, taxonomic revisions, biogeographic reviews, etc. have changed alien status, i.e. are excluded from the aliens' list or move between the aliens, cryptogenic and Data Deficient categories (for a definition of the terms see Zenetos et al. (2010); Zenetos et al. (2017) and Tsiamis et al. (2019).
- vi). nomenclature changes following updates in the World Register of Marine Species (WoRMS Editorial Board 2019);
- vii). changes in year and/or country of first record based on recent literature backdating previous records (e.g. *Aurelia solida* Browne, 1905: Gueroun et al. 2020) as well as removing species from national lists as non-substantiated (e.g. *Prionospio pulchra* Imajima, 1990 in Italy: Servello et al. 2019);

Each species presented in the results section was assigned its most likely primary pathway of introduction or secondary spread, as appropriate. Pathway descriptions follow the Convention on Biological Diversity (CBD) definitions (CBD (Convention on Biological Diversity) 2014) and the relevant abbreviations are as follows: CON = TRANSPORT- CONTAMINANT, including Contaminant on animals (except parasites, species transported by host/vector) and Parasites on animals (including species transported by host and vector), COR = CORRIDOR: Interconnected waterways/basins/seas (in the current

context this refers to the Suez Canal), ESC = ESCAPE FROM CONFINEMENT, referring to the accidental escape or intentional release of aquarium species (see IUCN (International Union for Conservation of Nature) 2017), T-S: TRANSPORT- STOWAWAY, including Ship/boat ballast water, Ship/boat hull fouling and Other means of transport, UNK = Unknown.

Mediterranean subregions are defined as per the MSFD delineation (Jensen et al. 2017), namely (a) the Western Mediterranean Sea (WMED); (b) the Ionian Sea and the Central Mediterranean Sea (CMED); (c) the Adriatic Sea (ADRIA); and (d) the Eastern Mediterranean Sea (EMED), encompassing the Aegean and Levantine basins. Country names are abbreviated according to the ISO 3166-1 alpha-2 code system into a two-letter acronym.

Results-discussion

Excluding Foraminifera, a total of 666 established marine alien species are reported in the Mediterranean by December 2019 (Additional file 1). The continuous literature search and update of the HCMR offline database since December 2016 resulted in a total of 70 additions to the inventory of established marine alien species for the Mediterranean Sea (Additional file 1) and 112 new species in the Mediterranean NIS if casual records are considered. At the same time 16 species were deleted from the list (Additional file 2).

Species to be removed from the established NIS inventory

The presence of the bivalve mollusk *Pseudochama corbieri* (Jonas, 1846) in Greece was disputed by Crocetta et al. (2017). Its record in Israel is based on one shell from the beach (Barash and Danin 1972), while in Cyprus the record is not substantiated by a picture (Demetropoulos 1971). Therefore, the species is removed altogether from the list of Mediterranean NIS.

A new scyphozomedusa, sampled as bycatch in the Adriatic, was initially named by Piraino et al. (2014) as a new species, *Pelagia benovici*, and later placed in a new genus *Mawia* by Avian et al. (2016). Subsequently, *Mawia* was observed and sampled in several locations of the northern Adriatic and Ionian Sea (Chartosia et al. 2018). Bayha et al. (2017), in a comprehensive phylogenetic analysis of Pelagiidae, included two unidentified specimens collected from the west coast of Africa (Senegal), which genetic analysis conclusively grouped together with *M. benovici* samples from the Adriatic. While this provides a potential source region for the species' introduction into the Mediterranean, the same study raises systematic questions about the phylogeny of the various species in the family and the erection of the new genus *Mawia*. Based on the discovery of paraphyly in the genus *Chrysaora*, Bayha et al. (2017) postulate that, in order to accept the

validity of *Mawia*, as well as previously established *Pelagia* and *Sanderia*, additional genera would have to be erected within Pelagiidae in order to maintain monophyly of these generic groupings. Therefore, the species is assigned the Data Deficient status.

According to Faulwetter et al. (2017), the increasing discovery of cryptic species through molecular methods is creating uncertainty as to the diversity and distribution of polychaete species worldwide. Several of the of non-native polychaete species recorded in the Mediterranean were proven to be a complex of cryptic and pseudo-cryptic species. In these cases, it is likely that the name refers to a complex of cryptic species and Mediterranean material could belong to an overlooked native species, e.g. *Eurythoe complanata* (Pallas, 1766), *Lumbrineris perkinsi* Carrera-Parra, 2001 that are now assigned to the cryptogenic category (Langeneck et al. 2020), Lezzi and Giangrande (2018) described from the Italian coast *Streblosoma pseudocomatus* which corresponds to *Streblosoma comatus* (Grube, 1859). Until there are further studies *S. comatus* is moved to the cryptogenic status.

A number of polychaete species that cannot be assigned to alien or cryptogenic status are classified as Data Deficient (Tsiamis et al. 2019). Such are the following seven polychaeta: *Erinaceusyllis serratosetosa* (Hartmann-Schröder, 1982), *Hesionura serrata* (Hartmann-Schröder, 1960), *Metasychis gotoi* (Izuka, 1902) *Neanthes agulhana* (Day, 1963), *Neopseudocapitella brasiliensis* Rullier & Amoureux, 1979, *Novafabricia infratorquata* Fitzhugh, 1983; and *Spirobranchus kraussii* (Baird, 1865).

As an example, Simon et al. (2019) based on phylogenetic analysis of DNA concluded that *S. kraussii* is a warm temperate/subtropical intertidal species restricted to South African coasts. It belongs to a globally distributed complex including some tropical fouling and invasive species. Yet, it is believed that the records of *S. kraussii* from the Levantine might actually correspond to other species/strains of unknown identity (Elena K. Kupriyanova, pers. commun) but surely an alien for the Mediterranean.

The revised check list of established NIS includes:

Missing records

Of these, 25 refer to species for which records pre-2017 had escaped our attention (missing records in Table 1). All these species are considered established but 9 of them are only established locally, i.e. they have documented populations in one location. The discovery of many of the missing records is owed to Servello et al. (2019), who confirmed the establishment of already recorded species in Italian waters, as well as to Abd El-Rahman (2005) who studied the zooplankton of the Mediterranean coast of Egypt and confirmed the establishment of alien copepods. Other notable mentions

Table 1 Established alien species reported before 2017 but missing from Zenetos et al. (2017)

Higher taxon	Species	First record	Geographic expansion
BRY	<i>Celleporella carolinensis</i> Ryland, 1979	1993-IT: Occhipinti Ambrogi and d'Hondt 1996	locally established -see Servello et al. 2019
BRY	<i>Microporella browni</i> Harmelin et al. 2011	2002-LB: Harmelin et al. 2011	locally established
BRY	<i>Thalamoporella rozieri</i> (Audouin, 1826)	2002-LB: Harmelin 2014	locally established
CNI	<i>Gonionemus vertens</i> A. Agassiz, 1862	1918-IT: Joseph 1919	FR: Picard 1951/IT- see Servello et al. 2019
CNI	<i>Scolionema suvaense</i> (Agassiz & Mayer, 1899)	1950-FR: Picard 1951	IT: see Servello et al. 2019
CNI	<i>Cassiopea andromeda</i> (Forskål, 1775)	1903-CY: Maas 1903	GR, IL, IT, LB, MT, TN, TR -see EASIN
CRU	<i>Acartia (Acanthacartia) fossae</i> Gurney, 1927	1970s-LB: Lakkis, 1976	EG: Abd El-Rahman 2005
CRU	<i>Acrocalanus gibber</i> Giesbrecht, 1888	1966-LB: Lakkis 1990	EG: Abd El-Rahman 2005
CRU	<i>Arietellus pavoninus</i> Sars G.O., 1905	1967-GR: Moraitou-Apostolopoulou 1969	EMED: Zenetos et al. 2010
CRU	<i>Centropages furcatus</i> (Dana, 1849)	1989-LB: Lakkis 1990	EG, GR,TR, LB-see EASIN
CRU	<i>Labidocera madurae</i> Scott A., 1909	1970s-LB: Lakkis 1976	EG: Abd El-Rahman 2005/TR: Lakkis et al. 2005
CRU	<i>Paracartia grani</i> Sars G.O., 1904	1975-ES: Bradford-Grieve 1999	FR, GR, IT, LB, SY, TN, TR- see EASIN
CRU	<i>Triconia rufa</i> (Boxshall & Böttger, 1987)	1982-LB: Malt et al. 1989	IT: see Servello et al. 2019/EG: Abd El-Rahman 2005
CRU	<i>Triconia umerus</i> (Böttger-Schnack & Boxshall, 1990)	2004-IT: Di Capua and Boxshall 2008	locally established -see Servello et al. 2019
CRU	<i>Livoneca redmanii</i> Leach, 1818	<2015-EG: Rania and Rehab 2015	locally established -see Abdel-Latif 2016
CRU	<i>Mesanthura cf. romulea</i> Poore & Lew Ton, 1986	<1989-EG: Samaan et al. 1989	CY, ES, GR, IT, MT, TN, TR-see Ulman et al. 2017
CRU	<i>Synidotea variegata</i> Collinge, 1917	1983-84-EG: Ramadan 1986	locally established -see Ramadan et al. 1998
CRU	<i>Neomysis integer</i> (Leach, 1814)	1939-FR: Băescu 1941	ES: Munilla and San 2005
CRU	<i>Megabalanus tintinnabulum</i> (Linnaeus, 1758)	1791-IT: Poli 1791 as <i>Lepas balanus</i> Linnaeus, 1758	DZ, EG, GR, HR, IL, MT, SI -see EASIN
MOL	<i>Lottia</i> sp. Gray, 1833	2015-IT: Scuderi and Eernisse 2016	locally established -see Servello et al. 2019
MOL	<i>Nerita sanguinolenta</i> Menke, 1829	1969-GR: Nordsieck 1973	EG, LY, TN, TR-see EASIN
RHO	<i>Caulacanthus okamurae</i> Yamada	2004-FR: Mineur et al. 2007	FR: confirmed by M. Verlaque
RHO	<i>Diplothamnion jolyi</i> C. van den Hoek, 1978	2012-MA: Moussa et al. 2015	locally established
RHO	<i>Spermothamnion cymosum</i> (Harvey) De Toni	2010-IT: Armeli 2013	locally established -see Servello et al. 2019
SIP	<i>Phascolosoma scolops</i> (Selenka & de Man, 1883)	1975-HR: Murina 1976	CY: Açik et al. 2005

Abbreviations for taxonomic groups are as follows: BRY Bryozoa, CNI Cnidaria, CRU Crustacea, MOL Mollusca, RHO Rhodophyta, SIP Sipuncula. Country codes follow the internationally accepted two-letter codes for countries (<https://www.worldatlas.com/aatlas/ctycodes.htm>)

include *Paracartia grani* Sars G.O., 1904, a species that was previously assigned cryptogenic status but has now been reinstated as alien (see Tsiamis et al. 2019) and the parasite *Livoneca redmanii* Leach, 1818, which was found parasitizing *Argyrosomus regius* in Egyptian waters (Rania and Rehab 2015).

Cassiopea andromeda (Forskål, 1775), a long-established species in the Mediterranean (e.g. see Maggio et al. 2019), is included here to rectify an omission in the Zenetos et al. (2017) inventory. The same

applies for the copepod *Arietellus pavoninus* Sars G.O., 1905, already established in the eastern Mediterranean, which was included in Zenetos et al. (2010) but was missed in Zenetos et al. (2017). If records of foraminifera were included in this list, the number would be much higher, however we opted to exclude them from the current work as the particular taxonomic group is due for a revision of its native/alien species in a comprehensive article (Langer, in preparation).

Table 2 New NIS reported in the 2017-19 period. In bold established NIS

Higher taxon	Species name	Year of 1st Introduction	Country of 1st introduction	Establishment success	Potential Pathway	Source
ASC	<i>Ascidia</i> aff. <i>curvata</i> (Traustedt, 1882)	2014-15	IL	cas	UNK	Gewing and Shenkar 2017
ASC	<i>Botrylloides diegensis</i> Ritter and Forsyth, 1927	unk	unk	est	UNK	Viard et al. 2019
BRY	<i>Calyptotheca alexandriensis</i> Abdel-salam et al. 2017	2015	EG	est	COR	Abdelsalam et al. 2017
CHL	<i>Codium pulvinatum</i> M.J.Wynne & R.Hoffman	2014	IL	est	COR	Hoffman et al. 2017
CHL	<i>Avrainvillea amadelpha</i> (Montagne) A.Gepp & E.S.Gepp	2012	LY	est	T-S	Verlaque et al. 2017
CHL	<i>Ulva tepida</i> Masakiyo & S.Shimada, 2014	2002	IL	unk	T-S/COR	Krupnic et al., 2018
CHL	<i>Ulva chaugulii</i> M.G.Kavale & M.A.Kazi	2015-16	IL	unk	T-S/COR	Krupnic et al., 2018
CNI	<i>Cotylorhiza erythraea</i> Stiasny, 1920	2003	IL	est	COR	Galil et al. 2017a
CNI	<i>Chrysaora</i> cf. <i>achlyos</i> Martin, Gershwin, Burnett, Cargo and Bloom, 1997	2018	GR	unk	T-S	Langeneck et al. 2019
CRU	<i>Stenothoe georgiana</i> Bynum & Fox, 1977	2010	ES	est	CON	Fernandez-Gonzalez and Sanchez-Jerez 2017
CRU	<i>Hatschekia siganicola</i> El-Rashidy & Boxshall, 2011	2016	LY	unk	CON	Abdelnor et al. 2019
CRU	<i>Arcania brevifrons</i> Chen, 1989	2016	IL	est	COR	Galil et al. 2017b
CRU	<i>Lysmata vittata</i> (Stimpson, 1860)	2017	EG	cas	COR	Abdelsalam 2018
CRU	<i>Panulirus longipes longipes</i> (A. Milne-Edwards, 1868)	2018	IL	cas	ESC	Spanier and Friedmann 2019
CRU	<i>Dioithona oculata</i> (Farran, 1913)	2013	TR	est	T-S	Terbiyik Kurt 2018
CRU	<i>Aoroides longimerus</i> Ren & Zheng, 1996	2015	FR	unk	T-S	Ulman et al. 2017
CRU	<i>Cymodoce fuscina</i> Schotte & Kensley, 2005	2002	LB	est	T-S	Castelló et al. 2020
CRU	<i>Xiphopenaeus kroyeri</i> (Heller, 1862)	2016	EG	est	T-S	Khafage and Taha 2019
CRU	<i>Laticorophium baconi</i> (Shoemaker, 1934)	2018	ES	unk	T-S	Gouillieux and Sauriau 2019
CRU	<i>Pleopis schmackeri</i> (Poppe, 1889)	2012	TR	est	UNK	Terbiyik Kurt and Polat 2017
CRU	<i>Pseudodiaptomus trihamatus</i> Wright S., 1937	2014	EG	est	UNK	Eltohamy et al. 2017
ECH	<i>Holothuria (Theelothuria) hamata</i> Pearson, 1913	2017	TR	cas	COR	Aydin et al. 2019
FISH	<i>Fistularia petimba</i> Lacepède, 1803	2016	IL	est	COR	Stern et al. 2017
FISH	<i>Priacanthus prolixus</i> Starnes, 1988	2016	TR	cas	COR	Gürlek et al. 2017
FISH	<i>Bathygobius cyclopterus</i> (Cuvier & Valenciennes 1837)	2017	EG	cas	COR	Akel In Stamouli et al. 2017
FISH	<i>Acanthurus sohal</i> (Forsskål, 1775)	2017	GR	cas	COR	Givos et al. 2018
FISH	<i>Arnoglossus nigrofilamentosus</i> Fricke et al. 2017	2017	IL	cas	COR	Fricke et al. 2017
FISH	<i>Caesio varilineata</i> Carpenter, 1987	2018	EG	est	COR	Bos and Ogowang 2018
FISH	<i>Ablennes hians</i> (Valenciennes, 1846)	2018	IL	cas	COR	Golani 2019 /Alshawy et al. 2019a
FISH	<i>Chaetodon auriga</i> Forsskål, 1775	2015	IT	cas	ESC	Tiralongo et al. 2018
FISH	<i>Abudefduf sexfasciatus</i> (Lacepède, 1801)	2017	GR	cas	ESC	Givos et al. 2018
FISH	<i>Chrysiptera hemicyanea</i> (Weber, 1913)	2017	MT	cas	ESC	Deidun et al. 2018
FISH	<i>Arothron hispidus</i> (Linnaeus, 1758)	2018	CY	cas	ESC	Bariche et al. 2018
FISH	<i>Variola louti</i> (Forsskål, 1775)	2018	CY	cas	ESC	Huseyinoglu & Jimenez, in Kousteni et al. 2019

Table 2 New NIS reported in the 2017-19 period. In bold established NIS (*Continued*)

Higher taxon	Species name	Year of 1st Introduction	Country of 1st introduction	Establishment success	Potential Pathway	Source
FISH	<i>Bodianus speciosus</i> (Bowdich, 1825)	2018	TR	cas	ESC	Filiz et al. 2019
FISH	<i>Heteropriacanthus cruentatus</i> (Lacepède, 1801)	2019	LB	cas	ESC/COR	Badreddine and Bitar 2019
FISH	<i>Holacanthus africanus</i> Cadenat, 1951	2017	MT	cas	T-S	Deidun et al. 2017
FISH	<i>Diplogrammus randalli</i> Fricke, 1983	2016	TR	cas	T-S/COR	Seyhan et al. 2017
FISH	<i>Dipterygonotus balteatus</i> (Valenciennes, 1830)	2017	LB	cas	T-S/COR	Bariche and Fricke 2018
FISH	<i>Apogon atradorsatus</i> Heller & Snodgrass, 1903	2019	SY	cas	T-S/COR	Alshawy et al. 2019b
FISH	<i>Encrasicholina punctifer</i> Fowler, 1938	2014	TR	cas	UNK	Çiftçi et al. 2017
FISH	<i>Chlorurus rhakoura</i> Randall & Anderson, 1997	2017	IT	cas	UNK	Insacco and Zava 2017
MAM	<i>Sousa plumbea</i> (G. Cuvier, 1829)	2016	TR	unk	UNK	Ozbilgin et al. 2018
MOL	<i>Cribea cossinea</i> T. Cossignani, 1997	2014	TR	cas	COR	Aslan and Ovalis 2017
MOL	<i>Viriola</i> sp.[cf. <i>bayani</i>] Jousseau, 1884	2016	GR	est	COR	Micali et al. 2017
MOL	<i>Rugalucina vietnamica</i> (Zorina, 1978)	2016	IL	cas	COR	Steger et al. 2018
MOL	<i>Alveinus miliaceus</i> (Issel, 1869)	2016	IL	est	COR	Steger et al. 2018
MOL	<i>Gari pallida</i> (Deshayes, 1855)	2017	IL	cas	COR	Lubinevsky et al. 2018
MOL	<i>Gregariella</i> cf. <i>ehrenbergi</i> (Issel, 1869)	2014	EG	est	T-S	Steger et al. 2018
MOL	<i>Euthymella colzumensis</i> (Jousseau, 1898)	2017	GR	unk	T-S/COR	Angelidis and Polyzoulis 2018
MOL	<i>Phidiana militaris</i> (Alder & Hancock, 1864)	2016	IL	cas	UNK	Rothman et al. 2017
MOL	<i>Varicopeza pauxilla</i> (A. Adams, 1855)	2016	TR	est	UNK	Öztürk et al. 2017
PAN	<i>Achelia sawayai</i> s.l. Marcus, 1940	2016	IT, MT	est	T-S	Ulman et al. 2017
PHY	<i>Chaetoceros pseudosymmetricus</i> Nielsen, 1931	2015	HR	unk	UNK	Čalić et al. 2018
PLAT	<i>Pseudempleurosoma</i> sp Yamaguti, 1965	2012	TN	un	CON	Boussellaa et al. 2018
PLAT	<i>Aponurus sigani</i> Abdel Aal, Banaja & Al-Zanbagi, 1984	2016	LY	unk	CON	Abdelnor et al. 2019
PLAT	<i>Pseudoceros duplicinctus</i> Prudhoe, 1989	2015	IL	unk	UNK	Velasquez et al. 2018
PLAT	<i>Pseudobiceros stellae</i> Newman & Cannon, 1994	2016	IL	unk	UNK	Velasquez et al. 2018
POL	<i>Boccardia proboscidea</i> Hartman, 1940	2014	FR	cas	CON	Radashevsky et al. 2019
POL	<i>Iphione muricata</i> (Lamarck, 1818)	2015	IL	est	COR	Goren et al. 2017
POL	<i>Caulleriella viridis</i> (Langerhans, 1881)	2006	GR	que	T-S	Maidanou et al. 2017
RHO	<i>Aglaothamnion hallia</i> (Collins) Aponte, D.L. Ballantine & J.N. Norris	2016	IT	cas	CON	Wolf et al. 2018
RHO	<i>Melanothamnus japonicus</i> (Harvey) Díaz-Tapia & Magg	2016	IT	est	CON	Wolf et al. 2018
RHO	<i>Kapraunia schneideri</i> (Stuercke & Freshwater) A.M.Savoie & G.W.Saunders	2016	IT	est	T-S	Wolf et al. 2018
TRA	<i>Halophila decipiens</i> Ostenfeld	2018	GR	est	T-S	Gerakaris et al. 2020

Taxonomic group abbreviations: ASC Ascidiacea, BRY Bryozoa, CHL Chlorophyta, CNI Cnidaria, CRU Crustacea, ECH Echinodermata, FISH Fishes, MAM Mammals, MOL Mollusca, PAN Pantopoda, PHY Phytoplankton, PLAT Platyelminthes, POL Polychaeta, RHO Rhodophyta, TRA Tracheophyta. The Pathway column indicates the most likely primary pathway of Introduction: CON TRANSPORT- CONTAMINANT, COR CORRIDOR, ESC ESCAPE FROM CONFINEMENT, T-S TRANSPORT- STOWAWAY, UNK Unknown. Country codes follow the internationally accepted two-letter codes for countries <https://www.worldatlas.com/aatlas/cytcodes.htm>

New species

In the period 2017-2019, 65 new NIS species have been reported (Table 2) of which 23 are established. In cases where the establishment status of the species was not clear from the literature, confirmation was sought from experts: i.e. for the alga *Codium pulvinatum* M.J.Wynne

& R. Hoffman and the polychaete *Iphione muricata* (Lamarck, 1818), which are both established in Israel (pers. comm. by Razy Hoffman and Liron Goren respectively). The record of the polychaete *Boccardia proboscidea* Hartman, 1940 in France must be treated with caution. The French specimen was retrieved from an oyster at a

restaurant in southern France, with a putative origin in the main aquaculture facility of the nearby Leucate lagoon (Radashevsky et al. 2019). However, due to the high uncertainty associated with the origins of the oyster specimen, this finding requires confirmation and further investigation before a sound Mediterranean record is established (Radashevsky et al. 2019). Approximately one third (1/3) of the recently reported species are demersal fishes, the majority of which have presumably entered either via the Suez Canal or are aquaria releases; nevertheless, the additions include representatives from a broad range of taxonomic groups.

All new established NIS were observed after 2012, with the exception of *Botrylloides diegensis* Ritter and Forsyth, 1927, *Ulva tepida* Masakiyo & S. Shimada, 2014 and *Cotylorhiza erythraea* Stiasny, 1920. *Ulva tepida* was collected in Israel in 2002 and then again in 2015-2016 but was only conclusively identified with genetic markers and reported in 2018 (Krupnik et al. 2018). The same study reported *U. chaugulii* for the first time from the Mediterranean in 2015-2016, although the authors point out that, due to the high phenotypic plasticity of *Ulva* species, earlier records of *U. linza* Linnaeus (see Einav and Israel 2008) may represent one or both of these species (Krupnik et al. 2018). The establishment success of both *U. tepida* and *U. chaugulii* is currently unknown. Concerning *B. diegensis*, Viard et al. (2019), based on genetic studies and a re-examination of GenBank sequences from various Mediterranean locations, propose that the presence of this species may have been strongly underestimated in the Mediterranean region, as it is commonly confused for *Botrylloides leachii* (Savigny, 1816), such that its year and location of first introduction cannot be easily ascertained. *Cotylorhiza erythraea* on the other hand, has been observed off the Israeli coast since 2003 but its identity was only recently confirmed with the help of molecular analyses (Galil et al. 2017a). Not surprisingly, the countries with the highest number of newly recorded and established NIS were Israel (17 species in total / 6 established), Turkey (10/3) and Egypt (7/5). Nevertheless, the Suez Canal (i.e. the corridor pathway) is not the only important pathway of introduction for new species (n=19+7), where 19 is the number of species whose introduction is attributed exclusively to the corridor pathway and 7 are the species which could have entered also via alternative pathways. The transport-stowaway (T-S) pathway, representing ships ballast, hull fouling and other vectors, contributed almost equally to new species introductions reported in the 2017-2019 period (n=13+6), where 13 is the number of species whose introduction is attributed exclusively to the T-S pathway and 6 are the species which could have entered also via alternative pathways, while escape from

confinement of pet species from aquaria (ESC) and transport-contaminant (CON), both as parasites and as hitchhikers on aquaculture transports, are considered responsible for the introduction of 8 and 7 new species respectively. Finally, the primary pathway of introduction remains undetermined for 12 of the 65 new species.

Species that have changed their establishment success

Twenty two species previously considered as casual records have established viable populations (Table 3). The time spans between consecutive records for the species of this category vary considerably but are as long as 50-90 years in some cases. The amphipod *Bemlos leptocheirus*, recorded for the first time near the entrance of the Suez Canal almost a century ago (Schellenberg 1928), reappeared in the Mediterranean in 2015, recorded by Ulman et al. (2017) in two Greek marinas, and is now considered established. The bryozoan *Hippopodina* sp has been sporadically reported from the Eastern Mediterranean Sea as *H. feegensis* (Busk, 1884) since 1966 (Powell 1969). The species was recently re-described by Tilbrook (1999), leading Ulman et al. (2017) to conclude that the specimens found in Turkish and Greek marinas belong to the yet undescribed *Hippopodina* sp. collected by Tilbrook (2006) from Massawa Harbor, Erythraea (K. J. Tilbrook, 2017, personal communication in Ulman et al. 2017). Previous records of *H. feegensis* in Rodos, Greece (Corsini-Foka et al. 2015) may need to be re-examined and re-assigned to *Hippopodina* sp. A (Ulman et al. 2017). The bivalve *Isognomon legumen* (Gmelin, 1791), which is now considered established on the basis of new and re-examined records, constitutes another case of difficult identification/misidentification. First reported in Israel by Mienis et al. (2016), the species' presence is now confirmed from multiple locations in Greece, Turkey and Italy (Crocetta et al. 2017; Micali et al. 2017; Stamouli et al. 2017; Scuderi and Viola 2019). The opisthobranch *Berthellina citrina* (Rüppell & Leuckart, 1828), which was previously excluded from alien species lists of the Mediterranean (Zenetos et al. 2004) due to possible misidentifications with the native *Berthellina edwardsii* (Vayssi re, 1897) (Cervera et al. 2004), has now been identified by molecular analysis and reported from three different locations in southern Turkey (Yoke s et al. 2018). Genetic analyses were also instrumental in verifying the presence of the pomacentrid *Abudefduf vaigiensis* (Quoy & Gaimard, 1825) in the Mediterranean Sea, which had been excluded from the list of established species in Zenetos et al. (2017), after it was concluded by Tsadok et al. (2015) that the population in Israel actually belonged to *A. saxatilis*. Since then, established populations of *A. vaigiensis* have been reported from Malta (Vella et al. 2016) and

Table 3 Alien Species that became established in the 2017–2019 period

Higher taxon	Species name	Original source	Additional sources
BRY	<i>Hippopodina</i> sp.	1966-IL: Powell 1969	1996-GR: Morri et al. 1999 / 2016-TR: Ulman et al. 2017
BRY	<i>Watersipora arcuata</i> Banta, 1969	2013-IT: Ferrario et al. 2015	2016-TR, ES, MT, IT: Ulman et al. 2017
CNI	<i>Oulastrea crispata</i> (Lamarck, 1816)	2012-FR: Hoeksema & Ocaña Vicente, 2014	2017-ES: Mariani et al. 2018
CRU	<i>Bemlos leptocheirus</i> (Walker, 1909)	1924-EG: Schellenberg 1928	2015-GR: Ulman et al. 2017
CRU	<i>Charybdis feriata</i> (Linnaeus, 1758)	2004-ES: Abelló and Hispano 2006	2015-IT: Tiralongo in Karachle et al. 2016/ 2017-ES: Colmenero et al. 2019
CRU	<i>Cymothoa indica</i> Schioedte & Meinert, 1884	2003-LB: Trilles and Bariche 2006	<2015-EG: Rania and Rehab 2015
CRU	<i>Halimede ochtodes</i> (Herbst, 1783)	2013-EG: Moussa et al. 2016	2013-EG: Akel in Lipej et al. 2017
CRU	<i>Halimede tyche</i> (Herbst, 1801)	1998-IL: Galil 2000	2016-LB: SPA/RAC–UN Environment/MAP 2017
CRU	<i>Ianiropsis serricaudis</i> Gurjanova, 1936	2012-IT: Marchini et al. 2016	2014-IT: Ferrario et al. 2017/2015-FR: Ulman et al. 2017
CRU	<i>Oithona davisae</i> Ferrari F.D. & Orsi, 1984	2000-ES: Saiz et al. 2003	2004-5-IT: Zagami et al. 2018 / 2015-TR: Terbiyik Kurt and Beşiktepe 2019 2018- GR: Anadolu & Michaloudi, in Dragicevic et al., 2019
CRU	<i>Sicyonia lancifer</i> (Olivier, 1811)	2015-TR: Gönülal et al. 2016	IL-Galil & Lubinevsky in Stern et al. 2019
FISH	<i>Abudefduf vaigiensis</i> (Quoy & Gaimard, 1825)	1957-IT: Tardent 1959	2013-MT: Vella et al. 2016 / 2018-LY: Osca et al. 2020
FISH	<i>Ostracion cubicus</i> Linnaeus, 1758	2011-LB: Bariche 2011	2017-TR: Gökoğlu & Korun in Gerovasileiou et al. 2017
FISH	<i>Pomacanthus imperator</i> (Bloch, 1787)	2009-IL: Golani et al. 2010	2017-SY: Capapé et al. 2018a; Saad et al. 2018 / 2019-TR: Gürlek et al. 2019 /2015-19-IL: Rothman & Stern in Stern et al. 2019
MOL	<i>Baeolidia moebii</i> Bergh, 1888	2007-TR: Turk and Furlan 2011	2017-CY: Paz-Sedano et al. 2019
MOL	<i>Berthellina citrina</i> (Rüppell & Leuckart, 1828)	1940-PA: O'Donoghue and White 1940	2005-TR: Yokes & Ünsal Karhan in Yokes et al., 2018
MOL	<i>Cuthona perca</i> (Er. Marcus, 1958)	1976-IT: Cesari 1994	2015-SI: Lipej & Trkov in Yokeş et al. 2018
MOL	<i>Goniobranchus obsoletus</i> (Rüppell & Leuckart, 1830)	2015-IL: Halevy et al. 2015	2018-CY: Kleitou et al. 2019
MOL	<i>Isognomon legumen</i> (Gmelin, 1791)	2015-IL: Mienis et al. 2016	2016-GR: Micali et al. 2017 / 2017-TR: Ovalis & Zenetos in Stamouli et al. 2017 /2017-IT: Scuderi and Viola 2019
MOL	<i>Plocamopherus tilesii</i> Bergh, 1877	2009-TR: Yokeş et al. 2012	TR: B. Yokeş pers commun
PHY	<i>Chaetoceros bacteriastroides</i> G.H.H.Karsten, 1907	2002-IT: Sarno and Zingone 2008	2010-HR: Čalić et al., 2017
PLAT	<i>Neolalolepidapedon hawaiiense</i> Yamaguti, 1965	2006-TN: Merella et al. 2007	LY: Salem 2017

Taxonomic group abbreviations: *PHY* Phytoplankton, *BRY* Bryozoa, *CNI* Cnidaria, *CRU* Crustacea, *FISH* Fishes, *MOL* Mollusca, *PLAT* Platyelminthes. Country codes follow the internationally accepted two-letter codes for countries (<https://www.worldatlas.com/aatlas/ctycodes.htm>)

Libya (Osca et al. 2020), in both cases supported by DNA sequencing.

A worrying development is the widespread establishment of *Oithona davisae* Ferrari and Orsi 1984, as already anticipated by Karachle et al. (2017). This cyclopoid copepod, previously only reported from Spain within the Mediterranean (Saiz et al. 2003), has now been recorded with considerable populations from the Aegean Sea (Dragičević et al. 2019; Terbiyik Kurt and Beşiktepe 2019), the port of Venice (Zagami et al. 2018) and southern Italy (Vidjak et al. 2019), presumably carried with ballast waters and aquaculture transports. It displays an invasive character in San Francisco Bay (Ferrari and Orsi 1984) and the Black Sea (Seregin and Popova 2019) by competitive exclusion of native copepod

species, while it is suspected that it can affect pelagic food webs through increased consumption of flagellates and interference with larval fish feeding (Karachle et al. 2017). The Indo-West Pacific rock shrimp *Sicyonia lancifer* (Olivier, 1811) is now confirmed as established in Israel, with multiple specimens having been collected by trawl fishermen in 2019 (Galil & Lubinevsky in Stern et al. 2019). The species was already present in a number of locations in Turkey and one in Israel by 2016 (Gönülal et al. 2016; Pataña and Mutlu 2016) but due to the sporadic specimens and novelty of the invasion, it was not considered established in the Zenetos et al. (2017) update.

For the nudibranch *Plocamopherus tilesii* Bergh, 1877, local establishment in Turkish waters was confirmed by

Yokeş (pers. comm.) who has caught 12 specimens since the first record in 2009, during seasonal trawl surveys in Mersin Bay. Another notable species with multiple new occurrences in the past 3 years is the Lessepsian fish *Pomacanthus imperator* (Bloch, 1787), which has spread along the Levantine coast from Israel as far as southern Turkey (Gürlek et al. 2019). While it was initially hypothesized that the species' introduction may have also resulted from an aquarium escape (Golani et al. 2010), recent genetic evidence indicates introduction through the Suez Canal as the most plausible pathway (Stern et al. 2019).

As much as the spread pattern of *P. imperator* is a typical example of natural dispersal, the case of *Watersipora arcuata* Banta, 1969 is exactly the opposite. A relatively recent introduction, this fouling bryozoan was only known from one location in the Ligurian Sea, Italy (Ferrario et al. 2015) up to the compilation by Zenetos et al. (2017). In a matter of 2-3 years the species was discovered in Spain, Malta, Sicily, Turkey (Ulman et al. 2017) and the Tyrrhenian Sea (Ferrario et al. 2017), always in marinas for recreational craft. Another species most likely spreading via hull fouling is the colonial scleractinian coral *Oulastrea crispata* (Lamarck, 1816). The species, which was only recorded once in Corsica in 2012 (Hoeksema and Ocaña 2014), has now been found in two additional locations in Spain (Mariani et al. 2018) and is considered established in the western Mediterranean.

The parasite *Neoallopepidapedon hawaiiense* Yamaguti, 1965, which was thus far recorded only once in Tunisia in 2007 from *Fistularia commersonii* Rüppell, 1838 (Merella et al. 2007), has also changed its establishment success in the Mediterranean. The species has now been also reported from Libya, in the same host, by Salem (2017), and is considered established in the central Mediterranean. Regarding the establishment status of parasites with complex life cycles, one could argue that establishment success can only be affirmed if the intermediate hosts have been found carrying the parasites as well; otherwise a plausible hypothesis would be that the findings belong to residual infections that took place before the definitive host's migration (Merella et al. 2010). Besides the fact that this is an overly strict criterion, given the scarcity of distributional information on many of these parasites, the alternative assumption would be that each alien parasite record represents a new introduction event, which does not seem plausible either. Thus, while high uncertainty in their establishment success is acknowledged, alien parasites follow the same criteria for establishment outlined in the methods section and in Zenetos et al. (2017) and Zenetos et al. (2008).

Lastly for this group, a small number of species which were considered established until Zenetos et al. (2017) have now been re-classified as casual, due to the absence of any further records.

These are: *Papilloculiceps longiceps* (Cuvier, 1829), an Indian ocean fish species reported only from Israel (Golani and Ben 1990); *Parvocalanus latus* Andronov, 1972, a species native in the Indian Ocean reported only from S. Turkey (Uysal et al. 2002); *Terapon theraps* Cuvier, 1829, an Indo-Pacific species with only two records of single specimens in Slovenia (Lipej et al. 2008) and Greece (Minos et al. 2012) and whose presence cannot be attributed to any pathway of introduction.

Species that have expanded their distribution into new MSFD regions

A total of 36 species have expanded their distribution into new MSFD regions, of which 21 are already established in the new locations (Table 4).

The main pathways implicated in their spread are natural dispersal from neighbouring areas (unaided pathway) and hull fouling (n=13), while ship-mediated pathways as a whole are considered responsible for the spreading of 24 species. The number of hull-fouling species records has undoubtedly been augmented since Zenetos et al. (2017) by the extensive study of Ulman et al. (2017), who sampled a large number of recreational marinas in the Mediterranean, targeting specifically alien species. It is also worth noting that the majority of large, conspicuous species, i.e. fishes and molluscs that disperse naturally (n=11), were recorded by citizen scientists and communicated to the authors through increasingly expanding initiatives and networks with national experts (e.g. expansion records of *Pterois miles* (Bennett, 1828 and , *Etrumeus golanii* in Table 4, but also *Pomacanthus imperator* and *Charybdis feriata* (Linnaeus, 1758) in Table 3).

The Central Mediterranean received the highest number of expanding species (n=19), which is not surprising, given its central position in the region, which is critical both for natural dispersal but also for its busy shipping routes and transshipment hubs (Crocetta et al. 2015; Deidun et al. 2018). The Western Mediterranean was the recipient of only 7 expanding species, primarily through shipping vectors, with the exception of two Lessepsian fishes and one fish parasite. *Etrumeus golanii*, which has already attained commercial significance in the Eastern Mediterranean (DiBattista et al. 2012), has recently spread through the central basin all the way to the Alboran Sea (Tamsouri et al. 2019). *Pteragogus trispilus*, another Lessepsian immigrant, appears to be pushing the lower limits of its thermal envelope both in the Aegean (Yapici et al. 2015) and along the African coast, having been observed in the Gulf of Tunis in 2016 (Hamed et al. 2018).

Ten species expanded their Mediterranean distribution into the Adriatic Sea, most of them already widespread in two or three MSFD sectors of the basin. Of

Table 4 Species expanding their distribution into new MSFD areas

Higher taxon	Species	From	To	status	pathway	Expansion record(s)
ASC	<i>Perophora multiclathrata</i> (Sluiter, 1904)	WMED	CMED	unk	T-S (fouling)	IT: Lezzi et al., 2018
PHY	<i>Chaetoceros bacteriastroides</i> G.H.H.Karsten, 1907	WMED	ADRIA	est	T-S (ballast)	HR: Čalić, M., et al., 2018
BRY	<i>Parasmittina egyptiaca</i> (Waters, 1909)	EMED	CMED	unk	T-S (fouling)	IT: Ulman et al., 2017
BRY	<i>Watersipora arcuata</i> Banta, 1969	WMED	CMED, EMED	est	T-S (fouling)	ES, IT, MT, TR: Ulman et al., 2017
CHL	<i>Ulva ohnoi</i> M.Hiraoka & S.Shimada, 2004	WMED	CMED, EMED	est	T-S (fouling)	IL: Krupnik et al., 2018 / TN: Miladi et al., 2018
CRU	<i>Paracaprella pusilla</i> Mayer, 1890	EMED, WMED	CMED	est	T-S (fouling)	TN: Fersi et al., 2018
CRU	<i>Stenothoe georgiana</i> Bynum & Fox, 1977	WMED	CMED	est	T-S (fouling)	IT: Ulman et al., 2017
CRU	<i>Oithona davisae</i> Ferrari F.D. & Orsi, 1984	WMED	EMED, CMED, ADRIA	est	T-S (ballast)	GR: Dragičević et al., 2019; TR: Terbiyik Kurt & Beşiktepe, 2019 / IT: Zagami et al., 2018 / IT: Vidjak et al., 2019
CRU	<i>Dyspanopeus sayi</i> (Smith, 1869)	CMED	EMED	cas	T-S (ballast)/CON	GR: Ulman et al., 2017
CRU	<i>Anilocra pilchardi</i> Bariche & Trilles, 2006	EMED, CMED	WMED	unk	UNA	TN: Ounifi Ben Amor et al., 2017
CRU	<i>Ianiropsis serricaudis</i> Gurjanova, 1936	ADRIA	WMED	est	T-S (fouling)	IT: Ferrario et al., 2017 / FR: Ulman et al., 2017
FISH	<i>Bregmaceros nectabanus</i> Whitley 1941	EMED	CMED	est	UNA	GR: Ketsilis-Rinis & Dimitriou in Chartosia et al., 2018
FISH	<i>Etrumeus golanii</i> Di Battista, Randall & Bowen, 2012	EMED, CMED	WMED	est	UNA	DZ: Kassar & Hemida in Stamouli et al., 2017 / TN: Rafrafi-Nouira et al., 2017 / MA: Tamsouri et al., 2019
FISH	<i>Parupeneus forsskali</i> (Fourmanoir & Guézé, 1976)	EMED	CMED	est	UNA	TN: Capapé et al., 2018b
FISH	<i>Pteragogus trispilus</i> Randall, 2013	EMED, CMED	WMED	cas	UNA	TN: Hamed et al., 2018
FISH	<i>Pterois miles</i> (Bennett, 1828)	EMED, WMED	CMED	est	UNA	IT: Azzurro et al., 2017 / GR: Mitsou & Maximiadi in Yokeş et al., 2018 / LY: Al Mabruk & Rizgalla, 2019
FISH	<i>Sciaenops ocellatus</i> (Linnaeus, 1766)	EMED	CMED	est	UNA	IT: Langeneck et al., 2017
FISH	<i>Synchiropus sechellensis</i> Regan, 1908	GR: EMED	CMED	unk	UNA	GR: Teneketzis & Christidis in Yokeş et al., 2018
MOL	<i>Dendostrea cf folium</i> (Linnaeus, 1758)	EMED	ADRIA	est	T-S (fouling)	AL: Xharahi et al. in Gerovasileiou et al., 2017
MOL	<i>Fulvia fragilis</i> (Forsskål in Niebuhr, 1775)	EMED, CMED, WMED	ADRIA	est	T-S/UNA	AL: Xharahi et al. in Gerovasileiou et al., 2017 / ME: Gvozdenović et al., 2019
MOL	<i>Malleus regula</i> (Forsskål in Niebuhr, 1775)	EMED	CMED	est	T-S (fouling)	IT: Prato & Rubino in Kousteni et al., 2019
MOL	<i>Sepioteuthis lessoniana</i> Férussac [in Lesson], 1831	EMED, CMED	ADRIA	est	UNA	ME: Dragičević et al. in Stern et al., 2019
MOL	<i>Biuve fulvipunctata</i> (Baba, 1938)	EMED, CMED, WMED	ADRIA	est	UNA	HR: Petani & Crocetta in Kousteni et al., 2019
MOL	<i>Conomurex persicus</i> (Swainson, 1821)	EMED, CMED	ADRIA	unk	T-S/UNA	AL: Xharahi et al. in Gerovasileiou et al., 2017
MOL	<i>Diodora ruppellii</i> (G. B. Sowerby I, 1835)	EMED, WMED	CMED	cas?	T-S (fouling)/UNA	LY: Rizgalla et al., 2019

Table 4 Species expanding their distribution into new MSFD areas (*Continued*)

Higher taxon	Species	From	To	status	pathway	Expansion record(s)
MOL	<i>Godiva quadricolor</i> (Barnard, 1927)	WMED, ADRIA	CMED	est	T-S/CON	IT: Furfaro et al., 2018
MOL	<i>Haminoea cyanomarginata</i> Heller & Thompson, 1983	EMED, CMED, WMED	ADRIA	unk	T-S/UNA	HR: Dragicevic et al. in Chartosia et al., 2018
PLAT	<i>Allolepidapedon fistulariae</i> Yamaguti, 1940	EMED, WMED	CMED	unk	UNA	LY: Salem, 2017
PLAT	<i>Glyphidohaptor plectocirra</i> (Paperna, 1972) Kritsky, Galli & Yang, 2007	EMED	CMED	unk	UNA	LY: Abdelnor et al., 2019
PLAT	<i>Maritigrella fuscopunctata</i> (Prudhoe, 1978)	CMED	EMED	unk	T-S/UNA	IL: Velasquez et al., 2018
POL	<i>Chaetozone corona</i> Berkeley & Berkeley, 1941	EMED, CMED	ADRIA, WMED	est	T-S (ballast)	IT (ADRIA): Munari et al., 2017; Grossi et al., 2017 / IT (WMED): Munari et al., 2017
POL	<i>Desdemonia ornata</i> Banse, 1957	EMED, ADRIA, WMED	CMED	unk	T-S/CON	TN: Boudaya et al., 2019
POL	<i>Dorvillea similis</i> (Crossland, 1924)	EMED	WMED	est	T-S (fouling)/UNA	IT: Langeneck & Tempesti in Dragicevic et al., 2019
POL	<i>Hydroides brachyacantha</i> Rioja, 1941	EMED	WMED	unk	T-S (fouling)	ES: Ulman et al., 2017
POL	<i>Palola valida</i> (Gravier, 1900)	EMED	ADRIA	unk	T-S (fouling)	ME: Spagnolo et al., 2019
RHO	<i>Chondria curvilineata</i> F.S.Collins & Hervey, 1917	EMED, WMED	CMED	est	T-S	IT: Alongi in Gerovasileiou et al., 2017

The pathway column refers to the most likely pathway of secondary spread. Taxonomic group and Pathway abbreviations as in Table 2

these, *Sepiotheuthis lessoniana* and *Biuve fluviopunctata* seem to be spreading unaided from the neighbouring Ionian Sea (Stern et al. 2019; Kousteni et al. 2019 respectively), while for the other species shipping vectors are implicated in their expansion. The Eastern Mediterranean, most commonly the starting point for the spread of naturally dispersing Lessepsian migrants, received 5 species, all most likely associated with ship-mediated pathways. The Indo-Pacific flatworm *Maritigrella fuscopunctata*, which was first observed in Malta (Crocetta et al. 2015) may constitute an exception, as its presence was already suspected along the Levantine coast and was later confirmed in Israel (Velasquez et al. 2018), such that entrance through the Suez Canal cannot be excluded.

OTHER changes

Nomenclature has changed for 20 species, while there were year and/or country changes of first records in 13 cases (Additional file 2). These include: *Plagusia squamosa* (Herbst, 1790), *Prionospio pulchra* Imajima 1990, *Aurelia solida* Browne, 1905; *Ulva ohnoi* M. Hiraoka & S. Shimada, *Magallana gigas* (Thunberg, 1793), *Hypnea spinella* (C.Agardh) Kützing, *Leodice antennata* Savigny in Lamarck, 1818, *Siganus luridus* (Rüppell, 1829) and *Upe-neus moluccensis* (Bleeker, 1855). Noteworthy are the

records of *Plagusia squamosa* (Herbst, 1790) since 1903 in Italy (see Servello et al. 2019) and *Aurelia solida* Browne, 1905 in Tunisia since at least 1994 (Gueroun et al. 2020).

General discussion

To summarise, the current update adds 70 species to the established alien species inventory of the Mediterranean Sea (Additional file 1). Besides the 25 missing records, there are 23 newly introduced species between 2017-2019 which are already established. At the same time period, 22 species that were previously considered casual, based on 1-2 location records and/or single specimens, are now well-established, as anticipated by Zenetos et al. (2017), some of them with an impressive spatial distribution (see *Oithona davisae*, *Isognomon legumen*, *Pomacanthus imperator* and *Watersipora arcuata* in Table 3). Similarly, a considerable number of species have expanded their distribution into new MSFD areas, with the Central Mediterranean and the Adriatic Sea the main recipients of this expansion. A number of reasons can be invoked for this apparent increase in the rate of spread and establishment of Mediterranean alien species. Two of them are related to the rate of discovery of new presence records, driven by intensified research efforts on marine NIS. EU regulations, such as the Marine Strategy Framework Directive (EC (European Commission) 2008),

the Biodiversity Strategy (EC (European Commission) 2011; EC (European Commission) 2014), the IAS Regulation (EU Regulation 2014), the Ballast Water Management Convention (IMO (International Maritime Organization) 2004; IMO (International Maritime Organization) 2017), have resulted in a large demand in relevant data production and reporting and are the driving force behind dedicated research projects and national monitoring schemes for NIS. Furthermore, the increased appreciation of stakeholder involvement (Azzurro et al. 2019) and the burst in citizen science initiatives and networks (e.g. Zenetos et al. 2013; Crocetta et al. 2017; Giovos et al. 2019) has undoubtedly improved the spatial scale and temporal resolution of alien species detection, monitoring and surveillance.

The above notwithstanding, climate change is also expected to have played a role in this accelerated rate of alien species expansion. Warming of the Mediterranean Sea surface waters between 1985–2006 has been estimated at 0.04 °C/year, leading to an overall SST increase of approximately 1°C for the eastern basin, with the Aegean Sea and the Adriatic among the hotspots of this warming trend (Nykjaer 2009). For marine species, geographic ranges conform closely to their thermal limits (Sunday et al. 2012; Payne et al. 2016), which in turn show higher plasticity at their lower end (Stuart-Smith et al. 2017). Expansion records of Indo-Pacific species discussed in previous sections indicate that a number of species are likely already favoured by increased temperatures, exhibiting their northernmost records in the Mediterranean (e.g. *Sepioteuthis lessoniana* Férussac [in Lesson], 1831, *Biuve fulvipunctata* (Baba, 1938), *Haminoea cyanomarginata* Heller & Thompson, 1983) or pushing their way into cooler western Mediterranean waters (e.g. *Etrumeus golanii*).

Attention needs to be paid to the fact that the observed rate of new introductions does not appear to be related to the enlargement of the Suez Canal, verifying the findings of Zenetos (2017, 2019). When all potential pathways are considered for the new species introduced between 2017–2019, it is only 4 species per year that seem to enter the Mediterranean through the Suez Canal, a number much lower than the 7 species per year, reported by Zenetos et al. (2017) for the period 2015–2017. An appreciable number of alien species were introduced to Mediterranean waters via shipping pathways (7 in total), predominantly zoobenthic and planktonic species, as well as benthic plants. Aquaria releases have also contributed 7 species in total to the Mediterranean xenodiversity, all but one demersal fish with, as of yet, only casual records since 2017. A characteristic example is the high-valued aquarium species *Abudefduf sexfasciatus* (Lacepède, 1801), native to the Red Sea, which was

however observed for the first time in Greek waters, too far away from the Suez Canal (Giovos et al. 2018). *Chrysiptera hemicyanea* (Weber, 1913) on the other hand, a typical coral-reef dweller, is not found in the Red Sea and is almost certainly released from an aquarium into Maltese waters (Deidun et al. 2018). It remains to be seen whether some of these species will be confirmed as aquarium releases or will be proven Lessepsian migrants by additional records and/or genetic evidence, as was the case for *Acanthurus sohal* (Forsskål, 1775) (Bariche et al. 2019) and *Pomacanthus imperator* (Bloch, 1787) (Stern et al. 2019).

In agreement with Zenetos et al. (2017), we consider this a “provisional” list, presenting the changes in Mediterranean marine alien species since the end of 2016. We acknowledge that even the current update may contain errors, as species invasions are dynamic phenomena, where new information continually comes to light, whether from new observations or from re-examination of older material, changes in nomenclature and phylogenetic studies. Finally, we re-affirm the critical role of international collaboration and consultation with local and taxonomic experts in keeping these important policy tools as accurate and up-to-date as possible in order to provide well-informed management and policy advice.

Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s41200-020-00191-4>.

Additional file 1.

Additional file 2.

Acknowledgements

We would like to thank the following colleagues for advice provided on the establishment success of selected species/taxa: Dani Golani (*Papilloculiceps longiceps*, *Coryogalops ocheticus* and *Terapon theraps*), Nir Stern (*Papilloculiceps longiceps*), Dori Edelist, Gil Rilov, Shevy Rothman (*Papilloculiceps longiceps*, *Abudefduf sexfasciatus*), Marcello Kovacic (*Coryogalops ocheticus*), Melih Ertan Çinar (*Spiophanes algidus*), Tuba Terbiyik Kurt (zooplankton), Liron Goren (*Iphinoe muricata*), Razy Hoffman (*Codium pulvinatum*), Marc Verlaque (2 macroalgae), Carla Morri (*Diphasia digitalis*), Fabio Crocetta (molluscs), Serge Gofas (*Pseudochama corbierei*), Ghazi Bitar (*Diphasia digitalis*), Baki Yokes (*Plocamopherus tilesii*), Paolo Merella (Lessepsian parasites), Xavier Turon (ascidians) and the anonymous reviewers whose constructive criticism has improved our manuscript. Finally, we would like to extend our sincere gratitude and appreciation to the editor, John Bishop, whose dedicated effort and commitment to detail substantially contributed to the integrity of this work.

Authors' contributions

AZ conceived the study, collected the literature, maintains the HCMR offline database and compiled the tables. MG contributed to the data collection and proofing and table collation. Both authors contributed equally to the drafting of the manuscript and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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Received: 13 February 2020 Accepted: 1 July 2020

Published online: 31 August 2020

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