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Data Paper

Unpublished Mediterranean records of marine alien and cryptogenic species

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Abstract

Good datasets of geo-referenced records of alien species are a prerequisite for assessing the spatio-temporal dynamics of biological invasions, their invasive potential, and the magnitude of their impacts. However, with the exception of first records on a country level or wider regions, observations of species presence tend to remain unpublished, buried in scattered repositories or in the personal databases of experts. Through an initiative to collect, harmonize and make such unpublished data for marine alien and cryptogenic species in the Mediterranean Sea available, a large dataset comprising 5376 records was created. It includes records of 239 alien or cryptogenic taxa (192 Animalia, 24 Plantae, 23 Chromista) from 19 countries surrounding the Mediterranean Sea. In terms of records, the most reported Phyla in descending order were Chordata, Mollusca, Chlorophyta, Arthropoda, and Rhodophyta. The most recorded species was *Caulerpa cylindracea*, followed by *Siganus luridus*, *Magallana* sp. (cf. *gigas* or *angulata*) and *Pterois miles*. The dataset includes records from 1972 to 2020, with the highest number of records observed in 2018. Among the records of the dataset, *Dictyota acutiloba* is a first record for the Mediterranean Sea. Nine first country records are also included: the alga *Caulerpa taxifolia* var. *distichophylla*, the cube boxfish *Ostracion cubicus*, and the cleaner shrimp *Urocaridella pulchella* from Israel; the sponge *Paraleucilla magna* from Libya and Slovenia; the lumpfish *Cyclopterus lumpus* from Cyprus; the bryozoan *Celleporaria vermiformis* and the polychaetes *Prionospio depauperata* and *Notomastus aberans* from Malta.

Key words: non-native species, non-indigenous, distribution, citizen science, invasive alien species, geo-referenced records, Mediterranean Sea

Introduction

The biodiversity of the Mediterranean Sea faces many cumulative threats due to anthropogenic activities and global change (Coll et al. 2012; Micheli et al. 2013). Biological invasions, often facilitated by climate change, have been considered as a major driver of change in Mediterranean marine ecosystems (Katsanevakis et al. 2014a; Azzurro et al. 2019a; Morri et al. 2019) with important impacts at all levels of biodiversity (Katsanevakis et al. 2014b). Therefore, substantial effort is put by both marine scientists and managers to increase our knowledge on the spatio-temporal dynamics and impacts of alien species in the region, with the ultimate aim of deploying mitigation actions in order to protect native biodiversity and ecosystem functioning.

Effective management and conservation of marine ecosystems require suitable spatio-temporal information on the distribution of species and the status of ecological features, which, in the Mediterranean Sea, is often incomplete or lacking adequate detail (Levin et al. 2014). Regularly updated geo-referenced records of alien species are valuable for assessing their invasion progress and temporal dynamics, investigating their ecological requirements, and developing species distribution models to forecast their present and future distributions. However, while new records in the Mediterranean at basin-, ecoregion-, or country-scale are commonly published, observations of species presence often remain unpublished when they are not “first records” in a given country or ecoregion and fall within the already documented invasion range. Thus, useful spatio-temporal information remains buried in the personal files of researchers or scattered repositories. Such information is valuable for a multitude of research efforts, especially in light of the current hastened pace of climate change and anthropogenic impacts on coastal habitats (He and Silliman 2019).

To collect such spatio-temporal information, an invitation to submit unpublished records of alien and cryptogenic species in the Mediterranean was sent to numerous marine biologists from all Mediterranean countries. The main goal was to create a collective large dataset that will be freely available to the scientific community and the public, complementing already published records. The aims of this paper are to make this dataset available and describe its taxonomic and spatio-temporal coverage.

Dataset compilation

In total, 126 marine scientists from 16 countries participated in this effort and contributed 5376 records (see Supplementary material Table S1). Each record was represented by one line in an Excel sheet, and corresponded to the observation of an alien or cryptogenic species at a specific point in space and time. The required fields for each record, providing the most essential data, were species name, latitude, longitude, country, year, the name of the "observer", and the "type of observation".

"Observer" was the marine scientist who made the identification of the species. In cases where a specimen was either collected or photographed/filmed by a citizen, and delivered to a marine biologist for identification, both the name of the scientist and the name of the citizen (in brackets) appear in the field "observer". Unpublished data collected through citizen-science initiatives were only included if species identifications were adequately verified by scientists. Specifically, such unpublished data by the following citizen science projects were included in the present dataset: "Is it Alien to you? Share it!!!" (Giovos et al. 2019), "Seawatchers" (Azzurro et al. 2013), "Corsica Alien Network" (Barralon et al. 2019), "Aliens in the Sea" (Mannino et al. 2017).

"Type of observation" was a binomial selection of either "visual only" or "collected specimen", in order to indicate respectively whether the record was based only on visual observation (e.g. during SCUBA diving or snorkelling, or photo/video taken by a citizen) or specimen collection and identification in a laboratory.

In addition to the required fields, there were additional optional fields, which included: exact date, depth of observation/collection, habitat, number of individuals observed, and additional comments. The Kingdom and Phylum of each species, as well as its biogeographic status (alien or cryptogenic *sensu* Essl et al. 2018) were also included. This information was retrieved from the European Alien Species Information Network (EASIN),

Figure 1. Taxonomic coverage of the dataset: (A) distribution pool by Kingdom; (B) frequency distribution of the number of records per species; (C) records by Phylum; (D) records by species (for the twenty most frequently observed species).

which has a transparent mechanism for quality assurance and updates through an Editorial Board of experts (Tsiamis et al. 2016).

Taxonomic coverage

The dataset includes 239 taxa, of which 192 are Animalia, 24 Plantae, and 23 Chromista. Most of the taxa (206) were classified as alien, and only 33 as cryptogenic. In terms of individual records, the majority belong to Animalia (67.1%), followed by Plantae (27.7%) and Chromista (5.2%) (Figure 1A). The Phylum with most records is Chordata with 1477 records (of which 89.7% were Actinopterygii and 10.3% Ascidiacea), followed by Mollusca, Chlorophyta, Arthropoda and Rhodophyta (Figure 1C). The majority of taxa observed (55.2%) were recorded no more than 5 times (Figure 1B), although there were four taxa with more than 200 records: *Caulerpa cylindracea*, followed by *Siganus luridus*, *Magallana* sp. (cf. *gigas* or *angulata*) and *Pterois miles* (Figure 1D). Taxa were identified based on collected specimens for 25.9% of the records, or visually (either *in situ* or through photos/video) for the remaining 74.1%.

Spatial and temporal coverage

The dataset includes observations made between 1972 and January 2020. Only 1.6% of the observations were recorded in the ‘70s, ‘80s, and ‘90s. The year with the most records is 2018 (23.7%), followed by 2019 (17.1%) and 2017 (12.1%) (Figure 2A). There are records from 19 countries, with the highest number of records reported from Greece (22.7%), followed by Italy (14.4%), Malta (12.7%), and Spain (10.3%) (Figure 2B). The species recorded in the highest number of countries is *Caulerpa cylindracea*, followed by *Fistularia commersonii, Siganus luridus,* and *Percnon gibbesi* (Figure 2C).

As anticipated, the records are not uniformly distributed in the Mediterranean, as their spatial distribution is driven both by the actual distribution patterns of alien and cryptogenic species and the specificities of this dataset, reflecting the uneven distribution of experts, taxonomic expertise, and sampling effort. A high density of records is observed in several locations, e.g. Malta, Slovenia, Venice lagoon (Italy), SE Cyprus, Lebanon, while records along the continental coastline of France and the north African coastline are scarce, with the exception of Tunisia (Figure 3).

In 77.6% of the records, the depth or depth range is indicated, with most records in shallow waters. Among these records, depths ≤ 1 m are reported in 30.1% of cases, depths between 1–5 m in 36.1%, and depths between 30–100 m in only 9.9%, whereas only four observations took place at depths > 100 m.

Remarkable new records of alien species

Among the records of the dataset, there is one first record for the Mediterranean Sea, of a new invasive alien seaweed species, from the Levantine shore of Israel, namely *Dictyota acutiloba* J. Agardh (Figure 4A). Many first country records of other aliens are also included in our dataset: first record of the green alga *Caulerpa taxifolia* var. *distichophylla* (Sonder) Verlaque, Huisman & Procaccini, from Israel (Figure 4B); first record of the sponge *Paraleucilla magna* Klautau, Monteiro & Borojevic, 2004 from Libya (Figure 4C) and Slovenia; first record of the lumpfish *Cyclopterus lumpus* Linnaeus, 1758 from eastern Mediterranean (Cyprus) (Figure 4D); first record of the cube boxfish *Ostracion cubicus* Linnaeus, 1758 from Israel (Figure 4E); first record of the cleaner shrimp *Urocaridella pulchella*

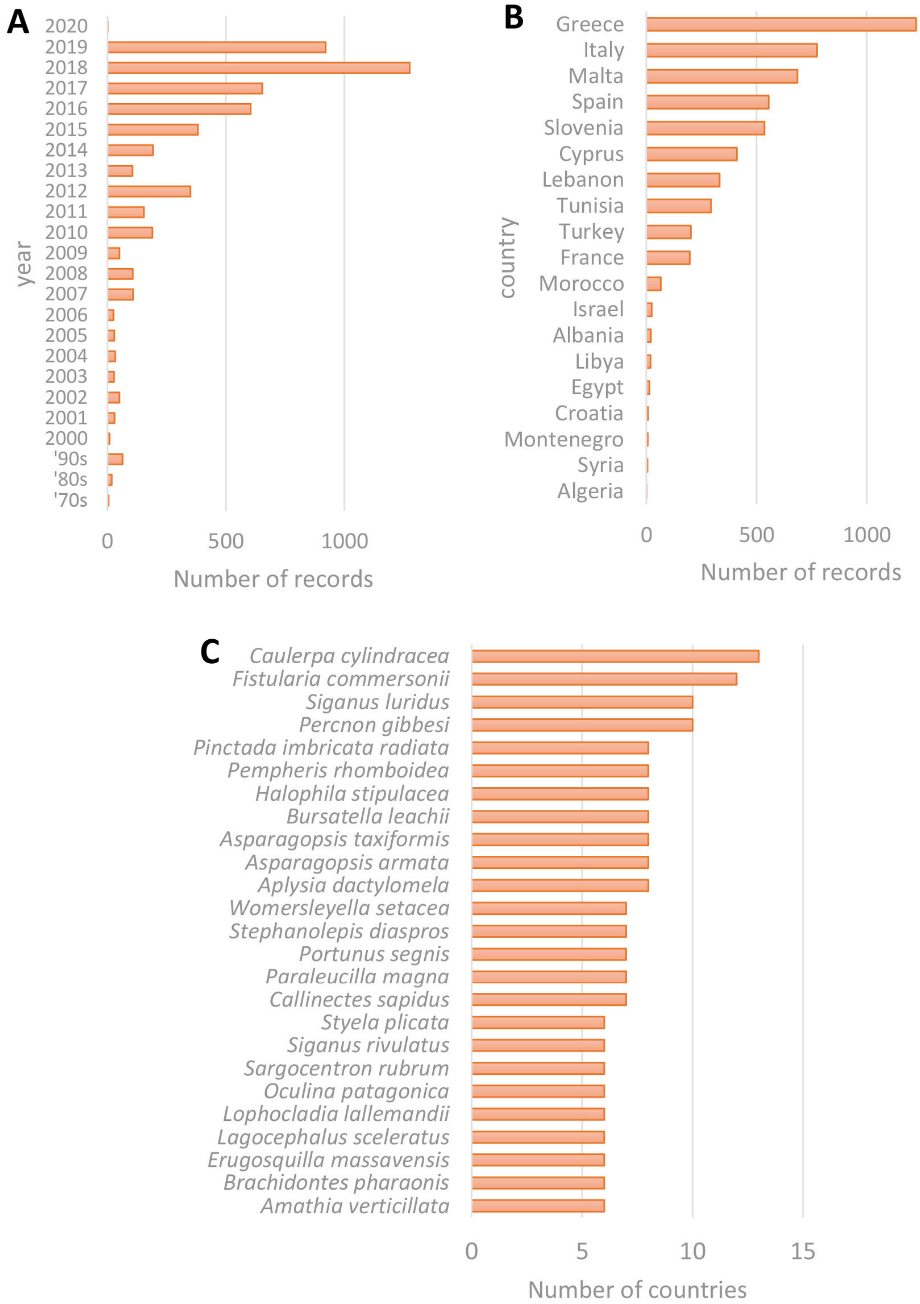

Figure 2. Spatio-temporal coverage of the dataset: (A) temporal distribution of records; (B) records per country; (C) country-coverage of species (for species recorded in more than 5 countries).

Yokeş & Galil, 2006 from Israel (Figure 4F); first record of the bryozoan *Celleporaria vermiformis* (Waters, 1909) from Malta; first records of two polychaete species from Malta, i.e. *Prionospio depauperata* Imajima, 1990, and *Notomastus aberans* Day, 1957.

Dictyota aculitoba is a brown seaweed that probably originated from the Pacific region. This species has a south Pacific distribution (Guiry and Guiry 2020). It was first observed growing on subtidal rocks, near the port of the city of Haifa, at the end of the first decade of the present millennium. Therefore, we assume that it arrived through shipping. However, the ID of this newcomer was not clear until recently. Morphological and molecular

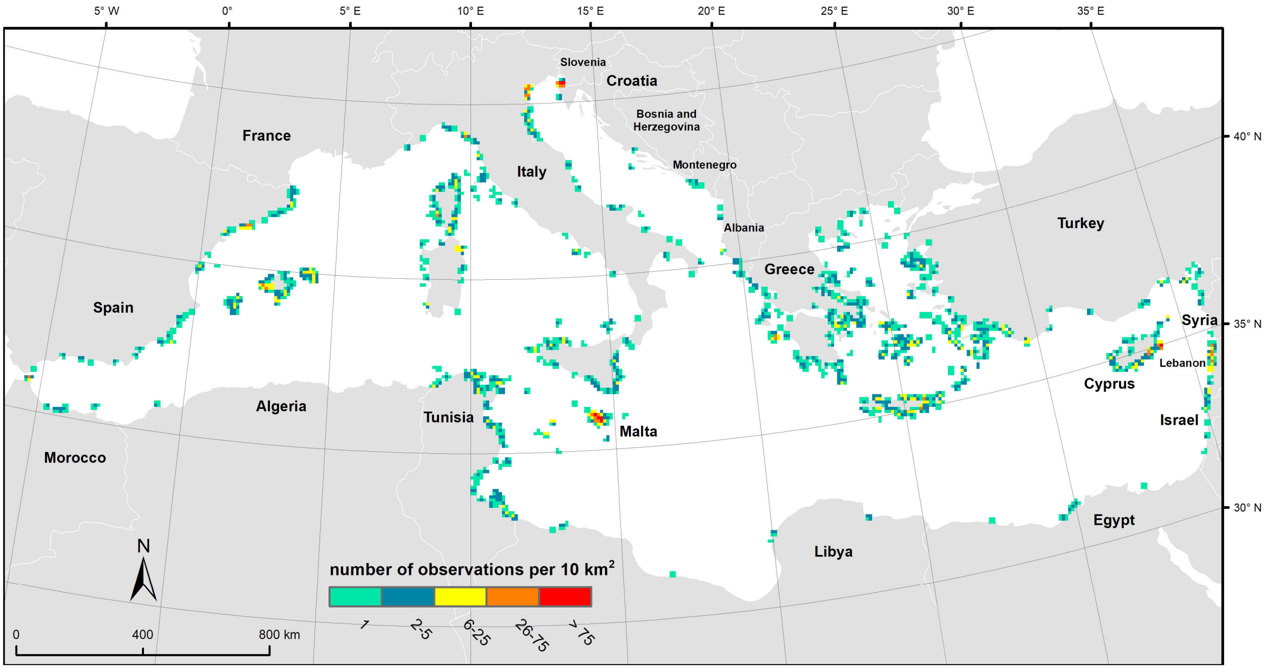

Figure 3. Number of alien and cryptogenic records per 10 km × 10 km grid cell, included in the dataset.

studies indicated that it was not one of the local Mediterranean species among the genus *Dictyota*. Although the presence of *D. aculitoba*, as an alien in the Mediterranean Sea, was mentioned in Tsiamis et al. (2020), there was no previous information regarding its distribution in this sea, and Tsiamis et al. (2020) posted in their table of Appendix B only rankings, indicating its presence and invasiveness. Since the first observation in Haifa Bay, it became invasive and spread northwards up to the border of Lebanon. High blooms, pointing at its invasiveness, are mainly observed during spring and summer along over 35 km of the northern shore of Israel. There is a high chance that it is also present in South Lebanon.

Caulerpa taxifolia var. *distichophylla* is a gracile variant of the famous invasive green seaweed species *Caulerpa taxifolia*, known for its unflattering name as the "killer alga", because it has negative effects on the local marine flora and causes a loss of biodiversity in native marine ecosystems (Hoffman 2014). This variety probably originated from the South Pacific and Australia (Guiry and Guiry 2020). It was first observed and collected from the Mediterranean Sea in 2003, from Syria, successively recorded from Turkey in 2006, Sicily (Jongma et al. 2013), Malta (Schembri et al. 2015), Cyprus (Çiçek et al. 2013), Greece (Aplikioti et al. 2016), Lebanon (Bitar et al. 2017), Libya (Shakman et al. 2017), Tunisia (Chartosia et al. 2018) and Algeria (Kousteni et al. 2019). Lately, Bitar et al. (2017) also provided distribution for this taxon from Lebanon with a southern distribution in Byblos. The first specimen from Israeli waters was collected more than 100 km south of the latter location, at a subtidal site, nearby Nahlieli Islet. *Caulerpa taxifolia* var. *distichophylla* appears to mainly grow on sandy bottom (as seen in Figure 4B).

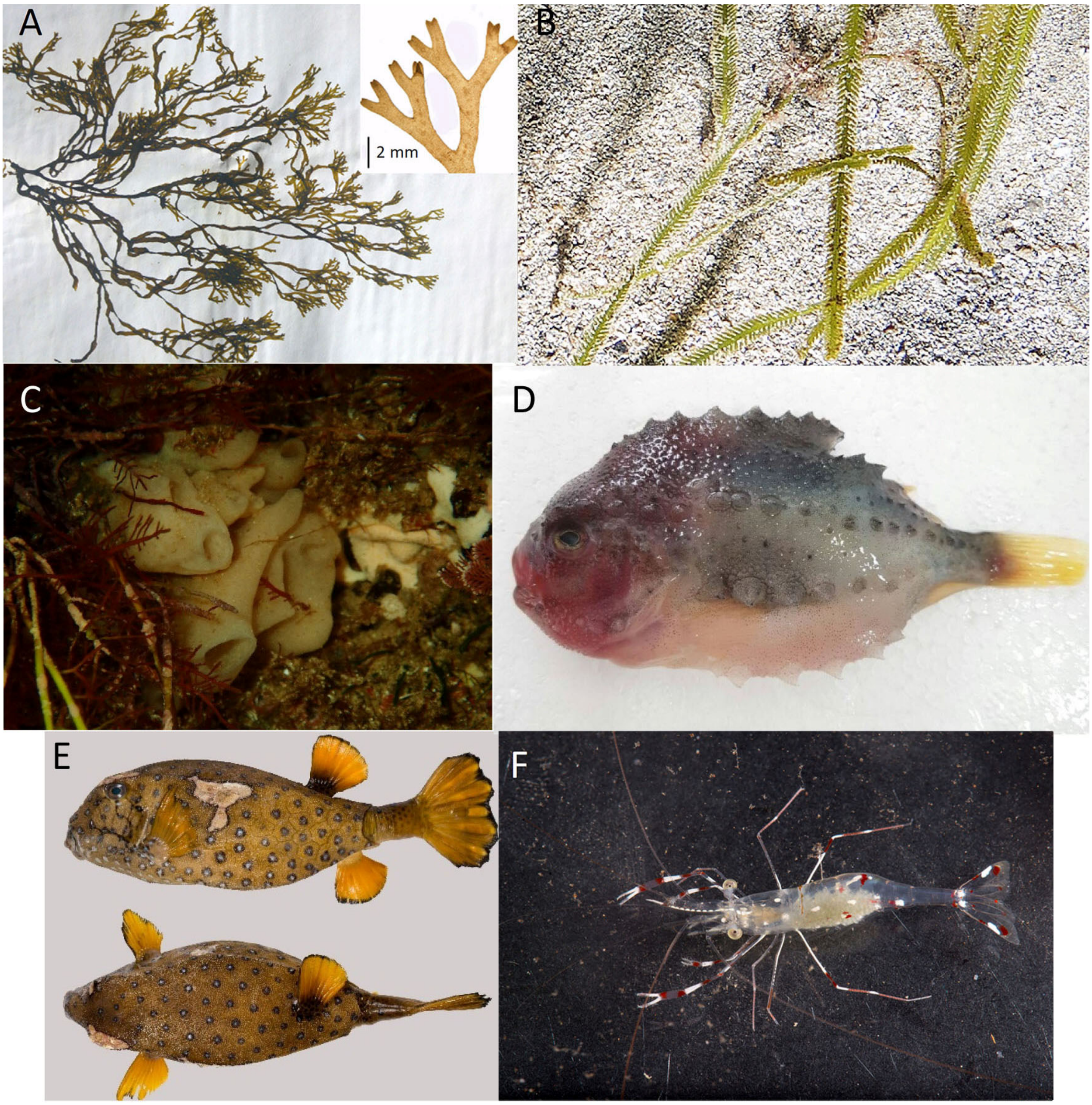

Figure 4. Remarkable new records included in the dataset: (A) *Dictyota acutiloba*, a first record in the Mediterranean Sea, observed in Israel, recorded by Razy Hoffman (photo: Razy Hoffman); (B) first record of *Caulerpa taxifolia* var. *distichophylla* in Israel, recorded by Razy Hoffman (photo: Shevy Rothman); (C) first record of the calcareous sponge *Paraleucilla magna* in Libya, recorded by Jamila Rizgalla (photo: Jamilla Rizgalla); (D) first record of *Cyclopterus lumpus* in Cyprus, recorded by Louis Hadjioannou (photo: Christos Christofi); (E) first record of *Ostracion cubicus* in Israel, recorded by Shevy Rothman (photo: Oz Rittner); (F) Ovigerous-female of *Urocaridella pulchella*, first record in Israel, recorded by Ya'arit Levitt-Barmats (photo: Oz Rittner).

Paraleucilla magna is a calcareous sponge occurring at shallow depths in turbid waters, commonly as fouler in mussel farms and marinas, with a high capacity to colonize hard substrata (Longo et al. 2007). It is also found in clean and calm waters (Klautau et al. 2004). *P. magna* was first collected and described in Brazil (Rio de Janeiro State), being found in abundance along the entire Brazilian coast (Klautau et al. 2004). The species was first recorded in the Mediterranean in 2000 in Spain (Longo et al. 2004, backdated by Frotscher and Uriz 2008) and then in Mar Piccolo and Mar

Grande of Taranto (Italy) in 2001 by Longo et al. (2004), who suggested it was an alien species. Subsequently it spread to other localities along the Italian coast (Longo et al. 2007), followed by Malta (Zammit et al. 2009), Croatia (Cvitković et al. 2013), Turkey (Sea of Marmara by Topaloğlu et al. 2016; Aegean Sea by Evcen and Çinar 2020, including material collected in 2004), the Iberian Peninsula (Dailianis et al. 2016; Guardiola et al. 2016), Cyprus (Ulman et al. 2017), Montenegro (Mačić and Petović 2017), Greece (Gerovasileiou et al. 2017), France (Ulman et al. 2017), Tunisia (Chebaane et al. 2019), and Algeria (Bachetarzi et al. 2019). Described as a species with strong seasonality (Klautau et al. 2004), adults were observed to disappear following larval release (Guardiola et al. 2011; Longo et al. 2012). It is believed to have spread in the Mediterranean basin aided by bivalve farming, known among Italian mussel farmers for over 20–30 years as "pane", i.e. the Italian word for bread (Longo et al. 2007). The speed by which it spread to various locations almost simultaneously suggests shipping traffic as another possible vector (Longo et al. 2007; Ulman et al. 2019). Here we report for the first time the presence of *P. magna* in Libya (Figure 4C) and Slovenia. Specimens of this sponge were found in the sites of mussel farms in Slovenia, growing down to 2 m depth. In Libya, sponges were found during multiple field surveys extending from May to October 2019 in a natural bay called "Regatta", about 12 km from the Tripoli Harbour. Several *P. magna* specimens were found with sizes ranging between 5 and 10 cm in height. The species was most abundant between May and June 2019, attached to rocks at 0.5–1.0 m depth. Its abundance declined, and it ultimately disappeared in the following months from July to September, and then reappeared in the beginning of October. The surveyed area was of mixed sandy and rocky substrate covered by sponges and algae.

The lumpsucker or lumpfish *Cyclopterus lumpus,* the only member of the genus *Cyclopterus*, is a primarily benthic species found on rocky substrates in the north-east and north-west Atlantic, in cold waters, mainly at high latitudes (Kudryavtseva and Karamushko 2002). Until now, it has been recorded only once in the Mediterranean, in September 2004, when one specimen was caught 13 km from the coast, off Molunat Bay, southern Adriatic (Dulčić and Golani 2006). Here we report a second record for the Mediterranean and the first in the Levantine Sea. A single specimen was found in a market in Cyprus (Figure 4D), caught by a professional fisher by net at around 25 m depth in June 2017 off Protaras (35.028°N; 34.060°E). Like Dulčić and Golani (2006), we also postulate that this fish may have arrived in the region either by ballast water, or even as an escape/release from public or private aquaria, since it is a popular aquarium fish that survives well in aquaria (Dulčić and Golani 2006).

The yellow boxfish *Ostracion cubicus* naturally occurs in the Indo-Pacific Ocean, in the Red Sea and East Africa, the Persian Gulf, to the Hawaiian and Tuamoto islands (Froese and Pauly 2019). It was first recorded in the Mediterranean Sea in January 2011 off the northern Lebanese coast, where a single individual was speared, photographed and then discarded (Bariche 2011). Later, in March and November 2015, two additional records from Tyre and Beirut, respectively, were reported from Lebanon (Dailianis et al. 2016). Finally, in April 2017 a single individual was observed and photographed by a SCUBA diver in the Gulf of Antalya, Turkey (Gerovasileiou et al. 2017). We hereby report the fifth and southernmost occurrence of *O. cubicus* in the Mediterranean Sea, which constitutes the first record of this species from the Israeli coastline. In December 2017, a single individual was speared by a fisher at 8 m depth on a breakwater in Ashdod port, southern Israel. A second individual with a bluish body colouration, presumably an adult male, was visually detected during the same dive; however, this report could not be further verified. The specimen (Figure 4E) measured 290 mm in total length, fresh coloration yellow with scattered pale blue spots edged with dark margins. The specimen had large lesions above its left eye and on the middle left side of the body, which may have been inflicted by a prior injury (Figure 4E). A fresh tissue sample from the caudal peduncle was taken for genetic analysis. The contiguous COI sequence and its trace files were uploaded to BoLD system www.boldsystems.org under the BIM project (Biota of the Israeli Mediterranean; accession voucher BIM641-19). While *O. cubicus* has been assumed to have entered the Mediterranean through the Suez Canal (Bariche 2011), the present record from an artificial structure inside an international port suggests it may have entered Israeli waters via maritime shipping.

Urocaridella pulchella is the first representative of this genus from the Mediterranean Sea (Yokeş and Galil 2006). The genus members are considered cleaner shrimps, found usually in small groups, in shallow-water reef substrates and crevices throughout the Indo-Pacific Ocean (Anker and De Grave 2016; Prakash and Baeza 2018). The species was first collected and described in 2003 from Turkey (Kaş), and was suggested to be an alien species (Yokeş and Galil 2006). Only a few years later the species was recorded from the Red Sea—Saudi Arabia (Ďuriš 2017) and Egypt (Horká et al. 2018)—supporting that *U. pulchella* is indeed of Red Sea origin. The first record from Israel, reported herein, is the second record of the species from the Mediterranean Sea, visually observed and photographed in 2014 in Nahariyya (northern Israel), during a night dive. A year later several other individuals were observed along Tel Aviv beach (central region of Israel). In 2016, five specimens were collected at 20 m depth during a dive in Akhziv reservoir (northern Israel), including three ovigerous-females (Figure 4F). COI and 16S sequences were obtained for two specimens, one from Turkey and the second from Israel, using Geneious R7 (v.7.1.5; http://www.geneious.com; Kearse et al. 2012). Using Maximum-likelihood (ML) method, the Mediterranean specimens clustered together with the Egyptian one (GenBank accession no. KY197952 and KY197943 for COI and 16S, respectively). This molecular analysis also demonstrated the difference between *U. pulchella* and *U. antonbruunii* (Bruce, 1967), known from Gulf of Aqaba (Y. Levitt-Barmats *pers. observ*.).

In the framework of a two-year monitoring program conducted on behalf of the Maltese Environment and Resources Authority (AIS/ERA), extensive surveys were conducted in Maltese waters, and the related data (part of this dataset) included first records of *Celleporaria vermiformis, Prionospio depauperata,* and *Notomastus aberans*. *Prionospio depauperata* is a NE Pacific species, first reported from south Turkey in 2005 (Dagli and Cinar 2009) and later (2009) from the Aegean Sea, Turkey (Dagli et al. 2011). Its present records in Malta at two soft-sediment sites at depths 17–18 m, are the first records in the central Mediterranean. *Notomastus aberans* is a species originating from the Indian Ocean-Red Sea, first reported from France and Greece (Harmelin 1968), already known from the central Mediterranean since 1965 (Tunisia: de Gaillande 1970), and also reported since 1992 from the Strait of Messina (Cosentino and Giacobbe 2006). Herein, we report records of 27 individuals from 11 soft-bottom sites. *Celleporaria vermiformis* is a recently reported Red Sea bryozoan (first reported in Lebanon: Harmelin 2014) that was recently discovered in fouling marinas in Turkey, Cyprus and Greece (Ulman et al. 2017). Its present record in Malta was from artificial substrates, pontoons and other structures in harbour areas.

Discussion

This collective effort is providing open access to a large dataset of alien and cryptogenic species records from the Mediterranean Sea. It can be used extensively in assessments of biological invasions in the region by complementing published records. This effort demonstrates that there is a huge amount of information related to the marine environment, scattered in personal databases and repositories, which could be retrieved easily, homogenized and made available to the scientific community. It also demonstrates that effective state-level monitoring networks in the Mediterranean are largely missing despite the requirements by EU (e.g. for the implementation of the Marine Strategy Framework Directive 2008/56/EC) and the Barcelona Convention (e.g. UNEP/MAP 2017).

Such not-yet-openly-available information exists for all fields of marine sciences (physical, chemical, geological and biological), which would greatly benefit from similar efforts to utilize previously collected and unreported data. Hence, this work can serve as a paradigm for other fields of marine sciences as well, provided that a large number of scientists are willing to participate in such a coordinated effort.

It has been estimated that less than 1% of the ecological data collected is accessible after the publication of associated results (Reichman et al. 2011). The more data made available and usable, the greater the benefit for science and society, and the better use of public money supporting research. However, encouraging scientists to share their data can be a big challenge. We believe that such collective efforts are beneficial for all contributors as their new published data are recognized and cited, and a large dataset that can be used for research objectives is provided, which may stimulate new collaborations. These benefits should be sufficient to overcome the – often observed – cultural reluctance to publish data openly. By continuing this effort on a regular basis, valuable datasets will continuously be made available to the scientific community, supporting monitoring efforts of biological invasions in the Mediterranean.

The great amount of information provided here is also a further evidence of the potential of engaging fishers and other sea users in the process of data collection and monitoring. Such a strategy could be effective beyond the local scale, at the sub-regional or even regional scale (Azzurro et al. 2019b).

As a next step, datasets like this one can feed large regional or global and subject-oriented data collections, e.g. the Global Biodiversity Information Facility (GBIF 2020), and EASIN (Katsanevakis et al. 2015). Such collections aim to further benefit research by making vast quantities of biodiversity information usable, thus assisting large-scale assessments and meta-analyses.

Our dataset, although partly representative of the status of biological invasions in the Mediterranean Sea, is not unbiased, as the included records were dependent on the specific group of participating scientists and their taxonomic and geographical areas of research, varying sampling effort among countries, unbalanced development of citizen science initiatives among countries, and specificities of each species (e.g. some can be identified visually with very high certainty, while others require examination of specimens in the laboratory by experts or even molecular studies). Nevertheless, some patterns observed in the data are indicative of the degree of establishment (as a proxy for the invasiveness of some species). For example, *Caulerpa cylindracea*, the most invasive alien seaweed species known from the Mediterranean Sea (Katsanevakis et al. 2016) was the most reported species in this dataset, with 738 new records, from more countries than any other species.

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Disclaimer

The responsibility for correct identification and reporting rests with the observer of each record, as stated in the Supplementary material Table S1.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Dataset of unpublished Mediterranean Records.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2020/Supplements/BIR_2020_Katsanevakis_etal_Table_S1.xlsx