

## Research Article

## Tapping into hard-to-get information: the contribution of citizen science campaigns for updating knowledge on range-expanding, introduced and rare native marine species in the Malta-Sicily Channel

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### Abstract

Considerable research effort has recently been invested into the reporting of Non-Indigenous Species (NIS) within the Mediterranean Sea, with species' first records from the Basin holding most prestige within the biological community. This invariably leads to a discard of secondary, unpublished records, which represent a vast repository of information. This study documents a total of 49 unpublished records (represented by 89 individuals) of nine Atlantic range-expanding and introduced species, as well as rarely-reported native and cryptogenic species, within the Malta-Sicily Channel, gleaned through citizen science efforts conducted on the islands of Malta and Sicily. The study also represents the second record of *Pomadasyus incisus* (Bowdich, 1825) from Maltese waters, as well as the second record of *Selene dorsalis* (Gill, 1863) from the Mediterranean.

**Key words:** central Mediterranean Sea, Non-Indigenous Species (NIS), unpublished records, first records, distribution of marine species, biogeography

### Introduction

The redistribution of Earth's species is among the most evident consequences of global warming (Molinos et al. 2016), with these changes being usually greater for marine environments as a result of their high environmental connectivity (Burrows et al. 2011). Climate change, in fact, is further leading to a global redistribution of coastal biota via physiologically-driven species range shifts and altered species interactions (He and Silliman 2019).

The redistribution of biota is facilitated in those ecological areas and corridors, corresponding to transitional areas and biogeographical boundaries (Bianchi 2007). In this context, the Mediterranean qualifies as a biogeographical boundary since it lies at the crossroads between the Offshore South Atlantic and the North-West North Atlantic realms to its west and the Black Sea and the Red Sea (Erythrean) realms to its east (Costello et al. 2017).

Concurrent with the advent of thermophilous marine species from contiguous tropical and sub-tropical regions into the Mediterranean through the Suez Canal, the so-called “Lessepsian invasion” (Galil et al. 2018; Zenetos and Galanidi 2020), the entry of natural range-expanding Atlantic species as well as of Atlantic exotic species into the Basin, has been well-documented in recent years (e.g. Evans et al. 2020).

Katsanevakis et al. (2020) have recently collated a repository of unpublished records for marine alien and cryptogenic species recorded from the Mediterranean. In general, marine species originating from the Atlantic, with the exception of *Percon gibbesi* (H. Milne Edwards, 1853) and *Aplysia dactylomela* (Rang, 1828), were excluded from this recent study.

Some of the same introduction pathways known to be responsible for the entry of Lessepsian species into the Mediterranean, including vessel and offshore platform ballast water, are also plausible for the Atlantic exotic species (excluding the range-expanding ones) recorded in the present study. For instance, an interview with the staff of an Italian drilling platform (Scarabeo 9, Saipem) originating in Soyo, Angola revealed that a *Cephalopholis taeniops* (Valenciennes, 1828) individual, weighing about 4 kilograms, was recorded during a sea chest inspection conducted on the same platform in the aftermath of a trip from Angola to Las Palmas harbour, Canary Islands (Insacco and Zava 2017). In addition, Pajuelo et al. (2016) documented eleven non-native fish species (originating mostly from tropical areas of the Atlantic) from oil platforms and rig docking areas within the Las Palmas harbour (Canary Islands).

First records of a species from a region are essential to the field of ecology and biogeography in order to construct timelines (Hobbs et al. 2010). Generally, once the contest for the publication of the first record of a species from an area has been settled, additional, subsequent reports of the same species are often overlooked such that they are rarely published. This is unfortunate given the wealth of information represented within these repositories of unpublished records (e.g. Tantipisanuh and Gale 2018), which could be useful in identifying spatio-temporal trends in a species’ spread for management purposes and which may remain buried within researchers’ private databases.

Our study adopts the definition of “natural range-expanding species” proposed within Marchini et al. (2015), namely that this group represents “eastern Atlantic species having most likely entered the Mediterranean Sea through the Straits of Gibraltar, lacking evidence of human transport.” Essl et al. (2019) have recently proposed the adoption of the term “neonatives” as an alternative for this class of newcomers. Recently, Evans et al. (2020) utilised a number of published records of recent Atlantic fish newcomers from the Mediterranean as part of a mathematical assessment of their biological traits. This was done with the aim of identifying the most likely origin of the same newcomer species.

In this study, we focus on the Malta-Sicily Channel, a 100-km-long stretch of water lying along the eastern flank of the Strait of Sicily, which has witnessed intense maritime traffic by virtue of its strategic location (Deidun et al. 2018). The Strait of Sicily is a region of hydrodynamic and biogeographic significance, given that it is considered to be the boundary between the Western and Eastern Basins of the Mediterranean (Manzella et al. 1988), as well as the westernmost extremity of the Lessepsian province within the Mediterranean (Azzurro and Andaloro 2004; Azzurro et al. 2017). It is no wonder that this area is considered to be a strategic observation outpost within the Central Mediterranean for the monitoring of marine non-indigenous species (NIS) and the range extension of those entering the Mediterranean through the Gibraltar Strait (Azzurro et al. 2014).

### Materials and methods

The unpublished rare marine species' records included in this study are documented from data repositories relevant to a number of citizen science campaigns conducted within Malta and Sicily. The "Spot the Rare" and the "Alien Fish" citizen science campaigns for instance were launched at the Museo Civico di Storia Naturale in Comiso in 2015, collating within a regional database all citizen science and professional fishermen reports of exotic and rare marine species. The campaigns were disseminated through posters distributed within the target landing ports situated along the southern coast of Sicily, through the Museum's Facebook page ([www.facebook.com/museo.civico.comiso](http://www.facebook.com/museo.civico.comiso)), or by using direct telephone contact with the participating project naturalists.

The "Spot the Alien Fish" and the "Spot the Alien citizen science campaigns" were launched at the University of Malta in 2017 and in 2019, respectively, pursuant to collating within a national database all citizen science reports pertaining to Non-Indigenous Species (NIS) within Maltese waters. Reports to the campaigns can be submitted by a dedicated web portal ([www.aliensmalta.eu](http://www.aliensmalta.eu)) as well as through the corresponding campaign social media pages and email address.

The main objective of our study was to provide an assessment of the repository of unpublished citizen science records for a total of eleven species (described below), selected by virtue of their biogeographic interest given that they either represent (i) range-expanding species native of the eastern Atlantic, (ii) Atlantic species introduced into the Mediterranean or (iii) rarely-reported native Mediterranean species. Within the ambit of this study, considerations on the current biogeographical status of the Malta-Sicily Channel are also made and these are integrated with the findings of the Katsanevakis et al. (2020) study.

The databases of the relevant marine NIS citizen science campaigns were tapped with the aim of extracting unpublished records of range-expanding species from Maltese and Sicilian waters, with the oldest species' records

within these databases dating back to 2011 (for instance, for *Aplysia dactylomela*, which was recorded in August 2011 from the island of Ustica in the south Tyrrhenian Sea). Despite this, only citizen science reports submitted since 2015 were included in the current study since full record attributes (date, location, depth, etc) only started being recorded from this point onwards. In order to be included within our assessment, citizen science reports for the eleven species of interest had to satisfy the following criteria: (i) report has not been published prior to the current study; (ii) report has been substantiated through an accompanying original photo or through the provision of the specimen itself and (iii) report included information pertaining to geographical location, number of individuals of the species, and date.

A total of eleven species having a native Atlantic or Mediterranean origin were included in our study. The cohort of eleven species includes two species native of the eastern Atlantic – *Aplysia dactylomela* (Rang, 1828) and *Gaidropsarus granti* (Regan, 1903) – whose vector of introduction into the Mediterranean has not yet been fully elucidated (Moles et al. 2017 and Bello 2018, respectively), as well as a rarely-reported species native to the Mediterranean (*Parasquilla ferussaci* Roux, 1828). However, whilst *A. dactylomela* is being listed as an Atlantic range-expanding species, *G. granti* is being listed as a cryptogenic species, given its collection at a number of deep sites within the Mediterranean (e.g. at a depth of 300 m off SE Rhodes – Zachariou-Mamalinga 1999; at the Ulysses Seamount at a depth of 300–700 m, Orsi-Relini and Relini 2014) as well as being known from the Azores in the Atlantic (Santos et al. 1997). Given that the current distribution of these two latter species includes areas of the north-east Atlantic which are contiguous to the Mediterranean, these were classified as Atlantic range-expanding species, along with four other species included in this study (i.e. *Pisodonophis semicinctus*, *Seriola fasciata*, *Pomadasy incisus* and *Abudefduf saxatilis*). *Parasquilla ferussaci* has been listed tentatively as a native Mediterranean species, given the broad distribution within the Mediterranean Sea of its collection sites (e.g. Sardo et al. 2020). A change in fishing strategies, technology and gear have been identified by some authors (e.g. Colmenero and Raso 2009) as the reason behind the recent increase in reports of this species from the basin.

Species of Atlantic origin not considered to be range-expanding ones are referred to as “introduced” species of Atlantic origin. Just four species (*Callinectes sapidus*, *Cephalopholis taeniops*, *Selene dorsalis* and *Acanthurus monroviae*) out of the eleven species under review are considered to have an “introduced” status. The native range for each fish species was gleaned from Froese and Pauly (2020), whilst the native range for *Parasquilla ferussaci* and for *Callinectes sapidus* was gleaned from Monod (1951) and from Nehring (2011), respectively. The current status of each of the species under review within the Mediterranean was inferred on the merits of the

**Table 1.** Full list of the eleven species considered within this study.

Species included in the study	Taxonomic group	Native range	Inferred current Mediterranean status
<i>Aplysia dactylomela</i>	Mollusca (Opisthobranchia)	Unknown	Atlantic range-expanding species
<i>Callinectes sapidus</i>	Crustacea (Decapoda)	Temperate, sub-tropical and tropical Western Atlantic	Introduced species of Atlantic origin
<i>Parasquilla ferussaci</i>	Crustacea (Stomatopoda)	Eastern Central Atlantic	Native to the Mediterranean and the eastern Atlantic
<i>Pisodonophis semicinctus</i>	Osteichthyes	Tropical, sub-tropical Eastern Atlantic	Atlantic range-expanding species
<i>Gaidropsarus granti</i>	Osteichthyes	Unknown	Cryptogenic, possibly native to the Mediterranean and to the eastern Atlantic
<i>Cephalopholis taeniops</i>	Osteichthyes	Tropical, sub-tropical Eastern Atlantic	Introduced species of Atlantic origin
<i>Selene dorsalis</i>	Osteichthyes	Tropical, sub-tropical Eastern Atlantic	Introduced species of Atlantic origin
<i>Seriola fasciata</i>	Osteichthyes	Tropical, sub-tropical Western Atlantic	Atlantic range-expanding species
<i>Pomadasys incisus</i>	Osteichthyes	Tropical, sub-tropical Eastern Atlantic	Atlantic range-expanding species
<i>Abudefduf saxatilis</i>	Osteichthyes	Tropical and sub-tropical West and East Atlantic	Atlantic range-expanding species
<i>Acanthurus monroviae</i>	Osteichthyes	Tropical East Atlantic	Introduced species of Atlantic origin

current known native and introduced distribution of each species and the location of the first Mediterranean record of the species.

## Results

The full list of Atlantic and Mediterranean native species is included in Table 1, within which the current Mediterranean status of each of the eleven species under review is inferred, whilst the main descriptors of each species are given in Table 2. Supplementary material Table S1 gives the details of the unpublished records for each of the species under consideration. Original photos (with the exception of *Selene dorsalis* (Gill, 1783)) of the eleven species are given in Figure 1, whilst Figure 2 represents the inter-annual variation in the number of citizen science reports received for the species under consideration.

Three-quarters (73.4%) of the 49 unpublished records of the eleven marine species under review were made during the June–September period, in support of the fact that the majority of the same records were made by amateur fishers, SCUBA divers, snorkelers or by members of the public and not by professional fishers, with the former categories generally being seasonal sea users only. The 49 unpublished citizen records documented in the current study represented a total of 89 individuals, with the number of individuals included within each citizen science report ranging from 1 (the case in 84.4% of the reports received) to a maximum of 20 individuals (the case for a *Callinectes sapidus* report). With the exception of *Callinectes sapidus*, all the species under review were first recorded from the Mediterranean within the western half of the Basin. The species documented within this study were recorded in a variety of ways, ranging from observation of the live individual in the field during SCUBA diving and

**Table 2.** Probable introduction pathway and extent of incursion within eastern Mediterranean Basin for the species under consideration.

Species	Probable introduction pathway	Coordinates of the first Mediterranean record of the species	Coordinates of the easternmost location within the Mediterranean Sea at which species was recorded	Study reporting the easternmost record within the Mediterranean Sea of the species
<i>Aplysia dactylomela</i>	Not conclusively established	35.414655°N; 12.598606°E (island of Lampedusa, southern Strait of Sicily)	36.759092°N; 36.079831°E (Iskenderun Bay, north-east coast of Turkey)	Mannino <i>et al.</i> (2017)
<i>Callinectes sapidus</i>	Transport as a stowaway	45.295058°N; 12.446780°E (north-western Adriatic Sea)	32.892429°N; 35.076822°E (north Israeli coast)	Holthuis and Goldieb (1955)
<i>Parasquilla ferussaci</i>	Probably native to the Mediterranean	37.966030°N; 11.353292°E (south-western Tyrrhenian Sea)	39.134821°N; 26.333374°E (north-eastern Aegean Sea, off the west coast of Turkey)	Irmak <i>et al.</i> (2008)
<i>Pisodonophis semicinctus</i>	Range expansion via Gibraltar strait*	36.695736°N; 2.509104°E (central Algerian coast)	36.8164472°N; 30.6398444°E (Antalya Bay, south-west coast of Turkey)	Gokoglu <i>et al.</i> (2019)
<i>Gaidropsarus granti</i>	Possibly native to the Mediterranean	43.979030°N; 8.866413°E (northern Ligurian Sea)	43.536666°N; 15.781388°E (eastern Adriatic Sea, off the Croatian coast)	Dragicevic <i>et al.</i> (2017)
<i>Cephalopholis taeniops</i>	Transport as a stowaway	33.029429°N; 13.186050°E (off Tripoli, western Libyan coast)	32.826940°N; 35.027332°E (north Israeli coast)	Salameh <i>et al.</i> (2009)
<i>Selene dorsalis</i>	Transport as a stowaway	35.854195°N; 14.574070°E (south-eastern coast of Malta)	36.4666667°N; 14.7333333°E (Malta-Sicily Channel, eastern Strait of Sicily)	Vella and Deidun (2007)
<i>Seriola fasciata</i>	Range expansion via Gibraltar strait*	39.440073°N; 2.633817°E (south-western coast of Mallorca, Balearic Islands)	36.7343667°N; 30.5878889°E (Antalya Bay, south-west coast of Turkey)	Kapiris <i>et al.</i> (2014)
<i>Pomadasyus incisus</i>	Range expansion via Gibraltar strait*	36.106094°N; 0.132834°E (western coast of Algeria)	33.896357°N; 35.463799°E (off Beirut, central Lebanese coast)	Carus (1893)
<i>Abudefduf saxatilis</i>	Range expansion via Gibraltar strait*	41.004265°N; 1.168743°E (north-eastern coast of Spain)	32.900113°N; 34.952601°E (off the northern coast of Israel)	Goren & Galil (1998); Tsadok <i>et al.</i> (2015)
<i>Acanthurus monroviae</i>	Range expansion via Gibraltar strait*	36.701639°N; -2.075887°E (south-western coast of Spain)	32.652861°N; 14.275333°E (western Libyan coast, to the east of Tripoli)	Bariche <i>et al.</i> (2020)

snorkeling or even during a walk along the coast (*Aplysia dactylomela* was largely recorded through this method), to collection by anglers and fishing through pot, trammel nets and trawling. The citizen scientists submitting most reports in Malta were anglers/rod-fishers, whilst in Sicily fishermen and fish market hawkers submitted most citizen science reports.

## Discussion

The current study has managed to achieve its stated goal of updating current knowledge on the status of a number of Atlantic and rare native marine species within the Malta-Sicily Channel. In so doing, the same study has underpinned the frequently-untapped value for ecology and biogeography of repositories of unpublished species records emerging through citizen science efforts, which, if rigorously validated, can supplement corresponding data emerging from conventional scientific surveys.

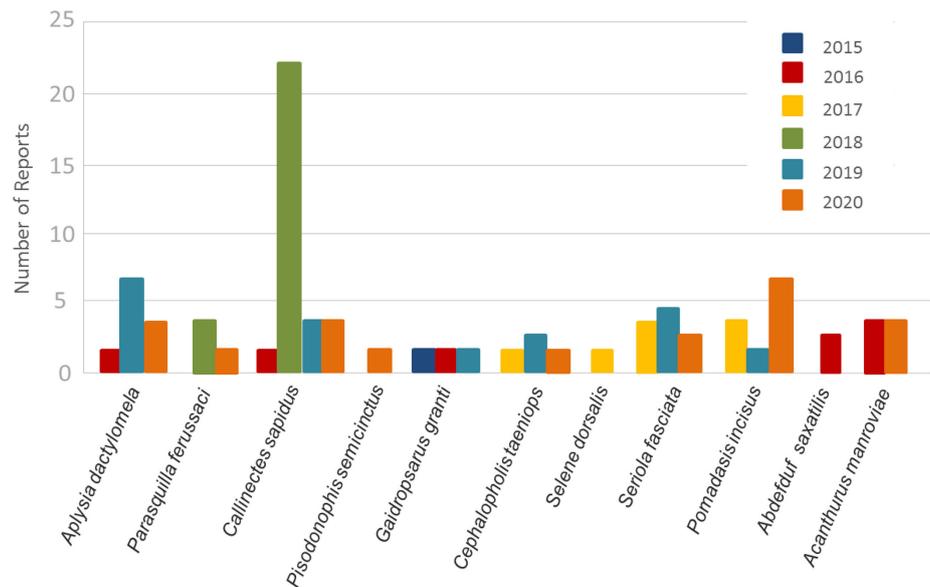
### *Attributes of the 11 species*

From the individual abundance and number of reports received for each species, one can infer that six of the eleven species under consideration, in particular *P. ferussaci*, *S. fasciata*, *A. monroviae*, *A. dactylomela*, *C. sapidus* and *C. taeniops*, are firmly established within the Strait of Sicily. The remaining five species are only observed occasionally within the region and can be considered as casuals, although they can be abundant in contiguous regions.



**Figure 2.** Voucher photos for each of the eleven species under review in the current study: (A) *Aplysia dactylomela* Rang, 1828 (Punta dell'Arpa, Ustica Island, south Tyrrhenian Sea; 29.8.2011; photo: Bruno Zava); (B) *Callinectes sapidus* Rathbun, 1896 (off Licata, south-west coast of Sicily; 17.10.2016; preserved specimen at the Comiso Natural History Museum with label MSNC 4539; photo: Gianni Insacco); (C) *Parasquilla ferussaci* Roux, 1828 – (Gulf of Catania, Sicily; 14.9.2018; photo: Lorenzo Molino); (D) *Pisodonophis semicinctus* (Richardson, 1848) – (off Termini Imerese, north coast of Sicily; 5.3.2018; photo: Giovanni Zizzo); (E) *Gaidropsarus granti* (Regan, 1903) (Scoglitti, south-east coast of Sicily; 30.8.2019; photo: Gianni Insacco); (F) *Cephalopholis taeniops* (Valenciennes, 1828) – (Secchitella, Linosa Island, Pelagian Islands; 9.9.2019; photo: Rocco Canella, Pelagos 2.0 Diving Center, Lampedusa); (H) *Selene dorsalis* (Gill, 1863) (this photo refers to a published record made off Marsascala, south-east coast of Malta, on the 10<sup>th</sup> July 2007 – Vella et al. 2009 – given that no photo of the unpublished record included in the current study exists); (G) *Seriola fasciata* (Bloch, 1793) – (Sikka l-Bajda, north-east Malta, 15.07.19; photo: Marlon Grech); (I) *Pomadasys incisus* (Bowdich, 1825) – (Mgiebah, north-east coast of Malta; 15.05.20; photo: Andrew Sammut); (J) *Abudedefduf* cf. *saxatilis* (Linnaeus, 1758) caught and placed in an aquarium (caught at Senglea, eastern coast of Malta; 15.06.16 photo: Arnold Sciberras); (K) *Acanthurus monroviae* Steindachner, 1876 (Senglea, eastern Malta; 22.06.16; photo: Alan Deidun).

In addition to the unpublished records documented in this study, additional unpublished records for some of the Atlantic range-expanding species are also emerging through ongoing studies by other research groups, suggesting that the same species are well established in the Strait of Sicily. For instance, Falsone et al. (2020) and Geraci et al. (2020) are examples of alternative studies which report additional sightings of *C. sapidus* and of *S. fasciata*, respectively, in the Strait of Sicily. From what we know of these



**Figure 2.** Locations of new records of *Callinectes sapidus*. Previous records in the Iberian captures in this study are shown with white circles. For details see Supplementary material.

species, none of the eleven species recorded in this study are considered hazardous (i.e. neither toxic nor venomous). In terms of commercial importance, four of the Atlantic range-expanding species (*C. taeniops*, *S. fasciata*, *P. incisus* and *A. monroviae*) as well as one introduced Atlantic species (*C. sapidus*), are exploited, mainly by amateur fishers.

Most of the Atlantic range-expanding species considered in this study are not recent additions to the Mediterranean marine biodiversity. For instance, one of the same species (*P. incisus*) has been first recorded in the Mediterranean in the nineteenth century, whilst only four of the remaining species (*Abudedefduf saxatilis*, *Aplysia dactylomela*, *Cephalopholis taeniops* and *Selene dorsalis*) have been first recorded from the Mediterranean during the past twenty years.

*Pisodonophis semicinctus* (Richardson, 1848) is a species that is considered to have expanded its native range from the Atlantic to the Mediterranean Sea (Ambrogi 2002), and our discovery of the species in 2018 off the northern coast of Sicily (Figure 1) represents the first report of the species for the southern Tyrrhenian and the third for Sicily (Insacco and Zava 1999; Cantone et al. 2003). Additional records of the species from the north-western Mediterranean Sea (Bodilis et al. 2012; Gökoğlu et al. 2020) as well as other specimens caught in Turkey could support the hypothesis of a progressive diffusion of the species toward the eastern part of the Mediterranean, as suggested by Ragonese and Giusto (2000).

Given the lack of data from Tunisian waters, the frequency cited in the current study of the targeted species within the Strait of Sicily is probably an underestimate. Similarly, one has to take into consideration the different outreach strategies deployed within citizen science campaigns in the Maltese Islands and in Sicily. For instance, the marine NIS campaigns in the Maltese Islands largely made use of online outreach means,

including social media, which taps into knowledge held by amateur and sports fishers and by SCUBA divers, but which does not elicit a broad response from professional fishers. At the same time, citizen science campaigns in Sicily involve a higher degree of engagement with fishing communities, resulting in a higher number of reports being provided by professional fishers. This might explain why *P. ferussaci* and *G. granti*, two species exclusively recorded in the current study from depths exceeding 100 m, were solely reported in Sicily. Their “absence” within the Maltese citizen science campaign database might not reflect the species’ current distribution, but might simply be due to a relative lack of interaction with Maltese professional fishers.

#### *Additional Atlantic species known from the Strait of Sicily*

Besides the Atlantic range-expanding and introduced species reviewed in the current study, a number of additional species of Atlantic origin, for which no new unpublished records are being reported, are known from the Strait of Sicily. These include the widely-distributed *Percnon gibbesi* crab species, first recorded from the Strait of Sicily in 1999 (Relini et al. 2000), and the *Penaeus aztecus* shrimp species, first recorded in the Strait of Sicily in 2017 (Scannella et al. 2017). Both species are native of temperate and sub-tropical regions of the western Atlantic. Additional range-expanding Atlantic fish species previously recorded from the Strait of Sicily and not addressed within this study include *Pontinus kuhlii* (Bowdich, 1825), *Enchelycore anatina* (Lowe, 1838), *Elops* sp. Linnaeus, 1766 and *Holacanthus ciliaris* (Linnaeus, 1758), first recorded from the Strait of Sicily in 2014 (Castriota and Deidun 2014), in 2015 (Deidun et al. 2015), in 2019 (Deidun and Zava 2020) and in 2020 (Deidun et al. 2020), respectively.

#### *Barrier or gateway?*

Within the Mediterranean, the Sicily channel separates the western from the eastern sectors of the basin and it has long been thought to act as a filter to the eastwards intrusion of Atlantic species and the western migration of Lessepsian species (Quignard and Tomasini 2000). Some authors (e.g. Guidetti et al. (2010) suggest that the Strait of Sicily’s hypothetical status as a biogeographical barrier to the further eastward spread of Atlantic range-expanding species is less significant than postulated, i.e. that the Strait is actually a biogeographical crossroads rather than a barrier. In fact, of the eleven non-cosmopolitan species, only *Selene dorsalis* has not been recorded to date eastward of the Strait of Sicily. Given the tropical origin of the species included in this study (with the exception of *G. granti* and of *P. ferussaci*), this is hardly surprising, given the higher water temperatures generally encountered in eastern parts of the Mediterranean. The degree of eastward spread within the Mediterranean of the eleven non-cosmopolitan species of Atlantic origin appears, at least to

some extent, to be dependent on their date of first entry into the Mediterranean. For instance, species for which records exist from the Levantine Basin (e.g. *P. incisus*, *C. sapidus*, *P. semicinctus*, *P. ferussaci*) are also amongst the oldest-known from the western Mediterranean. Similarly, *Selene dorsalis* represents one of the most recent Atlantic newcomers, with its known distribution within the Mediterranean not extending beyond the Strait of Sicily. In addition, another relatively recent Atlantic newcomer—*A. monroviae*—has, to date, not extended further east than Libyan waters within the Mediterranean. Despite this trend, outliers exist. For instance, *C. taeniops* was first recorded from the Mediterranean in 2002, representing one of the most recent newcomers from the Atlantic, although it has spread to the Levantine Basin (Salameh et al. 2009). A similar scenario is observed for *A. saxatilis*. One can infer that, in addition to the timeline of the species' entry into the Mediterranean, species-specific behavioural traits and life strategies are instrumental in defining the distribution of the same species within the Mediterranean.

## Conclusions

The study has further underpinned the importance of continuous monitoring of the Malta-Sicily Channel as an ideal outpost in detecting recent colonization events by exotic marine species entering the Mediterranean from either the Gibraltar Strait or the Suez Canal. The corpulent nature of the dataset documented in this study further underscores the importance of citizen science campaigns in regularly supporting formal monitoring and policy-formulation exercises on the thematic of Non-Indigenous Species (NIS) by tapping into ecological knowledge held by relevant stakeholders which is normally difficult to tap into through conventional data-collection protocols.

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### Supplementary material

The following supplementary material is available for this article:

**Table S1.** Descriptors of the unpublished records for the species under consideration.

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