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Review

Local ecological knowledge *versus* published literature: a review of non-indigenous Mollusca in Greek marine waters

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Abstract

A review of the scientific literature and an analysis of unpublished material identified ~ 50 possible alien molluscs from Greece, four of which were newly reported here. Records of ~ 100 additional taxa, which would strongly inflate the alien species numbers, were excluded. Among the ~ 50 candidate species, 43 were confirmed as alien and 12 as cryptogenic. Twenty-nine alien species were considered established, and four deemed invasive. Our results are consistent with the position of Greece in the east-west Mediterranean gradient, as well as the Aegean marine environment. The contribution of well-informed citizen scientists appears to be crucial to our overall knowledge of alien molluscan biotas because only 12 alien taxa were detected during formal research projects, while 31 were first found by amateurs. No molluscan introductions were confirmed from Greece pre-1960s, and subsequent periods had variable numbers of introductions, ranging from 0 (1976–1980) to 9.5 (2006–2010). The areas with the highest alien species concentrations were the Saronikos Gulf, near the Piraeus port area, and the Dodekanisa, near the Levantine coastline. Despite a general decline in taxonomic expertise and in local knowledge, we show that these are still needed when compiling and analyzing alien species inventories that subsequently influence policy and management decisions.

Key words: biological invasion, alien species, citizen science, biogeography, Mediterranean Sea

Introduction

The increase in human activities and the recent climate change have made ecosystems progressively more disturbed and susceptible to biological invasions worldwide (Stachowicz et al. 1999). Alien species spreading in marine environments has received less attention than those in terrestrial and freshwater habitats (Vilà et al. 2010). However, the importance of species introductions is now attracting substantial interest in the marine and coastal ecosystems. Indeed, the number of alien marine species detected in European waters has nearly doubled every 20 years since the beginning of the twentieth century (Hulme 2009), and these introductions are considered to be one of the main anthropogenic threats to biodiversity (Molnar et al. 2008).

Mollusca are a major component of the marine fauna worldwide, accounting for 20–25% of the species, and among the taxa that contain the highest number of invasive species with high ecological impacts (Molnar et al. 2008). Mediterranean alien molluscan taxa have been widely studied (Gofas and Zenetos 2003; Zenetos et al. 2004) and > 200 species have been documented in this sea so far (Sabelli and Taviani 2014). The greatest number of confirmed alien species in the Mediterranean Sea originated in the Red Sea, entering via the Suez Canal (through the so-called Lessepsian migration) (Zenetos et al. 2010, 2012). After Israel (Galil 2007), Lebanon (Crocetta et al. 2013a, 2013b, 2014; Bitar 2014), and Turkey (Öztürk et al. 2014), Greece has the fourth highest number of alien and cryptogenic Mollusca in the Mediterranean (Zenetos et al. 2009c, 2011b).

The alien malacofauna of Greece has been the subject of numerous works focusing either on individual species (e.g., Koutsoubas and Voultsiadou-Koukoura 1991; Zenetos et al. 2009a, 2009b; Crocetta and Russo 2013; Karachle et al. 2016) or reporting data and new records in local checklists (e.g., Zenetos et al. 2005b; Manousis and Galinou-Mitsoudi 2013, 2014; Crocetta et al. 2015c). Several local or national reviews have been published in which the Greek Mollusca were included (e.g., Zenetos et al. 2009c, 2011b; Corsini-Foka et al. 2015). In addition, potential records of alien molluscs from Greece have been reported in Greek and Mediterranean molluscan books (e.g., Koronéos 1979; Tenekides 1989; Manousis 2012; Perna 2013). Unfortunately, several recent articles and reviews are based on records that were not confirmed, e.g., records uncritically taken from checklists in old literature, grey literature, and records not supported by photos of the species and suspected to be based on misidentifications. Moreover, the rationale for possible inclusion or exclusion has not always been explained, therefore leaving the reader in doubt as to the validity of these records. Thus, the re-evaluation of earlier reports is needed in the light of modern knowledge and taxonomic studies. In addition, the Convention on Biological Diversity (2000) requires the "compilation and dissemination of information on alien species that threaten ecosystems, habitats, or species, to be used in the context of any prevention, introduction and mitigation activities". Moreover, while establishing Good Environmental Status (GES) parameters, the D2 Descriptor (addressing NIS - Non Indigenous Species) of the European Union's Marine Strategy Framework Directive (MSFD) proposes a qualitative/normative definition to be used among GES criteria. To perform species-presence inventories or to list species encountered in widespread locations is now considered more accurate and cost-effective, and these assessments of species spatial occurrence/distributions may be considered as surrogates for species abundance and level of invasiveness. Consequently, among the main criteria for assessing GES, an inventory of NIS present in a marine area/country/region, as well as temporal occurrence and trends in new introductions, were recently included (European Commission 2015). Alien species inventories therefore play definitive roles in informing regional policy and management decisions, as well as in identifying resource allocation priorities. At the same time, the scientific community is called upon to assess carefully the accuracy and veracity of the inventories (Ojaveer et al. 2014).

Within the framework of several projects supporting the study of Mediterranean alien fauna, we compiled and verified existing records (published and institutional reports) to set up an updated and annotated list of alien, intra-Mediterranean transfer, and cryptogenic marine molluscs in Greece (Figure 1) based upon the analysis of published information and unpublished material coming from dedicated research programmes and citizen scientists.

Material and methods

The definition of *alien species* (non-native, non-indigenous, exotic) used herein follows that of the European Commission (2008): "a species, subspecies or lower taxon, introduced outside its natural past or present distribution; includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce". We also retained the term *intra-Mediterranean transfers* (Gofas and Zenetos 2003): "species moved by humans within the same macro area"—e.g., native from the Adriatic and introduced in the western Mediterranean. However, some species recently recorded from the Mediterranean Sea, or even present in the area for centuries, cannot be ascribed with certainty to a native or an alien/intra-Mediterranean transfer status, and may fall into the category of *cryptogenic species* (Carlton 1996): "a species that cannot be included with confidence among native nor among introduced ones", a term that is here used in *sensu lato* and includes all species for which uncertainties occurred.

Bibliographic data

This study is based on an extensive literature survey where no boundary dates were fixed; therefore, this review covers literature published about Greece since the beginning of scientific writing and observations. We searched for records of alien molluscan species in the waters of Greece in both indexed and non-indexed journals (often manually), as well as relevant institutional reports and grey literature. However, we particularly focused on recent records of species labelled as aliens in Greek waters, species considered to be alien in the Mediterranean basin and recorded from Greece, and species already included in previous alien-species check-lists. Particular attention was given to the reliability of published records and to the status of species labelled as non-indigenous. All species identifications were confirmed by the examination of voucher material preserved in museums and private/institutional collections, and of photographs included in published articles.

We excluded several categories of records:

- species only recorded on the basis of shells, unless their presence is confirmed by published

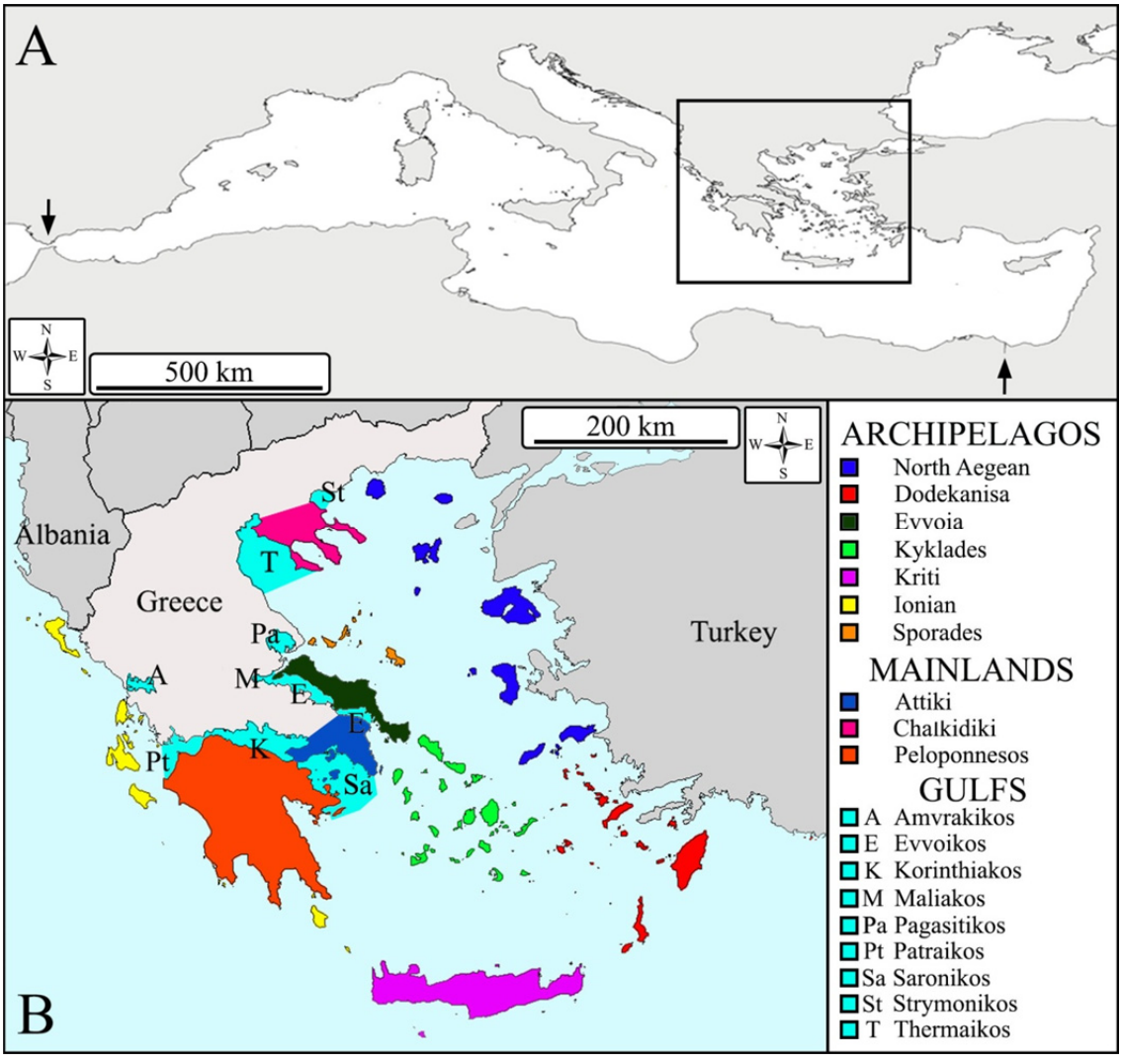

Figure 1. A. Geographical position of Greece within the Mediterranean Sea. Black arrows indicate the Strait of Gibraltar (left) and the Suez Canal (right). B. Greek locations mentioned in the present paper (main manuscript and Appendix 1–2).

records of living specimens in other Mediterranean countries or by their significant presence in biogenic sediments in Greece or nearby countries;

- species reported upon based on incorrect identifications, or incorrect or spurious locality data;
- old records of alien or potentially alien species unless supported by clear images or by the direct examination of specimens, and there are no doubts with regards to the existence of living individuals.

All confirmed species identifications were updated to the latest nomenclature available, following the World Register of Marine Species (WoRMS Editorial Board 2017).

Unpublished data

Unpublished data were obtained from ongoing research projects within the Hellenic Centre for Marine Research (HCMR) and from informed citizens (the so called *citizen scientists*: Delaney et al. 2008; Thiel et al. 2014). The latter have been the subject of a targeted leaflet covering the most popular alien taxa, including molluscs (Crocetta and Zenetos 2015). Key contributors were amateur shell collectors, followed by underwater photographers, fishermen, and tourists. However, internet-based contributions in the Mediterranean are also a valuable source of information (e.g., Azzurro et al. 2013; Kleitou et al. in Crocetta et al. 2015a). We therefore screened

photos stored in several web groups, including: "Hellenic Conches" (https://www.facebook.com/groups/helleniconches/) and "Underwater photography in Greece" (https://www.facebook.com/groups/331466433724867/), both mostly contributed to by Greek subscribers. In the case of straightforward identifications, we asked the contributors for the permission to use the data as well as any relevant additional information. These data were augmented by additional information obtained through the Ellenic Network on Aquatic Invasive Species (ELNAIS), a dynamic online information platform aiming to collect and report spatial information on aquatic alien species in Greek waters (Zenetos et al. 2015a). Records reported to ELNAIS were further validated before being included in this study. Finally, unpublished data for *Siphonaria pectinata* (Linnaeus, 1758), a species not included in previous reviews, were sought in the Goulandris Natural History Museum (GNHM) to better determine its first detection in Greece.

Database development

A database of taxa recently reported from Greece was developed for the present study. In contrast to rejected species, where mostly the rationale for exclusion was explained, detailed information was provided for each included alien taxon, including: i) taxonomic notes; ii) date and literature reference of the first sighting/collection; iii) presence of additional confirmed records; iv) possible misspellings, synonyms, different genus/species combinations or misidentifications published from Greece; v) presence of unpublished records; vi) various notes on accuracy of identification and/or finding data; vii) status as alien or cryptogenic in the Mediterranean Sea as a whole; viii) establishment success in Greece and possible invasiveness; ix) most likely primary or secondary pathway/s in the Mediterranean and in Greece (see detailed explanations in Appendix 2).

Results and discussion

Unpublished data

The different groups of citizen scientists contacted allowed us to obtain records that spanned three molluscan classes. While amateur shell collectors are mostly interested in shelled molluscs, including microshells that can be only found by the analysis of sediments under a stereo-microscope, underwater photographers are mostly interested in conspicuous and photogenic taxa, such as the large alien sea slugs or cephalopods. We obtained 173 unpublished records, covering 29 taxa (25 aliens and 4 cryptogenics, including one possible intra-Mediterranean transfer) (Appendix 1). To these should be added 4 lots of *Siphonaria pectinata* (Linnaeus, 1758) from GNHM (Appendix 1), one of which confirmed the presence of this species from Greece as early as 1973. Due to the presence of some earlier reports (e.g., Zenetos et al. 2008a, 2008b, 2011b, 2013), the majority of new unpublished data (138 records) are from 2010 to 2015. However, some researchers/amateurs not contacted previously had older records of some alien taxa in their logbooks or photo archives. Moreover, some shell collectors preserve their specimens with full data and often collect large amounts of biogenic sediment that may remain unsorted for decades. Thus we obtained some older, unreported, data, the three oldest ones (apart those of *S. pectinata*) dating back to 1994.

Records of four gastropods constituted new sightings for Greece, namely *Cerithidium perparvulum* (Watson, 1886), *Cerithiopsis pulvis* (A. Issel, 1869), *Cerithiopsis tenthrenois* (Melvill, 1896), and *Pyrunculus fourierii* (Audouin, 1826) (Table 2; Figure 2; Appendix 1–2) (for a previous record of *C. tenthrenois* from Greece based on a misidentification of *Cerithiopsis* cf. *nana* Jeffreys, 1867 see Appendix 2). All these four species are here reported from Greece from empty shells (single ones for three of them, 10 shells for *C. perparvulum*) found in biogenic sediments in Astypalaia and Rodos (Dodekanisa). However, they are well documented invaders from nearby Turkish shores (Çinar et al. 2011; Öztürk et al. 2014), and their presence in Greece is not surprising, and is likely to be confirmed by future work. Their late local discovery may be easily based on the fact that most of the past benthic studies in Greece have focused on soft substrates; consequently, species living on hard substrates may easily have been overlooked unless Greek research was reinforced by the help of citizen science. In addition, records of two bivalve species were of interest for analyzing temporal trends and establishment success (see below).

The mollusc species most often reported to us were *Conomurex persicus* (Swainson, 1821) and *Pinctada imbricata radiata* (Leach, 1814), accounting for 27 and 25 records, respectively, followed by *Bursatella leachii* (Blainville, 1817) (18 records), *Brachidontes pharaonis* (P. Fischer, 1870), and *Cerithium scabridum* Philippi, 1848 (10 records each) (Appendix 1). Although depth was often not reported, or records were based on beached specimens (26 records), the deepest an alien species was found was 24 m for *Bursatella leachii* (Blainville, 1817), and 22 m for *Melibe viridis* (Kelaart, 1858) and *Flabellina rubrolineata* (O' Donoghue, 1929). These depths agree with the common bathymetric range of Mediterranean alien species, usually limited

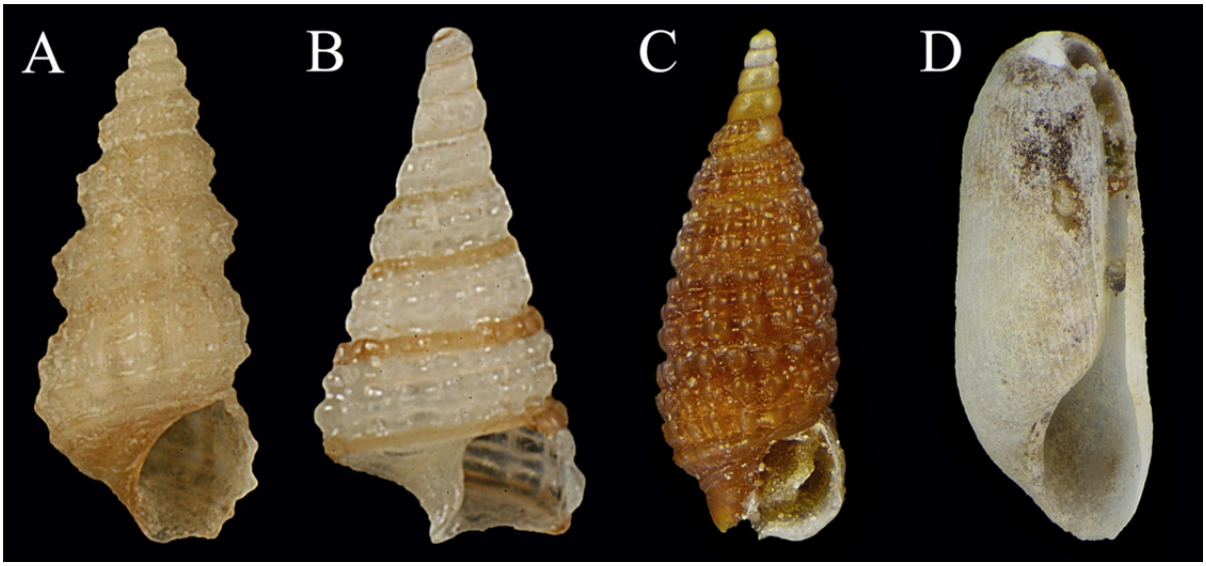

Figure 2. Alien molluscan species newly recorded from Greece (see Appendix 1–2 for further details). Specimens not to scale, sizes reported as total height. A. *Cerithidium perparvulum* (Watson, 1886) – 2.1 mm (Carlo Sbrana private collection); B. *Cerithiopsis pulvis* (A. Issel, 1869) – 1.6 mm (Carlo Sbrana private collection); C. *Cerithiopsis tenthrenois* (Melvill, 1896) – 1.9 mm (Lionello Paolo Tringali private collection); D. *Pyrunculus fourierii* (Audouin, 1826) – 3.2 mm (Lionello Paolo Tringali private collection). Photographs by Stefano Bartolini (A–B) and Andrea Nappo (C–D).

to the infralittoral zone. From a geographical point of view, the majority of records came from the Dodekanisa (67 records), followed by the Saronikos Gulf (54 records).

Bibliographic data: species excluded from Greece

Taxonomic knowledge has progressed greatly in the last few decades, and it is now clear that some species widely reported in early literature (usually from 1700 to around 1980) never actually lived in areas where they were recorded. In Greece, in particular, many records of Atlantic species have now been falsified; e.g., *Littorina littorea* (Linnaeus, 1758), *Littorina obtusata* (Linnaeus, 1758), *Buccinum undatum* Linnaeus, 1758, and *Colus jeffreysianus* (P. Fischer, 1868) (see Athanassopoulos 1917; Belloc 1948). Despite methodological advances, we identified a number of similar cases even in the recent literature, with taxa that still are mistakenly reported as being present in Greek waters; e.g., *Chamelea striatula* (da Costa, 1778), *Mytilus edulis* Linnaeus, 1758, *Cerastoderma edule* (Linnaeus, 1758), *Nassarius reticulatus* (Linnaeus, 1758), and *Modiolus modiolus* (Linnaeus, 1758) (De Smit and Bába 2000, 2002; Goigne 2001; Dimitriadis and Koutsoubas 2008; Manousis et al. 2010). Although potentially alien species, they were not included in previous alien species lists (Zenetos et al. 2005a, 2009c), and were excluded *a priori* also in this study. By excluding these taxa, the number of potential alien molluscs from Greece was estimated as ~ 150. However, we also excluded *a priori* an additional ~ 50 potential alien species illustrated in a recent popular guidebook of molluscs from Greece (Manousis 2012), where a number of native and alien species included are based on misidentifications (see Appendix 2 for details on some of them subsequently published in scientific literature). Moreover, many taxa included in the guide are inconsistent with the known biogeographical distribution of the species, which suggests that many of the illustrated specimens were not even collected in Greek waters. Examples are *Gibbula cineraria* (Linnaeus, 1758), a species that does not occur in the Mediterranean Sea (see Templado 2011; Nekhaev 2013), as well as *Arctica islandica* (Linnaeus, 1767), only known from the Mediterranean Sea as a fossil (Zenetos et al. 2005b) but illustrated in the guidebook as a living specimen with an intact periostracum.

The number of species to be reassessed was in this way reduced to ~ 100 taxa. Of these, 58 species recorded in the recent literature as aliens or as (potentially) locally introduced by man were rejected, in addition to two further potential alien species, namely *Trochus squarrosus* Lamarck, 1822 and *Murex trapa* Röding, 1798, whose presence in Greece was never formally published, and the material

Table 1. Marine Mollusca recorded from Greece as aliens whose presence or whose status is here rejected, rationale for rejection (RAT), and correct identifications proposed here (in case of misidentifications). See Appendix 2 for bibliographic references and further details. Unpublished rejections with respect to the most recent bibliography or species rejected for the first time from Greek lists are highlighted in bold. Abbreviations used: D – incorrect or invalid locality data; M – misidentification/s; P – possible misidentification/s due to similarities with native species and impossibility to check the original material; R – misreading/s; S – records based on empty shells, or records based on material presumably imported through the souvenir trade; U – unchecked data excluded due to unreliability of the source.

TAXA reported in literature	RAT	Correct identifications
***Cellana rota* (Gmelin, 1791)**	P	
***Emarginula decorata* Deshayes, 1863**	M	? *Emarginula divae* van Aartsen and Carrozza, 1995 or *Emarginula huzardii* (Payraudeau, 1826) – NATIVE
***Scissurella jucunda* Smith, 1890**	M	*Sinezona* sp. or *Scissurella* sp. – NATIVE?
***Tectus fenestratus* (Gmelin, 1791)**	S	
***Clanculus jussieui* [var. *striata*] Monterosato, 1880**	U	
***Trochus erithreus* Brocchi, 1821**	M	*Trochus squarrosus* Lamarck, 1822 + Trochidae sp.
***Trochus squarrosus* Lamarck, 1822**	S	
***Umbonium vestiarium* (Linnaeus, 1758)**	U	
***Angaria delphinus* (Linnaeus, 1758)**	S	
***Tricolia miniata* (Monterosato, 1884)**	U	
***Cerithium litteratum* (Born, 1778)**	S	
***Planaxis sulcatus* (Born, 1778)**	P	
***Alvania dorbignyi* (Audouin, 1826)**	M	*Alvania colossophilus* Oberling, 1970 – NATIVE
***Alvania pagodula* (Bucquoy, Dautzenberg and Dollfus, 1884)**	U	
***Rissoa guerinii* Récluz, 1843**	U	
***Rissoina bertholleti* A. Issel, 1869**	U	
Conomurex decorus (Röding, 1798)	M	*Conomurex persicus* (Swainson, 1821) – ALIEN
***Crepidula porcellana* Lamarck, 1801**	D	
***Erronea caurica* (Linnaeus, 1758)**	D	
***Notocochlis cernica* (Jousseaume, 1874)**	M	*Notocochlis dillwynii* (Payraudeau, 1826) – NATIVE
***Boreotrophon clathratus* (Linnaeus, 1767)**	U	
Coralliophila monodonta (Blainville, 1832)	S	
***Murex forskoehlii forskoehlii* Röding, 1798**	R, M	*Murex trapa* Röding, 1798
Rapana rapiformis (Born, 1778)	D	
***Murex trapa* Röding, 1798**	S	
***Gibberula* cf. *olivella* Cossignani, 2001**	M	*Gibberula* sp. – NATIVE?
***Nassarius crenulatus* (Bruguière, 1792)**	M	*nomen dubium*
***Nassarius stolatus* (Gmelin, 1791)**	S	
***Conus inscriptus* Reeve, 1843**	S	
Pyrgulina fischeri Hornung and Mermod, 1925	M	*Odostomella bicincta* (Tiberi, 1868) – NATIVE
Bulla ampulla Linnaeus, 1758	M	*Bulla arabica* Malaquias and Reid, 2008 – ALIEN
***Liloa mongii* (Audouin, 1826)**	M	Cephalaspidea sp.
***Pleurobranchus forskalii* Rüppell and Leuckart, 1828**	M	*Pleurobranchus testudinarius* Cantraine, 1835 – NATIVE
***Acar plicata* (Dillwyn, 1817)**	M	*Acar clathrata* (Defrance, 1816) – NATIVE
***Tegillarca granosa* (Linnaeus, 1758)**	S	
***Arcuatula senhousia* (Benson in Cantor, 1842)**	M	*Musculus costulatus* (Risso, 1826) – NATIVE
Brachidontes variabilis (Krauss, 1848)	M	*Brachidontes pharaonis* (P. Fischer, 1870) – ALIEN
Pinctada margaritifera (Linnaeus, 1758)	M	*Pinctada imbricata radiata* (Leach, 1814) – ALIEN
***Spondylus* cf. *multisetosus* Reeve, 1856**	M	*Spondylus* cf. *spinosus* Schreibers, 1793 – ALIEN
***Crassostrea virginica* (Gmelin, 1791)**	P	*Crassostrea*/*Magallana* sp./spp. – ALIEN
***Magallana angulata* (Lamarck, 1819)**	P	*Crassostrea*/*Magallana* sp./spp. – ALIEN
***Magallana gigas* (Thunberg, 1793)**	P	*Crassostrea*/*Magallana* sp./spp. – ALIEN
Dendostrea frons (Linnaeus, 1758)	M	*Dendostrea* cf. *folium* (Linnaeus, 1758) – ALIEN
***Lima marioni* P. Fischer, 1882**	U	
***Limatula* cf. *pusilla* (H. Adams, 1871)**	M	? *Limatula* cf. *gwyni* (Sykes, 1903) or *Limatula* sp. – NATIVE?
Centrocardita akabana (Sturany, 1899)	M	*Cardites antiquatus* (Linnaeus, 1758) – NATIVE
***Transkeia bogii* van Aartsen, 2004**	M	? *Diplodonta rotundata* (Montagu, 1803) – NATIVE?
***Transkeia globosa* (Forsskål in Niebuhr, 1775)**	M	*Diplodonta brocchii* (Deshayes, 1850) – NATIVE
***Ungulina rubra* de Roissy, 1804**	U	
Chama aspersa Reeve, 1846	M	*Chama asperella* Lamarck, 1819 – ALIEN
***Pseudochama corbierei* (Jonas, 1846)**	M	*Pseudochama gryphina* (Lamarck, 1819) – NATIVE
***Fulvia australis* (G. B. Sowerby II, 1834)**	M	*Laevicardium crassum* (Gmelin, 1791) – NATIVE
***Fulvia laevigata* (Linnaeus, 1758)**	M	*Fulvia fragilis* (Forsskål in Niebuhr, 1775) – ALIEN
Circe scripta (Linnaeus, 1758)	S	
Circenita callipyga (Born, 1778)	M	*Gouldia minima* (Montagu, 1803) – NATIVE
***Clausinella punctigera* (Dautzenberg and H. Fischer, 1906)**	M	*Clausinella fasciata* (da Costa, 1778) – NATIVE
***Dosinia erythraea* Römer, 1860**	M	*Dosinia exoleta* (Linnaeus, 1758) – NATIVE
***Ruditapes philippinarum* (Adams and Reeve, 1850)**	P	
***Cucurbitula cymbium* (Spengler, 1783)**	M	*Rocellaria dubia* (Pennant, 1777) – NATIVE
Teredothyra dominicensis (Bartsch, 1921)	D	

Table 2. Marine Mollusca recorded from Greece whose status as aliens is here confirmed: first sighting/collection date (DATE), establishment success/invasiveness (EST/INV), most probable primary and secondary pathway/s in Greece (PATH) (in the presence of two or more pathways, listed in alphabetical order) and live/dead status (L/D). Species for which the first Mediterranean record was in Greece are marked with an asterisk *. Species for which we report significant unpublished data are highlighted in bold. See Appendix 2 for bibliographic references and further details. Abbreviations used: C – casual; CS – corridor spread; D – dead; E – established; EC – escape from confinement; I – invasive; L – live; TC – transport-contaminant; TS – transport-stowaway; U – unknown; US – unaided spread.

TAXA	DATE	PATH	EST/INV	L/D
CLASS GASTROPODA CUVIER, 1795				
**Nerita sanguinolenta* Menke, 1829	1969	U(US?)	C	D
Smaragdia souverbiana (Montrouzier, 1863)	≤1993	US	E	U(L?)
***Cerithidium perparvulum* (Watson, 1886)**	**2010**	**US**	**C**	**D(L?)**
Cerithium scabridum Philippi, 1848	2007	US	E	L
Rhinoclavis kochi (Philippi, 1848)	2016	US	C	D
***Cerithiopsis pulvis* (A. Issel, 1869)**	**2010**	**US**	**C**	**D**
***Cerithiopsis tenthrenois* (Melvill, 1896)**	**1994**	**US**	**C**	**D**
**Viriola* sp. [cf. *corrugata* (Hinds, 1843)]	2016	U(US?)	C	D(L?)
Sticteulima sp. [cf. *lentiginosa* (A. Adams, 1861)]	2015	TS/US	C	D
Conomurex persicus (Swainson, 1821)	1983	TS/US	E/I	L
***Crepidula fornicata* (Linnaeus, 1758)**	**1985**	**TC/TS**	**E**	**L**
Ergalatax junionae Houart, 2008	2007	US	E	L
Rapana venosa (Valenciennes, 1846)	1986	CS/TS	C	L
Oscilla galilae Bogi, Karhan and Yokeş, 2012	2016	US	C	D
Syrnola fasciata Jickeli, 1882	2012	US	E	L
Bulla arabica Malaquias and Reid, 2008	1998	TS	E	L
**Haminoea cyanomarginata* Heller and Thompson, 1983	2001	TS/US	E	L
Ventomnestia girardi (Audouin, 1826)	1994	US	E	D(L?)
Acteocina mucronata (Philippi, 1849)	1991	US	C	D
***Pyrunculus fourierii* (Audouin, 1826)**	**2013**	**US**	**C**	**D**
Bursatella leachii (Blainville, 1817)	1975	TS/US	E	L
Syphonota geographica (A. Adams and Reeve, 1850)	2002	US	E	L
Goniobranchus annulatus (Eliot, 1904)	2004	TS/US	E	L
Hypselodoris infucata (Rüppell and Leuckart, 1830)	2007	US	E	L
Polycerella emertoni A.E. Verrill, 1881	1995	TS	C	L
**Melibe viridis* (Kelaart, 1858)	1970	TS/US	E	L
Flabellina rubrolineata (O' Donoghue, 1929)	2009	US	E	L
CLASS BIVALVIA LINNAEUS, 1758				
Anadara transversa (Say, 1822)	1993	TS	E	L
Brachidontes pharaonis (P. Fischer, 1870)	1975	TS/US	E	L
Septifer cumingii Récluz, 1848	2010	US	E	L
Isognomon legumen (Gmelin, 1791)	2016	US	E	L
Pinctada imbricata radiata (Leach, 1814)	1961	EC/TS/US	E/I	L
***Malleus regula* (Forsskål in Niebuhr, 1775)**	**≤1996**	**US**	**E**	**L**
Spondylus cf. *spinosus* Schreibers, 1793	2008–13	TS	C	L
Crassostrea/*Magallana* sp./spp.	≤1989	EC?	E	L
Dendostrea cf. *folium* (Linnaeus, 1758)	2005	TS/US	E/I	L
Chama asperella Lamarck, 1819	2007	TS/US	E	L
Chama pacifica Broderip, 1835	2005	US	E	L
***Fulvia fragilis* (Forsskål in Niebuhr, 1775)**	**1997**	**TS/US**	**E/I**	**L**
Clementia papyracea (Gmelin, 1791)	1985	US	C	D
**Petricolaria pholadiformis* (Lamarck, 1818)	1985	TS	E	L
Mya arenaria Linnaeus, 1758	1984	TS	E	L
CLASS CEPHALOPODA CUVIER, 1795				
Sepioteuthis lessoniana Férussac in Lesson, 1831 complex	2009	US	E	L

reported was misidentified as other alien species (Table 1; details in Appendix 2). Some species were previously rejected in other papers (e.g., Zenetos et al. 2011b), but they were re-analyzed here in the light of more current knowledge. It is the case of *Pyrgulina fischeri* Hornung and Mermod, 1925 and *Circenita callipyga* (Born, 1778), both confused with native taxa; *Conomurex decorus* (Röding, 1798), *Bulla ampulla* Linnaeus, 1758, *Brachidontes variabilis* (Krauss, 1848), and *Fulvia laevigata* (Linnaeus, 1758) [recorded as *Fulvia papyracea* (Bruguière, 1789)], confused with different alien taxa (see Appendix 2). A special

mention is needed for the Caribbean shipworm *Teredothyra dominicensis* (Bartsch, 1921), only known from a single specimen found in 2011 in a piece of driftwood recovered off the coast of Fourni (Shipway et al. 2014; Shipway, *pers. comm*.). Since then, no records have occurred, and therefore the Greek record should be ranked as an invalid locality datum (Marchini et al. 2015; Zenetos et al. 2017). Additional mentions are also needed for first records of four alien species, namely *Cerithium scabridum* Philippi, 1848, *Rhinoclavis kochi* (Philippi, 1848), *Cerithiopsis tenthrenois* (Melvill, 1896), and *Brachidontes pharaonis* (P. Fischer, 1870). First records from Greece of all these taxa were incorrect (due to misidentifications or unchecked data excluded due to unreliability of the source), but subsequent records were real, and therefore we have listed them only among accepted taxa (Table 2; details on rejections in Appendix 2).

Records of 47 species are here newly rejected from the Greek species lists. The six categories of rejection were: i) misidentification/s (~ 51%); ii) records based on empty shells, or records based on material presumably imported through the souvenir trade (~ 17%); iii) unchecked data excluded due to low confidence in taxonomic identification (~ 15%); iv) possible misidentification/s due to similarities with native species and the impossibility of checking the original material (~ 10%); v) incorrect and/or invalid locality data (~ 7%); vi) misreading/s (~ 1%).

Among misidentifications, some examples were notable. The case of *Centrocardita akabana* (Sturany, 1899), for example, applies to the whole Mediterranean (see also discussions in Zenetos et al. 2017 and detailed explanations in Appendix 2). Some species often reported from Greece, such as *Trochus erithreus* Brocchi, 1821, *Murex forskoehlii forskoehlii* Röding, 1798, and *Cucurbitula cymbium* (Spengler, 1783) are again listed as falsified based on mixtures of misidentifications and misreadings (detailed explanations in Appendix 2). Apart from old records, all these species are also recorded in the very recent literature, but misidentifications and problems of reliability with papers by Manousis (2012) and Manousis et al. (2012) were already highlighted and discussed for other taxonomic groups (e.g., Mienis 2013; Crocetta and Tringali 2017; Romani et al. 2017).

Among unchecked data excluded due to low taxonomic confidence are those appearing in some articles by De Smit and Bába (2000, 2001, 2002). These records were published in regional journals but the material was never illustrated nor were any specimens deposited. We attempted to contact the authors, but one of them died in 2007 (Levente 2007) and the whereabouts of the first author (from The Netherlands) are unknown (R.A. Bank, *pers. comm.*). Additional discussion is again included in Table 1 and Appendix 2.

Among records based on single empty shells (and never recorded from other Mediterranean countries), or records based on material presumably imported through the souvenir trade, we highlight some reservations. The identifications are correct, yet these species were never recorded as living individuals from anywhere in the Mediterranean despite their large shell sizes and/or unmistakable morphology. They are provisionally excluded, but may re-enter the list if living specimens are eventually found.

Alien, intra-Mediterranean transfer, and cryptogenic species confirmed from Greece

An updated checklist of the 43 marine molluscan taxa (27 Gastropoda, 15 Bivalvia, and 1 Cephalopoda) recorded from the Greek territorial seawaters and whose status as aliens was confirmed is provided in Table 2. Taxonomic or nomenclatural problems occur with at least six taxa. Two microgastropods are herein listed as *Sticteulima* sp. [cf. *lentiginosa* (A. Adams, 1861)] and *Viriola* sp. [cf. *corrugata* (Hinds, 1843)], and may even represent undescribed species. However, both species also occur in, and are presumably native to, the Red Sea (Tringali 1994; Rusmore-Villaume 2008), and therefore their alien status is here confirmed. One taxon belonging to the genus *Crassostrea* Sacco, 1897 or *Magallana* Salvi and Mariottini, 2016 is reported as *Crassostrea*/*Magallana* sp./spp. In fact, *Crassostrea virginica* (Gmelin, 1791), *Magallana angulata* (Lamarck, 1819), and *Magallana gigas* (Thunberg, 1793) have been recorded from Greece based on morphological identifications (Dimitrakis 1989; Goigne 2001; Prummel 2003; Manousis and Galinou-Mitsoudi 2013), but the taxonomic status of these species is still controversial or requires evaluation using molecular tools. Two bivalve species were tentatively ascribed to a possible taxon, although their identifications may later prove to be erroneous: *Dendostrea* cf. *folium* (Linnaeus, 1758), whose molecular identification has been problematic (see Crocetta et al. 2015b); and *Spondylus* cf. *spinosus* Schreibers, 1793, recorded from Greece as *Spondylus* cf. *multisetosus* Reeve, 1856 (see Manousis and Galinou-Mitsoudi 2013). Also the only cephalopod listed here belongs to an unresolved species complex, and we included it as *Sepioteuthis lessoniana* Férussac in Lesson, 1831 complex. Detailed taxonomical explanations for all these taxa are reported in Appendix 2. Finally, the inclusion of *Oscilla galilae* Bogi, Karhan and Yokeş,

Table 3. Marine Mollusca recorded from Greece here ascribed to cryptogenics *sensu lato* (including intra-Mediterranean transfer): status (ST), first sighting/collection date (DATE), establishment success/invasiveness (EST/INV), and live/dead status (L/D). Species for which we report significant unpublished data are highlighted in bold. See Appendix 2 for bibliographic references and further details. Abbreviations used: C – casual; CG – cryptogenic species; D – dead; E – established; I – invasive; IM – intra–Mediterranean transfer species; L – live.

TAXA	ST	DATE	EST/INV	L/D
CLASS GASTROPODA CUVIER, 1795				
Murchisonella mediterranea Peñas and Rolán, 2013	CG	2008–11	C?	L
Atys macandrewii E.A. Smith, 1872	CG	2009	E	D(L?)
Aplysia dactylomela Rang, 1828	CG	2005	E/I	L
Aplysia cf. *parvula* Mörch, 1863	CG	1970–85	E	L
Tayuva lilacina (Gould, 1852) complex	CG	2012	C	L
***Siphonaria pectinata* (Linnaeus, 1758)**	**IM?**	**1973**	**E**	**L**
CLASS BIVALVIA LINNAEUS, 1758				
Bankia carinata (J.E. Gray, 1827)	CG	2008–13	?	?
Lyrodus pedicellatus (Quatrefages, 1849) complex	CG	≤1940	?	?
Nototeredo norvagica (Spengler, 1792)	CG	≤1940	?	?
Teredo navalis Linnaeus, 1758	CG	≤1883	?	?
Xylophaga dorsalis (Turton, 1819)	CG	≤1883	?	?
Xylophaga praestans E.A. Smith, 1903	CG	1987	?	?

2012 among true aliens needs explanation. It is a minute taxon only recently described from the Mediterranean Sea and widely distributed all over it easternmost coastline, including Greece, but with no additional published records from other areas worldwide (Bogi et al. 2012; Micali et al. 2017). We traced its origin to the Indo-Pacific, where this genus is widely distributed and where specimens belonging to this species-group and even possibly conspecific with Mediterranean samples are present at least in Thailand (e.g., Robba et al. 2007 as *Miralda* sp.). Being that native species of the genus *Oscilla* A. Adams, 1861 are absent from the Mediterranean, we considered those listed above as concrete evidence supporting a recent introduction.

Twelve species were labelled as cryptogenics *sensu lato* (Table 3; Appendix 1–2), as they could not be confirmed with certainty to be aliens. Among them, *Siphonaria pectinata* (Linnaeus, 1758) was cautiously included as "intra-Mediterranean transfer", pending results of a wide population genetic study (see discussions in Crocetta 2016). Three taxa were labelled as cryptogenic due to uncertainties in their taxonomic status and recent records from the Mediterranean Sea. They all belong to the Heterobranchia, a comprehensive clade of minute to large species whose taxonomy is still an "ongoing work", and are *Murchisonella mediterranea* Peñas and Rolán, 2013, *Aplysia* cf. *parvula* Mörch, 1863, and specimens we labelled as belonging to the *Tayuva lilacina* (Gould, 1852) complex (detailed explanations in Appendix 2). Two additional taxa, *Aplysia dactylomela* Rang, 1828 and *Atys macandrewii* E.A. Smith, 1872, were only recently recorded from the Mediterranean Sea. *Aplysia dactylomela* was originally considered to be a circumtropical species, but recent molecular studies have revealed that Mediterranean specimens belong to *A. dactylomela* from the Atlantic, rather than to its cryptic Indo-Pacific congeneric species *Aplysia argus* Rüppell and Leuckart, 1830, as often suspected in the past (see Valdés et al. 2013). Preliminary molecular analysis of Mediterranean specimens are more consistent with a natural dispersal through the Gibraltar Strait, although its distribution limited to the central and the eastern parts of the basin would suggest the hypothesis of a human-mediated introduction in the Mediterranean (Valdés et al. 2013), and therefore the question remains opened. The same holds for *A. macandrewii*, a taxon with an Atlantic distribution, first sighted in the Mediterranean Sea in 1990 (Cachia and Mifsud 2007). Its unmistakable shell pattern with whitish bands suggest that it could not have gone overlooked in the Mediterranean basin for centuries. However, unlike *A. dactylomela*, it occurs throughout the entire basin. Because *A. macandrewii* is also widely recorded along the Spanish Mediterranean coast (Micali et al. 2016), a natural colonization through Gibraltar seems more likely. Finally, six additional cryptogenic species from Greece included wood-boring molluscs belonging to the Teredinidae Rafinesque, 1815 (4 species) and Xylophagidae Purchon, 1941 (2 species). The taxonomy of species belonging to these two families is still widely debated, with the recent discovery of cryptic or new species even in the oversampled Mediterranean Sea using a combined molecular and morphological approach (Borges et al. 2012; Romano et al. 2014). In the case of old records, such as that of *Teredo navalis* Linnaeus,

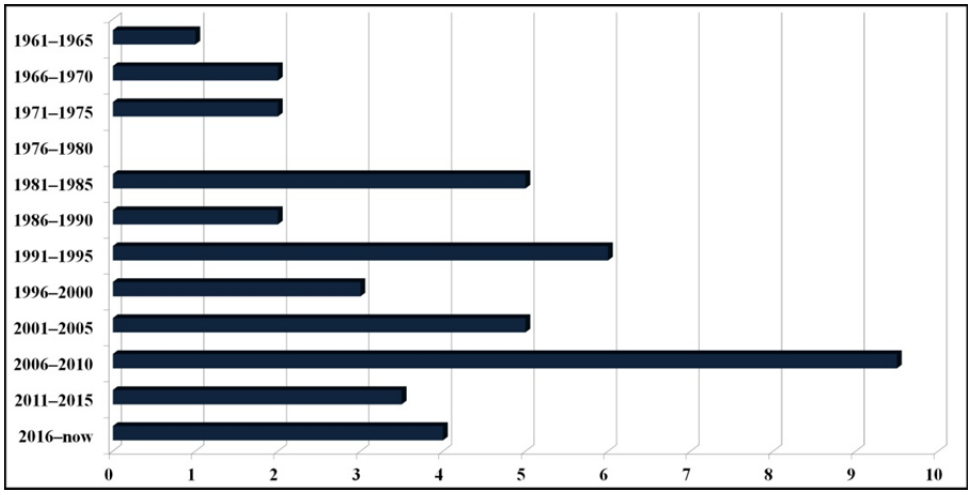

Figure 3. Marine alien Mollusca from Greece: rate of sighting/collection year (as number of species per 5-years periods).

1758 (first recorded in Greece ≤ 1883: see Nieder 1883), but also for recent ones, additional anatomical or genetic work may be warranted for the six distinct species (Table 3), but this may be impractical or impossible at this stage. On the other hand, several of these wood-boring Mollusca are widespread in the Mediterranean Sea, and to avoid including them is unwise because the records were clearly based on wood-boring molluscs, and only identifications are unverified. Therefore, we included all of them, with reservations. *Xylophaga praestans* E.A. Smith, 1903 warrants special mention. This taxon is so far known from Greece on the basis of one record (Janssen 1989; see also review by Zenetos et al. 2005b), and even its mere presence in the Mediterranean Sea is overall doubtful (Turner 1971). Nevertheless, the species still appears in recent Mediterranean or national checklists, and general molluscan atlases (e.g., Schiaparelli 2008; Templado and Villanueva in Coll et al. 2010; Huber 2015). The article by Janssen (1989) also contains several as yet unconfirmed records of other Atlantic species for the Mediterranean Sea (Mienis 2003a; Crocetta et al. 2015c).

Temporal trends

We plotted the rate at which first records of marine alien molluscan species were reported for 5-year intervals (Figure 3). Careful analysis of the literature and of the unpublished material analyzed here, as well as interviews with authors, led to the correction/explanation of several first sighting/collection dates or published records, including *Crepidula fornicata* (Linnaeus, 1758), *Malleus regula* (Forsskål in Niebuhr, 1775), *Fulvia fragilis* (Forsskål in Niebuhr, 1775), and *Brachidontes pharaonis* (P. Fischer, 1870) (Appendix 1–2). In particular, the first record of *B. pharaonis* was by Koronéos (1979) [as *Brachidontes variabilis* (Krauss)]. However, re-examination of the original material and the illustration revealed a misidentification for the native *Mytilaster lineatus* (Gmelin, 1791), which lacks the characteristic *Brachidontes* ribs (Appendix 2). For three species, we could not analyze the original material; therefore, we included them with the acceptance/publication date preceded by the symbol "≤". For *Spondylus* cf. *spinosus* Schreibers, 1793, no first record date was published. Since field studies were carried out in 2008–2013 (Manousis and Galinou-Mitsoudi 2013), we have assigned it as 0.5 to the period 2006–2010 and 0.5 to the period 2011–2015.

The lack of confirmed historical series, as well as the general absence of molluscan studies, suggests there were few to no molluscan introductions to Greece before the 1960s. A similar situation from Italy has been explained by a lack of field research attributable to the World Wars and two postwar periods (Crocetta 2012). The subsequent periods were characterized by a variable number of introductions, ranging from 0 (1976–1980) to 9.5 (2006–2010) (Figure 3).

Pathways for introduction

Possible introduction pathways of 13 taxa had more than one possibility (Table 2), and data on these species were weighted when extrapolating percentages. The analysis of most probable pathway(s) of arrival in Greece suggested that unaided spread (e.g., larval drift) account for ~ 61% of the Greek introductions, followed by ~ 29% of transport-stowaway, ~ 3% of escape from confinement and ~ 1% of both corridor

spread and transport-contaminant. Unknown pathway accounted for ~ 5%.

The high value for unaided spread (32 taxa) is mostly due to the geographic origin of the alien molluscan fauna. Thirty-three alien species (~ 77%) are native to the wide Indo-Pacific area, whilst only five species [*Crepidula fornicata* (Linnaeus, 1758), *Polycerella emertoni* A.E. Verrill, 1881, *Anadara transversa* (Say, 1822), *Petricolaria pholadiformis* (Lamarck, 1818), and *Mya arenaria* Linnaeus, 1758] are native to the Atlantic. Three species [*Bursatella leachii* (Blainville, 1817), *Syphonota geographica* (A. Adams and Reeve, 1850) and *Pinctada imbricata radiata* (Leach, 1814)] have a circumtropical distribution, whilst the native area of two species [*Melibe viridis* (Kelaart, 1858) and *Crassostrea*/*Magallana* sp./spp.] is yet unknown (Appendix 2). Although some of the Indo-Pacific species have not yet been recorded from the Red Sea, the majority of alien species may have entered the Mediterranean Sea through the Suez Canal, and reached Greece via unaided spread when carried by the prevailing Mediterranean currents (Bergamasco and Malanotte-Rizzoli 2010) (Table 2; Appendix 2). Consistent with this hypothesis, many first Greek sites of easy to be detected species are from the eastern Greek islands close to Turkey [e.g., *Cerithium scabridum* Philippi, 1848, *Chama pacifica* Broderip, 1835, and *Dendostrea* cf. *folium* (Linnaeus, 1758) in Rodos (Dodekanisa); *Ergalatax junionae* Houart, 2008 in Kriti] (Appendix 2).

Transport-stowaway was the suspected pathway for 19 taxa (Table 2; Appendix 2). This vector is likely for several species [e.g., *Anadara transversa* (Say, 1822), *Petricolaria pholadiformis* (Lamarck, 1818), and *Mya arenaria* Linnaeus, 1758)] that were first found in Saronikos Gulf. Arrival of two species mentioned above may also be due to escape from confinement (aquaculture/mariculture) because *A. transversa* is often associated with cultivated mussel beds (Lodola et al. 2011; Nerlović et al. 2012) and *M. arenaria* has a high commercial interest (Crocetta and Turolla 2011). However, this pathway is unlikely in Greek waters because musselculture is barely developed in the Saronikos Gulf (Conides and Kevrekidis 2005; Theodorou et al. 2011). Transport-stowaway is also suspected for other species such as *Bulla arabica* Malaquias and Reid, 2008 and *Fulvia fragilis* (Forsskål in Niebuhr, 1775). In fact, it is unlikely that they first arrived anywhere but Saronikos Gulf (Vardala-Theodorou 1999; present paper) because they are conspicuous species unlikely to be overlooked.

Goniobranchus annulatus (Eliot, 1904) and *P. imbricata radiata* are associated with more than one pathway/vector. Two colour forms of *G. annulatus* are known from Greece: i) one with few yellow spots and a median purple line between the two purple circles, which is only known from Persian Gulf, and ii) one with scattered yellow spots all over the body and lacking the medium purple line between the two purple circles, which is known from the Red Sea (Appendix 2). No taxonomic studies have been conducted on these two colour forms; therefore, we have listed both under a single species. However, the Persian Gulf colour form has been only found in Salamina Island (Saronikos Gulf) (Daskos and Zenetos 2007), suggesting its arrival via transport-stowaway route. The Red Sea colour form is currently widespread on eastern Mediterranean shores, including the Dodekanisa (Kastellorizo and Rodos) (Zenetos et al. 2011b; Kondylatos and Corsini-Foka in Tsiamis et al. 2015) and Kriti (Poursanidis in Mytilineou et al. 2016), suggesting its arrival via unaided spread from Turkey. The pearl oyster *P. imbricata radiata*, was first found in 1961 in the Salamina Island/Attiki area (Saronikos Gulf), where it presumably arrived via naval transportation (transport-stowaway) (Serbetis 1963). The same author imported it for aquaculture in four Greek areas [Chalkis (Evvoia), Kriti, Astypalaia (Dodekanisa), and Lemnos (North Aegean Islands)], from where it may have escaped. However, *P. imbricata radiata* may also have reached the Greek Aegean Islands via unaided spread from the nearby easternmost Mediterranean shores due to the long larval phase of *Pinctada* species (up to ~ 30 days before settlement: Gervis and Sims 1992). Despite the absence of earlier records from Turkey (first recorded in 1982: Çinar et al. 2011), its presence in Cyprus since at least 1899 (Katsanevakis et al. 2009) suggests that its spread to the west along the Levantine coasts has been overlooked.

Crepidula fornicata (Linnaeus, 1758) is another species introduced through multiple pathways. It has been considered as introduced to Greece due to transport-stowaway (Zenetos et al. 2009c). Unpublished records, however, first detected it from Nea Peramos (Saronikos Gulf) (Appendix 1) where mussel culture is present, which suggests its introduction via transport-contaminant. Greek records of *Crassostrea*/*Magallana* also may represent escape from confinement; however, there was no confirmed information even suggesting introduction into Greek waters for aquaculture purposes (A. Zenetos, *unpublished data*; see also Belloc 1948; Theodorou et al. 2015) apart an unconfirmed report that specimens were imported in 2007 to the Thermaikos Gulf (Katsanevakis et al. 2008). Finally, the only species with a pathway of corridor spread is *Rapana venosa* (Valenciennes, 1846), presumably spreading from the Black Sea where it was introduced in 1947 (Drapkin 1953)

with widespread negative effects (Snigirov et al. 2013). However, the transport stowaway pathway is hypothesized for its introduction into Italy (Crocetta 2012), and may also have acted in Greece.

Of the 43 alien Mollusca listed as confirmed here, only five taxa were first recorded from Greece with respect to the whole Mediterranean basin: *Nerita sanguinolenta* Menke, 1829; *Viriola* sp. [cf. *corrugata* (Hinds, 1843)]; *Haminoea cyanomarginata* Heller and Thompson, 1983; *Melibe viridis* (Kelaart, 1858); and *Petricolaria pholadiformis* (Lamarck, 1818) (Table 2). We listed the pathway of introduction of *N. sanguinolenta* and *Viriola* sp. as "unknown"; however, having been both found only in the Dodekanisa, they may easily have arrived via unaided spread, and simply their spreading from another Mediterranean country was overlooked until their finding in Greece. Curiously, *Haminoea cyanomarginata* is a species described from the Red Sea and better known in its invaded area than in its native one. It was first found in Greece in 2001 in Porto Germeno (Korinthiakos Gulf) (Zenetos et al. 2004; Mollo et al. 2008) and later from Turkey, Malta, and Italy (Crocetta and Vazzana 2009). The absence of records from Egypt, Israel, Lebanon, Syria, and Cyprus suggests a local introduction by transport-stowaway. Similarly, *M. viridis* was first recorded from Kephalonia (Ionian Islands) in 1970 and, since 1990, is recorded from large areas of the Mediterranean (Tsiakkiros and Zenetos 2011; Crocetta and Bariche in Tsiamis et al. 2015). Finally, *P. pholadiformis* is only confirmed so far in Greece (Zenetos et al. 2009b). It is native of the eastern Coast of North America and may have arrived in Greece by transport-stowaway vector. In this view, it has only been found in the Saronikos Gulf, which includes the sixth most central port in the worldwide network of maritime traffic (Kaluza et al. 2010) and where about 100 alien and cryptogenic species have been detected (Zenetos et al. 2015b).

Establishment success and invasiveness

To date, 29 out of 43 alien taxa (~ 69%) are considered to be established. The established status of *Malleus regula* (Forsskål in Niebuhr, 1775) and of *Isognomon legumen* (Gmelin, 1791) were here updated based on the unpublished data gathered and the critical analysis of the literature. The former species was previously reported from Greece based on an empty shell from Symi (Dodekanisa) (Giannuzzi-Savelli et al. 2001), as the specimens from Astypalaia (Dodekanisa) recorded as such by Angelidis in Lipej et al. (2017) are instead *I. legumen*. We now report *M. regula* as a common presence in Astypalaia (Dodekanisa), where several specimens were collected in 2011–2013 in three bays (Panormos, Micro Vai and Vai: Appendix 1). However, this taxon is also well known from nearby Turkish shores, where it colonizes most of the crevices of the infralittoral fringe (FC and LPT, personal observations); therefore, its establishment in Greece was expected. On the contrary, *Isognomon legumen* was so far only known on the basis of two specimens from Karpathos (Dodekanisa) (Micali et al. 2017). However, the misidentified specimens reported by Angelidis in Lipej et al. (2017) first highlighted above, as well as its records from two different Greek sites and the presence of both adults and juveniles, clearly point to its local establishment. One species, *Smaragdia souverbiana* (Montrouzier, 1863) was first recorded in Greece about two decades ago (Buzzurro and Greppi 1994); however, this record was originally considered as questionable due to the absence of additional records or images of specimens (Zenetos et al. 2009c). Recently, this species has experienced a considerable spread in Greece, with records from three different areas (Zenetos et al. 2013; Evagelopoulos et al. 2015), necessitating a re-evaluation of the original record.

Among the species we reported as established, published and unpublished observations show that the effects of alien species on the newly colonized sites can vary according to local environmental features. Cold-water species such as the gastropod *Crepidula fornicata* (Linnaeus, 1758) and the bivalves *Anadara transversa* (Say, 1822), *Crassostrea*/*Magallana* sp./spp., *Petricolaria pholadiformis* (Lamarck, 1818), and *Mya arenaria* Linnaeus, 1758 are only able to survive and reproduce in a few locations in Greece. Conversely, *A. transversa* and *Crassostrea*/*Magallana* sp./spp. were able to invade the whole northern Adriatic Sea, where they are considered dominant species in soft and hard substrates, respectively (Morello et al. 2004; Crocetta 2011; Lipej et al. 2012). Populations of *Crassostrea*/*Magallana* are not exploited in Greece due to low numbers and narrow distributions. The same holds true for *C. fornicata*, *P. pholadiformis*, and *M. arenaria*. In contrast, the crepidulid invasion along the Atlantic European shores has led to the disruption of activities of dredging, harvesting, and oyster farming (Blanchard 1997). *Petricola pholadiformis* has a wide introduced distribution in northern Europe (Katsanevakis et al. 2014), and the colonization of the Black Sea by *M. arenaria* resulted in replacement of native species such as the small bivalve *Lentidium mediterraneum* (O.G. Costa, 1830) and caused a noticeable impact on benthic community structure and its biodiversity (Zaitsev and Öztürk 2001).

Among tropical species considered as established, several have either not spread further in Greece or not reached the high densities observed along other Mediterranean shores. For example, *Cerithium scabridum* Philippi, 1848 and *Brachidontes pharaonis* (P. Fischer, 1870) have almost entirely colonized easternmost Mediterranean shores, leading to the almost complete replacement of the small native Cerithidae Fleming, 1822 and Mytilidae Rafinesque, 1815 (Mienis 2003b; Crocetta et al. 2013b), but have not caused similar problems in Greece so far. The same holds true for the *Sepioteuthis lessoniana* Férussac in Lesson, 1831 complex, being found so far only from the Dodekanisa area, where it is sold for human consumption but not distinguished from native squids (Corsini-Foka et al. 2010).

Four species were labelled as invasive in Greek waters: *Conomurex persicus* (Swainson, 1821), *Pinctada imbricata radiata* (Leach, 1814), *Dendostrea* cf. *folium* (Linnaeus, 1758), and *Fulvia fragilis* (Forsskål in Niebuhr, 1775). Adults of *C. persicus* have almost entirely colonized shallow soft and hard substrates in the whole Eastern Mediterranean (Zibrowius and Bitar 2003), including Greece, whilst juveniles may be also found on rocky substrates with algal cover. Ecological impacts subsequent to its colonization have not been fully studied in the Mediterranean Sea, although Mutlu and Ergev (2006) suggested that the presence of juveniles was strongly correlated with a decrease in the density of *Jania rubens* (Linnaeus) J.V. Lamouroux of a magnitude consistent with the potential grazing impact of the gastropods. Empirical observations carried out by one of the authors (FC) along the Greek and Turkish soft sea bed suggested that, where adults are present, native molluscan biodiversity is reduced. Furthermore, it is speculated that adults of *C. persicus* feed on detritus; therefore, suggesting that the diversity and biomass of microscopic infaunal species may be locally reduced by its colonization. Due to high local densities, *C. persicus* has been exploited in Rodos (Dodekanisa) in recent years, and is sporadically found in restaurants in Greece (Katsanevakis et al. 2008) and consumed locally. The same also holds for the species in Israel (Mienis 1999). *Pinctada imbricata radiata* is also widespread around Greece, mostly attached to hard substrates. As already reported, it was imported for aquaculture in several areas of Greece, although these attempts seem to have been unsuccessful. Despite early attempts of mariculture in Kriti, the first field presence of this pearl oyster from the main Greek Island was from 2003 (Zenetos et al. 2008b). Recent field work in the island coastlines suggests successful colonization of this area, with its presence recorded in 12 of 36 sites sampled and with high abundances in at least three (F. Crocetta, *unpublished data*). *P. imbricata radiata* is also consumed locally but we have no evidence of use in restaurants. *Dendostrea* cf. *folium* (Linnaeus, 1758) was only recently recorded from Greece (2010: Zenetos et al. 2011b), although its presence was first noted in 2005 in Rodos (Dodekanisa) (Ovalis and Zenetos in Karachle et al. 2016). This species was first mistaken for the native *Ostrea stentina* Payraudeau, 1826 but, soon after its first record, molecular techniques confirmed its identification as an Indo-Pacific immigrant (Crocetta et al. 2015b). Its presence was subsequently reported in several Greek sites (Zenetos et al. 2013; Bianchi et al. 2014; Corsini-Foka et al. 2015; Angelidis in Karachle et al. 2016; Appendix 2), where it now dominates the infralittoral fringe. We also suspect that its distribution is wider than that currently known due to misidentifications by both marine biologists and citizen scientists (shell collectors, scuba divers), who are still not as yet aware of the presence this species. Finally, *F. fragilis* is again currently known from several sites (Goigne 2001; Zenetos et al. 2005b, 2008b; Young 2006; Angelidis 2013; Manousis and Galinou-Mitsoudi 2013; Angelidis in Lipej et al. 2017; Appendix 2), and has widely colonized several muddy locations since its record from Saronikos Gulf (Vardala-Theodorou 1999; present paper).

With regards to the 14 species we considered as casual, nine are difficult-to-identify or -to-detect micro-species (usually < 1 cm) [*Cerithidium perparvulum* (Watson, 1886), *Cerithiopsis pulvis* (A. Issel, 1869), *Cerithiopsis tenthrenois* (Melvill, 1896), *Viriola* sp., *Sticteulima* sp., *Oscilla galilae* Bogi, Karhan and Yokeş, 2012, *Acteocina mucronata* (Philippi, 1849), *Pyrunculus fourierii* (Audouin, 1826), and *Polycerella emertoni* A.E. Verrill, 1881], and so their current establishment status may be biased by taxonomic impediments and the absence of field research. We hope that bringing attention to these species may lead to more records, or that non molluscan specialists may provide us with unidentified molluscan material currently stored in institutional collections. Of the remaining five species, *Nerita sanguinolenta* Menke, 1829 is so far known from a single record based on an empty shell (Nordsieck 1973); its identification should be straightforward due to its size and the absence of Mediterranean congeneric species. The same holds true for *Rapana venosa* (Valenciennes, 1846), which is among the largest known Mediterranean gastropods, and is so far only known from Greece on the basis of a single record of two living specimens and one shell (Koutsoubas and Voultsiadou-Koukoura 1991; Manousis et al. 2012). If established in Greek coastal

waters, it is unlikely to have been overlooked. *Clementia papyracea* (Gmelin, 1791) was only recently recorded from Greece on the basis of specimens collected in 1985 (Crocetta et al. 2016). However, the exceeding fragility of its valves makes it substantially more difficult to find than the majority of alien species, and it requires SCUBA diving procedures and molluscan taxonomic knowledge to be identified in the field. Finally, *Spondylus* cf. *spinosus* Schreibers, 1793 and *Rhinoclavis kochi* (Philippi, 1848) are among the most recent arrivals. The record of the former from Epanomi (Thermaikos Gulf) (Manousis and Galinou-Mitsoudi 2013) does not suggest an arrival via unaided spread, but rather an arrival of a small number of larvae via a transport-stowaway mechanism. This species is as yet not recorded from the Turkish Aegean coastline. In contrast, the record of *R. kochi* is based on few empty shells from Gavdos (Kriti) (Poursanidis and Zaminos in Lipej et al. 2017). However, given its common presence in Turkey, the finding of more specimens is expected.

Among species we labelled as cryptogenics in Greece, four [*Atys macandrewii* E.A. Smith, 1872, *Aplysia dactylomela* Rang, 1828, *Aplysia* cf. *parvula* Mörch, 1863, and *Siphonaria pectinata* (Linnaeus, 1758)] are considered as established, and *A. dactylomela* has also been labelled as invasive, with 20 published records subsequent to its first finding in Greece in 2005 (Sterniuk-Gronek 2005; Appendix 2). The only species with more published records are *P. imbricata radiata* and *C. persicus*, with 31 and 24 published records, respectively (Appendix 2). However, both of these species have been known from Greece for several decades (1961 and 1983: Serbetis 1963; Verhecken 1984), while *A. dactylomela* is a relative newcomer to the country. Finally, specimens of the *Tayuva lilacina* (Gould, 1852) complex lack an external/internal shell, and therefore require specific SCUBA diving skills and underwater photography to be found, as well as detailed sea slug taxonomic knowledge. Regardless of which species they belong (either the native or the alien), discussions above are on the basis of the first records made in 2012 only (Crocetta et al. 2015c).

Concluding remarks

Out of approximately 100 records of extra-Mediterranean molluscan species in Greek waters, only half belonged to alien (43 species) and cryptogenic species (12) (Tables 1–3). The combined rejected records from this study plus the 50 "de facto" excluded taxa are double that of the accepted ones, a situation similar to that documented for Italy (Crocetta 2012). Our results highlight the necessity of reliable local ecological knowledge for compiling accurate species inventories. In fact, whilst morphological taxonomic studies on minute species or of narrow specialist's interest may often be accepted and uncommented upon for decades, periodic reassessments are critical in alien species' inventories that play important roles in regional policy and management decisions, thus there must be high confidence in the validity of species identifications. In our case, the inflation of "bibliographically introduced" alien records on the Mollusca is mostly attributed to local and international shell collectors and other groups among citizen scientists, such as tourists, who are eager for new findings and can publish their presumptive results in amateur journals. Publications in such non-peer reviewed journals, but also errors in indexed ones, can lead to an artificial increase in the number of alien-species records (see also Zenetos et al. 2004), and thus emphasizes the need for periodic updates and re-evaluation. On the other hand, the contribution of citizen scientists is still crucial for our understanding of the overall distribution of the Mediterranean molluscan biota, including in Greece. In fact, it was previously stated that the first reports of 14 species of marine NIS in Greek waters (6%) were attributed to citizen scientists (Zenetos et al. 2013). On a better screening of the literature, which reports upon the 43 validated marine alien Mollusca in Greece, it appears that only 12 (~ 28%) taxa have been found during formal research projects or by institutional researchers, whilst the remaining 31 (~ 72%) Mollusca have been first found by amateurs (mostly shell collectors and SCUBA divers/photographers), although several of these findings were then published under the supervision of experts.

Comparing the alien molluscan diversity of nearby Mediterranean countries, the number of true alien species ascertained for Greece was greater than in Malta (Evans et al. 2015) and Albania (Zenetos et al. 2011a; Xharahi et al. in Gerovasileiou et al. 2017) due to the limited coastline of the former and the geographic position and paucity of field studies of the latter. The numbers were roughly similar to those for Italy (~ 35 species: Crocetta 2012; Crocetta et al. 2013c) and perhaps the Turkish Aegean shores (~ 30 taxa: Çinar et al. 2011; Öztürk et al. 2014). Explanations for the relatively low number of alien species in the Aegean versus Levantine coasts of Turkey are not clear. Although the geographic position of South Turkey (vicinity to the Suez Canal) is assumed to be the key factor, hydrography of the Aegean marine environment may also play a role. Whereas most of the alien species reported from southern Turkey are of tropical origin, a large part of

the Aegean Sea experiences wide annual fluctuations in sea surface temperatures, which are cold in winter (Nittis and Perivoliotis 2002), so as to make the area non-viable for thermophilic species—even if surface currents favor their arrival. A further reason may be an artefact due to sparse field monitoring even in the most exposed areas (the Dodekanisa and the Saronikos Gulf), but this seems to be excluded by the similarities in the numbers of species recorded from the opposite Turkish coastline. Even though the total number of species is limited, the ratio of species of Indo-Pacific origin and of species introduced from other areas through shipping and aquaculture is consistent with the position of Greece in the east-west Mediterranean gradient (Zenetos et al. 2010), and is likely to persist even if the number of alien species increases. This therefore suggests that further attention should be aimed at searching for potential newcomers in the Dodecanese area.

Interestingly, the main conclusion of this study is that most of these 43 alien mollusca have arrived in Greek waters from other parts of the Mediterranean where they were already established. This may have been achieved both by natural spread and by small-scale (fishing, recreational boats) to medium/large-scale transport (shipping). However, despite the fact that the Mollusca globally are among the first biological invaders (Molnar et al. 2008), and that colonization of the Mediterranean basin by non-native species started but a few centuries ago (Por 1978), the lack of reliable time series, as well as the general absence of molluscan studies, seems to indicate the only Greek molluscan introductions before the 1960s were by shipworms. An increasing trend of new introductions was observed after the 1980s, peaking in the 2006–2010 period. Indeed the peak in records from 1991 to 2016 is not only due to an increase in local introductions, but also due to an increased research effort by local scientists supported by Greek institutions and by wide collaboration with citizen scientists. Moreover, it is also documented that, at a global scale, climate change amplifies the entry and spread of tropical alien species (Raitsos et al. 2010).

Shipping only played a secondary role as a potential pathway in Greece and is mostly evident in selected hot spots (Saronikos and Thermaikos Gulfs) where there is heavy shipping traffic. Strangely, the role of the Saronikos area is low to medium in elevating molluscan species counts, when this could be a major hub of introduction due to the amount of maritime traffic and sites where dismantled ships are moored for long periods. As already stated for Lessepsian species, even ship-transferred alien Mollusca records in the area are only reported considerably after their first records in other Mediterranean seaports such as Iskenderun, Izmir and Tunis. Nevertheless, as for other taxonomic groups such as macroalgae and polychaetes (Katsanevakis et al. 2013; Tsiamis et al. 2013), Saronikos Gulf remains a hot spot for alien molluscan species.

The present update, established by a joint contribution from Mediterranean molluscan taxonomic knowledge and local expertise, provides a key estimate of the current numbers of alien molluscan species in Greece and an analysis of their temporal trends, pathways, establishment success, and invasiveness. Nevertheless, it is expected that due to progress in taxonomic studies (including use of molecular techniques), better biogeographic knowledge, and new invasions, reassessments will be needed periodically.

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Supplementary material

The following supplementary material is available for this article:

Appendix 1. Unpublished data.

Appendix 2. Bibliographic data.

This material is available as part of online article from:
http://www.aquaticinvasions.net/2017/Supplements/AI_2017_Crocetta_etal_Appendix1.xlsx
http://www.aquaticinvasions.net/2017/Supplements/AI_2017_Crocetta_etal_Appendix2.xlsx