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An Overlooked Group of Citizen Scientists in Non-Indigenous Species (NIS) Information: Shell Collectors and Their Contribution to Molluscan NIS Xenodiversity

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Abstract: This work reports on 60 marine alien mollusks from nine countries across the Mediterranean Sea and the Sea of Marmara collected by two Belgian citizen scientists. Some of their published observations concerning collection dates are compared with the year of first publication for these alien mollusks reported in the literature, which enable us to backdate some of their introductions and set new first Mediterranean records for two species. This underlines the importance of collaboration between volunteers and institutional scientists in tracing variations and changes in the environment and biodiversity.

Keywords: alien species; Mediterranean sea; mollusca; citizen science; shell collectors

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1. Introduction

The role of citizen science (CS) in invasion biology [1,2], and in particular in biodiversity monitoring, has recently been highlighted in the literature [3,4].

Citizen science has existed for centuries, but the recent adoption of information and communications technology in this field (e.g., web- or mobile application-based interfaces for citizen training and data generation) has led to a massive surge in its popularity, mainly due to reduced geographic barriers to citizen participation [5].

Data produced via the cooperation of citizen scientists with biological invasion experts, either directly or via information systems such as iNaturalist [6] or other dedicated networks (see [7] EASIN—European Alien Species Information Network), has led to the detection of new non-indigenous species (NIS) and the documentation of their spread, all of which helps to develop policy and environmental management for invasive alien species (IAS) and large-scale biodiversity conservation [8].

Marine citizen science (MCS) is highly underrepresented in the citizen science literature, despite the instrumental (data-focused) and capacity-building (society-focused) benefits such projects offer for marine conservation. Nevertheless, the MCS literature has experienced continual growth since its first publications in the early 1990s [9].

In the marine environment, the most active group of citizen scientists are fishers. According to Kousteni et al. [8], with regards to fishes and mollusks, the main categories of citizen scientists at the pan-European level included school children, students, divers, naturalists, and various volunteers. Most of the CS records of mollusks were reported in the NE Atlantic Ocean, mostly in the Greater North Sea. At the Mediterranean level, it appears that the most active CS group are fishers [10–12] followed by naturalists [12]. In Greece, 31 alien molluscan taxa were first detected by amateurs, mostly shell collectors, and scuba divers/photographers [13].

The valuable contribution of amateur malacologists, hereafter called SCs (shell collectors), in reporting alien molluscan species in the Mediterranean has been underestimated. The aim of this work is to highlight the role of SCs as the oldest and most reliable non-institutional data providers on molluscan NIS in European seas, and particularly in the Mediterranean.

2. Methodology

Mollusks were collected by Christiane Delongueville (C.D.) and Roland Scaillet (R.S.) during more than 160 trips conducted in the period from 1981 to 2018 in nine countries across the Mediterranean Sea and as far north as the Turkish coasts of the Marmara Sea (Table 1). The areas visited are shown in Figure 1.

Table 1. Sampling trips per country. Details on the visited locations and dates are in the Supplementary Files.

Country	Year
Greece (GR)	1981, 1995, 2016, 2018
Cyprus (CY)	1984, 1987, 1988, 1990, 2005, 2007, 2009, 2012
Italy (IT)	1985, 1987, 1989, 1997, 2000, 2005, 2009, 2012, 2017
Türkiye (TR)	1986, 1989, 1990, 1991, 1992, 1993, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2009, 2012
Israel (IL)	1987, 1998
Malta (MT)	1988
France (FR)	1990, 1992, 1994, 1998, 1999, 2001, 2003, 2009
Spain (ES)	1997, 2001
Tunisia (TN)	1986, 1990, 2001, 2004, 2006, 2007, 2010, 2011, 2012

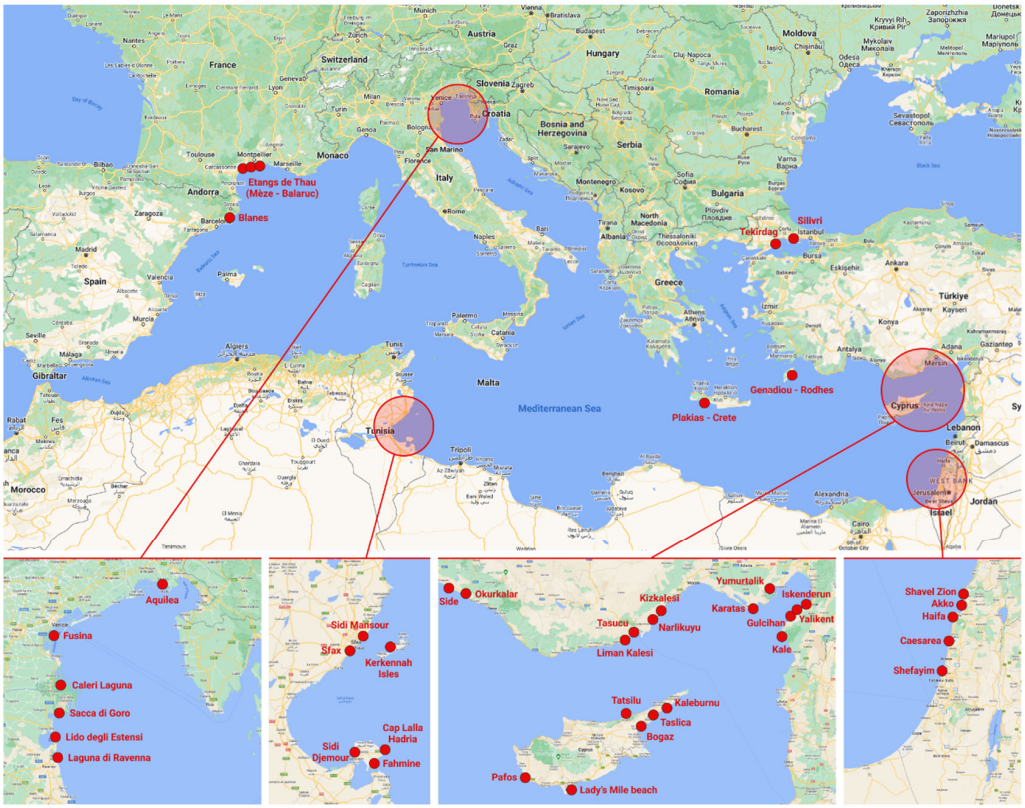

Figure 1. Map with areas visited. Some areas were visited more than once in different years. Solid red circles indicate the exact locations. For details, see Supplementary File.

We hereby define an "observation" as any collection of a species conducted at a site at a certain time, regardless of the number of specimens. A total of 418 observations were made, the vast majority along Mediterranean coasts, with only 10 observations along the Marmara coast (Dardanelles to Bosphorus). Although many records, mostly micromollusks, are based on empty shells, they are considered valid NIS records because their presence is confirmed by published records of living specimens in the country or other neighboring Mediterranean countries [13].

Most of the shells (86%) were collected by C.D. and R.S. (hand-picked, snorkeling, scuba diving), while 14% of records come from material provided by fishermen. All collection details (locations, habitat, depth, and status of shells) can be found in the Supplementary File. C.D. and R.S. have a zoological background and have collaborated with institutional malacologists and citizen scientists for over 40 years. Their background and the vast literature they have accumulated over the years, together with the numerous discussions they have had with scientists, have allowed them to validate their identifications and publish in numerous journals. All the shells are kept in the personal collection of C.D. and R.S.

Nomenclature was checked against WoRMS [14].

Data on the first records and corresponding dates and sources of alien mollusks in Israel, Türkiye, Cyprus, and Greece was retrieved from the literature and the unpublished HCMR Data base administrated by Argyro Zenetos (A.Z.). At the pan-Mediterranean, scale these data was retrieved from Galanidi et al. [15].

3. Results

In the course of a total of 418 observations, 60 alien molluscan species were identified, the most frequent of which are listed in Table 2. The majority of species belong to the class of Gastropoda, while 22 species belong to Bivalvia. Among the observed specimens, 54.3% were collected alive; the rest were empty shells, mostly beached or found in shell grit.

Table 2. Records per species > 10 records.

Species	Observations
Ruditapes philippinarum (Adams & Reeve, 1850)	11
Crassostrea/Magallana sp.	12
Rhinoclavis kochi (Philippi, 1848)	12
Septifer cumingii Récluz, 1849	12
Chama pacifica Broderip, 1835	14
Malleus regula (Forsskål in Niehbur, 1775)	15
Arcuatula senhousia (Benson in Cantor, 1842)	18
Pinctada radiata (Leach, 1814)	20
Cerithium scabridum Philippi, 1848	21
Ergalatax junionae Houart, 2008	23
Brachidontes pharaonis (P. Fischer, 1870)	26
Conomurex persicus (Swainson, 1821)	29

Table 3 shows the first observation per country. Some of the records are reported here for the first time in a given country or a Marine Strategy area (MSFD—Marine Strategy Framework Directive) of a country (e.g., *Brachidontes pharaonis* first record from the Levantine Sea subdivision of Greece); others are backdating species reported in the literature at a later date (e.g., *Bulla arabica* Malaquias and Reid 2008 found in South Türkiye in 1992 and thus backdating the 2000 record, etc.). The findings of *Lioberus ligneus* (Reeve, 1858) in South Türkiye in 1993 and the finding of *Dendostrea* cf. *folium* in South Türkiye in 1989 backdate all previous records and constitute the first Mediterranean records. The number of species found in each country is positively related to the number of observations made in each country; it is more pronounced in the eastern Mediterranean (Figure 2). However,

it is not consistent with the number of visits per country. It correlates well in the eastern Mediterranean, peaking in Türkiye (fifteen visits, revealed fifty NIS), whereas in the western Mediterranean, e.g., in France, only four NIS were detected during eight visits, as opposed to Cyprus (eastern Mediterranean), where eight trips rendered nineteen NIS (Figure 2).

Table 3. NIS detected per country. Date refers to the first year the species was detected. In bold, records that constitute first records for a country, including new record for an MSFD area within the country. In parentheses, previously reported date. Abbreviations of countries are based on the International Naming Convention [16]. BS denotes Black Sea.

Species	IL	CY	TR	GR	IT	TN	MT	FR	ES
Acteocina mucronata (Philippi, 1849)		2009	1993						
Afrocardium richardi (Audouin, 1826)			**(2000) 1991**						
Amathina tricarinata Linnaeus, 1767			2005						
Anadara kagoschimensis Tokunaga, 1906			**1990 (BS)**		1985				
Anadara natalensis (Krauss, 1848)			2002						
Arcuatula senhousia (Benson in Cantor, 1842)					1997			1990	
Brachidontes pharaonis (P. Fischer, 1870)	1987	1984	1985	**(2000) 1981**	2017				
Bulla arabica Malaquias & Reid, 2008			**(2000) 1992**						
Bursatella leachii de Blainville, 1817						2006			
Cellana rota (Gmelin, 1791)	1998								
Cerithidium diplax (Watson, 1886)			2002						
Cerithiopsis pulvis (Issel, 1869)	1987	2009	1989						
Cerithiopsis tenthrenois (Melvill, 1896)	1987	**(1985) 1984**	**(1990) 1989**						
Cerithium scabridum Philippi, 1848	1987	2005	1985			2001			
Chama asperella Lamarck, 1819		**2009**	**1990 (BS)**						
Chama pacifica Broderip, 1835	1998	2007	2002						
Cingulina isseli (Tryon, 1886)	1987	2009	1992						
Conomurex persicus (Swainson, 1821)		1988	1985	1995					
Crassostrea/Magallana sp.			2002		1985			1992	2001
Crepidula fornicata (Linnaeus, 1758)								1992	1997
Cucurbitula cymbium (Spengler, 1783)			2005						
Dendostrea cf *folium* (Linnaeus, 1758)		**(2008) 2007**	**(1993) 1989**						
Diala semistriata (Philippi, 1849)			**2002**						
Diodora ruppellii (Sowerby G.B. I, 1835)	1987		2002						
Ergalatax junionae Houart, 2008		2005	2002						
Finella pupoides Adams A., 1860			1989						
Fulvia fragilis (Forsskål, 1775)						2001			
Gafrarium savignyi (Jonas, 1846)			2002						
Gibborissoia virgata (Philippi, 1849)	1998		2002						
Indothais lacera (Born, 1778)							**1988**		
Leucotina natalensis E.A. Smith, 1910			1989						
Lienardia mighelsi Iredale & Tomlin, 1917			2007						
Lioberus ligneus (Reeve, 1858)			1993						
Malleus regula (Forsskål in Niehbur, 1775)	1987	2009	1989						
Megastomia lorioli (Hornung & Mermod, 1924)			**2002**						
Mnestia girardi (Audouin, 1826)		**(1992) 1990**	1993						
Monetaria annulus (Linnaeus, 1758)						2006			
Monotygma lauta (Adams A., 1853)			**1989**						
Naria turdus (Lamarck, 1810)						2004			
Pinctada radiata (Leach, 1814)	1998	1984	1985			1986			

Table 3. *Cont.*

Species	IL	CY	TR	GR	IT	TN	MT	FR	ES
Pseudominolia nedyma (Melvill, 1897)			1993						
Purpuradusta gracilis notata (Gill, 1858)	1987	**(2000) 1988**	1993						
Pyrgulina pupaeformis (Souverbie, 1865)	1987		**1989**						
Rapana venosa (Valenciennes, 1846)			1989		1989				
Rhinoclavis kochi (Philippi, 1848)	1987	2012	1989						
Rissoina bertholleti Issel, 1869	1987	2012	2002						
Ruditapes philippinarum (Adams & Reeve, 1850)			**2004 (BS)**		1997			2001	
Septifer cumingii Récluz, 1849		2009	2005	2016					
Siphonaria crenata de Blainville, 1827			2009						
Smaragdia souverbiana (Montrouzier, 1863)			**1989**						
Sphenia rueppellii A. Adams, 1851			2005						
Spondylus spinosus Schreibers, 1793	1998		2001						
Syrnola lendix (A. Adams, 1863)			2002						
Syrnola fasciata Jickeli, 1882			1989						
Trochus erithreus Brocchi, 1821		1987	**(1992) 1990**						
Turbonilla edgarii (Melvill, 1896)			1989						
Viriola cf. bayani (Jousseaume, 1884)				2018					
Xenostrobus securis (Lamarck, 1819)					1997				
Zafra savignyi (Moazzo, 1939)			1989						
Zafra selasphora (Melvill & Standen 1901)	1987		**1989**						

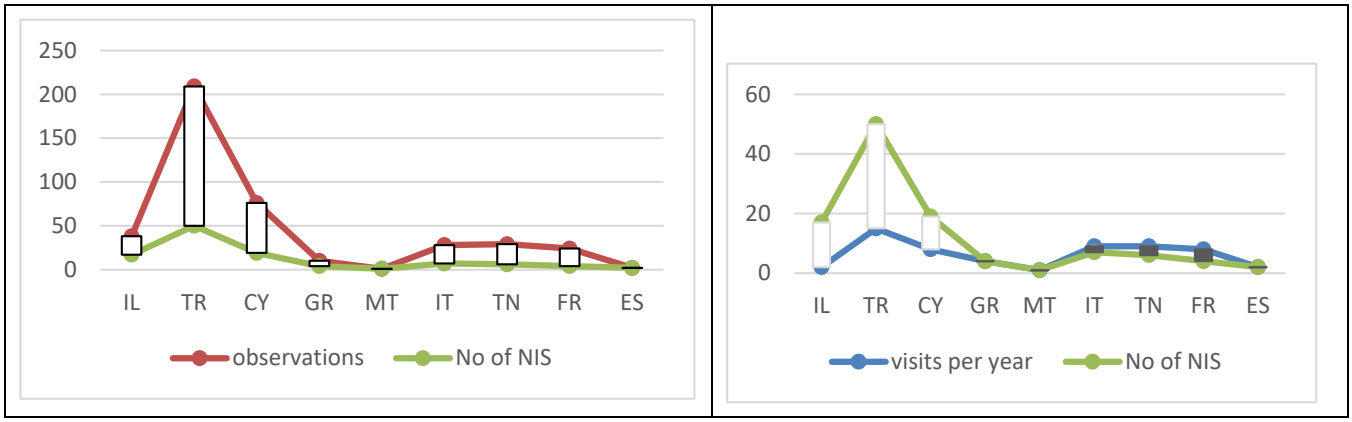

Figure 2. Number of NIS detected in each area related to (**left**) number of observations per country; (**right**) number of trips per country. White bars indicate positive correlation, black bars negative correlation.

Observations of *Chama asperella* (2009, Cyprus), *Diala semistriata* and *Megastomia lorioli* (2002, S. Türkiye), and *Indothais lacera* (1988, Malta) (Figure 3) constitute the first country/MSFD subdivision records. These specimens are illustrated in Figure 3A,C,D,F.

In addition, the finding of *Rapana venosa* (Valenciennes, 1846) in 1989 constitutes the first record for S. Türkiye, and that of *Chama asperella* (Lamarck, 1819) in 1990 from Silivri harbor constitutes the first record for the Sea of Marmara. These specimens are illustrated in Figure 3B,E.

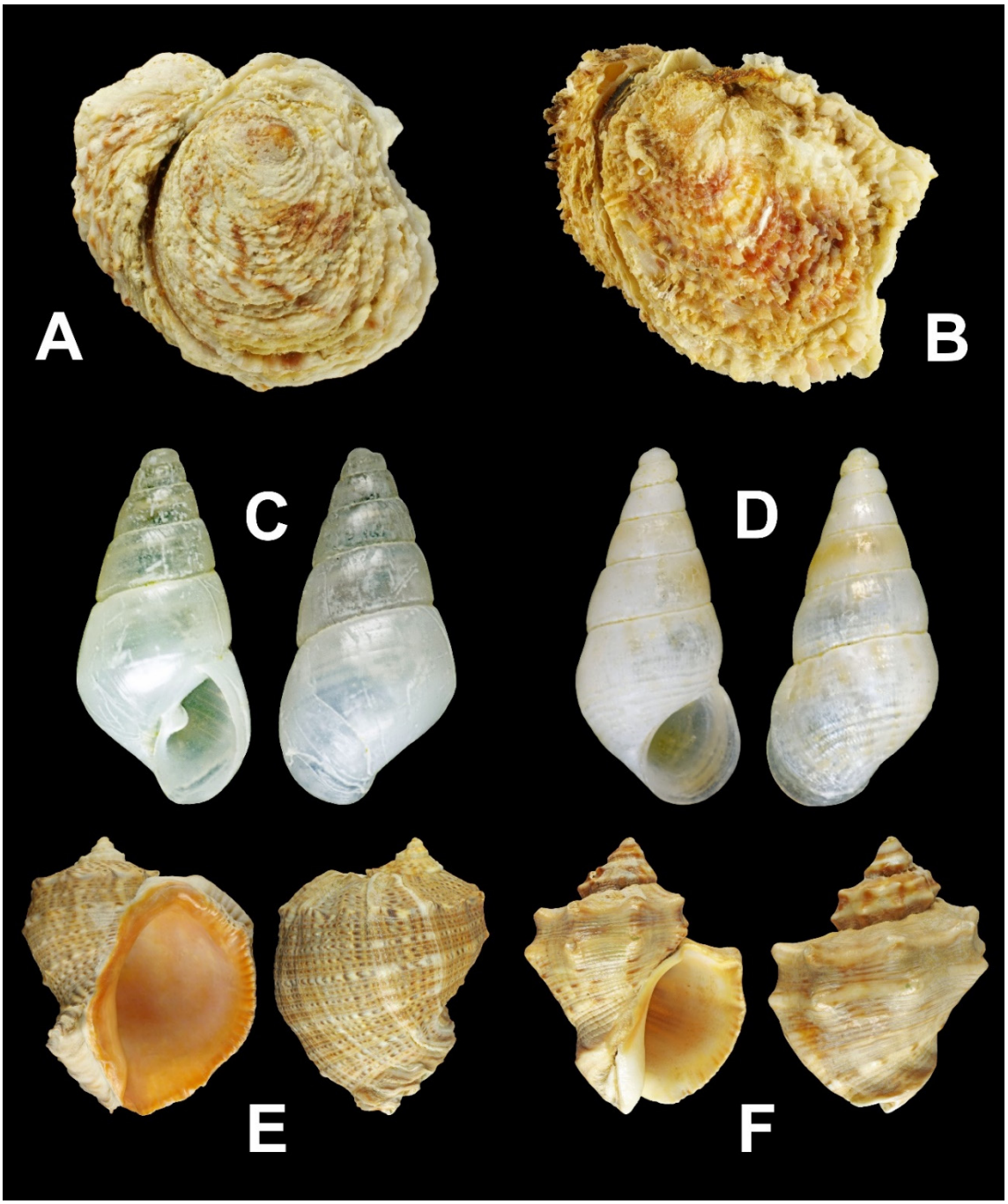

Figure 3. (**A**) *Chama asperella*, Taslica (Cyprus), 25.1 mm. (**B**) *Chama asperella*, Silivri harbor (Sea of Marmara), 29.0 mm. (**C**) *Megastomia lorioli*, Yumurtalik (S. Türkiye), 2.6 mm. (**D**) *Diala semistriata*, Liman Kalesi (S. Türkiye), 2.7 mm. (**E**) *Rapana venosa*, Taşucu (S. Türkiye), 102.2 mm. (**F**) *Indothais lacera*, Marsaxlokk (Malta), 39.5 mm.

4. Discussion

In this work, we collate and report on a considerable number of largely unpublished records of 60 alien molluscan species in nine countries across the Mediterranean Sea and the Sea of Marmara. Some of the observations have been previously published by C.D. and R.S., either at country level [17] or as separate species findings [18–26].

In agreement with Galanidi et al. [15], the highest number of molluscan NIS observed in this study was found in the eastern Mediterranean. Although no pathway analysis was attempted in this work, excluding *Crepidula fornicata* and *Crassostrea*/*Magallana* sp., the vast

majority of the molluscan NIS encountered originate in the Indo-Pacific and have most likely been introduced to the eastern Mediterranean via the Suez Canal either by spreading (Lessepsian immigrants) or with vessels.

The year of first detection of a NIS is essential in analyzing trends of introductions at any spatial level. The primary MSFD criterion concerning new NIS introductions states, "The number of non-indigenous species which are newly introduced via human activity into the wild, per assessment period (6 years), measured from the reference year (2011) as reported for initial assessment under Article 8(1) of Directive 2008/56/EC, is minimised and where possible reduced to zero". Therefore, precision in establishing the year of first detection (a proxy of the real first introduction) is crucial in assessing the number of new introductions in an area at a given interval.

Three of our observations coincide with findings reported in the literature in the same year (1989) from South Türkiye by SCs. They are the following: *Monotygma lauta* (Adams A., 1853) [27]; *Smaragdia souverbiana* (Montrouzier, 1863) [28], and *Zafra selasphora* (Melvill and Standen 1901) [29].

It is worth noting that ten of our observations backdate the year of first detection as reported in the literature by at least a year. These are the following:

1. *Afrocardium richardi* (Audouin, 1826), Türkiye 1991, backdating the 2000 record of [30] published in [22];
2. *Brachidontes pharaonis* (P. Fischer, 1870), east Rhodes (Levantine coast of Greece) 1981, backdating the 2010 record for the Levantine MSFD in [31];
3. *Bulla arabica* Malaquias and Reid 2008, S. Türkiye 1992, backdating the 2000 record in [32];
4. *Cerithiopsis tenthrenois* (Melvill, 1896), S. Türkiye 1989, backdating the 2000 record in [33];
5. *Cerithiopsis tenthrenois* (Melvill, 1896), Cyprus 1984, backdating the 1985 record in [34];
6. *Dendostrea* cf. *folium* (Linnaeus, 1758), S. Türkiye 1989, backdating the record of 1993 in [35];
7. *Dendostrea* cf. *folium* (Linnaeus, 1758), Cyprus 2007, backdating the record 2008 in [36]
8. *Mnestia girardi* (Audouin, 1826). Cyprus 1990, backdating the 1992 record of [37], published in [38] as *Cylichnina girardi* (Audouin, 1826);
9. *Purpuradusta gracilis notata* (Gill, 1858), Cyprus 1988, backdating the 2000 record in [39];
10. *Trochus erithreus* Brocchi, 1821, S. Türkiye, 1990, backdating the 1992 record in [40].

Of the species above, the soundest case is that of the bivalve *Brachidontes pharaonis,* one of the first Lessepsian invaders into the Mediterranean [40], which is widespread in the Levantine basin (eastern Mediterranean). Yet its presence in east Rhodes (Levantine coast of Greece) was not noted before 2010 [31]. The present work backdates its presence in this area by 29 years and shows how a species that is easy to recognize can go unnoticed due to the lack of scientific work in the area.

The following observations, even though they belong to species previously known and reported in a country, are considered first country records since the exact year of their detection had not been provided in the respective literature: (a) *Chama asperella* in Cyprus [24] as *Chama aspersa* Reeve, 1846; (b) *Diala semistriata* in Türkiye [38] as *Diala varia* Adams A., 1861; *Megastomia lorioli* in Türkiye [38] as *Odostomia lorioli* (Hornung and Mermod, 1924). To these, *Indothais lacera,* collected from Malta in 1988, should be added as the first record from Malta (also the first record from the central Mediterranean).

Finally, the most interesting observation is that of the mytilid *Lioberus ligneus* (Reeve, 1858) from S.Türkiye in 1993 [41], which backdates all previous records in the Mediterranean by at least six years. [It is worth noting that the previously reported first record, from 1999 in Lebanon, was reported with a lag of 14 years by Crocetta et al. [42]. This is an example that highlights the importance of international-level collaboration between formally trained/institutional taxonomic experts on the one hand and dedicated and experienced shell collectors on the other to fill in the gaps in our knowledge of alien Mollusca distribution.

Of the 60 species, 11 NIS (*Anadara kagoshimensis*, *Arcuatula senhousia*, *Brachidontes pharaonis*, *Chama pacifica*, *Conomurex persicus*, *Fulvia fragilis*, *Crassostrea/Magallana* sp., *Pinctada radiata*, *Rapana venosa*, *Ruditapes philippinarum*, *Spondylus spinosus*) have been classified as invasive with moderate-to-high impacts on biodiversity, ecosystem services, or human health [43].

Amateur malacologists (SCs) are the oldest citizen science group contributing to biodiversity. However, their findings are not always published. With a few exceptions, they are hidden in drawers of private collections, and sometimes come to light years later if donated to natural history museums. When it comes to alien species, surprisingly, their contribution is countable. There have been several publications on alien mollusks in the Mediterranean attributed to SCs, starting in the 1950s, when invasion biology had not yet been developed as a formal/separate scientific field. In fact, approximately 37% of alien mollusks in Israel [62 out of the 166 molluscan NIS listed by Galil et al. [44]] were reported by SCs (notably, Henk Mienis and Jacobus J. van Aartsen are the two most renowned members of the SC community). In Türkiye, this figure is even higher [68 species represent 55% of the 123 alien mollusks reported by Çinar et al. [45]]. If joint publications of SCs with molluscan experts are considered, the percentage increases to 40% for Israel and 62% for Türkiye. The south Turkish, Cypriot, and Greek coasts, favorites among tourist destinations, have attracted the attention of many SCs, many of whom have published their findings [including German [40], Dutch [30], Italian [13,27–29,33,37], and Belgian [17–26,38,41] SCs]. In Cyprus and Greece, the alien mollusks reported by SC reach 58% and 40%, respectively.

The iNaturalist program [6] has been recognized as a key tool for collecting biodiversity data produced by CS in multiple nations globally. However, SCs have their own means of publishing their findings. These are dedicated journals published by their malacological societies, such as *La Conchiglia* (Italy: ceased), *Triton* (Israel), *Bollettino Malacologico* (Italy), *Iberus* (Spain), *Xenophora* and *Xenophora Taxonomy* (France), *Basteria* (The Netherlands), and *Novapex* (Belgium). Yet, despite all these outlets, a number of observations remain unpublished. These valuable resources should not be neglected by taxonomic experts and invasion scientists studying xenodiversity and NIS trends.

CS who report their observations care about nature, and their aim is to learn more about the places they visit and to protect them. SCs are an important tool for monitoring biodiversity since they are numerous, frequently present in the field, and working on a voluntary basis without requiring grants/being constrained by grants to make their observations.

Some scientific natural history institutions and (or) museums have recognized the importance of CS being in the field and producing interesting zoogeographical observations. They work closely with these CS and include institutions like, in this case, the Royal Belgian Institute of Natural Sciences (RBINS—Brussels, Belgium), but also, amongst others, the "Muséum National d'Histoire Naturelle (MNHN—Paris, France)" and the Steinhardt Museum of Natural History, Tel Aviv, Israel.

At the Mediterranean scale, it is estimated that approximately 40% of all Mediterranean NIS Mollusca [90 out of the 225 NIS [46,47]] have been detected by SCs. Taking into account that Mollusca is the most abundant taxonomic group among NIS in the Mediterranean [15], it is clear that the collaboration of institutional experts with malacological societies and SCs will promote our knowledge on biodiversity changes, and particularly on the introduction and spread of NIS at any spatial scale.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d16050299/s1.

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