Saronikos Gulf: a hotspot area for alien species in the Mediterranean Sea

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Review

Saronikos Gulf: a hotspot area for alien species in the Mediterranean Sea

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Abstract

Shipping is the greatest pathway of non-indigenous species (NIS) introductions, and port areas are considered as alien hotspots. In this study, we analyzed data covering a 112-year period and found that Saronikos Gulf in Greece, hosting one of the largest container port terminals in Europe, is a hotspot of NIS introductions. To date, 89 NIS have been recorded, of which 8 are characterized as invasive. Most species belong to the taxonomic group of Mollusca (33%), followed by Pisces (22%). For the first time in the Mediterranean Sea, we report the presence of the micromolluscs *Sinezona plicata* (Hedley, 1899) and *Ringicula* sp. Moreover, we provide evidence for the trend of NIS introduction in the Saronikos Gulf across the past 70 years, the pathways of introduction and their importance through time, as well as the distribution of the most invasive species in the Saronikos Gulf. The information provided herein can assist the implementation of the EU Marine Strategy Framework Directive and inform NIS management. As Transport-Stowaway remains the main pathway of NIS introduction in the Saronikos Gulf, our principal recommendation is to reinforce regulations for the adoption of better antifouling practices and more effective ballast water treatment and management.

Key words: Aegean Sea, Piraeus port, invasive species, new micromolluscs, pathways, trends, shipping

Introduction

Following the reports of increasingly spectacular rises in the number of non-indigenous species (NIS) and their impact on native communities across the world, biological invasions are being recognized as an important element of global change (Seebens et al. 2017). The Mediterranean Sea is a hotspot area for marine NIS due to its wide temperature range, degraded habitats, high volume of shipping traffic and occurrences of aquaculture units, as well as man-made constructions, namely the Suez Canal, that allowed the movement of tropical species from the Red Sea into the Mediterranean (Zenetos et al. 2017). Moreover, the large number of recorded NIS in the Mediterranean, is associated with its long history of marine monitoring (Flagella and Abdulla 2005). By 2018, a total of 957 NIS (established and non-established) had been documented in the Mediterranean Sea (Zenetos 2019). Mediterranean port areas are considered to be hotspots for the introduction of NIS (Tempesti et al. 2020b), for example 32 harbours along the Catalan coast have been reported as such (López-Legentil et al. 2015; Livorno: Tempesti et al. 2020a); the Grand Harbour in Valletta, Malta (Romeo et al. 2015) and Alsancak Harbour, Turkey (Çinar et al. 2006).

The establishment of NIS transported by vessels poses a significant threat to marine ecosystems and economies worldwide (Saebi et al. 2020). The transport on the hulls of ships of boring, fouling, crevicolous or adherent species is certainly the most ancient vector of marine NIS introduction (Zibrowius 1992). Shipping has been implicated in the dispersal of numerous neritic organisms, from protists and macrophytes to fish. To date, shipping remains the greatest pathway for NIS introductions in the European seas, being responsible for about 43.8% of the total introductions occurred since 1950 (EEA 2019; Korpinen et al. 2019). Shipping is also an important vector for secondary introduction – the dispersal of a NIS beyond its primary location of introduction (Zibrowius 1992). Major harbours exposed to a strong inflow of ship-borne NIS as well as lagoons used for aquaculture may serve as foci for secondary ship-mediated dispersal of NIS within the Mediterranean Sea (Zibrowius 2002).

It has been argued that polluted or physically degraded environments are more prone to invasions than pristine sites (Piola and Johnson 2008; Tsiamis 2012). Port environments constitute particular cases, subject to intense maritime traffic and thus to NIS introductions. In addition, the marine communities in ports consist of opportunistic species that are capable of adapting in various ways to the alteration of chemical-physical parameters of the water. A study of macrofouling organisms discovered that higher abundance of specific NIS was found in a polluted than in a non-polluted marina: the cosmopolitan serpulid worm *Hydroides elegans* (Haswell, 1883) that dominated the fauna in the polluted marina was only infrequently found in the non-polluted marinas (Kocak et al. 1999).

The Saronikos Gulf, including the industrial zone of Elefsis Bay and the Port of Piraeus, is one of the most developed and industrialized areas of the Eastern Mediterranean Sea. The Port of Piraeus, apart from being one of the largest seaports in the Mediterranean Sea, is the main container port in the Eastern Mediterranean basin and one of the top ten container ports in Europe (Eurostat 2018). The Saronikos Gulf is one of the most well studied areas in Greece in terms of marine biodiversity, with a long monitoring project (1985–ongoing). This monitoring project also includes geological, chemical hydrographic studies (Karageorgis et al. 2020; Pavlidou et al. 2014; Kontoyiannis 2010) as well as overall ecological parameters (Simboura et al. 2014; Tsiamis et al. 2013; Dimiza et al. 2016; Pavlidou et al. 2019).

Following a 15-years old review of NIS recorded in the broader area of the major Hellenic ports (Pancucci-Papadopoulou et al. 2006), plenty of new introductions of NIS in the Saronikos Gulf included various taxa such as polychaetes, macrophytes, but mostly molluscs (Crocetta et al. 2017), scattered in scientific papers, technical reports and grey literature. The aim of the present work is to provide an updated review of the marine NIS recorded in the Saronikos Gulf by 2020. We provide detailed information on species status, establishment success, abundance and spread, as well as evidence regarding trends and pathways of introduction. The current work can support the implementation of the European Union Marine Strategy Framework Directive (MSFD, EC 2008, 2017), in particular the reporting obligations concerning the Descriptor 2 on NIS (D2) and its criteria related with new introductions (D2C1) and the abundance and spread of invasive NIS (D2C2) and their impact (D2C3).

Materials and methods

The study area

The Saronikos Gulf with an area of 2600 km^2 and a maximum depth of approximately 450 m is the marine body that is directly influenced by the Athens metropolitan area. Until 1995, the urban effluents of Athens with its more than 4 million inhabitants were discharged untreated in the shallow waters of the Keratsini Bay through the Central Sewage Outfall. Major sources of pollution for the gulf include also the port of Piraeus with intensive navigation and shipping activities, and the significant industrial activity occurring along the coast of Attica and particularly in the eastern part of the Gulf of Elefsis. The Saronikos Gulf could be divided in four sections due to geomorphological differences, hydrological characteristics and depth (Karageorgis et al. 2020) (Figure 1).

The marine environment of the Saronikos Gulf has been monitored since 1985 in the framework of the National Monitoring Program for the Assessment and Control of Marine Pollution in the Mediterranean (MED-POL) MAP/UNEP under the supervision of the Greek Ministry of Environment as well as in the framework of the EU Water Framework Directive (WFD) since 2012, and the EU MSFD since 2018.

The biota source of data

A database developed by the first author (AZ) in the Hellenic Centre for Marine Research (HCMR) for supporting the Ellenic Network on Aquatic Invasive species (ELNAIS: http://elnais.hcmr.gr), includes information on marine NIS in Hellenic waters (Zenetos et al. 2015). The main data provider is the scientific community. To be more specific, data archived in ELNAIS are based on:

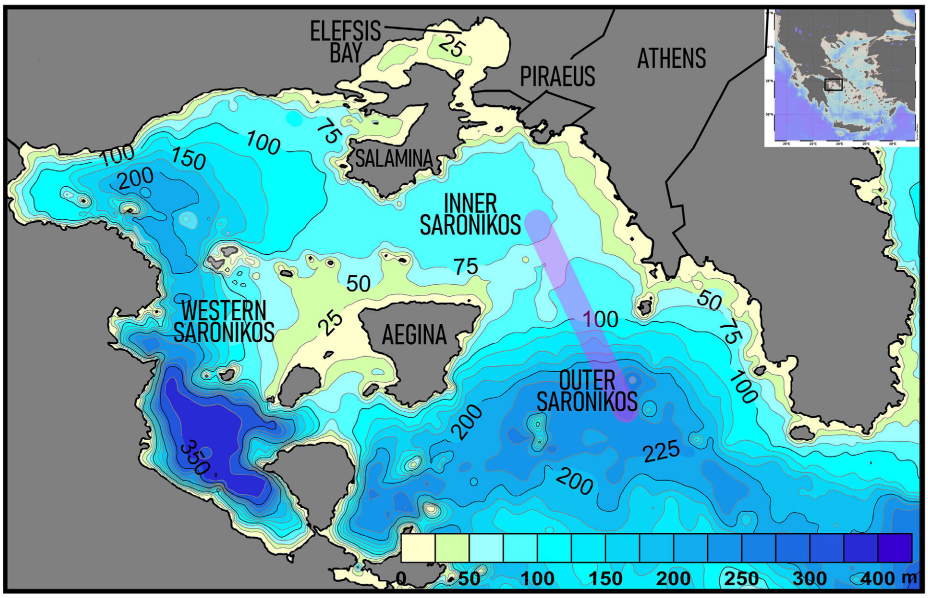

Figure 1. Study area reproduced from Karageorgis et al. 2020. Purple bar indicates the main shipping route to Piraeus Port.

1. **Scientific literature**: publications in scientific journals.
2. **Grey literature**: MSc and PhD theses, communications to conferences. Invalid occurrences of species with no description/photo of the specimen or with an ambiguous description of the record were excluded.
3. **Technical reports**: species occurrences included in HCMR technical reports.
4. **HCMR fisheries database**: The "IMAS-Fish" database (Kavadas et al. 2013) includes data on marine biological resources (Pisces, Crustacea, Cephalopoda) collected during the MEDITS (Mediterranean Trawling Survey), and other fisheries surveys being conducted in Greek Seas since 1998. Moreover, macrobenthic species, recorded since 2014 during the MEDITS survey, have been recently added.
5. **Citizen science observations**: circumstantial field observations contributed by citizens, such as shell collectors. All records were validated by experts of the ELNAIS research team.

Parameters of NIS examined

NIS status

We have distinguished the following categories, based also on Essl et al. (2018):

1. non-indigenous: species that have crossed biogeographic barriers by human agency, with substantial evidence (i.e. low uncertainty) on their non-indigenous status;
2. cryptogenic: species with some evidence on their non-indigenous status but with uncertainty due to unknown biogeographic origin; and crypto-expanding species: species with some evidence on their non-indigenous status but with uncertainty due to unclear mode of introduction from the native range (natural spread *vs* human mediated);

3. data deficient: species for which the lack of data does not allow for an assessment regarding the native or non-indigenous status or only permits a very tentative assessment; species with unresolved taxonomic status (complex species)
4. excluded: species native in the Mediterranean Sea, species introduced unaided through the Gibraltar Strait or species proved to be misidentifications of other taxa.

For species categorized as NIS, the following data are also provided:

Establishment success

We have followed the terminology of Zenetos et al. (2018):

1. established (Est): a species with at least a self-maintaining population currently known to occur in the wild;
2. invasive (Inv): an established species that is spreading rapidly, with documented impacts on the ecosystem and its services;
3. casual (Cas): a species whose only a single or few specimens have been recorded;
4. unknown (Unk): mainly for records whose recent population status is not reported/published as well as for newly reported species.

Year of first detection

For addressing time trends of NIS introductions, we have used the date of first observation of each NIS in the Saronikos Gulf, which is considered to be the best possible estimate of the year of first introduction.

Pathways of introduction

Pathways of introduction of NIS in the Saronikos Gulf follow the scheme adopted by CBD (2014), following also the subsequent critical work performed in the framework of certain pathways projects (Pergl et al. 2020). It is seldom possible to ascertain the precise mode of introduction pathway since some species may conceivably be transported by several vectors. The evidence for shipping as a significant pathway is, however, usually indirect: based on the association of new species records with harbours and in the absence of records in neighbouring marine areas.

Native range

The native range of each NIS was retrieved from the native distribution of species as provided in Tsiamis et al. (2018).

Taxonomy

Nomenclature followed WoRMS (WoRMS Editorial Board 2020).

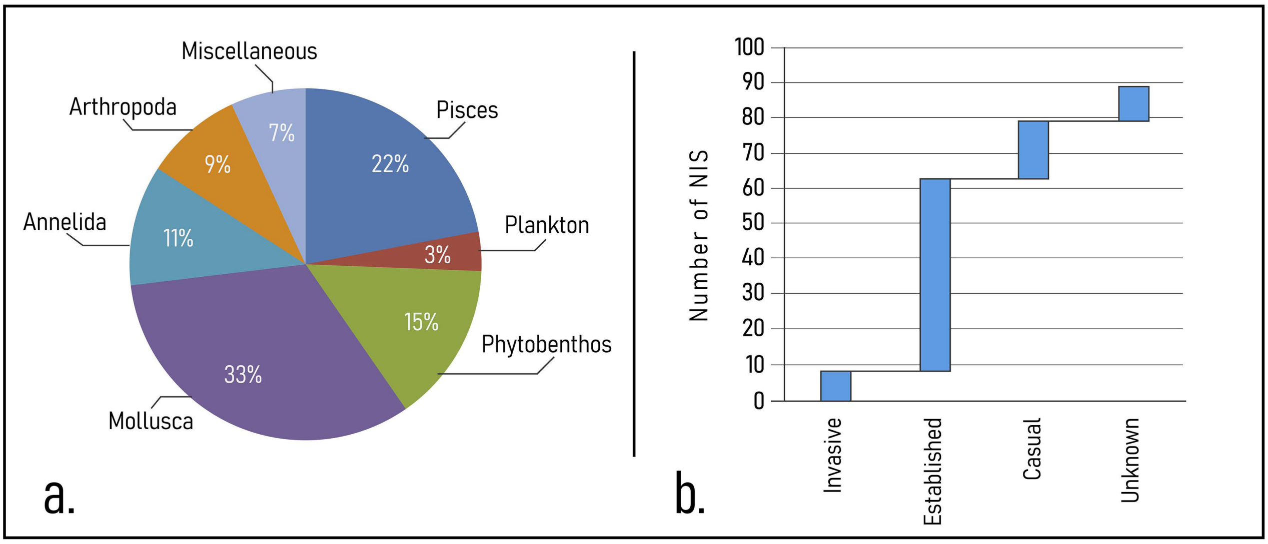

Figure 2. a) Contribution of major taxonomic/ecofunctional groups to the diversity of marine NIS of the Saronikos Gulf; b) establishment success.

Results

In total, 89 marine NIS have been recorded in the Saronikos Gulf by 2020 (see Supplementary material Table S1). In addition, 23 species are classified as cryptogenic or cryptoexpanding, seven species as data deficient and 13 species are excluded (see Tables S2–S4). In particular, the red macroalga *Asparagopsis armata* Harvey has been excluded since its records refer only to the tetrasporiophyte stage (*Falkenbergia rufolanosa* (Harvey) F.Schmitz) which most possibly correspond to the tetrasporiophyte of *Asparagopsis taxiformis* (Delile) Trevisan (Tsiamis 2012).

We analyzed 667 records of marine NIS in total, derived from 69 publications (including peer reviewed papers and 2 PhD theses), 190 records found in unpublished technical reports and databases, and 146 records provided by citizen scientists.

Most of the first NIS records in the Saronikos Gulf come from scientific papers (58%). Citizen scientists have contributed substantially to the detection of new NIS in the Gulf (42%), with very high contribution for the molluscan taxa (24 out of 29 species) (Table S1). Among the marine NIS of the Saronikos Gulf, 9 of them corresponded to the first introduction events for the whole Mediterranean Sea (Table S1). In addition, from the whole 209 marine NIS reported by 2020 from the Aegean Sea Greek territorial waters (Katsanevakis et al. 2020) 40 NIS were first reported from the Saronikos Gulf (Table S1).

The dominating group of marine NIS in the Saronikos Gulf is Mollusca (33%), followed by Pisces (22%) and phytobenthos (15%) (Figure 2a). The majority of the NIS are established in the Saronikos Gulf (55 taxa), while 16 NIS are casual, eight are characterized as invasive, and the population status of 10 species is unknown (Figure 2b).

Here, we report the presence of two new micromolluscan species in the Saronikos Gulf. We refer to the species *Ringicula* sp. and *Sinezona plicata*

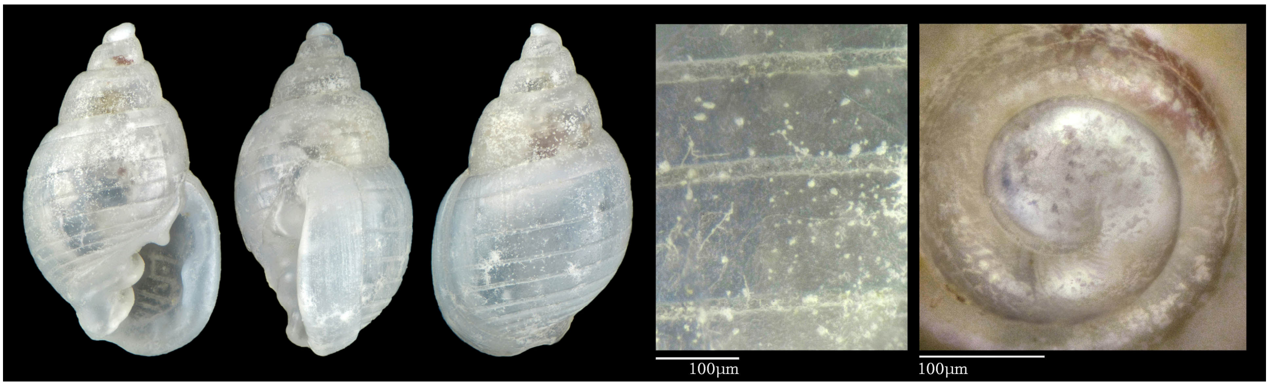

Figure 3. *Ringicula* sp. from the Saronikos Gulf. Size: W. 1.22 mm H. 2.14 mm. Photo: C. Kontadakis.

(Hedley, 1899) both stored in the personal collection of P. Ovalis. Although the records are based on empty shells only, the proximity of their finding location to the shipping route towards Piraeus Port indicates a ship transfer. On 12 September 2019, four shells of *Ringicula* sp (Figure 3) were found in a box retrieved by a fishing vessel operating off Sounio, at a depth of 45 m. The specimens could not be assigned to any known *Ringicula* species in the Mediterranean (S. Gofas, H. Mienis *pers. comm.*). Systematics of *Ringicula*, including in the Mediterranean Sea, is in a state of dismay and so we provisionally leave it as *Ringicula* sp.

In September 2019, three shells of *Sinezona plicata* (Figure 4) were found in a bottle filled with mud, retrieved from a depth of about 100 m by a professional fisher fishing SW of Patroklos Islet, Saronikos Gulf. *Sinezona plicata* has a broad tropical Pacific distribution (Geiger 2006), but is absent from the Red Sea.

Description of *Sinezona plicata*: Depressed trochiform shell (Figure 4a–d). Protoconch with single fine spiral towards periphery, varix connected to embryonic cap (Figure 4a, e), aperture sinusoid (Figure 4b, c). Whorls inflated, lateral margin always extending beyond selenizone and keels. Lower part of base with pronounced axial lamellae, crossed by distinct spiral threads (Figure 4b, d). Umbilicus shallow, wide, walls smooth, with sharp edge towards base (Figure 4b).

According to Geiger and Jansen (2004) *S. plicata* is readily distinguished from other species by the pronounced expansion of the base below the selenizone, in combination with the strong axials folds crossed by strong and dense spirals giving the shell the appearance of a filigree. Juveniles, although having an open slit and not a foramen (Figure 4a, b), also display these sculptural characteristics.

Noteworthy is also the presence of the invasive lionfish *Pterois miles* (Bennett, 1828) in the Saronikos Gulf, reported here for the first time (observed by SG). Such evidence support the westward and northward expansion of the species in the Mediterranean Sea (Dimitriadis et al. 2020).

Time-trends analysis revealed that there has been an accelerating trend of new NIS introductions in the Gulf during the last two decades (Figure 5).

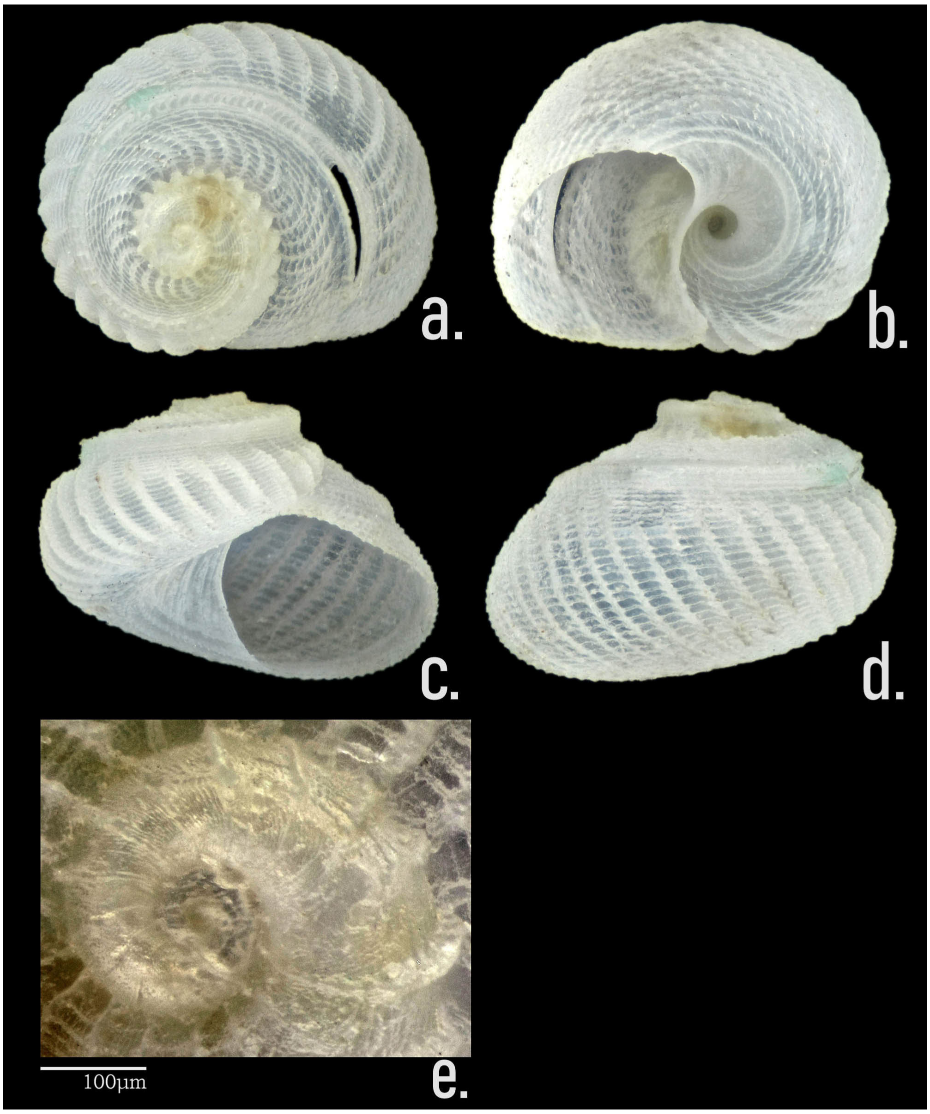

Figure 4. *Sinezona plicata* from Saronikos Gulf. Size W = 1.90 H = 2.34 mm. Photo: C. Kontadakis.

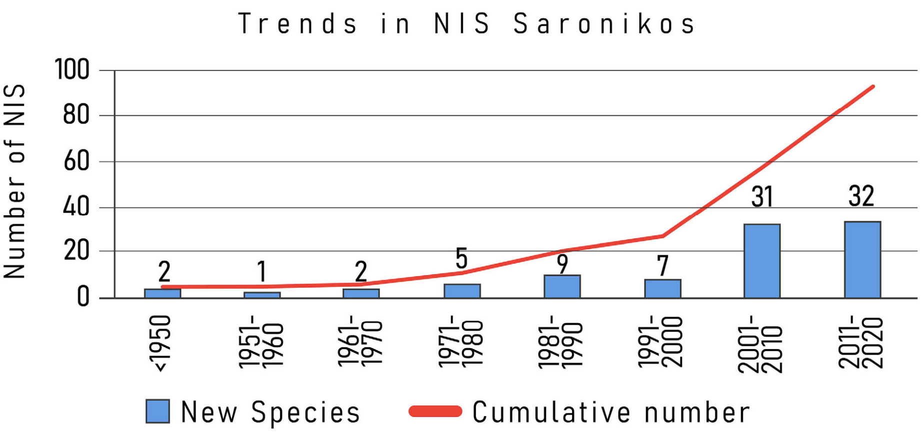

Figure 5. Number of new NIS introductions in the Saronikos Gulf per decade. The cumulative number of NIS in the Gulf is also provided.

The vast majority of the marine NIS in the Saronikos Gulf has been introduced either Unaided (natural dispersal from infested neighbouring areas) or through Transport-Stowaway (shipping) (Figure 6a). Figure 6b depicts

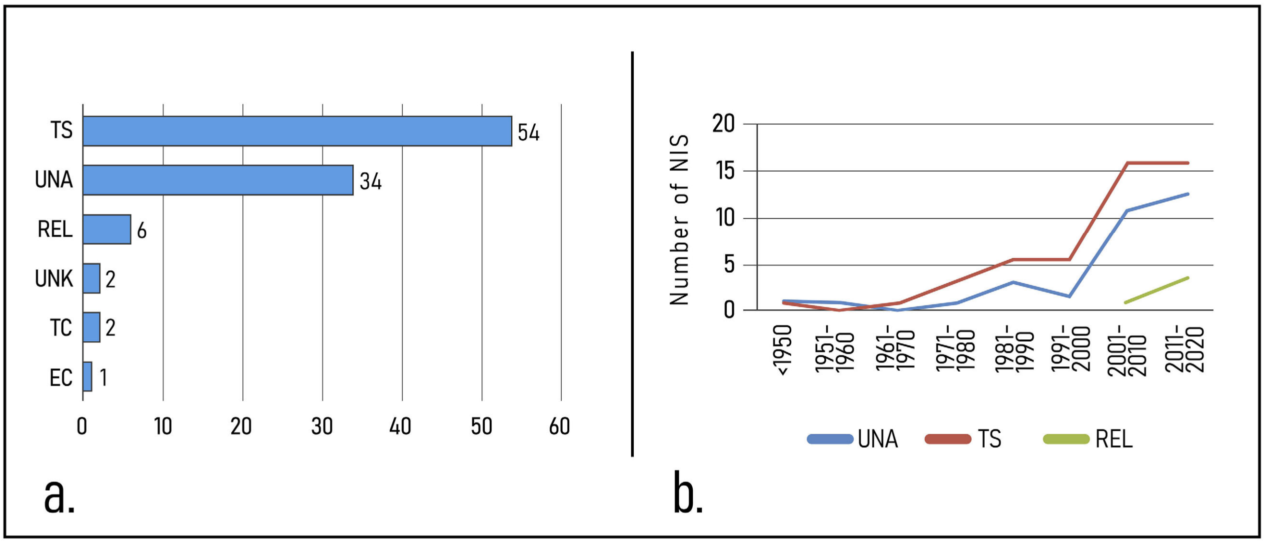

Figure 6. a) Pathways of introduction of marine NIS in the Saronikos Gulf. TS = Transport-Stowaway (vessels), UNA = Unaided, REL = Releases, UNK = Unknown, TC = Transport-Contaminant, EC = Escape from Confinement; b) trends in the 3 major pathways. Note: Several NIS are linked to more than one pathway.

the trend in introduction of the three main pathways. An increase of both 'vessel transferred' and "unaided" introduced NIS is clear after 2000 while remarkable is the increase of NIS attributed to the "release" pathway (aquaria-kept species released in the sea). Finally, the great majority of marine NIS in the Gulf has its native distribution range in the Western Indo-Pacific, the Central Indo-Pacific and the Tropical Atlantic (see Table S1).

The invasive species

Based on their high abundance and impact studies conducted elsewhere in the Mediterranean (Katsanevakis et al. 2014), eight marine NIS are characterized as invasive in the Saronikos Gulf. These are: the Mollusca *Pinctada imbricata radiata* (Leach, 1814), *Crepidula fornicata* (Linnaeus, 1758) and *Conomurex persicus* (Swainson, 1821); the macroalgae, *Caulerpa cylindracea* Sonder, *Codium fragile* (Suringar) Hariot, *Stypopodium schimperi* (Kützing) M.Verlaque & Boudouresque, and the Pisces *Siganus luridus* (Rüppell, 1829), and *S. rivulatus* Forsskål & Niebuhr, 1775. Their distribution in the Saronikos Gulf is depicted in Figure 7.

Discussion

The Saronikos Gulf has historically been a hub for introduced species. As an old Mediterranean port, it has been inhabited by ship transferred organisms since old times. Cryptogenic species such as the typical hull fouling molluscs *Teredo navalis* Linnaeus, 1758 and *Lyrodus pedicellatus* (Quatrefages, 1849) have been reported in the Gulf since 1940 (Roch 1940) but could have been present in the area earlier. Noteworthy is the fact that the Saronikos Gulf is the gateway for 11 NIS in the Mediterranean Sea. Among them is *Lophocladia lallemandii* (Montagne) F.Schmitz whose finding

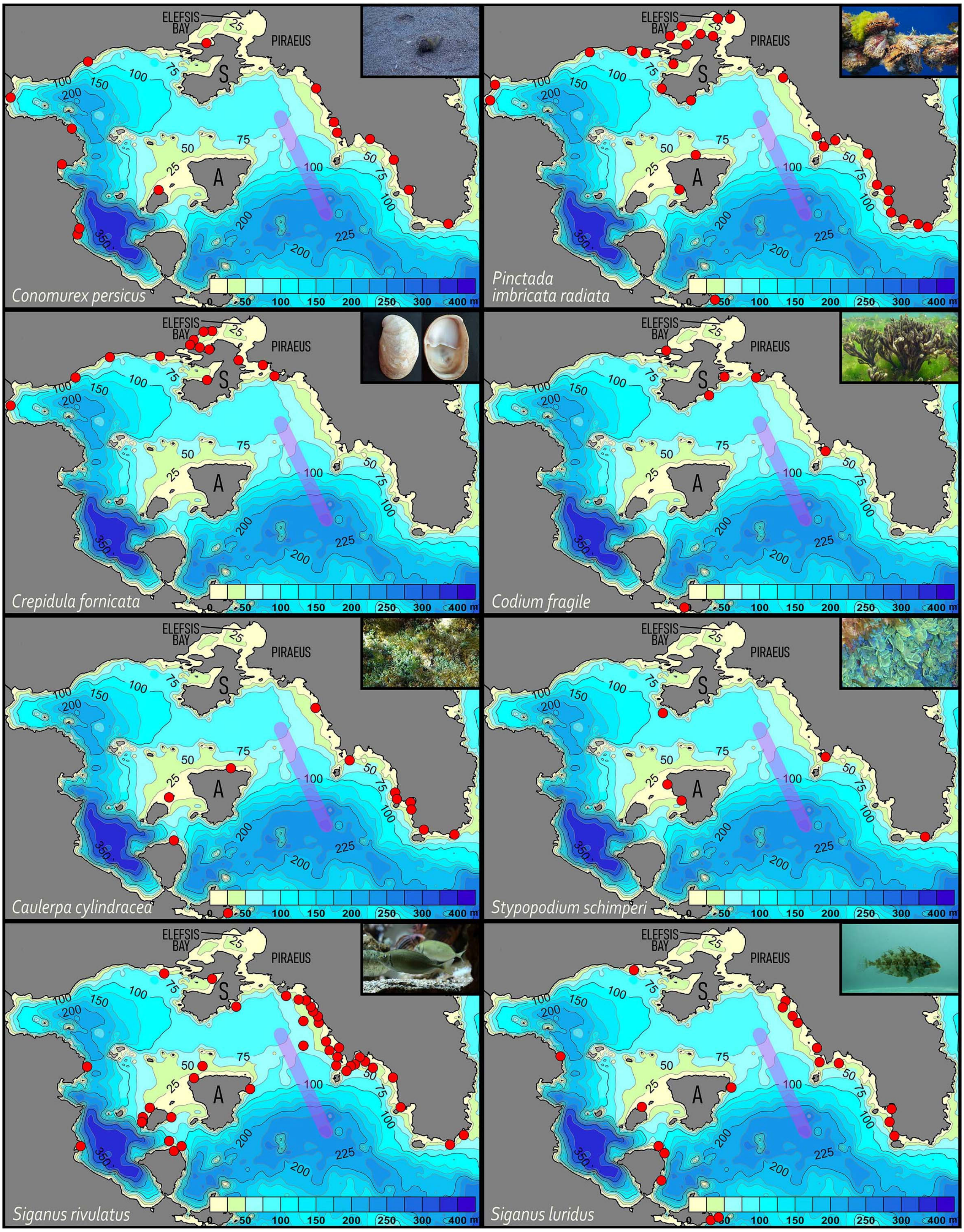

Figure 7. Distribution of the 8 invasive alien species in the Saronikos Gulf. A = Aegina Island, S = Salamina Island.

dates back to 1908 (Petersen 1918) and is nowadays widespread in the Mediterranean. The other 10 species are mostly very recent records (since 2017) limited to the Gulf.

Currently, a total of 89 alien species are reported in the Saronikos Gulf. More than 70% of them are established (55 species) or have become invasive (8 species). Herein, we found that the trend in NIS introductions has been increasing particularly since 2000 when scientific effort in the area was intensified. This increase follows a general increasing trend of NIS in Greek waters (Zenetos et al. 2018; Zenetos 2019; Zenetos et al. *submitted*). The number of new NIS in the 2011–2020 period is expected to be further increased considering the time lapse in reporting (Zenetos et al. 2019).

Latest findings of new marine NIS in the Saronikos Gulf include: five fishes *Acanthurus* cf. *gahhm* (Forsskål, 1775), *Chaetodipterus faber* (Broussonet, 1782) (Giovos et al. 2020; Karachle et al. in Bariche et al. 2020), *Lutjanus argentimaculatus* (Forsskål, 1775) (Tiralongo et al. 2019), *Abudefduf* cf. *saxatilis* (Linnaeus, 1758) (Zenetos and Miliou 2020), and *Pterois miles* reported herein for the first time); the scyphozoan *Chrysaora* cf. *achlyos* Martin, Gershwin, Burnett, Cargo & Bloom, 1997 (Langeneck et al. 2019); the seagrass *Halophila decipiens* Ostenfeld (Gerakaris et al. 2020) and the four gastropods *Euthymella colzumensis* (Jousseaume, 1898) (Ovalis and Zenetos in Dragičević et al. 2019), *Eunaticina papilla* (Gmelin, 1791) (Ovalis and Zenetos in Ragkousis et al. 2020), *Cerithiopsis pulvis* (Issel, 1869) (Mpazios et al. 2020), and *Pyrgulina pupaeformis* (Souverbie, 1865) (Manousis et al. 2020). Noteworthy are the findings of the micromolluscs *Sinezona plicata* and *Ringicula* sp., which are herein reported for the first time in the Gulf and the Mediterranean Sea. However, these micromolluscs findings must be treated with care as their presence is documented only from empty shells. The list presented herein is clearly an under-estimate, due to incomplete knowledge of some taxa, the inability to distinguish aliens from some native species, and the lack of concerted and standardized efforts to survey port and port-proximate environments for alien biota.

Mollusca is the most numerous group of NIS with 29 representatives, the majority of them (21 species) introduced after 2000. Their reporting is attributed vastly (82%) to citizen scientists (amateur shell collectors) who in close collaboration with taxonomists have published the results (e.g. Daskos and Zenetos 2007; Ovalis and Zenetos 2007; Manousis et al. 2018, 2020, Mpazios et al. 2020).

Of the 29 molluscan NIS the pearl oyster *Pinctada imbricata radiata*, the Persian conch *Conomurex persicus* and the Atlantic slipper limpet *Crepidula fornicata* have exhibited invasive behavior in the study area (rapid spatial expansion and/or high abundances). *Pinctada imbricata radiata* and *Conomurex persicus* are widespread all around the Gulf from Elefsis Bay to the outer Gulf, as opposed to *Crepidula fornicata* whose distribution is limited. The true distribution of the first two species, although not documented in literature, is assumed to be all around the Saronikos Gulf as supported by the findings of amateur shell collectors who detect it on rocky substrata all along the Gulf. In contrast *C. fornicata* that has an invasion history as long as *C. persicus* is locally invasive (Elefsis Bay and the Western Saronikos (Figure 7)).

With regards to phytobenthos, *Halophila decipiens* is reported for the first time in the Gulf and at the whole Mediterranean Sea (Gerakaris et al. 2020). Of the 13 alien macrophytes occurring in the Gulf, three exhibit invasive behaviour: the green algae *Caulerpa cylindracea* and *Codium fragile*, as well as the brown alga *Stypopodium schimperi.* The first species is quite widespread along the Gulf coasts. On the other hand, *C. fragile* and *S. schimperi* present a more limited distribution but they occasionally monopolise the sea bottom, in particular along the coasts of Salamina Island (Tsiamis 2012).

Of the 20 alien fishes reported to-date in the study area, 12 were detected after 2010. Four of them, the reticulated leatherjacket (*Stephanolepis diaspros*), the two herbivorous siganids (*Siganus rivulatus* and *S. luridus*) and the small-sized sideburn wrasse (*Pteragogus pelycus)* have been shown to occur respectively in 52.4, 19.1 and 14.3% of boat-seine hauls conducted in the Saronikos Gulf in 2008 (Lefkaditou et al. 2010). The majority of Pisces records is attributed to citizen scientists (e.g. Zenetos et al. 2016; Giovos et al. 2018). About half the fish NIS are known to have established populations in the Saronikos Gulf, whereas the status of some recently recorded species such as *Upeneus pori* (Ben-Tuvia and Golani, 1989) that is already established or invasive in other areas of the Aegean Sea (Katsanevakis et al. 2020) remains unknown. Surprisingly, *Pterois miles* that was first recorded in August 2020, has already been established in the Gulf as evidenced by the multiple observations of citizens and scientists reported to the NGO i-sea and ELNAIS. Currently, only two fish species are considered invasive in the study area. These are the two herbivorous siganids (*Siganus luridus* and *S. rivulatus*) of tropical origin that have massively colonized the eastern Mediterranean including the Southern and Central Aegean Sea (Katsanevakis et al. 2020). Siganids are caught in small-scale fisheries and at local level and make up a significantly high proportion of the total fish abundance and biomass. Brodersen and Vassilopoulou (2018) documented an increasing trend in the total catch of *S. luridus* and *S. rivulatus* in the Saronikos Gulf in the period 2014–2016 (by 8.8% and 3.6% in terms of abundance and biomass, respectively) when compared to the period 2004–2006. Unlike other regions of the Aegean Sea, such as the Dodecanese, siganids do not have a commercial value and are treated as discards in the Saronikos Gulf. The lack of market value for these species may have contributed to their proliferation and population increase (Giakoumi 2014).

Transport-Stowaway has contributed to 54% of NIS introductions in the study area, followed by unaided introduction with 34% and releases 6%. This is in contrast with the broader picture in the Aegean Sea where unaided introduction has contributed to 56% of entries and Transport-Stowaway to 35% (Katsanevakis et al. 2020). However, the Saronikos Gulf appears to be a gateway for many NIS species in Greek waters. Approximately 20% of the NIS species in Greece were initially reported from the Saronikos Gulf and many spread to the Aegean Sea. Others, such as the molluscs *Crepidula fornicata* and *Mya arenaria*, are still limited to the Gulf. Most of the fish and crustacean species have entered unaided from the Aegean whereas vessels (Transport-Stowaway) are considered responsible for the transfer of most polychaetes, molluscs and macroalgae NIS which arrived either through fouling on ship hulls or in ballasts. Transfer with vessels is the most plausible pathway with medium uncertainty, assigned to many Indo-Pacific species already established in the Levantine Sea that are absent from the nearby Aegean Sea (Kyklades islands complex).

The dominant role of the pathway Transport-Stowaway of NIS introduction in the Saronikos Gulf is not a surprise as the gulf hosts the 4th largest container port terminal in Europe (https://www.porteconomics.eu/2020/02/21/top-15-container-ports-in-europe-in-2019-teu-volumes-and-growth-rates/). Worldwide, international shipping, followed by aquaculture, represent the major means of marine NIS introduction (Seebens et al. 2013). Moreover, some of the largest recreational ports/marinas of Greece are situated in the study area, such as Alimos Marina with a capacity of hosting 1000 vessels (http://www.alimos-marina.gr/). Recreational vessels, besides assisting the secondary spread of NIS that have already been introduced in the region by commercial boats, can be an important vector for primary introduction of NIS (Clarke Murray et al. 2011; Ferrario et al. 2017).

This study provides evidence demonstrating that the Saronikos Gulf is a hotspot area for NIS in the Mediterranean Sea. The information presented herein, i.e. the full list of species recorded, the trend of NIS introduction, the pathways of introduction and their importance through time, as well as the distribution of the most invasive species in the Saronikos Gulf, can assist the implementation of the EU Marine Strategy Framework Directive and inform NIS management. Development of additional efficient and cost-effective ship-borne NIS policies requires an accurate estimation of NIS spread risk from both ballast water and biofouling (Saebi et al. 2020). It is critical to reduce the introduction of NIS in the area through international shipping. This could be achieved with the adoption of better antifouling practices and effective implementation of the Ballast Water Management Convention (BWMC). Regarding species that reach the area unaided, their populations could be controlled through their targeted removal and their commercial and/or recreational utilization (Giakoumi et al. 2019). Such a strategy could also be used for NIS that are introduced through other pathways.

Besides defining distribution patterns and population trends of NIS in the study region, it is important to assess their impacts on native biodiversity and ecosystems. Specifically, observational and experimental studies should be conducted to assess the impacts of the eight most invasive NIS in the Saronikos Gulf. This gap will be covered in the long term by the MSFD monitoring activities, while a better first picture will be acquired from the results of the ongoing projects ALIENS port (https://alienports.hcmr.gr/) and “ECOHULLCLEAN”.

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Supplementary material

The following supplementary material is available for this article:

Table S1. List of Alien species in Saronikos Gulf.

Table S2. List of cryptogenic and crypto-expanding species in the Saronikos Gulf.

Table S3. List of Data Deficient species.

Table S4. List of excluded species.

Appendix 1. References for supplementary tables.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2020/Supplements/BIR_2020_Zenetos_etal_SupplementaryMaterial.xlsx