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Review

Deep cleaning of alien and cryptogenic species records in the Greek Seas (2018 update)

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Abstract

This work presents a current (2018) annotated list of marine NIS and cryptogenic species in Greek marine waters. For this purpose, we updated information from previous lists, included new data from several new NIS and cryptogenic records and recent taxonomic studies, and followed current taxonomic modifications for the alien/cryptogenic status of several introduced species. Our extensive literature survey and revisions resulted in the exclusion of 61 species, which were included in previous lists, and the addition of 41 new alien species reported in the 2016–2018 period plus ten old NIS records. The current number of introduced species in Greek waters whose presence is not questionable includes 214 alien species and 62 cryptogenic species. Approximately 80% of the introduced species in Greek Seas consists of the taxa—in decreasing order—Mollusca, Polychaeta, Crustacea, Fishes, and Macroalgae. Nevertheless, a considerable increase in the number of NIS Bryozoa and Ascidiacea was observed within the last decade. Unaided natural dispersal of Lessepsian immigrants (57%) and transport-stowaways (36.7%) are the major pathways of introduction reported for Greek waters. However, with few exceptions (6.8% of species), the confidence level in assigning a pathway was medium to low. Several species reported from adjacent marine areas are expected to reach Greek waters within the next years. The intensification of underwater observations by citizen scientists combined with further research in hot spot areas, understudied habitats and overlooked taxa will significantly raise the number of NIS species in Greek waters. This study can serve as a basis that could greatly benefit from the coordination and harmonization of monitoring initiatives under international, EU and Regional Policies, and the compilation of new data from established monitoring programs, and rapid assessment surveys.

Key words: marine introduced species, revision, validation, uncertainties, pathways, Greece

Introduction

The biodiversity of the Mediterranean Sea is very high, reflecting the wide range of climatic and hydrological conditions that allowed the survival of both temperate and subtropical organisms primarily originating from the Atlantic Ocean. It has been characterized as "an outstanding centre of biodiversity but also one of the most threatened Seas, mainly by human activity" (Cuttelod et al. 2009). The characterization of the Eastern Mediterranean as "a hot spot for marine alien species", here called NIS (Non Indigenous Species), is well-documented by the quantity and quality of biological invasions (Streftaris et al. 2005; Nunes et al. 2014).

Greece lies in the Eastern Mediterranean Sea, along the natural spread route of many of the Indo-Pacific taxa entering from the Red Sea, according to the prevailing Mediterranean currents (Bergamasco and Malanotte-Rizzoli 2010). However, its native biota is also threatened by NIS introduced via other vectors, such as transport on ship hulls of commercial and/or recreational vessels as well as with ballast water (Zenetos et al. 2012), intentional (aquaculture) and accidental introductions accompanying imported species (Zenetos et al. 2012), and escapes/releases from aquarium trade (Zenetos et al. 2016). Sufficient high-quality information on NIS ecology, distribution, pathways of introduction, impacts, is considered a strong prerequisite for the efficient prevention, early detection, rapid response and management of biological invasions, and the effective implementation of legislation (Katsanevakis et al. 2015).

So far, the alien biota of Greece has been mostly compiled/reviewed in four main articles (Pancucci-Papadopoulou et al. 2005a, b; Zenetos et al. 2009, 2011). The latest report (Zenetos et al. 2015) is based on 2014 data but does not include an inventory of species. A thorough revision of non-indigenous Mollusca in Greek marine waters has been carried out recently (Crocetta et al. 2017), while macroalgae were critically studied earlier (Tsiamis 2012). In addition, annotated checklists of the Ascidiacea, Bryozoa and Polychaeta species reported from Greek waters were recently compiled within the framework of the Greek Taxon Information System (GTIS) of the LifeWatchGreece Research Infrastructure (Antoniadou et al. 2016; Bailly et al. 2016; Gerovasileiou and Rosso 2016; Faulwetter et al. 2017), including several NIS. However, research activities have been intensified during the last decade and new records of alien Porifera, Bryozoa, Echinodermata, Ascidiacea, and Vertebrata have been published recently (Corsini-Foka and Kondylatos 2015; Crocetta et al. 2015; Tsiamis et al. 2015; Karachle et al. 2016; Kondylatos et al. 2016; Zenetos et al. 2016, 2017b; Gerovasileiou et al. 2017; Stamouli et al. 2017; Ulman et at. 2017; Frantzis 2018; Giovos et al. 2018; Manousis et al. 2018 – see ELNAIS news https://elnais.hcmr.gr/ accessed on 30.5.2018).

Moreover, due to the recent reassessments of the alien or cryptogenic status of some alien species by Zenetos et al. (2017a) and the rapidity of taxonomic and molecular advances, it was deemed necessary to review, update and validate the list of alien and cryptogenic species of Greece carefully. Therefore, the aim of this work was to review published data and to address the taxonomic uncertainties as well as uncertainties in the mode of introduction of NIS in Greek waters.

Methodology

An extensive literature survey was conducted. Indexed papers were searched, but an attempt was also made to cover grey literature as much as possible (i.e. non peer-reviewed and/or non-indexed papers, and PhD theses) due to many historical journals not being indexed, and faunal records still being published in non-indexed journals. Collected data were re-analysed and taxonomically adjusted, according to the World Register of Marine Species (WoRMS Editorial Board 2018), although there were several exceptions; e.g. in some cases WoRMS has not adopted the latest taxonomic review nomenclature such as in the case of the genus *Loimia* Malmgren, 1866 which according to Jirkov and Leontovich (2017) is considered a synonym of *Axionice* Malmgren, 1866. In such a case and according to the latest checklist on Greek polychaete fauna (Faulwetter et al. 2017) we followed the latest revisions in the nomenclature of the species.

For the final list, only taxa with high certainty of presence in Greece were considered as validated, based on at least one of the following criteria: a) at least one record in the Greek seas has been sufficiently documented (with detailed descriptions and/or illustrations); b) genetic data have confirmed the record; c) voucher specimen(s) are deposited in a museum collection. The rest of the species temporarily remain unverified.

A new subdivision of introduced species in alien, cryptogenic and debatable (species with an unresolved taxonomic status) was introduced so as to distinguish between alien status and population status (establishment success).

The following data are provided for each introduced species listed:

- ✓ Updated nomenclature;
- ✓ Date of the first finding (year) in Greece. We refer to the first collection/ observation date (when reported) and not the publication date. For unpublished data, we searched through museum collections and contacted the authors of the first report when possible. In cases where it was impossible to clarify the first collection/observation date, we noted that the species was found before the publication date (e.g. before 1955);
- ✓ Alien, cryptogenic, or debatable status;
- ✓ Population Status (= Establishment success) in Greece, defined on the basis of the following terminology: Casual (Cas), a species whose only a single or few specimens have been recorded; Established (Est), a species with at least a self-maintaining population currently known to occur in the wild; Invasive (Inv), an established species that is spreading rapidly, with documented impacts on the ecosystem and its services; Unknown (Unk), mainly for old records whose recent population status is not reported/published as well as for newly reported species; and (Que) species whose presence in the country is questionable and needs to be confirmed (re-examination of material if available).
- ✓ Most plausible pathway(s) of introduction in Greek waters, according to the CBD classification (CBD 2014) as follows:

  (COR) = CORRIDOR, interconnected waterways/ basins/seas; this is the case of Lessepsian immigrants;

(UNA) = UNAIDED: Natural dispersal across borders of NIS that have been introduced through other pathways as in the case of Lessepsian immigrants

(EC) = ESCAPE FROM CONFINEMENT, i.e. aquaculture/mariculture; aquarium species; live food and live bait. Intentional (accidental or irresponsible) release of live organisms from confinement, including cases such as the disposal of aquaria kept species into the environment falls into this category.

(TC) = TRANSPORT-CONTAMINANT, i.e. contaminated nursery material; contaminated bait; food contaminant (including live food); contaminant on animals (except parasites, species transported by host/vector); parasites on animals (including species transported by host and vector); contaminant on plants (except parasites, species transported by host/vector); parasites on plants (including species transported by host and vector);

(TS) = TRANSPORT-STOWAWAY, i.e. angling/fishing equipment; hitchhikers on ship/boat (excluding ballast water and hull fouling); ship/boat ballast water; ship/boat hull fouling; other means of transport;

(UN)= UNKNOWN, when more than 3 potential pathways are suspected.

The link between species and pathways was based on scientific literature, i.e. on published justification by experts of why a species is believed to be introduced via a specific pathway. More than one pathway/vector was assigned to a species when different introduction events by different pathways/vectors occurred within Greek Seas. A degree of certainty was assigned to each pathway according to Katsanevakis et al. (2013b). In brief, the following rating scheme was applied.

1. There is direct evidence of a pathway/vector;
2. A most likely pathway/vector can be inferred: in some cases, a specific vector could not be inferred, e.g. some species probably introduced by shipping could not be further linked to ballast waters or hull fouling and were classified as "shipping/unknown";
3. One or more possible pathways/vectors can be inferred;
4. when pathway is "*UNKNOWN*" and there is doubt as to any specific pathway explaining an arrival.

Results and discussion

Zenetos et al. (2017a) acknowledged that no list at national/regional scale is fully reliable unless it is the result of close collaboration among local experts. Yet, even then, all lists need constant revision. Every checklist also requires continuous updating in the light of new information on: a) new arrivals [e.g. *Isognomon legumen* (Gmelin, 1791) (see Micali et al. 2017)] and/or overlooked species (e.g. some taxa such as bryozoans that can easily go unnoticed); b) range expansion of already known species resulting in a change of their establishment success, e.g. *Penaeus hathor* (Burkenroad, 1959) (see Kondylatos and Corsini-Foka 2017) and whose status was switched from casual to established; and *Pterois miles* (Bennett, 1828) that proved to be invasive since 2017 (M. Corsini-Foka, pers. observation); c) changes in identification/nomenclature resulting from both traditional taxonomy and molecular studies, e.g. *Ciona robusta* Hoshino and Tokioka, 1967. Nowadays, *C. robusta* can be safely assigned the status of introduced in the Mediterranean, being reported there since the 19th Century (Savigny 1816, as *Phallusia intestinalis*), most often under the name *C. intestinalis* (Zenetos et al. 2017a and references therein).

Consequently, the list of alien and cryptogenic species in Greek waters that was first compiled in 2005 (Pancucci-Papadopoulou et al. 2005a, b), and then updated in 2009 (Zenetos et al. 2009), 2010 (Zenetos et al. 2011), and 2014 (Zenetos et al. 2015) is now outdated and includes some inevitable errors. Thus, the current effort elucidates any discrepancies with previous inventories, adding new records, removing species that are native to the Mediterranean Sea and misidentifications, as well as discussing questionable cases.

A. Species reported as alien or cryptogenic in previous lists/publications, now removed from the list

Species reported in previous check lists of alien biota in Greece, including those reported in recent publications, which were removed following the current review are listed in Appendix 1.

Regarding **microalgae** species, the presence of *Proboscia indica* (H. Peragallo) Hernandez-Becerril and *Prorocentrum triestinum* J. Schiller in the Mediterranean Sea has been considered as the outcome of marginal dispersal and not due to anthropogenic introductions and should thus be excluded (see also Gómez 2008). In our opinion, *Alexandrium taylori* Balech should be also excluded, due to the aforementioned reason. Regarding *Karenia brevis* (C.C. Davis) Gert Hansen and O. Moestrup, Gómez (2008) questioned the correct identification of the Mediterranean records; hence, we prefer to exclude this species from the Greek NIS list. *Alexandrium insuetum* Balech, a species only known from the Mediterranean Sea and west Pacific Ocean

(Gómez 2006), is possibly native to the Mediterranean Sea, since Steidinger and Tangen (1997) reported differences in the sulcal plates between the Mediterranean and Pacific specimens, questioning the conspecificity of the two populations. Finally, *Histioneis detonii* Rampi has been rarely reported from the Mediterranean and the Pacific (Gómez 2006), but there are no indications supporting its alien status in the Mediterranean Sea.

As regards **macroalgae**, *Bonnemaisonia hamifera* Hariot has been reported once, but without documentation, in conference proceedings focusing on corals (Skoufas and Tsirika 2003), originating from the North Aegean Sea. In the absence of confirmed records of the species in the Eastern Mediterranean Sea, we would exclude this species from the Greek NIS list. In addition, *Chondria pygmaea* Garbary and Vandermeulen, an epiphyte of the common alien seagrass *Halophila stipulacea* (Forsskål) Ascherson, reported by Tsiamis et al. (2010), as "*highly probable presence, needs observation*", should be excluded since this species has never been observed in the Greek seas until today.

Zenetos et al. (2011) listed six **foraminiferan** species based mostly on Koukousioura et al. (2010) who reported them as cryptogenic. The status of the amphisteginids *Amphistegina lessonii* d'Orbigny, 1826, *Amphistegina madagascariensis* d'Orbigny, 1903 and *Amphistegina lobifera* Larsen, 1976 is problematic. Currently, the former two are removed because of potential misidentification/synonymy with the cryptogenic *A. lobifera*, an invasive species in coastal ecosystems of the Aegean Sea (Triantaphyllou et al. 2012).

An example of the accumulation of errors transferred from one checklist to another, the **polychaete** *Sigambra constricta* (Southern, 1921) was reported by Arvanitidis (2000) from the Aegean Sea based on records from the Turkish Aegean (Ergen 1987) and the Sea of Marmara (Rullier 1963); the species was subsequently erroneously included in the Greek checklist by Simboura and Nicolaidou (2001). In the current review, nine polychaete species were excluded. These include five species recorded from the Turkish Aegean coastline, which were erroneously included on Greek checklists (Simboura and Nicolaidou 2001) and another four species [*Hydroides dianthus* (Verrill, 1873), *Leocrates chinensis* Kinberg, 1866, *Lumbrineris perkinsi* Carrera-Parra, 2001, *Marphysa disjuncta* Hartman, 1961] that actually represent putative native species (Faulwetter et al. 2017). Among the misidentified species, *Marphysa disjuncta* Hartman, 1961 was reported from Greece by Simboura et al. (2010), but Kurt Şahin (2014) doubts its presence in the Mediterranean after re-examination of material that was assigned to *Marphysa cinari* Kurt-Sahin, 2014 (see Faulwetter et al. 2017).

The rationale for excluding 16 **molluscan** species, listed as aliens in previous reviews, is fully explained in Crocetta et al. (2017). All these species are listed in Appendix 1; exclusion parameters range from misidentifications [e.g. *Centrocardita akabana* (Sturany, 1899) and *Pseudochama corbierei* (Jonas, 1846)] to incorrect or invalid locality data [*Rapana rapiformis* (Born, 1778)] and records based on empty shells or material presumably imported through the souvenir trade [e.g. *Cerithium litteratum* (Born, 1778)]. Some species often reported from Greece were also listed as falsified, based on combinations of misidentifications and misreading [e.g. *Trochus erithreus* Brocchi, 1821, *Murex forskoehlii forskoehlii* Röding, 1798, and *Cucurbitula cymbium* (Spengler, 1783)]. A high number of additional deletions based on records published in specialist papers were also previously corrected by Crocetta et al. (2017), but these taxa are not reported here. Eastern Mediterranean specimens formerly ascribed to the *L. pedicellatus* complex were recently ascribed to the Mediterranean endemism *Lyrodus mersinensis* Borges and Merckelbach, 2018 (see Borges and Merckelbach 2018), and therefore *L. pedicellatus* is excluded from the cryptogenic list. To the aforementioned species five additional species should be added that were recently recorded from various Greek localities by Angelidis and Polyzoulis (2018), Lolas et al. (2018), and Manousis et al. (2018). Angelidis and Polyzoulis (2018) first recorded *Euthymella colzumensis* (Jousseaume, 1898) from the Mediterranean Sea based on a single empty shell from Astypalaia. According to material and methods used in Crocetta et al. (2017) and followed here for molluscs, its presence in Greece should be excluded until new Mediterranean and/or Greek findings are reported. In addition, the authors considered published records of *Viriola* sp. [cf. *corrugata* (Hinds, 1843)] to be ascribed to *Viriola* cf. *bayani* Jousseaume, 1884, and previous Greek records of *Isognomon legumen* (Gmelin, 1791) to be ascribed to both *I. legumen* and *Isognomon australica* (Reeve, 1858). As already pointed out, the taxonomy of species belonging to *Viriola* Jousseaume, 1884 needs to be reviewed, and, in particular, *V. bayani* and *V. corrugata* show wide similarities (see discussions in Marshall 1983; Crocetta et al. 2017; Steger et al. 2018). Pending additional and convincing studies, we here cautiously prefer to leave Mediterranean specimens as undetermined, although we move them here as to be possibly ascribed to *V. bayani*, in agreement with latest literature. With regards the two isognomonid taxa, a part of the general invertebrate book by Vine (1986) used by Angelidis and Polyzoulis (2018) to state the presence of *I. australica* in the Red Sea, there is a general agreement in considering it as locally absent (e.g. Dekker and Orlin 2000; Rusmore-Villaume 2008; Huber 2010). The contemporary presence in Astypalaia of two taxa belonging to *Isognomon* Lightfoot, 1786, one of which apparently absent from the Red Sea, seems unlikely. Therefore, to avoid the inflation of alien molluscan records and pending molecular confirmations, we prefer here to ascribe both records to the Red Sea taxon *I. legumen*. Lolas et al. (2018) recorded *Nassarius vittatus* (A. Adams, 1853) while studying molluscan assemblages associated with *Cystoseira* in the Pagasitikos Gulf, but this record is unsubstantiated and presumably based on a misidentification for native taxa belonging to the *Tritia corniculum* (Olivi, 1792) complex. Finally, Manousis et al. (2018) first recorded *Aspella anceps* (Lamarck, 1822) and *Nucella lapillus* (Linnaeus, 1758) from Greece. The former, a cryptogenic species in the Mediterranean Sea, was recorded as based on worn shells lacking the intricalx, and thus cannot be positively identified at species level. For the same reason, we cannot exclude that such a record is based on fossil *Aspella* shells. On the other hand, the record of *N. lapillus* is based on two live specimens found at 10 m depth. This species only lives at tide level, therefore suggesting that these specimens may have been most likely mechanically discarded in the field.

As for **crustaceans***,* the titan acorn barnacle *Megabalanus coccopoma* (Darwin, 1854) and the isopod *Paradella dianae* (Menzies, 1962) have only been reported from ship hulls moored in Saronikos Gulf (Polychronidis et al. in Siokou et al. 2013) and Heraklion port (Ulman et al. 2017), respectively. Following strict classification criteria [exclusively associated with its vector: Marchini et al. 2015], they are not considered as valid records in Greece. The Indian Ocean amphipod *Stenothoe gallensis* Walker, 1904 was long considered an alien species in the Mediterranean Sea until Krapp-Schickel (2013) demonstrated that the Mediterranean material was a misidentification of *Stenothoe cattai* Stebbing, 1906. As there is no evidence that the East Atlantic shrimp *Synalpheus africanus* Crosnier and Forest, 1965 has entered the Mediterranean with a human vector, it is removed from the current list. The velvet swimming crab *Necora puber* (Linnaeus, 1767) is excluded from the list because its record is based on an old unsubstantiated finding only (Athanassopoulos 1917). Collections of Athanassopoulos (1917) were examined in detail by Koukouras et al. (1992), who were unable to find any preserved specimens of *Necora puber* in the Zoology Museum of Aristotle University of Thessaloniki.

The wide distribution of the copepod *Pseudocalanus elongatus* (Boeck, 1865) in the north Atlantic and Black Sea raises questions on its alien status in the Mediterranean. It is assumed that it could be a boreal relict (Zenetos et al. 2012) and as such it is removed from our list.

Three **bryozoans** that were indicated as NIS in a recent checklist of marine Bryozoa of Greece (Gerovasileiou and Rosso 2016) are excluded in this work (Appendix 1). These are: the ctenostome *Amathia gracillima* (Hincks, 1877), whose records in the Mediterranean Sea are doubtful (see Ferrario et al. 2018); the cheilostome *Crisularia plumosa* (Pallas, 1776), which was erroneously (possibly a typographic error) listed as NIS in Rosso and Di Martino (2016); and the cheilostome *Parasmittina raigii* (Audouin, 1826) whose taxonomic status in the Mediterranean Sea is not unanimously accepted, probably being a misidentification based on the use of wrong synonymies (A. Rosso, pers. commun.). The congeneric bryozoan *P. egyptiaca* (Waters, 1909) was recently reported from Agios Nikolaos marina in Kriti by Ulman et al. (2017) but is not included in the current work as it was found only on boat-hulls.

The alien **ascidian** *Rhodosoma turcicum* (Savigny, 1816) that was included in the recent checklist of Ascidiacea of Greece (Antoniadou et al. 2016) was also omitted in this work, as its record remains unverified and was based on secondary literature sources (Koukouras et al. 1995), possibly not from Greek waters (see Appendix 1).

Following Zenetos et al. (2012), **fishes** of tropical Atlantic origin that may have expanded their distribution range into the Mediterranean Sea unaided such as *Enchelycore anatina* (Lowe, 1838), *Gaidropsarus granti* (Regan, 1903), *Seriola fasciata* (Bloch, 1793), *Sphoeroides pachygaster* (Muller and Troschel, 1848) and vagrant species of Atlantic origin such as *Rhizoprionodon acutus* (Rüppel, 1837) and *Alopias superciliosus* Lowe, 1841 have been excluded.

Another species recently excluded is *Iniistius pavo* Valenciennes, 1840, an Indo-Pacific labrid, which was a misidentification of a juvenile *Xyrichtys novacula* (Linnaeus, 1758) (see Corsini-Foka et al. 2015).

In addition, some species have been removed from the list of Greek NIS either because they are old, undocumented records, and have been reported only once [*Anguilla japonica* Temminck and Schlegel, 1846, *Micropterus salmoides* (Lacepède, 1802)*,* and *Huso huso* (Linnaeus, 1758)] and/or because they are freshwater species accidentally reported in estuarine waters [the Danube sturgeon *Acipenser gueldenstaedtii* Brandt and Ratzeburg, 1833*,* the parasitic nematode *Anguillicoloides crassus* (Kuwahara, Niimi and Itagaki, 1974), the oomycete *Aphanomyces astaci* Schikora, 1906, and the signal crayfish *Pacifastacus leniusculus* (Dana, 1852)].

B. Present status: additions, population status

As regards the bacterium *Trichodesmium erythraeum* Ehrenberg ex Gomont, too little is known on the geographical distribution of prokaryotic biota to assess native and introduced ranges and it shall then be considered cryptogenic (Sabeur et al. 2016).

Four new alien **macroalgae** should be added to the list of Greek alien species since the last update for the group by Tsiamis (2012). The brown alga *Cutleria multifida* (Turner) Greville, a species previously thought to be native to the Mediterranean Sea, is now considered as alien according to molecular work carried out by Kawai et al. (2016). The brown alga *Scytosiphon dotyi* Wynne was recently found by Tsiamis and Panayotidis (2015) in Kriti Island but reported with reservations due to the lack of reproductive structures (classified as "questionable" in the current list). The cryptogenic alien red alga *Palisada maris-rubri* (Nam and Saito) Nam was reported from Rodos Island by Tsiamis and Gerakaris (in Tsiamis et al. 2015) based on specimens collected in 2006. Although *Palisada maris-rubri* has been reported as alien to us there is some uncertainty regarding the alien status of the species in the Mediterranean. The species might had been overlooked in the past, taking into account the complex identification difficulty within the *Laurencia* group. Finally, the cryptogenic red alga *Pyropia koreana* (Hwang and Lee) Hwang, Choi Oh and Lee should be added in the list of Greek cryptogenics. The species had been reported from the North Aegean Sea as *Porphyra olivii* Orfanidis, Neefus and Bray (Brodie et al. 2007), and later proved to belong to *Py. koreana* based on the molecular study of Vergés et al. (2013). The Indo-Pacific species *Padina boryana* Thivy was reported by Nizamuddin (1981, as *P. tenuis* Bory) from several localities in the South Aegean Sea. Yet, Verlaque et al. (2015) considers the Greek records of Nizamuddin as doubtful. *Pylaiella littoralis* (Linnaeus) Kjellman has been reported from Chalkidiki by Anagnostidis (1968, with reservations) and from Kephalonia Island by Schnetter and Schnetter (1981), but without a description or illustrations. Thus, the occurrence of *P. littoralis* in Greece is questionable and needs to be confirmed. Similarly, *Ceramium strobiliforme* Lawson and John record from Greece is lacking documentation, reported only once from Zakynthos Island by Tsirika and Haritonidis (2005). Finally, the Indo-Pacific species *Chondria collinsiana* Howe was first reported from the Mediterranean Sea by Athanasiadis (1987: 91) based on a single infertile plant collected in Sithonia Peninsula (North Aegean Sea). However, his record was later questioned by Verlaque (1994: 5) who stated that it might correspond to the Atlantic species *Chondria curvilineata* Collins and Hervey. Pending new findings, Athanasiadis (1987) record should be referred as debatable. Considering the recent additions and exclusions (Appendix 1, 2), the total number of alien and cryptogenic marine macrophytes in Greece increases from 36 (Tsiamis 2012) to 39 taxa.

Given the uncertainty of introduced **foraminiferan** in the Mediterranean (Merkado et al. 2013; Martin Langer, pers. comm. 17.5.18) all previous alien records from Greece are moved to cryptogenics while four new foraminiferans are added to the cryptogenics list. *Euthymonacha polita* (Chapman, 1900) and *Acervulina inhaerens* Schulze, 1854 were reported from Kavala by Delliou et al. (2015) while the Indo-West Pacific *Clavulina* cf. *multicamerata* Chapman, 1907 was found in Saronikos Gulf [Triantaphyllou and Dimiza in Katsanevakis et al. 2014]. *Amphisorus hemprichii* Ehrenberg, 1839 was found on rhizomes and leaves of *Posidonia oceanica* collected by boat-seine at a depth of 20 to 40 m in Karakonero (Rodos Island) (Corsini-Foka et al. 2015).

The introduced status of *A. lobifera* and *Sorites orbiculus* (Forskål, 1775) is worth mentioning because studies on them are controversial. Meriç et al. (2016) reported fossil records of *A. lobifer*a from Turkey establishing thus its native status, while Guy-Haim et al. (2017), support that *A. lobifera* was introduced via the Suez Canal. However, reports of Miocene and Pliocene occurrences show that amphisteginids have long been present in the European area of the Tethys and in the Mediterranean, a remnant of the former seaway (Langer 2008). Historically, amphisteginid foraminifera were native to the Mediterranean and are currently expanding into previously occupied territory. As such they represent successful returnees that were temporarily displaced during the Messinian Salinity Crisis (Langer et al. 2012).

Sorites orbiculus has also been present in the Mediterranean before the opening in the Suez Canal. According to Ahuva Almogi (pers. comm. 18.05.2018) in Israel there are records of this species in at least two occasions during the Pleistocene (~ 200,000 years before present, also an interglacial period) and during the late Holocene. Still by genetics it was shown by Merkado et al. (2013) that one variant of this species/group that lives in the Gulf of Aqaba in very shallow water on stones, was identified in the same habitat also off Shiqmona, Haifa.

As regards **molluscan** species, only three changes are noted since the recent review published by

Crocetta et al. (2017). In particular, *Diodora funiculata* (Reeve, 1850) was recently recorded by Manousis et al. (2018) based on three live specimens, and it is here listed as casual. At the same time, the establishment status of *Viriola* sp. [cf. *bayani*] was updated from casual to established, based on published records from Angelidis and Polyzoulis (2018) and Steger et al. (2018 (see above for discussions) and unpublished records from Saronikos Gulf (P. Ovalis, pers. comm.), and the same holds for *Rhinoclavis kochi* (Philippi, 1848). The latter taxon was so far known from Greece as based on six empty shells recorded by Poursanidis and Zaminos in Lipej et al. (2017) from Gavdos Island, to which 32 additional shells were added by Manousis et al. (2018) from two different sampling sites in Karpathos Island. Although no live specimens were still recorded in Greece, the high number of shells recorded let us to speculate that the species certainly lives in Greece.

Altogether, 44 taxa are listed here as true aliens and 11 as cryptogenic. However, the latter group includes Teredinidae (3 species) and Xylophagidae (2 species), all reported from Greece with reservations (see discussions in Crocetta et al. 2017). The majority of these species originate in the Indo-Pacific area and mostly spread to the Dodekanese Islands unaided, although several of them have also been recorded in other areas, such as the Saronikos Gulf and the Ionian Sea. Among them, *Conomurex persicus* (Swainson, 1821), *Dendostrea* cf. *folium* (Linnaeus, 1758), and *Fulvia fragilis* (Forsskål in Niebuhr, 1775) are worth mentioning due to their invasiveness. *Conomurex persicus* has almost entirely colonised the shallow soft and hard substrates in the entire Eastern Mediterranean; *Dendostrea* cf. *folium* dominates the infralittoral fringe of hard substrates, whilst *F. fragilis* has already been reported from the whole of Greece, including the Ionian Sea. Among the remaining taxa, 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.

Most **decapod** species and the stomatopod *Erugosquilla massavensis* (Kossmann, 1880) are of Indo-Pacific/Red Sea origin and are established in the south-eastern Aegean (Appendix 2), apart from *Alpheus rapacida* de Man, 1908, which was detected only along the north-eastern Aegean coastline. Among the Indo-Pacific species, only *Penaeus hathor* (Burkenroad, 1959), *Thalamita poissonii* (Audouin, 1826) and *E. massavensis* also occur in the south-western Aegean Sea, with the last two also established in Kriti (Skarvelis et al. 2015; ELNAIS, 2018). The latest decapod record is that of the brachyuran crab *Matuta victor* (Fabricius, 1781) (Kondylatos et al. 2018) recently reported from Israel (Galil and Mendelson 2013). Till recently, the portunid crabs *Gonioinfradens paucidentatus* (A. Milne Edwards, 1861) and *Gonioinfradens giardi* (Nobili, 1905) were synonymized (Leene 1938). The taxonomic status of *G. paucidentatus* in Greek waters is now under revision, after the detection of *G. giardi* off the Mediterranean Israeli coast and its molecular and morphological distinction from *G. paucidentatus* (Galil et al. 2018). *Gonioinfradens paucidentatus* is the first Indo-Pacific decapod that spread to the central Aegean Sea and the Kyklades Islands (Kondylatos et al. 2017). The remaining five species of decapods reported from Greek waters are of Atlantic origin, namely, *Callinectes sapidus* Rathbun, 1896, *Percnon gibbesi* (H. Milne Edwards, 1853), *Penaeus aztecus* Ives, 1891, *Calappa pelii* Herklots, 1851 and *Dyspanopeus sayi* (Smith, 1869). The first three, *C. sapidus*, *P. gibbesi* and *P. aztecus*, are invasive decapods widely distributed in both the Ionian and the Aegean basins, while *C. pelii* exhibits a casual occurrence in Ionian and western Aegean waters. Recently, *Dyspanopeus sayi* was found for the first time in Aegean waters, in Kriti (Ulman et al. 2017). Considering its wide expansion in the western Mediterranean and the Adriatic, its occurrence in Ionian waters could be expected. The alien status of the crab *Sirpus monodi* Gordon, 1953 has been questioned by Pancucci-Papadopoulou and Naletaki (2007) and we have thus attributed cryptogenic status to this species. It may have been overlooked due to its small size. Recent studies (Fryganiotis and Chintiroglou in Katsanevakis et al. 2014; Tempesti et al. 2016; Ulman et al. 2017) have added five **isopods** to our list, namely, *Paracerceis sculpta* (Holmes, 1904); *Paranthura japonica* Richardson, 1909; *Sphaeroma walkeri* Stebbing, 1905; *Mesanthura* cf. *romulea* Poore and Lew-Ton, 1986, and *Cymodoce fuscina* Schotte and Kensley, 2005, the finding of the last consisting its first record in the Mediterranean. The finding of the amphipod *Bemlos leptocheirus* (Walker, 1909) in Heraklion Old Venetian Harbour, Kriti (Ulman et al. 2017) is interesting, since it is one of the early Lessepsian immigrants reported, never reported again after its first record from Egypt as early as 1924 (Schellenberg 1928). Finally, *Amphibalanus amphitrite* (Darwin, 1854), which was recorded in Evia Island in the 1970's by Koukouras and Matsa (1998), was added to the list of cryptogenics.

A total of 49 **polychaete** species are listed as introduced in Greece (Appendix 2). The majority of these records are based on one or few specimens, and were only reported in Greece from articles, checklists or PhD theses. Among these records, approximately 39 (80%) are accompanied by photos and material and/or are deposited in a museum/private collection. Compared to previous lists (Zenetos et al. 2009, 2011), the present one includes 14 new non-native or cryptogenic species with casual occurrence in Greece [*Dorvillea similis* (Crossland, 1924), *Eurythoe complanata* (Pallas, 1776), *Exogone breviantennata* Hartmann-Schröder, 1959, *Hydroides brachyacantha* Rioja, 1941, *Leiocapitellides analis* Hartmann-Schröder, 1960, *Leonnates persicus* Wesenberg-Lund, 1949, *Lepidonotus tenuisetosus* (Gravier, 1902), *Linopherus canariensis* Langerhans, 1881, *Lumbrinerides neogesae* Miura, 1981, *Mediomastus capensis* Day, 1961, *Neanthes agulhana* (Day, 1963), *Neomediomastus glabrus* (Hartman, 1960), *Sigambra parva* (Day, 1963), *Timarete punctata* (Day, 1963)], and one with established status (*Branchiomma bairdi* (McIntosh, 1885).

Several of the polychaete records of NIS species in Greece were proved to be a complex of cryptic and pseudo-cryptic species. In these cases, it is likely that the name refers to a complex of cryptic species and Mediterranean material could belong to an overlooked native species, e.g. *Metasychis gotoi* (Izuka, 19022) an old record, which is assigned to the cryptogenic category. According to Faulwetter et al. (2017), the increasing discovery of cryptic species through molecular methods is creating uncertainty as to the diversity and distribution of polychaete species worldwide. Many species seem to be restricted to much smaller geographic areas than was previously assumed and many of these species are probably absent from the Mediterranean Sea.

Other changes include switching the status between alien and cryptogenic or debatable. Such are the cases of *Terebella ehrenbergi* Gravier, 1906 and *Capitellethus dispar* (Ehlers, 1907) both with confusing taxonomy. The taxonomy of the *T. ehrenbergi* is confused, as two different descriptions exist in literature: *T. ehrenbergi* sensu Day, 1967 and *T. ehrenbergi* sensu Rullier, 1972. It is currently unknown whether Mediterranean species belong to *T. ehrenbergi* Gravier, 1906 or to a different species. According to Faulwetter et al. 2017, Ben-Eliahu (1976b) compared material from the Israeli coasts of the Mediterranean with museum specimens from the Red Sea identified by Gravier and by Fauvel and found morphological differences which however, may be a size-dependent character and it is currently unknown whether Mediterranean species belong to *Terebella ehrenbergi* Gravier, 1906 or to a different species. *Capitellethus dispar* can be confused with several species of *Notomastus*; and is considered as debatable by Çınar et al. (2014).

Of the 49 polychaete species reported as introduced, 35 are alien species, 12 are documented or are suspected to be cryptogenic, while debatable is the status of 2 species.

Only one **bryozoan** species, namely *Hippopodina feegeensis* (Busk, 1884), was listed in previous NIS lists compiled for the Greek Seas (Pancucci-Papadopoulou et al. 2005b; Zenetos et al. 2009). This species was reported in Milos Island (Morri et al. 1999) and more recently in Rodos by Corsini-Foka et al. (2015). However, Ulman et al. (2017) pointed out that these records should perhaps be re-assigned to the alien congeneric *Hippopodina* sp. A, which was found in the same location (Mandraki Port, Rodos). The recent compilation of the first annotated checklist of marine Bryozoa of Greece by Gerovasileiou and Rosso (2016) listed 11 additional NIS. By excluding three species (see Appendix 1), the remaining eight are the ctenostome *Amathia verticillata* (delle Chiaje, 1822) and the cheilostomes *Bugula neritina* (Linnaeus, 1758), *Bugulina fulva* (Ryland, 1960), *Crepidacantha poissonii* (Audouin, 1826), *Crisularia serrata* (Lamarck, 1816), *Exechonella antillea* (Osburn, 1927), *Microporella coronata* (Audouin, 1826), and *Scrupocellaria scruposa* (Linnaeus, 1758). Nevertheless, the alien status of *E. antillea* is debatable while the presence *M. coronata* is considered questionable. The former was reported from Chios Island by Hayward (1974) but the taxonomic status of its Mediterranean records remains unverified (Harmelin et al. 2016). The inclusion of *M. coronata* in the checklist of Bryozoa of Greece by Gerovasileiou and Rosso (2016) was based on the assumption that Aegean specimens of *M. orientalis* Harmer, 1957 could belong to the former species [as suggested by Harmelin et al. (2011) and followed by Rosso and Di Martino (2016)] and thus although an alien species its presence remains questionable. Another three bryozoans were reported from hard substrata in marinas of Kriti and Rodos by Ulman et al. (2017), namely, *Celleporaria brunnea* (Hincks, 1884), *C. vermiformis* (Waters, 1909), and *Tricellaria inopinata* d'Hondt and Occhipinti Ambrogi, 1985.

A total of 12 alien and cryptogenic bryozoans have been included in this work, significantly raising the number of bryozoans considered in previous lists. Several of these records were overlooked in previous NIS lists as they are mostly based on old publications (e.g. Hayward 1974) or grey literature sources such as PhD theses (e.g. Ganias 1990 and other sources in Gerovasileiou and Rosso 2016). Nevertheless, half of these species (6) have not been reported within the last decade and thus their establishment status remains unknown. Taxonomic descriptions and/or photographic evidence of the examined material were unavailable for only 2 species.

Given that no **ascidian** species were included on the first Greek NIS lists (Pancucci-Papadopoulou et al. 2005b; Zenetos et al. 2009), a significant increase of non-indigenous ascidian records was evident in the Greek Seas within the last decade. The first publications focusing on non-native ascidians in Greek waters concerned the species *Phallusia nigra* Savigny, 1816 and *Herdmania momus* (Savigny, 1816), which were reported in Rodos and Kastellorizo islands, respectively (Kondilatos et al. 2010; Gerovasileiou and Issaris in Katsanevakis et al. 2014). In the annotated checklist of Ascidiacea of Greece (Antoniadou et al. 2016), based on the Aegean ascidian checklist published by Koukouras et al. (1995), as well as data from literature published thereafter, the cryptogenic species *Ecteinascidia turbinata* Herdman, 1880 was reported from Greece by Monniot (1983). Recent changes in the alien/ cryptogenic status of several ascidian species made by Zenetos et al. (2017a) lead to the current inclusion of several species in the Greek list of NIS. These are the alien species *Ascidiella aspersa* (Müller, 1776), *Ciona robusta* Hoshino and Tokioka, 1967 [reported as *Ciona intestinalis* (Linnaeus, 1767)], *Diplosoma listerianum* (Milne Edwards, 1841), *Styela plicata* (Lesueur, 1823) and the cryptogenic species *Botryllus schlosseri* (Pallas, 1766) and *Clavelina lepadiformis* (Müller, 1776). The above species are considered established, as they were reported in Greek waters decades ago (e.g. Hartmeyer 1904; Pérès and Picard 1958; Koukouras and Siamidou-Efremidou 1978; Morri et al. 1999) but were recently reported again in marinas of Kriti and Rodos along with the alien species *Symplegma brakenhielmi* (Michaelsen, 1904) (Ulman et al. 2017; Ulman 2018). All ascidian species have established populations in the area. Taxonomic descriptions and/or photographic documentation are available for eight of the ten species (A. Ulman, pers. comm.).

The number of **echinoderm** species increases to three, with the addition of *Diadema setosum* (Leske, 1778) to the already listed (Pancucci-Papadopoulou et al. 2005b) *Ophiactis savignyi* (Müller and Troschel, 1842) and *Synaptula reciprocans* (Forsskål, 1775). The alien sea urchin *Diadema setosum* (Leske, 1778), which was first recorded in Kastellorizo (Latsoudis in Tsiamis et al. 2015) is already established in the south-eastern Aegean (Dounas and Krystalas in Mytilineou et al. 2016).

Additional invertebrate taxa: The current list includes one sponge (*Paraleucilla magna* Klautau, Monteiro Borojevic, 2004) and the hydrozoan *Sertularia marginata* (Kirchenpauer, 1864). The only alien sponge known so far from the Mediterranean Sea, the calcarean *P. magna,* was found in a mussel farm in the Gulf of Thessaloniki (north Aegean) in 2014, where high abundance and coverage was noted (Azevedo et al. in Gerovasileiou et al. 2017). More recently, this species was reported in the marinas of Heraklion and Agios Nikolaos in Kriti and in Mandraki Port, Rodos (Ulman et al. 2017; Ulman 2018). The hydroid *S. marginata* was discovered in 1990 in Paros island and deposited in the Natural History Museum of Geneva (HNG-INVE-29463) (González-Duarte et al. 2013), but was not reported in earlier lists of Greek aliens. Morri et al. (2009) considered a possible introduction through the Strait of Gibraltar, while its mode of introduction in the eastern Mediterranean by vessels is speculated. Interesting is the occurrence of the jellyfish *Pelagia benovici* Piraino et al., 2014 in the North Ionian. Over the weekend of June 2018 (June 29th–July, 1st), a dense jellyfish population emerged at the entrance of the Igoumenitsa Bay (Ionian Sea) (Anastasiadis and Piraino in Chartosia et al. 2018).

The sipunculan *Aspidoshiphon mexicanus* that was hitherto reported as alien (Zenetos et al. 2009) was moved to cryptogenics.

No changes/additions were made to the remaining invertebrate taxa (i.e. Protista, Ctenophora).

The most recent alien **fish** recorded in Greek Seas detected in 2017 are the Red Sea goatfish *Parupeneus forsskali* (Fourmanoir and Guézé, 1976), observed in the waters of Rodos Island (Kondylatos and Corsini-Foka in Stamouli et al. 2017) and the Scissortail Sergeant *Abudefduf sexfasciatus* (Lacepède, 1801) and the Sohal Surgeonfish *Acanthurus sohal* (Forsskål, 1775) observed in Saronikos and Kalymnos respectively (Giovos et al. 2018). Twenty-five of the Indo-Pacific/Red Sea fishes appear to be established, with four of them exhibiting invasive behaviour. These are: *Fistularia commersonii* Rüppell, 1838, *Lagocephalus sceleratus* (Gmelin, 1789), *Siganus luridus* (Rüppell, 1829) and *Siganus rivulatus* Forsskål and Niebuhr, 1775. Two species, namely *Sphyraena chrysotaenia* Klunzinger, 1884 and *Torquigener flavimaculosus* Hardy and Randall, 1983 exhibit a fast population expansion in the southern Aegean, and constitute significant portion of the fish catches (Corsini-Foka et al. 2018) but further studies are pending to document their invasive character. Eight species are reported as casual records. No information on the occurrence of the Lessepsian fishes *Equulites klunzingeri* (Steindachner, 1898), *Parexocoetus mento* (Valenciennes, 1847) and *Saurida lessepsianus* Russell, Golani and Tikochinski, 2015 in Greek seas has been collected during the past 30 years at least (see Papaconstantinou 2014). The single juvenile of the

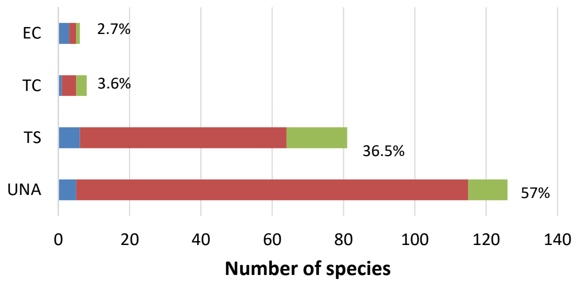

Figure 1. Number of alien species reported in the Greek Sea by pathway of introduction. UNA = Unaided, TS = Transport-Stowaway. TC = Transport contaminant, EC = Escape from Confinement.

Indo-West Pacific fish *Lutjanus sebae* (Cuvier, 1816) reported from the Saronikos Gulf, south-western Aegean Sea, was seemingly released by an aquarium hobbyist (Zenetos et al. 2016). The absence of records of *Abudefduf sexfasciatus* and *Acanthurus sohal* from areas close to the Suez Canal suggest that both observations are the result of aquarium intentional releases, rather than a Lessepsian migration (Giovos et al. 2018).

The Indo-Pacific native mullet, *Planiliza haematocheila* (Temminck and Schlegel, 1845), was reared in Black Sea cage fish farms. Many of these farms collapsed in the 1990s and specimens were carelessly released in the Azov and Black Sea areas. Soon after, the species was observed in the Turkish Aegean Sea and the Thracian Sea, Northern Aegean. Actually, it is fished in various lagoons in Macedonia and Thrace, Northern Greece, and appears frequently in the local fish markets (Corsini-Foka and Economidis 2007; Minos et al. 2010).

In Appendix 2, Table 2 three recent records namely *Acanthurus monroviae* Steindachner, 1876, found in the south-western Aegean waters (Batjakas et al. 2015); *Plectorhinchus gaterinus* (Forsskål, 1775), detected in the cold north Aegean waters Corsini-Foka and Sarlis 2016), and *Lagocephalus spadiceus* (Richardson, 1845) collected from South Kriti (Kiparissis et al. 2018) are included as debatable. Although their origin is known their presence cannot be attributed to a pathway. *Acanthurus monroviae* is of eastern Atlantic origin and its presence could be due to natural range expansion or intentional release from an aquarium. *Plectorhinchus gaterinus* is of West Indian Ocean origin and its presence should be considered with some reservation for two reasons: the unusual detection of the species of 10 cm as a prey item of a medium sized cephalopod, and the place of its detection i.e., a marine region that is considered quite inhospitable to alien fish native to tropical environment. Finally, although the presence of *L. spadiceus* has been verified by molecular studies, it cannot be classified as Lessepsian (as suggested by Kiparissis et al. 2018) because it is absent from the Red Sea. Further studies are needed to confirm whether *L. spadiceus* occurs in the Red Sea (Matsuura et al. 2011).

Among the latest records is that of a **cetacean,** the Indian Ocean humpback dolphin, *Sousa plumbea* (G. Cuvier, 1829), which was sighted near the port of Heraklion, Kriti, Greece (Frantzis 2018).

C. Pathways of introduction

It is vital that uncertainties in pathway assessments are transparent by providing an estimate of the related confidence and highlighting possibilities for alternative pathways (Essl et al. 2015; Katsanevakis and Moustakas 2018). The present work attempts to quantify uncertainties in the mode of introduction of NIS in Greek waters.

An analysis of the primary pathways of introduction in Greek waters, considering only true aliens, (Appendix 2, Table 1, Figure 1) revealed that high certainty of pathway/vector could be assigned for only 15 species (6.4%), while for most species the certainty was medium (uncertainty level 2). For 8 species, no pathway could be allocated with certainty.

Unaided spread accounted for 57% of the introduction events. Indeed, natural dispersal of established alien species in the Levantine Sea that have been introduced through the Suez Canal (Lessepsian immigrants) appeared to be the main introduction pathway for Greek NIS. However, only in five cases of Lessepsian species did the confidence level score highest. For another 110 species, the confidence in assigning this pathway scored high (uncertainty category 2), because it was the most plausible one although evidence from direct observation is lacking. Finally, for 11 cases, the "Uncertainty Category" scored 3, because other vectors may also be responsible for introduction.

Among the taxa introduced via the Suez Canal, which spread further to Greek waters, fishes were the protagonist group with a total of 36 species, followed by crustaceans (25 species) and molluscs (23 species). Transport-Stowaway accounted for 36.7% of all introductions (81 species). However, this could be inferred with certainty for only six species (< 10%), which were detected both on ship hulls and in the wild in port areas. For the vast majority, the pathway was assumed based on either the location (e.g. port, marina), and/or habitat preference (i.e. fouling species).

The precise vector (e.g. ballast waters, hull fouling, or angling fishing) was undefined for approximately

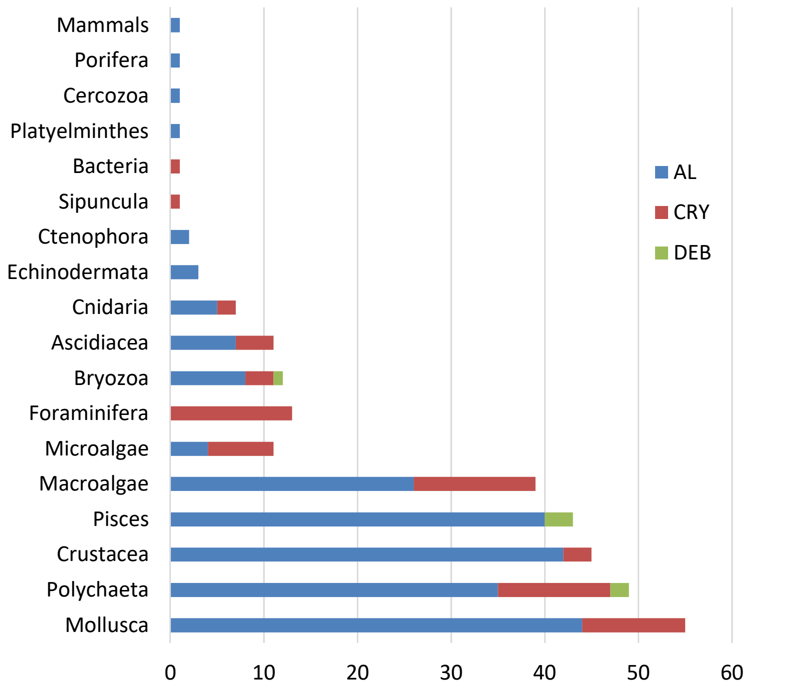

Figure 2. Number of alien (AL), cryptogenic (CRY), and debatable (DEB) species per group as of May 2018.

20% of the cases among which many molluscs and isopods, while in 13.5% of cases, hull fouling was assumed to be the most plausible vector. This applied mostly to fouling species such as serpulid polychaetes (eight species), bryozoans (seven species), macroalgae (five species) and ascidians (four species). Finally, angling and fishing were considered responsible for the transfer of seven macroalgae (3.1%).

In addition to the hull fouling species, the highest confidence in the mode of introduction was attributed to intentionally imported species that were either released into the wild (two cases) or escaped (two cases).

D. Overall assessment

Most studies of marine invasions are plagued by uncertainties, which in most cases are totally ignored or (if acknowledged) are not properly addressed or quantified (Katsanevakis and Moustakas 2018).

Considering the recent additions and exclusions of 58 species (Appendix 1), the overall number of introduced species (alien, cryptogenic, debatable) in Greek waters amounts to 297 species. Most of them are true aliens (221 species: Appendix 2 – Table 1), followed by cryptogenic (70 species: Appendix 2 – Table 2) and debatable cases (6 species: Appendix 2 – Table 2). Their distribution per taxonomic group is illustrated in Figure 2. The taxa making up approximately 80% of NIS diversity are, in decreasing order, Mollusca, Polychaeta, Crustacea, Fishes and Macroalgae. This figure is similar to that estimated for alien species across the Mediterranean Sea (Zenetos et al. 2010). At Pan-European level the ranking of the taxa composition of all non-indigenous species was very similar to the Mediterranean one with Mollusca first followed by Crustacea and fishes (Katsanevakis et al. 2013a). Crustacea constitute an exception, ranking 3rd in Greece versus 2nd in the Mediterranean. This can be attributed to limited studies in Greece on crustacean groups other than Decapoda.

Of the 297 introduced species, approximately 254 are validated. The non-validated records belong to: a) cryptogenic and debatable species listed in checklists (e.g. *Nototeredo norvagica* (Spengler, 1792) (see Roch 1940); *Xylophaga dorsalis* (Turton, 1819) (see Jeffreys 1883); b) records of common species such as *Ascidiella aspersa* (Müller, 1776), *Botryllus schlosseri* (Pallas, 1766) and *Teredo navalis* Linnaeus, 1758, for which it was not deemed necessary to illustrate/describe them or report if they are deposited in a museum collection; c) records of microalgae and macroalgae not documented (eg *Pylaiella littoralis, Ceramium strobiliforme)* not documented; d) recent additions of species reported originally in grey literature sources.

A comparison with previous works is presented in Figure 3. An increase is clear for most taxonomic groups. The seemingly steady number in introduced fish since 2011 is an artefact due to the omission of

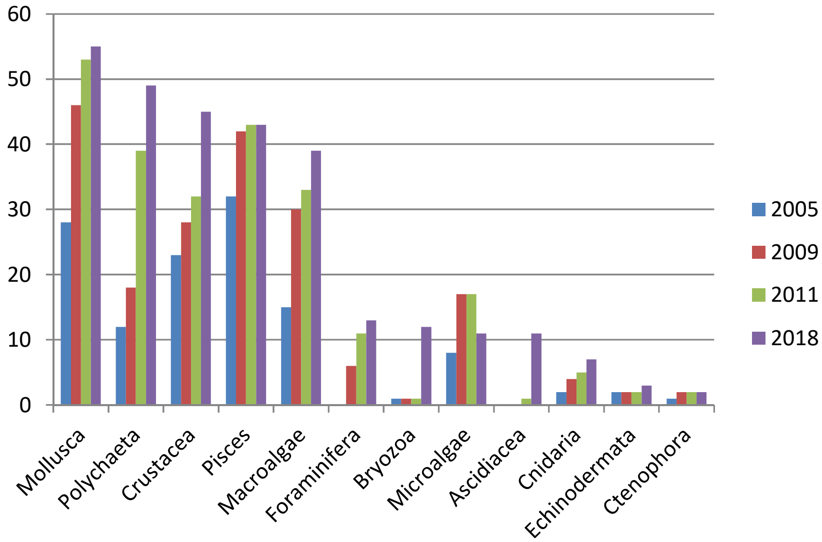

Figure 3. Diversity of introduced species in Greek Seas per taxonomic group. 2005 data set: based on Pancucci et al. 2005); 2009 data set: based on Zenetos et al. 2009; 2011 data set: based on Zenetos et al. 2011; 2018 data set: present study. Taxa with only one representative (Sipuncula, Porifera, Cercozoa, Tracheophyta, Mammalia) are not shown.

10 species (see Appendix 1). On the contrary, the exclusion of nine polychaete species was compensated by the addition of 19 new species. Similarly, the omission of five crustacean species was covered by the addition of 18 new species, belonging mostly to Peracarida. The increase of NIS diversity in terms of Bryozoa (from 1 to 12 species) is noteworthy, while a significant increase of ascidian NIS records from the Greek Seas is noted within the last decade. To date, seven alien and four cryptogenic ascidians have been reported from Greek waters, representing 13% of the Ascidiacea of Greece (Antoniadou et al. 2016).

Summing up, of the 221 alien species in Greek Seas 55 are based on casual records while 148 have established populations, Of the latter 17 species are classified as invasive. Of the 70 cryptogenic species, 41 are established (among which 2 invasive) and 12 are known from casual records. The population status of the rest remains unknown or is questioned.

Conclusively, among those species whose presence in the Greek Seas is not questionable, 214 species are aliens and 62 are cryptogenic.

E. Species expected to arrive in the near future (HORIZON SCANNING)

The European Union (EU) has published the Regulation 1143/2014 on Invasive Alien Species (IAS), which includes the IAS of Union concern. EU Member States are required to take action to prevent and mitigate the populations of the IAS of Union concern (European Commission 2014). No marine species are included yet in the Union concern list (with the exception of the brackish species *Eriocheir sinensis*), but the list has a dynamic character and several marine species might be included in the near future. Horizon scanning is seen as critical to identify the most threatening potential NIS that do not yet occur in an area, but are likely to arrive, establish and impact biodiversity and human health, and be risk-assessed for future listing in EU Regulation (European Commission 2014). A need for establishing a horizon scanning for marine NIS at Mediterranean and national scale is among the tasks scheduled within the MEDCIS project (http://medcis.eu).

Although no Horizon scanning has been carried out at Mediterranean level (see Roy et al. 2015), in a recent work covering the marine NIS in South-East Europe, Karachle et al. (2017) identified more than 45 species as still expected in Greece. The groups with the highest numbers of expected species were Ascidiacea (eight species), Decapoda and Annelida (seven species each). The ten most likely species to arrive were (in taxonomic order): the macroalgae *Codium parvulum* (Bory de Saint Vincent ex Audouin) P.C.Silva, and *Galaxaura rugosa* (J.Ellis and Solander) J.V.Lamouroux; the hydrozoan *Macrorhynchia philippina* Kirchenpauer, 1872; the polychaete *Leodice antennata* Savigny in Lamarck, 1818; the decapods *Metapenaeus stebbingi* Nobili, 1904 and *Matuta victor* (Fabricius, 1781); the ascidian *Ecteinascidia thurstoni* Herdman, 1890; the fishes *Decapterus russelli* (Rüppell, 1830), *Jaydia smithi* Kotthaus, 1970 and *Plotosus lineatus* (Thunberg, 1787). Of these, *Matuta victor* made its appearance on 3rd July 2018 in Rhodes island (Kondylatos et al. 2018).

When taking into account the higher number of alien Mollusca already recorded from Turkey, as well as the fact that rocky habitats are still understudied in Greece, future surveys may easily reveal the occurrence of additional alien species already common in the neighbouring country, of which *Finella pupoides* A. Adams, 1860, *Rissoina bertholleti* Issel, 1869, *Zafra savignyi* (Moazzo, 1939) and *Zafra selasphora* (Melvil and Standen, 1901) should be mentioned.

Increasingly accurate surveys may reveal the occurrence of some species of crabs already reported from the Aegean coasts of Turkey, such as *Eurycarcinus integrifrons* de Man, 1879 (see Doğan et al. 2016) and *Micippa thalia* (Herbst, 1803) (Galil et al. 2017), while the occurrence of other species detected along the south-eastern coast of Turkey, such as *Actaea savignii* (H. Milne Edwards, 1834) and *Ashtoret lunaris* (Forskål, 1775) (see Galil et al. 2017), could be expected sooner or later in the south-eastern Aegean waters of Greece. Constant monitoring of commercial prawn fishery in eastern and southern Aegean waters and/or dedicated scientific surveys could be helpful in improving knowledge on the occurrence of alien shrimps already detected along the Aegean coasts of Turkey, some of which appear abundant, such as *Metapenaeus affinis* (H. Milne Edwards, 1837) (Bakir and Aydin, 2016).

In the south-eastern Aegean waters of Turkey, 40 Lessepsian fish species have been recorded to-date (Bilecenoğlu et al. 2014; Akyol and Ünal 2016; Yapici et al. 2016; Yapici and Filiz in Stamouli et al. 2017) 29 of which are the same as those found in the adjacent Aegean waters of Greece (Papaconstantinou 2014; Corsini-Foka et al. 2015; Kondylatos et al. 2016; Kondylatos and Corsini-Foka in Stamouli et al. 2017). In addition to the aforementioned fish, other species could be expected, in particular *Nemipterus randalli* Russell, 1986, well-established along the Aegean coasts of Turkey.

Intensification of underwater observations by citizen scientists (see Giovos et al. 2018; Manousis et al. 2018), mainly in the extremely diversified rocky habitats of the Aegean islands, will probably reveal a wider distribution of alien species than have been known to date. Furthermore, collaboration between ELNAIS and other ongoing initiatives aiming to catalogue Greek biodiversity by a network of Greek and international taxonomists, such as the Greek Taxon Information System (Bailly et al. 2016), is expected to cover potential bias related to underestimations for understudied taxa (e.g. various invertebrate groups) whose records are largely based on old and possibly overlooked literature sources.

Ideally, a thorough re-examination of the original material would be necessary for those taxa whose records are based on old publications and which are not accompanied by taxonomic descriptions and/or photographic evidence. Further research in understudied habitats (e.g. lower sublittoral hard substrates, marine caves), typically species-rich in particular invertebrate taxa (e.g. bryozoans, ascidians) is also expected to reveal additional non-indigenous species.

The current review and analysis can serve as a basis which could greatly benefit from: (a) coordination and harmonization of monitoring surveys in association with other international and regional projects; (b) rapid assessment surveys: monitoring at hot spot areas (locations at high risk for the introduction of NIS), such as ports, marinas and aquaculture sites; and (c) contribution of validated citizen science data: development of citizen science networks and networks of taxonomic experts (see INVASIVENET: Lucy et al. 2016, EASIN Editorial Board; Tsiamis et al. 2016).

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Supplementary material

The following supplementary material is available for this article:

Appendix 1. List of excluded NIS reported in previous works

Appendix 2. List of alien and cryptogenic species

This material is available as part of online article from:
http://www.reabic.net/journals/mbi/2018/Supplements/MBI_2018_Zenetos_etal_Appendix1.xlsx
http://www.reabic.net/journals/mbi/2018/Supplements/MBI_2018_Zenetos_etal_Appendix2.xlsx