Brief History of Bioinvasion Research in the Mediterranean Sea

The eminent European marine naturalists of the sixteenth century – Belon, Rondelet, Salviani, Gesner and Aldrovandi – recorded solely species native to the Mediterranean Sea, though mercantile horizons have already expanded with geographical discoveries and shipping was no longer confined to European seas.

Ulisse Aldrovandi
Born: 11 September 1522, Bologna
Died: 4 May 1605 (aged 82), Bologna
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The Suez Canal is an artificial sea-level waterway in Egypt, connecting the Mediterranean Sea to the Red Sea through the Isthmus of Suez. After 10 years of construction, it was officially opened on November 17, 1869.

Keller (1883, 1888), a professor of Zoology in Zurich, traveled to Egypt in 1882 and 1886 and identified 10 Mediterranean species and 17 Red Sea species from the Canal itself, 5 Mediterranean species in the Red Sea, and 4 Red Sea species in the Mediterranean. Doubts had been raised concerning some of his identifications, as well as his sources, however, the importance of his work lies in confirming the role of the canal as a ‘corridor’ for the movement of species and in the transformation of the adjacent marine biotas.
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At the same time ship fouling too was recognized as a vector for introduction of marine alien species: in 1873 the three-masted *Karikal* arrived at the port of Marseille from India carrying on its hull a small forest of “living beings” (Catta 1876). Catta, with farsighted acumen, warned of faunal changes stemming from ship-transported organisms.
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In fact, fouling serpulid polychaetes were already identified as the first alien species in the Mediterranean: *Hydroides dianthus* (Verrill, 1873) was documented in the port of Izmir as early as 1865, and *H. dirampha* Mörch, 1863 and *H. elegans* Haswell, 1883 were recorded in the harbour of Naples in 1870 and 1888, respectively (Carus 1889; Zibrowius 1973).
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By the 1970s 140 alien species were known to have crossed the Suez Canal into the Mediterranean (Steinitz 1970) and it was perceived that the littoral biota of the Levantine sea has been undergoing a rapid and profound change (Holthuis 1961; George and Athanassiou 1967; Geldiay and Kocatas 1968; Por 1978; Galil and Lewinshon 1981).

The European Commission Environmental Programme and the Mediterranean Science Commission (CIESM) organized a workshop on “Introduced species in European coastal waters” (Boudouresque et al. 1994), followed by workshops entitled “Ship-transported alien species in the Mediterranean and Black Sea” and “Impact of mariculture on Mediterranean coastal ecosystems” (www.ciesm.org), and a widely acclaimed illustrated atlas provided information on alien fish, decapod crustaceans, mollusks and macrophytes in the Mediterranean (www.ciesm.org/atlas).
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‘Alien’ and ‘Invasive’ – Which and Where

Alien species (= Introduced species): a species that is transported intentionally or accidentally by a human-mediated vector into habitats outside its native range; it could not occupy that habitats without direct or indirect introduction or care by humans [International Council for the Exploration of the Sea (ICES); International Union for Conservation of Nature (IUCN)].

Invasive species: an alien species which maintains itself and spreads beyond its point of introduction, without assumption as to adverse environmental or economic impact.
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in the Mediterranean Sea

and present challenges. Springer, Dordrecht, p 463-478]

‘Alien’ and ‘Invasive’ – Which and Where

680 multicellular species are recognized as aliens in the Mediterranean Sea.

Molluscs (31 %), crustaceans (17 %) and bony fish (16 %) make the largest contributions to the
number of documented alien species in the Mediterranean and comprise 64 % of total alien
species richness in the sea (Galil 2012). Macrophytes (14 %), annelid polychaetes (9 %), bryo-
zoans and cnidarians (each 3 %), and all other taxa (7 %) complete the number.

The great majority of these are littoral benthic or demersal species.

The record grossly underestimates the total number of alien species. The magnitude of
the gap is difficult to assess and differs among taxa, locations and habitats as research efforts
vary greatly along the coasts of the Mediterranean. Data is entirely absent for many of the
small-sized invertebrate phyla because of limited search effort and erosion of taxonomic
expertise.
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‘Alien’ and ‘Invasive’ – Which and Where

The alien unicellular biota is nearly entirely invisible though it is well established that anthropic dispersal and redistribution of propagules in ballast water and sediments and shellfish transplantation facilitate range expansions not only of harmful algal blooms (HABs) causatives and other microalgae, but of other microbial components as well, including viruses, bacteria, etc. (Hallegraeff and Bolch 1992; Pierce et al. 1997; Galil and Hülsmann 1997; Smayda 2007).
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‘Alien’ and ‘Invasive’ – Which and Where

There are considerable differences among the peri-Mediterranean countries in the number of alien species recorded (Galil 2012).

Far more alien species have been documented in the Levantine Basin than the entire western Mediterranean: 346 multicellular alien species were reported along the 180 km long coast of Israel (1.92 species per km), whereas only 56 alien species were reported off the 1,660 km long Mediterranean coast of peninsular Spain (0.03 species per km).

And whereas most of the alien species in the eastern Mediterranean have presumably entered through the Suez Canal, shipping and massive shellfish farming are the drivers in the western Mediterranean (Fig. 27.1).
Food Web Interactions of Alien and Native Fish

An analysis of the trophic level of alien species is essential for estimating their impact on native species through competition and predation.

To date, little information is available regarding the diet of most native and alien species in the Mediterranean, nor do we have solid information on their biomass. This gap is especially significant in the Levant, where aliens have been gradually replacing native species.

Fish are the only taxa for which sufficient and reliable information on the trophic level is available.
Metamorphoses: Bioinvasions in the Mediterranean Sea


Food Web Interactions of Alien and Native Fish

A comparison of alien and native species in the Mediterranean based on data extracted from FISHBASE (Froese and Pauly 2012a, b) revealed that the average trophic levels of native and alien fish species are similar.

The native herbivores are either small sized [e.g. *Scartella cristata* (Linnaeus, 1758), *Parablennius sanguinolentus* (Pallas, 1811) and *Parablennius gattorugine* (Brünnich, 1768)] of negligible biomass (Goren and Galil 2001) or relatively rare [e.g. *Sarpa salpa* (Linnaeus 1758)], while the two alien herbivores, *Siganus rivulatus* Forsskål, 1775 and *S. luridus* (Rüppell, 1829) comprise about one third of the fish biomass in shallow rocky habitats, impacting the local macrophytes and food web (Goren and Galil 2001; Lundberg et al. 2004).
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Sala et al. (2011) who studied the impact of the two siganids (Siganus rivulatus and S. luridus) on the Mediterranean coast of Turkey, where they comprise 46–57 % of the total fish biomass in rocky habitats, found they outcompeted native sea urchins, denuded rocky ledges from their algal cover and formed extensive “barrens”.

Siganus rivulatus; Osteichthyes, Actinopterygii, Perciformes, Siganidae, Siganus

Siganus luridus; Osteichthyes, Actinopterygii, Perciformes, Siganidae, Siganus
Alien Jellyfish and Comb Jellies in the Mediterranean

Periodic outbreaks of indigenous scyphozoan jellyfish have long been noted in the Mediterranean (UNEP 1991; CIESM 2001).

Various anthropogenic perturbations including eutrophication, overfishing, global warming and the increase of littoral man-made hard substrates have been suggested as contributing to the proliferation of jellyfish populations in recent decades (CIESM 2001; Daskalov et al. 2007; Purcell 2007, 2012; Richardson et al. 2009; Riisgard et al. 2012).

But whereas most jellyfish outbreaks in the western and central Mediterranean consist of native species, alien species have taken over in the eastern part of the sea.
Alien Jellyfish and Comb Jellies in the Mediterranean

The SE Levant is unique in hosting four alien scyphozoan jellyfish concurrently, in addition to two alien ctenophores (Fig. 27.3).

Fig. 27.3 Gelatinous alien species in the Mediterranean Sea, with distribution maps and date of first record per country. From top: Phyllorhiza punctata Lendenfeld, 1884, Rhopilema nomadica Galil, 1990, Cassiopea andromeda (Forsskål, 1775), Marivagia stellata Galil & Gershwin, 2010, Mnemiopsis leidyi A. Agassiz, 1865, Beroe ovata Bruguière, 1789 (Photos by IOLR, R. Gevili, G. Paz, G. Rilov, S. Shafi (After Galil 2012)
Alien Jellyfish and Comb Jellies in the Mediterranean

The Erythraean *Rhopilema nomadica* Galil, 1990, first recorded in the Mediterranean in the early 1970s, is notorious for the swarms it has formed each summer since the early 1980s along the SE Levantine coast (Galil et al. 1990). *Rhopilema* swarms adversely affect tourism, fisheries and coastal installations. The annual swarming results each year in envenomation victims suffering adverse effects that may last weeks and even months after the event (Benmeir et al. 1990; Silfen et al. 2003; Yoffe and Baruchin 2004; Sendovski et al. 2005). Coastal trawling and purse-seine fishing are disrupted for the duration of the swarming due to net clogging and inability to sort yield. Jellyfish-blocked water intake pipes pose a threat to desalination plants and seawater cooling systems of coastal power plants: in the summer of 2011 Israel Electric removed tons of jellyfish from its seawater intake pipes at its largest power plants (Fig. 27.4).

Fig. 27.4  *Rhopilema nomadica* Galil, 1990. Jellyfish removed from blocked seawater cooling systems of a coastal power plant, Israel, summer 2011
Metamorphoses: Bioinvasions in the Mediterranean Sea


Alien Jellyfish and Comb Jellies in the Mediterranean

The comb jelly *Mnemiopsis leidyi* A. Agassiz, 1865, indigenous in western Atlantic coastal waters (40°N to 46°S), has spread in the past three decades to the Black, Caspian, Baltic and North seas (Mianzan 1999; Shiganova et al. 2001a, b; Javidpour et al. 2006; Faasse et al. 2006). The introduction of the zooplanktivorous *M. leidyi* to the Black Sea in the 1980s set in motion a dramatic chain of events that culminated in a crash of the sea’s major fishery and massive economic losses that garnered the species a slot on the International Union for Conservation of Nature (IUCN) list of 100 ‘World’s Worst’ invaders (http://www.issg.org/ worst100_species.html).
Alien Jellyfish and Comb Jellies in the Mediterranean

Given the severe ecological and economical harm elsewhere, the introduction of *M. leidyi* into the Mediterranean is of major concern.

It was first recorded in the Mediterranean Sea in 1990 in the western Aegean Sea presumably swept with the outflow of the Black Sea water masses (Shiganova et al. 2001b), shortly thereafter off Turkey's Aegean and Mediterranean coasts (Uysal and Mutlu 1993; Kideys and Niermann 1994) and off the Syrian coast (Shiganova 1997). As all those locales are in the vicinity of ports, and no population persisted long, it was suggested that it had been introduced with ballast water (Shiganova et al. 2001b).

Its presence in the Bay of Piran, northern Adriatic Sea (Shiganova and Malej 2009) too was presumably caused by “... ballast water originating from the Black Sea, as there is direct connection between the Port of Koper and various Black Sea ports” (Shiganova and Malej 2009).

Suddenly, in 2009, large swarms appeared along the Ligurian, Tyrrenian, and Ionian shores of Italy, the Mediterranean coast of Spain including the Balearic Islands and the SE Levant (Boero et al. 2009; Fuentes et al. 2009; Galil et al. 2009).

Since January 2009 swarms of *M. leidyi* have been intermittently observed along the Israeli coast, where summer SST tops 30 °C.
Metamorphoses: Bioinvasions in the Mediterranean Sea


Metamorphoses: The changing of the Mediterranean Littoral

Alien macrophytes, invertebrates and fish – all of 680 species that have been recorded in the Mediterranean Sea (Galil 2012) – are found in most littoral habitats, forming some prominent micro-communities (sensu Last et al. 2010).

It is believed that engineering and keystone invasive aliens cause major changes in community composition and structure and alter ecosystem processes over spatial and temporal scales and a wide range of impacts (Ehrenfeld 2011).

A large minority of established invasive aliens (as much as 30 %; ≈ 40 species) are highly disruptive and affect ecosystem functions substantially (Strayer 2010; Simberloff 2011).
Metamorphoses: The changing of the Mediterranean Littoral

Physical alteration is the most frequently recorded pathways of ecosystem change, either through substantial change in species population size and density, or through structural conversion of the physical character of the habitat (Crooks 2002; Simberloff 2011; Strayer and Hillebrand 2012).

Few examples of invasive aliens that can cause discernible and sometimes dramatic physical alterations to habitats in the Mediterranean Sea are reported in Fig. 27.5.

**Fig. 27.5** Invasive alien species in the Mediterranean Sea, with distribution maps. From top: *Caulerpa taxifolia* (Vahl) C. Agardh, *Caulerpa racemosa* var. *cylindracea* (Sonder) Verlaque, Huisman and Boudouresque, *Womersleyella setacea* (Hollenberg) R.E.Norris 1992, *Ficopomatus enigmaticus* (Fauvel, 1923), *Brachidontes pharaonis* (Fischer P., 1870), *Siganus rivulatus* Forsskål, 1775.
Metamorphoses: The changing of the Mediterranean Littoral

An invasive Australian strain of the tropical alga *Caulerpa taxifolia*, unintentionally introduced into the Mediterranean in 1984 with aquaria outflow (Jousson et al. 1998), has since spread to Spain, France, Italy, Croatia and Tunisia. Its propensity to form dense meadows on various infralittoral bottom types, especially in areas of elevated nutrient loads, led to formation of homogenized microhabitats. The alga’s dense clumps of rhizomes and stolons and the defensive secondary metabolites alter total species richness, density and biomass of resident biota. It is considered “a real threat for the balance of the marine coastal biodiversity” (Boudouresque et al. 1994; Verlaque and Fritayre 1994; Francour et al. 1995; Villele and Verlaque 1995; Ceccherelli and Cinelli 1999; Harmelin-Vivien et al. 1999; Levi and Francour 2004; Longpierre et al. 2005; Francour et al. 2009; Guillem et al. 2010).
Metamorphoses: Bioinvasions in the Mediterranean Sea


Metamorphoses: The changing of the Mediterranean Littoral

The extremely invasive *Caulerpa racemosa* var. *cylindracea*, was discovered in the Mediterranean in 1990, and has since spread from Cyprus to Spain. Its fast growing stolons allow it to overgrow other macroalgae, mainly turf and encrusting species, and to curtail species number, percent cover and diversity of the macroalgal community, even in highly diverse, native macroalgal assemblages with dense coverage. The drastic change in the composition of the phytobenthos brought about a modification of the macrobenthos and consequent ecosystem functioning. A study of the meiofauna revealed an increase in average density but a significant decrease of diversity, and profound change in the crustacean assemblage, where harpacticoid copepods proliferate at the expense of others (Argyrou et al. 1999; Carriglio et al. 2003; Verlaque et al. 2003; Piazzi et al. 2001, 2003; Klein and Verlaque 2008; Piazzi and Balata 2008; Baldacconi and Corriero 2009; Vazquez-Luis et al. 2009; Box et al. 2010; Deudero et al. 2011; Lorenti et al. 2011; Zuljevic et al. 2011).
Metamorphoses: Bioinvasions in the Mediterranean Sea


Metamorphoses: The changing of the Mediterranean Littoral

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Invasive alien species in the Mediterranean Sea, with distribution maps

Metamorphoses: Bioinvasions in the Mediterranean Sea


Metamorphoses: The changing of the Mediterranean Littoral

The invasive rhodophyte *Womersleyella setacea* (Rhodophyta; Florideophyceae, Ceramiales) was discovered in Italy in 1986, presumably introduced with vessel fouling. It forms thick, persistent carpets in deep sublittoral rocky substrata, causing substantial negative effects on native communities, modifying benthic assemblages and outcompeting gorgonians. It lowers values of diversity and causes significant differences in species composition and abundance. It is avoided by herbivorous fishes (Benedetti-Cecchi and Cinelli 1989; Verlaque 1994; Piazzi and Cinelli 2000; Piazzi et al. 2007; Antoniadou and Chintiroglou 2007; Tomas et al. 2011; Cebrian and Rodriguez-Prieto 2012).
Metamorphoses: The changing of the Mediterranean Littoral

The reef building serpulid worm *Ficopomatus enigmaticus* is found in brackish to hypersaline sheltered coasts, estuaries and lagoons. An engineering species, it forms extensive reefs - large, complex structures where no hard substrate had existed before. The structural conversion from flat soft-bottom to dimensionally complex dense tube colonies provide refuge for invertebrates (Bianchi and Morri 1996, 2001; Fornos et al. 1997; Ben Eliahu and Ten Hove 2011).
Metamorphoses: Bioinvasions in the Mediterranean Sea


Metamorphoses: The changing of the Mediterranean Littoral

The gregarious intertidal Erythraean mytilid bivalve *Brachidontes pharaonis* (Fischer P., 1870) is one of the earliest invasive aliens recorded in the Mediterranean. Where suitable conditions are present it forms extremely dense aggregations (1,000/m²) on natural and man-made hard substrates. It locally displaced the smaller-sized and thinner shelled native mytilid *Mytilaster minimus* (Fuchs 1878; Safriel et al. 1980; Safriel and Sasson-Frostig 1988; Rilov et al. 2002; Mienis 2003; Sara et al. 2006; Crocetta et al. 2009; Cilia and Deidun 2012).
Metamorphoses: Bioinvasions in the Mediterranean Sea


Metamorphoses: The changing of the Mediterranean Littoral

The herbivorous Erythraean rabbitfish *Siganus rivulatus*, first recorded in the Mediterranean in 1924, replaced native herbivorous fish along the Levant. It formed “barrens” in the rocky infralittoral dramatically reducing habitat complexity.

Invasive alien species in the Mediterranean Sea, with distribution maps

Two opposite state of Mediterranean rocky reefs: macroalgal forest (on the left) and barren (on the right) (From: CoNISMa. http://www.conisma.it/total/t_aim.html. Accessed 07/10/2016)
Propagule Pressure

“Propagule pressure” is recognized as the primary determinant of invasion success (Wonham et al. 2001; Verling et al. 2005; Von Holle and Simberloff 2005; Simberloff 2009).

Large inocula are more likely to lead to establishment and that the establishment chance increases with introduction frequency.

Large and recurring introductions enable nascent alien populations to overcome limitations associated with small population sizes, and weather adverse environmental or demographic events.

Recurring introductions of individuals from the same donor location into the same recipient location sustain nascent populations even if initial transfers were of insufficient size or badly timed (Lockwood et al. 2005; Roman and Darling 2007).
Metamorphoses: Bioinvasions in the Mediterranean Sea


Propagule Pressure

Of the three high propagule conveyances – shipping, mariculture, Suez Canal – the latter supplies the largest number of successfully established aliens in the eastern and central Mediterranean Sea by virtue of the magnitude, frequency, and duration of the trans-isthmian corridor invasion.
Propagule Pressure

The Suez Canal that opened in 1869 was 8 m deep, its cross section 304 m² (about 38 m width). Repeatedly deepened and widened, in 2014 it was 24 m deep and its cross section 5,200 m² (about 217 m width).

The Suez Canal Authority (SCA) further increased the Canal’s depth and width to double its capacity (from 49 to 97 ships a day) and to reduce transit time (www.suezcanal.gov.eg).
Propagule Pressure

The implications of a greater Suez Canal combined with higher through-current velocities on propagule pressure of Erythraean aliens are all too clear: increasing the delivery of multiple aliens/invaders, thus establishing an ever larger invasion in the Mediterranean Sea.