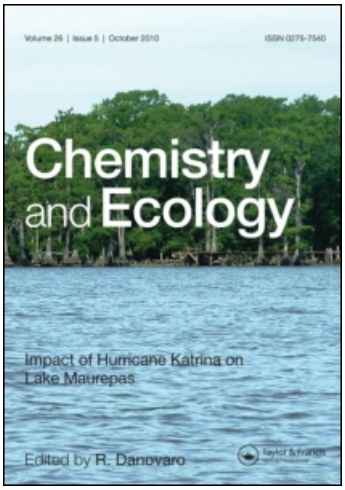

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Nonindigenous species along the Apulian coast, Italy

Cinzia Gravili[a]*, Genuario Belmonte[a], Ester Cecere[b], Francesco Denitto[a], Adriana Giangrande[a], Paolo Guidetti[a], Caterina Longo[c], Francesco Mastrototaro[c], Salvatore Moscatello[a], Antonella Petrocelli[b], Stefano Piraino[a], Antonio Terlizzi[a] and Ferdinando Boero[a]

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Thirty-eight nonindigenous marine species (NIS) (macroalgae, sponges, hydrozoans, molluscs, polychaetes, crustaceans, ascidiaceans and fish), are reported from the Apulian coast of Italy. Shipping, aquaculture and migration through the Suez Canal are the main pathways of introduction of the NIS. In Apulian waters, 21% of NIS are occasional, 18% are invasive and 61% are well-established. It is highly probable that more NIS will arrive from warm-water regions, because Mediterranean waters are warming. Furthermore, some of the successful NIS must have the ability to become dormant in order to survive adverse conditions, either seasonal or during long journeys in ballast waters. The identification of NIS depends greatly on the available taxonomic expertise; hence the paucity of taxonomists hinders our knowledge of NIS in our seas. We propose the creation and maintenance of a network of observatories across the Mediterranean to monitor the changes that take place along its coasts.

Keywords: nonindigenous species (NIS); transport vectors; Apulian coast; Mediterranean Sea

1. Introduction

The Mediterranean Sea is undergoing a sharp modification in its physical features, leading to changes in the composition of its biota, and stimulating the scientific community to forecast the potential ecological scenario of a tropicalised Mediterranean Sea to come [1] by reviewing and analysing the responses of the Mediterranean biota to global warming [2]. Changes in Mediterranean marine communities are detectable by comparative analyses of present-day taxonomic inventories with past floro-faunistic lists. The terminology used to define the zoogeographical status of any species is rather intricate and cumbersome, with a plethora of terms and definitions, often with intertwined meanings, all issued by authoritative sources that, subsequently, contradict each other. In the present article, indigenous species are those recorded from a given geographical area (in this case the Mediterranean Sea) over a significant length of time. We label nonindigenous species (NIS) those recorded only recently from the basin. Our interest,

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here, is to highlight the change in Apulian biota by listing all extramediterranean species (i.e. NIS) that are now present along the Apulian coast. Some have arrived as a result of direct or indirect human activity, crossing biogeographical barriers that might be almost insurmountable by their own means of dispersal; others arrived by expansion of their natural range, presumably because of newly established conditions that are conducive to their thriving. As used here, the term NIS includes species that fit the definition of *recent colonists* comprising species which, with or without direct human intervention, have extended their natural geographical range, with or without spatial discontinuities, *in recent (and short) time.* Human-mediated species introduction is one of the major factors adversely affecting biological diversity, and the introduction of NIS in aquatic habitats is a global phenomenon. In some cases, NIS can become invasive, with severe impact on the local biota [3]. One of the main pathways of introduction is transport by vessels, especially in ballast waters [4,5].

The success of introduced organisms depends on many factors, including their adaptability to new environments and survival under unfavourable conditions, linked to life-cycle features such as high reproductive potential and dispersal ability [6,7]. Polluted or physically degraded environments are more exposed to invasion than pristine ones [3]. Moreover, introduction can be facilitated by climate change, which affects many ecological properties, such as local dispersal mechanisms, and competitive interactions between NIS and native species [8].

In the present article, a comprehensive inventory of the nonindigenous aquatic, mainly marine, flora and fauna of the Apulian coast, Italy, is reported. Because of its geographical position, the region can be considered a crossroads between the western and eastern Mediterranean basins. This list includes macroalgae, sponges, hydrozoans, molluscs, polychaetes, crustaceans, ascidians and fish. The distribution of each NIS within the Mediterranean is provided.

2. Methods

This study is based on the records of aquatic NIS reported over the last 20 years from Apulian waters, taking into account both published and unpublished data. The distribution of each taxon was reconstructed through a literature review dating back to the early 1800s. According to their establishment success, NIS are classified into casual (few records), established (widely recorded at some sites) and invasive (able to disseminate from their area of initial introduction) [9]. Only the most recent references are cited.

2.1. *Native range, distribution in the Mediterranean Sea and worldwide distribution*

Although the precise origin of many Apulian NIS is not known, the geographic origin, including, where possible, both the type locality and the date of the first record, is given for each species. The geographical distribution in the Mediterranean Sea and worldwide is also reported in Table 1.

2.2. *Date and location of records*

The date and location of the first observation in the Mediterranean Sea were gleaned from the literature. The actual date of first collection, where possible, has been distinguished from the publication date. The date and location of the first observation along the Apulian coast are also reported.

Table 1. List of nonindigenous species (NIS) per group.

Taxon	Species	Native range	1st record in the Mediterranean Sea (date – location)	1st record along the Apulian coast (date – location)	Pathways of introduction	Status	Other records in the Mediterranean Sea	Distribution in the rest of the world	Main references
MACROALGAE									
Chlorophyta									
Bryopsidales, Caulerpaceae	*Caulerpa racemosa* (Forsskål) J. Agardli var. *cylindracea* (Sonder) Verlaque, Huisman *et* Boudouresque	Western Australia	1991 – Lybia	1996 – Mar Grande of Taranto (Ionian Sea)	U	I	Italy, Albania, Canary Islands, Corsica, Croatia, Cyprus, France, Greece, Lybia, Malta, Spain, Tunisia, Turkey	USA, Guadalupe, Mexico, Costa Rica, Panama, Bahamas, Barbados, Cuba, Jamaica, Antilles, Puerto Rico, Trinidad & Tobago, Virgin Islands, Brazil, Colombia, Venezuela, Kenya, Australia	[11,17–21,33,71,72]
Bryopsidales, Codiaceae	*Codium fragile* (Suringar) Hariot subsp. *fragile*	Japan	1946 – France	2001 – Mar Piccolo of Taranto (Ionian Sea)	A	C	Italy (Adriatic Sea), Algeria, Balearic Islands, Corsica, France, Morocco, Slovenia, Spain, Tunisia, Turkey	Alboran Island, Azores, Britain, Canary Islands, Ireland, USA, Canada, New Zealand, Australia, the Mediterranean	[11,15,60,71,72]
Ochrophyta									
Laminariales, Alariaceae	*Urndaria pinnatifida* (Harvey) Suringar	Japan	1981 – Thau Lagoon (France)	1998 – Mar Piccolo of Taranto (Ionian Sea)	A	E	Italy (Lagoon of Venice); Mar Piccolo	Britain, France, the Netherlands, Spain, USA, Mexico, Argentina, China, Japan, Korea, Russia, New Zealand, Australia, Tasmania	[9,11,14,15,60,71,72]

(*Continued*)

Table 1. Continued.

Taxon	Species	Native range	1st record in the Mediterranean Sea (date – location)	1st record along the Apulian coast (date – location)	Pathways of introduction	Status	Other records in the Mediterranean Sea	Distribution in the rest of the world	Main references
Rhodophyta									
Ceramiales, Rhodomelaceae	*Osmundea oederi* (Gunnerus) G. Furnari	Atlantic Ocean, North Sea	1987 – Mar Piccolo of Taranto (Apulia, Italy) as *O. truncata*	1st record in the Mediterranean Sea	U	E		Britain, France, Ireland, Helgoland, Norway as *O. ramosissima*	[23]
Ceramiales, Rhodomelaceae	*Womersleyella setacea* (Hollenberg) R.E. Norris	Hawaii Islands	1987 – Var (France) as *Polysiphonia setacea*	2001 – Mar Piccolo of Taranto (Ionian Sea)	U	C	Tyrrhenian Sea, Adriatic Sea, Alboran Sea, Balearic Islands, Corsica, France, Greece, Malta, Spain	Philippines, Fiji, Bermuda, Canary Islands, Maldives, Indonesia, Micronesia, Samoan Archipelago	[9,11,22,60,71,72]
Gigartinales, Hypneaceae	*Hypnea cornuta* (Kützing) J. Agardh	Guinea, Atlantic Ocean	1869 – Greece as *H. valentiae*	2000 – Mar Piccolo of Taranto (Ionian Sea)	U	E	Egypt, Israel	Bermuda, USA, Mexico, Belize, Cuba, Virgin Islands, Antilles, Colombia, Venezuela, Kenya, Mauritius, South Africa, Tanzania, Seychelles, Bahrain, Iran, Kuwait, Pakistan, Saudi Arabia, Yemen, China, Japan, Korea, Taiwan, Malaysia, Philippines, Vietnam, Australia, Fiji	[9,16,71,72]

Gigartinales, Solieriaceae	*Agardhiella subulata* (C. Agardh) Kraft *et* M.J. Wynne	Atlantic Ocean, western Canada	1987 – Mar Piccolo of Taranto (Apulia, Italy)	1st record in the Mediterranean Sea	U	E (disappeared)	Italy (Lagoon of Venice), Lake of Ganzirri (Sicily), France (Thau Lagoon)	USA, Carribean Sea, Bahamas, Barbados, Cuba, Jamaica, Puerto Rico, Trinidad & Tobago, Virgin Islands, India, Sri Lanka, Mauritius, Brazil, Colombia, Galapagos Islands, Venezuela, Senegal, the Netherlands, Korea	[9,13,14,71,72]
Gigartinales, Solieriaceae	*Solieria filiformis* (Kützing) P.W. Gabrielson	Antilles	1987 – Mar Piccolo of Taranto (Apulia, Italy) (already present in 1922 and misidentified as *Gracilaria confervoides*)	1st record in the Mediterranean Sea	U	E (disappeared)	Italy (Lagoon of Venice)	Britain, USA, Australia, Canary Islands, Cape Verde Islands, Cuba, Trinidad & Tobago, Brazil, Colombia, Venezuela, Gabon, Ghana, Mauritania, Senegal, Iran, Israel	[13,14,72]

(*Continued*)

Table 1. Continued.

Taxon	Species	Native range	1st record in the Mediterranean Sea (date – location)	1st record along the Apulian coast (date – location)	Pathways of introduction	Status	Other records in the Mediterranean Sea	Distribution in the rest of the world	Main references
Halymeniales, Halymeniaceae	*Grateloupia turuturu* Yamada	Japan	1984 – Thau Lagoon (France) as *G. doryphora*	2006 – Mar Piccolo of Taranto (Ionian Sea)	A	E	Lagoon of Venice as *G. doryphora*	Great Britain, France, the Netherlands, Portugal, Spain, Canary Islands, Angola, Cote d'lvoire, Gambia, Ghana, Liberia, Mauritania, Namibia, Senegal, China, Japan, Korea, Russia, Tasmania	[14]
PORIFERA									
Amphoriscidae	*Paraleucilla magna* Klautau *et al.*, 2004	Rio De Janeiro, Arraial do Cabo and Alcatrazes Archipelago - Brazil (Atlantic Ocean)	2001 – Mar Piccolo and Mar Grande of Taranto (Puglia, Italy)	1st record in the Mediterranean Sea	SF, A?	I	Mar Piccolo and Mar Grande of Taranto, Porto Cesareo, Brindisi (Puglia, Italy), Naples (Campania, Italy), Malta	Southern Brazil (Atlantic Ocean)	[24–26]
HYDROZOA									
Campanulariidae	*Clytia hummelincki* (Leloup, 1935)	West Indies, Caribbean Sea (Atlantic Ocean)	1996 – Copanello (Calabria, Italy)	1997 – Adriatic and Ionian Seas (Apulia)	SF	I	Dalmatian coast (Di Camillo 2002, pers. obs., unpubl.), Majorca Isle (Schuchert 2005, pers. obs., unpubl.), Adriatic and Ionian Seas (Apulia), Sardinia, Ponza (Naples), Portofino (Liguria)	Gulf of Mexico, South Africa, Papua New Guinea, Bonaire, the Netherlands Antilles (Bermuda), Brazil, North Sulawesi, Indonesia, Galapagos	[6,9,27,29,30,73]

Campanulariidae	*Clytia linearis* (Thornely, 1900)	New Britain (Papua New Guinea), Indo-Pacific	1924 – Suez Canal as *Clytia foxi*	1991 – Ionian coast (Boero, pers. obs., unpubl.)	L	I	French coast, Gulf of Genoa, Gulf of Naples, Spanish coast, Turkey, Greece, Isle of Ischia, Fregene, Latium, Tuscan Archipelago, Lebanese waters, Alboran Sea off the coast of Morocco, Aegean Sea, Ustica, Otranto (Apulia), Chafarinas Islands, South Mediterranean, Levant Sea, Adriatic and Ionian Apulian coasts	Tropical and subtropical waters of the Atlantic, Pacific and Indian Oceans, Red Sea	[27–29,31,34,73]
Clavidae	*Cordylophora caspia* (Pallas, 1771)	Caspian Sea	1936 – Alexandria (Egypt)	1988 – Palude del Capitano	A, SB	I	French coast, Italy (Fondi Lagoon, Latina, Po River Delta, Venice Lagoon)	Circumglobal in temperate and subtropical regions, usually in brackish waters such as in estuaries, river deltas and lagoons	[73,74]
Eudendriidae	*Eudendrium merulum* Watson, 1985	Clonmel Island, Bass Strait, Victoria, Australia (south-west Pacific)	1984 – Portofino (Ligurian Sea, Italy)	2004 – Otranto (between the Adriatic and the Ionian Seas)	U	E	Italy (Panarea, Palermo, Ustica, Gulf of Naples), Croatian coast, Aegean Sea, Sea of Marmara (Turkish coast), Chafarinas Islands, French coast (doubtful record), Levant Sea	Circumtropical	[27,34,73,75]

(*Continued*)

Table 1. Continued.

Taxon	Species	Native range	1st record in the Mediterranean Sea (date – location)	1st record along the Apulian coast (date – location)	Pathways of introduction	Status	Other records in the Mediterranean Sea	Distribution in the rest of the world	Main references
MOLLUSCA									
Aplysiidae	*Aplysia (Pruvotaplysia) parvula* Guilding in Moerch, 1863	Worldwide distribution in tropical to warm temperate waters	1970 – Malta and Sicily	2000 – Otranto (between the Adriatic and the Ionian Seas)	L	E	Malta and Sicily	Worldwide distribution in tropical to warm temperate waters	[9,76]
Aplysiidae	*Bursatella leachi* de Blainville, 1817	Red Sea	1940 – Israel	1973 – Taranto Sea (Ionian Sea)	L	E	Israel, Turkey, Malta, Sicily, Tunisia, Slovenia, Greece	Circumtropical distribution	[9,11,37,76]
Mytilidae	*Musculista senhousia* (Benson in Cantor, 1842)	Pacific Ocean	1989 – Western Mediterranean along the French coast	2001 – Taranto Sea (Ionian Sea)	A	E	Israel, French coast; Adriatic Sea, in the brackish lagoons of Ravenna, in the Sacca di Goro, Comacchio Bay, and in the Tyrrhenian Sea in the Gulf of Olbia	Western Pacific from Siberia to Singapore, NW America, Australia	[9,11,41,76]
Tethydidae	*Melibe viridis* (Kelaart, 1858)	Indian and Western Pacific Oceans	1970 – Bay of Argostoli, Cefalonia Island, northeastern Ionian Sea as *Melibe* sp.	1999 – Porto Cesareo (Ionian Sea)	L	E	Greece, Strait of Messina, Croatia and Taranto Seas	Indo-Pacific distribution from South Africa, East Africa, Australia, Philippines and Japan	[9,11,33,38–40,76]
POLYCHAETA									
Dorvilleidae	*Ophryotrocha japonica nomen nudum* (Pleijel & Eide, 1996)	Pacific Ocean, Asia	2000 – Ravenna (Adriatic Sea)	Mar Piccolo of Taranto (Ionian Sea)	SB	E		Asian and American coasts of the Pacific Ocean	[33,42]

Sabellidae	*Branchiomma luctuosum* Banse, 1870	Red Sea	1983 – Lago Lucrino (Tyrrhenian Sea)	Taranto	L	I	Italy [Ischia, Portici (Terlizzi, pers. comm.)]; Port of Salerno and Pozzuoli (Gambi, unpubl. data); Aegean Sea; Gulf of Taranto; Gulf of Valencia	Red Sea, East Atlantic (Martin, pers. comm.)	[33,43,46,77]
Sabellidae	*Fabriciola ghardaqa* Banse, 1959	Red Sea	1999 – Brindisi (Adriatic Sea)	1st record in the Mediterranean Sea	L	C	Israel	Red Sea, Israel	[33,43]
Sabellidae	*Megalomma claparedei* Gravier, 1908	Red Sea	2000 – South Adriatic Sea	1st record in the Mediterranean Sea	L	C	Majorca Isle (Schuchert, 2005, pers. obs., unpubl.)	Red Sea	[33,44]
Sabellidae	*Novafabricia infratorquata* Fitzhugh, 1983	Caribbean (Carrie Bow)	2000 – Otranto (between the Adriatic and the Ionian Seas)	1st record in the Mediterranean Sea	U	C	Ibiza	Atlantic Ocean, Carribean	[33,45]
CRUSTACEA									
Branchiopoda Anostraca									
Artemiidae	*Artemia franciscana* (Kellogg, 1906)	Redwood City, San Francisco Bay, California, USA	1985 – Algarve Province (Portugal)	2004 – Margherita di Savoia (FG) salterns	A, W	I	Portugal, Spain, Morocco (Laguna Mar Chica)	North America, Central and South America, Iran, Iraq, India, Pakistan, China, Japan, New Zealand, Australia, Kenya, Madagascar	[49–53]
Copepoda									
Acartiidae	*Acartia tonsa* Dana, 1849	Atlantic Ocean, via Baltic-Black Sea	1985 – Marseille (France)	2006 – Lesina lake (FG)	SB, AQ	E	Sacca di Scardovari (Italy), Cagliari harbor, Marmara Sea, Varano lake (Belmonte, pers. obs.)	Gulf of Mexico, Chile, North-West Atlantic, North-East Atlantic, North Sea, Baltic Sea, Black Sea	[47]

(*Continued*)

Table 1. Continued.

Taxon	Species	Native range	1st record in the Mediterranean Sea (date – location)	1st record along the Apulian coast (date – location)	Pathways of introduction	Status	Other records in the Mediterranean Sea	Distribution in the rest of the world	Main references
Acartiidae	*Paracartia grani* Sars, 1904	Atlantic Ocean, via Gibraltar	1984 – Malaga (Spain)	2009 – Varano lake (FG) (Belmonte, pers. obs.)	SB	E	Lebanon, Italy, Greece	North-East Atlantic, North Sea	[54]
Decapoda									
Calappidae	*Calappa pelii* Herklots, 1851	Eastern Atlantic	Alboran Sea, Chafarinas island in 1991 (Silvestre, pers. comm.)	Gulf of Taranto (Ionian Sea)	SF	C		Eastern Atlantic	[48,56]
Dromiidae	*Dromia spinirostris* Miers, 1881	Eastern Atlantic	Gulf of Taranto (Ionian Sea)	1st record in the Mediterranean Sea	SF	C		Tropical and subtropical East Atlantic, from Mauritana to Angola and Cape Verde Island	[48,56]
Majidae	*Herbstia nitida* Manning and Holthuis, 1981	Annobon Island, and other islands in the Gulf of Guinea	2002 – Grotta di Ciolo (Capo di Leuca, LE)	1st record in the Mediterranean Sea	G	E	Grotta di Ciolo (Capo di Leuca, LE)	Gulf of Guinea (Eastern Atlantic Ocean) and Mediterranean Sea	[48,57]
Penaeidae	*Marsupenaeus japonicum* (Bate, 1888)	Indo-West Pacific	1924 – Egypt as *Penaeus canaliculatus*	1985 – Offshore between Termoli and Varano	L, A	E	Syria, southern Turkey, Israel, Cyprus, France, Lebanon, Adriatic Sea, Greece, Rhodes Island, Greece, Ionian Sea – Amvrakikos Gulf, Aegean Sea – Vistonikos Gulf, Marmara Sea, Spain, Mar Menor (I. Arnol, pers. comm.)	Indo-Pacific, East Africa to Fiji	[48,78]

Plagusiidae	*Percnon gibbesi* (H. Milne Edwards, 1853)	Atlantic Ocean (California to Chile, Florida to Brazil, Madeira to Gulf of Guinea)	2000 – Linosa Island	2006 – Ciolo Bay (Capo di Leuca, LE) (Licchelli, pers. obs.)	G, SB	E	Balearic Islands, Sicily (Buzzurro, pers. comm., 2000), Pantelleria Island (Passamonti, pers. comm., 2000), Calabria (Gattelli, pers. comm., 2002), Central Tyrrhenian Sea, Eastern basin	Atlantic Ocean and Mediterranean Sea	[48,58]
Portunidae	*Callinectes sapidus* Rathbun, 1896	Atlantic Ocean	1949 – Venice (Italy) as *Neptunus pelagicus*	2006 – Ugento (LE)	SB	E	Israel, Greece, northern Aegean, southern Turkey, France, Egypt, Lebanon, Ligurian Sea, Central Adriatic Sea, Malta, Cyprus, Italy, Ionian Sea, Croatia	Western Atlantic, from Nova Scotia to Uruguay; recorded off the Atlantic coasts of Europe as early as 1900, from the Baltic Sea to Netherlands and France	[48,55]
ASCIDIACEA									
Holozoidae	*Distaplia bermudensis* Van Name, 1902	Western Atlantic Ocean (Bermuda)	2000 – Taranto Sea (Ionian Sea)	1st record in the Mediterranean Sea	SF, A?	E		Western Atlantic Ocean, Brazil, Caribbean, Guyana, Bermuda, Guadalupe	[62]

(*Continued*)

Table 1. Continued.

Taxon	Species	Native range	1st record in the Mediterranean Sea (date – location)	1st record along the Apulian coast (date – location)	Pathways of introduction	Status	Other records in the Mediterranean Sea	Distribution in the rest of the world	Main references
Styelidae	*Microcosmus squamiger* Hartmeyer & Michaelsen, 1928	Probably Australian origin	1963 – Bizerte (Tunisia) as *M. exasperatus*	1971 – Taranto Sea (Ionian Sea) as *M. exasperatus*	SF, A?	E	Italy (Genova harbour, Tyrrenean Sea, Savona, Imperia, Corsica, Magra river estuary, Taranto), Spanish coast, Gibraltar Strait	South Africa, Western Indian Ocean, Hawaii Islands, Southern California	[59,60]
Styelidae	*Polyandrocarpa zorritensis* (Van Name, 1931)	Pacific Ocean (Perù)	1974 – La Spezia (North Tyrrhenean Sea)	2001 – Taranto Sea (Ionian Sea)	SF, A?	E	Delta Ebro River (Spain)	Pacific Ocean, Japan, Atlantic, South California	[61]
PISCES									
Cichlidae	*Oreochromis niloticus niloticus* Linnaeus, 1758	African origin, native from Sudan into east Africa through the Congo to Liberia	1999 – Lesina Lagoon, Italy	1st record in the Mediterranean Sea	A	E	Israel, Egypt, Malta, France and Ex-Czechoslovakia	Africa: coastal rivers of Israel, Nile from below Albert Nile to the delta, Jebel Marra, in West Africa natural distribution covers the basins of the Niger, Benue, Volta, Gambia, Senegal and Chad	[68]

Fistulariidae	*Fistularia commersonii* Rüppel, 1835	Indo-Pacific and Eastern Central Pacific	2000 – off Ashdad-Jaffa (Israel)	2000 – Tricase Porto (Adriatic Sea)	L	E?	Aegean Sea (Greece), Anatolian Turkish coast, Tunisian coast, Italy (Sicilian waters, Northern Tyrrhenian Sea, Sardinia), Alboran Sea (Spain), Libian coast, Central and Southern Adriatic Sea (Croatia and Italy)	Indo-Pacific, from Red Sea and Last Africa to Rapa and Eastern Island, north to southern Japan, south to Australia and New Zealand, Eastern-Central Pacific, Mexico to Panama, including offshore islands	[63]
Tetraodontidae	*Sphoeroides marmoratus* (Lowe, 1839)	Eastern Atlantic Ocean	1977 – Gallipoli (Italy), but misclassified as *Lagocephalus lagocephalus*	1st record in the Mediterranean Sea	G	C	Spanish coast	Eastern Atlantic, form Portugal to Angola, and the Mediterranean Sea; specimens classified as *Sphoeroides splengleri* from the eastern Atlantic and Mediterranean Sea are likely to be misidentifications of *S. marmoratus*	[64–67]

Notes: *Pathway of introduction codes*: A, aquaculture; AQ, aquarium trade; G, range expansion through Gibraltar Strait; L, Lessepsian; SB, shipping ballast; SF, shipping fouling; U, unknown; W, dispersal by waterfowl. *Status codes*: C, casual; E, established; I, invasive.

2.3. *Pathways of introduction*

Possible pathways of introduction were tentatively identified, considering species' biology. Rarely, however, was the pathway established with certainty: even when stated, the mode of introduction is in most cases hypothetical.

3. Results

3.1. *Diversity of nonindigenous taxa along the Apulian coast*

Thirty-eight NIS are currently known along the Apulian coast. Macroalgae and crustaceans are represented by nine species each (23%), followed by five polychaetes (13%), four hydrozoans (11%), four molluscs (11%), three ascidians (8%), three fish (8%) and one sponge (3%) (Table 1).

3.2. *Macroalgae*

Marine macroalgae are among the most notorious NIS globally [10]. In the Mediterranean Sea, 84 species are considered to be new introductions [11]. Most records from the western basin are of temperate or warm–temperate species, native to Japan and the Pacific Ocean. They have most likely been inadvertently imported with Asian oysters. A smaller number of warm-water or tropical species entered through the Suez Canal, mostly inhabiting the eastern basin [12].

Nine species have been reported from the Apulian coast, mostly from Mar Piccolo, Taranto (Table 1). *Agardhiella subulata* and *Solieria filiformis* dominated the unattached algal populations in Mar Piccolo to the late 1990s [13]; a massive cultivation attempt, however, presumably led to their decline and they are currently absent [14]. *Codium fragile* subsp. *fragile*, reported as invasive worldwide, was observed twice in Mar Piccolo (July 2001 and 2002) [15]. *Undaria pinnatifida* was first recorded from Mar Piccolo in 1998, where its population increased until 2004, then declined, and it nearly disappeared in 2008. *Undaria* is native to Japanese cold waters, where it grows and reproduces best below 12–13 °C. The observed decline in Mar Piccolo was probably because of the increase in water temperature observed in recent years in winter months, a constraint that may have impaired regular gametophyte–sporophyte alternance and overall persistence in the new habitat [14,15]. In 2009, only a few immature thalli without sporophylls were observed (Cecere, pers. obs.).

Hypnea cornuta is also widespread in the Mar Piccolo of Taranto [16], whereas *Caulerpa racemosa* var. *cylindracea* (Figure 1) is widely distributed along the whole Apulian coast [17–20], where it caused a decline in the coverage reached by native benthic organisms [21]. *Womersleyella setacea* was also recorded from two localities in the Ionian Sea (Porto Cesareo and the Taranto coastal sounds), but it is not considered invasive [22]. *Grateloupia turuturu* was recorded in the Mar Piccolo of Taranto, with a population of increasing density [14].

The first record of *Osmundea oederi* in the Mediterranean Sea was also recently reported from the Gulf of Taranto [23]. Owing to the complexity of the taxonomy of the genus *Osmundea* and of the *Laurencia* complex in general, the occurrence of this species in the Mediterranean Sea may have been neglected so far, being confused with other *Osmundea* species belonging to Mediterranean seaweed communities [23]. In Mar Piccolo, it was collected in winter (December–March) at a depth of 0.5–1 m, close to the mouth of a small river (Cecere and Petrocelli, pers. obs.).

Figure 1. *Caulerpa racemosa* var. *cylindracea*. Scale bar: 1 cm.

Figure 2. *Paraleucilla magna*. Scale bar: 5 cm.

3.3. *Porifera*

In the Mediterranean Sea, the only sponge considered to be a NIS is the calcareous species *Paraleucilla magna* (Figure 2), reported from the southern Italian coasts (north-western Ionian Sea, southern Adriatic Sea), central Tyrrhenian Sea and Malta (Table 1) [24–26]. Such records, mainly from areas strongly affected by human activity, suggest that both bivalve farming and shipping are the most probable vectors of introduction into the western Mediterranean [24]. Moreover, the rapid colonisation pattern and the remarkable abundance of *Paraleucilla magna* allow us to consider it as an invasive species [24].

3.4. *Hydrozoa*

Sixty-three hydrozoan species are considered to be NIS in the Mediterranean [27]. Most species in the eastern Mediterranean entered through the Suez Canal, whereas, in the north-western and central Mediterranean, shipping and the expansion of the natural range through the Strait of Gibraltar are more likely entrance pathways.

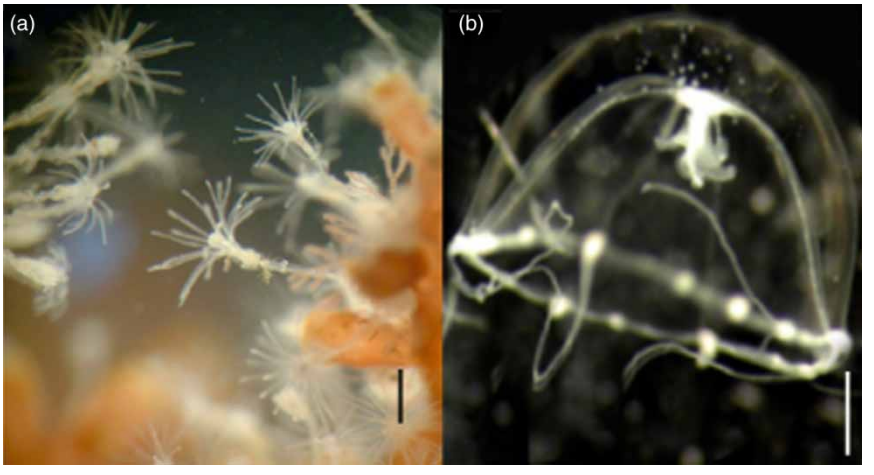

Figure 3. *Clytia hummelincki*. (a) Colony; (b) 5-day-old immature medusa. Scale bars: (a) 1 mm; (b) 0.5 mm.

Four hydrozoan NIS have been recorded from the Apulian coast (Table 1).

Clytia linearis is one of the most common Mediterranean hydroids on shallow hard bottoms. It was recorded from the Suez Canal [28], as *Clytia foxi*, and is probably the first successful Lessepsian hydroid [29].

The circumtropical *Clytia hummelincki* (Figure 3(a),(b)) is a successful invader frequent in shallow sea urchin barrens, where it forms a 'belt' [30]. Boero et al. [29] hypothesised that the rapid expansion of *Clytia hummelincki* might be the result of efficient dispersal of the medusa stage, mainly obtained by displacement with currents.

Mediterranean records of NIS hydrozoans are on the increase [30–34], mostly from the Levant Sea [34,35] and the African coast [36].

3.5. *Mollusca*

To date, about 160 established Mediterranean species are considered as nonindigenous, mostly of either Erythrean or Indo-Pacific origin [9].

Four NIS molluscs have been recorded along the Apulian coast (Table 1).

Bursatella leachi is one of the first NIS reported from the Apulian coast. Tortoricci and Panetta [37] reported it from the Taranto Seas, where it still forms an established population.

Melibe viridis was often reported as *Melibe fibriata* [38], which is now considered a synonym of *Melibe viridis* [39]. Along the Apulian coast *Melibe viridis* was reported from both Porto Cesareo (Lecce) and the Taranto Seas [39,40].

The population of *Musculista senhousia* in the Taranto Seas reached high densities ($\sim$2300 specimens $\cdot$ m^{-2}) in 2003, but have recently decreased to $<$10 specimens $\cdot$ m^{-2} [41].

3.6. *Polychaeta*

Zenetos et al. [33] reported 63 NIS polychaetes in the Mediterranean, but only 5 are reported from the Apulian coast (Table 1).

Ophryotrocha japonica colonises harbour and brackish environments. It was recently reported along the Italian coast, forming a large population in Mar Piccolo [42]. *Fabriciola ghardaqa* and *Megalomma claparedei* [43,44] were both described from the Red Sea. Each species was found

Figure 4. *Branchiomma luctuosum*. Scale bar: 2 cm.

only once along the South Adriatic coast. Also *Novafabricia infratorquata* was found only once, with few individuals, between the Adriatic and Ionian Seas (Otranto) [45]. *Branchiomma luctuosum* (Figure 4) is the only well-established NIS polychaete along the Apulian coast. It occurs along most of the Italian coast and can be considered invasive [46].

3.7. *Crustacea*

Galil [3] reported 66 NIS malacostracans from the Mediterranean Sea. More have been recorded from the Levantine Basin [47] than the western one [11]. The discrepancy in numbers could be attributed to the massive introduction through the Suez Canal.

Fourteen NIS malacostracans were reported from Italy, and nine are present in Apulian waters [48] (Table 1). We report both marine and brackish water NIS.

Artemia franciscana (Anostraca) arrived from North America. It was initially recorded from Portugal [49] and later from France [50]; it was then reported from Spain and Morocco [51,52]. This invasive species is present in the Apulian salterns of Margherita di Savoia [53].

Acartia tonsa was recently reported from Lesina [47] and Varano, where it now represents the dominant copepod taxon throughout the year (Belmonte, pers. obs.).

Paracartia grani was reported from the Mediterranean only recently [54] and exclusively from ports or enclosed basins. Its presence is seasonal (summer) and it is not abundant in the Apulian Varano lagoon (Belmonte, pers. obs.).

Callinectes sapidus (for Apulian waters see Gennaio et al. [55]) was transported into the Mediterranean in ballast tanks from the northeast coast of the USA.

Dromia spinirostris and *Calappa pelii*, both found in the Apulian side of the Gulf of Taranto, are supposed to have been introduced by means of ship fouling [56].

Herbstia nitida, originally described from the Gulf of Guinea, could have been simply overlooked in the Mediterranean due to its peculiar habitat, i.e. submarine caves [57].

Percnon gibbesi entered the Mediterranean recently, where it is the most invasive decapod species [58]. Its rapid expansion and ability to establish large populations in anthropogenically impacted areas such as ports, as well as in natural habitats, indicate that it will probably spread further. The species was recently reported from southern Apulia (Licchelli, pers. obs.).

Marsupenaeus japonicus has entered the Levantine Basin through the Suez Canal, but its establishment in Italian coastal sounds is probably due to the permeability of local mariculture farms [48].

3.8. *Ascidiacea*

Three NIS ascidians have been recorded along the Apulian coast (Table 1).

Microcosmus squamiger lives in shallow rocky habitats, particularly bays and harbours. It is frequently confused with *Microcosmus exasperatus* [59]. An established population is present in the Taranto Seas [60]. *Polyandrocarpa zorritensis* was recently (June 2001) found in the Taranto Seas, where it has established a population [61]. The record of *Distaplia bermudensis* in the Taranto seas, where it has established a population, is the first in the Mediterranean Sea [62].

3.9. *Pisces*

Three NIS fish have been recorded from Apulian waters (Table 1).

The bluespotted cornetfish *Fistularia commersonii* was recorded off Tricase Porto (southwestern Adriatic) [63]. A specimen of Guinean pufferfish, *Sphoeroides marmoratus*, was caught in Apulian waters in September 1977 by a local fisherman off Gallipoli (Ionian Sea). The specimen, preserved in the collections of the 'Pietro Parenzan' Museum of Marine Biology (Italy), was erroneously identified as *Lagocephalus lagocephalus* [64]. Re-examination of the specimen [65] revealed meristic and morphological features consistent with those reported for *Sphoeroides marmoratus* [66]. *Sphoeroides marmoratus* has often been confused with the western Atlantic species *Sphoeroides spengleri* [65]. It is likely that all eastern Atlantic records of the latter fish are misidentifications of *Sphoeroides marmoratus* [67].

Oreochromis niloticus niloticus was collected in the Lesina Lagoon [68]. The species had been farmed in Israel, Egypt, Malta, France and the former Czechoslovakia [69].

3.9.1. *Characterisation of entry mechanisms and origins*

NIS have entered Apulian waters in a variety of vectors, including shipping (ballast and/or fouling), aquaculture, dispersal by waterfowl, range expansion through the Gibraltar Strait and the Suez Canal, and the aquarium trade. Table 1 indicates the most probable vectors for each species, but in some cases vectors are either unknown (21%) or, at the present state of knowledge, it is impossible to select one among several possibilities (i.e. the multiple mechanism category) (24%). Shipping activity accounts for 34% of the NIS, highlighting the importance of ballast waters and ship hull fouling as vectors. Aquaculture is the second most common mechanism (31%), playing a substantial role in the transfer of NIS into Apulian waters, particularly for macroalgae and crustaceans. Twenty-four percent of the NIS reached Apulian waters after entering the Mediterranean through the Suez Canal.

4. Discussion

In the past few years the number of NIS in Apulian waters has increased significantly. Introductions of alien species continue and an increase in the number of successful colonisation events has been observed. This may be related to the adaptation time of 'invaders' to

their new habitat or, more simply, to the increased interest of the scientific community during recent decades.

To date, 38 NIS specie have been listed, of which 8 are occasional and 23 are established, but only 7 seem to be truly invasive and deserve proper attention. Twelve of the 38 NIS recorded from Apulia constitute new records for the Mediterranean Sea.

The geographical location of Apulia is central in the Mediterranean Sea and its biological communities may be affected by arrivals of new species from all directions. Lessepsian migration throughout the Suez Canal probably has its western extremity on the Italian coast, but Apulia seems to also accept species arriving from the west (Atlantic). In both cases, a warmer affinity and subtropical derivation of most species is evident.

The majority of NIS in Apulian waters are of Indo-Pacific origin (53%), followed by Atlantic species (42%), but most arrived as a direct result of human activites and not by expansion of their native distribution range.

It is well known that the gradual warming of the seawater in the Mediterranean may result in more favourable conditions for the establishment of thermophilic NIS, and although the ecological impact of most NIS remain unknown, this leads to the overall reinforcement of a subtropical character of the biota of Apulian waters.

In particular, the Taranto area seems to be conducive for the establishment of NIS and deserves greater attention, being a hotspot of alien biodiversity. Indeed, because it houses the shipyard of the Italian Navy, the largest Italian mussel farms, as well as an expanding trade port, it is particularly exposed to the introduction of NIS. In the Mar Piccolo of Taranto, *Paraleucilla magna* is seasonally abundant, showing a propensity for colonising natural hard substrata. It is resistant to pollution and seems to be a structurally important species of the fouling community, probably because of the heavy deterioration of the area. *Paraleucilla magna* prefers to settle on mussel shells and may affect their growth, forcing local shellfish farmers to invest much effort in decreasing sponge growth [24]. *Branchiomma luctuosum* also became a component of Taranto harbour fouling, forming extensive canopies. Although previously considered to be in possible competition with the native *Sabella spallanzanii*, *Branchiomma luctuosum* has been found living with this species apparently without deleterious effects (Giangrande unpub. obs.).

Moreover, the ecological importance of hydrozoan invasive NIS (*Clytia hummelincki* and *Clytia linearis*) resides in the feeding habits of their medusae, which are potentially important as predators of fish eggs and larvae, as well as being competitors with fish larvae and zooplanktivorous fish for zooplankton prey [29]. The invasive NIS *Cordylophora caspia* (a species peculiar to brackish waters such as estuaries, river deltas and lagoons) shows a highly adaptive ecophysiology, because it has been demonstrated that *Cordylophora caspia* can successfully invade pure freshwater biotopes [70]. Comparably, *Caulerpa racemosa* was revealed to be highly invasive, overgrowing other organisms both on hard and soft bottoms, including *Posidonia* beds, but the ecological impact of *Caulerpa racemosa* invasion remains to be determined.

However, Mediterranean NIS may also have a cold water origin (e.g. the copepod *Acartia tonsa*, from the North and Baltic Seas), apparently in contradiction with the so-called tropicalisation of the Mediterranean biota as a consequence of global warming. In that case, the competitive advantages of the newly introduced species may remain high even under less favourable environmental conditions.

After having reached the Mediterranean Sea, some NIS clearly show a progressive expansion of their invasive distribution. For example, the anostracan *Artemia franciscana* showed an eastward expansion in the Mediterranean Sea. In these cases, screening of new sites will be critical to assess the spatial and temporal level of invasion, the repeated establishment of multiple founder populations, the colonisation pattern and the evaluation of impact on native species.

More generally, little is known about the biology of most of the 38 NIS listed, and their true impact on local communities is therefore not yet quantifiable. Further monitoring and taxon-specific investigations will provide the best contribution to the understanding of ecological outcomes of marine biodiversity changes in the Mediterranean Sea.

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