

## Mediterranean Marine Science

Vol 14, No 1 (2013)



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doi: [10.12681/mms.383](https://doi.org/10.12681/mms.383)

#### To cite this article:

PECAREVIC, M., MIKUS, J., BRATOS CETINIC, A., DULCIC, J., & CALIC, M. (2013). Introduced marine species in Croatian waters (Eastern Adriatic Sea). *Mediterranean Marine Science*, 14(1), 224–237.  
<https://doi.org/10.12681/mms.383>

## Introduced marine species in Croatian waters (Eastern Adriatic Sea)

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Handling Editor: Argyro Zenetos

Received: 24 October 2012; Accepted: 28 February 2013; Published on line: 26 March 2013

### Abstract

The Croatian part of the Adriatic Sea covers more than 35% of the total Croatian territory, which means that monitoring changes in marine ecosystems and the conservation of biodiversity are of great importance. Following global changes, Croatia is experiencing increasing problems due to the introduction of new species that include aliens (due to aquaculture activities and shipping) and species from other Mediterranean subregions that are extending their geographic range. This work provides a checklist of introduced species in Croatian waters. A total of 113 species (15 phytoplankton, 16 zooplankton, 16 macroalgae, 44 zoobenthic and 22 fish species) have been recorded in the eastern part of the Adriatic Sea, of which 61 species are alien and 52 introduced, due to climate change.

**Keywords:** Alien species, range expansion, Croatia, Adriatic Sea, Mediterranean Sea.

### Introduction

The Adriatic Sea is an elongated semi-enclosed basin in the Northeastern Mediterranean Sea. It extends in a southeast – northwest direction, with a shallow northern part and a deeper southern part. Adriatic Sea ecosystems are influenced by regular exchange of water with the Mediterranean Sea (Gačić *et al.*, 2010).

Water temperature in the deeper layers of the Adriatic Sea is above 11 - 12 °C during the whole year. In the warm part of the year, the seasonal thermocline is formed at 10 to 30 m of depth. In the summer, upper water layers reach temperatures of 22 - 25 °C (Buljan & Zore-Armanda, 1976). In the winter, the temperatures of open surface water fluctuates between 6 and 15 °C, with lower temperatures in the northern part and higher ones in the southern part of the basin (Pérès & Gamulin-Brida, 1973). During this period, vertical mixing in the water column occurs, thus transporting nutrients from the deep areas to the surface, which increases autotrophic production (Gačić *et al.*, 2002). The average salinity of the Adriatic Sea is 38.3 ‰, with the lower values observed during the winter months (Buljan & Zore-Armanda, 1976). The Adriatic Sea is characterized by varying trophic conditions; a productive and potentially eutrophic northern part, an oligotrophic southern part and also clearly oligotrophic open waters (Viličić *et al.*, 1989).

Considering all major characteristics, three biogeo-

graphic regions can be recognized in the Adriatic Sea: a shallow northern sub-basin and a deep southern sub-basin separated by a central sub-basin of intermediate depth (Zavatarelli *et al.*, 1998).

The first studies of Adriatic Sea flora and fauna started in the early 18<sup>th</sup> century and a comparatively large amount of data has been collected till the present time (Zavatarelli *et al.*, 1998).

Like many other countries, Croatia is facing increasing problems due to the introduction of new species. Although several projects on the biological and ecological characteristics of the Eastern Adriatic ecosystems are being conducted continuously and the results of such research is published in scientific literature, there is still no national data base or report bringing together all available data on introduced species in the Adriatic Sea. Therefore, the aim of this paper is to provide complete data about introduced marine species in Croatian seawaters, whether introduced by Man (alien) or unintentionally due to climate change.

### Materials and Methods

This article comprises all available data regarding introduced species in the Croatian part of the Adriatic Sea (the Eastern Adriatic Sea). It brings together data from available scientific literature, reports, websites such

as MAMIAS (UNEP-MAPRAC/SPA, 2013) as well as personal knowledge and unpublished data. Phytoplankton species designated as new in Croatian Sea are those that have not been listed in the most recent checklist of Eastern Adriatic phytoplankton (Viličić *et al.*, 2002). The status of introduced species for other taxa was assigned to species of foreign origin, which were recorded in the Adriatic Sea. Certain species were rejected as non indigenous species, since new knowledge demonstrated that they should be considered as native species.

A list of all introduced species in the Eastern Adriatic Sea is presented in two tables. Table 1 includes non indigenous species whose findings are likely due to maritime transport, aquaculture or an unknown vector but classified as “aliens” in Zenetos *et al.* (2010), while Table 2 comprises vagrant species of Atlantic and Indo-Pacific origin and Mediterranean species which have entered the Eastern Adriatic Sea recently, presumably due to climate change.

The taxonomy of the species presented in this paper follows the WoRMS (World Register of Marine Species) (Appeltans *et al.*, 2012).

## Results and Discussion

### *Introduced planktonic species in the Eastern Adriatic Sea*

#### *Introduced phytoplankton*

*Akashiwo sanguinea* (K. Hirasaka) G.Hansen & Ø.Moestrup, 2000 is often found in samples from the Southern and Middle Eastern Adriatic (Carić *et al.*, 2011), but is not included in the Eastern Adriatic phytoplankton checklists (Viličić *et al.*, 2002); it was, therefore, regarded as a new species in Croatian waters.

*Ceratoperidinium yeye* Margalef, 1969 was found in net samples from the coastal waters of the Eastern Adriatic Sea in both the Northern and the Middle Adriatic during the summer of 2003, when seawater temperature was above 20 °C (Ninčević Gladan *et al.*, 2006). *Ceratoperidinium* is a rare dinoflagellate genus reported from both the western and the eastern Mediterranean Sea (Margalef, 1969; Gómez & Abboud-Abi, 2003). Literature data on *Ceratoperidinium* ecology and distribution is very scarce.

Nine new species for the Croatian phytoplankton database, *Gymnodinium abbreviatum* Kofoid et Swezy, 1921, *G. agiliforme* Schiller, 1928, *G. grammaticum* (Pouchet) Kofoid et Swezy, 1921, *G. ostenfeldii* Schiller, 1928, *G. uberrimum* (G.J.Allman) Kofoid & Swezy, 1921, *Gyrodinium ascendans* Kofoid, 1931, *G. obtusum* (Schütt) Kofoid & Swezy, 1921, *G. pingue* (Schütt) Kofoid & Swezy, 1921 and *Woloszynskia neglecta* (Schilling) R.H.Thompson, 1950, were recorded at the Maslinova Bay fish farm (Skejić *et al.* 2012). All these species are cosmopolitan and thus their origin in the Adriatic remains unknown.

*Neoceratium paradoxides* (Cleve) F.Gomez, D.Moreira & P.Lopez-Garcia, 2009 and *Ornithocercus splendidus* F.Schütt, 1895 are two newly recorded phytoplankton species in the Adriatic Sea, found for the first time in the deep South Adriatic in 2008 (Batistić *et al.*, 2012). Both are known from the northern Levantine Basin (Polat & Koray, 2007) so their occurrence might be related to documented changes in Ionian Sea circulation that result in the flow of Aegean and Levantine waters into the Adriatic Sea (Batistić *et al.*, 2012).

*Ostreopsis ovata* Fukuyo, 1981 is an epiphytic, potentially toxic dinoflagellate living on macroalgae, found in the Northern Adriatic for the first time in 2006 (Monti *et al.*, 2007). *O. ovata* was isolated from macroalgae in two areas, the Gulf of Trieste (Italy) and close to Rovinj (Croatia) and was identified by scanning electron microscopy and by fluorescence light microscopy.

*Scaphodinium mirabile* Margalef, 1963, often reported in the Mediterranean Sea (Gómez & Gorsky, 2003), was recorded for the first time in the Eastern Adriatic Sea in Mali Ston Bay in 2002, in the shellfish farm area (Čalić, 2010) and later, in 2011, was also found in the Port of Ploče.

#### *Introduced zooplankton*

*Arctapodema australis* (Vanhöffen, 1902) and *Eucheilota paradoxica* Mayer, 1900 were found in samples from the Southern Adriatic collected in 1967 (Schmidt & Benović, 1977). *A. australis* was rare until 2002 but after that it was frequently found in Croatian waters and today it represents one of the typical Southern Adriatic medusae (Lučić *et al.*, 2009). The ability of hydroids to produce resting stages and settle on floating objects (including ships) enables them to achieve a wide distribution (Cornelius, 1981).

*Arietellus pavoninus* Sars G.O., 1905 is a tropical copepod which was presumably ship transferred (e.g. ballast water) via the Suez Canal or via the Gibraltar Strait (Kovalev, 2006) and was found in the Eastern Adriatic Sea (Hure & Kršinić, 1998).

*Corymorpha annulata* (Kramp, 1928) was reported in the Adriatic Sea (Schmidt & Benović, 1977), but since a single specimen was found with no additional records, more observations are needed to confirm the presence of this rare Indo-Pacific medusa in the Adriatic Sea.

The pteropod *Desmopterus papilio* Chun, 1889 and the heteropod *Protatlanta souleyeti* (E. A. Smith, 1888) were found for the first time in the Adriatic Sea during investigation at a deep-sea station in the northern part of the South Adriatic Pit (Batistić *et al.*, 2004).

*Haliscera bigelowi* Kramp, 1947 is a typically bathypelagic hydromedusa recorded for the first time in the Adriatic Sea in spring 2002 at a deep-sea station in the South Adriatic (Benović *et al.*, 2005). It is probably a recent invader of the Adriatic, as are certain other planktonic cnidarians (Kršinić & Njire, 2001).

The presence of the immigrating Atlantic calyco-phoran *Lensia subtiloides* (Lens & van Riemsdijk, 1908) was recorded in the Southern Adriatic Sea (Batistić & Garić, 2012).

The calyco-phoran siphonophore *Muggiaea atlantica* Cunningham, 1892 was recorded for the first time in the coastal southeastern (Gamulin & Kršinić, 2000) and central Adriatic (Batistic, 1999). After these first records it has been observed that native species *Muggiaea kochi* is progressively being replaced by *M. atlantica* in the coastal waters of the Eastern Adriatic, especially in eutrophicated areas (Batistić *et al.*, 2007).

*Niobia dendrotentaculata* Mayer, 1900, a tropical Atlantic origin species, after its first record in the Adriatic in 2001, again occurred in August 2006 and accounted for 44% of total hydromedusan abundance (Batistić & Garić, 2010).

*Peniculus fistula* Von Nordmann, 1832 is a parasitic pennellid copepod, wide spread in the Atlantic and Indo-Pacific waters, and relatively common in Mediterranean fishes (Raibaut *et al.*, 1998). This species was recorded for the first time in the Eastern Adriatic Sea during an investigation of the biology of garfish *Belone belone* Linnaeus, 1761 (Vidjak *et al.*, 2008). Garfish were caught from February to March 2008 near the Islands of Korčula and Dugi Otok.

Polychaetes *Phalacrophorus pictus* Greef, 1879 and *Pontodora pelagica* Greef, 1879 were found in plankton samples from the Southern Adriatic Sea during the investigated period 1993-2011 (Batistić & Garić, 2012).

An occurrence of *Sagitta galerita* Dallot, 1971 was recorded in the Croatian waters of the Southern Adriatic (Batistić & Garić, 2012).

*Thalia orientalis* Tokioka, 1937 has been found in Croatian waters since January 2008 and has replaced its formerly dominant congener *T. democratica* in the coastal and open Southern Adriatic waters (Batistić *et al.*, 2009).

*Trichydra pudica* Wright, 1858 was recorded in the Eastern Adriatic Sea for the first time in 1973 (Schmidt & Benović, 1979).

### **Introduced benthic species in the Eastern Adriatic Sea** *Introduced phytobenthos*

*Acrothamnion preissii* (Sonder) E.M. Wollaston, 1968 is a tropical filamentous alga which was first recorded in the Eastern Adriatic in 2007 when it was found near Dubrovnik (Despalatović *et al.*, 2008). This invasive red alga has a negative impact on domestic benthic and epiphytic communities because it creates turfs, which outgrow native species of algae and prevent their settlement (Despalatović *et al.*, 2008).

*Asparagopsis armata* Harvey, 1855 was introduced in the Mediterranean Sea unintentionally with oysters

(Ribera & Boudouresque, 1995) and naturally through the Strait of Gibraltar (Pacios *et al.*, 2011); it is widely distributed along the Western Mediterranean coastline. In the Adriatic Sea it was first reported in 1978 in Montenegro (Špan & Antolić, 1983) and later in 1991 in the Gulf of Trieste (Giaccone, 1978). In the same year, the tetrasporophyte (*Falkenbergia* phase) of this alga was found in Slovenian coastal waters and in 1997 gametophyte plants were found in Croatian waters, near Senj (Orlando-Bonaca, 2010).

*Asparagopsis taxiformis* (Delile) Trevisan de Saint-Léon, 1845 is a red alga whose gametophyte phase is spreading along Mediterranean coasts carried by currents or on ship hulls (Boudouresque & Verlaque, 2002). The first record in the Eastern Adriatic Sea is from 2007 when specimens of *A. taxiformis* were found on rocky shallow water substrate in the Dubrovnik area, and also in the Mljet National Park (Despalatović *et al.*, 2008).

*Caulerpa racemosa* var. *cylindracea* (Sonder) Verlaque, Huisman & Boudouresque, 2003 is a tropical green alga aggressively widespread throughout the Mediterranean basin since the early 1990s (Piazzi *et al.* 2001). It was found for the first time in Croatia in autumn 2000 near the Pakleni Islands (Žuljević *et al.*, 2003), and has now been recorded along the entire coast, mostly in the Southern and Middle Adriatic Sea (Žuljević *et al.*, 2010).

*Caulerpa taxifolia* (Vahl) Agardh, 1817 is a tropical green alga whose first occurrence in the Mediterranean was recorded in Monaco in 1984; since then it has been successfully invading Mediterranean coasts (Meinesz *et al.*, 2001). In the Eastern Adriatic, the species was initially observed at three locations: Island of Hvar and Island of Krk in 1994, and Barbat Channel in 1996 (Špan *et al.*, 1998). The records from Malinska and the Harbor of Vr-sar represent the highest northern latitudes at which this invasive alga has been found (Iveša *et al.*, 2006).

*Chondria coerulescens* (J. Agardh) Falkenberg, 1901 was recorded in Rijeka Bay (Battelli & Arko Pijevac, 2003) where this red alga has established a population (Antolić *et al.*, 2011a).

*Chondria pygmaea* Garbary & Vandermeulen, 1990 is an epiphytic red alga found for the first time along the Croatian coast, in the Gulf of Kvarner, in 1997 (Sartoni & Rossi, 1998). This finding is important because it is the most western occurrence of this alga and shows that *C. pygmaea* is a successful migrant, which can develop within a wide ecological range (Sartoni & Rossi, 1998).

*Codium fragile* ssp. *fragile* (Suringar) Hariot, 1889 is a green alga which is widespread thanks to its high environmental tolerance and has also extended its range to the Adriatic Sea (UNEP-MAP-RAC/SPA, 2013).

*Colpomenia peregrina* Sauvageau, 1927 is called the "oyster thief" because it attaches to oysters and then floats off with them. Records from the Eastern Adriatic are rare, but its presence there is possible (Cabioch *et al.*, 1992).

*Desmarestia viridis* (O.F.Müller) J.V.Lamouroux, 1813 has only four records in the Mediterranean Sea, and one of them is from the Eastern Adriatic coast where this alga was found in 1948 (Occhipinti Ambrogi, 2002). However, according to Boudouresque and Verlaque (2002) some populations may be native in the Northern Adriatic.

*Lophocladia lallemandii* (Montagne) F. Schmitz 1893 is an invasive macroalga recorded for the first time in the Eastern Adriatic Sea in 1970 (UNEP-MAP-RAC/SPA, 2013).

*Parviphycus antipai* (Celan) B.Santelices, 2004 has been recorded frequently in the Mediterranean Sea (Boudouresque, 1972; Boisset, 1986) and probably overlooked in the Adriatic Sea. The first record from the Adriatic Sea was in 1997 when a few isolated plants, growing in epiphytic communities on crustose fleshy species, were collected near the Island of Cres (Sartoni & Rossi, 1998).

*Polysiphonia banyulensis* Coppejans, 1976 has been recorded frequently in the North-Western Mediterranean (Cossu *et al.*, 1993). The 1997 record from the Adriatic Sea extends the distribution area of this epiphytic red alga, which is now known from widely separated geographical areas (Sartoni & Rossi, 1998).

*Polysiphonia paniculata* Montagne, 1842 was found in Croatian waters in 1975 (UNEP-MAP-RAC/SPA, 2013). This red alga was also included in the recent check list of the benthic macroflora from Rijeka Bay (Antolčić *et al.*, 2011b).

*Ulva fasciata* (= *U. lactuca sensu Linnaeus*) was recorded in the middle part of the Eastern Adriatic Sea (Ercegović, 1980).

*Womersleyella setacea* (Hollenberg) R.E.Norris, 1992 is a tropical alga that was first noted in the Adriatic Sea in 1997, near the Island of Cres (Sartoni & Rossi, 1998). Later on it was found near Cape Oštro and Rabac (Batelli & Arko-Pijevac, 2005) and near the Island of Dugi Otok (Kružić, 2008b). Nikolić *et al.* (2010) assume that the entire coastline of the Adriatic Sea is affected by this invasive alga.

#### Introduced zoobenthos

Two barnacle species, namely *Amphibalanus eburneus* (Gould, 1841) and *A. improvisus* (Darwin, 1854), were recorded in the Rovinj area (Zavodnik & Igić, 1968; Igić, 1986) where they were probably introduced by shipping activity (Galil *et al.*, 2011).

*Anadara transversa* (Say, 1822) is a bivalve that was recently recorded as empty complete shells from the Adriatic Croatian shores (Peharda *et al.*, 2010). Six specimens of *A. transversa* were found in Lim Bay, Northern Adriatic, attached by byssus to a tile near a mesh bag of *Mytilus galloprovincialis* at a depth of 4.4 m (Nerlović *et al.*, 2012).

*Aplysia dactylomela* Rang, 1828 is a gastropod firstly recorded in the Eastern Adriatic near the Island of Sušac

in the 2006 (Turk, 2006). It appears that this species also lives in the Mljet area (Despalatović *et al.*, 2008).

*Arcuatula senhousia* (Benson in Cantor, 1842) is a Western Pacific bivalve, found in Savudrija Bay in 2003 by local fisherman (Crocetta, 2011).

*Aspidosiphon (Akrikos) mexicanus* (Murina, 1967) is an Atlantic sipunculan species recorded in the Eastern Adriatic in 1986 (Murina & Zavodnik, 1986) and its present status in Croatian waters is unknown (UNEP-MAP-RAC/SPA, 2013).

*Astroides calycularis* (Pallas, 1767) is a warm water coral which was recorded for the first time in the Adriatic Sea in 1899 in Rijeka Bay, but there are many doubts about correct determination (Zibrowius & Grieshaber, 1977; Zavodnik & Kovačić, 2000). During the last century it was recorded along the entire Eastern Adriatic coast (Pax & Müller, 1962; Grubelić *et al.*, 2004). The recent northernmost record is from the rocky shore of the Islet of Borovik in the Northern Adriatic (Kružić *et al.*, 2002).

*Balanus trigonus* Darwin 1854 is an introduced barnacle, which represents an example of anthropogenous cosmopolitanism in the Adriatic Sea (Igić, 2007). It was probably introduced in the Adriatic Sea by fishing ships from the northwestern coast of Africa (Relini, 1968).

*Brachidontes pharaonis* (P. Fischer, 1870) is an Indo-Pacific mytilid with a highly variable shell and is considered to be a variant of *Brachidontes ustulatus* (Lamarck, 1819) (Huber, 2010). It was firstly mentioned in the Croatian Adriatic by Hrs-Brenko and Legac (2006). Orlando Bonaca (2001) listed it as "occasional" and no follow-up is known from the area (Despalatović *et al.*, 2008). The findings in Croatia are likely due to maritime transport linked with the oil terminal of Trieste.

*Bugula fulva* Ryland, 1960 is an Atlantic bryozoan found in samples taken along and just offshore of the Istrian Peninsula and Rovinj area (Hayward & McKinney, 2002).

*Bursatella leachii* De Blainville, 1817 is a gastropod with a worldwide distribution in warm temperate and tropical waters. This Lessepsian migrant was recorded for the first time in the Eastern Adriatic in the Rovinj area (De Min & Vio, 1998). After that it was also reported from the Island of Hvar and the Split area (Despalatović *et al.*, 2008). *Callinectes sapidus* was firstly found in the Eastern Adriatic Sea in 2004 near Ston in a hypersaline lagoon (salt ponds) (Onofri *et al.*, 2007). Findings in the Neretva River estuary in 2004 and 2006 confirm the spreading of this species throughout the Adriatic Sea (Dulčić *et al.*, 2011b).

*Cladocora debilis* Milne Edwards & Haime, 1849, a scleractinian coral, was found for the first time in spring 2002 on the cliffs, south of Lastovo Island (Kružić *et al.*, 2007).

*Cladopsammia rolandi* Lacaze-Duthiers, 1897 is a colonial scleractinian coral which was recorded for the first time in the Adriatic Sea in 2002, when colonies were found in the Lastovo Island area (Kružić, 2008a). In 2005, numerous colonies were found at two locations, in the

south-western part of the Island of Mljet (Kružić, 2008a). Those findings in the Southern Adriatic are the northernmost findings of *C. rolandi* in the Mediterranean Sea.

Eight coral species, *Alicia mirabilis* Johnson, 1861, *Balanophyllia* (*Balanophyllia*) *regia* Gosse, 1853, *Caryophyllia* (*Caryophyllia*) *cyathus* (Ellis & Solander, 1786), *Coenocyathus cylindricus* Milne Edwards and Haime, 1848, *Dendrophyllia ramea* (Linnaeus, 1758), *Guynia anulata* Duncan, 1872, *Halcampoides purpureus* (Studer, 1879) and *Sphenotrochus* (*Sphenotrochus*) *andrewianus* Milne Edwards and Haime, 1848 were recorded for the first time in the Adriatic Sea during the “Thais” expedition, in the period 1995-1998 (Kružić, 2002). Since these findings do not indicate recent settlements it is possible that limited populations were previously overlooked (Kružić, 2002).

*Coscinospira hemprichii* Ehrenberg, 1839, *Cushmanina striatopunctata* (Parker & Jones, 1865), *Elphidium striatopunctatum* (Fichtel & Moll, 1798) and *Planispirinella exigua* (Brady, 1879) are introduced benthic foraminifera recorded in Croatian waters (UNEP-MAP-RAC/SPA, 2013). *C. hemprichii* was also found later in the lakes of Mljet Island (Vaniček *et al.*, 2000).

*Crassostrea gigas* (Thunberg, 1793) larvae were recorded in Limski Bay in the Northern Adriatic Sea (Hrs-Brenko, 1982). *C. gigas* settles on boats and ships and is often found in mariculture areas; therefore, anthropogenic activity might be the vector of introduction.

*Eudendrium carneum* Clarke, 1882 was perhaps introduced in the Mediterranean by human activity, as it often occurs on ship hulls and is thus potentially easily introduced to other regions (Millard, 1975); it has also been found in the Eastern Adriatic (UNEP-MAP-RAC/SPA, 2013). It is possible that besides *E. carneum*, another species from this genus, namely *E. cf. merulum*, Watson, 1985 is also present in Croatian waters (UNEP-MAP-RAC/SPA, 2013).

*Ficopomatus enigmaticus* (Fauvel, 1923) is a cryptic species; the first Adriatic record is from the Venetian lagoons in 1934 and today it builds huge aggregate “reefs” in the Po River Delta (Bianchi & Morri, 1996). The species is also established in Slovenia (Lipej *et al.*, 2012). In Croatian waters, it was recorded for the first time in 2006 in the Bay of Šibenik (Mikuš *et al.*, 2007). Recent records from two new locations along the eastern coast of the Adriatic Sea, Krka River Estuary and Neretva River Delta, have been reported in 2009 (Cukrov *et al.*, 2010).

*Halgerda willeyi*, Eliot 1903 is a nudibranch recorded for the first time in Croatian waters in July 1988, at the southernmost tip of the island of Cres, near Baldarin Bay (Turk, 2000).

*Hemigrapsus sanguineus* (de Haan, 1835) was recorded in August 2001 along the northwestern coast of the Peninsula of Istria, when a single adult male specimen of this East Asian crab was collected (Schubart, 2003). The current absence of *H. sanguineus* in southern Europe and the western Mediterranean suggests an in-

dependent human-mediated introduction of the Croatian specimen (Schubart, 2003).

*Hippolyte prideauxiana* Leach, 1817 is a caridean shrimp, collected in 2002 at Kostrena, near the city of Rijeka, in the Northern Adriatic. This record, the first for the Adriatic Sea, widens the previously known geographic distribution of this species (Kirinčić, 2006).

*Idas simpsoni* (J.T. Marshall, 1900) is a rare bivalve mollusc that attaches itself by byssus to the skull of the whales. It was recorded for the first time in the Adriatic Sea in 2003 on a skull that was trawled up from a depth of 430 m near the Island of Mljet. On that occasion, more than 127 specimens of *I. simpsoni* were collected from the skull of a fin whale *Balaenoptera physalus* (Linnaeus, 1758) (Bolotin *et al.*, 2005).

*Marteilia refringens* Grizel, Comps, Bonami, Cousserans, Duthoit & Le Pennec, 1974 is a protistan parasite responsible for marteiliosis in the flat oyster *Ostrea edulis* and the mussels *Mytilus edulis* and *M. galloprovincialis* respectively. Zrnčić *et al.* (2001) detected *Marteilia* sp. in *Mytilus galloprovincialis* in Croatia.

*Megabalanus tintinnabulum* (Linnaeus, 1758) was found near Rovinj, Pula and Rijeka, reported as *Balanus tintinnabulum* (Kolosváry, 1947).

*Melibe viridis* (Kelaart, 1858) is an Indo-Pacific gastropod recorded along all Mediterranean coasts, including Croatian, where it was found for the first time in 2001 near the Island of Hvar, which is the northernmost record in the Mediterranean (Despalatović *et al.*, 2002).

*Metasychis gotoi* (Izuka, 1902) and *Nereis persica* Fauvel, 1911 were reported as introduced species in Croatian waters but their status is questionable (UNEP-MAP-RAC/SPA, 2013).

*Neopseudocapitella brasiliensis* Rullier & Amoureux, 1979 was found in the harbour and the near vicinity of Rovinj (Zavodnik *et al.*, 1985).

*Ochetostoma erythrogrammon* Leuckart & Ruppell, 1828 was reported for the first time in 1962 when a sample from Velebit Canal was found to contain four specimens. This is the first report of the genus from the Mediterranean Sea (Saiz Salinas & Ruthensteiner, 2005).

*Phascolosoma scolops* (Selenka & de Man, 1883) was found in the northern part of the Croatian Adriatic Sea (Murina, 1976) and is the only one found in the Mediterranean (Murina & Zavodnik, 1986).

*Pinctada imbricata radiata* (Leach, 1814) is a species known as a pearl oyster, recorded for the first time in Croatian waters in 2006, when two juvenile specimens were found in the northern part of the Adriatic Sea coast, off Pula, at a depth of 59 m (Dogan & Nerlović, 2008). The presence of *P. imbricata radiata* in this area could be the result of shipping since this finding is near the location of previous findings in the Trieste Bay (Dogan & Nerlović, 2008).

*Siphonaria pectinata* (Linnaeus, 1758) is a warm water gastropod, recorded for the first time in the Eastern

Adriatic in 2003, when a numerous population was found in the Split area (Despalatović *et al.*, 2008). The possible vector of introduction is shipping, as two international maritime transport harbours are located in the vicinity of the location of the first record.

#### *Introduced ichthyofauna in the Eastern Adriatic Sea*

*Alectis alexandrinus* (Geoffroy Saint-Hilaire, 1817) is a species that is distributed in the southern parts of the Mediterranean Sea. One specimen, caught near Split in summer 1973 and kept in the Natural Museum in Genova (Italy), was scientifically proven as *A. alexandrinus* in 2005 (Dulčić, 2005).

*Caranx crysos* (Mitchill, 1815) is an Atlantic species, recorded for the first time in the Adriatic Sea near Plićina Ćrvar (western coast of the Peninsula Istria) in 2008 (Dulčić *et al.*, 2009b). This is the northernmost finding of this species in the Mediterranean. There are no additional records for this species in the Adriatic Sea.

*Caranx rhonchus* Geoffroy Saint-Hilaire, 1817 is a common predatory fish in the eastern Atlantic and in 2011 it was recorded for the first time in the southern part of the Eastern Adriatic Sea in Mali Ston Bay (Kožul & Antolović, 2013).

*Cyclopterus lumpus* Linnaeus, 1758 naturally occurs in the Atlantic, and it was found in the Adriatic Sea for the first time near Molunat Bay in 2004 (Dulčić & Golani, 2006). Shipping, e.g. ballast water, is the most probable vector of introduction. There are no additional records for this species in the Adriatic Sea.

*Elates ransonnettii* (Steindachner, 1876) normally lives in the Pacific Ocean, from south Chinese shores to north Australia. The first record in the Adriatic Sea is from 2010, when a single specimen was caught in Kaštela Bay (Dulčić *et al.*, 2010). There are no additional records for this species in the Adriatic Sea.

*Enchelycore anatina* (Lowe, 1838) is a subtropical species that was recorded for the first time in the Adriatic Sea in 2010. Two specimens were recorded using an underwater camera near the Island of Sušac (Lipej *et al.*, 2011). There are no additional records for this species in the Adriatic Sea.

*Epinephelus aeneus* (Geoffroy Saint-Hilaire, 1817) is a thermophilic species from the eastern Atlantic and the southern Mediterranean Sea. This species was recorded for the first time in 1998 near Dubrovnik (Glamuzina *et al.*, 2000) and additionally near the Island of Dugi Otok in 2006 (Dulčić *et al.*, 2006). There is evidence of northward spreading of groupers, and this is the northernmost occurrence of this species.

*Equulites (Leiognathus) klunzingeri* (Steindachner, 1898) is a Lessepsian migrant, recorded in the Adriatic Sea for the first time near the Island of Mljet in 2000 (Dulčić & Pallaoro, 2002). There are no additional records for this species in the Adriatic Sea.

*Fistularia commersonii* Rüppel, 1838 is a Lessepsian migrant, recorded in the Adriatic Sea for the first time in 2006 near the Island of Sv. Andrija and near the Italian coast (Bari) (Dulčić *et al.*, 2008). There are also new additional records in Montenegro (Joksimović *et al.*, 2008) and the Island of Šipán (two juvenile specimens). Based on additional records, the existence of a self-sustaining population in the Adriatic is possible.

*Holacanthus ciliaris* (Linnaeus, 1758) was found for the first time in the Adriatic Sea, Trogir Bay, in 2011. So far, this is the only record in the Eastern Adriatic Sea.

*Lagocephalus lagocephalus lagocephalus* (Linnaeus, 1758) is a thermophilic species distributed in tropical and subtropical waters in the Atlantic, Indian and Pacific Oceans. The first report of the species is from the Southern Adriatic, from the area near Molunat Bay in 2004 (Dulčić & Pallaoro, 2006). There are no additional records for this species in the Adriatic Sea.

*Lobotes surinamensis* (Bloch, 1790) is a tropical and subtropical species. It was recorded for the first time in the Adriatic Sea in 2010 near the Island of Biševo (Dulčić & Dragičević, 2011a). Based on the additional records (Island of Šipán), the presence of a self-sustaining population in the Adriatic is possible.

*Mycteroperca rubra* (Bloch, 1793) is a thermophilic species distributed in the eastern Atlantic and Mediterranean Sea. This species was recorded for the first time in 2000 near Dubrovnik (Glamuzina *et al.*, 2002). There are some reports of additional records of this species in the Adriatic.

*Pagrus major* (Temminck & Schlegel, 1843) was recorded for the first time in the Adriatic Sea in the Zadar archipelago, near the Island of Molat, in 2004 (Dulčić & Kraljević, 2007). Its presence in the Adriatic is probably due to the escape from mariculture facilities. Based on the additional records, the existence of a self-sustaining population in the Adriatic is possible.

*Pampus argenteus* (Euphrasen, 1788) is an Indo-Pacific species; the only specimen found in the Mediterranean Sea was caught in the Eastern Adriatic Sea, near Rijeka, in 1896. This was the first Lessepsian migrant reported in the Mediterranean Sea (Dulčić *et al.*, 2004). Besides active migration as a probable vector of introduction, another possible vector of introduction could be shipping.

*Paranthias furcifer* (Valenciennes, 1828) was found in Marina Bay near Trogir in 2011 (Pećarević & Mikuš, 2012). This fish was found near an oil platform that arrived from the Gulf of Mexico and, therefore, shipping could be the vector of introduction.

*Plectorhinchus mediterraneus* (Guichenot, 1850) is a thermophilic species distributed along the West African coast and in the Western Mediterranean. The first records for the Adriatic coast were reported in 1993 from Trieste Bay and Savudrija Bay (Lipej *et al.*, 1996). There are no additional records for this species in the Adriatic Sea.

*Siganus luridus* (Rüppel, 1829) is a Lessepsian mi-

grant, recorded in the Adriatic Sea for the first time in the summer of 2010 in Trieste Bay (Poloniato *et al.*, 2010). There are some additional records of this species from the Island of Mljet in 2010 (Dulčić *et al.*, 2011a) and the Island of Šipan in 2012, and it seems that this species has established a population in the Adriatic Sea.

*Siganus rivulatus* Forsskål, 1775 is a Lessepsian migrant, recorded in the Adriatic Sea for the first time in 2000 near the Island of Bobara in the Southern Adriatic (Dulčić & Pallaoro, 2004). There are some additional records of this species that have not been verified yet.

*Sphoeroides pachygaster* (Müller & Troschel, 1848) was recorded in Croatian waters for the first time in 1992 (Pallaoro & Jardas, 1996). A juvenile specimen was captured again in 2002, off Cape Kamenjak (Peninsula of Istria, Northern Adriatic) and represents the northernmost report in the Adriatic Sea and the entire Mediterranean area (Dulčić, 2002).

*Sphyraena chrysotaenia* Klunzinger, 1884 is a Lessepsian migrant, recorded in the Adriatic Sea for the first time in 2000 near Molunat Bay in the Southern Adriatic (Pallaoro & Dulčić, 2001). According to several additional records, this species has established a population.

*Sphyraena viridensis* Cuvier, 1829 is a thermophilic species distributed in the eastern Atlantic and the Mediterranean Sea. The first record in the Adriatic Sea from the area of Dubrovnik in the Southern Adriatic in 2003 (Kožul *et al.*, 2005), was followed by records from the Northern Adriatic, near the Port of Rijeka in 2008 (Dulčić *et al.*, 2009a). Several specimens were caught in the Middle Adriatic as well, and it seems that this species has established a population in the Adriatic Sea.

In total, at least 113 introduced species have been recorded in the eastern part of the Adriatic Sea, including 15 phytoplankton, 16 zooplankton, 16 macroalgae, 44 zoobenthic and 22 fish species (Tables 1 and 2).

For the majority of the introduced phytoplankton species, the vector of introduction might be related to climate change, areal expansion and changes in sea circulation resulting in the flow of Aegean and Levantine waters into the Adriatic Sea. *Gymnodinium* is a relatively little-known genus with poorly described species on the eastern coast of the Adriatic Sea, Viličić *et al.* (2002) recorded three species in the entire eastern basin.

Sixteen introduced zooplankton species are listed in this paper. However, some of the protozoan planktonic species, reported as non indigenous species for the Northern Adriatic, i.e. tintinnid ciliates *Tintinnopsis mortenseni* Schmidt, 1901 (found in the ballast water of a ship in the Port of Koper) and *Codonellopsis orthoceras* Haeckel (Jørgensen), 1924, have already been found in other parts of the Adriatic Sea (David *et al.*, 2007). *T. mortenseni* usually occurs in the Middle Adriatic Sea (Kaštela Bay) in March (Kršinić, 1980), while *C. orthoceras* was found

in the surface layer of the open waters of the Southern Adriatic (Kršinić & Grbec, 2006). That is the reason why those species were not considered as non indigenous for the Eastern Adriatic.

Introduced benthic algae were found along the entire coast of the Eastern Adriatic. Fast establishment of their populations and successful expansion were enabled by the lack of natural predators and/or high possibility of vegetative reproduction. In favourable new environments these species have become invasive and have a negative impact on natural habitats and communities. Introduced green algae in the Adriatic Sea give rise to major concerns since two non indigenous *Caulerpa* species have rapidly spread across a large part of the Croatian coast overthrowing native benthic communities (Žuljević *et al.*, 2010). There are certain indications that the secondary spread of both *Caulerpa* species has been caused by shipping activities, e.g. ballast waters, anchors, fishing nets, etc. (Verlaque *et al.*, 2003). Introduced red algae were reported in the Eastern Adriatic Sea from the 1997. For some of them the invasive character has been well documented (e.g. *Womersleyella setacea* (Hollenberg) R.E.Norris, 1992). Streftaris and Zenetos (2006) classified *W. setacea* among the 100 worst marine alien species in the Mediterranean, and there is a great chance that this species could be assigned the status of the worst alien macrophyte in the Adriatic Sea as well. New records of brown algae are not so frequent in the Eastern Adriatic, but there are two potentiality introduced species. Most of the vectors of introduction of benthic algae are unknown, but the human factor, e.g. shipping and aquaculture, is not excluded.

Introduced zoobenthic species are quite numerous in the Eastern Adriatic. Introduction of some zoobenthic species is related to climate change and range expansion, while for other species the vectors of introduction are mainly associated with shipping activities. Recent research on the zoobenthos in Croatian waters has resulted in the discovery of numerous scleractinian species that proved to be new to the area (Kružić, 2002) and the previously uncertain occurrence of certain species (e.g. *A. calycularis* and *D. ramea*) was confirmed (Kružić *et al.*, 2002).

A large number of a new fish species has been recorded in the last few decades, and the abundance of species that were previously rare in the Adriatic Sea has also increased. The highest growth was observed among thermophilic species, which were firstly present in the Southern Adriatic but can now be found at more northern latitudes too. Lessepsian migrant *Stephanolepis diaspros* Fraser-Brunner, 1940 and thermophilic species *Tylosurus acus imperialis* (Rafinesque, 1810) were found far south, off the Croatian coast. The findings were reported for the Montenegro coast (Bello, 1995; Dulčić & Pallaoro, 2003). Additional records suggest that *T. acus imperialis* has established a population in the Adriatic Sea. However,



**Table 1:** List of non indigenous species introduced in the Eastern Adriatic Sea (Croatia) by human or unknown vectors. Legend: Location: NA – Northern Adriatic, MA – Middle Adriatic, SA – Southern Adriatic; Vector: AQ – aquaculture, LM – Lessepsian migrant, SH – shipping, , UN – unknown; Status: C – casual, E – established, S – spreading.

| Taxon                                      | First record | Location | Vector | Status | Reference                          |
|--|--------------|----------|--------|--------|------------------------------------|
| <b>Pyrrhophyta (Dinophyceae)</b>           |              |          |        |        |                                    |
| <i>Ostreopsis ovata</i>                    | 2006         | NA       | UN     | C      | Monti <i>et al.</i> , 2007         |
| <b>Chlorophyta</b>                         |              |          |        |        |                                    |
| <i>Caulerpa racemosa</i>                   | 2000         | MA       | SH     | E      | Žuljević <i>et al.</i> , 2003      |
| <i>Caulerpa taxifolia</i>                  | 1994         | MA       | SH     | E      | Špan <i>et al.</i> , 1998          |
| <i>Codium fragile</i> ssp. <i>fragile</i>  | 1983         | NA       | UN     | E      | UNEP-MAP-RAC/SPA, 2013             |
| <i>Ulva fasciata</i>                       | <1969        | MA       | UN     | C      | Ercegović, 1980                    |
| <b>Rhodophyta</b>                          |              |          |        |        |                                    |
| <i>Acrothamnion preissii</i>               | 2007         | SA       | UN     | C      | Despalatović <i>et al.</i> , 2008  |
| <i>Asparagopsis armata</i>                 | 1997         | NA       | UN     | S      | Orlando-Bonaca, 2010               |
| <i>Asparagopsis taxiformis</i>             | 2007         | SA       | UN     | C      | Despalatović <i>et al.</i> , 2008  |
| <i>Chondria coerulescens</i>               | 1997         | NA       | UN     | E      | Battelli & Arko Pijevac, 2003      |
| <i>Chondria pygmaea</i>                    | 1997         | NA       | LM     | C      | Sartoni & Rossi, 1998              |
| <i>Lophocladia lallemandii</i>             | 1970         | NA       | UN     | E      | UNEP-MAP-RAC/SPA, 2013             |
| <i>Polysiphonia paniculata</i>             | 1975         | NA       | UN     | C      | UNEP-MAP-RAC/SPA, 2013             |
| <i>Womersleyella setacea</i>               | 1997         | NA       | UN     | E      | Sartoni & Rossi, 1998              |
| <b>Pheophyta</b>                           |              |          |        |        |                                    |
| <i>Colpomenia peregrina</i>                | <1992        | -        | UN     | C      | Cabioč'h <i>et al.</i> , 1992      |
| <i>Desmarestia viridis</i>                 | 1948         | NA       | UN     | C      | Occhipinti Ambrogio, 2002          |
| <b>Foraminifera</b>                        |              |          |        |        |                                    |
| <i>Coscinospira hemprichii</i>             | 1911         | NA, SA   | UN     | S      | UNEP-MAP-RAC/SPA, 2013             |
| <i>Cushmanina striatopunctata</i>          | 1913         | NA       | UN     | C      | UNEP-MAP-RAC/SPA, 2013             |
| <i>Elphidium striatopunctatum</i>          | 1911         | NA       | UN     | C      | UNEP-MAP-RAC/SPA, 2013             |
| <i>Planispirinella exigua</i>              | 1910         | NA       | UN     | C      | UNEP-MAP-RAC/SPA, 2013             |
| <b>Cercozoa</b>                            |              |          |        |        |                                    |
| <i>Marteilia refringens</i>                | 1998         | NA       | UN     | C      | Zrnčić <i>et al.</i> , 2001        |
| <b>Cnidaria</b>                            |              |          |        |        |                                    |
| <b>Hydrozoa</b>                            |              |          |        |        |                                    |
| <i>Arctapodema australis</i>               | 1967         | SA       | SH     | E      | Schmidt & Benović, 1977            |
| <i>Corymorpha annulata</i>                 | 1973         | SA       | UN     | C      | Schmidt & Benović, 1977            |
| <i>Eucheilota paradoxa</i>                 | 1967         | SA       | SH     | E      | Schmidt & Benović, 1977            |
| <i>Eudendrium carneum</i>                  | <2000        | -        | UN     | C      | UNEP-MAP-RAC/SPA, 2013             |
| <i>Eudendrium cf. merulum</i>              | 1969         | -        | UN     | C      | UNEP-MAP-RAC/SPA, 2013             |
| <i>Haliscera bigelowi</i>                  | 2002         | SA       | UN     | C      | Benović <i>et al.</i> , 2005       |
| <i>Trichydra pudica</i>                    | 1973         | SA       | UN     | C      | Schmidt & Benović, 1977            |
| <b>Mollusca</b>                            |              |          |        |        |                                    |
| <b>Bivalvia</b>                            |              |          |        |        |                                    |
| <i>Anadara transversa</i>                  | 2011         | NA       | UN     | C      | Nerlović <i>et al.</i> , 2012      |
| <i>Arcuatula senhousia</i>                 | 2003         | NA       | UN     | C      | Crocetta, 2011                     |
| <i>Brachidontes pharaonis</i>              | <2006        | NA       | SH     | C      | Hrs-Brenko & Legac, 2006           |
| <i>Bursatella leachii</i>                  | <1998        | NA       | LM     | S      | De Min & Vio, 1998                 |
| <i>Crassostrea gigas</i>                   | <1980        | NA       | SH     | C      | Hrs-Brenko, 1982                   |
| <i>Pinctada imbricata radiata</i>          | 2006         | NA       | SH     | C      | Dogan & Nerlović, 2008             |
| <b>Gastropoda</b>                          |              |          |        |        |                                    |
| <i>Aplysia dactylomela</i>                 | 2006         | MA       | UN     | S      | Turk, 2006                         |
| <i>Halgerda willeyi</i>                    | 1988         | NA       | UN     | C      | Turk, 2000                         |
| <i>Melibe viridis</i>                      | 2001         | MA       | UN     | C      | Despalatović <i>et al.</i> , 2002  |
| <i>Siphonaria pectinata</i>                | 2003         | MA       | SH     | E      | Despalatović <i>et al.</i> , 2008  |
| <b>Echiura</b>                             |              |          |        |        |                                    |
| <i>Ochetostoma erythrogrammon</i>          | 1962         | NA       | UN     | C      | Saiz Salinas & Ruthensteiner, 2005 |
| <b>Annelida</b>                            |              |          |        |        |                                    |
| <i>Ficopomatus enigmaticus</i>             | 2006         | MA       | SH     | S      | Mikuš <i>et al.</i> , 2007         |
| <i>Metasychis gotoi</i>                    | 1934         | -        | UN     | C      | UNEP-MAP-RAC/SPA, 2013             |
| <i>Neopseudocapitella brasiliensis</i>     | <1985        | NA       | UN     | E      | Zavodnik <i>et al.</i> , 1985      |
| <i>Nereis persica</i>                      | 1983         | -        | UN     | C      | UNEP-MAP-RAC/SPA, 2013             |
| <b>Crustacea</b>                           |              |          |        |        |                                    |
| <i>Arietellus pavoninus</i>                | <1998        | SA       | SH     | C      | Hure & Kršinić, 1998               |
| <i>Amphibalanus eburneus</i>               | <1968        | NA       | SH     | E      | Zavodnik & Igić, 1968              |
| <i>Amphibalanus improvisus</i>             | <1986        | NA       | SH     | E      | Igić, 1986                         |
| <i>Balanus trigonus</i>                    | <1968        | NA       | SH     | E      | Igić, 2007                         |
| <i>Callinectes sapidus</i>                 | 2004         | SA       | UN     | E      | Onofri <i>et al.</i> , 2007        |
| <i>Hemigrapsus sanguineus</i>              | 2001         | NA       | UN     | C      | Schubart, 2003                     |
| <i>Megabalanus tintinnabulum</i>           | 1947         | NA       | SH     | E      | Kolosváry, 1947                    |
| <b>Bryozoa</b>                             |              |          |        |        |                                    |
| <i>Bugula fulva</i>                        | <1998        | NA       | UN     | C      | Hayward & McKinney, 2002           |
| <b>Chordata</b>                            |              |          |        |        |                                    |
| <b>Pisces</b>                              |              |          |        |        |                                    |
| <i>Cyclopterus lumpus</i>                  | 2004         | SA       | SH     | C      | Dulčić & Golani, 2006              |
| <i>Elates ransonnetii</i>                  | 2010         | MA       | SH     | C      | Dulčić <i>et al.</i> , 2010        |
| <i>Equulites (Leiognathus) klunzingeri</i> | 2000         | SA       | LM     | C      | Dulčić & Pallaoro, 2002            |
| <i>Fistularia commersonii</i>              | 2006         | SA       | LM     | E      | Dulčić <i>et al.</i> , 2008        |
| <i>Holacanthus ciliaris</i>                | 2011         | MA       | SH     | C      | Dulčić (unpublished data)          |
| <i>Pagrus major</i>                        | 2004         | MA       | AQ     | E      | Dulčić & Kraljević, 2007           |
| <i>Pampus argenteus</i>                    | 1896         | NA       | LM     | C      | Dulčić <i>et al.</i> , 2004        |
| <i>Paranthias furcifer</i>                 | 2011         | MA       | SH     | C      | Pećarević & Mikuš, 2012            |
| <i>Siganus luridus</i>                     | 2010         | SA       | LM     | E      | Dulčić <i>et al.</i> , 2011a       |
| <i>Siganus rivulatus</i>                   | 2000         | SA       | LM     | C      | Dulčić & Pallaoro, 2004            |
| <i>Sphyraena chrysotaenia</i>              | 2000         | SA       | LM     | E      | Pallaoro & Dulčić, 2001            |

**Table 2.** List of introduced species which have expanded their distribution range in the Eastern Adriatic Sea (Croatia) due to climate change. Legend: Location: NA – Northern Adriatic, MA – Middle Adriatic, SA – Southern Adriatic; Species origin: AT – Atlantic, ME – Mediterranean, IP – Indo-Pacific; Status: C – casual, E – established, S – spreading.

| Taxon  | First record | Location | Species origin | Status | Reference                            |
|--|--------------|----------|----------------|--------|--------------------------------------|
| <b>Pyrrhophyta (Dinophyceae)</b>                 |              |          |                |        |                                      |
| <i>Akashiwo sanguinea</i>                        | <2011        | SA, MA   | AT             | S      | Carić <i>et al.</i> , 2011           |
| <i>Ceratoperidinium yeye</i>                     | 2003         | NA, MA   | IP             | C      | Ninčević Gladan <i>et al.</i> , 2006 |
| <i>Gymnodinium abbreviatum</i>                   | 2006         | MA       | AT             | C      | Skejić <i>et al.</i> , 2012          |
| <i>Gymnodinium agiliforme</i>                    | 2006         | MA       | AT             | C      | Skejić <i>et al.</i> , 2012          |
| <i>Gymnodinium grammaticum</i>                   | 2006         | MA       | AT             | C      | Skejić <i>et al.</i> , 2012          |
| <i>Gymnodinium ostenfeldii</i>                   | 2006         | MA       | AT             | C      | Skejić <i>et al.</i> , 2012          |
| <i>Gymnodinium uberrimum</i>                     | 2006         | MA       | AT             | C      | Skejić <i>et al.</i> , 2012          |
| <i>Gyrodinium ascendans</i>                      | 2006         | MA       | AT             | C      | Skejić <i>et al.</i> , 2012          |
| <i>Gyrodinium obtusum</i>                        | 2006         | MA       | AT             | C      | Skejić <i>et al.</i> , 2012          |
| <i>Gyrodinium pingue</i>                         | 2006         | MA       | AT             | C      | Skejić <i>et al.</i> , 2012          |
| <i>Neoceratium paradoxoides</i>                  | 2008         | SA       | AT             | C      | Batistić <i>et al.</i> , 2012        |
| <i>Ornithocercus splendidus</i>                  | 2008         | SA       | AT             | C      | Batistić <i>et al.</i> , 2012        |
| <i>Scaphodinium mirabile</i>                     | 2002         | SA       | AT             | S      | Čalić, 2010                          |
| <i>Woloszynskia neglecta</i>                     | 2006         | MA       | AT             | C      | Skejić <i>et al.</i> , 2012          |
| <b>Rhodophyta</b>                                |              |          |                |        |                                      |
| <i>Parviphycus antipai</i>                       | 1997         | NA       | AT, IP, ME     | C      | Sartoni & Rossi, 1998                |
| <i>Polysiphonia banyulensis</i>                  | 1997         | NA       | ME             | C      | Sartoni & Rossi, 1998                |
| <b>Cnidaria</b>                                  |              |          |                |        |                                      |
| <b>Anthozoa</b>                                  |              |          |                |        |                                      |
| <i>Alicia mirabilis</i>                          | 1998         | SA       | AT, ME         | C      | Kružić, 2002                         |
| <i>Astroides calycularis</i>                     | 1899         | NA       | AT, ME         | E      | Zibrowius & Grieshaber, 1977         |
| <i>Balanophyllia (Balanophyllia) regia</i>       | 1998         | SA       | AT, ME         | C      | Kružić, 2002                         |
| <i>Caryophyllia (Caryophyllia) cyathus</i>       | 1998         | SA       | AT, ME         | C      | Kružić, 2002                         |
| <i>Cladocora debilis</i>                         | 2002         | SA       | AT, ME         | C      | Kružić <i>et al.</i> , 2007          |
| <i>Cladopsammia rolandi</i>                      | 2002         | SA       | AT, ME         | E      | Kružić, 2008a                        |
| <i>Coenocyathus cylindricus</i>                  | 1998         | SA       | AT, ME         | C      | Kružić, 2002                         |
| <i>Dendrophyllia ramea</i>                       | 1998         | SA       | AT, ME         | C      | Kružić, 2002                         |
| <i>Gyneria annulata</i>                          | 1998         | SA       | AT, ME         | C      | Kružić, 2002                         |
| <i>Halcampoides purpureus</i>                    | 1998         | SA       | AT             | C      | Kružić, 2002                         |
| <i>Sphenotrochus (Sphenotrochus) andrewianus</i> | 1998         | SA       | AT, ME         | C      | Kružić, 2002                         |
| <b>Hydrozoa</b>                                  |              |          |                |        |                                      |
| <i>Lensia subtiloides</i>                        | 1974         | SA       | AT             | E      | Batistić & Garić, 2012               |
| <i>Muggiaea atlantica</i>                        | 1974         | SA       | AT             | E      | Gamulin & Kršinić, 2000              |
| <i>Niobia dendrotentaculata</i>                  | 2001         | SA       | AT             | E      | Batistić & Garić, 2010               |
| <b>Mollusca</b>                                  |              |          |                |        |                                      |
| <b>Bivalvia</b>                                  |              |          |                |        |                                      |
| <i>Idas simpsoni</i>                             | 2003         | SA       | AT             | C      | Bolotin <i>et al.</i> , 2005         |
| <b>Gastropoda</b>                                |              |          |                |        |                                      |
| <i>Desmopterus papilio</i>                       | 1993         | SA       | AT             | C      | Batistić <i>et al.</i> , 2004        |
| <i>Protatlanta souleyeti</i>                     | 1994         | SA       | AT, IP         | C      | Batistić <i>et al.</i> , 2004        |
| <b>Sipuncula</b>                                 |              |          |                |        |                                      |
| <i>Aspidosiphon (Akrikos) mexicanus</i>          | 1986         | NA       | AT, ME         | C      | Murina & Zavodnik, 1986              |
| <i>Phascolosoma scolops</i>                      | <1976        | NA       | IP             | C      | Murina, 1976                         |
| <b>Annelida</b>                                  |              |          |                |        |                                      |
| <i>Hippolyte prideauxiana</i>                    | 2002         | NA       | AT, ME         | C      | Kirinčić, 2006                       |
| <i>Phalacrophorus pictus</i>                     | <2011        | SA       | AT             | C      | Batistić & Garić, 2012               |
| <i>Pontodora pelagica</i>                        | <2011        | SA       | AT, IP         | C      | Batistić & Garić, 2012               |
| <b>Crustacea</b>                                 |              |          |                |        |                                      |
| <i>Peniculus fistula</i>                         | 2008         | MA       | AT, IP         | C      | Vidjak <i>et al.</i> , 2008          |
| <b>Chaetognatha</b>                              |              |          |                |        |                                      |
| <i>Sagitta galerita</i>                          | <2011        | SA       | IP             | C      | Batistić & Garić, 2012               |
| <b>Chordata</b>                                  |              |          |                |        |                                      |
| <b>Tunicata</b>                                  |              |          |                |        |                                      |
| <i>Thalia orientalis</i>                         | 2008         | SA       | AT             | E      | Batistić <i>et al.</i> , 2009        |
| <b>Pisces</b>                                    |              |          |                |        |                                      |
| <i>Alectis alexandrinus</i>                      | 1973         | MA       | AT, ME         | C      | Dulčić, 2005                         |
| <i>Caranx crysos</i>                             | 2008         | NA       | AT             | C      | Dulčić <i>et al.</i> , 2009b         |
| <i>Caranx rhonchus</i>                           | 2011         | SA       | AT             | C      | Kožul & Antolović, 2013              |
| <i>Enchelycore anatina</i>                       | 2010         | MA       | AT, ME         | C      | Lipej <i>et al.</i> , 2011           |
| <i>Epinephelus aeneus</i>                        | 1998         | SA       | AT, ME         | S      | Glamuzina <i>et al.</i> , 2000       |
| <i>Lagocephalus lagocephalus lagocephalus</i>    | 2004         | SA       | AT, IP         | C      | Dulčić & Pallaoro, 2006              |
| <i>Lobotes surinamensis</i>                      | 2010         | MA       | AT, IP, ME     | E      | Dulčić & Dragičević, 2011a           |
| <i>Mycteroperca rubra</i>                        | 2000         | SA       | AT, ME         | S      | Glamuzina <i>et al.</i> , 2002       |
| <i>Plectorhynchus mediterraneus</i>              | 1993         | NA       | AT, ME         | C      | Lipej <i>et al.</i> , 1995           |
| <i>Sphaeroides pachygaster</i>                   | 1992         | NA       | AT, IP         | S      | Pallaoro & Jarda, 1996               |
| <i>Sphyræna viridensis</i>                       | 2003         | SA       | AT, ME         | E      | Kožul <i>et al.</i> , 2005           |

er, these two fish species were not included in Table 1 and the total number of non introduced species in Croatian waters.

Species biodiversity in the Adriatic Sea is influenced by water masses from the Mediterranean Sea. Mediterranean water enters the Adriatic basin from the Ionian Sea through the Strait of Otranto and flows to the northern part due to the northward coastal current. Therefore, Ionian Sea water masses, consisting of Levantine Intermediate Water and Ionian Surface Water, flow along the eastern coast of the basin. The volume of this flow varies, depending on climatic fluctuations that occur from the Atlantic to the southeast Mediterranean, but is generally greater during the winter (Batistić *et al.*, 2012).

Recorded changes in Ionian Sea circulation, consisting in the mixing of higher salinity Aegean/Levantine water with lower salinity water of Atlantic origin (Gačić *et al.*, 2010), could possibly explain the presence of Levantine and Atlantic species in the Eastern Adriatic Sea. This refers to Eastern Adriatic ichthyofauna in particular.

Regarding other introduced species in the Eastern Adriatic, possible vectors of introduction could be aquaculture activities and shipping. However, it should be noted that Croatian ports are mainly import ports thus ballast water volume is not significant. That could be the reason for fewer numbers of non indigenous planktonic species in the Eastern Adriatic in comparison with other taxa. In contrast, in the Northern Adriatic ports ballast water is an important vector of introduction of non indigenous species (David & Jakomin, 2003).

Since the Croatian part of the Adriatic Sea covers more than 35% of the total Croatian territory, monitoring of changes in marine ecosystems and biodiversity conservation are of great importance. Introduction of species in the Eastern Adriatic Sea is increasing due primarily to climate change, but other vectors should not be neglected. In order to monitor changes in Adriatic flora and fauna in the best possible way, the establishment of a national data base is necessary, as well as collaboration with other Adriatic and Mediterranean countries

## Acknowledgements

This research was supported by the Ministry of Science, Education and Sports of the Republic of Croatia. We would like to extend our gratitude to all our colleagues researchers who have collected many valuable data about the Adriatic Sea during the past years. Special thanks to Dr. Argyro Zenetos for her support and useful comments.

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