review article
received: 15. 10. 2001

UDC 574.5(262.3-17)

A SURVEY OF THE INTRODUCED NON-INDIGENOUS SPECIES IN THE NORTHERN ADRIATIC SEA

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ABSTRACT

A synthesis of non-indigenous species being introduced to the northern Adriatic Sea, based on literature records and unpublished information, is given. Thirty-five introduced species were recorded, twenty-six animals and nine algae. The majority of them have been introduced with vessels, for aquaculture purposes (also as accompanying species) or through the Suez Canal (the so-called Lessepsian migrants). The fate of these species is unpredictable not only in the northern Adriatic, but in the entire Mediterranean Sea.

Key words: non-indigenous species, introduction, northern Adriatic Sea

RESOCONTO DELLE INTRODUZIONI DI SPECIE NON-INDIGENE NELL'ADRIATICO SETTENTRIONALE

SINTESI

L'articolo riporta un resoconto delle introduzioni di specie marine non-indigene nell'Adriatico settentrionale, basato su dati di letteratura ed informazioni non ancora pubblicate. In totale è stata registrata la presenza di trentacinque specie alloctone, ventisei delle quali appartenenti al regno animale e nove a quello vegetale. La maggioranza di esse è stata introdotta con le navi, importata per la maricoltura (con rispettive specie accompagnatrici) o attraverso il Canale di Suez (migranti Lessepsiani). La sorte di tali specie appare imprevedibile non solo nell'Adriatico settentrionale, ma nell'intero bacino Mediterraneo.

Parole chiave: specie non-indigene, introduzioni, Adriatico settentrionale

INTRODUCTION

The introduction of species to habitats outside their native ranges is a growing problem due to the unexpected impacts these species might cause on indigenous species and ecosystems (Nolan, 1994; Gollasch & Leppäkoski, 1999). Nowadays, it is quite impossible to predict how a species will behave when it is introduced into a new environment. Because of this unpredictability every effort should be made to prevent or at least to monitor the introduction of species from an ecosystem into another (Verlaque, 2001).

Marine non-indigenous species (also called introduced, non-native, alien, or exotic organisms) are mostly transported intentionally for aquaculture purposes or unintentionally with marine traffic (Zibrowius, 1994; Gollasch & Leppäkoski, 1999). Ships provide habitats for a large variety of organisms due to their transport of ballast water, sediments in ballast tanks and hull fouling (Gollasch & Leppäkoski, 1999).

Compared to the substantial body of knowledge gathered on terrestrial species introductions, data on the dynamics of marine species introduction remain very scarce. Relatively comprehensive inventories of marine flora and fauna are too recent for us to be able to identify in them the species that were probably introduced, without the risk of error being unacceptably high. Often, the authors of inventories have not specified that certain mentioned species were probably introduced, mostly because they feel that this assumption is too hypothetical (Ribera & Boudouresque, 1995).

In the northern Adriatic Sea, only a minor research about the presence of non-native species has been carried out (De Min & Vio, 1998), but scientists have recorded cases of introductions of non-indigenous species that could badly affect local ecosystems. However, some information about non-indigenous species in this area is known from the reports by Lipej (2000), Lipej & Makovec (2000), Lipej *et al.* (2000) and Orlando (2001). David (1999) provided a review of the existing regulations for the accidental introduction of species with ballast waters.

The aim of this paper is to compile the checklist of non-indigenous marine animals and algae found in the northern Adriatic Sea. Data were collected from different sources such as bibliographical references and scientific citations, information available at specific web sites, and information obtained by other researchers and naturalists.

MODALITY OF INTRODUCTION OF SPECIES

According to Boalch (1994), introductions of non-indigenous species can be divided into natural introductions (which may be temporary or permanent), accidental introductions by man (brought in with other organisms, by ships or other vectors or brought in for research or commerce and subsequently escaping), or purposeful introductions. Natural introduction (like in the Mediterranean the natural invasion of species through the Straits of Gibraltar) are frequently the result of local changes in environmental conditions, so that a species normally occurring outside the considered area can extend its range and move into it. These types of introductions do not appear to be harmful. Accidental introductions are much more numerous.

The most ancient vector of species introduction is certainly the transportation on the ships' hulls of fixed (fouling) or non-fixed (clinging) species (Ribera & Boudouresque, 1995). Fouling concerns small-sized species and large species whose life history includes a microscopic stage. Since 1972, antifouling paints of ships have generally contained the highly toxic tributyltin (TBT) (Gollasch & Leppäkoski, 1999). This substance has considerably reduced the number of fouling organisms, but in some areas, like harbors or shipyards, the accumulation of the TBT prevents the reproduction of several gastropod species and also some algae seem to be affected (Gollasch & Leppäkoski, 1999). Therefore, in the beginning of the 1990s the use of TBT was banned for boats smaller than 25 m (Gollasch & Leppäkoski, 1999).

Carlton & Geller (1993) note that ballast water is the least selective means of transportation of species from the ecological and taxonomic points of view, and it is a vector that has no equivalent on land. The survival time in ballast water for some species may exceed 18 days (Salt, 1992), so that many of these organisms are still alive after their intercontinental voyage at the time of deballasting.

Many scientists who are using marine non-native species fail to take the elementary precautions required to prevent the escape of these organisms from their cultures, *e.g.* some laboratories dispose through their own direct outfalls sites for seawater. The survival capacity of such species in fresh water is also poorly known (Ribera & Boudouresque, 1995).

Some economically important alien species have been introduced intentionally for aquaculture purposes, with consequent accidental introduction of accompanying species (Zibrowius, 1994; Ribera & Boudouresque, 1995; Gollasch & Leppäkoski, 1999).

With a few exceptions, the importation, sale and possession of marine species are not subject to any specific regulations. Some companies offer in their catalogues also the invasive marine algae *Caulerpa taxifolia* and *Sargassum muticum* (Ribera & Boudouresque, 1995).

The migration of the Red Sea species through the Suez Canal has added by far the greatest number of newcomers in the Mediterranean Sea. With the inauguration of the Suez Canal in 1869, a remarkable faunal and floral movement started. Hundreds of species are still traversing the canal and settling in the Mediterra-

nean in a process called "Lessepsian migration", after Ferdinand Marie de Lesseps, the French engineer who built the canal (Galil, 1994).

There are four successive phases in the introduction of a species (Ribera & Boudouresque, 1995), first of all the arrival of a few specimens of an exotic species that does not automatically imply its naturalization. During the settlement phase, the species constitute populations of individuals born *in situ*. This phase may results in a naturalization of the species. Once naturalized, the introduced species starts the expansion phase, trying to occupy the whole biotope and the whole of the geographical range to which it may have access. The persistence phase, the last one, may takes two forms: the decline followed by stabilisation at a lower level than the maximum attained during the expansion phase, or a plateau close to the maximum attained.

A species is considered introduced when it has satisfied many criteria (Ribera & Boudouresque, 1995). The most important are that the species is new in the area in question and that there is a geographical discontinuity between its new station and the species' known range (Ribera & Boudouresque, 1995).

INTRODUCED FAUNA

According to the available data, twenty-six non-indigenous animal species are known to occur in the northern Adriatic Sea (Tab. 1).

The increase of marine traffic between the Mediterranean Sea and the Far East that has followed the opening of the Suez Canal, and the import of Indo-Pacific Mollusca for aquaculture purposes, have facilitated the diffusion in the northern Adriatic Sea of twelve exotic species (De Min & Vio, 1998). According to De Min & Vio (1998), the chemical-physical conditions such as those of some subtropical or tropical estuary areas have promoted the colonization of seven non-native species (*Rapana venosa* (Fig. 1), *Bursatella leachii, Scapharca inaequivalvis, Musculista senhousia, Xenostrobus secures, Tapes philippinarum, Crassostrea gigas*) and of five occasional, too (*Strombus decorus, Brachydontes pharaonis, Perna picta, Pinctada radiata, Saccostrea commercialis* (the reproduction of this species in the Venice Lagoon has failed)).

A tropical species of Nudibranchia (Gastropoda) *Halgerda* sp. has been found at the southern tip of Cres island (Quarnero archipelago) at the end of july 1988, which is also the first record of any *Halgerda* species in the Mediterranean (Turk, 2000). The author supposes that the most probable vector of introduction for this species is ballast water.

There are also some records about the presence of exotic Decapoda (Crustacea) in the northern Adriatic Sea (CIESM, 2000): *Callinectes danae, Callinectes sapidus, Dyspanopeus sayi* and *Rhithropanopeus harrisii*.

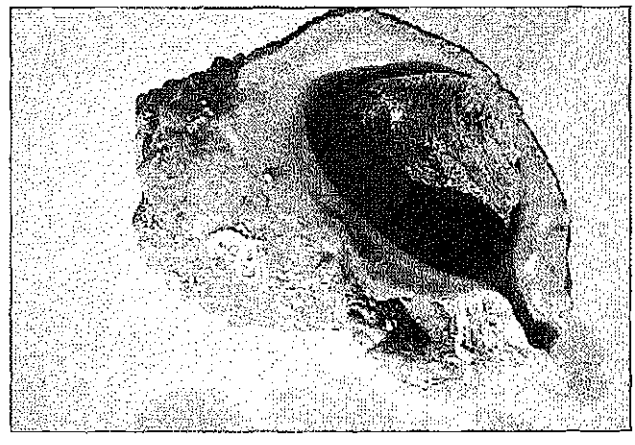

Fig. 1/Sl. 1: *Rapana venosa.* ***(Photo/Foto: T. Makovec)***

In 1987, the Copepoda (Crustacea) *Acartia tonsa* was recorded for the first time in the northern Adriatic in the Lagoon of Scardovari (Occhipinti, 2000). Since then it has supplanted the native congeneric *Acartia margalefi* in the Venice Lagoon and in the Po River Delta (Occhipinti, 2000).

The circumtropical barnacle *Balanus trigonus* (Crustacea) was probably introduced as a fouling organism, and was first recorded in the Adriatic Sea near Trieste (Relini, 1968). In Croatian coastal waters it has been found near Rovinj and Pula (Igic, 1982) and in the Rijeka Bay (Zavodnik, 1998; Zavodnik & Kovačić, 2000).

In the coastal wetlands of the northern Adriatic the fish *Gambusia affinis* has been found, introduced in relation to the problems with mosquitoes (Leiner *et al.*, 1995, Marčeta, 1999). Because of their aggressive behaviour, mosquitofish may negatively affect populations of small native fish through predation and competition (Nico & Fuller, 2000).

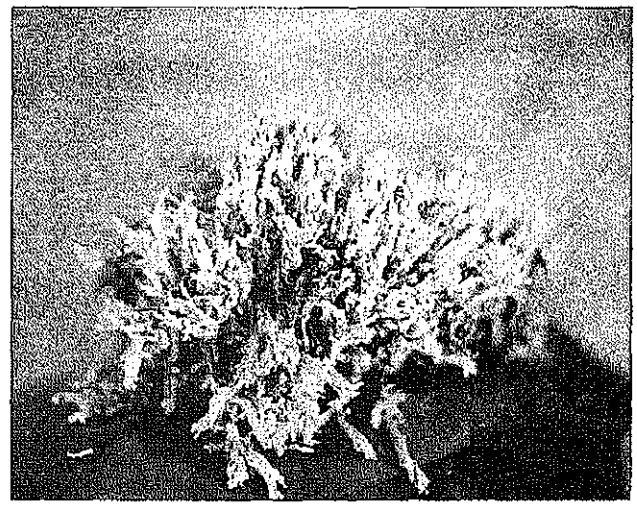

Fig. 2/Sl. 2: *Ficopomatus enigmaticus.* ***(Photo/Foto: T. Makovec)***

In the Sečovlje Salina Landscape Park, the Polychaeta *Ficopomatus enigmaticus* (Fig. 2) (Avčin, 1984) was recorded. This species originates from the Southern Hemisphere and it has probably been introduced on ships' hulls and commercial mollusc shells (Thorp, 2000).

In 1995, the Siphonophora (Hydrozoa) *Muggiaea atlantica*, a representative of the Atlantic fauna, was found for the first time in the Adriatic Sea off Dubrovnik (Gamulin & Kršinić, 2000). The species arrived to the northern Adriatic in 1996, reached a high density in July 1997, followed by its mass extinction a month later (Gamulin & Kršinić, 2000).

Other introduced species in the northern Adriatic Sea are (Cognetti, 1994; Occhipinti Ambrogi, 1994): the Amphipoda (Crustacea) *Echinogammarus pungentoides*, the Isopoda (Crustacea) *Paraceneis sculpta*, the Bryozoa *Tricellaria inopinata*, and the Gastropoda *Littorina saxatilis*.

The data presented in the paper of Arbulla *et al.* (2000) was not taken in consideration, because there were a lot of uncertainties regarding the non-native species.

INTRODUCED FLORA

Nine species of introduced macrophytes are known from the northern Adriatic Sea (Tab. 2).

Nowadays, the most notorious introduced alga in the whole Mediterranean Sea is the tropical alga *Caulerpa taxifolia* (Fig. 3), which has been displayed over the last fifteen years in tropical aquaria at the Oceanographic Museum in Monaco. Its accidental introduction into the natural environment dates from 1984 (Meinesz & Hesse, 1991). The first record of the alga in the Adriatic Sea was in Stari Grad Bay (Hvar Island, Croatia) in the summer of 1994 (Žuljević & Antolić, 1998). Few months later divers spotted the alga in Malinska, Island of Krk (Žuljević & Antolić, 1998). The third and last recording was in October 1996 on the northwest side of Dolin Island in the Barbat Channel (Žuljević & Antolić, 1998). It was estimated that the alga had been brought into the areas of the Stari Grad Bay and Malinska Harbour in 1991 and into the Barbat Channel in 1995 (Špan *et al.*, 1998; Žuljević & Antolić, 1998). The site in Malinska was only partially eradicated while the site in the Barbat Channel was eradicated in total (Žuljević & Antolić, 1998).

Tab. 1: Non-indigenous fauna in the northern Adriatic Sea.
Tab. 1: Tujerodna favna v severnem Jadranu.

Taxa	Class	Origin	Vector	First record	Source
Acartia tonsa	Crustacea	Indo-Pacific	aquaculture	1987	Occhipinti (2000)
Balanus trigonus	Crustacea	Circumtropical	shipping	1968	Zavodnik (1998)
Brachydontes pharaonis	Bivalvia	Indo-Pacific	Lessepsian introduction	1996	De Min & Vio (1998)
Bursatella leachii	Gastropoda	Circumtropical	Lessepsian introduction	1986	De Min & Vio (1998)
Callinectes danae	Crustacea	Western Atlantic	?	1981	CIESM (2000)
Callinectes sapidus	Crustacea	Western Atlantic	ballast waters	1949	CIESM (2000)
Crassostrea gigas	Bivalvia	Japan	aquaculture	1969	De Min & Vio (1998)
Dyspanopeus sayi	Crustacea	N-W Atlantic	ballast waters	1992	CIESM (2000)
Echinogammarus pungen-	Crustacea	?	aquaculture	?	Cognetti (1994)
Ficopomatus enigmaticus	Polychaeta	Australia	?	?	Avčin (1984)
Gambusia affinis	Osteichthyes	Central America	purposeful introduction	1936	Leiner *et al.* (1995)
Halgerda sp.	Gastropoda	Indo-Pacific	ballast waters	1988	Turk (2000)
Littorina saxatilis	Gastropoda	Atlantic	?	1792	Occhipinti Ambrogi (1994)
Muggiaea atlantica	Hydrozoa	Atlantic	?	1996	Gamulin & Kršinić (2000)
Musculista senhousia	Bivalvia	Indo-Pacific	Lessepsian introduction	1986	De Min & Vio (1998)
Paraceneis sculpta	Crustacea	?	?	?	Cognetti (1994)
Perna picta	Bivalvia	Atlantic	shipping	1996	De Min & Vio (1998)
Pinctada radiata	Bivalvia	Indo-Pacific	Lessepsian introduction	1996	De Min & Vio (1998)
Rapana venosa	Gastropoda	Japan	shipping	1973	De Min & Vio (1998)
Rhithropanopeus harrisii	Crustacea	N-W Atlantic	ballast waters	1994	CIESM (2000)
Saccostrea commercialis	Bivalvia	Australia	aquaculture	1980	De Min & Vio (1998)
Scapharca inaequivalvis	Bivalvia	Indo-Pacific	ballast waters	1969	De Min & Vio (1998)
Strombus decorus	Gastropoda	Indian Ocean	shipping	1996	De Min & Vio (1998)
Tapes philippinarum	Bivalvia	Indo-Pacific	aquaculture	1983	De Min & Vio (1998)
Tricellaria inopinata	Bryozoa	Indo-Pacific	?	1982	Occhipinti Ambrogi (1994)
Xenostrobus securis	Bivalvia	Australia	shipping	1992	De Min & Vio (1998)

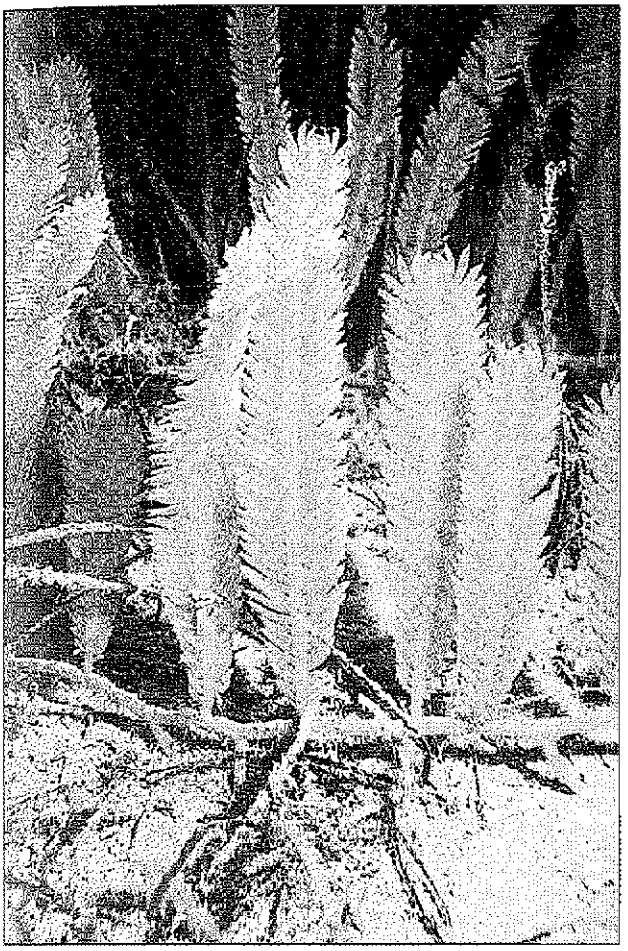

Fig. 3/Sl. 3: Caulerpa taxifolia. ***(Photo/Foto: M. Richter)***

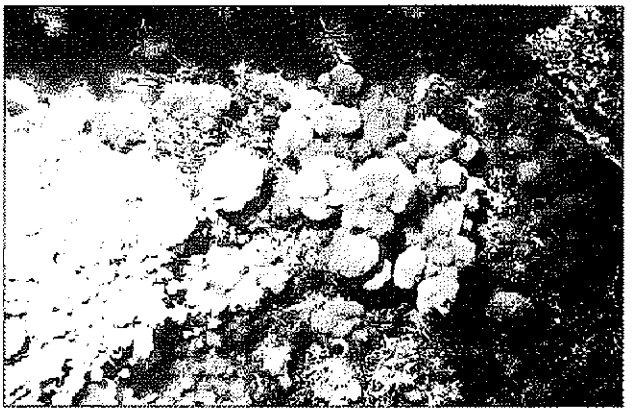

Fig. 4/Sl. 4: Asparagopsis armata - Falkenbergia rufolanosa ***phase. (Photo/Foto: M. Richter)***

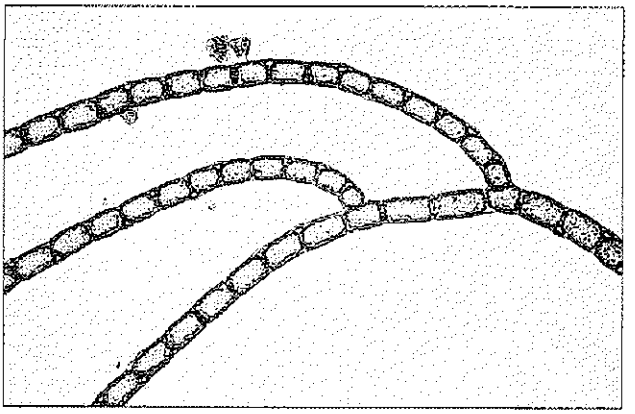

Fig. 5/ Sl. 5: Bonnemaisonia hamifera - Trailliella ***phase (Photo/Foto: M. Richter)***

The non-indigenous red alga *Asparagopsis armata* was recorded for the first time in the northern Adriatic, in Slovenian coastal waters, in 1991 (M. Richter, *pers. comm.)*, but only the tetrasporophyte - *Falkenbergia rufolanosa* phase (Fig. 4). Six years later the gametophyte plants were recorded in Croatian waters near Senj (M. Richter, *pers. comm.)*. This species originates from Australia and/or possibly New Zealand and it was introduced to the Mediterranean Sea unintentionally with oysters (Ribera & Boudouresque, 1995).

In 1995, the red algae *Bonnemaisonia hamifera* was found in Slovenian coastal waters, but only the filamentous tetrasporophyte - *Trailliella* "pink cotton wool" phase (M. Richter, *pers. comm.)* (Fig. 5). This species originates in the Pacific and was probably introduced with shellfish from Japan (Tittley, 2000).

The green alga *Ulva scandinavica* (originating from Sweden and Norway) was recorded for the very first time in the coastal waters of Slovenia in September 1998 (Battelli & Tan, 1998). It was also the first record of this species in the Adriatic Sea. Before that, *U. scandinavica* was recorded in the Mediterranean Sea only on the west and south coast of Italy (Battelli & Tan, 1998).

The presence of *Codium fragile* subsp. *tomentosoides* in the northern Adriatic Sea was noticed for the first time in 1992 (Munda, 1992). Its presence in Slovenian coastal waters was confirmed many times (Munda, 1993; Battelli & Vuković 1995; Battelli, 1996). This species (Fig. 6) originated in the Pacific Ocean around Japan. It spread remotely either as an associated unintentional introduction attached to shellfish as oysters, attached to ships' hulls or as spores in ballast tanks. In the Mediterranean Sea it was reported for the first time in French waters in 1950, and subsequently appeared at both near and distant sites, with no apparent link with either the direction of the currents or the distance (Fig. 7) (Ribera & Boudouresque, 1995).

The invasive seaweeds *Undaria pinnatifida, Sargassum muticum* and *Antithamnion pectinatum* have been recorded in the Venice Lagoon (Curiel *et al.*, 1994; 1995; 1996; 1998). The brown seaweed *Sargassum muticum* (Fig. 8) was first introduced into France along with *Crassostrea gigas* in the late 1960s (Critchley *et al.*, 1983). The subsequently rapid expansion of the alga has led to a dramatic increase in the number of permanent

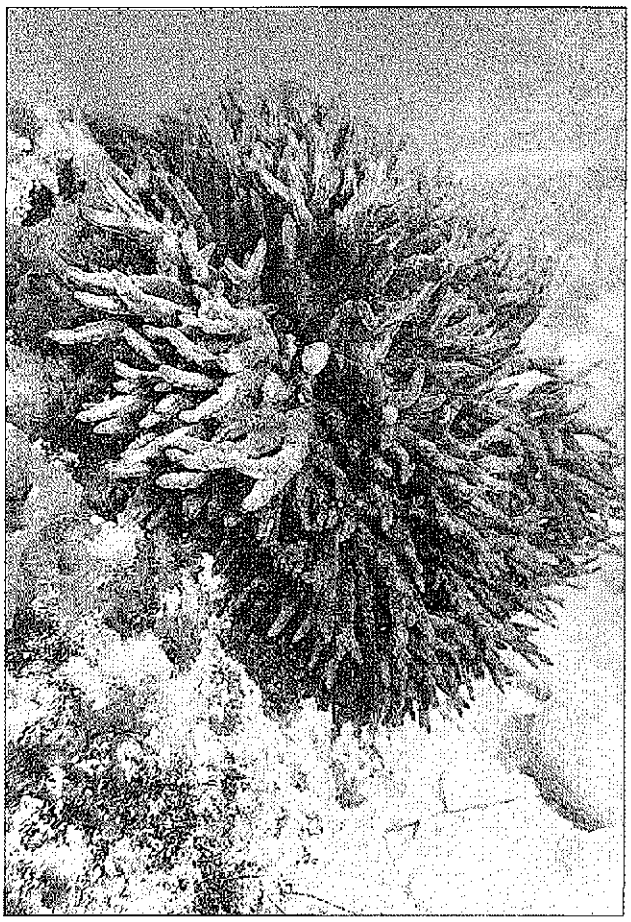

Fig. 6/ Sl. 6: Codium fragile. ***(Photo/Foto: M. Richter)***

populations along the European Atlantic coast and in the western Mediterranean. Also the introduction of *Undaria pinnatifida* and *Antithamnion pectinatum* in European waters was caused by the importation of the Japanese oyster in mariculture (Rueness, 1989). All these species have quickly colonized the hard substrata in the Venice Lagoon, competing with indigenous species, and the lack of potential predators in the colonized area (such as sea urchin *Paracentrotus lividus*) probably enhances their spread. According to several authors, manual eradication may be ineffectual, due to their efficient reproduction mechanisms and preliminary data showed quick recolonization of the area (Curiel *et al.*, 1998).

Recently, another alga from the genus *Sorocarpus* has been reported for the Venice Lagoon, which is also the first record in the Mediterranean (Curiel *et al.*, 1999). The authors have not made any hypotheses about the origin and the period of arrival of the settlement, due to the lack of knowledge of its distribution in the lagoon area.

CONCLUSIONS

Although the northern Adriatic Sea is just a small portion of the Mediterranean marine realm, it has been certainly affected by the invasion of non-indigenous species. These organisms have been introduced mostly by shipping, through the Suez Canal or for aquaculture purposes. Twenty-six introduced animals and nine algae have been recorded to date. It is quite reasonable to expect that the list will be expanded in the near future.

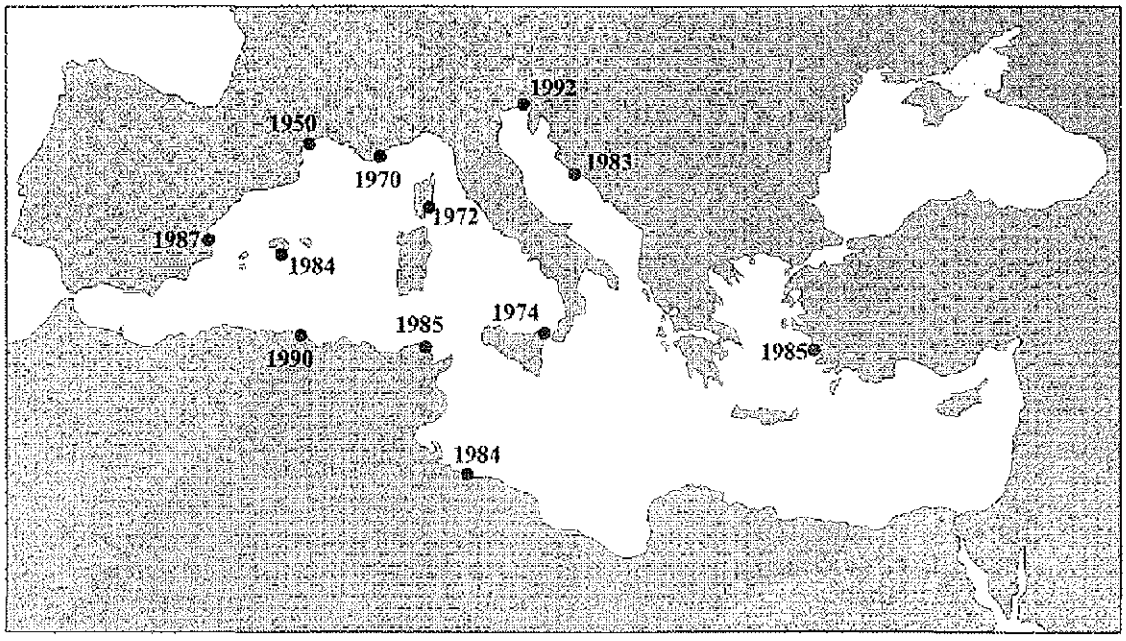

Fig. 7: Chronology of the expansion of *Codium fragile* ***in the Mediterranean (modified from Ribera, 1994).***
Sl. 7: Kronologija širjenja vrste *Codium fragile* ***v Sredozemlju (dopolnjeno po Riberi, 1994).***

Tab. 2: Non-indigenous flora in the northern Adriatic Sea.
Tab. 2: Tujerodna flora v severnem Jadranu.

Taxa	Division	Origin	Vector	First record	Source
Antithamnion pectinatum	Rhodophyta	Japan	aquaculture	1994	Curiel *et al.* (1996)
Asparagopsis armata	Rhodophyta	Australia	Gibraltar	1991	Richter *(oral. comm.)*
Bonnemaisonia hamifera	Rhodophyta	Pacific	Gibraltar	1995	Richter (*oral. comm.*)
Caulerpa taxifolia	Chlorophyta	Pantropical	aquarium	1994	Žuljević & Antolić (1998)
Codium fragile subsp. *tomentosoides*	Chlorophyta	Pacific Ocean	Gibraltar	1992	Munda (1992)
Sargassum muticum	Phaeophyta	Japan	aquaculture	1992	Curiel *et al.* (1995)
Sorocarpus sp.	Phaeophyta	?	?	1996	Curiel *et al.* (1999)
Ulva scandinavica	Chlorophyta	Sweden	?	1998	Battelli & Tan (1998)
Undaria pinnatifida	Phaeophyta	Japan	aquaculture	1992	Curiel *et al.* (1994)

As the future of the introduced species in the whole Mediterranean Sea is unpredictable, it would be necessary to start an international collaborative program to survey the rate of invasion and to develop a global data bank on introduced species and receptive habitats. It would also be proper to set up an international monitoring programme of ballast waters. The exchange of ballast water as far as possible from the coast is nowadays believed to be the most reliable method to minimise the risk of transfer of unwanted organisms (Gollasch & Leppäkoski, 1999).

But if not accompanied with a proper enforcement of existing national and international legislations (above all the articles concerning the transfer of living marine organisms), even the best research and monitoring programs shall have little chance to control and minimize the introduction of potentially harmful marine non-indigenous species. Nowadays, the current legislations appear very inadequate and insufficient (De Klemm, 1994; Verlaque, 2001).

Fig. 8/Sl. 8: *Sargassum muticum.* ***(Photo/Foto: M. Richter)***

ACKNOWLEDGEMENTS

I wish to thank Asst. Prof. Dr. Lovrenc Lipej for his advice and help during the preparation of the paper, Marjan Richter for his information and photos, Dr. Aleksander Vuković for sharing with me his knowledge, Tihomir Makovec for his photos and technical help, and Vladimir Bernetič for his help in the search for the literature.

PREGLED VNOSOV TUJERODNIH VRST V SEVERNI JADRAN

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POVZETEK

Avtorica podaja pregled zabeleženih vnosov tujerodnih vrst v severnem Jadranu, temelječem na bibliografskih zapisih ter še ne objavljenih podatkih. Na tem območju je bilo opaženih petintrideset alohtonih vrst, od tega devet alg in šestindvajset živali. Med algami je najbolj znana eksotična vrsta Caulerpa taxifolia, *ki je bila v severnem Jadranu prvič opažena leta 1994. Mehkužci so najpogosteje vnešene živali.*

Tujerodni morski organizmi se na več načinov nenehno širijo po svetu in tako prihajajo tudi v severno-jadranske vode. Plovba je najpomembnejši vnosni vektor. Strokovnjaki menijo, da so balastne vode z ekološkega in taksonomskega vidika najmanj selektiven način prenosa organizmov. Plovila prevažajo organizme tudi na svojem trupu in dnu. Eksotični organizmi vstopajo v Sredozemsko morje tudi skozi Sueški prekop, ki je bil zgrajen leta 1869. Tretji zelo pomembni vir vnosa tujerodnih vrst pa je marikultura. Japonsko ostrigo (Crassostrea gigas) *so prvič uvozili v Evropo v šestdesetih letih in nehote z njo pripeljali tudi nekatere vrste alg, kot sta* Sargassum muticum *in* Undaria pinnatifida, *ki se zelo hitro širita na trdih podlagah Beneške lagune.*

Strokovnjaki se s tujerodnimi vrstami premalo časa ukvarjajo, da bi lahko natančno ocenili njihov vpliv na novo okolje. Večina teh vrst kmalu pogine, tiste, ki pa preživijo, lahko povzročijo ogromno škodo. Da do takih posledic v severnem Jadranu ne bi nikoli prišlo, bi bilo treba izboljšati obstoječo zakonodajo ter temeljito in kontinuirano nadzorovati vse možne vire vnosa tujerodnih vrst.

Ključne besede: tujerodne vrste, vnos, severni Jadran

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