Marija Crnčević*
Melita Peharda**

ISSN (0469-6255)
(51-56)

INTRODUCTIONS OF EXOTIC MARINE SPECIES ASSOCIATED WITH SHIPPING ACTIVITIES

UNOS EGZOTIČNIH MORSKIH VRSTA U SVEZI S AKTIVNOSTIMA BRODOVA

UDK 574.512.623
Review
Pregledni članak

Summary

An overview of some present day knowledge regarding introductions of exotic marine species associated with shipping activities is given in this paper. Transports of organisms via biofouling on ocean-going ships, water ballast and dispersal along rivers or canals are explained, illustrated by examples and their consequences and possible solutions are discussed. Special attention has been given to following species: Dreissena polymorpha, Mnemiopsis leidyi, Alexandrium sp. and Caulerpa taxifolia.

Sažetak

U ovom je radu pregledno opisan dio spoznaja o unosu egzotičnih morskih vrsta u svezi s aktivnostima brodova. Objašnjen je prijenos organizama pomoću sljedećih vektora: obrast na prekooceanskim brodovima, balastna voda i rasprostranjivanje rijekama i kanalima (prolazima). Navedeni su primjeri unesenih vrsta te su objašnjene posljedice i moguća rješenja. Detaljnije su opisane sljedeće vrste organizama: Dreissena polymorpha, Mnemiopsis leidyi, Alexandrium sp. i Caulerpa taxifolia.

*Marija Crnčević
The Polytechnic of Dubrovnik, Ćira Carića 4, Dubrovnik

**Melita Peharda
Institute of Oceanography and Fisheries,
Laboratory Dubrovnik, P.O.Box 39, Dubrovnik

Throughout the earth's history, species were introduced into new environments through natural processes. However, the current rate of species introduction is a direct result of human activities (Huston 1994). Our fascination with the new and unknown has resulted in "transplanting" numerous plant and animal species from their natural environments into our shore waters, ponds and aquaria. Unknown number of species has either accidentally or intentionally been transported by humans into regions where they have not historically occurred (Lodge 1993, Norse 1993, Huston 1994).

Current scientific and popular literature uses terms such as biological invasions, biological pollution, or alien, exotic, nonindigenous, nonnative, or introduced species for naming this phenomenon (Norse 1993). According to Huston (1994), understanding the ecology of invasions requires addressing following issues: the rates and mechanisms of transport or movement of organisms, the characteristics of organisms that allow them to be successful invaders, and the properties of ecosystems that make them susceptible or resistant to invasions. Describing properties of ecosystem is beyond the scope of this paper and will not be discussed.

Biofouling on ocean-going ships, sea water and freshwater ballast, dry ballast, active or passive dispersal along rivers or canals (e.g. Suez Canal), intentional fisheries introductions, aquaculture, escapes from farms, aquaria and scientific laboratories are some of the identified mechanisms for species dispersal (Leppakoski and Goda 1991, Ribera and Boudouresque 1995). In this paper we will provide an overview of introduction mechanisms associated with shipping activities – biofouling on ocean going ships and water ballast. Also, we will explain introductions caused by construction of Suez Canal. Example of Suez will be included because it is indirectly related to shipping activities. At the end, we will shortly explain the introduction and dispersal of exotic algae Caulerpa taxifolia in the Adriatic Sea.

Since the early times of Phoenicians and Vikings, wooden ships moved marine animals and plants on their keels (Nolan 1994). In the 16th century, when European trade routes expanded from the Atlantic Ocean to Pacific and further, new marine environments became susceptible to the introduction of exotic species (Carlton 1994). During the 1800s and early 1900s, fouled hulls were probably the main mechanism for introducing exotics into marine environment (www.marine.csiro.au/CRIMP/mechanisms2.html). It is probable that certain species that today have a worldwide distribution actually correspond to ancient introductions (Ribera and Boudouresque 1995).

Biofouling generally concerns small-sized species; nevertheless, large species whose life history includes a microscopic stage may be transferred by this vector (Ribera and Boudouresque 1995). Numerous species belonging to different animal and plant taxa have been transported via biofouling. Most data dealing with this problematic comes from the Australian region. Research conducted on the overseas vessels in Australian ports identified fouling species from the following taxa: sponges, hydroids, mussels, barnacles, bryozoans and ascidians (Rainer 1995).

Attributes of modern vessels such as faster speeds, low port residency times, more frequent maintenance, and the use of highly effective antifouling paints have greatly reduced the possibility of nonindigenous species transport via biofouling (Carlton and Hodder 1995). However, research conducted by Rainer (1995) indicates that some algae, barnacles and polychaete worms are able to settle and grow on antifouling coatings, even on the exposed section of a hull. This author showed that underwater areas without antifouling coverings, such as the propeller and propeller shaft, and under shipping blocks, may have dense populations of barnacles and tube worms. Further on, more protected areas, such as behind gratings on inate vents, and particularly under bilge kills and near the stern, can support a much greater variety of sessile fouling species (Rainer 1995). According to Hewitt and Martin (1996), fouling on the hulls of coastal vessels and pleasure craft is likely to be an important mechanism for the translocation of sedentary and encrusting species away from a port of first entry.

Antifouling paints in current use have different chemical compositions. More effective once are based on tin and are highly toxic (Readman et al. 1993, Hewitt and Martin 1996). Environmentally friendly antifouling paints are copper-based and are not as effective (Hewitt and Martin 1996). Taking this into consideration as well as the results of the research conducted by Rainer (1995), we can conclude that more research is needed on finding more effective environmentally friendly antifouling paints as well as on alternative methods for protection of ship parts on which antifouling paint is not used.

The potential for the spread of aquatic organisms by ships' ballast water has existed since the late 1870s, when water replaced the heavy materials used to stabilize cargo ships at sea (Bonny 1994). Ballast water is salt or fresh water intentionally pumped up into a vessel for trim, stability, manoeuverability, and comfort (Carlton 1985) (see Fig. 1.). Vessels almost always carry ballast water when they are without cargo, but even loaded vessels frequently carry some ballast water for trim. The total capacity of ballast tanks of the vessel varies. It has been estimated that the world shipping fleet is transporting approximately 10 billion tones of ballast water around the globe per year and that on average more than 3000 species of plants and animals are being transported daily around the world (Carlton and Geller 1993, UNDP Report 1998 in Paterson and Colgan 1998).

Despite considerable spatial variation in supply patterns, the movement of ballast water appears to be a single largest source of non indigenous species transfer throughout the world (Carlton 1985). In addition, it is probably the best documented transport vector. Chu et al. (1997) found that species richness of the ballast sample decreased with the age of the ballast water. Species diversity in a ballast tanks also depends on the location and seasonality of the water ballasted. Carlton and Geller (1993) found 367 taxa in the sea water ballast of ships sailing from Japanese ports to Oregon. Their samples contained representatives from all major trophic groups and most temperate shallow-water marine communities.

The full danger of ballast-mediated invasions can be clearly illustrated with the following examples: introduction of the zebra mussel (Dreissena polymorpha) into the Great Lakes (Roberts 1990), comb jelly (Mnemiopsis leidyi) into the Black Sea (Vinogradov et al. 1989) and fitoplankton Allexandrium sp. into Australia (Hallegraeff et al. 1990).

In 1985 or 1986, Dreissena was introduced from southern Russia into the Great Lakes. Lack of natural ecological constraints fostered the rapid expansion of this freshwater bivalve mollusk throughout the waterways of United States and Canada. Due to two of its features: efficient suspension feeding and notorious biofouling; the zebra mussel soon caused a multitude of ecological as well as economic problems. The ability of the zebra mussel to remove contaminants from the

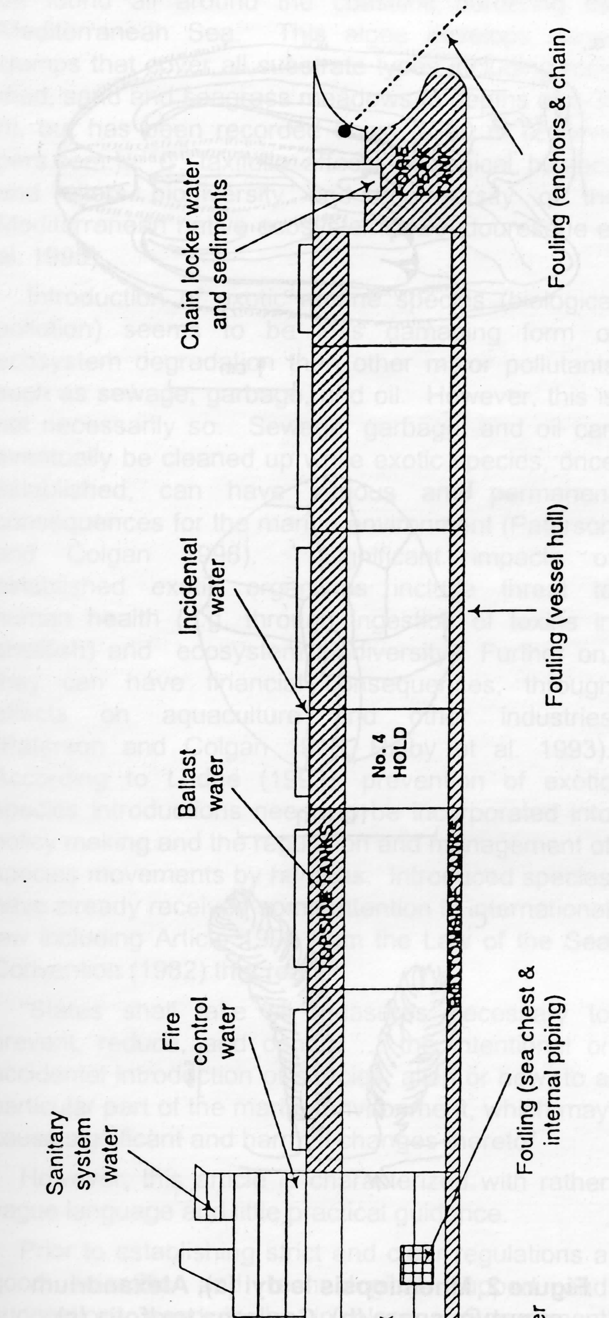

Figure 1. Potential transport vectors associated with a typical bulk carrier. Figure taken from Hayes and Hewitt (1998)
Slika 1. Mogući prijenosni vektori u svezi s tipičnim brodom za rasuti teret Slika od Hayes i Hewitta (1998)

water and concentrate them on the lake floors and shorelines is only one example of the negative impact of this species. Today, millions of dollars are allocated for ongoing studies of zebra mussel biology and for the development of environmentally benign control strategies (Ludyanskiy et al.1993). So far, an effective solution has not been found.

Mnemiopsis leidyi (Fig. 2a.) was introduced into the Black Sea via ballast water in the early 1980s (Vinogradov et al. 1989). Starting in the summer and autumn of 1988, the mass development of Mnemiopsis began causing significant changes in the structure of the Black Sea plankton community (Zaika and Sergeyeva 1992, Shuskina and Musayeva 1990, Zaitsev 1992). A sharp decrease of anchovy and other pelagic fish stocks occurred at the time and was linked to the Mnemiopsis introduction (Kideys 1994). In 1995, Harbison and Vinogradov suggested a possible solution including introduction of a native predator, the butterfish Peprilus triacanthus, as a form of biological control. Due to lack of funding needed for further research before practical measures could take place - this problem is still not solved.

There have been many reports on the occurrence of toxic dinoflagellates belonging to Alexandrium (Fig 2b.) genus in Australian waters. This small sized dinoflagellate, which can potentially cause Paralyzing Shellfish Poison (PSP), poses a significant threat to shellfish, shellfish industries and human health (Giacobbe and Maimone 1994, Peterson and Colgan 1998). Alexandrium sp. can be inadvertently introduced when their cysts are discharged with the water or sediment contained in ship's ballast tank. Upon a release of ballast, Alexandrium sp. is transferred to the water column and enters the food web. According to Hallegraeff and Bolch (1991), 40% of cargo vessels entering Australian ports contained viable dinoflagellate cysts and 6% carried the cysts of the dinoflagellates Alexandrium catenella and A. tamarense (up to an estimated 300 million cysts per ship). In the Mediterranean, Alexandrium minutum was first recorded in the inshore waters of Sicily in 1990 (Giacobbe and Maimone 1994). However, Alexandrium minutum never dominated algal community in the Mediterranean (Giacobbe et al. 1996).

Dreissena, Mnemiopsis and Alexandrium sp. are probably most famous and studied examples of ballast-mediated introductions and after almost ten years of research there is still no solution to the problems that they caused. The question that comes to mind is how many other alien species are out there altering the ecosystems and are we using Dreissena, Mnemiopsis and Alexandrium as escape goats while overlooking other issues? The answer is: we do not know. According to Carlton and Geller (1993), ballast water acts as a phyletically and ecologically nonselective transport vector that is capable of transporting entire coastal planktonic assemblages across oceanic barriers to similar habitats. Unknown number of species has been transported this way and data are available for only few of these introductions. Leppakoski and Goda (1991) argue that most exotics do not have any influence on man's economic interests and that their ecological impact has been more or less unobservable. But what practical actions can we take without waiting for the results of further research?

Most ships are ballasted in ports and will typically entrain the neritic and estuarine organisms living there. Unloading of ballast water also occurs in ports - transported organisms are released in the environment somewhat similar to their natural. Possible solution for reducing transfer of unwanted marine organisms is ocean exchange of ballast water. This can be done in two ways: either by reballasting or by continuous flushing of ballast tanks (Carlton and Geller 1993, Rigby and Hallegraeff 1994). Exchange of ballast water should preferably be carried out in deep ocean areas or open seas which are not rich in nutrients and planktonic life forms unlike coastal and estuarine waters (Rigby and Hallegraeff 1994). Australia and USA came up with a legislation that forces ship captains to discharge ballast water before entering their territorial waters (Nolan 1994). Similar legislation also exists for Great Lakes, where ocean-going ships are required to exchange fresh water ballast with salt water before entering the Lakes (Drake 1994). To conclude, some possible solutions already exist but more research is still urgently needed.

Opening of Suez Canal in 1869 linked the Mediterranean and Red Sea. This resulted in invasion of the Mediterranean, mostly Levantin basin, by nearly 300 species of the Red Sea and Indo-West the Pacific origin. These organisms have been called "Lessepsian migrants" and now represent about 4% of the Mediterranean species diversity (Por 1978 in Boudouresque 1996). The low biodiversity of Levantin basin, caused by historic isolation, explains the great success that the Lessepsian immigrants have enjoyed (Spanier and Galil 1991). An example of problem related to this immigration are mass aggregations of the jellyfish that exert a significant impact on fisheries, coastal installations and tourism. Coastal fishing was disrupted for several weeks in the summer of 1990 due to the damage done to fishing nets and inability to sort the yield. On the other hand, some established species are being the commercially exploited (Spanier and Galil 1991).

Presently, the major concern regarding nonindigenous species in the Adriatic Sea is continuing spread of a tropical green algae Caulerpa taxifolia (Fig. 2c). According to Špan et al. (1998), until now C. taxifolia has been found on three

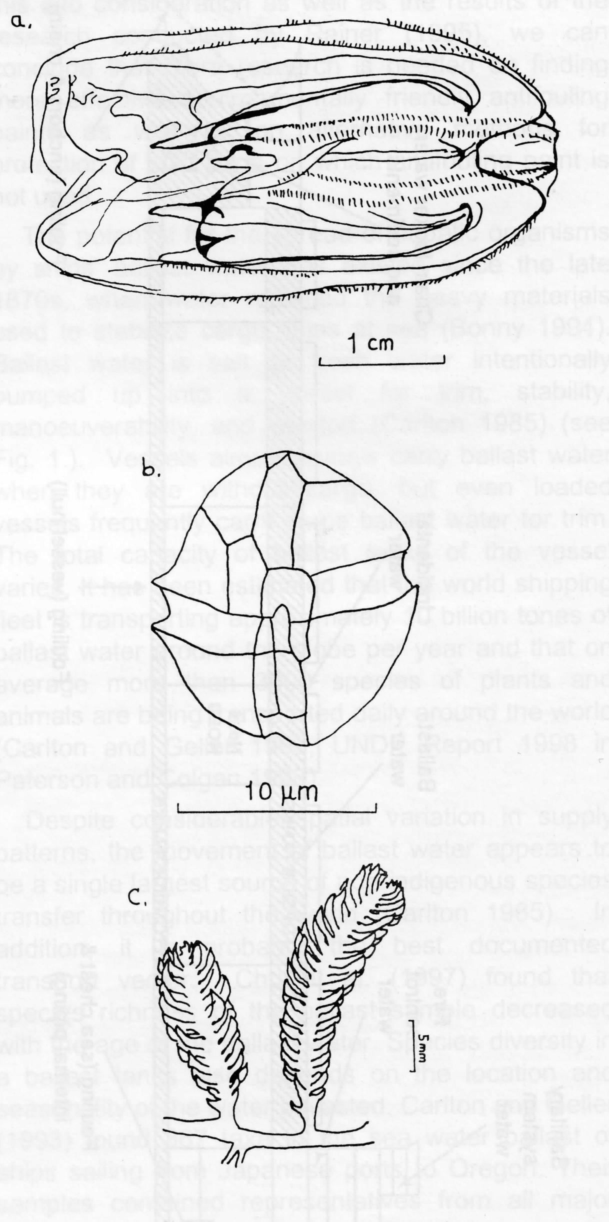

Figure 2. Mnemiopsis leidyi (a), Alexandrium minutum spore (b), Caulerpa taxifolia (c) (Illustration made by Valter Kožul)

Slika 2. Mnemiopsis leidyi (a), Alexandrium minutum spore (b), Caulerpa taxifolia (c) (Ilustrirao Valter Kožul)

locations in the Adriatic Sea: Stari Grad Bay (Hvar Island), Malinska (Krk Island) and Dolin Island. This alga was probably brought in the Adriatic Sea region in 1991 by the anchor casing (Sant et al. 1994). In the Mediterranean, C. taxifolia was recorded for the first time in 1984 in the Monaco offshore waters. The most likely hypothesis is that this algae came from the tropical aquarium display in Monaco's Oceanographical Museum. (Boudouresque et al. 1995). Since that time, this species has spread to many locations on the French, Spanish, Italian and Croatian coast. It is expected that due to its ecological characteristics C. taxifolia will eventually be found all around the coastline bordering the Mediterranean Sea. This algae develops dense clumps that cover all substrate types including rock, mud, sand and seagrass meadows to depths of 0-35 m, but has been recorded down to 90 m (Žuljević pers.com.). C. taxifolia affects ecological balance and alters biodiversity and ecodiversity of the Mediterranean native ecosystems (Boudouresque et al. 1995).

Introduction of exotic marine species (biological pollution) seems to be less damaging form of ecosystem degradation than other major pollutants such as sewage, garbage, and oil. However, this is not necessarily so. Sewage, garbage, and oil can eventually be cleaned up while exotic species, once established, can have serious and permanent consequences for the marine environment (Paterson and Colgan 1998). Significant impacts of established exotic organisms include threat to human health (e.g. through ingestion of toxins in shellfish) and ecosystem biodiversity. Further on, they can have financial consequences, through effects on aquaculture and other industries (Paterson and Colgan 1998, Rigby et al. 1993). According to Lodge (1993), prevention of exotic species introductions needs to be incorporated into policy making and the regulation and management of species movements by humans. Introduced species have already received some attention in international law including Article 1996 from the Law of the Sea Convention (1982) that reads:

"States shall take all measures necessary to prevent, reduce, and control ... the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto"

However, this article is characterized with rather vague language and little practical guidance.

Prior to establishing strict and clear regulations a good scientific and technological support and suggestions need to be in place. Government authorities and multinational companies become seriously concerned with problems related to introduction of exotic species only for the past few years. This resulted in support - research funds - to scientific and technological community. Today there are many research programs dealing with this problematic and no simple and definite solution has yet been found. We can only hope that it comes soon.

ACKNOWLWDGEMENT

ZAHVALA

Authors are grateful to Ante Žuljević for reading and correcting part of manuscript related to Caulerpa taxifolia.

Literature

Literatura

[1] Bonny M. 1994. Ballast water - the scourge of the oceans. Search, 25: 72-74.

[2] Boudouresque C.F. 1996. The Red Sea - Mediterranean link: unwanted effects of canals. In: Proceedings of the Norway/UN Conference on Alien Species, Trondheim, July 1996 (eds. O.T. Sandlund, P.J. Schei and A. Viken). Pp. 107-115.

[3] Boudouresque C.F., Meinesz A., Ribera M.A. and E. Ballesteros 1995. Spread of the green alga Caulerpa taxifolia (Caulerpales, Chlorophyta) in the Mediterranean: possible consequences of a major ecological event. Scentia Marina, 59(1):21-29.

[4] Carlton J.T. 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. Oceanography and Marine Biology Annual Rewiew, 23: 313-371.

[5] Carlton J.T. 1994. Biological invasions and biodiversity in the sea: the ecological and human impacts of nonindigenous marine and estuarine organisms. In: Proceedings of the conference & workshop on nonindigenous estuarine and marine organisms (NEMO) Seattle, Washington, April 1993. National Oceanic and Atmospheric Administration, US Department of Commerce. Pp. 5-11.

[6] Carlton J.T. and J.B. Geller 1993. Ecological roulette - the global transport of nonindigenous marine organisms. Science, 261:78-82.

[7] Carlton J.T. and J. Hodder 1995. Biogeography and dispersal of coastal marine organisms: experimental studies on a replica of a 16th-century sailing vessel. Marine Biology, 121:721-730.

[8] Chu K.H., Tam P.F., Fung C.H. and Q.C. Chen 1997. A biological survey of ballast water in container ships entering Hong Kong. Hydrobiologia, 352: 201-206.

[9] Drake J.A. 1994. Some thoughts on biological invasions: towards a new invasion ecology In: Proceedings of the conference & workshop on nonindigenous estuarine and marine organisms (NEMO) Seattle, Washington, April 1993. National Oceanic Atmospheric Administration, US Department of Commerce. Pp. 13-16.

[10] Giacobbe M.G. and G. Maimone 1994. First report of Alexandrium minutum Halim in Mediterranean lagoon. Cryptogamie, Algol., 15(1):47-52.

[11] Giacobbe M.G., Oliva F.D. and G. Maimone 1996. Environmental factors and seasonal occurrence of the dinoflagellate Alexandrium minutum, a PSP potential producer, in a Mediterranean Lagoon. Estuarine, Coastal and Shelfish Science, 42: 539-549.

[12] Hallegraeff G.M., Bolch C.J., Bryan J. and B. Koerbin 1990. Microalgal spores in ships' ballast water: a danger to aquaculture. In Toxic Marine Phytoplankton, Elsevier, New York (eds. Graneli, E. et al.). Pp.475-480.

[13] Hallegraeff G.M. and C.J. Bolch 1991. Transport of toxic dinoflagellate cysts via shipsÕ ballast water. Marine Pollution Bulletin, 22(1): 27-30.

[14] Harbison, G.R. and M.E. Vinogradov 1995. An action plan for the control of the introduced ctenophore, Mnemiopsis leidy, in the Black and Azov Seas. A Report Prepared for the United Nations Environmental Program.

[15] Hayes K.R. and C.L. Hewitt 1998. Risk assessment framework for ballast water introductions. CRIMP Technical report No 14, CSIRO Division of Marine Research, Hobart, 75pp.

[16] Hewitt C.L. and R.B. Martin 1996. Port surveys for introduced marine species - background considerations and sampling protocols. CRIMP Technocal report No 4. CSIRO Division of Marine Research, Hobart, 40pp.

[17] Huston M.A. 1994. Biological diversity -- the coexistance of species on changing landscapes. Cambridge University Press,

681 pp.

[18] Kideys A.E. 1994. Recent dramatic changes in the Black Sea ecosystem: the reason for the sharp decline in turkish anchovy fisheries. Journal of Marine Systems, 5:171-181.

[19] Leppakoski, E.J. and T. Goda 1991. Introduced species - resources or threat in brackish-water seas? Examples from the Baltic and the Black Sea. Environmental management and appropriate use of enclosed coastal seas - EMECS '90. Marine Pollution Bulletin, 23:219-223.

[20] Lydyanskiy M.L., McDonald D. and D. MacNeill 1993. Impact of the zebra mussel, a bivalve invader. Bioscience, 43(8): 533-544.

[21] Lodge D.M. 1993. Biological invasions: lessons for ecology. Trends in Ecological Evolution, 8(4):133-137.

[22] Nolan C. 1994. Introduced species in European coastal waters. In: Proceedings of the conference & workshop on nonindigenous estuarine and marine organisms (NEMO) Seattle, Washington, April 1993, 17-23. National Oceanic and Atmospheric Administration, US Department of Commerce.

[23] Norse E.A. 1993. Global marine biological diversity: a strategy for building conservation into decision making. Island Press, Washington, D.C., 383pp.

[24] Paterson D. and K. Colgan 1998. Invasive marine species. An international problem requiring international solutions. Australian Quarantine and Inspection Service, 18pp.

[25] Por, F.D. 1978. Lessepsian migrations. The influx of Red Sea biota ino the Mediterranean by way of the Suez Canal. - Springer verlag, Berlin/Heidelberg/New York.

[26] Rainer S.F. 1995. Potential for the introduction and translocation of exotic species by hull fouling: a preliminary assessment. CRIMP Technical report No 1. CSIRO Division of Marine Research, Hobart, 18pp.

[27] Readman J.W., Wee Kwong L.L., Grondin D., Bartocci J., Villeneuve J.P. and L.D. Mee 1993, Coastal water contamination from a triazine herbicide used in antifouling paints. Environmental Science and Technology, 27: 1940-1942.

[28] Ribera M.A. and C.F. Boudouresque 1995. Introduced marine plants, with special reference to macroalgae: mechanisms and impact. In Progress in Phycological Research, Biopress Ltd., (eds F.E. Round and D.J. Chapman), 11:217-268.

[29] Rigby G. and G. Hallegraeff 1994. The transfer and control of harmful marine organisms in shipping ballast water: Behaviour of marine plankton and ballast water exchange trials on the MV "Iron Whyalla". Journal of Marine Environmental Engineering, 1:91-110.

[30] Roberts R. 1990. Zebra mussel invasions threatens US Waters. Science, 249:1370-1372.

[31] Sant, N., O. Delgado, C. Rodrigez-Prieto and E. Ballesteros 1994. The effects of desication on photosynthesis of Caulerpa taxifolia (Vahl.) C. Agardh. In: GIS Posidonie publ. (eds. Boudouresque, C.F., A. Meinesz and V. Gravez). Pp. 315-319.

[32] Shushkina E.A. and E.I. Musayeva 1990. Increasing abundance of the immigrant ctenophore Mnemiopsis in the Black Sea (Report of an expedition by the R/V Akvanavt and Gidrobiolog in april 1990). Oceanology, 30(4):521-522.

[33] Spanier E. and B.S. Galil 1991. Lessepsian migration: a continuous biogeographical process. Endeavour, New Series, 15(3): 102-106.

[34] Špan A., Antolić B. and A. Žuljević 1998. The genus Caulerpa (Caulerpales, Chlorophyta) in Adriatic Sea. In Rapport du Commission International pour l'Exploration Scientifique de la Mer Mediterranee, 35(2):584-585.

[35] United Nations Convention on the Law of the Sea 1982. U.N.DOC.A/CONF.62/121.

[36] United Nations Development Report 1998. Removal of barriers to the effective implementation of ballast water control and management measures in developing countries, Mission Report.

[37] Vinogradov M. Ye, E.A. Shushkina, E.I. Musayeva and P. Yu Sorokin 1989. A newly acclimated species in the Black sea: the ctenophore Mnemoipsis leidyi (Ctenophora: Lobata). Oceanology, 29(2):220-224.

[38] Zaika V.Y. and N.G. Sergeyeva 1992. Diurnal variation in population structure and vertical distribution of the ctenophore Mnemiopsis maccradyi in the Black Sea. Hydrobiological Journal, 27(5):1-6.

[39] Zaitsev Yu P. 1992. Recent changes in the trophic structure of the Black sea. Fisheries Oceanography, 1(2):189-189.

[40] www.marine.csiro.au/CRIMP/mechanisms2.html

Rukopis primljen: 2.2.1999.