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Ship Ballast Water as a Main Vector of Marine Introductions in the Mediterranean Sea

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Abstract

Marine invasive species are currently recognized as one of the most significant threats to global biodiversity. Marine bioinvasions are more likely in the Mediterranean Sea because of its wide temperature range, degraded habitats, historical and high volume of shipping traffic, and high occurrence of aquaculture. One of the main vectors of marine introductions globally and Mediterranean-wide is commercial shipping. Of the 3,000–4,000 species transferred around the world via commercial vessels, approximately 30% of these species may have been redistributed in the Mediterranean. Ships and marine invasive species arriving in the Mediterranean are mainly from temperate to cold-water regions. Standardized research and management approaches between countries are required to address the threat of ballast water borne marine invasives on a global scale. Regionally, a Mediterranean program involving the different states is currently needed to develop a common line of research and management operations.

Key words: ballast water, marine introductions, invasive species, Mediterranean Sea, shipping, standardized research and management

1 Introduction

Species extinction has been well recognized as a real and pressing possibility for ecological systems[1]. While past extinctions were the result of natural climatic changes and cataclysmic events, the present biodiversity crisis is driven by human activities[2]. In marine systems, efforts to conserve biodiversity have traditionally been overlooked due to the perception that marine habitats are richer and more diverse in species and therefore naturally more resilient than terrestrial counterparts[3]. Recently, this perception has been deemed unwise as many factors are known to adversely affect marine systems. Although the ultimate threat to marine biodiversity is unconstrained human population growth and associated over consumption, five main

1 Grosholz, E.D.: *Ecological and evolutionary consequences of coastal invasions*. In: *Trends in Ecology and Evolution.* No. 17 (2002), pp. 22–27.

2 Hill, K.: *What is biodiversity? Report from the Smithsonian Marine Station at Fort Pierce.* URL: http://www.sms.si.edu/irlspec/total_biodiv.htm. (page last updated Aug. 2001).

3 *Ibid.*

human-induced threats are highlighted as priorities to marine conservation[4]. These threats are (i) overexploitation, (ii) physical alteration of habitat, (iii) marine pollution, (iv) global climate change and changes in atmospheric composition; and (v) species introductions[5,6].

Recently, the introduction of non-indigenous marine species has emerged as a major threat due to the potentially high ecological impact on recipient communities[7]. Exotic species may cause the extinction of native species and increasingly, lead to further reductions in global biodiversity[8]. A species is defined as introduced if it has been intentionally or accidentally inserted by human activity within or outside a national jurisdiction[9,10].

2 Main Vectors of Marine Invasive Species in the Mediterranean Sea

The Mediterranean basin can be divided into two principal sectors, delimited by the Sicily Canal, and with different thermal regimes. The western part of the basin is a warm temperate region, while the eastern is sub-tropical. The eastern Mediterranean is especially susceptible to biological invasions because of its natural placement between the Pontic and Eritrean regions, the maritime traffic from the Indian Ocean, and a higher occurrence of fish and shellfish farms[11]. Due to its wider sea temperature range, the western Mediterranean is the main recipient of exotic marine plants as it can ecologically accommodate species belonging to a wide range of biogeographical origins[12]. A number of human activities lead to the introduction of organisms

4 Hixon, M.A, Boersma, P.D., Hunter, M.L., Micheli, F., Norse, E.A., Possingham, H.P., Snelgrove, P.V.R.: *Oceans at risk: research priorities in marine conservation biology.* In: Soulé, M.E., Orians, G.H. (eds). *Conservation Biology: research priorities for the next decade.* Washington, DC: Island Press, 2001, pp. 125–154.

5 *Ibid.*

6 Wilson, E.O. (ed.): *Biodiversity.* Washington: National Academy of Sciences/Smithsonian Institution, 1988.

7 Williamson, M.: *Biological invasions*. London: Chapman and Hall, 1996.

8 Lodge, D.M.: *Biological invasions: lessons for ecology*. In: *Trends in Ecology and Evolution.* Vol. 8 (1993), No.4, pp. 133–137.

9 Carlton, J.T., Thompson, J.K., Schemel, L.E., Nichols, F.H.: *The remarkable invasion of San Francisco Bay (California, USA) by the Asian clam Potamocorbula amurensis. I. Introduction and dispersal.* In: *Marine Ecology Progress Series*. Vol. 66 (1990), pp. 81–95.

10 Intermediate Technology Development Group (ITDG): *Proceedings from the Sixth Conference of the Parties to the Convention on Biodiversity (CBD/COP6).* The Hague, ITDG, 2002. URL: http://itdg.org/?id=cop6_home (accessed January 2005).

11 Galil, B.S., Zenetos, A.: *A sea exchange – exotics in the Eastern Mediterranean Sea.* In: Leppäkoski, E., Gollasch, S., Olenin, S. (eds). *Invasive Aquatic Species of Europe. Distribution, Impact and Management*. London: Kluwer Academic Publishers, 2002, pp. 325–336.

12 Ribera, M.A.: *Review of non-native marine plants in the Mediterranean Sea.* In: Leppäkoski, E., Gollasch, S., Olenin, S. (eds). *Invasive Aquatic Species of Europe. Distribution, Impact and Management*. London: Kluwer Academic Publishers, 2002, pp. 291–310.

in this marine environment. These include aquaculture, the opening of the Suez Canal, fishing, and shipping activities[13].

Aquaculture

Many marine introductions have occurred due to the intentional import of species for culture purposes that may then lead to accidental introductions to local habitats. The introduction of *Crassostrea gigas* and *Tapes philippinarum* in the Adriatic Sea, Eastern Mediterranean, for oyster farming has displaced the autochthonous *Ostrea edulis* and *Tapes decussatus*[14]. Furthermore, the unintentional transport of organisms associated with commercially cultured species has also been recorded in many instances[15]. The invasion of the mollusc *Rapana venosa* in the Northern Adriatic and Black Sea is likely due to the transport of egg masses with marine farming products[16].

Lessepsian migrations

The opening of the Suez Canal in 1869 resulted in a noticeable increase in Mediterranean diversity. The terms "Lessepsian" or "Erythrean" refer to species that crossed the Suez Canal from the Red Sea into the Mediterranean Sea. For example, the Red Sea carangidae, *Alepes djedaba* first recorded in Palestine in 1927[17], now occurs as a very common species in the Eastern Levant[18]. The Red Sea polychaete, *Branchiomma luctuosum*, now common in Mediterranean harbors and lagoons[19], has been documented to displace the autochthonous *Sabella spallanzanii*[20]. New observations of Lesspesian species are increasingly documented, a sign that migrations from the Red Sea to the Mediterranean have not stopped.

Aquarium Introductions

Caulerpa taxifolia is a famous case study species, not only in the Mediterranean, but also globally, for demonstrating the invasive potential of an aquarium species introduced

13 Ruiz, G.M., Carlton, T.J., Grosholz, E.D., Hines, H.A.: *Global invasions of marine and estuarine habitats by non-indigenous species: mechanisms, extent and consequences.* In: *American Zoologist.* (1997), No. 37, pp. 621–632.

14 Relini, G., Occhipinti, A., Gambi, M. C., Toccaceli, M.: *La problematica delle specie alloctone nei mari Italiani.* In: *Notiziario S.I.B.M.* No. 41 (2002), pp. 70–75.

15 Mann, R., Occhipinti, A. and Harding, J..M.: *ICES Special Advisory Report on the Current Status of Invasions by the Marine Gastropod Rapana venosa.* In: *ICES CM 2002/ACME:06 Ref. E, F – ICES Report of the Working Group on Introductions and Transfers of Marine Organisms held in Gothenburg, Sweden 20–22 March 2002.* Copenhagen: ICES, 2002, pp. 117–134.

16 *Ibid.*

17 Steinitz, W.: *Beiträge zur Kenntnis der Küstenfauna Palästinas.* In: *Pubblicazioni della Stazione Zoologica di Napoli.* Vol. 8 (1927), No. 3–4, pp. 311–353.

18 CIESM: *Atlas of exotic fishes in the Mediterranean.* 2002. URL: http://www.ciesm.org/atlas (accessed January 2005).

19 Sordino, P., Gambi, M. C.: *Prime osservazioni sulla biologia riproduttiva e sul ciclo vitale di Branchiomma luctuosum (Grube1869) (Polychaeta Sabellidae).* In: *Oebalia Suppl.* No. 17 (1992), pp. 425–427.

20 Gambi, M.C.: *La problematica delle specie alloctone nei mari italiani: il porto di Salerno.* Data report. Rome: Ministero dell'ambiente, 2001.

into the wild. *C. taxifolia* was introduced near the coast of Monaco in 1982[21] and has rapidly increased its distribution to the entire Mediterranean. Currently it forms continuous meadows from near sea-surface to 30m of depth and has been recorded as deep as 100m[22]. *C. taxifolia* has been shown to out compete native seagrasses that provide critical habitats for many native flora and fauna[23,24] and its toxic compounds discourage the cropping effect of local, native herbivores.

Fishing

The use of plants as packing for fish bait and for fishing nets has been considered another vector of marine introductions, albeit one of marginal significance[25]. At least three plants are known to have been introduced into the Mediterranean Sea by fishing activity. These exotic species are the marine plants *Fucus spiralis*[26], *Polysiphonia fucoides*[27] and *Womersleyella setacea*[28].

3 Ballast Water as a Major Vector for Marine Introductions in the Mediterranean

The use of ballast water for ship stability dates back to the 19th century, when water replaced heavy, dry or wet, solid material[29]. Water for ballast is stored in tanks, in many different chambers that vary in number and size. These tanks can be located on the sides of the ship, on the bottom, and in the aft and fore regions of the ship. Water is loaded at departure and depending on weather conditions, may be discharged and reloaded during the cruise, or when entering the harbor and during exchange of cargo. Usually water is drawn from ballast tanks through one or more intakes. In the

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21 Meinesz, A.: *Killer algae. The true tale of a biological invasion*. Chicago: University of Chicago Press, 1999.

22 Belsher, T., Meinesz, A.: *Deep water dispersal of the alga Caulerpa taxiformis introduced in the Mediterranean.* In: *Aquatic Botany.* No. 51(1995), pp. 163–169.

23 Piazzi, L., Ceccherelli, G., Cinelli, F.: *Threat to macroalgal diversità: effects of the introduced green alga Caulerpa racemosa in the Mediterranean Sea*. In: *Marine Ecology Progress Series*. No. 210 (2001), pp. 149–159.

24 Ceccherelli, G., Piazzi, G., Cinelli, F.: *The role of vegetative fragmentation in the recruitment process of Caulerpa taxifolia and Caulerpa racemosa.* In: Gravez, V, Ruitten, S, Boudouresque, C.F., La Direac', H.L., Meinesz, A., Scabbia, G., Verlaque, M. (eds). *Fourth international workshop on Caulerpa taxifolia*. Marseille: GIS Posidonie, 2001, pp. 111–117.

25 *Op. Cit.* 12.

26 Sancholle, M.: *Présence de Fucus spiralis (Phaeophyceae) en Méditerranée occidentale.* In: *Cryptogamie, Algologie.* No. 9 (1988), pp. 157–162.

27 Verlaque, M., Riouall, R.: *Introduction de Polysiphonia nigrescens et d'Antithamnion nipponicum (Rhodophyta, Ceramiales) sur le littoral méditerranéen français*. In: *Cryptogamie, Algologie.* No. 10 (1989), pp. 313–323.

28 Verlaque, M.: *Contribution à la flore des algues marine de Méditerranée : espèces rares ou nouvelles pour les côtes française*. In: *Botanica Marina.* No. 32 (1989), pp. 101–113.

29 Carlton, J.T.: *Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water.* In: *Oceanography Marine Biology Annual Review*. No. 23 (1985), pp. 313–371.

tank the light is absent and oxygen, salinity and temperature values can be variable according to the location of the tank and the trading area[30,31].

Examples of worldwide ballast water introductions

An enclosed sea such as the Mediterranean with its high-volume of shipping routes and degraded habitats is particularly susceptible to ship-transported bioinvasion. Commercial shipping activity has played a major role in the introduction of organisms to nonnative habitats through fouling, ballast water, and sediment. Ballast water is the most significant vector of marine introductions across the globe because of the large amount of water held in ship tank systems and the increase in shipping traffic and ships[32]. Approximately 3,000–4,000 species are redistributed around the world via the ballast water of these commercial vessels each day[33].

Particularly damaging examples of worldwide species introductions via ballast water include:

- the zebra mussel *Dreissena polymorpha* and the Asian clam *Potamocorbula amurensis* in the US[34 35];
- the comb jelly (*Mnemiopsis leidyi*) in the Black and Azov Seas[36];
- the toxic dinoflagellate (*Gymnodinium catenatum*) and the northern Pacific seastar (*Asterias amurenisis*) in Australia[37].

Alien species have been carried by Mediterranean ships since the commencement of interoceanic maritime routes five centuries ago[38]. Bioinvasions of the Mediterranean are increasing due to the high number of shipping routes and local degradation of habitats[39]. Over the past half-century, shipping has greatly expanded in the Mediterranean Sea. Between 1985 and 2001, a 77% increase was recorded in the volume of

30 *Op. Cit.* 29.

31 Gollasch, S., Lenz, J., Dammer, M., Andres, H.G.: *Survival of tropical ballast water organism during a cruise from the Indian Ocean to the North Sea.* In: *Journal of Plankton Research.* Vol. 22 (2000), No. 5, pp. 923–937.

32 *Ibid.*

33 *Ibid.*

34 Griffiths, D.W., Schloesser, D.W., Leach, J.H., Koalak, W.P.: *Distribution and dispersal of the zebra mussel (Dreissena polymorpha) in the Great Lakes Region*. In: *Canadian Journal of Fishery and Aquatic Science*. No. 48 (1991), pp. 1381–1388.

35 *Op. Cit.* 9.

36 Shunshkina, E.A., Musayeva, E.I.: *Structure of the planktonic community of the Black Sea epipelagic zone and its variation caused by invasion of a new ctenophore species*. In: *Oceanology.* No. 30 (1990), pp. 225–228.

37 CSIRO: *Marine pest information.* 2001. www.marine.csiro.au/crimp/Marine_pest_infosheets.html

38 CIESM: *Alien marine organisms introduced by ships in the Mediterranean and Black seas*. In: *CIESM Workshop Monographs*. No. 20 (2002). URL: http://www.ciesm.org/ publications/ Istanbul02.pdf (accessed January 2005).

39 *Ibid.*

ship cargo loaded and unloaded in Mediterranean ports. Today, an estimated total of 200,000 commercial ships cross the Mediterranean Sea annually and approximately 30% of the international sea-borne volume originates from or is directed towards the 300 ports in the Mediterranean Sea. These figures are expected to grow three or four fold in the next 20 years[40].

The total number of alien species in the Mediterranean has probably been underestimated and their impact poorly understood. Despite the long and ancient history of shipping in the Mediterranean, this significant vector has only recently been studied under the framework of *Algal Introduction to European Shores*, a European Union project[41]. The taxa most likely introduced by means of ballast water include marine plants, cnidarians, molluscs, polychaetes, decapods crustaceans, isopods, amphipods, bryozoans, ascidians and fishes. Of these ship borne invasive species, 30% of plants, 38% of molluscs and over 55% of crustaceans introduced into the Mediterranean originate from temperate to cold-water regions. In support of these observations, shipping traffic data collected by Dobler[42] show that over 60% of piloted vessels in the Mediterranean sail from North Atlantic waters.

4 The Mediterranean Basin Contains the Highest Number of Introduced Marine Plants in the World

One example of very successful invasives in the Mediterranean Sea is marine plants. Currently, the Mediterranean has the largest number of introduced marine plants in the world[43]. Since the beginning of the 20th century, the number of introduced macrophytes has more than doubled every 20 years[44]. Today, more than 90 species of marine plants, mainly of the phylym Rhodophyta, have been introduced into the basin. Their origin is mostly from the Indo Pacific Ocean[45].

Although fouling rather than ballast water exchange seems to be a more important vector of plant introductions in the Mediterranean, it is difficult to assess whether or not this is a sampling artifact[46]. In addition, it is difficult to identify the vector involved

40 Dobler, J. P.: *Analysis of shipping patterns in the Mediterranean and Black seas*. In: CIESM: *Alien marine organism introduced by ships in the Mediterranean and Black seas.* CIESM Workshop Monographs, No. 20 (2002), pp. 19–28.

41 Guala, I., Flagella, M.M., Andreakis, N., Procaccini, G., Kooistra, W.H.C.F., Buia, M.C.: Aliens: algal introductions to European shores. In: *Biogeographia*, *Marine Biogeography of the Mediterranean* Sea: pattern and dynamics of biodiversity. No. 24 (2003), pp. 45–52.

42 *Op. Cit.* 40.

43 Boudouresque, C. F., Verlaque, M.: *Assessing scale and impact of ship-transported alien macrophytes in the Mediterranean Sea*. In: *CIESM Workshop Monographs.* No. 20 (2002), pp. 53–61.

44 Ribera, M. A., Boudouresque, C.F.: *Introduced marine plants, with special reference to macroalgae: mechanisms and impact.* In: *Progress in Phycological Research*. No. 11 (1995), pp. 187–268.

45 *Op. Cit.* 12.

46 *Op. Cit.* 43.

once the species has become established[47]. However, some introduced plants have been associated with ballast water exchange and identified as invasive with a negative impact on recipient communities[48]. The most significant cases of such algal invasions in the Mediterranean include the green alga *Caulerpa racemosa* var. *cylindracea*[49]. Since first being recorded in Libya[50] this Australian taxon has rapidly spread in the basin[51].

5 Potential Impacts of Invasive Species

The impact of marine bioinvasions can be ecological, economic, or safety-related with extinction of native species as the most severe effect that can result from invasion[52,53]. The difficulty of predicting the impact of invasive species is due to the complex interactions between species in a food web and competitive effects within an ecological community[54,55]. To date, the ecological consequences of invasions have been mainly studied in benthic communities[56]. Invasive species in these communities may have direct and indirect effects on native species at different trophic levels, on food-web properties, and ecosystem processes. In some cases, new invasions have accelerated the impacts of historically benign introductions on native species[57]. Understanding the features that make an ecosystem vulnerable to invasions is critical to understanding the potential impacts of invasions[58,59]. Disturbed or altered habitats and low species richness may also account for higher vulnerability to invasion in some

47 Wallentinus I.: *Introduced marine algae and vascular plants in European aquatic environments.* In: Leppäkoski, E., Gollasch, S., Olenin, S. (eds). *Invasive Aquatic Species of Europe. Distribution, Impact and Management.* London: Kluwer Academic Publishers, 2002, pp. 27–52.

48 Boudouresque, C. F., Verlaque, M.: *Biological pollution in the Mediterranean Sea: invasive versus introduced macrophytes*. In: *Marine Pollution Bulletin.* No. 44 (2002), pp. 32–38.

49 Verlaque, M., Durand, C., Huisman, J.M., Boudouresque, C.F., Le Parco, Y.: *On the identity and origin of the Mediterranean invasive Caulerpa racemosa (Caulerpales, Chlorophyta).* In: *European Journal of Phycology.* No. 38 (2003), pp. 325–339.

50 Nizamuddin, M.: *The green marine algae of Libya.* Bern: Elga publ., 1991.

51 Boudouresque, C. F., Verlaque, M.: *Biological pollution in the Mediterranean Sea: invasive versus introduced macrophytes.* In: *Marine Pollution Bulletin.* No. 44 (2002), pp. 32–38.

52 Williamson, M.: *Biological invasions*. London: Chapman and Hall, 1996.

53 Haugom, G.P., Behrens, H., Andersen, A.B.: *Risk based methodologies to assess invasive aquatic species in ballast water*. In: Leppäkoski, E., Gollasch, S., Olenin, S. (eds). *Invasive Aquatic Species of Europe. Distribution, Impact and Management*. London: Kluwer Academic Publishers, 2002, pp. 467–476.

54 Lodge D.M.: *Biological invasions: lessons for ecology*. In: *Trends in Ecology and Evolution.* Vol. 8 (1993), No. 4, pp. 133–137.

55 Grosholz, E.D.: *Recent biological invasion may hasten invasional meltdown by accelerating historical introductions.* In: *Proceedings of the National Academy of Science.* Vol. 102 (2004), No. 4, pp. 1088–1091.

56 Grosholz, E.D.: *Ecological and evolutionary consequences of coastal invasions*. In: *Trends in Ecology and Evolution.* No. 17 (2002), pp. 22–27.

57 *Op. Cit.* 55.

58 Occhipinti, A.: *Susceptibility to invasion: assessing scale and impact of alien biota in the Northern Adriatic*. In: *CIESM Workshop Monographs*. No. 20 (2002), pp. 69–73.

59 Ruiz, G.M., Hewitt, C.L.: *Toward understanding patterns of coastal marine invasions: a prospectus*. In: Leppäkoski, E., Gollasch, S., Olenin, S. (eds). *Invasive Aquatic Species of Europe. Distribution, Impact and Management*. London: Kluwer Academic Publishers, 2002, pp. 529–547.

habitats[60]. However, understanding the impact of marine invasives is limited by the paucity of surveys as the relevant data are not available for many global regions and the existing data are incomplete and collected from a composite of methods[61]. What is clear is that coastal marine systems are closer to invasional "meltdown" than previously thought and need closer examination[62].

Marine invasive species also have social repercussions. Case studies demonstrate that the global economic costs of marine invasives may be in the order of tens of billions of US dollars[63]. Public health concerns are also associated with ballast mediated organisms and pathogens such as *Vibrio cholerae*[64]. Approximately 93% of the ships arriving in Chesapeake Bay from foreign harbours contain this bacterium in their ballast tanks[65]. Finally, programmes attempting to eradicate non-native marine species have been very costly and time consuming[66,67].

6 International Conventions Addressing Ballast Water

In 1975, the states bordering the Mediterranean adopted the *United Nations Environment Programme Mediterranean Action Plan* to improve the health of the basin. Subsequently, relevant legal provisions that address marine invasives were outlined by the *Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean* (Barcelona Convention 1995) within the framework of the UNEP-Mediterranean Action Plan. The protocol states that:

> Parties shall regulate in specially protected areas the introduction of any species not indigenous to the specially protected areas in question, or of genetically modified species, as well as the introduction or reintroduction of species that are or have been present in the specially protected area, and that Parties shall take all appropriate measures to regulate the intentional or accidental introduction of non-indigenous species or genetically modified species to the wild and prohibit those that may have harmful impacts on the ecosystem, habitats, or species in the protocol area [Articles 6(d) and 13 (l)].

Furthermore, a number of legal instruments exist that address the issue of ballast water introductions globally. One of the most significant is the United Nations Convention on the Law of the Sea (UNCLOS 1982). UNCLOS states that:

60 *Op. Cit.* 38.
61 *Op. Cit.* 59.
62 *Op. Cit.* 57.
63 Raayamakers, S.: *The ballast water problem: Global ecological, economic and human health impacts.* In: *RECSO/IMO Joint seminar on tanker ballast water management and technologies.* Dubai, UAE: RECSO/IMO, 2002.
64 Drake, L.A.: *Ship-transported vireo and bacterio-plankton.* In: *CIESM Workshop Monographs.* No. 20 (2002), pp. 35–39.
65 Ruiz, G.M., Rawlings, T.K., Dobbs, F.C., Drake, L.A., Mullady, T., Huq, A., Colwell, R.R.: *Global spread of microorganisms by ship.* In: *Nature.* No. 408 (2000), pp. 49–50.
66 *Op. Cit.* 21.
67 *Op. Cit.* 63.

> States shall take all measures necessary to prevent, reduce and control pollution of the marine environment using technologies under their jurisdiction or control, or 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 [Article 196(1)].

In 1992, the United Nations' International Maritime Organization (IMO) was requested to supply instruments for co-operation in the field of international navigation, safety and equity in shipping. The IMO was commissioned by the UN Conference on Environment and Development (UNCED) to develop and encourage the adoption of appropriate rules on ballast water discharge. Subsequently, the IMO Marine Environment Protection Committee (MEPC) developed guidelines (i) to prevent the introduction of organisms and pathogens via ballast water or discharged with the sediment (Resolution A.774 (18), 1993) and (ii) to minimize the effect of dangerous organisms and pathogens by controlling and managing the ballast water of ships (Resolution A.868 (20) 1997). The latter includes a recommendation that ballast water exchange is carried out in the open ocean, or if this is not possible, in areas 200 nautical miles from the nearest land and in water at least 200m in depth[68]. Deep waters would contain organisms that are generally unable to survive in coastal zones and vice versa[69]. Ballast water exchange must comply with ship stability and security regulations and be approved by the ship's Classification Society via the ship's "Trim and Stability" booklet[70].

The guidelines include advised practices that would reduce the risk of ballast water introductions. These include:

(i) avoiding uptake in the presence of algal blooms or contaminants and during the night (when zooplankton migrates towards the water surface);
(ii) exercising caution when water is loaded in shallow areas; and
(iii) discharging ballast water, and sediments if present, to shore facilities.

The IMO also recommends the mechanical treatment of ballast water where available. Mechanical treatment to remove organisms from ballast water would include:

(i) Filtration where it is loaded;
(ii) Cyclonic separation to remove larger particles and organisms (centrifugal action ejects particles heavier than the water);
(iii) The use of high velocity ballast water pumps during intake and discharge to increase the mortality of organisms due to mechanical damage;

68 The GEF/UNDP/IMO Global Ballast Water Management Programme (GloBallast) website. URL: http://globallast.imo.org. London: IMO, 2000-2005.

69 Taylor, A., Rigby, G., Gollasch, S., Voigt, M., Hallegraeff, G., Mccollin, T., Jelmert, A.: Leppäkoski, E., Gollasch, S., Olenin, S. (eds). *Invasive Aquatic Species of Europe. Distribution, Impact and Management*. London: Kluwer Academic Publishers, 2002, pp. 484–502.

70 *Ibid.*

(iv) physical inactivation of organisms through heat treatment (temperature around 40°C), cooling treatment (temperature near the freezing point), ultraviolet irradiation by causing photochemical reactions of DNA, RNA and proteins[71]. Chemicals and biocide inactivation is achieved by using reducing agents such as ozone, hydrogen peroxide, chlorination and oxygen deprivation treatments[72].

Several states have taken unilateral action to prevent, minimize, and eliminate the risk of harmful introductions of aquatic organisms. However, such initiatives have been met with varying success in different countries. As a result, common regulations and guidelines for effective and uniform implementation have been recommended. In February 2004, IMO adopted a new international convention with the purpose of addressing the spread of harmful aquatic organisms carried by ships' ballast water. *The International Convention for the Control and Management of Ships Ballast Water and Sediment* will require all ships to implement a management plan for ballast water and sediments. Furthermore, all ships will have to carry a ballast water record book and will be required to manage ballast water according to given standards and procedures. The Convention states that contracting parties must also ensure that ports and terminals (where the cleaning or repair of ballast tanks occurs) have adequate facilities for the reception of water and sediments (Article 5; http: globallast.imo.org). This Convention will enter into force 12 months after 30 countries (35% of global shipping) have ratified it.

7 Recommendations for Future Research and Management

Today, the problem of marine bioinvasions clearly requires a concerted effort at the regional and international levels. The ratification of the *International Convention for the Control and Management of Ships Ballast Water and Sediment* (2004) by all Mediterranean states is important so that its guidelines are enforced and so that efforts are collective and comprehensive. The *Ballast Water Convention* calls on contracting Parties to promote and facilitate scientific and technical research on ballast water management and to monitor the effects of ballast water in waters under their jurisdiction. Independent, perhaps disconnected, research programs on marine invasion already exist in many countries throughout the world. A Mediterranean program involving different collaborating countries is necessary to develop a common line of investigation and operations. An important step forward would be to standardize methodologies in order to compare information between geographical sites on a regional and global scale. In addition, testing hypotheses regarding marine invasions and developing robust predictions is crucial in guiding management and policy decision-making. Finally, the characterization of commercial shipping patterns in the Mediterranean will give information on possible source locations so that risk management approaches may be used.

71 *Op. Cit.* 69.

72 Tamburri, M.N., Wasson, K., Masayasu, M.: *Ballast water deoxygenation can prevent aquatic introductions while reducing ship corrosion.* In: *Biological Conservation.* No. 103 (2002), pp. 331–340.