ENVIROMENTAL RISK ASSESSMENT OF MARINE INVASIVE SPECIES CARRIED BY BALAST WATER

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ABSTRACT

Ballast water carried by ships is a significant vector to transfer of marine organisms beyond their natural ecoregions, resulting in economic, social and environmental negative impacts. The aim of this study is to investigate the risks of environmental negative impacts of marine invasive species by environmental risk assessment method and identify the high-risk invasive species, vessels and voyages for prioritization of inspections, compliance tests and monitoring activities. All marine species investigated for the risk assessment are chosen from Turkish coasts and the new method for risk classification is developed and specified for local risk assessments of marine invasive species carried by ballast water.
Keywords: Invasive species, Ballast water, risk assessment, risk classification

1. Introduction

Over two-thirds of the world's surface is covered by water and oceans serving as an important transportation route for both people and merchandise and more than 90% of all worldwide trade goods are carried by ships on the ocean [1]. All ships are carefully designed to carry those goods and people all around the world. However ships don't always travel with cargo or full cargo, so they have to take some weight to operate safely through the water with enough depth. Ballast is defined as any solid or liquid material that is taken into a vessel to increase the draft, change the trim, and regulate the stability or to maintain stress loads within acceptable limits. After steel-hulled ships and developed pumping technology, sea water converted the major ballast of selection. Ballast water is taken to ballast tanks of ships at source port while unloading cargo and at destination port new cargo is taken on board while ballast water discharging to new port.

While taking ballast water into the ballast tanks, large number of organisms from source port is also taken to the tanks from different species and different life stages such as eggs, cysts, spores or adults. Organisms taken from source port generally will be invasive species for destination port so that they became introduced or invasive species for the new ecosystem [2].

Even habitats with similar conditions, like same depth, salinity and temperature regimes, from different part of world, can have very different kind of species. Ecological barriers provide an isolation of biogeographic regions from each other. Those ecological barriers started to get cracked by anthropogenic activities such as transportation and shipping. By shipping, organisms can be carried widely beyond their native areas and they are introduced to new regions, where they can become established and spread if the conditions of the new environment are suitable [3].

Invasive species can be extremely dangerous for any environment by displacing native species with outcompeting or preying on those native species, besides they can change all food web and alter basic physical activities such as nutrient cycling and sedimentation [4]. For example the North American comb jellyfish, *Mnemiopsis leidyi* was released with ballast water to the Black Sea in 1980s and affected all the ecosystem [5]. *Vibrio cholerae* introduced in Peru in 1991, was the reason of nearly a million people's diseases and the death of more than ten thousand by

1994 [6]. *Caulerpa taxifolia,* because of its rapid spread and high growth rate, it can easily be the dominant in the habitat and when Mediterranean Sea was invaded by it, the killer alga was a serious problem for the *Posidonia oceanica* which is extremely important for marine ecosystem. It invades the areas of these sea grasses and causes the extinction of them. It releases a kind of acid which is toxic for many species. It does not have any harm to human health but it alters the habitats and reduces the biodiversity [7].

At any given moment some 10,000 different species are being transported between biogeographic regions in ballast tanks alone [8]. If invasive species finds a new environment welcoming and become established, eradication is nearly impossible [9]. However negative impacts can be controlled by early detection, prevention of new introductions and effective management methods [10]. On the other hand, dealing with invasive species requires to establish priorities such as the most harmful organisms, the most likely pathways and the most dangerous routes. With prioritization, limited sources and funds can be distributed effectively and the most effective invasive species management plan can be chosen [11].

Negative effects of invasive species can not be generalized even for a single specie because the effects of a single invasive species can be different for different biogeographic regions. For one ecosystem the invasive species can be very harmful by leading native species extinction however for another ecosystem it can have no harm to native species at all. Therefore ecological impact of any invader needs to be studied with local approaches. Generalization of negative effects of any single invader is misleading.

There are some studies focusing on global investigation of invasive species with a global approach and assume that the invaders have the same negative impacts for any ecoregion where they are not belong[12-14] Those studies give really important ideas about how dangerous the invasive species can be, however most of the invaders have different effects on different areas. For example, *Mnemiopsis leidyi* was the cause of the anchovy extinction in early 1990s in Black Sea and it was the reason of huge economic collapse of fishing industry. The main reason for those situations was that *Mnemiopsis leidyi* was the predator of anchovy and there was no predator of the *Mnemiopsis leidyi* in the environment so their population reached high amounts while anchovy population decreased dramatically. Obviously *Mnemiopsis leidyi* is a massive problem for Black Sea and new introductions of that species needs to be prevented. On the other hand, when *Mnemiopsis leidyi* is introduced into a new ecoregion which has *Beroe ovata* as native species, there will be considerably less ecological impact on that ecoregion. *Beroe ovata* keeps *Mnemiopsis leidyi* population under control by preying on that species. That example indicates that investigations of the negative effects of invasive species are not only related with the characteristics of invaders but also related with the environmental conditions. While determining a risk index value or ecological impact value, the environmental conditions and characteristics of species should be considered together. Therefore, the risk index value for every invasive species will be special and different for each different ecoregions.

In this study the aim is to investigate invasive species in Turkish coasts and to determine an ecological impact factor for each species by concerning their negative effects on native species and natural ecosystems in national scale. According to general risk definition, risk is related with frequency or possibility and the significance of the consequence. Ecological impact factor of invasive species is used as consequence factor for risk assessment and total ballast water volume carried by ships from the natural environment of invasive species to Turkish coasts is used as frequency factor. This risk ranking method developed in this study can be easily used for other ecosystems and countries for more accurate and specific risk assessment of invasive species introduced to their national coasts. Prioritization of invaders, vessels and voyages by this method provides better management of ballast water and better allocation of funds for prevention of invasions.

2. Materials and Methods

2.1 Materials

Information and data of each individual invasive species were collected and integrated from a wide variety of sources but the main resource was Ballast Water Management Status Assessment Report for Turkey [15]. All 10 species presented in this study has been identified as alien species in Turkish seas which are Black Sea, Mediterranean Sea, Marmara Sea and Aegean Sea, according to the Ballast Water Management Status Assessment Report for Turkey. The given information about invasive species were their scientific names, common names, native ranges, non-native introductions and their ecological impacts on native ecosystems.

2.2 Environmental Risk Assessment

Environmental Risk Assessment (ERA) is a process that evaluates the likelihood or probability that adverse effects may occur to environmental values, as a result of human activities. The summary of steps in the ERA approach can be seen in figure 1.

Environmental risk assessment process starts with determining environmental pressure which means an anthropogenic factor affecting some environmental values and processes. In our case the environmental pressure was invasive species and their negative effects on native life in the ecosystem.

Environmental value is a part of the environment which is significant to the ecosystem ecologically, socially or economically. The term “value” does not refer solely its economic sense. When considering marine invasive species, environmental values are;

- Native species
- Water quality
- Nutrient cycling
- Sedimentation process
- Community structure and food web
- Human health

For understanding the effects of the invasive species and actually to detect invasive species existence in the environment some indicators are used. In ERA process, indicator means a parameter changing with time and changes can be observed, measured and used for understanding what is happening in the environment.

Many different kinds of indicators can be used including both living and nonliving assets giving qualitative and quantitative information. Indicators used in this study are;

- Single species distribution change
- Population of native species
- Migration of native species
- Invasion rate of invaders

- Growth and reproduction rate of invaders
- Management difficulty of invasive species

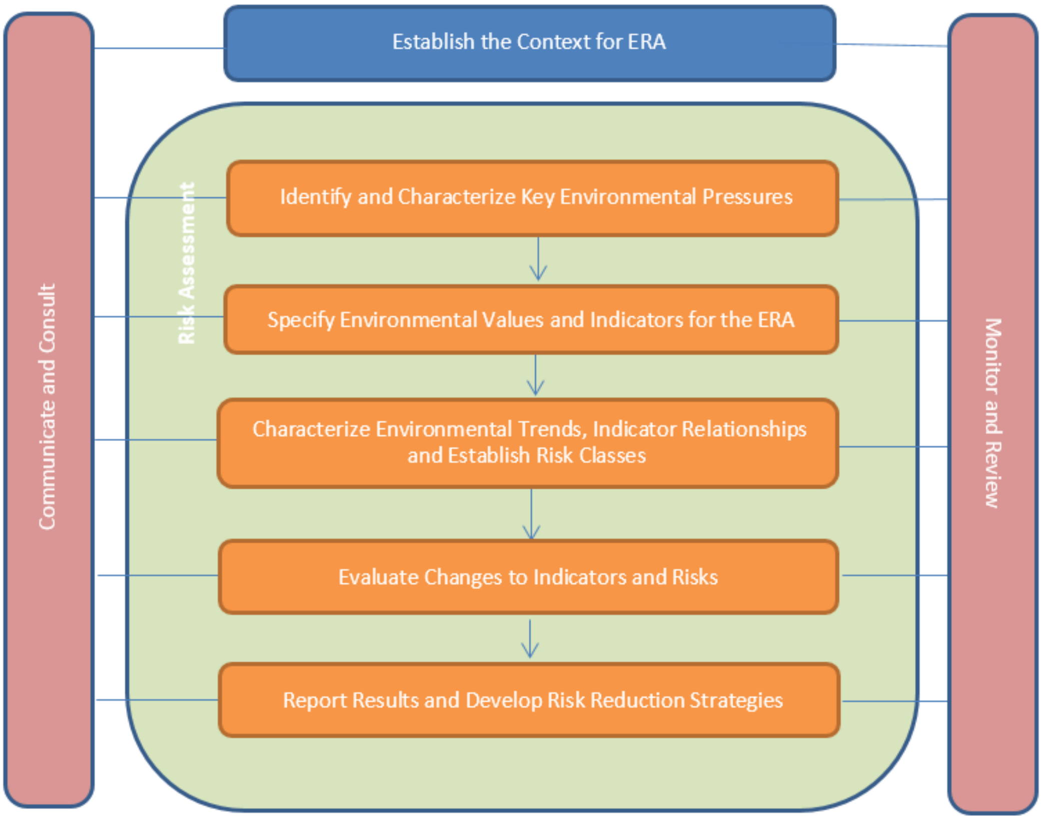

Fig 1. Flowchart of the ERA process

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2.3 Ecological Impact Factor

The number of invasive species introduced an ecosystem does not reflect the hazard caused by invasive species. Some marine invaders can adopt the new environment only with few disruptions while others can damage whole ecosystem and may cause extinction of some native species. An ecological impact factor was determined for each marine invasive species in this

study by combining their qualifications with a threat scoring system based on several existing threat classification systems [12-14]
In this study four characteristics of invasive species were examined and from each characteristic, every single species got an impact number and all these numbers are summed up for total ecological impact factor for every single invasive species. Table 1 shows the negative impact of invaders on a native ecosystem.

Table 2 presents the reproduction and invasive potential of invaders by a scoring system, as '4' refer that the species has high reproduction rate and rapidly invaded areas after past introductions and has huge potential of invasion after new introductions. '1' is used for species with low reproduction rate and has not invaded huge areas after past introductions but still has some potential for spreading with new introductions.

Table 3 simply shows the number of seas invaded by invasive species. Turkey has 4 seas which are Black Sea, Marmara Sea, Aegean Sea and Mediterranean Sea.

Table 1. Negative Impact on Ecosystem of Invaders [4]

Negative Impact on Ecosystem	Score
Negative impact on entire ecosystem and biodiversity, reason for extinction of native species	4 (Very High)
Impact on multiple species, keystone species or change dominant native species	3 (High)
Impact on single native species with little disruption	2 (Medium)
No important impact on any species and ecosystem	1 (Low)

Table 2. Reproduction and Invasive Potential [4]

Reproduction Rate and Invasive Potential	Score
High reproduction rate, currently spreading rapidly	4 (Very High)
Medium reproduction rate, currently spreading less rapidly	3 (High)
Low reproduction rate and did not spread yet but huge future potential for spreading	2 (Medium)
Low reproduction rate and did not spread and low future potential for spreading	1 (Low)

Table 3. Number of Invaded Seas

Invaded Seas	Score
All four seas of Turkey (Marmara, Black, Mediterranean and Aegean)	4 (Very High)
Established in three seas of Turkey	3 (High)
Established in two seas of Turkey	2 (Medium)
Only established in one sea	1 (Low)

Table 4 shows the management difficulty of invasive species which means the effort required to reverse the threat or remove the species completely.

Table 4. Management Difficulty Levels of Invasive Species

Management Difficulty	Score
Irreversible and cannot be contained or controlled	4 (Very High)
Reversible with difficulty and/or can be controlled with significant ongoing management	3 (High)
Reversible with some difficulty and/or can be controlled with periodic management	2 (Medium)
Easily reversible with no ongoing management necessary (eradication)	1 (Low)

2.4 Frequency Factor

Risk is a measure of the likelihood that an undesirable event will occur together with a measure of the resulting consequence within a specified time i.e. the combination of the frequency and the severity of the consequence.

Therefore, for determination of risk classes or risk ranking of invasive species there is a need to know the likelihood of the discharging the ballast water carrying those invasive species. To measure this likelihood, native environment of every single invasive species must be known and the total amount of ballast water carried from those environment needs to be recorded or calculated.

The amount of the ballast water coming from different ecosystems and regions to Turkey was shown in Table 5. Our goal was to make prioritization of the invasive species observed in Turkish coasts which indicates us the most dangerous routes and ships, therefore limited funds for supervision of ships can be allocated accurately. For this goal a comparable method needed to be chosen. Therefore the frequency factor is taken as;

$$F.F = \frac{\text{Total Amount of Ballast Water Carried from Native Seas}}{\text{Total Amount of Ballast Water Carried from All Seas}}$$

Table 5. Amount of Ballast Water Carried to Coasts of Turkey, 2006-2010 [12]

Seas	Amount of Ballast Water (Tones)
East Pacific	785646
South Atlantic	1479877
Caspian Sea	22083
Indian Ocean	1746505
Persian Gulf	669718
Red Sea	751193
Northwest Atlantic	2265604
Northwest Pacific	1396405
Northeast Atlantic	3997390
Northeast Pacific	278385
North Sea	7280
South Pacific	181116
Total Amount	**13581202**

2.5 Risk Ranking

All individual invasive species were examined for ecological impact factor and frequency factor. After determination of those values for every single invasive species, a risk index number assigned by multiplying ecological impact factor and frequency factor

3. Results and Discussion

Risk index numbers for each marine invaders in the coasts of Turkey was calculated and presented in Table 7. As an example, detailed risk index calculation for *Mnemiopsis leidyi* which is the invasive species with the highest risk index number is shown in table 7, was given. Detailed ecological impact score calculation can be seen in Table 6 and the risk index calculations were performed according to the following equations.

Table 6. Ecological Impact Score of *Mnemiopsis leidyi*

Mnemiopsis leidyi	**From : Atlantic Coasts of North and South America**	
Ecological Impact	Extinction of Anchovy, Cause to serious decrease of the many fish population, pollution in the sea bottom after they die.	4
Reproduction Rate and Invasive Potential	Adult ones can produce 2000-8000 eggs during spawning, very high invasive potential	4
Invaded Regions	Black Sea, Mediterranean Sea, Marmara Sea, Aegean Sea	4
Management Difficulty	Can be controlled with significant ongoing management	3
	Ecological Impact Score	15

Frequency factor for *Mnemiopsis leidyi* determined as described,

$$F.F = \frac{\text{Total Amount of Ballast Water Carried from Native Seas}}{\text{Total Amount of Ballast Water Carried from All Seas}}$$

$$F.F = \frac{\text{B.W from South Atlantic + B.W from Northwest Atlantic}}{\text{Total Amount of Ballast Water Carried from All Seas}}$$

$$F.F = \frac{\text{3745481 tones}}{\text{13581202 tones}} = 0,28$$

Risk index for *Mnemiopsis leidyi* determined as;

$$\text{Risk Index} = \text{Ecological Impact Factor} \times \text{Frequency Factor}$$

$$\text{Risk Index} = 15 \times 0,28 = 4,20$$

Mnemiopsis leidyi was first discovered in the Black Sea in 1982[5]. However the invasive comb jelly reached its maximum population at the end of the 80s and preyed on planktonic organisms, larvae and eggs of native fishes which are exposed the risk of extinction. Mnemiopsis leidyi caused the extinction of anchovy, which has huge economic importance for fishery, and also resulted in high amount of pollution on the bottom of the sea with other negative effects on ecosystem [10]. Because of these negative impacts on environment it was scored with the highest number ‘4’.

Mnemiopsis leidyi has very high reproduction rate because adult ones can produce 2000-8000 eggs during spawning and the population of the invader reaches high amounts easily. After invasion of Black Sea, they spread through Marmara and Mediterranean seas quickly so they get also the highest score for reproduction rate and invasive potential assessment.

Mnemiopsis leidyi is followed by *Prorocentrum minimum* which is a native phytoplankton in Atlantic coasts of America and introduced to Black Sea by ballast waters. *Prorocentrum minimum* is a common, neritic, bloom-forming dinoflagellate, is the cause of harmful blooms in many estuarine and coastal environments. The toxic algae can be accumulated in the food chain and reach to humans via seafood consumption [16].

The invasive species with the lowest risk index number is *Rapana venosa* with no vital effect on ecosystem and native species [17]. Although it invaded three seas of Turkey which are Aegean Sea, Black Sea and Marmara Sea, negligible effects on ecosystems and easy management for eradication keeps it at the bottom of the risk index table.

Table 7. Risk Indexes of Marine Invaders

Species	Ecological Impact Number	Frequency Factor	Risk İndex	References
Mnemiopsis leidyi	15	0,28	4,20	[5]
Prorocentrum minimum	9	0,28	2,48	[16]
Caulerpa toxifolia	10	0,21	2,12	[7]
Collinectus sapidus	11	0,17	1,84	[18]
Polydora cornuta	11	0,17	1,84	[19]
Beroe ovata	9	0,17	1,50	[20]
Asterias amurensis	11	0,10	1,13	[21]
Phyllarhiza punctata	8	0,14	1,09	[22]
Bryopsis pennata	10	0,10	1,03	[23]
Rapana venosa	8	0,10	0,82	[17]

The results show that *Mnemiopsis leidyi* requires the most attention and prevention from future introductions because of its high risk index number. Therefore ships carrying ballast water from Atlantic Coasts of North and South America needs to be prioritized for investigations and controls. However most of the countries have limited funds for ballast water management so prioritization of ships and regions is essential as well as the local studies and classifications.

4. Conclusion and Risk Reduction Strategies

Species can be carried by multiple ways from their native range to other regions where they are identified as invaders. Although there are several vectors for transportation of marine invaders such as aquaculture and fisheries, drilling platforms, canals, aquarium industry and even dive practices, ships are the most important and common vectors for transportation of marine invasive species by ballast water exchange processes and hull fouling.

The spread of marine invasive species is taken more seriously with their noticeable and unneglectable harmful consequences for countries by huge economic and environmental impacts. That is why more environmental friendly regulations and implementations are required for prevention of invasive species. Even though global awareness of the situation and the number of studies dealing with alien species are increasing, there is a need for studies focusing invasive species problem on national scale with national resources and information because the ship traffic, total ballast water amount carried from other regions, native species and natural conditions are unique for every country and every ecosystem. According to those national level studies, specific and targeted national regulations should be prepared concerning all the needs of the environment and species.

It is clear that governments don't have unlimited sources and funds for prevention or management of invasive species. Regulations are not enough for dealing with the invasive species problem alone also effective and sufficient supervision on ships is required. Therefore prioritization of ships, routes and species according to the risk level is very significant which provides better allocation of limited sources. For example, in this study *Mnemiopsis leidyi* was found the most dangerous invader for coasts of Turkey and the native seas of this invader is well-known. Ships carrying ballast water from those native areas should be prioritized for investigations and supervisions. Besides the studies should focus on characterizations, control and eradication methods of *Mnemiopsis leidyi*. National level regulations, effective allocation of resources and the better control on ships will prevent to face the same problem caused by uncontrolled ballast water discharge with *Mnemiopsis leidyi* in early 1990s. [3]

General risk reduction approaches such as reducing uptake of invasive species on board while taking ballast water to ballast tanks, prevention and removal of ballast sediment, treatment of ballast water and discharging ballast water to reception facilities, are also required to be improved.

The effectivity of studies focusing on invasive species is related with the chosen range of the ecosystems. More localized studies provide a better resolution of the ecoregion and better understanding the dynamics of the ecosystem. National level studies lead well-detailed, well-designed and well-organized national regulations including all the actions like operational standards for ships and ports, prevention and control mechanism, management and eradication processes and clear responsibilities and roles of authorities. Negative impacts of marine invasive species can be taken under control with clarifying priorities, allocating limited sources and effective national regulations which are coherent with global regulations.

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