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REVIEW ARTICLE

Review on invasive alien species (IAS): Challenge and consequence to the aquatic ecosystem services

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ABSTRACT

The invasive alien species (IAS) are widely recognized as a significant threat to marine biodiversity and severely affect ecosystem services. There has been no measurable global assessment of their impacts and routes of introduction. This review highlights some aspects of invasive species and their impacts on the ecosystem in general. For many roots like global transportation, biological pest control, climate changes, and sometimes commercial, invasive species are introduced into the new environments. Afterward, the invasive species are rapidly dominant over the indigenous species because of their first growth, rapid reproduction, ecological competence, and phenotypic plasticity, consequently, altering the structure of Ecosystems and deterring the biological and physical organization of the system. Many policies have been introduced to stop the destruction produced by invasive animals and plants and to prevent upcoming invasions. Some critical components of getting rid of invasion are concern about transporting wildlife to new areas, Ballast water in tankers, aquarium species, and shipping.

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Introduction

Invasive Alien Species?

An invasive alien species (IAS) is an immigrant animal in an ecosystem that causes severe ecological or economic impairment to the environment and sources a major threat to local biodiversity by altering or shifting with the native habitats or species (Molnar et al., 2008; Riley et al., 2008; Pejchar & Mooney, 2009). IAS species have been transferred in a new bio-geographical area by human activity at a historical scale

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(Audemard et al., 2002). Those species can be familiarized to a new habitat via the ballast water of ocean-going ships, deliberate and unintentional releases of aquaculture species, aquarium samples or bait, and other means (Molnar et al., 2008) and initiating extinction of local floras and faunas, dipping biodiversity, instructing with indigenous organisms for partial resources, and fluctuating habitats. For instances, the American blue crab (*Callinectes sapidus*, Figure 1A,) is a predatory invasive species that capable to survive very extreme environments and has high fecundity rates. Now this species has widely spread throughout the Mediterranean Sea especially in the coast of Spain, Italy and France (Stasolla & Innocenti, 2014). This American crab has been recorded first in Ebro Delta in 2012, then it has rapidly expanded to the Mediterranean Sea and its adjacent rivers and wetlands. The massive invasion capacity of this crab established this species as a potential threat to the marine biota. This crab also makes threats on traditional fishing boat which is one of the most affected sectors of southern Spain fisheries sectors as the crab accidentally destroys the fishing nets. Another dominant candidate, the zebra mussels (*Dreissena polymorpha*, Figure 1B) are small freshwater shellfish mainly indigenous to the lakes and rivers that move into the Caspian, and Black seas in eastern Europe, are now widespread throughout the entire European water bodies and The Mediterranean Sea. They are frequently moving into new waterways attached with boats and also with ballast water discharged from commercial ships. This mussel was first introduced at 1980s, since causing millions of dollars in economic loss and altering ecosystems intensely.

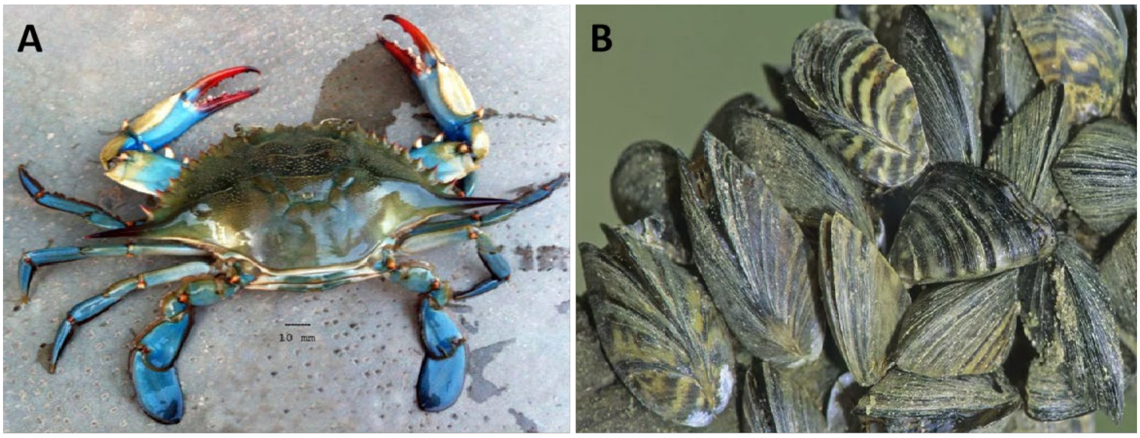

Figure 1. Two prominent invasive species in European water bodies. **A**) The American blue crab, An invasive species in the Mediterranean Sea. **B**) Zebra mussels originated from US and are now invasive to European water bodies (Figure adopted from the newsletter of Meghan Holmes, writer, New Orleans, LA).

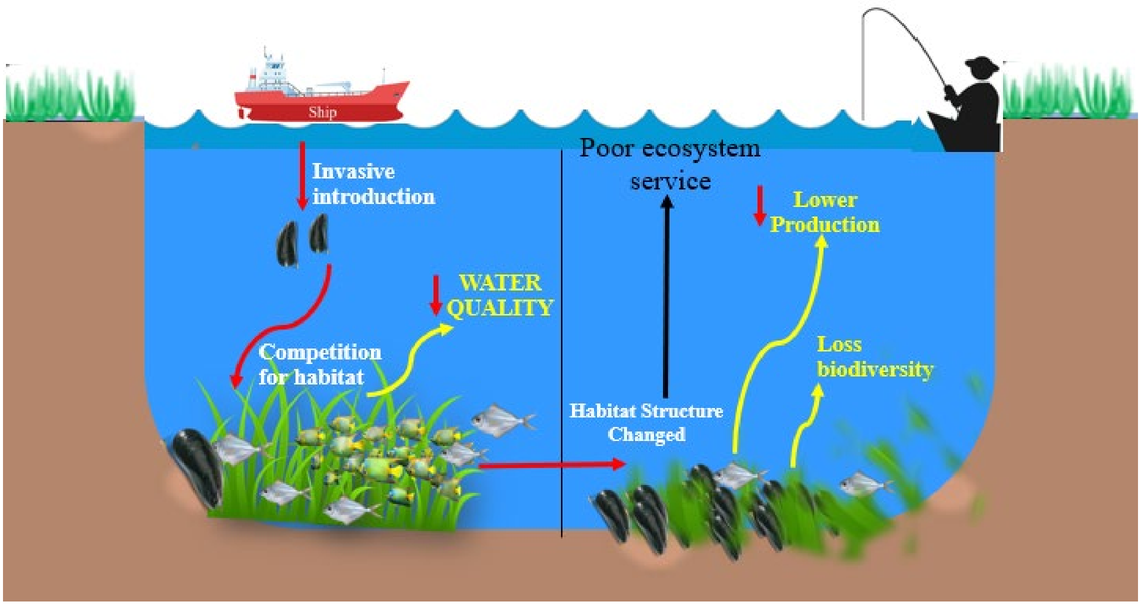

Figure 2. *Caulerpa taxifolia* an invasive assassin species for other algal species, seagrasses, and sessile invertebrate communities in the Mediterranean Sea (Photo modified from the Mark Hoddle, Extension Specialist and Director of Center for Invasive Species Research, University of California Riverside, USA).

Table 1. Origin and availability of some major invasive species with their ecological and economic impact. Source: Global Invasive Species Database (GISD, 2021)

Name of Invasive Species	Origin	Place of Invasion	Ecological Loss	Economic Loss
Gambusia holbrooki	Southeastern United States	Australia and Europe	Predating on amphibian eggs has negative influence on some frog species' choice of breeding habitat	Losing the biodiversity in Australia by predating the tadpoles of gold frog.
Hypophthalmichthys molitrix	Asia	Worldwide	Reducing native diversity by competing for and depleting zooplankton populations, altering the food web.	Carrying and transmitting the disease Salmonella typhimurium.
Hypophthalmichthys nobilis	Asia	Worldwide	Depleting zooplankton populations	Spreading disease through escape and introduction
Poecilia reticulata	Brazil, Guyana, Venezuela, Caribbean Islands	Worldwide except Antarctica	Threat to native cyprinids and killifishes	Carrier of exotic parasites
Cyprinus carpio	Eastern Russia and China	North America and Europe	Strong effects on benthic communities, stirring up bottom sediments during feeding, resulting in increased siltation and bio turbidity	Impacting growth rates and stocks of other fish by competition with carp, Providing protein in some third world countries
Eichhornia crassipes	South America	Africa, Asia, North America, Australia and New Zealand	Clogging up rivers makes it nearly impossible for animal life to move through them. Blocking sunlight and oxygen from getting to other plants below the water causing the ecosystem to change dramatically.	Reducing water flow thereby caused flooding. Impacting fishermen, sports-fisherman, water-skiers, and swimmers in recreational waters.
Elodea canadensis	Elodea canadensis	Europe	Negative impact on the functioning of the aquatic ecosystem will outcompete native aquatic plants.	It can impede water flow and adversely affect recreation activities
Sargassum muticum	Japan	Washington State, Europe	Forming a screen that prevents light, capturing nutrients, and disfavoring phytoplankton	Creating problems in shellfish farming, and getting entangled with the boat's propellers.
Dreissena polymorpha	Black, Caspian, Aral and Azov seas	Russia, Europe and North America	Severely impact native plankton, which reduces food for fish	fouling of intake pipes, ship hulls, navigational constructions and aquaculture cages
Asterias amurensis	China, Japan, Korea	Australia	Blamed for the decline of the critically endangered spotted handfish	In Japan, sea star outbreaks cost the mariculture industry millions of dollars

Invasive Species: Concerns to Habitat Degradation?

With the quick change in climate and different emerging contaminant, world biodiversity is at immense risk (Martin et al., 2010; Rizzo et al., 2017; Pierucci et al., 2019). The invasive species are achieving extra importance for the declination of oceanic diversity because of their unquantified hazard to ecosystem services (Thomsen et al., 2014; Walsh et al., 2016). The interactions between invasive species and native dwellers cause drastic changes in marine biotic and abiotic factors of the ecosystem. These changes have continuously transformed marine habitats around the world. Most importantly, these invaders displace native species, food webs, food chain and, alter the change community assembly and also alter essential processes, such as the sedimentation process and biogeochemical cycle (Molnar et al., 2008; Piazzi & Balata, 2009; Rizzo et al., 2017; Pierucci et al., 2019). Therefore, in a normal community, species grow together into an ecosystem balances the limit the population growth of any one species (Crooks, 2005; Simberloff, 2005; Sih et al., 2010; Narwani et al., 2013; Rizzo et al., 2017). These balances include predators, parasites, herbivores, diseases, and other organisms interacting for similar resources and limiting environmental factors (Cook et al., 2007; Crowl et al., 2008). For a better illustration of the consequence of invasion, *Caulerpa taxifolia* invasion in the Mediterranean Sea can be a good instance. *Caulerpa taxifolia* is an invasive alga native in tropical waters with populations naturally occurring in the Caribbean, Gulf of Guinea, Red Sea that is causing serious environmental problems in the Mediterranean Sea (Arnaud-Haond et al., 2017; De Montaudouin et al., 2018; Mannino et al., 2019). However, after the introduction, *Caulerpa* has colonized thousands of hectares of sea bottom in the Mediterranean. It is found from France to Croatia. Its range in the Mediterranean will likely continue to expand (Arnaud-Haond et al., 2017). In literature, there are several conceptually different ambiguous terms used in the context of invasion ecology. There are many probable routes and pathways of invasive introduction. A simple conceptual diagram is helpful to represent the possible route of introduction and their interaction with the native dwellers, and the consequence of the ecosystem summarized through a conceptual diagram (Figure 2).

Invasive Species: Why Concerned for Ecological Alteration?

For sure, IAS is widely accepted as one of the leading direct causes of biodiversity loss. Introduction of a new species in an ecosystem may have diverse cumulative effect of this system. It is not always meaningful that the introduced species has negative consequences for the environment. Something its blessing for the biota of the native environment through the association of the both individual. For instance, several fish species have been introduced into the Great Lakes for recreational fishing which was subsequently spread in water bodies and causing problem to the natives' inhabitants (Gozlan et al., 2010; Rothlisberger et al., 2012). Although they have not enough recorded evidence of adverse impacts on leisure opportunities and a food source (Griffiths et al., 1991). However, many species have altered the existing environment in order to makes it more favorable for them while adverse for natives' dwellers, which is known as ecological facilitation (Botts et al., 1996; Gallien et al., 2012; Douda et al., 2013; Pierucci et al., 2019). For instance, *Spartina alterniflora* invasion in the Bay of Arcachon, France that quickly changed the bottom structure with the speedy proliferation of the plant (Figure 3).

Figure 3. a). Change the environment by rapid proliferation and high growth of invasive *Spartina alterniflora*, that causes the decline of Spartina maritime in basin de Arcachon, France, Modified from Proença et al. (2019), U.M.R., 5805 EPOC, University of Bordeaux, Talence Cedex, France, b). Conceptual mechanism associated with different Invasive alien species (IAS), corresponding to their settlement and spread in varying environment (Rai & Singh, 2020).

How Do Invasive Species Introduce?

The introduction of invasive species, which often differ functionally from the components of the recipient community, generates ecological impacts that propagate along with the food web (Simberloff, 2005; Gallardo et al., 2016). There are several techniques for the introduction of invasive species in the marine environment, such as deliberate commercial introductions, transport on ships' hulls either of sessile, boring or vagile species including escapes from aquariums and the discard or release back into the sea of bait and edible species, related intended introductions, movement through seawater canals linking biogeographically distinct water bodies and most important the ballast water (Clarke Murray et al., 2011, 2014; Gollasch et al., 2019). Many of invasive species were intruded as unsuccessful attempts to control other harmful species from the water bodies. For example, In the 1800s, rats that introduce to the Virgin Islands on ships infested the sugar cane fields, initiating massive crop damage. The reasons for invasive species introduction are Ballast water, fouling ships, deliberate commercial introduction, Aquarium business (Padilla & Williams, 2004), and some accidental introduction (Figure 4). For example, at present, global shipping transport over 90% of the world's commodities in intercontinental traffics that introduces 40% of invasive species from different mainland (IMO, 2007; Phillips, 2009).

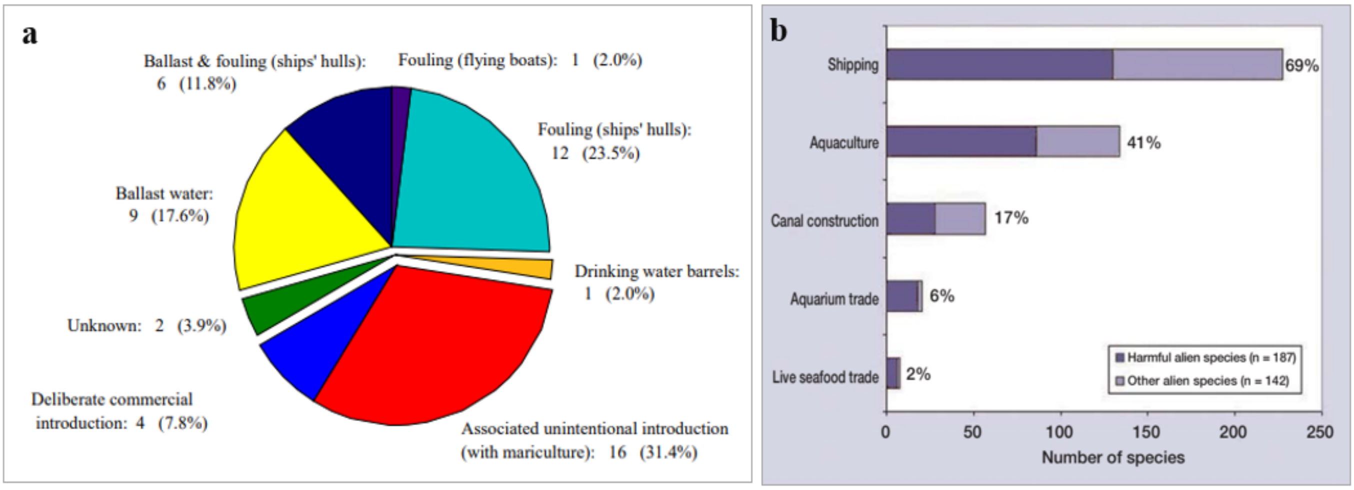

Figure 4. This figure indicates the probable method of introduction of invasive species in British water. a). Numerals indicate number of species involved and the percentage of total introductions (Eno, 1997), b). Number of marine alien species known or likely to be introduced by the most common human-assisted pathways (Adopted from Molnar et al., 2008).

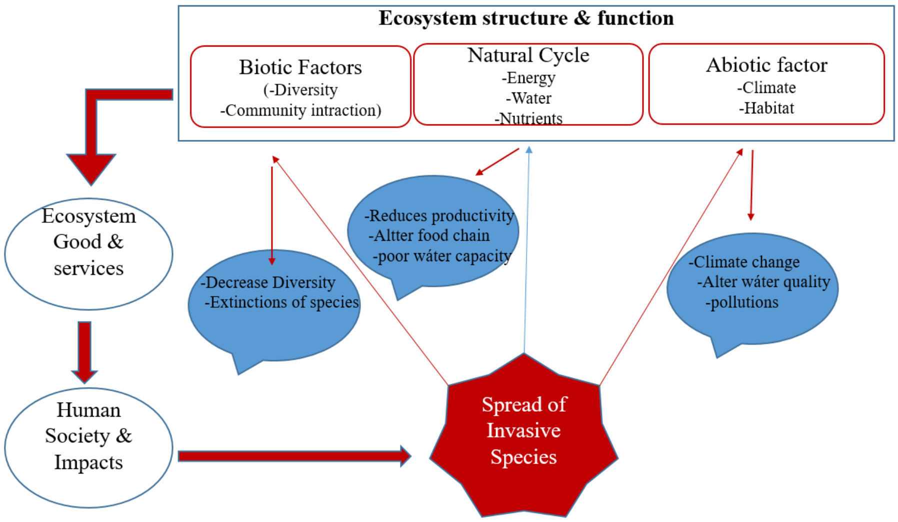

Figure 5. Mechanisms of ecosystem service alteration by invasive species. Those species mainly alter biotic and abiotic environment first and rapidly change the ecosystems (Figure modified from Charles & Dukes, 2008).

Methods of Ecosystem Modification

Ecosystems are characterized by biological, chemical and physical structure and functions, leading to ecosystem services' production and maintenance. The significant attention of ecosystem ecology is on functional processes and ecological mechanisms that maintaining the function and services produced by ecosystems including the alteration of primary production of biomass, decomposition and trophic relations. Ecosystem function corresponds to the process of energy transfer among the food webs and the central process that allows biochemical cycling and biochemical cycling. The invasive species mainly alter the ecosystem services (Figure 5) (Charles & Dukes, 2008; Traill et al., 2010). Most often these unwanted species may change community structure through exploitation, competition for resource uses. Their effects on other species including predation, herbivory, parasitism, and mutualisms and can modify the abundance of species with certain key traits which influence ecosystem processes (Chapin et al., 2000; Callaway & Ridenour, 2004; Ruitton et al., 2005; Charles & Dukes, 2008).

Impact of Invasive Species

Impacts on Habitat and Ecosystem

Invasive species are acting as major driver of global change having a number of harmful impacts on the areas that they were intruded. Several studies have been reported that they can rapidly modify the biodiversity and ecosystem functions in a virgin ecosystem (Pejchar & Mooney, 2009; Linders et al., 2019). The most significant of these is the widespread loss of habitat. Invasive species can change the food web in an ecosystem by destroying or replacing native food sources (Molnar et al., 2008). The invasive species may provide little to no food value for wildlife. But this invasive species can ridiculously alter the abundance or diversity of species that are important habitats for native wildlife. Many species establish in a new habitat with few disturbances, whereas others alter entire ecosystems or put native species at risk of extermination (Molnar et al., 2008; De Montaudouin et al., 2018; Linders et al., 2019). For example, the Burmese pythons the top predators in the Everglades are responsible for the decimation of local mammal and bird populations (Dorcas et al., 2012). They convert the habitat through their engineering effect and have strong invasive activity to the habitat (De Montaudouin et al., 2018; Linders et al., 2019). The resulting shell debris provides a hard substratum for attachment of juvenile *Crepidula fornicata*, perpetuating the population, and other epifauna, such as ascidians, ultimately destroying the entire natural ecosystem (Readman & Rayment, 2016; De Montaudouin et al., 2018).

Impacts on Biodiversity and the Environment

Invasive species are threats to the biodiversity including floras and faunas and overall ecosystem health by disrupting existing biological communities and ecological processes (Molnar et al., 2008; Linders et al., 2019; Proença et al., 2019). For instance, Asian carp recruited into the United States outcompete native fish for both habitat and foods, leading to significant alterations in natural fish populations that makes the ecosystem less diverse. And always these less diverse ecosystems are more vulnerable to further disturbances such as diseases and natural disasters (Dale et al., 2001; Molnar et al., 2008; Proença et al., 2019). In spites of having some economic and ecological benefits, alien invasions may result in extensive modification in the ecosystem structure, composition, functions and the distribution of the biota, leading homogenization of the world's fauna and flora's diversity (Charles & Dukes, 2008; Molnar et al., 2008; Traill et al., 2010; Proença et al., 2019).

Impact on Hydrodynamics, Nutrient and Water Cycling

Most often, the introduction of alien species alters the hydrodynamics of the existing ecosystem consequently changes the energy flows and trophic relationship of living biota. A study on golden apple snail (*Pomacea canaliculata*), a herbivore snail observed dramatically decreased aquatic plant populations in wetlands with implications for water parameters and purification (Carlsson et al., 2004; Moulin et al., 2007; Martin et al., 2010). Along with this, the nutrient cycling in aquatic system also be altered by invasive plants that fix nitrogen, and release compounds that alter nutrient availability or retention, including nitrogen and phosphorus, and change topsoil erosion or fire frequency (Dukes & Mooney, 2004; De Montaudouin et al., 2018).

Impact on Human Health

Invasive species are also harmful for human health. Many studies found that invasive zebra mussels produce toxins likes PCBS and PAHs in their tissues. When other predatory organisms prey on these mussels, the toxins are transfer into the food chain and finally can goes through the higher trophic level. Discharged ballast water from ships sometimes brings harmful bacteria like cholera. Invasive animals can also be vectors for these deadly disease (Gollasch et al., 2019). Encroachment of humans into previously remote ecosystems has exposed exotic diseases such as HIV (Pimentel et al., 2005) to the broader population. Throughout recorded history, epidemics of human diseases, such as malaria, yellow fever, typhus, bubonic plague, spread via some invasive vectors (Elton, 2020). A recent example of an introduced disease is the spread of the West Nile virus, which killed humans, birds, mammals, and reptiles (Lanciotti et al., 1999; Molnar et al., 2008). Examples of various types of impact of aquatic invasive alien species on human health are shown in Table 2.

Table 2. Various types of impact of aquatic invasive species on human health (Data modified from Pyšek & Richardson, 2010).

Type of Impact	Saltwater Invasive Invertebrates	Freshwater Invasive Animals
I. Cause or vector of human diseases or ailment	*Alexandrium catenella* (poisoning from consumed shellfish can lead to death), *Styela clava* (respiratory problems from sprays damage tissues)	*Eriocheir sinensis* (in native range, a host for the lung fluke parasite, causing diseases of lungs and other body parts), *Procambarus clarkiia* (host for trematodes that are potential parasites of humans)
Causes injuries	*Balanus improvisus, Ensis americanusa* (sharp shells inflict cuts), *Siganus rivulatus, Rhopilema nomadicaa* (painful stings)	*Dreissena polymorpha* (sharp shells inflict cuts), *Plotosus lineatus* (injuries caused by the barbed and venomous dorsal spine)
Causes allergies		*Cercopagis pengoi* (may cause allergic reactions in fisherman when they clean their nets)
Accumulation of toxins and their transfer to human food		*Neogobius melanostomus, Procambarus clarkiia* (heavy metals and cyanotoxins)
Impedes recreational activities and tourism	*Alexandrium catenella* (causing red tides)	

Invasive Species Impacts on the Economy

Not only to the biodiversity, invasive species have severe effects on global economy. Millions of dollars need to spend every year on eradicating invasive species and restoring the habitats they have invaded. For example, figures for the total cost of IAS in the USA range from US$131 billion cumulative to US$128 billion annually, and also China spent US$14.45 billion for this purpose. Economic losses can also occur through the loss of recreational and tourism revenues (Simberloff, 2001; Pimentel et al., 2005; Xu et al., 2006; Pejchar & Mooney, 2009). They can damage a wide array of environmental services that are important to recreation, including, but not limited to, water quality and quantity, plant and animal diversity, and species abundance. For instance, silver carp and common carp can be harvested for human food and exported to markets already familiar with the product in many developing Asian countries. According to the European Commission, the estimated annual economic losses (Euro) of some developed countries are given in the Table 3.

Table 3. Estimated annual economic losses (Euro) of EU and some developed countries (Data modified from the report of European Commission, 2013)

Country	Predictable Losses (trillion/year)
Globally	€ 1
US	€ 91
EU	€ 12
China	€ 11
New Zealand	€ 2
UK	€ 12

Control Measures for Invasive Species

There are several strategies have been taken to reduce the damage caused by invasive species along with to prevent future invasions. However, managing invasive alien species is particularly challenging in the ocean because marine ecosystems are extremely interconnected across broad spatial scales. Extermination of aquatic invasive species was only achieved when species were spotted early, and management responded swiftly (Pyšek & Richardson, 2010; Giakoumi et al., 2019). Many international and local laws and regulations have also been introduced to combat the future expansion of invasives. (Hunter & Hart, 2013). Usually, invasive control strategies in the marine environment follow a species-by-species approach. Though, trait-based prevention and management could result in more effective conservation outcomes as a set of management actions could benefit multiple invasive species sharing common traits. Furthermore, a comprehensive approach to invasive species management should consider, such as the expected impacts of these species on native ecosystems, the available technical intervention options, their expected likelihood of success and their cost, the risks associated with management, and the extent of public support and stakeholder support for the proposed interventions (Pyšek & Richardson, 2010; Ojaveer et al., 2014; Giakoumi et al., 2019).

The various options of management include-

Physical or Mechanical Control - involving physical removal of the invasive species by harvesting or using barriers or traps. These techniques mainly suitable for the removal of invasive plants.

Chemical Control - Can be executed by using pesticides, herbicides, insecticides, fungicides and other recommended chemicals. As well as adverse effects of using these chemicals in the ecosystem need to be considered.

Biological Control - This method is the most purposeful and ecologically sustainable approach of controlling invasion. In this process many biological individuals are used to reduce the invasive species populations.

Conclusion

Invasive species is a global problem and consider a prime disaster to species diversity. Depending on diverse taxa, geographic locations, and ecosystem types invasive species can alter ecosystem services by affecting populations, community interactions, ecosystem processes, biotics and abiotic variables. Almost all ecosystem services can be destructively impacted by invasive species, whereas some minor positive impacts exist. Sometimes the developed country can overcome the consequence of invasive activity, but it's really difficult for developing one, therefore, the ecosystem and species richness are a significant risk to those nations. It is high time to take initiatives to control invasive species distribution for a sound ecosystem.

Compliance With Ethical Standards

Authors' Contributions

JB: Manuscript design, writing, editing, analysis.
RG: Writing, editing, reading,
SSI: Draft checking, editing, and writing.
All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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