Chapter

Marine Bivalves' Ecological Roles and Humans-Environmental Interactions to Achieve Sustainable Aquatic Ecosystems

Andreia Filipa Mesquita, Fernando José Mendes Gonçalves and Ana Marta Mendes Gonçalves

Abstract

Bivalve species have a key role at the ecosystem level and a very interesting economic value. Globally, bivalve production is higher than 15 million tons. Thus, this work intends to highlight the economic value of these organisms, but mostly highlights the potential of this resource for water management and water quality improvement, and thus to the sustainability of aquatic systems, which gives them a particular interest. These organisms are under anthropogenic pressures becoming crucial to preserve aquatic systems and their communities, namely bivalve communities, and water quality by reducing pollution. UN Sustainable Development Goals (SDGs) highlight the main actions to reduce humans' footprint and to create globally a model to guarantee human security, to protect the environment and water quality and to combat climate changes. To achieve the UN SDGs, bivalves may have a high importance for sustainability and preservation of freshwater and marine systems (SDG 14), and for water management (SDG 6), due to their ability to improve the water quality by reduction of pollution. This work aims to highlight the main ecological roles of marine bivalves and the human actions that will contribute to achieve sustainable aquatic systems, and so the SDG 6 and SDG 14 by 2030.

Keywords: bivalves, food resources, water quality and management, sustainability, ecological roles

1. Introduction

Water is a valuable resource to human beings; however nowadays, 2.2 billion people continue without access to safe drinking water [1].

Freshwater ecosystems provide us several services, such as transport, natural purification, protection against floods, irrigation, and they are characterized by a high biodiversity of habitats. Unfortunately, the discrepancy between developing and developed countries is considerable. In developed countries, 3.5% of the land is covered by freshwater, compared to just 1.4% in developing countries [1]. Despite the importance of freshwater, this only includes less than 3% of all water in the world. By other side, oceans comprise about 97% of all water in the planet [2] and have an important ecological role, as habitat to many animal and plant species, of all sizes, being essential efforts to the conservation and preservation of these systems. In addition to the ecological importance, these ecosystems have a great value to the human development, since they provide many resources, including economic activities as fishing, communications, tourism, and recreation activities. Marine vegetation is responsible for the production of about 50% of atmospheric oxygen; mangroves, saltmarshes, and seagrasses have a key role as natural sinks of carbon; coastal habitats present high importance to the protection of habitats, communities and businesses against storm, and wave damage; and humans ascribe great esthetic, cultural and spiritual values from ocean ecosystems [3]. So, due to the great potential of these ecosystems, human populations have developed their activities and inhabited near the sea, with 67% of human population living less than 400 km from the sea [4].

Notwithstanding the great value of the aquatic systems to many species and to human well-being, these environments have been neglected and subjected to many pressures, such as resource overexploitation (e.g., overfishing) and input of pollutants from human activities (e.g., industrial and agricultural practices, shipping, beach activities). Therefore, these pressures result in dangerous effects to the entire ecosystems, including consequences to the biotic (e.g., changes in the structure and function of the communities) and to the abiotic (e.g., effects on water quality and sediment composition) elements. Considering the importance of each species and the ecosystem as a whole, it is essential to work for the preservation and conservation of these ecosystems, reducing the impacts of anthropogenic activities and improving water quality. So this work attempts to highlight the human role in the sustainable management of freshwater and marine aquatic systems, focusing on bivalve communities, due to their ecological and economic importance.

2. SDG 6 and SDG 14

Sustainable Development Goal 6 intends to achieve an equitable access to drinking water and sanitation for all people, through several targets. It includes the elimination or reduction of the pollutant inputs to aquatic systems, encouragement of the cooperation between countries for the implementation of integrated water resource management, and assurance of the protection and recovery of water related ecosystems (e.g., wetlands, lakes, and rivers). SDG 14 is focused on marine ecosystems' preservation and conservation. This is achieved through measures to prevent and reduce marine pollution, including land activities, to minimize ocean acidification and its consequences (e.g., decreased carbonate ions' interference with shell formation, affecting the survival of bivalves, plankton, and coral reefs) and by promoting the sustainable use of marine resources through economic benefit assessment.

Considering these two SDGs and their targets, it is crucial human beings and different sectors take actions to achieve the 2030 Agenda main goals. Several efforts are essential, such as effective policies to control the impact on aquatic systems, both from contaminant discharges and from resource overexploitation. Moreover, spreading the knowledge of environmental issues and involving people in environmental activities may also be fundamental to the awareness of the non-scientific communities, making easier the implementation of policies and the achievement of the goals. Ocean Literacy and Environmental Education programs for school students and the public in general may contribute to promote knowledge, awareness, and governmental action.

The critical position of bivalve species in the ecosystems, acting as a link between primary producers and secondary consumers, and their ability in filtering and cleaning the water and in accumulating great amounts of nutrients and contaminants is well known. Their role in carbon and nutrient cycles is fundamental to achieve clean water and ecosystem health. Thus, a compilation of bivalves' importance and the role of anthropogenic impacts on aquatic systems, for achieving SDGs 6 and 14 are provided in the section below.

3. Ecological and economical role of bivalves species

Bivalves (Bivalvia) are a large class, with almost 15,000 species (MolluscaBase 2021). These organisms are found worldwide in marine and freshwater ecosystems and they are reported as playing a key role at the ecological level, due to their large filtration ability. These organisms are filter feeders and filter plankton and other suspension particulates, contributing to the water cleaning and light penetration. They also have an essential part in the ecosystem hydrodynamics as well as in nutrient and carbon cycles [5]. Their high filtration ability and potential for use in bioremediation processes [6] make them potential key elements for the improvement and restoration of water quality. Moreover, they are a food source to many species, from invertebrates to fishes, birds, and mammals [7], acting as a link between primary producers and secondary consumers. Briefly, they can establish and change habitats and affect the trophic webs, directly and indirectly [8]. By this, bivalve species preservation is an important contribution to the ecosystem's equilibrium and resource sustainability, being a key element to achieve SDGs 14 and 6.

Despite the great ecological importance of these organisms, bivalve species also have a great economic value to humans, since they are used not only as ornamental objects but also as a food and protein source. For instance, in 2017, 40,000 tons of global oyster were imported, and about 170,000 tons of clams were exported and 180,000 tons imported, with China as the main exporter whereas Japan and Republic of Korea as the main importers [9]. Scallop import prices in the French market were US$15/kg for frozen scallop and US$20/kg for live scallop in 2019 [10]. Many species also have an esthetic value, providing ornamental objects such as pearls and decorative shells. Worldwide production of unworked pearls reached US$412 million and that of worked pearls was US$ 787 million in 2004 [11], promoting the fishing industry in coastal zones [11, 12]. In Europe, bivalve production in aquaculture systems is reported to be about 598 thousand tons per year, and global production exceeds 15 million tons, translating to about 20.6 billion dollars per year worldwide [13]. Bivalves' application for the human wellness are many, such as the ornamental and food resources, including the extraction of bioactive molecules with medical use, due to its antiviral [14] and antibacterial (e.g., the lectin MytiLec-1 extracted from *Mytilus galloprovincialis* and with the ability to inhibit the growth of Gram-positive and Gram-negative bacteria) [15] properties. They are also able to cause the apoptosis of cancer cells [16–18] and have the potential to the development of novel food products, due to antioxidant extracts from the bivalves shell [19–21]. Considering the important ecological and economic value of these organisms, the growing deterioration of bivalves' communities should also be a major concern to all and thus to the achievement of the goals of Agenda 2030.

4. Anthropogenic pressures

Anthropogenic activities, particularly the industrial and urban development, agricultural practices, tourism, and recreational aquatic activities [22–24] contribute to the aquatic ecosystems' pollution, as well as the exponential increase of the human population. Consequently, the food need leads to organisms' overexploitation. These pressures, pairwise the introduction of alien species, accidental or per esthetic and economic reasons, are leading to the habitats' degradation, affecting the aquatic ecosystems [25, 26] and interact by complex and unpredictable ways, with dangerous consequences to the systems, affecting their stability and resilience [27], resulting in bivalves communities' decline. Several researchers [24, 28–30] have dedicated their studies to understand the effects of environmental contaminants on aquatic ecosystems and consequently on the species.

Despite the pressures resulting directly from human activities, aquatic ecosystems are also very susceptible to climatic changes. Nowadays, global changes comprise a main concern to scientific, political, and social communities. IPCC [31] predicts a temperature increase of the Earth's surface of about 4°C until the end of twenty-first century, with dangerous impacts to the aquatic systems and organisms, being particularly aggravated by bivalves' species [32].

The main reasons and effects of the above-mentioned stressors are detailed in the further subsections, considering its impacts on the aquatic systems and particularly to the bivalves' populations. The selection of stressors was based on its increase and harmful effects, and comprises the: i) chemical contamination (including pharmaceuticals, pesticides, and metals) and microplastics, highly used in daily activities by human beings (e.g., pesticides used worldwide increased 1 million tons in the last 30 years) [33]; ii) overexploitation of resources, resulting from the increasing of the food requirements [34]; and iii) the climatic changes (**Figure 1**) [31, 35].

4.1 Contaminants

Many effects have been reported at the individual level (e.g., inhibition of the growth, reproduction, behavior, and survival) [22, 24, 30, 36], being usually associated with causes at a molecular level, such as changes in detoxication, neurological, immunological, metabolic and antioxidant processes, biomolecules, and DNA [29, 37–47].

4.1.1 Pharmaceuticals

Chemicals designed to act on specific molecular and metabolic pathways of animals and humans, nevertheless, may affect non-target species [29]. These contaminants enter on the aquatic systems mostly by industrial effluents, livestock wastes, human excretions, hospital wastes, and incorrect discarding of pharmaceuticals, incomplete drugs removal of many medicines, by wastewater treatment plants, and release of contaminated effluents and sludge containing drugs [48, 49].

4.1.2 Pesticides

Chemical formulations, mostly from agricultural use for pest control (including insects, weeds, parasites, fungi and rodents) [50], may affect the organisms directly, by their toxic effects, or indirectly, by the elimination of other species [51].

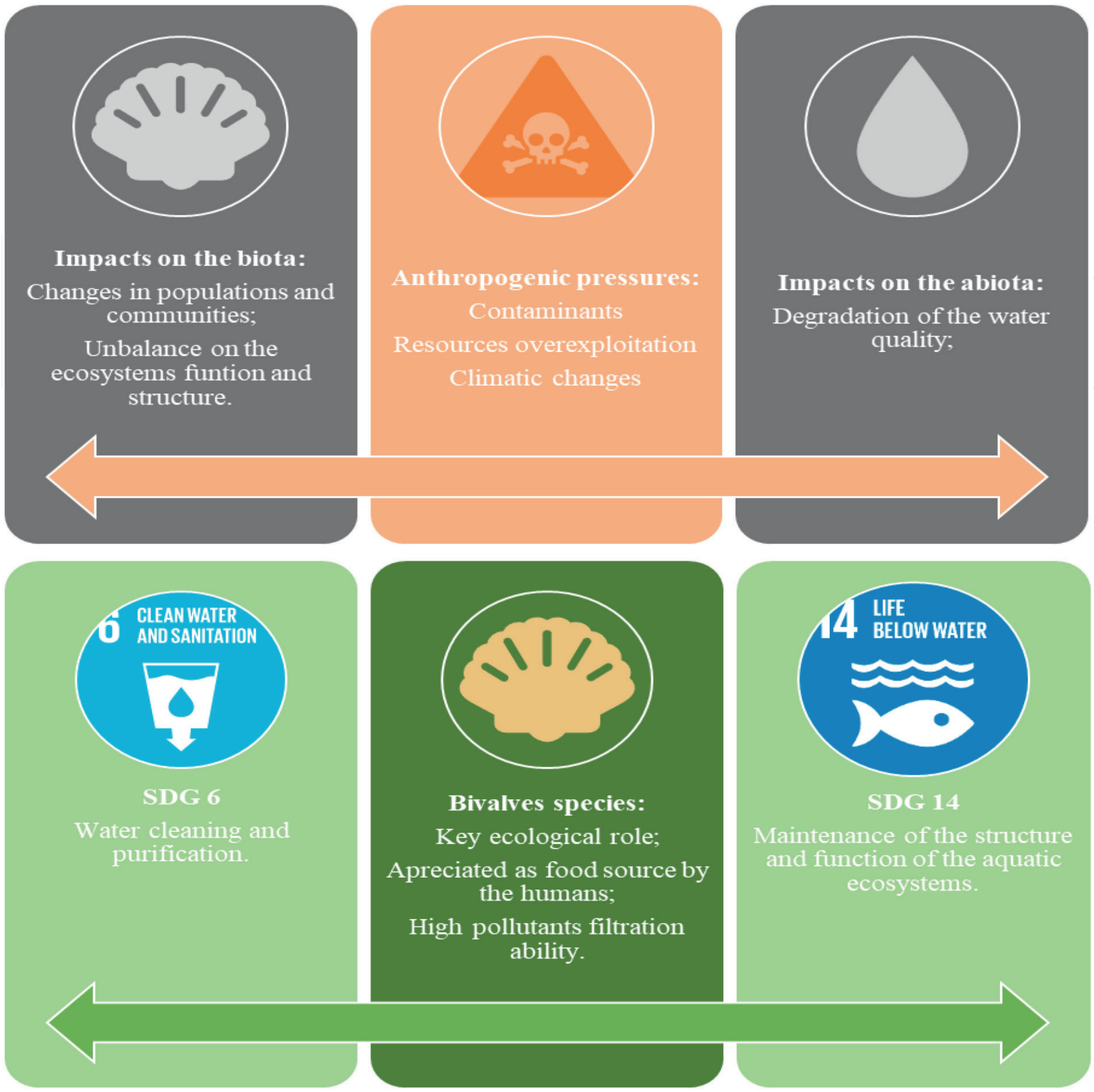

Figure 1.
Bivalves ecological roles and the impacts and pressures of human activities.

4.1.3 Metals

Metals can be from industrial and mining activity, metal plating, rainwater runoff, and sewage [52–54], or released by natural sources [55]. These compounds can be classified into two categories—essential metals and non-essential metals. Essential metals have a biological role in the organisms (e.g., copper, iron, magnesium and zinc) [56, 57], but still they may be toxic at high concentrations. Non-essential metals have no role in organic processes (e.g., mercury, lead, cadmium, and arsenic) [58, 59], being toxic even at very low concentrations [60].

4.1.4 Microplastics

These emerging contaminants are a worldwide concern among political and scientific communities, but also to the general public [61, 62]. These particulates may be from the degradation of bigger plastic elements or plastic initially produced with a little dimension for commercial application [8]. They are easily ingested by organisms from various trophic levels [63–66] and have the ability to accumulate in bivalves [28], with potential consequences to human health. Fang et al. [67] reported an ingestion of 2565 microplastics items by volunteers, after consumption of 225 g of mussels, an exposure classified as considerable [68, 69]. Moreover, studies estimate an annual ingestion of microplastics per person, as consequence of the shellfish consumption, of about 87 to 11,970 items [70]. The interest in microplastics studies is increasing, and some researchers have observed dangerous effects on bivalves, as a consequence of the exposure to these particles. Browne et al. [71] demonstrated microplastics translocation to hemolymph and to hemocytes. Structural and morphological changes on tissues and effects to the gills and digestive gland were shown by Alnajar et al. [28]. Other authors also stated reactive oxygen species production, oxidative stress generation, and DNA chain breaks [72, 73].

The above-mentioned contaminants have dangerous effects on bivalves' species and the remaining aquatic communities, and on water quality and consequently on human beings. Considering the 2.2 billion of people without safe access to drinking water and the resources provided by aquatic systems, the preservation of these ecosystems is essential. Some policy measures, such as fines, have been implemented to control contaminant discharges to aquatic systems; however, this problem remains. Therefore, aggravation of fines for those who do not comply, more intensive supervision, and more restrictive laws are necessary to ensure availability and sustainable management of water, and also to achieve a sustainable use of the oceans and the marine resources. Moreover, measures like attribution of economic benefits for the safe disposal of pollutants could be implemented, helping to restore an appropriate water quality. Another measure to reduce pollution is the application of natural fertilizers in agriculture fields, which are healthier for soils, cultivated products (also increasing their quality), human health, and the surrounding aquatic systems [74]. Improved irrigation techniques, like those already used in some countries where water resources availability is a problem, can help to reduce agricultural water use. These are some of the measures to achieve some of the targets of the SDGs 6 and 14 of Agenda 2030.

4.2 Overexploitation of resources

During the past century, the development and usage of resources to improve living standards proceeded rapidly, in some cases without concern for the sustainability of the systems and resources. The management and implementation of mitigating measures in threatened aquatic ecosystems were also conducted to restore ecological health, mainly in those surrounded by agriculture fields with intensive practice. The overexploitation of agriculture fields hasted to a depletion of land resources, which poses a new challenge to develop new food sources focused in marine resources [75]. Contrary to land systems, in the ocean the access to resources outside of national jurisdiction is practically unregulated. Furthermore, in territorial waters and exclusive economic zones, where there is regulation, it is often ineffective. Several consequences are frequently associated with non-regulation, such as overfishing, blocking of maritime shipping ways, coastal habitats destruction, introduction of dangerous alien species, and occasional and pollution above the resource assimilation ability [76].

Some researchers have reported population changes associated with overexploitation, namely the decrease of demographic, temporal, and spatial diversity [77], changes in population age and size, decrease of genetic diversity, and changes in growth rate and reproduction [78]. Moreover, variations in trophic structure as consequence of overexploitation are reported [79–82], as well as, biomass decline [83].

Among the many methods of overexploitation of resources, many research studies have been focused on fisheries using equipment that damage benthic habitats and pose risks to the administration, balanced use, and preservation of live resources [84–87]. Hand collection of mollusks (mussels, clams and oysters) is among the most susceptible of artisanal fisheries, due to its distribution and economic value in the coastal zones [88–90].

To achieve SDG 14, some measures (e.g., attribution of economic benefits to the sustainable use of marine resources, prohibition of subsidies that contribute to the overfishing, determination of fishing quotes) [91] should be applied to support sustainable fishing that ensures the continuation of the species and protect aquatic communities. However, fishing is the livelihood of many people, who often lack access to basic information, and therefore knowledge-sharing programs highlighting the importance of the ecosystems and resources preservation are badly needed.

4.3 Climatic changes

Nowadays, climatic changes are the main concern among political and scientific communities, with SDG 13 focusing on urgent action to combat climate change and its impacts. It is recognized that climatic changes affect all life forms, and marine ecosystems are not an exception. So several studies have showed the climatic change impacts on these systems [92, 93], namely warming and acidification of the oceans [94], changes in the nutrient dynamics, increase of CO_2 levels, and alterations in wind and flow patterns [95]. Consequently, the survival, growth, reproduction, and distribution of species are affected, and the impacts also may be observed at higher levels such as population, community, and ecosystem [96]. Some studies have linked climatic changes with dangerous biological effects on bivalve species, such as shell formation [94], abundance [97], development [98], larval stage [99], recruitment [100–102], and spawning [103].

Ecosystem monitoring is fundamental to understand the long-term evolution of ecosystems, allowing the detection of changes in biotic and abiotic parameters and intervention to restore ecosystem balance. Some efforts have been done by scientific research groups to monitoring these ecosystems, such as determining and quantification of metals [104–106], organic pollutants [107–109], and microplastics [110, 111]. The ocean acidification impact [112, 113], the development of technology [114], or even creation of marine sanctuaries [115] are other contributions to the monitoring programs. However, these programs are poorly funded by governments and are mainly dependent on the scientific research efforts, being crucial a more effective and higher financial support.

5. Conclusion

Anthropogenic pressures on aquatic systems are increasingly intense and need better understanding of their impacts on ecosystems and communities. This review highlights the dangerous effects of pressures from human activities, with a focus on contaminant inputs, resource overexploitation, and climatic changes. Moreover, this work intends to be an alert to the importance of aquatic ecosystems' recovery and preservation, and thus water quality, with a focus on the ecological role of bivalve species. This work also calls attention to the decline of these communities and the impacts on the ecosystem structure and functioning, not only in marine systems but also in freshwater environments, where bivalves may have a great potential for water cleaning and purification. Human beings have a key role in the preservation and conservation of aquatic systems, species, and water quality through the application of mitigation measurements and strategies. It is crucial to act to achieve the goals and targets proposed in Agenda 2030 for a better and a more sustainable future. The future depends on us!

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Author contributions

Conceived and designed the idea, A.F.M. and A.M.M.G.; organization of the team, A.M.M.G.; writing and bibliographic research, A.F.M.; supervision and manuscript revision, F.J.M.G. and A.M.M.G. All authors have read and agreed to the published version of the manuscript.

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