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MINI REVIEW

Ecological role and importance of oysters for environmental sustainability: a mini review

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Abstract. Oysters, a bivalve species, play an important role in balancing aquatic ecosystems. However, the role of oysters in environmental sustainability is poorly understood. Here, we answer the question of how oysters contribute to ecological health and environmental sustainability in coastal and marine ecosystems. We reviewed published articles and technical reports. We found that oysters contribute to minimizing eutrophication and provide habitat for many species. Moreover, oysters serve as a good source of food for many invertebrates and vertebrates, including fishes and birds. Additionally, oysters help prevent soil erosion and increase species diversity in aquatic ecosystems. Our research provides basic information about oysters' contributions to the sustainability of nature; however, more detailed research is needed to better understand how oysters and their environment work together to support and maintain healthy aquatic ecosystems.

Keywords: aquatic ecosystem, bivalves, environment, filter feeder, oysters

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Introduction

Increasing anthropogenic pressure, such as the presence of human-made pollutants in the aquatic environment, can alter ecosystem services, leading to sharp reductions in species diversity (Ulanowicz and Tuttle 1992, Newell 2004, Schulte et al. 2009). Aquatic ecosystems are affected by problems caused by humans, mostly nitrogenous and phosphorus products, for many years, and limited efforts have been made to reduce such nitrogenous and phosphorus waste in natural water systems. In addition to nitrogenous and phosphorus products, the presence of microplastics and harmful chemicals, which has been increasing in recent times, are also reported as major threats to aquatic environments (D'Costa 2022, Riveros et al. 2022). These threats directly contribute to the decline in populations of aquatic species. For example, in estuarine habitats, chemical fertilizers from agricultural lands and industrial waste are responsible for the contamination of nitrogenous and phosphorus chemicals that decrease the biological oxygen demand (BOD) of the water body. This eutrophication can cause species losses and decrease ecological productivity.

Many aquatic environments, such as estuarine, freshwater, and marine systems, serve as the backbone of terrestrial ecosystems. Therefore, protecting these environments is crucial for the sustainable conservation of nature. Oysters, which belong to the class Bivalvia in the phylum Mollusca, are also known for their ability to treat wastewater. They contribute to water purification primarily through filter feeding, a process in which they remove suspended particles, organic matter, excess nutrients (such as nitrogen and phosphorus), and even some contaminants and pathogens from the water column. By improving water clarity and quality, oysters play an essential role in maintaining the ecological balance of aquatic systems (Officer et al. 1982, Ulanowicz and Tuttle 1992, Newell 2004, Schulte et al. 2009). The introduction of oysters into a particular environment can help protect marine or estuarine ecosystems (Newell 2004, Lindahl et al. 2005, Schulte et al. 2009). Protecting these environments through natural processes, such as filtration by bivalves (e.g., oysters) can be cost-effective and sustainable.

There are more than 200 species of oysters reported worldwide (Officer et al. 1982, Ulanowicz and Tuttle 1992, Newell 2004). Some oysters are well-known as seafood and as a source of calcium carbonate, contributing to the economies of many countries such as the USA, France, and China (Grabowski et al. 2012, Botta 2020). However, due to overexploitation, oyster populations are decreasing in the wild, posing challenges for both the economy and biodiversity (Newell 2004, Baggett et al. 2015, Morris et al. 2019). Another potential impact on oysters is low salinity (< 10 ppt) in the water, which reduces growth and increases mortality. Many diseases are also associated with low-salinity water, altering oyster behavior and increasing mortality. The impacts of climate change, both direct and indirect, are also linked to the decline of wild oyster populations.

Increasing our understanding of the role of oysters in aquatic ecosystems can lead to better practices for sustainable aquatic biodiversity conservation. However, besides oysters' economic role, their usefulness for the conservation of nature is still poorly documented. In this review, we explore the ecological importance of oysters. Our study concentrated on understanding how oysters maintain aquatic ecosystem services. We focused on peer-reviewed articles, books, dissertations, and technical reports. Based on our review, we have outlined oysters' ecological roles, which contribute to the sustainable conservation of aquatic environments.

Oyster as a filter feeder species

Preventing aquatic habitats from eutrophication and restoring degraded water bodies using bivalve species such as oysters has been practiced for a long time (Lindahl et al. 2005, Schulte et al. 2009). There are various aspects of interactions among benthic filter-feeding communities that have been studied (Officer et al. 1982, Ulanowicz and Tuttle 1992, Newell 2004, Lindahl et al. 2005, Schulte et al. 2009). The benthic community can filter or recycle wastewater depending on the depth of the water and the density of the benthic population (Newell 2004, Lindahl et al. 2005, Schulte et al. 2009). However, wastewater filtered by bivalves can play a great role in maintaining aquatic ecosystems. Studies conducted by Bullivant et al. (1968), Dame et al. (1980), and Brown et al. (2008) have investigated how oysters contribute to removing plankton and organic particles from the water column. As filter feeders, they play an important role in removing excess nutrients from the water, which can help reduce the occurrence of harmful algal blooms and other negative effects of nutrient pollution (Beck et al. 2011).

Filter feeders are a type of suspension feeder that feed by straining suspended debris and food particles from water by passing through a specific filtering organ. Oysters, clams, krill, sponges, baleen whales, and a variety of fishes employ this feeding strategy. In addition, some birds, such as flamingos and certain duck species, are also good filter feeders. These species can play a vital role in water purification, hence, they are classified as ecosystem engineers. They are also crucial in bioaccumulation, and as a result, they serve as indicator species for aquatic bodies (Ulanowicz and Tuttle 1992, Newell 2004). However, because of its biology, the oyster can be considered a major species for wastewater treatment (Schulte et al. 2009, Weaver et al. 2018). Oyster reefs can significantly improve water quality by filtering sediments, algae, bacteria, detritus, and other suspended particulates in aquatic ecosystems (Officer et al. 1982, Ulanowicz and Tuttle 1992, Newell 2004, Lindahl et al. 2005, Schulte et al. 2009). It is estimated that one oyster is capable of filtering up to 50 gallons of water per day; however, this capacity varies depending on factors such as species, size, water temperature, salinity, and the concentration of suspended particles. Filtration rates may range from approximately 5 to 50 gallons per day under different environmental conditions. However, there are limited studies quantifying this variability across regions and species, and further research would be valuable to better understand the ecological role of oysters in water purification. Several countries have documented oyster production for water treatment (Lindahl et al. 2005, Schulte et al. 2009, Baggett et al. 2015, Weaver et al. 2018). For example, Shih and Chang (2015) demonstrate that oyster shell contact beds can effectively reduce wastewater pollutants, including bacteria, nutrients, and suspended solids. However, a small production of oyster culture for habitat improvement may not be sufficient. Therefore, if larger-scale oyster restoration projects generate quantifiable improvements in water quality in estuaries, this suite of benefits should be evaluated as part of the ecosystem services offered by oyster reefs.

Oysters for climate change impact mitigation

The increasing global temperature is one of the central issues of the twenty-first century (Doney et al. 2012, Weiskopf et al. 2020). Increasing carbon molecules in nature and the loss of greenery are responsible for climate change impacts on biodiversity. Climate change impacts can be responsible for declining aquatic biodiversity (Short and Necklaces 1999, Gutierrez et al. 2008, Tol 2009). One of the species that can help reduce the impact of climate change on aquatic ecosystem is oysters. Oysters sequester carbon in their calcareous shells and bio-deposits and may be one component in combating climate change (Dame et al. 1989, Peterson and Lipcius 2003, Gutierrez et al. 2008, Weaver et al. 2018). Oysters have the potential to mitigate the impact of climate change on aquatic ecosystems. Fodrie et al. (2017) developed a framework accounting for the burial of inorganic (carbonate) and organic carbon. On intertidal sandflat reefs aged ~10 years, carbonate accumulation led to net CO_2 emissions (~7.1 MgC $ha^{-1}yr^{-1}$). In contrast, shallow subtidal and salt marsh fringing reefs sequestered organic-rich carbon, functioning as sinks (–1.0 to –1.3 MgC ha^{-1} yr^{-1}), comparable to vegetated coastal habitats. Historical reef mining has likely released > 400 million Mg of organic carbon. The authors argue that preserving intact reefs supports coastal climate-mitigation efforts.

In addition, oysters sequester carbon in their shells and bio-deposits, which can help to reduce the amount of carbon dioxide in the atmosphere and combat ocean acidification (Weaver et al. 2018). Oyster reefs provide important habitat that supports biodiversity and have the potential to reduce storm surge and shoreline erosion, helping to mitigate the impacts of climate change (Coen and Luckenbach 2000). This can help to protect coastal communities and infrastructure from the impacts of sea level rise and other climate-related events. While the potential of oysters to mitigate the impacts of climate change is promising, more research is needed to fully understand the mechanisms underlying this process and to develop effective strategies for oyster-based carbon sequestration (Hoellein and Zarnoch 2014). Future research should focus on the effectiveness of oyster reefs in reducing greenhouse gas emissions, as well as their potential to provide other ecosystem services that can help to mitigate the impacts of climate change.

Oysters provide good habitat and food for many vertebrates and invertebrates

Oyster shells and their reefs can be useful as habitat for many species. Oyster reefs can protect small fish, crabs, etc. from predators. Some arthropods and fishes can utilize oyster reefs as good habitats. In addition, many endangered species can survive in oyster reefs. Organisms benefit from the protection of oyster reefs and the clearer water that can occur over the reef, but the oysters themselves do not benefit. The relationship can be either mutualistic or commensalistic. The oyster reef is home to a variety of species including the blue mussel (*Mytilus edulis*), the ribbed mussel (*Geukensia demissa*), the northern rock barnacle (*Balanus balanoides*), the ivory barnacle (*Balanus eburneus*), the sea grape (*Molgula* and *Bostrichobranchus* spp.), the shore shrimp (*Palaemonetes* spp.), the slipper shell (*Crepidula* spp.), the mud snail (*Ilyanassa obsoleta*), the mud tube worm (*Streblospio* spp.), Amphipods (*Gammarus* spp.), and the sand worm (*Nereis* spp.). In this regard, oyster reef ecosystems have mutualistic relationships that benefit both species—for example, oyster reefs provide habitat for certain fishes or shrimps, which in turn helps control pests and clean oyster shells. In communalistic relationships, one species benefits while the other is unaffected; for instance, small crabs or worms may live within oyster shells for shelter without harming the oysters. A specific mutualism is with anemones that deter oyster predators, while commensalism is seen in mud crabs using oyster reefs for refuge without affecting the oysters. These interactions enhance reef biodiversity and ecological function.

Harding et al. (2002) suggest that diverse species feed oysters, including invertebrates and vertebrates. A variety of worm species can cause substantial mortalities in oysters. We found that the following species consume oysters: the milky ribbon worm (*Cerebratulus lacteus*); the black fingered mud crab (*Panopeus herbstii*); the white fingered mud crab (*Rhithropanopeus harrisii*); the blue crab (*Callinectes sapidus*); the green crab (*Carcinus maenas*); the Dungeness crab (*Cancer magister*); the Japanese shore crab (*Hemigrapsus sanguineus*); the sea robin (*Prionotus carolinus*); the Asian rapa whelk (*Rapana venosa*); the knobbed whelk (*Busycon carica*); the channeled whelk (*Busycotypus canaliculatus*); the oyster drill (*Urosalpinx cinerea*); and the oyster flatworm (*Stylochus ellipticus*). The review also revealed that the moon snail (*Euspira catena*) and the shark eye (*Neverita duplicata*), etc. are also major predators of oysters. Moreover, the common sea star (*Asterias forbesi*) and the common starfish (*Asterias vulgaris*) are also major predators of oysters, with starfish consuming up to three adult bivalves per day and at least 15 oyster spat per day. We also found that oysters are a good source of food for many bird species, such as some species of gulls, including the American oystercatcher (*Haematopus palliates*) and the common eider (*Somateria mollissima*). In addition, some species of fish also prefer oysters, while some species of sea turtles, striped bass, bluefish, etc. are also directly or indirectly dependent on oysters for food.

However, due to the socio-economic importance of the oyster, overexploitation is contributing to the decline of oyster reefs (Wilberg et al. 2011, Zu Ermgassen et al. 2012, Baggett et al. 2015), and this threatens biodiversity. The degradation and loss of oyster reefs is a serious conservation threat as it impairs vital ecosystem functions such as providing nursery habitat for ecologically and economically valuable fishes and invertebrates (Powers et al. 2009, Wilberg et al. 2011, Zu Ermgassen et al. 2012, Baggett et al. 2015). However, oyster restoration efforts have historically focused on oyster fisheries enhancement in the US and in some European countries; consequently, in recent decades, there has been an increasing recognition of a broad array of ecosystem services provided by oyster habitats (Coen et al. 1999, Coen and Luckenbach 2000).

Oysters help to prevent soil erosion

Oysters have been shown to play a significant role in preventing soil erosion in coastal areas. Meyer et al. (1997) examined the effectiveness of oyster shells placed adjacent to intertidal marsh habitats, finding that they contributed to a reduction in wave-induced erosion along the lower edges of salt marshes. La Peyre et al. (2015) also identified specific ranges of shoreline exposure where oyster reefs are particularly effective at reducing marsh edge erosion and applied this knowledge in a case study within a Louisiana estuary. Oyster reefs can act as natural breakwaters that reduce the erosive force of waves and currents, thereby protecting nearby marsh habitat and preventing shoreline erosion. Several studies have investigated the effectiveness of oyster reefs in reducing erosion. For example, research by Chowdhury et al. (2021) found that oyster reefs can reduce wave energy, which in turn reduces erosion rates and contributes to oyster reefs supporting coastal resilience in the face of climate change and related rising sea levels. Similarly, Morris et al. (2019) found that oyster reef living shorelines provide natural coastal defenses. Oysters also play a key role in stabilizing sediments in estuarine environments. Oyster reefs help to trap sediments, which helps to build and maintain marsh habitat. La Peyre et al. (2014, 2015) found that oyster reefs can increase sedimentation at higher rates compared to unvegetated areas. In addition to their physical effects on erosion and sedimentation, oysters also contribute to the overall health and resilience of coastal ecosystems.

Oysters increase species diversity

The presence of oysters is an indicator of healthy water ecosystems (Volety et al. 2009, La Peyre et al. 2014). Studies state that species diversity of an ecosystem can be greater in the presence of oyster species. One study conducted in Mols Males Bay in California found high species diversity, such as fishes and aquatic invertebrates, in the bay where oysters were present. Overall, it can be stated that species diversity could be directly proportional to water quality (Coen and Luckenbach 2000, Brown et al. 2008, Brierley and Kingsford 2009, La Peyre et al. 2014). However, further studies are needed to prove this statement. Oysters are known to have a positive impact on species diversity in aquatic ecosystems. By creating habitat for a diverse range of marine species, oyster reefs can increase the overall biodiversity of a given area. Research by Peterson et al. (2003) found that oyster reefs can provide habitat for a range of species, including fishes, crabs, and shrimp. In addition, oysters themselves are an important food source for many species, further contributing to the overall diversity of the ecosystem. Oyster reefs also provide a range of ecological functions that support other species in ecosystems. For example, oysters help to filter and clean water, which can benefit other aquatic species that rely on clean water for survival. Oyster reefs also help to stabilize sediments and prevent erosion, which can provide habitat for additional species (Volety et al. 2009). Overall, the presence of healthy oyster populations can be a good indicator of healthy aquatic ecosystems. However, the relationship between oysters and species diversity is complex and can depend on a range of factors, including water quality, habitat availability, and the presence of other species in the ecosystem. Further research is needed to better understand the mechanisms underlying the relationship between oysters and species diversity and to determine the most effective strategies for promoting biodiversity in aquatic ecosystems.

Rapid growth and survival in extreme conditions

Oysters grow naturally in estuarine bodies of brackish water. They are juveniles at the age of one year and adults at the age of three years (Angell 1986, Bayne 2017). Oysters typically grow up to one inch per year. Oysters tolerate a wide range of temperatures and are commonly found in waters that range from 0 to 32°C. Some studies also state that oysters can survive temperatures of up to 40°C (Brown et al. 2005). Many studies relating salinity gradients to oyster mortality, however, report higher mortality in high salinities or during low rainfall years (due primarily to predation or disease) (Brown et al. 2008, Brierley and Kingsford 2009).

Modifications in temperature, wind patterns, hydrologic cycles, and sea level rise influence nutrient input and behavior, which in turn affect stratification, flushing times, and phytoplankton productivity. Reduced salinity, cyanobacterial blooms, and hypoxia/anoxia have been reported to be associated with massive freshwater discharges (Coen et al. 1999, Brown et al. 2008).

Reducing oyster mortality is the most practical way to mitigate the detrimental effects of climate change (Brander 2007, Brown et al. 2008, Brierley and Kingsford 2009). As a result, it is critical to know how oysters handle fluctuations and how excessive temporal or seasonal fluctuations can affect population dynamics. Temperature and salinity variations could be the most critical elements influencing oyster biology and physiology (Davis 1958, Brown et al. 2005). However, many studies have documented and modelled the impacts of salinity fluctuations on adult (> 76 mm) oysters, but to our knowledge, none have clearly evaluated the effects on spat (25 mm) or seed oysters (26–75 mm). This study could not cover the oysters in each country or continent. For example, we have limited information on how many countries are applying oyster culture for environmental sustainability. Similarly, our study could be more impactful if we could address the water filter rates of oysters and its subspecies. Such information could be more appropriate for the reader.

Future Research Directions

While this review highlights the ecological importance of oysters in coastal and marine ecosystems, several key research gaps remain. First, quantitative data on the extent of oysters' contributions to carbon sequestration, nutrient cycling, and erosion control are limited. Future studies should use long-term monitoring and experimental approaches to measure these ecosystem services under varying environmental conditions. Additionally, there is a lack of understanding of how oyster-associated biodiversity functions across different geographic regions and environmental stressors, including climate change and pollution. Research should also explore the socio-economic benefits of oyster reefs, such as fisheries support and coastal protection, to better inform ecosystem-based management. The findings of this review can support policymakers and conservationists by emphasizing the need for habitat protection, oyster reef restoration, and integrated coastal zone management. Incorporating oyster ecosystem services into environmental planning can enhance resilience against climate change while preserving biodiversity.

Conclusion

Our study led us to conclude that oysters can be applied in various ways to maintain biodiversity and that these tools will be used for wastewater treatment in various countries in the future. We also concluded that oyster culture or farming to restore the aquatic ecosystem is not only beneficial to wastewater treatment, but it is also helpful to protect the entire environment. Overall, the use of oysters in aquatic environment restoration and management has gained increasing attention in recent years, as their ecosystem services are recognized and valued. However, continued research is needed to fully understand the complex interactions between oysters, sediments, and wave dynamics in different coastal environments.

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