

Oyster reef restoration in controlling coastal pollution: India's perspective

P.Chakraborty*

Geological Oceanography Division, CSIR-National Institute of Oceanography,
Dona Paula-403004, Goa.

E-mail: pchak@nio.org

Abstract:

Coastal waters receive large amounts of nutrients and pollutants from different point and nonpoint sources. Excess supply of nutrients in coastal water may have detrimental effects, leading to hypoxia and anoxia from eutrophication. Depletion of dissolved oxygen may decrease fish populations in coastal waters. Conservation of bays, estuaries and coastal zones is must for sustainable development. Excellent ability of oyster in removing and controlling the concentrations of nutrients, pollutants, suspended particulate matters from bays and estuaries stimulated me to provide a viewpoint on oyster reef restoration in controlling nutrient/heavy metals fluxes and marine coastal pollution around India. Oyster reefs restoration in bays and estuarine system may decrease nutrient and heavy metals fluxes in coastal waters and reduce the intensity of oxygen depletion in the coastal Arabian Sea (seasonal) and Bay of Bengal. Extensive research is recommended on oyster reef restoration to control coastal pollution and for sustainable development around India.

Keywords: Oyster reef restoration, coastal pollution, sustainable development, Marine pollution, nutrient and metal flux

Introduction

Coastal zones of India are experiencing rapid development (Naik and Zlatanova, 2009). Conservation of bays, estuaries and coastal zones around India is must for sustainable development. The effects of anthropogenic activities, industrialization and urbanization on heavy metals and nutrients fluxes in marine coastal environment around India are not well known and can be a big concern (Chakraborty et al 2014).

In general, coastal waters receive large amounts of nutrients/trace metals/heavy metals/ polyaromatic hydrocarbon etc from different point and nonpoint sources. In particular, estuaries/bays receive more nutrients/trace metals/heavy metals/ polyaromatic hydrocarbons (PAH) inputs per unit surface area than any other type of ecosystem. Nutrients input to estuaries and coastal seas increase production of phytoplankton, which in turn can lead to increased production of fish. However, excess supply of nutrients can be highly damaging, leading to effects such as hypoxia and anoxia from eutrophication, harmful algal blooms, dieback of seagrasses and corals, and reduced populations of fish and shellfish in coastal waters. Trace/heavy metals have also been reported to act as toxicant at elevated level (Chakraborty et al., 2010). Thus, it is necessary to control nutrients/trace metals/heavy metals fluxes in coastal waters.

Excellent ability of oyster in removing and controlling the concentrations of nutrients, pollutants, suspended particulate matters from bays and estuaries (Jones et al., 2001; Cerco and Noel, 2007; Eppifanio and Srna, 1975; Lane et al., 2003; Meyer and Townsend, 2000) stimulated me to provide a viewpoint on oyster reef restoration in controlling marine coastal pollution around India. The diverse geology of adjacent land, the long coastline (~7000 km), climatic variability, different oceanographic settings, agricultural and anthropogenic activities along the coastline of India make it extremely difficult to predict distribution patterns and fluxes of nutrients and pollutants in coastal and estuarine systems. Therefore, it becomes difficult to understand the impact of oyster reef restoration in controlling marine coastal pollution without giving description of the coastal areas around India. The vast coastlines of India were divided into two regions (i) east coast and (ii) west coast of India. There are marked oceanographic differences between the east and west coasts of India (Murthy et al 2008). Part of western Bay of Bengal (BoB) (bordering the east coast of India) receives huge freshwater discharge from the Indian rivers compared to the eastern Arabian Sea (bordering the west coast of India) (Kumar et al., 2002). BoB has already been reported as less productive zone than Arabian Sea due to stratified surface layer in BoB (Kumar et al, 2002). The recent studies have pointed out that anthropogenic forcing (high nutrient supply, eutrophication and climate change) may enhance the intensity of oxygen depletion in the western Shelf of BoB (Sarma et al 2015). The BoB has also been

reported to be at the tipping point to become oxygen minimum zone if there is nutrient supply from anthropogenic sources.

However, prolific monsoon-driven upwelling system is found along India's west coast (Shetye et al., 1991). The presence of perennial oxygen minimum zone and development of seasonal oxygen depletion (during July-October) in the coastal areas of the Arabian Sea makes west coast completely different from the east coast of India (Naqvi et al, 2006; Naqvi and Jayakumar, 2006). Primary production in the Arabian Sea has been reported to be controlled primarily by the availability of nitrate (NO_3^-) (Sen Gupta and Naqvi, 1984; Naqvi et al., 2003), as concentrations of iron (Fe), the principal micronutrient, have been found to be above levels that limit primary productivity (in the west coast of India) (Measures and Vink, 1999; Smith, 2001). However, off Oman coast has been reported to be Fe limiting (Moffett et al 2015).

There are good numbers of studies that have rigorously reported about the distribution and speciation of nutrients/trace and heavy metals in coastal and estuarine water/sediments around India (Sarma et al., 2010; Panda et al., 2006; Martin et al., 2008; Panigrahi et al., 2009; Prasad and Ramathanan, 2008; Desouza et al., 1996; Satpathy et al., 2010; Chakraborty et al., 2012; Chakraborty et al, 2014a; Chakraborty et al., 2015a). However, there is very limited information available on the fluxes (fluvial, benthic, atmospheric and submarine) of nutrient/toxic metals/persistent organic pollutant from freshwater/atmospheric/benthic sources in the coastal water of India. The current state of knowledge suggests that increase in supply of nutrients in the BoB (bordering East coast of India) may deteriorate water quality by decreasing dissolved oxygen concentration (by increasing eutrophication) in the system (Diaz and Rosenberg, 2008). Similarly, increasing nutrient supply in the west coast of India may increase the intensity of seasonal oxygen depletion in the coastal Arabian Sea (Naqvi et al., 2002). Restoration of oyster reefs in bays and estuaries has been reported to absorb up to 10 times more nitrogen and mineralization of phosphorous (Newell et al 2005).

Recent studies have also reported that living oysters and their shells as sites of nitrification and denitrification (Kellogg et al., 2013, Caffrey et al, 2016). Oysters, the filter feeder, have also been identified to remove toxic heavy metals from bays and estuaries (Chakraborty et al., 2015b, 2016). Mineralization of phosphorus by oyster has also been reported in literature. Newell et al (2005) have suggested that oysters remove organic matter and nutrients, potentially reduce the negative effects of phytoplankton blooms caused by anthropogenic nutrient pollution. However, ammonium excretion can recycle some of the nitrogen to the water column, where it is available to support additional algal growth (Boucher and Boucher-Rodini, 1988 and Mazouni, 2004). Nitrate release from oysters and scallops cultured on ropes is evidence of nitrification associated with bivalves (Mazouni, 2004 and

Richard et al., 2007). In addition, significant rates of nitrification and denitrification in a variety of bivalve communities have been measured. It has shown that oysters can potentially removed toxic metals from suspended particulate matter in estuarine system (Lee et al., 1996; Hedge et al., 2009; Chakraborty et al., 2016). Thus, oyster reefs restoration in bays and estuarine around India may become useful in controlling nutrient (NO_3^{-1} , PO_4^{-3}) and toxic metals fluxes in coastal water. In this view point article, a qualitative effort was made to realize the probable implications of oyster reef restoration on marine environment in the east and west coast of India.

How does oyster reef control coastal water pollution:

Oyster reefs play important roles in bays and estuarine ecosystem by providing habitat for other Bay/estuarine species. They have been known to remove suspended particulate matters from water by filter feeding and clean Bay's/estuarine water. Oysters have

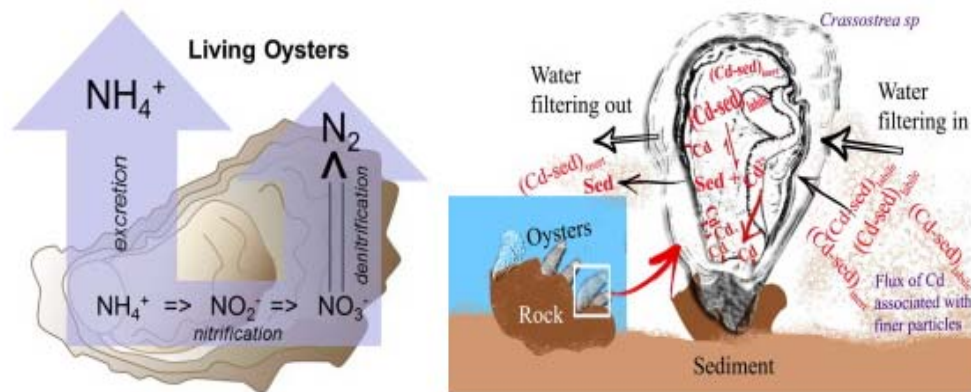


Figure 1: Mechanisms of nutrient (NO_3^-) and toxic metals possible mechanism being rapid denitrification removal from estuaries and bays by oysters (adapted from Caffrey et al 2016, Chakraborty et al., 2015; 2016)

been reported to remove different nutrients and toxic species from water column. Dyer and Orth (1994) have found that oysters lower ammonium concentrations in sediment porewater. Several oyster species (*Crassostrea virginica*, *Crassostrea gigas*, *Crassostrea hongkongensis*,) has been identified to facilitate denitrification processes (Pietros and Rice,2003; Pollack et al., 2013; Kellogg et al., 2013; Caffrey et al., 2016; Beck et al., 2011) and remove toxic metals from water column of bays and estuaries (George et al., 1978; Chakraborty et al, 2016, 2015; Rodriguez-Iruretagoiena et al., 2016). It has also been mentioned that loss of historic oyster reefs may affect resilience of estuaries to eutrophication (Caffrey et al., 2016). Figure 1 shows the possible pathways of nitrification/denitrification and toxic metals removal processes by oysters.

The exact mechanism of denitrification process on oysters is not known. Suspended particulate matter in water enters inside the organism (oyster) during filter feeding. Nitrification and

denitrification are the two key nitrogen transformations processes in bivalve communities (as shown in Figure 1a). In estuarine and marine environments, nitrification limits denitrification (Jenkins and Kemp, 1984 and Seitzinger, 1988). However, denitrification by oyster is an important process to remove fixed nitrogen from the ecosystem. Recent study by Caffrey et al suggests that denitrification process is significantly high on living oysters. However, denitrification rates, inside oyster cages and in sediments under them and how they vary by season and by oyster density are not known.

The most plausible pathways of trace/heavy metals/ toxin removal from estuarine water by oyster are depicted in Fig. 1b. Oysters (filter-feeder) filter in and out the surrounding water for food. Fine particles (suspended) in the water enter inside the organism during filter feeding. Metals associated with finer particles also enter inside the oysters. Bioaccumulation of metals/toxin in oyster increases with increasing concentrations of labile metal-complexes in the finer particles. The concentrations of bioaccumulation of metals in oysters depend on the speciation of metals/toxin in suspended particulate matter. Thermodynamically stable (inert) metal complexes do not participate in bioaccumulation process in oyster.

However, denitrifying capacity of the oyster species (*Crassostreamadrasensis*, *C. gryphoides*, *C. rivularis* and *Saccostreacucullata*) (www.Fao.org) found in Indian coast are not well documented in the literature. These species have been reported to remove suspended particulate matter and toxic metals from coastal marine system. Hence, further extensive studies are required to identify an oyster species that may facilitate nutrient and heavy metals removal from estuarine and bay waters in tropical environment around India.

Identification of a particular species and restoration of oyster reef may become useful in controlling nutrient supply, eutrophication and followed by oxygen depletion in estuary/bay and coastal water of India. In addition to that oyster reefs can be an alternative of artificial barriers which may also protect coastal areas from storms, and devastating cyclones (Piazza et al., 2005).

Controlled supply of limiting nutrients to coastal water may decrease oxygen depleted zone formation and reduce green house gases production:

Denitrification is one of very important reactions in low oxygen environment which is microbially controlled reduction of nitrate to dinitrogen gas (N₂) (Lam and Kuypers, 2011). In this reaction, organic carbon (OC) serves as an energy source, and nitrogen oxyanions (NO₃⁻, NO₂⁻) or oxides (NO, N₂O) serve as the terminal electron acceptor in the absence of dissolved oxygen:



During each step OC is utilized and CO₂ and H₂O is produced. Under certain circumstances, harmful intermediate greenhouse gases such as NO and N₂O can be produced. However, it is unclear exactly when this occurs.

Increased temperature and certain carbon types—such as those with higher *labile* carbon content has been reported to increase N₂O production during denitrification (Burgin and Hamilton, 2007). Restoration of oyster reef may reduce the flux of NO₃⁻ and other nutrients and may also decrease green house gas production in the coastal areas. However, it is also required to estimate the production of green house gases (if any, during the denitrification process) from oyster reef in different bays and estuaries of India. Peterson and Lipcius (2003) have also reported that oysters potentially reduce the emission of green-house gases from bays and estuaries by sequestering carbon from water column.

Probable impact of oyster reef restoration in the east coast of India:

The east coast of India receives intense rainfall during monsoon and run-offs from the major rivers of India (viz., Ganges, Brahmaputra, Mahanadi, Godavari and Krishna) and brings around 1100 cubic kilometres of freshwater into the bay between July and September (Chaitanya et al., 2014). It has been reported that dissolved oxygen is present at very low concentrations in of some part of the BoB. The microbial populations in low oxygen environment of BoB have also been identified very similar to other active oxygen minimum zones in the world oceans (Sarma et al 2015; Bistro, 2016). The BoB has been identified as an oxygen-minimum zone at a “tipping point” that could become a major player in controlling the nutrient inventories of the oceans if these last traces of oxygen could be removed due to anthropogenic activities (nutrient input, climate change) (Bistro , 2016). In addition to that east coast of India is more vulnerable to get storm and cyclone.

Suitable oyster reef restoration in different bays and estuaries (in the east coast of India) may effectively remove nutrients (by denitrification and, mineralisation of P), fine sediments and toxins (by adsorbing metals/toxin) from water column. This may become useful in controlling nutrient supply, eutrophication and followed by oxygen depletion in the coastal water of BoB. Restoration of oyster reef has also been identified as a solid natural barrier. Therefore, suitable oyster reef restoration may also help in protecting estuaries, bays and shorelines from cyclone and floods in the east coast of India.

Probable impact of oyster reef restoration in the west coast:

The typical characteristics of the west coast of India are associated with the semi-annual reversal in wind stress associated with the monsoon, water mass intrusions from marginal seas and the other

oceans, and no opening to the north with no subtropical convergence or deep water formation. This gives the upper waters of the Arabian Sea a unique thermohaline structure and circulation (Wyrski, 1971; Morrison and Olson, 1992; Morrison et al., 1999). It has been reported that upwelling-favourable conditions exist along the southern shelf, which is less conspicuous toward the north of the western continental margin of India. Coastal seasonal (July-October) oxygen depletive zone develops in the eastern Arabian Sea. It has been reported that nutrient supply and eutrophication from the adjacent land intensify the oxygen depletion in coastal water. Suitable oyster reef restoration in the bays and estuaries (in the west coast of India) may effectively remove nutrients, which may decrease the intensity of seasonal oxygen depletion in the coastal Arabian Sea of India.

Challenges and conclusions:

Oyster reef restoration in estuaries and bays can be an important step to control coastal pollution around India. Suitable oyster reef restoration in different bays/estuaries of east/west coast of India may reduce nutrient/metal fluxes to the water column and improve overall coastal marine health. However, lack of quantitative information on several aspects (nutrient, pollutant fluxes, identification of suitable oyster species for restoration, nutrient removal rate by oyster reef etc) prevented us to estimate the benefits of oyster reefs restoration in controlling marine pollution around India. These remediation projects require feasibility and cost studies, which would be different for the two coasts of India. Further extensive investigations are required to understand removal rates of nutrients and heavy metals by oyster reef in marine coastal environment around India. It is expected that suitable oyster reefs restoration in bays and estuarine system may control nutrients and heavy metals fluxes and improve coastal environment of Arabian Sea and BoB around India. Extensive research is also required to understand the impact of oyster reef restoration on ecology of different bays/estuaries for sustainable development along the coast of India.

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